



Research

## Biocultural restoration in Hawai'i also achieves core conservation goals

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**ABSTRACT.** Biocultural approaches to restoration have demonstrated multiple benefits for human communities, but the ecological benefits and trade-offs involved have received little attention. Using a case study from Hawai'i, we examined if forest restoration aimed at reviving and maintaining cultural interactions with the forest is compatible with other priority conservation metrics. We identified species of high biocultural value for an Indigenous (Native Hawaiian) community, and then tested if these species also have high conservation value in terms of their biogeographic origin, ability to support native wildlife, and ability to persist independently within the restored context. Additionally, we tested if an assemblage of species with high biocultural value can also support high functional trait diversity. We found bioculturally important species to have high conservation values for all metrics tested, except for the ability to conserve rare or endangered endemic species. However, a broader application of biocultural conservation, such as the revival of the “sacred forest” concept, can address this priority as part of a mosaic of different species assemblages and levels of access. We also found that biocultural value may, at least in part, be a function of coevolutionary time: the length of time over which a community has interacted with a given species. Given that forests are invaluable to many Indigenous communities and, given the existential threats many of these communities currently face, we suggest that forests containing species assemblages of high biocultural value, such as those in Hawai'i, be considered as critical cultural habitat.

**Key Words:** *biocultural value; coevolutionary time; critical cultural habitat; sacred forest; social-ecological system theory*

### INTRODUCTION

The reciprocal relationships between humanity and nature are at the foundation of social-ecological system theory and the concept of social-ecological resilience (Berkes et al. 2003, Winter et al. 2018a). These relationships are of growing interest to resource managers because it is now widely accepted that community interaction and support can be critical to the success of conservation and restoration projects (Higgs 2003, Chazdon 2008, Chang et al. 2019). Recognizing that the biophysical and sociocultural components of an ecosystem are interdependent parts of a whole, biocultural conservation approaches aim to conserve both (Maffi and Woodley 2010, Gavin et al. 2015). Biocultural restoration is one approach to forest restoration that acknowledges and builds on reciprocal relationships between humans and nature, and allows for contemporary and/or historical relationships between local communities and place to guide restoration design and practices, including species selection (Kimmerer 2013, Kurashima et al. 2017, Chang et al. 2019). The active restoration of species, species assemblages, and places of cultural value can not only rehabilitate degraded landscapes, but can also support the renewal and strengthening of cultural practice and identity, including revival of language, and connections of people to place and to each other, all of which can be critical to fostering social-ecological system resilience (Kurashima et al. 2017, McMillen et al. 2017, Pascua et al. 2017, Bremer et al. 2018, Winter et al. 2018a).

In spite of the recognized value of biocultural approaches to restoration (Chang et al. 2019), broadscale application has yet to be adopted. There are likely several reasons why biocultural approaches in restoration are rarely considered and/or implemented. One reason may relate to cultural differences and the tendency for conservation initiatives to be led by members of a colonizing culture who impose a foreign worldview of

conservation on Indigenous peoples and their places. This includes the idea that nature conservation can only take place in “pristine” landscapes devoid of people, which itself is based on a colonial-era worldview where humans are separate from nature, and was the basis for ousting local and Indigenous people in the process of creating the first national parks in the USA a century ago (see Adams and Hutton 2007 for a review). Although inclusive approaches have existed (at least on paper) for the last 40 years, the legacy of “fortress conservation” persists to this day, and many conservation organizations and state policies that claim to support local and Indigenous people still continue to disregard them in practice (Tauli-Corpuz et al. 2018).

Another reason for the resistance against biocultural approaches to conservation may be that non-Indigenous resource managers and researchers, who tend to lead and/or guide conservation efforts, often assume that utilizing culturally important species in restoration efforts will result in species assemblages dominated by common and introduced species, thereby excluding rare endemic taxa, in particular, the endangered species that are the priority focus of many conservation programs. In the Pacific Islands, culturally important species were intentionally transported among islands in a “biocultural toolkit,” specific bundles of plants and animals packed as food and materials, both for the voyage and for the new land. These toolkits, planted and managed in novel systems, provided both food and a link to Austronesian biocultural traditions as the diaspora expanded throughout Oceania (Whistler 2009, Winter et al. 2018b). In this context, biocultural approaches can include non-native species that might be considered the very antithesis of many conservation efforts. These factors generally translate into a concern that biocultural approaches to forest restoration may not be in alignment with core conservation goals.

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In addition, some research suggests a biocultural approach may focus on useful species at the expense of rare species. For example, culturally valuable species are often ecologically foundational species critical to the structure of forest communities (Shackleton et al. 2018), which can suggest that projects will be biased toward common species at the expense of endangered species. Studies in other locations, such as in India, have shown that forests subjected to different levels of use and management by local communities showed that more intensively managed areas can have similar levels of native plant diversity, but lower numbers of rare native species (Mandle and Ticktin 2013). Many plants valued for cultural use, such as medicines, are thought to have been selected in part because of their high availability or relative abundance (Voeks 2004, de Albuquerque 2006). In addition, because biocultural traditions are adaptive, many have evolved to include introduced species, including invasive species, that have become culturally important for food, medicine, handicrafts, and timber, etc. (Bennet and Prance 2000, Pfeiffer and Voeks 2008, Hart et al. 2017).

Alternatively, the fact that many culturally important species are ecologically foundational or keystone species could suggest that their restoration may, in turn, facilitate the restoration of other species and processes that depend on them. For example, many species valued as food for humans are also preferred by other animals (Shackleton et al. 2018). Wilson and Rhemtulla (2016) found that community-restored forests had more animal-dispersed species than naturally regenerated forests, and an overall higher species diversity. In addition, the diversity of uses and values important to people (food, medicine, timber, crafts, spiritual value, etc.) means that plants with a diversity of traits are valued. High diversity of functional traits is associated with increased ecosystem productivity and ecosystem resilience (Laliberté et al. 2010) and is, therefore, of growing interest in restoration programs (Ostertag et al. 2015, Lohbeck et al. 2018). This suggests that assemblages of culturally important plants could potentially support high functional trait diversity. In a study of functional trait diversity across forest areas subjected to different levels of management for culturally and economically important species, Mandle and Ticktin (2015) found no decrease in functional diversity in highly managed versus unmanaged forests.

Not only has the application of biocultural approaches to restoration been limited, but the ecological benefits and trade-offs involved in such approaches have also received little attention. For example, Benayas et al. (2009) carried out a meta-analysis to show that restoration of biodiversity is correlated with supporting, provisioning, and regulating services. However, they were unable to test the relationship between biodiversity restoration and cultural services because these are rarely quantified alongside other restoration benefits. Furthermore, the ability of biocultural approaches to restoration to meet core conservation goals, such as the restoration of habitat for endangered species, remains untested. In this paper, we draw on a case study from a Hawaiian social-ecological community to ask the following: can forest restoration that focuses on species of high biocultural value also meet other important conservation goals?

Hawai'i provides an ideal place to address this question because of the emphasis of many natural resource management

organizations on ecological restoration (Price and Toonen 2017), and the growing recognition that successful restoration projects often depend on engaging local communities, and that biocultural approaches to restoration can play a critical role in community resilience (Kurashima et al. 2017, Winter and Lucas 2017, Chang et al. 2019). Like other islands, the biota of the Hawaiian archipelago supports very high levels of endemism, and faces enormous conservation threats (Glen et al. 2013, Kueffer and Kinney 2017). In Hawai'i, about 90% of the native vascular flora are endemic (Wagner et al. 1999), and over 40% of endemic species are listed as endangered or threatened (USFWS 2012). At the same time, Hawai'i is home to an Indigenous culture that transformed the archipelago from an ecosystem into a social-ecological system (Winter et al. 2018a) at least 1000 years before present (Wilmhurst et al. 2011). Much of this transformation occurred through the creation of cultural landscapes using introduced species (Whistler 2009, Molnár and Berkes 2018, Winter et al. 2018b), all components of the Polynesian biocultural toolkit that are generally referred to as "canoe plants" or "Polynesian introductions." Today, many communities still maintain cultural, spiritual, and genealogical ties to specific places and species, especially in various pockets across the archipelago (McGregor 2007, Pascua et al. 2017), including Hā'ena (Andrade 2008), the location of this research.

Resource managers and conservation practitioners led by lineal descendants and other members of the Hā'ena community have been restoring the valley floor of Limahuli since 2001 by removing non-native plants and out-planting native species, largely endemic species (including single-island endemics) once found in the valley. Recently, these resource managers identified biocultural value as a priority metric of restoration success, in the hopes of restoring a species assemblage that would be conducive to reviving and maintaining cultural interactions with the forest. This metric is one of six other metrics of restoration success identified as a priority by restoration managers (Burnett et al. 2019). These are: (1) ability to conserve native plant species, especially endemics and single-island endemics; (2) ability to support native wildlife; (3) potential for species' long-term viability; (4) ability to recuperate from disturbance (motivated by Hā'ena's history of hurricanes); (5) ability to conserve water; and (6) long-term management costs. This research examined the first four of these.

Here, we ask if a biocultural restoration approach that focuses on reviving and maintaining cultural interactions with the forest is compatible with meeting other core conservation priorities. Specifically, we first identified those species with highest potential to maintain interactions between the local community and the forest, i.e., high biocultural value, using metrics described by Winter and McClatchey (2008, 2009). We then asked: do species with the highest biocultural value today, i.e., the highest potential to maintain human interactions with the forest, also have high ecological value in terms of their (a) biogeographic origin, i.e., invasive vs non-native vs indigenous (native to multiple eco-regions, e.g., Hawai'i and elsewhere), vs endemic (native to a single eco-region, e.g., Hawai'i only), (b) ability to support native wildlife (e.g., insect and bird species); (c) ability to regenerate and persist independently without continual intensive human intervention (e.g., reseeding or hand-pollination) in the restored context; and (d) ability to support high functional diversity? In recognition that cultural

relationships with plants are dynamic and evolving (Winter and McClatchey 2008, 2009, Winter 2012), we also explore how biocultural values of plant species from different biogeographic origins have changed since the end of the precolonial era in Hawai'i to the contemporary period.

We hypothesized that (i) species with the highest biocultural value would span all biogeographic origins, i.e., include both native and introduced species. We expected, however, that endemic forest species may have had higher biocultural values in the past when they were more abundant and accessible; (ii) species with high biocultural value would also be able to support other native wildlife because some highly culturally important species are ecologically foundational species in Hawai'i; (iii) species of high biocultural value today would have a high ability to persist, assuming that it is in part their persistence to date that has allowed for their continued cultural use; and (iv) since Hawaiians historically valued a wide range of species (Abbott 1992, Krauss 1993), possibly with an equally wide range of functional traits, restoring a species assemblage of high biocultural value would have similar functional trait diversity to that of one composed only of native species.

## METHODS

### Study site

Hā'ena, located on the northwest side of Kaua'i Island, is an *ahupua'a* (Indigenous social-ecological community; Winter and Lucas 2017) that is home to a Native Hawaiian community, which itself has demonstrated resilience by maintaining connection to place and perpetuating place-based resource management practices. This is due, in part, to the fact that Hā'ena was one of the few *ahupua'a* that remained intact until the last half of the 20th Century, and it also had Native Hawaiian elders, still living at the time of this study, who were the keepers of traditional resource management practices (Andrade 2008). This resilience helped Hā'ena to recover from multiple unexpected and catastrophic events that affected the social-ecological system over the last 200 years, e.g., tsunamis, hurricanes, abolishment of traditional religion and system of resource regulation, population collapse from foreign diseases, changes in the land tenure system leading to displacement from ancestral lands, widespread replacement of native forest by invasive species, and climate change (Scarton 2017). Limahuli Garden and Preserve, owned and operated by the nonprofit, National Tropical Botanical Garden and located in the largest of two valleys in Hā'ena, hosts one of the most biodiverse forests in the Hawaiian Islands (Wood 2006). However, like lowland forests across Hawai'i, the lower elevation areas are now heavily dominated by invasive species (Burnett et al. 2019).

### Assessing biocultural value

To assess the biocultural value of specific taxa, defined by resource managers at Limahuli Valley as the ability of species to help maintain cultural interactions with the forest, we generated a list of the plant species currently found in the area known as the Lower Limahuli Preserve, and a list of species that are not currently present but are of restoration interest to the local community. The list of species present in the valley was obtained by establishing 32 5x5 m plots across Lower Limahuli Preserve, including restored and unrestored areas. In each plot, we identified, tagged, and measured the height and diameter at breast

height (DBH) of all individuals > 1.34 m high. We also established four permanent 1x1 m subplots in each 5x5 m plot and documented the identity of all understory species (woody individuals < 1.34 m high, as well all herbaceous species) found in them (Burnett et al. 2019). The list of plant species of potential restoration interest was obtained through focus group discussions with members of the local community and recommendations by Limahuli's resource managers for common native species that were once found on the valley (Wood 2006), but not found in the plots.

To assess biocultural value for each species, we used the approach put forth by Winter and McClatchey (2008, 2009), which identifies the coevolutionary relationships between cultures and plants. Following Winter et al. (2018a), we built a matrix of the plant species documented in our plots and their biocultural functional groups (Appendix 1). We used 17 biocultural functional groups, e.g., food, medicine, ceremony, presence in stories/myths, presence in songs and dances, etc. These were obtained from an extensive review of the literature, including both English and Hawaiian language sources (Kaaiakamanu and Akina 1922, Hiroa 1957, Handy et al. 1972, Gutmanis 1976, Kamakau 1976, Abbott 1992, Krauss 1993, Chun 1994a, b, Malo 1996). We then assigned a numerical score to each plant species based on the historic and continued interactions that its presence can foster, calculating scores for two time periods: the 18th century "*ali'i* era," or period immediately preceding the colonial era, and the contemporary era. For each time period, one point was awarded for the existence of a Hawaiian name (including modern names) and one point for each use. We subsequently grouped the total scores into six biocultural value categories (BVCs), i.e., 0 documented contributions to cultural practice corresponds to a BVC of 1; 1-2 contributions = BVC 2; 3-4 contributions = BVC 3; 5-7 contributions = BVC 4; 8-10 contributions = BVC 5; and > 10 contributions = BVC 6). In the analysis, BVCs  $\geq 3$  were considered to be high cultural value because that was the point in the species list at which there was broad agreement of cultural importance in the focus groups.

The historical biocultural values were derived from relationships documented in the literature reviewed above and used as a proxy to represent biocultural relationships in generations past that existed during the precolonial period, i.e., the *ali'i* era, while the contemporary use values were determined from two focus group discussions with current residents of Hā'ena and its adjacent communities. The first one was held in a community center and consisted of 19 participants. Participants included both males and females, ranging in ages from 20s to 60s. The second focus group had five participants consisting of cultural practitioners who were not able to be a part of the first focus group. They ranged in ages from 30s to 60s, one of whom was female. The first focus group discussion took place as part of a broader community workshop on cultural ecosystem services (Pascua et al. 2017). Workshop participants represented multiple generations of local experts and were invited based on their roles as conservation practitioners and cultural practitioners in fishing, ranching, agriculture, and native forest restoration and/or outreach education programs. The second focus group discussion engaged additional local experts. In the focus group discussions, participants were asked to free-list all the plants they currently used for each use category.

The number of different uses of a given species is a very good predictor of that species' ability to foster relationships to the forest because, according to ethnobotanical theory, people are more likely to retain knowledge, use, and access to a plant that has a greater number of applications for humans (Gaoue et al. 2017). A medicinal species, for example, that may have few uses but is highly important culturally, will also be featured in stories and in the arts, and therefore would be captured in our system as having high biocultural value.

#### Assessing ecological metrics of restoration value

We assessed the ecological value for restoration of each species as described below and in Burnett et al. (2019).

##### *Ability to conserve native plant species, especially endemics and single-island endemics, i.e., irreplaceability*

We classified each species in terms of its biogeographic origin, in order of priority for restoration managers. This was in order of irreplaceability: from Kaua'i island endemics, to archipelago endemics, to archipelago indigenous species, to Polynesian introductions and modern introductions (post-1778, first arrival of Europeans). We also classified introduced species as invasive or not, based on the Hawai'i Pacific Weed Risk Assessment ([http://www.botany.Hawaii.edu/faculty/daehler/wra/full\\_table.asp.html](http://www.botany.Hawaii.edu/faculty/daehler/wra/full_table.asp.html)). We considered only species documented to cause significant ecological or economic harm in Hawai'i (H category) as invasive. One species, *Clusea rosea*, has not been evaluated by the Hawai'i Pacific Weed Risk Assessment, and we classified it as invasive based on observations from Limahuli's resource managers over the past 15 years.

##### *Ability to support native wildlife*

To assess the potential of each species to support native wildlife, we scored each species based on its ability to provide food or habitat to the native insects and birds present in the valley. The native birds present at the time of the study were the 'Apapane (*Himatione sanguinea*) and the Kaua'i 'Elepaio (*Chasiempis sclateri*), which were those that were extant after a wave of extinctions caused by introduced avian diseases that are spread by non-native mosquitos (Pratt et al. 2009). The 'Apapane consumes nectar and insects, while the 'Elepaio is an insectivore. Both bird species rely primarily on 'ōhī'a lehua (*Metrosideros polymorpha*) trees for nesting, foraging, and in the case of the 'Apapane, for nectar. We documented the native insects associated with each plant species using a database of Hawaiian insects and their plant hosts (<http://nature.berkeley.edu/~oboyski67/hawaii/InsectPlant.htm>) and supplementary literature searches (Burnett et al. 2019). We then categorized species into three broad groups: low = no known native insects or birds supported; moderate = < 5 native insects supported and no birds; high = host of > 5-30 species of native insects and/or a native bird. Hawai'i hosts no native terrestrial mammals except for an insectivorous, tree-roosting bat, which is present in Hā'ena, but is not host-specific in terms of tree species (USFWS 1998) and hence was not included.

##### *Potential for species' long-term viability*

Many species in Hawai'i are observed as unable to persist without continued intervention, even within a restored forest context, i.e., one that is fenced to exclude ungulates and that is weeded to be

free of invasive plant species. Reasons include the inability to survive and grow because of insect herbivory, plant pathogens, or lack of appropriate micro-environmental conditions; and/or the inability to reproduce because of loss of pollinators, dispersers, or heavy seed predation by rats. To assess the potential ability of native plants to persist over the long term in a restored context without continued intervention, two senior conservation managers ranked all native species in a checklist based on their ability to (a) survive and grow to adulthood, and (b) recruit (produce seedlings) within a restored context (Burnett et al. 2019). The ranking for both categories was on a scale of 0-3 and based on their 25 combined years of experience in restoration efforts in Hā'ena. Those species that ranked 0 or 1 either for the ability to grow and survive (< 50% of out-planted individuals survive and grow past the sapling stage; rare in the wild) or to reproduce (seedlings never, or only sometimes observed) were classified as having a low probability of persistence. Those that ranked 2 or 3 on either measure (> 50% of out-planted individuals survive and grow past the sapling stage; and seedlings frequently observed), were classified as having a high probability to persist. Finally, those that ranked 3 on both measures (> 70% of out-planted individuals survive and grow past the sapling stage; and seedlings abundant) were considered to have very high potential to persist over the long term. To assess if biocultural value scores for each species, as calculated earlier, vary as a function of the ecological metrics above, we carried out ordered logistic regressions using the R package MASS in R v1.0.136 (Venables and Ripley 2002).

##### *Ability to recover from disturbance*

To compare the potential ability of an assemblage of plants of high biocultural value, versus an assemblage of native plants typically used in restoration, to recover from disturbance, we focused on functional traits associated with response to disturbance, or "response traits" (Cornelissen et al. 2003). These were growth form, life form, maximum height, clonality, dispersal mechanism, and seed mass (Burnett et al. 2019; Appendix 2 Table A2.1). We calculated the multivariate functional dispersion of response traits, based on presence/absence of each species (Laliberté et al. 2010). We used presence/absence data rather than species densities, since species with low densities may make important contributions to resilience (Laliberté et al. 2010). The assemblage of plants of high biocultural value included all species with three or more documented contributions to cultural practice (category 3 or higher), in addition to the existing suite of non-native weedy understory species that restoration managers are currently unable to remove. The typical restoration assemblage was based on all species found in the restored plots. Analyses were carried out using the FD package in R v1.0.136 (Laliberté et al. 2014).

## RESULTS

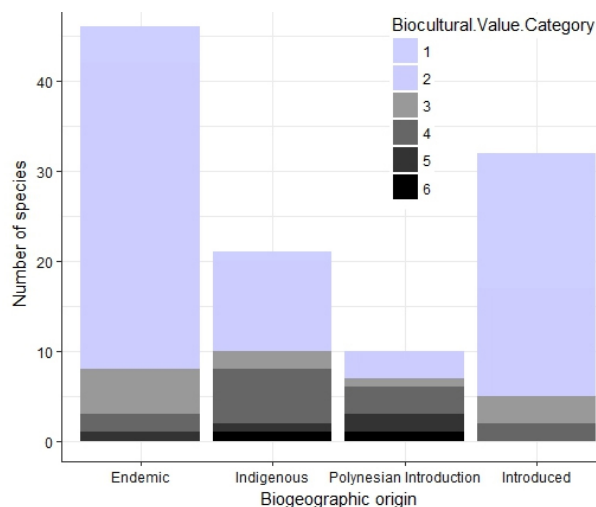
Eighty-seven species were identified in the 32 plots we established. An additional 22 species were added to the species list based on the focus group discussions and recommendations of the resource managers for restoration, for a total of 109 species (Appendix 1). Endemic and introduced species were the most numerous in our species list (Fig. 1). Of these, a little less than one third, 30 plant species, were of high biocultural value, (categories 3-6; Table 1, Appendix 1).

**Table 1.** Plant species with highest contemporary biocultural values (represented by biocultural value category) for the Hawaiian community of Hā'ena, Kaua'i. Category 6 is the highest ranking, with > 10 different contributions to cultural practice (see text). We considered species in categories 3 and higher as those of high biocultural value. Only species falling into categories 4-6 are shown here. For full list see Table A1.1.

Hawaiian Name	Scientific Name	Biogeographic origin	Contemporary biocultural value category	Contemporary biocultural relationships
<i>Kukui</i>	<i>Aleurites moluccanus</i> (L.) Willd	Polynesian Introduction	6	a-h, l-o, r, t
<i>Niu</i>	<i>Cocos nucifera</i> L.	Polynesian Introduction	6	a, c, h-j, l-p, t
<i>Hala</i>	<i>Pandanus tectorius</i> Parkinson	Indigenous	5	a-c, f, h, j, k, n, s
' <i>Ulu</i>	<i>Artocarpus altilis</i> (Parkinson) Fosberg	Polynesian Introduction	5	a, c-e, g, h, m, u
Ōhī'a lehua	<i>Metrosideros</i> ssp.	Endemic	5	a, d-h, m, n
Tī	<i>Cordyline fruticosa</i> Göpp.	Polynesian Introduction	5	a, b, d, i, k-n
' <i>Ohe</i>	<i>Phyllostachys</i> ssp.	Polynesian Introduction	4	a, c-g, p
' <i>Te'ie</i>	<i>Freyinetia arborea</i> Gaudich.	Indigenous	4	a, d-f, j, l-n,
<i>Maile</i>	<i>Alyxia stellata</i> Roem. & Schult.	Indigenous	4	a, d-f, m, n, s
<i>Palapalai</i>	<i>Microlepia strigosa</i> (Thunb.) C.Presl	Indigenous	4	a, b, d-f, m, n
<i>Ma'i'a</i>	<i>Musa</i> ssp.	Polynesian Introduction	4	a-e, r
' <i>A'alii</i>	<i>Dodonaea viscosa</i> Jacq.	Indigenous	4	a, b, e, f, n
<i>Laua'e</i>	<i>Phymatosorus grossus</i> (Langsd. & Fisch.) Brownlie	Introduced	4	a, e, f, m, n, s
' <i>Awa</i>	<i>Piper methysticum</i> G.Forst	Polynesian Introduction	4	a-f,
<i>Lama</i>	<i>Diospyros</i> ssp.	Endemic	4	a, d-g,
<i>Kupukupu</i>	<i>Nephrolepis</i> ssp.	Indigenous	4	a, d, f, m, n
' <i>Alahe'e</i>	<i>Psychdrax odorata</i> (G.Forst.) A.C.Sm. & S.P. Darwin	Indigenous	4	a, e, g, h, n
<i>Waiawī</i>	<i>Psidium guajava</i> L.	Modern Introduction, Invasive	4	a-c, g, h

a - known Hawaiian name, b - medicinal applications, c - source of food or drink, d - ceremonial usage, e - prominent in proverbs, stories, f - present in songs, chants, poetry, g - timber (carving, construction, other), h - biofuel, firewood, i - cordage, j - weaving, k - thatch material, l - non-timber gear (fishing, hunting, bird catching), m - decoration or ornaments, n - personal adornment, o - recreation or games, p - musical instrument, q - clothing material, r - dye, s - fragrance, t - oil source, u - glue, resin source,

**Fig. 1.** Contemporary biocultural value of plant species in Hā'ena classified by their biogeographic origins. Biocultural values were grouped into biocultural value categories (BVCs) based on the number of categorical cultural contributions they provide (0 contribution to cultural practice corresponds to a BVC of 1, 1-2 contributions = BVC 2, 3-4 contributions = BVC 3, 5-7 contributions = BVC 4, 8-10 contributions = BVC 5 and > 10 contributions = BVC 6). BVCs ≥ 3 are considered “high biocultural value” and are shown in grayscale.



### Ecological metrics of biocultural restoration

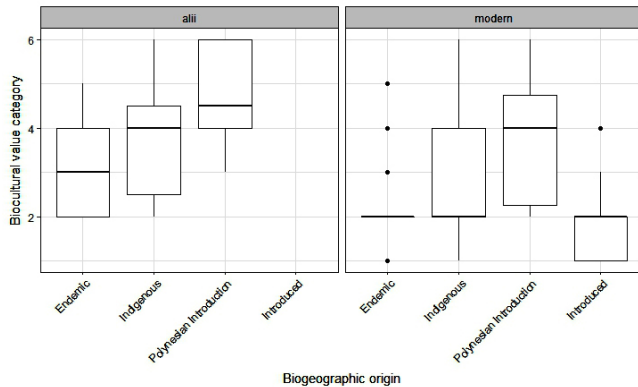
#### *Irreplaceability, or ability to conserve indigenous and endemic plant species*

Species of high biocultural value spanned all four categories of biogeographic origin: endemic, indigenous, Polynesian introduced, and modern introduction (Fig. 1). A third of the bioculturally important species were indigenous (10/30), and there were seven endemic, eight Polynesian introduced, and five modern introduced species. However, Polynesian introductions had the highest percentage of species of high biocultural value (85%, 6/7 species), followed by indigenous (52%, or 11/21), endemics (15% or 7/46), and modern introductions (17%, 6/35).

Although overall biocultural value has decreased over time (Fig. 2;  $v = -1.61$ ,  $SE = 0.33$ ,  $t = -4.8$ ,  $p < 0.001$ ), the relative biocultural value of species of different biogeographic origin has remained stable over time, i.e., no interaction between biogeographic origin and time period (Appendix 2 Table A2.2). That is, in both periods, Polynesian introductions had the highest values, followed by indigenous and endemic species. These differences were significant (Appendix 2 Table A2.2).

Two of the 30 species with high biocultural value today are considered invasive: the modern introductions of guava, *Psidium guajava* and *Psidium cattleianum*, which had BVCs of 4 and 3, respectively. For introduced species, the mean BVC was 2 and there is no significant difference in biocultural value between invasive and noninvasive species ( $v = 0.3$ ,  $SE = 0.75$ ,  $t = 0.4$ ,  $p = 0.68$ ).

**Fig. 2.** Change in biocultural value of plant species from the ali'i era (recorded from the early 1800s), to present.

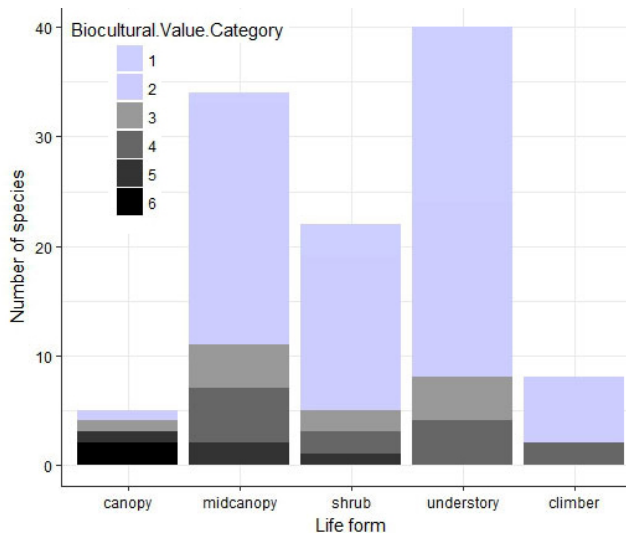


Species with high biocultural value were distributed across all life forms, but highest concentrations were among trees. Four of the five canopy trees were of high biocultural value, with the modern introduction and invasive tree, *Clusia rosea*, being the only one with low biocultural value. Just under one-third of midcanopy trees were of high biocultural value (11/35). In contrast, only about 18-25% of shrubs (5/22), understory species (8/40), climbers (2/8) were of high biocultural value.

*Ability to support native wildlife and persist over the long-term*

Biocultural value was significantly higher for plant species with high ability to support native wildlife than for those with a low ability to support native wildlife (Fig. 3a;  $v = 1.07$ ,  $SE = 0.4$ ,  $t = 2.4$ ,  $p = 0.01$ ; Appendix 2, Table A2.3). Plant species with high and very high potential to persist without continued intervention also had significantly higher biocultural value than those with low potential to persist (Fig. 3b;  $v = -1.35$ ,  $SE = 0.61$ ,  $t = 2.19$ ,  $p = 0.03$ ; Appendix 2, Table A2.4).

**Fig. 3.** Biocultural value of plant species as a function of life form. Biocultural value categories  $\geq 3$  are considered “high biocultural value” and are represented in grayscale.



The functional dispersion of the high biocultural value species assemblage was 0.395, and higher than that of the typical restoration assemblage (all those species currently recorded from the restoration plots at Limahuli), which was 0.335. If a species assemblage for restoration were selected by choosing the 30 species with top-ranking biocultural value (defined as having a BVC 3 or higher), most of these species would survive and reproduce without human intervention over the long term in today’s context, and half would have moderate to high ability to support native insects or birds (Fig. 4). However, although 60% of the species are native to Hawai’i, about a quarter are endemic to Hawai’i; thus the assemblage holds much lower utility in terms of the restoration goal of conserving irreplaceable species.

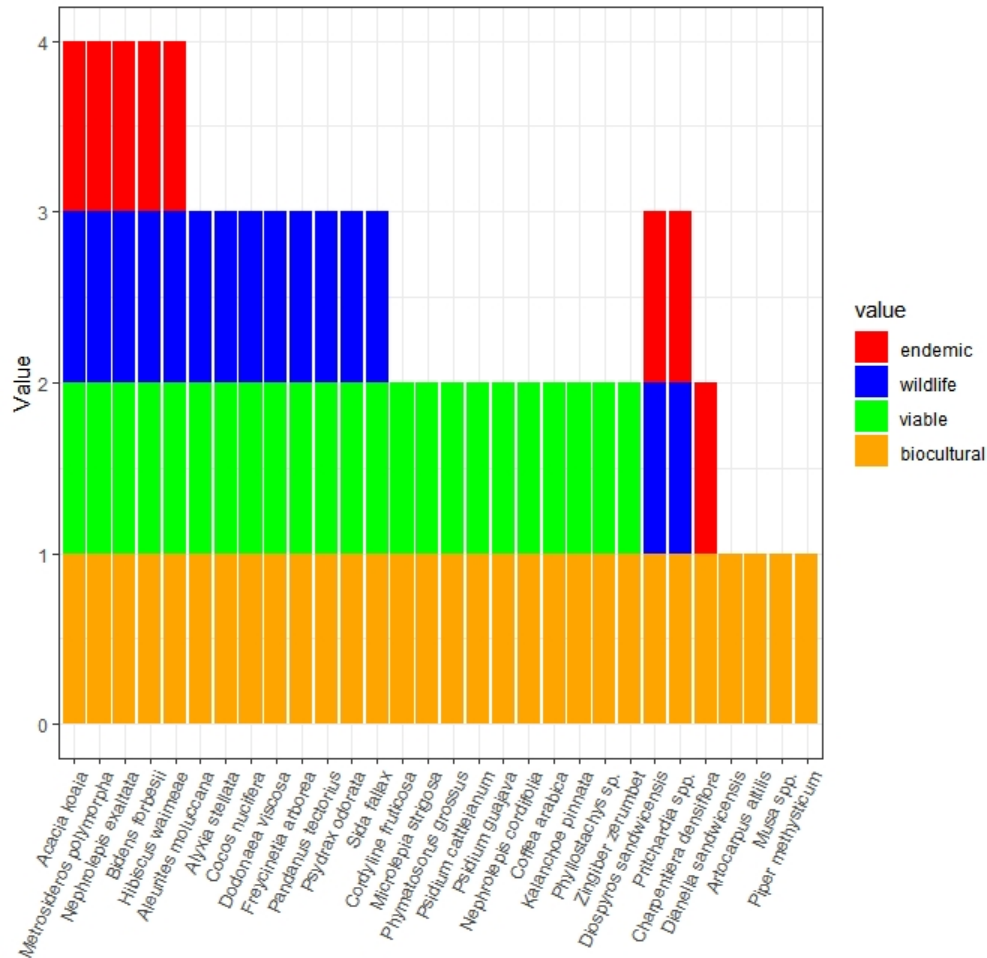
**DISCUSSION**

Resource managers from government agencies and NGOs recognize the value, and in many cases the necessity, of engaging Indigenous people and local communities (IPLCs) to ensure the success of conservation efforts and are also seeking to scale them up (Higgs 2003, DellaSalla et al. 2003, Kurashima et al. 2017, Burnett et al. 2019). Interest in biocultural approaches to conservation and restoration in Hawai’i has increased in recent decades with the rise of cultural revitalization movements (Chang et al. 2019, Gon and Winter 2019). Still, in Hawai’i at least, many hold reservations about the ability of biocultural approaches to foster effective conservation. Our study focused on a site where the process was driven by resource managers who were responding to the needs expressed by Native Hawaiian leaders in Hā’ena specifically and in the field of conservation broadly. Our findings indicate that restoration focused on species with the highest potential to maintain cultural interactions with forested areas today (defined here as those with the highest biocultural value), can also meet multiple other conservation objectives. However, we found that species with the highest biocultural value tended to be either Polynesian introduced species or common indigenous species; and they, therefore, overlapped little with species of maximum conservation concern, e.g., single-island endemics and archipelago endemics (Fig. 4).

*Biocultural value and biogeographic origin*

Our first hypothesis, that plants with the highest biocultural value would span all biogeographic origins, was supported; but we found unequal proportions of species of high biocultural value across biogeographic categories. Nearly three quarters of Polynesian introductions had high biocultural value today while few introduced species did. In addition, a greater proportion of indigenous species had high biocultural value compared to endemic species. There are at least two possible explanations for this. One reason for fewer endemic species of high biocultural value today is because many of them have become rare, as suggested by the “resource availability hypothesis” (Gaoue et al. 2017). However, in Limahuli at least, this is not likely to be the cause because our results show that the Hawaiian endemics also appear to have held less biocultural value than indigenous species historically. Another possible explanation is that these endemic species have always been rare, and their low availability would thereby affect the likelihood of their being selected for cultural use (Voeks 2004, de Albuquerque 2006). Although some endemic species are very abundant both locally and across the islands (e.g., ‘ōhi‘a lehua or *Metrosideros polymorpha*), many others such as single-island endemics are indeed confined to very limited ranges.

Fig. 4. Restoration success metrics provided by species of high biocultural value.



The lower biocultural value of endemic versus indigenous and Polynesian-introduced species may also be a function of “coevolutionary time,” the time over which a community or culture has interacted with a given species. The first Polynesians arrived to Hawai‘i ca 1000 AD after centuries of voyaging across the Pacific Islands (Abbott 1992, Whistler 2009). They were already using many species indigenous to both Hawai‘i and elsewhere in the Pacific Islands before arriving to Hawai‘i. Therefore, these plants may be expected to have more uses and feature more prominently in Hawaiian stories and ceremonies as they have coevolved with Polynesian cultures for thousands of years, rather than over a single millennium as with endemic species.

Polynesians hold a worldview that recognizes the relationships between biodiversity, land, and people (Timoti et al. 2017). As such, this study’s findings that Polynesian-introduced species in Hawai‘i maintain high biocultural value are notable because it suggests these species hold the strongest potential to foster continued interactions between communities and forested places. In our study, of the six species that ranked highest in terms of

their biocultural value, four are Polynesian introductions and one (*hala* or *Pandanus tectorius*) is indigenous. *Hala* is also a cultural keystone across the Pacific Islands, and was also likely included in the portable biocultural toolkit of early Polynesian voyagers (Whistler 2009). Almost all these species of high biocultural value are important in ceremony, stories, and the arts (song, dance, chants) today, in addition to having specific uses (such as *hula* or medicine). These species, therefore, facilitate the perpetuation of cultural ecosystem services in Hawai‘i, which were described by Pascua et al. (2017) as knowledge (*ike*), spiritual landscapes (*mana*), social interactions (*pilina kanaka*), and physical and mental well-being (*ola mau*). In the words of one community member who walked through one of the Limahuli forest restoration sites, “I didn’t know any of the trees, but then I saw *kukui* [*Aleurites moluccanus*, a Polynesian introduction], and I felt all right.” Although forest restoration programs across the state typically remove Polynesian introduced species, the very strong connection of people to these naturalized species suggests that leaving them could have important benefits, especially with regard to garnering community support for restoration projects.

Biocultural traditions are highly adaptive, so it is not surprising that we found that species of high biocultural importance included modern introductions as well. These tended to be trees favored for their fruit and firewood such as guava (*waiawī* or *Psidium guajava*, and *kuawa* or *Psidium cattleianum*). These also included non-natives that replaced natives with similar properties and that are used in cultural practices important today, such as *Phymatosorus grossus*, a non-native fern that has a similar smell to the native fern *Microsorium spectrum*. The latter is too rare to be easily accessible for gathering, and the former is common in and around human communities; and, therefore, has become a substitute species in *hula* and *lei*-making traditions. Although both species of guava are considered invasive in Hawai'i, all the other invasive species documented in our plots had low biocultural value. Given that restoration initiatives that include invasive species put the long-term persistence of other desirable species at risk, these may be best managed in home gardens and away from forest areas. Overall, although our results show losses in biocultural value over time, losses and gains in the biocultural value vary across species. Future research could explore the evolving relationship between Indigenous Hawaiian culture and the forest in more depth, and could identify trends, factors, and common traits in this evolving relationship at the species level.

We analyzed a narrow approach to biocultural restoration focusing on recreating an assemblage of species with high biocultural value as we describe here. In places where the protection of rare endemic species is an important conservation goal, a broader approach to biocultural restoration can be employed such as is done on a landscape scale. Many Indigenous cultures maintain the notion of a "sacred forest" as refugia for rare species, and designate areas accordingly (Bhagwat and Rutte 2006, Berkes 2018). In Hawaiian social-ecological systems, sacred forest (*wao akua*) is a designation given to the montane cloud forest regions in core watershed areas that are occupied by species assemblages with high levels of endemism (Winter and Lucas 2017). Such designations are traditionally associated with access restrictions to ensure their protection. Restoring such designated areas as part of a broader biocultural approach can create a mosaic of forest types that cumulatively maximize the synergistic benefits of various species assemblages, ranging from those with high biocultural value in the accessible areas, to those focused on maintaining high endemism in more restricted zones.

#### *Biocultural value and ability to support native wildlife*

Our second hypothesis, that plant species ranked at high ability to support native birds and insects also had higher biocultural value than those with low ability to support native wildlife, was supported. This is consistent with other research demonstrating overlap between cultural and ecological keystones or foundational species across the globe (Shackleton et al. 2018). Another reason that plants of high biocultural value have a high ability to support native wildlife is because they tend to be trees that are more likely to host birds or high numbers of insects, than herbaceous species. This does not include only native species; two Polynesian introduced trees (*kukui* or *Aleurites moluccana*, and 'ōhi'a'ai or *Syzygium malaccense*) were also ranked as moderately able to foster native wildlife because they are hosts to native insect species. The high biocultural value of many tree species is consistent with previous research (Winter and Lucas 2017, Gon et al. 2018), which explored the role of forests in the Hawaiian

social-ecological system, and demonstrated that both forested areas and groves of trees existed in *wao kanaka*, a social-ecological zone designated for human habitation and agro-ecology, in the precontact era.

#### *Biocultural value of species and their ability to persist and recuperate*

Our third hypothesis, that species of high biocultural value today would have a high ability to persist, was supported. The result that species ranked as having a high or very high ability to persist had significantly higher biocultural value than those with a lower ability to persist may be because the species with lower biocultural values tended to be single-island endemic species, many of which have lost their pollinators or dispersers and/or are unable to compete with invasive species, reducing their potential to persist.

Our fourth hypothesis, that restoring a species assemblage of high biocultural value would have similar functional trait diversity to that of one composed only of native species, was supported. The high functional diversity of response traits for high-biocultural value species assemblages, i.e., traits associated with responses to changing environmental conditions, suggests that such assemblages may be at least equally or more able to recuperate after disturbance, than the assemblage of indigenous and endemic species typically used for restoration at Limahuli. The potential for recuperation after disturbance is a major consideration for Limahuli resource managers, based on the history of hurricanes in the region. Although we are unaware of other research that has compared functional trait diversity between assemblages of plants with different levels of biocultural value, research has shown that forests managed for cultural and economic use do not have lower functional diversity than unmanaged sites (Mandle and Ticktin 2015). Additionally, in Hawai'i, the value of increasing functional trait diversity by including non-native, noninvasive trees in restoration initiatives has been demonstrated (Ostertag et al. 2015). Our results show that species of high biocultural value span all lifeforms and sizes. The variety of culturally valued traits is a likely contributor to the higher diversity of functional traits. For example, large, animal-dispersed seeds are valued for food and oil, while smaller wind-dispersed seeds are important for garlands (*lei*). Similarly, understory ferns are highly valued for the arts (*hula*), while trees are valued for firewood, etc.

#### **CONCLUSIONS**

At a point in history where there have been global losses in the diversity of both humanity and the natural systems humanity is founded on, conservation needs to be focused on restoring cultural diversity as much as biological diversity. Biocultural approaches help facilitate knowledge revival and protection, and the regeneration of cultural identity and expressions (Lyver et al. 2019). Biocultural approaches to restoration such as those examined in this research, which incorporate the values of IPLCs into projects aimed at restoring landscapes, should be considered by resource managers working in areas containing or adjacent to human populations. When applied at a landscape scale that includes mosaics of sacred forest, biocultural conservation can also help to achieve core conservation goals focused on rare and endangered species. Our results support already established international policy in conservation (e.g., the Hawai'i Commitments, IUCN 2016) and provide an even stronger



foundation for regional and local policy to embrace biocultural restoration as an important solution to address coupled sociocultural and environmental issues.

Biocultural approaches to forest restoration can not only increase the potential for continued interactions between communities and forests, but, as described by Chang et al. (2019), they can create pathways for feedback loops within social-ecological systems, e.g., the knowledge transfer from elder to grandchild, that drive sociocultural investment in biodiversity protection at an intergenerational scale. Such feedback loops create a lens through which local communities can come to see value in rare endemic species that would otherwise have no immediately perceived value. Our results highlight that this approach can also help support various other functions critical to long-term restoration success, including the ability to support native wildlife, to recuperate from disturbance, and to persist without continued human intervention. The latter two, in particular, are critical considerations for scaling up restoration projects, a major goal and challenge in Hawai'i (Price and Toonen 2017), as well as on many islands elsewhere where invasive species dominate (Kueffer and Kinney and 2017).

Today, the health, function, and very existence of many forested areas are threatened because of habitat destruction and degradation. We propose that forested areas with species assemblages of high biocultural value can be designated as "critical cultural habitats" akin to critical habitat designations for endangered species. Aiming to protect and restore critical cultural habitat could be a viable goal for resource managers with purview over areas adjacent to or surrounding Indigenous communities, because such an approach can not only facilitate restoration of forest while engaging, rather than alienating, local human communities, but can also simultaneously achieve other conservation goals. Our results indicate that the forests of the social-ecological community (*ahupua'a*) of Hā'ena, particularly those in Limahuli Valley, maintain a high level of biocultural value on a landscape scale; and can, therefore, be designated as critical cultural habitat.

The methods used in this research resulted in differing biocultural values for species that botanists classified as indigenous and those classified as endemic. Ethnotaxonomy does not always share such classifications (Winter 2012). Future research could elucidate whether these results hold true when considering ethnotaxonomic classifications. The results of this research point to a correlation that could have important implications for the further development of social-ecological system theory, namely, the finding that biocultural value seems to be correlated with coevolutionary time. This suggests that the longer a culture engages with a species, the higher the likelihood that it will have greater biocultural value. If this holds true, coevolutionary time can be considered a proxy measure for biocultural value until more methodical assessments can be made for the value of a given species. Future research could explore this notion in more depth.

*Responses to this article can be read online at:*  
<http://www.ecologyandsociety.org/issues/responses.php/11388>

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Appendix 1. Supplemental table of data used in this study.

Table A1.1. List of the observed species in the study area, Limahuli Valley (Hā'ena, Halele'a, Kaua'i). The list includes the corresponding species code used in data analysis, biogeographic status (endemic, indigenous, "Polynesian" = Polynesian introduction, "modern" = modern introduction), biocultural value (past and present), biocultural categories (past and present), and biocultural categories lost and gained between past and present.

Species	Species Code	Status	Biocultural Value Category (Ali'i era)	Biocultural Value Category (contemporary)	Biocultural Categories (Ali'i era)	Biocultural Categories (contemporary)	Lost categories (contemporary)	Gained categories (contemporary)
<i>Acacia koaia</i>	ACAKOA	endemic	5	3	a, b, d-h, n, p,	a, g, h	b, d-f, n, p	-
<i>Adenostemma viscosum</i>	ADEVIS	indigenous	2	2	a, b	a, b	-	-
<i>Adiantum hispidulum</i>	ADIHIS	modern	-	1	-	-	-	-
<i>Ageratina riparia</i>	AGERIP	modern	-	1	-	-	-	-
<i>Alectryon macrococcus</i>	ALEMAC	endemic	4	2	a-c, g, h, n	a	b, c, g, h, n	-
<i>Aleurites moluccana</i>	ALEMOL	Polynesian	6	6	a-h, l-o, r, t, u	a-h, l-o, r, t	u	-
<i>Alyxia stellata</i>	ALYTE	indigenous	5	4	a, b, d-f, m, n, s	a, d-f, m, n, s	b	-
<i>Arachis glabrata</i>	ARAGLA	modern	-	1	-	-	-	-
<i>Artocarpus altilis</i>	ARTALT	Polynesian	6	5	a-i, l, m, p, q, u	a, c-e, g-i, m, u	b, f, i, l, p, q	-
<i>Averrhoa carambola</i>	AVECAR	modern	-	2	-	c	-	c
<i>Bidens forbesii forbesii</i>	BIDFOR	endemic	3	3	a, b, n	a, b, n	-	-
<i>Blechnum appendiculatum</i>	BLEAPP	modern	-	1	-	-	-	-
<i>Canavalia napaliensis</i>	CANNAP	endemic	3	2	a, b, n	a, n	b	-
<i>Carex wahuensis</i>	CARWAH	endemic	2	1	a	-	a	-
<i>Charpentiera densiflora</i>	CHADEN	endemic	4	3	a, b, d-f	a, d,e	b, f	-
<i>Chrysodracon aurea</i>	CHRHAL	endemic	3	2	a, b, d, n	a, d	b, n	-
<i>Cibotium glaucum</i>	CIBGLA	endemic	2	2	a, n	a, n	-	-
<i>Citrus x sinensis</i>	CITSIN	modern	-	2	-	b, c	-	b, c
<i>Clidemia hirta</i>	CLIHIR	modern	-	1	-	-	-	-
<i>Clusea rosea</i>	CLUROS	modern	-	2	-	m	-	m
<i>Cocos nucifera</i>	COCNUC	indigenous	6	6	a-p, s, t	a, c, h-j, l-p, t	b, d-g, k, s	-
<i>Coffea arabica</i>	COFARA	modern	-	3	-	a, c, g	-	a, c, g
<i>Cordyline fruticosa</i>	CORFRU	Polynesian	5	5	a-d, i, k-o	a, b, d, i, k-n	c, o	-
<i>Crepidomanes minutum</i>	CREMIN	indigenous	2	2	a	a	-	-
<i>Cyanea hardyi</i>	CYAHAR	endemic	2	2	a	a	-	-
<i>Cyathea cooperi</i>	CYACOO	modern	-	1	-	-	-	-
<i>Cyclosorus dentatus</i> (Forssk.) Ching	CYCDEN	modern	-	1	-	-	-	-
<i>Cyclosorus interruptus</i>	CYCINT	indigenous	2	2	a, n	a	n	-
<i>Cyclosorus parasiticus</i> (L.) Farw.	CYCPAR	modern	-	1	-	-	-	-

<i>Cyperus javanicus</i>	CYPJAV	indigenous	4	2	a, b, d, i, j, n	a, b	d, i, j, n	-
<i>Cyrtandra confertiflora</i> (Wawra) C.B. Clarke	CYRCON	endemic	2	2	a, b	a	b	-
<i>Cyrtandra wainihaensis</i> H. Lév.	CYRWAI	endemic	2	2	a, b	a	b	-
<i>Delissea rhytidosperra</i>	DELRHY	endemic	2	2	a, b	a	b	-
<i>Deparia marginalis</i>	DEPMAR	endemic	2	1	a	-	a	-
<i>Dianella sandwicensis</i>	DIASAN	indigenous	3	3	a, b, i, r	a, i, r	b	-
<i>Dimocarpus longan</i>	DIMLON	modern	-	2	-	c	-	c
<i>Dioscorea bulbifera</i>	DIOBUL	Polynesian	3	2	a-c	a	b, c	-
<i>Dioscorea pentaphylla</i>	DIOPEN	Polynesian	3	2	a-c	a	b, c	-
<i>Diospyros sandwicensis</i>	DIOSAN	endemic	5	4	a-h	a, d-g	b, c, h	-
<i>Diplazium esculentum</i>	DIPESC	modern	-	2	-	c	-	c
<i>Dodonaea viscosa</i>	DODVIS	indigenous	5	4	a, b, d-h, m, n	a, b, e-g, n	d, h, m	-
<i>Dryopteris sp.</i>	DRYOPT	endemic	2	1	a	-	a	-
<i>Elephantopus mollis</i>	ELEMOL	modern	-	1	-	-	-	-
<i>Eragrostis variabilis</i>	ERAVAR	endemic	4	2	a, b, f, k, n	a	b, f, k, n	-
<i>Euphorbia haeleleana</i>	EUPHAE	endemic	2	1	a, b	-	a, b	-
<i>Freycinetia arborea</i>	FREARB	indigenous	5	4	a, b, d-f, i, j, l-n,	a, d, f, j, l-n	b, e, i	-
<i>Gahnia beecheyi</i>	GAHBEE	endemic	4	2	a, b, d, m, n	a	b, d, m, n	-
<i>Gardenia remyi</i>	GARREM	endemic	4	2	a, b, g, n, r	a, n	b, g, r	-
<i>Heteropogon contortus</i>	HETCON	indigenous	3	2	a, k, m, n	a, k	m, n	-
<i>Hibiscus kokio subsp.</i>	HIBKOKKAU	endemic	4	2	a, b, m, n, r	a, n	b, m, r	-
<i>Hibiscus waimeae subsp. hanneriae</i>	HIBWAIHAN	endemic	4	3	a, b, m-o, r	a, n, o	b, m, r	-
<i>Kadua acuminata</i>	KADACU	endemic	2	2	a, b	a	b	-
<i>Kalanchoe pinnata</i>	KALPIN	modern	-	3	-	a, b, o	-	a, b, o
<i>Lantana camara</i>	LANCAM	modern	-	1	-	-	-	-
<i>Lepisorus thunbergianus</i>	LEPTHU	indigenous	2	2	a	a	-	-
<i>Lipochaeta connata</i>	LIPCON	endemic	3	2	a, b, n	a, b	n	-
<i>Lobelia niihauensis</i>	LOBNII	endemic	3	2	a, f, m	a	f, m	-
<i>Metrosideros polymorpha</i>	METPOL	endemic	6	5	a, b, d-h, l-o	a, d-h, m, n	b, l, o	-
<i>Microlepis strigosa</i>	MICSTR	indigenous	4	4	a, b, d-f, m, n	a, b, d-f, m, n	-	-
<i>Microsorium grossum</i>	MICGRO	modern	-	4	-	a, b, e, f, m, n, s	-	a, b, e, f, m, n, s
<i>Musa spp.</i>	MUSSP	Polynesian	6	4	a-f, l-o, q, r	a-e, r	f, l-o, q	-
<i>Nephelium lappaceum</i>	NEPLAP	modern	-	2	-	c	-	c
<i>Nephrolepis cordifolia</i>	NEPCOR	indigenous	4	4	a-d, f, h, m, n	a, d, f, m, n	b, c, h	-
<i>Nephrolepis exaltata</i>	NEPEXA	endemic	4	4	a-d, f, h, m, n	a, d, f, m, n	b, c, h	-
<i>Nestegis sandwicensis</i>	NESSAN	endemic	4	2	a, b, f-h,	a, g	b, f, h	-

<i>Nototrichium sandwicense</i>	NOTSAN	endemic	2	2	a, b	a	b	-
<i>Ochrosia kauaiensis</i> St. John	OCHKAU	endemic	3	2	a, b, r	a	b, r	-
<i>Ophioderma pendulum</i> subsp. <i>Falcatum</i> (C. Presl) R. T. Clausen	OPHPENFAL	indigenous	2	2	a	a	-	-
<i>Opismenus hirtellus</i>	OPLHIR	modern	-	1	-	-	-	-
<i>Oxalis</i> sp.	OXASP.	modern	-	1	-	-	-	-
<i>Pandanus tectorius</i>	PANTEC	indigenous	6	5	a-e, f, h, j, k, n, s	a-c, f, h, j, k, n, s	d, e	-
<i>Paspalum conjugatum</i>	PASCON	modern	-	1	-	-	-	-
<i>Paspalum urvillei</i>	PASURV	modern	-	1	-	-	-	-
<i>Peperomia blanda</i>	PEPBLA	indigenous	2	2	a, b	a, b	-	-
<i>Persea americana</i>	PERAME	modern	-	2	-	c	-	c
<i>Phlebodium aureum</i>	PHLAUR	modern	-	2	-	a	-	a
<i>Phyllostachys</i> sp.	PHY SP.	Polynesian	6	4	a-g, j, o, p	a, c-g, p	b, j, o	-
<i>Physalis peruviana</i>	PHYPER	modern	-	2	-	a, c	-	a, c
<i>Piper methysticum</i>	PIPMET	Polynesian	4	4	a-f, l	a-f	l	-
<i>Pipturus kauaiensis</i>	PIPKAU	endemic	4	2	a-c, i, q	a, b	c, i, q	-
<i>Pisonia umbellifera</i>	PISWAG	endemic	2	2	a, u	a, u	-	-
<i>Pittosporum napaliensis</i>	PITNAP	endemic	2	2	a, b	a	b	-
<i>Pluchea carolinensis</i>	PLUCAR	modern	-	1	-	-	-	-
<i>Plumbago zeylanica</i>	PLUZEY	indigenous	3	2	a, b, r	a	b, r	-
<i>Polyscias racemosa</i>	POLRAC	endemic	2	1	a	-	a	-
<i>Pritchardia</i> spp.	PRISPP	endemic	5	3	a-e, j, k, m-o	a, c, e, k	b, d, j, m-o	-
<i>Psidium cattleianum</i>	PSICAT	modern	-	3	-	a-c, h	-	a-c, h
<i>Psidium guajava</i>	PSIGUA	modern	-	4	-	a-c, g, h	-	a-c, g, h
<i>Psilotum nudum</i>	PSINUD	indigenous	3	2	a, b, n	a, n	b	-
<i>Psychotria mariniana</i>	PSYMAR	endemic	3	2	a, b, o, h	a, o	b, h	-
<i>Psydrax odorata</i>	PSYODO	indigenous	4	4	a, b, e, g, h, n	a, e, g, h, n	b	-
<i>Pteralyxia kauaiensis</i>	PTEKAU	endemic	2	2	a, b	a	b	-
<i>Rauvolfia sandwicensis</i>	RAUSAN	endemic	3	2	a, b, h	a	b, h	-
<i>Rubus rosifolius</i>	RUBROS	modern	-	2	-	a, c	-	a, c
<i>Sadleria cyatheoides</i>	SADCYA	endemic	3	2	a, e, f	a	e, f	-
<i>Santalum pyrularium</i>	SANFRE	endemic	4	2	a, b, e-g, n, s	a	b, e-g, n, s	-
<i>Scaevola gaudichaudiana</i>	SCAGAU	endemic	3	2	a, b, e, n	a, e	b, n	-
<i>Scaevola procera</i>	SCAPRO	endemic	3	2	a, b, e, n	a, e	b, n	-
<i>Schefflera actinophylla</i>	SCHACT	modern	-	2	-	a, n	-	a, n
<i>Schiedea stellarioides</i>	SCHSTE	endemic	2	2	a	a	-	-
<i>Sida fallax</i>	SIDFAL	indigenous	5	3	a, b, f, n, r	a, b, f, n	r	-

<i>Smilax melastomifolia</i>	SMIMEL	endemic	2	2	a, b	a	b	-
<i>Sphenomeris chinensis</i>	SPHCHI	indigenous	4	2	a, b, d, f, m, n, r	a, n	b, d, f, m, r	-
<i>Syzygium malaccense</i>	SYZMAL	Polynesian	4	2	a-c, g, h	a, c	b, g, h	-
<i>Theobroma cacao</i>	THECAC	modern	-	2	-	c	-	c
<i>Touchardia latifolia</i>	TOULAT	endemic	3	2	a, b, i	a, i	b	-
<i>Vandenboschia cyrtotheca</i> (Hillebr.) Copel.	VANCYR	endemic	2	2	a	a	-	-
<i>Wikstroemia oahuensis</i>	WIKOAH	endemic	3	2	a, b, d, l	a	b, d, l	-
<i>Zingiber zerumbet</i>	ZINZER	Polynesian	4	3	a-c, m, n, s	a, b, n, s	c, m	-



Appendix 2.

Table A2.1. Functional traits used to calculate functional dispersion of each restoration scenario

Functional Trait	Variable type	Most common sources
Growth form	Categorical: categories based on Cornelissen et al. 2003	Literature: Wagner et al. 1999, Palmer 2003, <a href="http://www.hort.perdue.edu">www.hort.perdue.edu</a>
Maximum height	Continuous	Literature: Wagner et al. 1999, <a href="http://worldagroforestry.org">worldagroforestry.org</a>
Raunkier life form	Categorical	Literature: Wagner et al. 1999
Clonality	Binary (yes/no)	Literature: Palmer 2003; Expert opinion of Limahuli managers
Seed mass	Continuous	Literature: Kew Royal Botanical Garden seed information database ( <a href="http://data.kew.org/sid/">data.kew.org/sid/</a> ); Data from NTBG seedlab
Seed dispersal mechanism	Categorical (wind; animal-internal, animal-external; unassisted)	Literature: Sakai et al. 1995*, <a href="http://www.worldagroforestry.com">www.worldagroforestry.com</a>

\*For species with seeds >6mm length, we assumed that dispersal is unassisted since native dispersers are no longer present and introduced birds in Hawai‘i do not successfully disperse seeds larger than 6 mm in length.

Table A2.2. Results of logistic ordered regression model testing the effects of biogeographic origin and time period on biocultural value. Species biogeographic origin compared to Polynesian introductions, time compared to *ali'i* era.

	Value	Std Error	t value	p value
Indigenous	-2.08	0.61	-3.39	<0.001
Endemic	-3.19	0.59	-5.04	<0.001
Introduced	-4.65	0.71	-6.49	<0.001
Time _modern	-1.52	0.33	-4.66	<0.001

Table A2.3. Results of logistic ordered regression model testing the relationship between species biocultural value and the ability of a given species ability to conserve native wildlife (insects and bird).

Ability to support wildlife (compared to “low”)	Value	Std Error	t value	p value
Moderate	0.94	0.58	1.63	0.1
High	1.07	0.43	2.48	0.01

Table A2.4. Results of logistic ordered regression model testing the relationship between species biocultural value and its ability to persist over the long term without continued intervention.

Ability to persist (compared to “low”)	Value	Std Error	t value	p value
High	1.35	0.61	2.19	0.03
Very high	0.95	0.61	1.86	0.06