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CONTRIBUTED PAPERS

Extinction risk of the endemic vascular flora of Kauai, Hawaii, based on IUCN assessments

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Article impact statement: Extreme extinction risk of the endemic vascular flora of Kauai Hawaii calls for urgent conservation measures.

Abstract

The International Union for Conservation of Nature's Red List of Threatened Species (IUCN Red List) is the world's most comprehensive information source on the global conservation status of species. Governmental agencies and conservation organizations increasingly rely on IUCN Red List assessments to develop conservation policies and priorities. Funding agencies use the assessments as evaluation criteria, and researchers use meta-analysis of red-list data to address fundamental and applied conservation science questions. However, the circa 143,000 IUCN assessments represent a fraction of the world's biodiversity and are biased in regional and organismal coverage. These biases may affect conservation priorities, funding, and uses of these data to understand global patterns. Isolated oceanic islands are characterized by high endemicity, but the unique biodiversity of many islands is experiencing high extinction rates. The archipelago of Hawaii has one of the highest levels of endemism of any floristic region; 90% of its 1367 native vascular plant taxa are classified as endemic. We used the IUCN's assessment of the complete single-island endemic (SIE) vascular plant flora of Kauai, Hawaii, to assess the proportion and drivers of decline of threatened plants in an oceanic island setting. We compared the IUCN assessments with federal, state, and other local assessments of Kauai species or taxa of conservation concern. Finally, we conducted a preliminary assessment for all 1044 native vascular plants of Hawaii based on IUCN criterion B by estimating area of occupancy, extent of occurrence, and number of locations to determine whether the pattern found for the SIE vascular flora of Kauai is comparable to the native vascular flora of the Hawaiian Islands. We compared our results with patterns observed for assessments of other floras. According to IUCN, 256 SIE vascular plant taxa are threatened with extinction and 5% are already extinct. This is the highest extinction risk reported for any flora to date. The preliminary assessment of the native vascular flora of Hawaii showed that 72% (753 taxa) is threatened. The flora of Hawaii may be one of the world's most threatened; thus, increased and novel conservation measures in the state and on other remote oceanic islands are urgently needed.

KEYWORDS
conservation assessment, endangered plants, endemicity, extinction, oceanic island biodiversity

Resumen

La Lista Roja de la Unión Internacional para la Conservación de la Naturaleza (Lista Roja UICN) es la fuente más completa a nivel mundial de información sobre el estado de conservación de las especies. Las agencias gubernamentales y las organizaciones para la conservación dependen cada vez más de las valoraciones en esta lista para desarrollar sus políticas y prioridades de conservación; también los organismos de financiamiento usan las valoraciones como criterios de evaluación y los investigadores aplican metaanálisis a los datos de la lista para abordar preguntas fundamentales y aplicadas a las ciencias de la conservación. Sin embargo, las casi 143,000 valoraciones de la UICN representan sólo una fracción de la biodiversidad mundial y están sesgadas en cuanto a la cobertura regional y de organismos. Estos sesgos pueden afectar a las prioridades de conservación, al financiamiento y al uso de estos datos para entender los patrones globales. Las islas oceánicas aisladas se caracterizan por un alto endemismo, aunque la biodiversidad única de muchas de estas islas está experimentando un índice elevado de extinciones. El archipiélago de Hawái tiene uno de los niveles más altos de endemismo de cualquier región florística con el 90% de los 1,367 taxones nativos de flora vascular clasificado como endémico. Usamos las valoraciones de la UICN para todas las plantas vasculares endémicas de una sola isla (ESI) en Kauai, Hawái, para evaluar la proporción y los impulsores de la declinación de plantas amenazadas en el entorno de una isla oceánica. Comparamos las valoraciones de la UICN con las federales, estatales y otras valoraciones locales de las especies o taxones de Kauai que son de importancia para la conservación. Por último, realizamos una valoración preliminar para las 1,044 especies de plantas vasculares nativas de Hawái con base en el criterio B de la UICN mediante la estimación del área de ocupación, la extensión de la ocurrencia y el número de localidades para determinar si el patrón hallado para la flora vascular ESI de Kauai es comparable con la flora vascular nativa de las islas hawaianas. Comparamos nuestros resultados con los patrones observados en las valoraciones de otras floras. De acuerdo con la UICN, el 95% de los taxones de plantas vasculares ESI de Kauai están amenazadas y el 5% ya se encuentra extinto. A la fecha, este es el riesgo de extinción más alto reportado para cualquier flora. La valoración preliminar de la flora vascular nativa de Hawái mostró que el 72% (753 taxones) se encuentra amenazado. La flora de Hawái puede ser una de las más amenazadas a nivel mundial; por lo tanto, se necesitan urgentemente medidas novedosas e incrementadas en el estado y en otras islas oceánicas remotas.

PALABRAS CLAVE

biodiversidad de islas oceánicas, endemismo, extinción, plantas en peligro de extinción, valoración de la conservación

基于世界自然保护联盟的评估分析夏威夷考艾岛特有维管植物区系的灭绝风险

【摘要】《世界自然保护联盟濒危物种红色名录(IUCN Red List)》是关于全球物种保护状况最全面的信息来源。政府机构和保护组织越来越依赖于《IUCN红色名录》的评估来制定保护政策和确定保护优先次序。同时, 资助机构将其用作评价标准, 研究者也使用红色名录数据的荟萃分析来解决保护科学的基础问题和应用问题。然而, 已有的约143,000项IUCN评估只代表了世界生物多样性的一小部分, 并且在地区和生物的覆盖度上有所偏倚。这些偏倚可能会影响到保护优先次序、资金分配, 以及利用这些数据来了解全球格局。孤立的海洋岛屿具有高地方性的特点, 但许多岛屿独特的生物多样性正面临着高灭绝风险。夏威夷群岛是所有植物区系中地方性最强的地区之一, 当地1367种维管植物中有90%被列为地方特有种。我们利用IUCN对夏威夷考艾岛范围内完全在单一岛屿特有的维管植物区系的评估, 分析了海洋岛屿环境中受威胁植物的比例及其种群下降的原因。我们还将世界自然保护联盟的评估与考艾岛物种或类群的联邦、州及其它地方性保护评估进行了比较。最后, 我们根据IUCN标准B对夏威夷所有1044种本地维管植物进行了初步评估, 通过估计占有面积、出现范围和出现地点的数量来确定考艾岛完全在单一岛屿特有的维管植物区系格局是否与夏威夷群岛的本地维管植物区系类似。我们进一步比较了本研究的结果与其他植物区系的评估格局。

根据IUCN的数据, 考艾岛256种完全在单一岛屿特有的维管植物中, 有95%面临灭绝风险, 而5%已经灭绝。这是迄今为止在所有植物区系中发现的最高的灭绝风险。对夏威夷本地维管植物区系的初步评估表明, 72%的植物(753个类群)受到威胁。夏威夷的植物区系可能是世界上面临最大威胁的植物区系之一;因此, 迫切需要在这个州及其它偏远的海洋岛屿上采取更多、更具创新性的保护措施。
【翻译:胡怡思;审校:聂永刚】

关键词: :保护评估, 濒危植物, 地方性, 灭绝, 海洋岛屿生物多样性

INTRODUCTION

Up to 1 million species of plants and animals are threatened with extinction (IPBES, 2019). Although extinction of species is common, it is normally balanced by speciation (Barnosky et al., 2011). Comparison of fossil and modern extinction data suggests that losing the species currently considered threatened with extinction would be similar to another mass extinction event (Barnosky et al., 2011). An average of 2.3 plant species per year have gone extinct over the past 250 years, and while this rate is slower than for some other organisms, it is still above the baseline turnover rate (Humphreys et al., 2019). Hawaii has exceptionally more plant extinctions than other geographical regions, which is alarming because plant extinctions endanger other organisms, ecosystems, and human well-being (Humphreys et al., 2019).

The current framework for plant conservation is provided by the Global Strategy for Plant Conservation (GSPC), which is a program of the United Nations Convention on Biological Diversity (CBD) aiming to halt continuing loss of plant diversity (CBD, 2021).

The International Union for Conservation of Nature's Red List of Threatened Species (IUCN Red List), established in 1964, is the world's most comprehensive and widely acknowledged information source on the conservation status of species. It provides information and analyses on the status, trends, and threats to species to inform and catalyze action for biodiversity conservation. Governments and conservation organizations are increasingly relying on IUCN Red List assessments to develop conservation policies and priorities (IUCN, 2022). Funding organizations, including the Global Environment Facility, The Mohamed bin Zayed Species Conservation Fund, and Fondation Franklinia, also use the IUCN Red List to guide funding priorities for conservation.

The most recent update of the IUCN Red List, 2021–3, includes 142,577 species (IUCN, 2022), which represents about 7% of global biodiversity. Despite massive international efforts, few taxonomic groups are completely assessed and the level of data and documentation varies among regions, ecosystems, and taxonomic groups, and there are many recognized gaps and biases. Terrestrial systems are better covered than other environments, and there is a strong bias toward animals. In this latest update, 58,343 plants have been assessed, corresponding to nearly 15% of the world's estimated 400,000 plant species (WFO, 2021). It is unknown what proportion of unlisted taxa are threatened. Efforts to assess more taxa are challenged by lack of funding, expertise, and accurate biological data. Among resource-limited organizations and agencies, the urgent need to implement on-the-ground conservation for threatened taxa takes priority over data collection and assessment of additional species.

Countries and regions often use locally adapted conservation assessment systems, such as that associated with the U.S. Endangered Species Act (USFWS, 2021), for conservation planning. However, with the increasing use of the IUCN Red List for developing prioritization and policies and an increasingly international conservation agenda, including the GSPC, current gaps and biases of the IUCN Red List may affect global analyses and funding decisions at the expense of taxa and regions that are not well represented on the IUCN Red List.

Oceanic island systems are generally characterized by high endemicity due to their isolation (Francisco-Ortega et al., 2007), but the unique biodiversity of many islands is currently subject to exceptionally high extinction rates (Humphreys et al., 2019) due to habitat reduction from fire and large-scale land conversion to agriculture (Armstrong & Bier, 1983; Gon et al., 2018; Kirch, 1982), invasive plants and animals, predation from non-native animals, disease, and loss of pollinators and seed dispersers (Bruegmann et al., 2002; Kier et al., 2009; Sakai et al., 2002; Wood et al., 2019). Endemic taxa may be intrinsically threatened due to their restricted distribution (Ellstrand & Elam, 1993; Işik, 2011) and are therefore highly important to conservation prioritization (Orsenigo et al., 2018).

The archipelago of Hawaii has one of the highest levels of endemism in the world; nearly 90% of its 1367 native plant taxa are endemic (Francisco-Ortega et al., 2007; Wagner et al., 1999, 2005). Of these 1229 endemic taxa, 703 (57%) are single-island endemic (SIE) taxa. The oldest of the main islands, Kaua'i, harbors nearly 36% of all SIE taxa (Wagner et al., 2005) (Figure 1).

The flora of the Hawaiian Islands is undergoing significant extinctions; 134 endemic plants are considered extinct or extinct in the wild (Wood et al., 2019). Thirty-seven percent of the extant endemic or 33% of the native flora (454 taxa) are listed as threatened or endangered under the U.S. Endangered Species Act (USFWS, 2021) and the State of Hawaii, and many species are still lacking assessments. The Plant Extinction Prevention Program (PEPP) has compiled a conservation priority list containing 257 plant taxa. Generally, these taxa have fewer than 50 individuals left in the wild (PEPP, 2021). The Hawaii Strategy for Plant Conservation (HSPC), modeled after the GSPC, addresses the unique challenges facing the Hawaiian archipelago and includes a list of species of conservation importance (SCI),

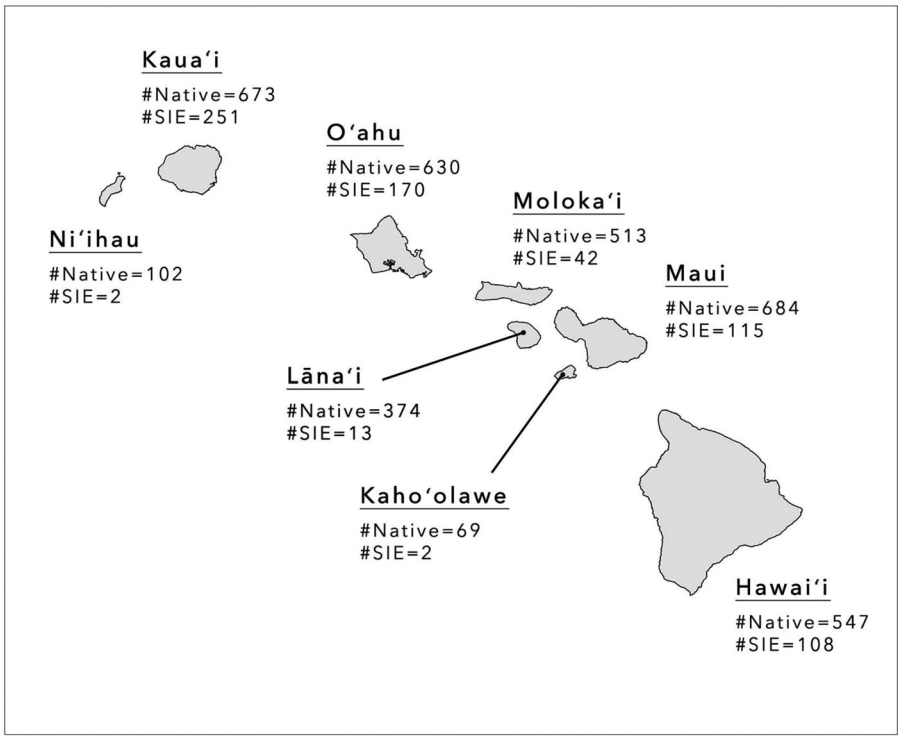

FIGURE 1 Number of native and single-island endemic (SIE) vascular plant taxa on each of the 8 main Hawaiian islands based on Wagner et al. (2005)

which as of September 2021 included 727 taxa (53% of the native flora; 59% of the endemic flora) that are considered important for a variety of reasons, including IUCN Red List status as endangered (EN) or critically endangered (CR), extinction vulnerability, habitat restoration, and cultural significance (Keir & Weisenberger, 2014).

While a complete IUCN Red List assessment of the flora of Hawaii is urgently needed, sufficient data are not available for the majority of the flora (Wagner et al., 2005) (Figure 1), especially for multi-island species, which are monitored by different entities on different islands.

We used the IUCN Red List assessment of the complete SIE vascular plant flora of Kauai to determine the proportion and drivers of decline of threatened plants in an oceanic island setting. We then compared results of the IUCN Red List taxa assessments with federal, state, and other local assessments of species or taxa of conservation concern. Finally, we explored whether the threatened pattern found for the SIE vascular plants of Kauai is comparable to that of native vascular flora across the archipelago of Hawaii and to patterns observed for completed assessments of other floras.

METHODS

Kauai single-island endemic vascular plant taxa checklist

Following the approach of Orsenigo et al. (2018), we focused on SIE vascular plants for the island of Kauai (Figure 2 & Appendix S1). Substantial collections and monitoring data have been assembled for these taxa over the past 5 decades by National Tropical Botanical Garden (NTBG, 2021) and collaborating partners, including the Kauai branches of the Department of Land and Natural Resources (DLNR), the Plant Extinction Prevention Program (PEPP), The Nature Conservancy (TNC), and the U.S. Fish and Wildlife Service (USFWS).

We excluded multi-island, indigenous, and introduced taxa. However, 4 taxa, which historically were multi-island species, but which are now restricted to Kauai, were also assessed as Kauai single-island taxa (*Brighamia insignis*, *Kadua cookiana*, *Panicum niihauense*, and *Plantago princeps* var. *anomala*). We focused on vascular plants because they are taxonomically well understood and have been more intensively monitored than nonvascular plants.

In alignment with the IUCN Species Survival Commission Hawaiian Plant Specialist Group (HPSG), we used the Flora of the Hawaiian Islands website (Wagner et al., 2005) as a basis to build the taxonomic list of recognized taxa of native vascular plants endemic to Kauai. While this is the most updated published checklist of all Hawaiian vascular plant taxa, in a few cases further taxonomic updates were needed to follow the IUCN Red List taxonomy. Specifically, we included *Cryptocarya mannii*, *Lysimachia ovoidea*, and *Melicope knudsenii* as Kauai SIE species (Appelhans et al., 2014; Flynn & Watson, 2015; Morden et al., 2015). *Cyanea salicina* is considered a synonym of *C. recta* by local botanists; differentiation is questionable because the type specimen contains only vegetative characters. Therefore, both taxa were assessed together as *C. recta*. After the completion of the campaign, an update of the Flora of the Hawaiian Islands (Wagner et al., 2005) included *Dracaena halemanuensis* as a Kauai SIE taxon. But no IUCN Red List assessment has been made, so it is not included here. The Kauai SIE species *Bidens forbesii*, *Cyr-*

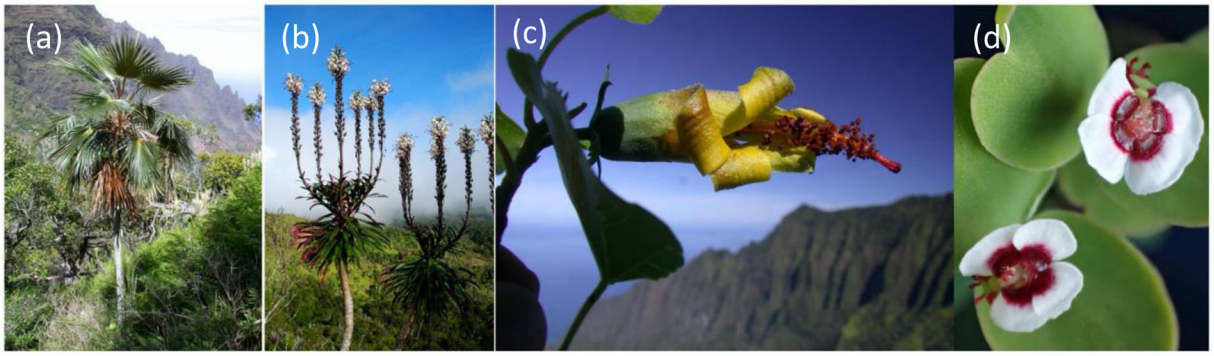

FIGURE 2 Examples of the Kauai single-island endemic (SIE) vascular flora: (a) *Pritchardia minor* (Arecaceae) (endangered), (b) *Lobelia villosa* (Campanulaceae) (endangered), (c) *Hibiscadelphus woodii* (Malvaceae) (critically endangered), and (d) *Euphorbia eleanoriae* (Euphorbiaceae) (critically endangered). Photos by Kenneth R. Wood, National Tropical Botanical Garden

tandra kealiae, and *Dubautia imbricata* have been assessed for both species and subspecies or variety level, but only the lower taxa were included here to avoid duplication.

IUCN Red List data

Assessment of the Hawaiian flora for the IUCN Red List has been ongoing since 1998, when The World Conservation Monitoring Centre (WCMC) submitted a large number of assessments of endangered taxa to the IUCN Red List. A local assessment campaign followed in 2003 (IUCN, 2022). However, many of the assessed taxa from these early campaigns were categorized as data deficient (DD). Leading up to the World Conservation Congress in Hawaii in 2016, local contributors submitted 208 assessments of Hawaiian plant taxa, and efforts to assess the flora, focused on the most rare and endangered plants, have continued at a modest pace.

We obtained data from 128 IUCN Red List assessments from 2015 to 2019 of the SIE vascular flora of Kauai (IUCN, 2022). In addition, we conducted new assessments of 128 SIE vascular plant taxa of Kauai, which are included in the IUCN Red List (Appendix S1), except for the assessment of *Nototrichium divaricatum*, which will be published in the next 2022 update. All assessments were peer reviewed by other Hawaii, or in most cases Kauai, assessors, and by the IUCN Red List Unit before publication.

A few of these assessments are updates of previous assessments of presumably extinct or nearly extinct taxa for which new populations had been discovered (e.g., *Cyanea kuhihewa*, *Hibiscadelphus woodii*), in some cases resulting in a change of status from extinct (EX) or extinct in the wild (EW) to CR. Detailed accounts are provided in the assessments for individual taxa (IUCN, 2022) (Appendix S1). Although some taxa are in need of periodic assessment updates, which could potentially change their status, we considered the potential number of cases small and not likely to affect our overall conclusions.

The assessments of all taxa followed the IUCN Red List criteria for placing taxa in 1 of 8 categories—EX, EW, CR, EN, vulnerable (VU), near threatened (NT), least concern (LC), or DD—based on current guidelines and criteria defined by the IUCN Standards and Petitions Committee (IUCN, 2019). The 5 evaluation criteria used and defined by the IUCN (2019) are population size reduction (criterion A); geographic range size and fragmentation, few locations, decline, or fluctuations (B); small and declining population size and fragmentation, fluctuations, or few subpopulations (C); very small population or very restricted distribution (D); and quantitative analysis of extinction risk (E). A taxon will by default be placed in the highest threat category obtained by any of the criteria.

For the new assessments of taxa conducted as part of this study, we used a comprehensive database of distributions, including herbarium specimens, conservation collections of living material, and field survey data, compiled by NTBG and collaborators over 5 decades of extensive fieldwork and monitoring (NTBG, 2021) as a basis for calculating or estimating geographic range and population metrics.

Following standard recommendations from the IUCN Red List Unit, area of occurrence (AOO) was calculated by laying a 2×2 km grid over point locality data of the taxon with ArcGIS implemented in ArcMap software (ESRI, 2011) and extent of occurrence (EOO) was calculated by drawing a minimum convex polygon around all point locality data of the taxon with ArcMap software. For taxa assessed before 2020, a 1×1 km grid was used for calculating AOO.

With the aid of recent herbarium data and personal field knowledge of the distribution and abundance of Kauai SIE taxa, polygons were drawn around each taxon's known distribution. Separate valley sites were designated as subpopulations. For each valley subpopulation, we determined AOO, elevational range, and number of mature individuals and ultimately summed for totals. The number of individuals was straightforward for the rarest taxa due to continuous monitoring. For more common taxa, the number of individuals within a 100^2-m area was estimated first and then extrapolated for the total area of occurrence within each subpopulation. For the number of locations, each unique plant community was considered as a separate location, and an additional location was added if the taxon was in a protected, fenced exclosure.

Populations were considered severely fragmented if more than 50% of the population occurred in isolated subpopulations, between which there was little or no genetic exchange, such that subpopulations were sufficiently small that they might

not be viable in the long term. Fragmentations are generally amplified in the Hawaiian Islands by other extrinsic conditions, such as loss of or reduction in pollinators (Kearns et al., 1998; Walsh et al., 2019; Wood et al., 2019).

Current trends were considered decreasing for AOO, EOO, number of subpopulations, number of mature individuals, and quality and extent of habitat based on estimated or observed data, including effects of invasive weeds and animals (Weller et al., 2018); climate change, including more extreme temperatures and fluctuations in precipitation; and increase in stochastic events, such as landslides and hurricanes (Fortini et al., 2013).

No assessments were submitted as DD. While the quality and depth of data accompanying each assessment varied, there were sufficient data to designate a taxon's status based on IUCN criteria B, C, and D. Quantitative data over time needed for application of criteria A and E were generally not available.

Although assessment practices vary between assessors and over time, and guidelines from the IUCN Red List are regularly updated, the assessments from 2015 onward are generally comparable with the current IUCN guidelines (IUCN, 2019).

Use and trade

Information on human use of taxa was obtained from the Hawaiian Ethnobotany Online Database hosted by the Bernice P. Bishop Museum (Bishop Museum, 2021). Sometimes use was restricted to a specific species or taxon (e.g., *Lysimachia daphnoides*), but in many cases, an entire genus (e.g., *Bidens*, *Coprosma*, *Dubautia*, *Myrsine*, and *Pritchardia*) or a set of related taxa was used interchangeably, in which case any taxon from that genus was considered subject to the same uses (Bishop Museum, 2021) (Appendix S1).

We did not assess whether reported use was only historical, but generally use was not considered a major threat. Plant use in general is often focused on common species (Cámara-Leret et al., 2017; Palmer, 2004; Stepp & Moerman, 2001). Hawaiian plant use is largely influenced by Polynesian seafarers who brought along on their voyages a set of useful plants (Whistler, 2009). However, unintended harvest by mistake or because traditional taxonomy considers a rare plant part of a more common species concept could be affecting rare species, which is largely uninvestigated for Hawaiian plants.

Federal and local conservation status

For comparison, we also coded our Kauai SIE taxa set according to their status as threatened or endangered under the U.S. Endangered Species Act (USFWS, 2021), the PEPP list (PEPP, 2021), and the Hawaii Strategy for Plant Conservation list of SCI (Laukahi, 2021) (Appendix S1). We observed only 1 case of taxonomic discrepancy. It was related to *Schiedea spergulina*, for which 2 former subspecies were assessed as threatened and endangered, respectively, under the U.S. Endangered Species Act (USFWS, 2021). We adopted the threatened category for this species. *Euphorbia eleanoriae* has been included previously in the PEPP list, but was excluded in the most recent update (PEPP, 2021) due to recent findings of new subpopulations by drone surveys along cliffs that increased counts of the wild population significantly (B. Nyberg, personal observation).

Preliminary conservation assessment of the native vascular flora of the Hawaiian Islands

To estimate whether the patterns obtained for the SIE vascular flora of Kauai provide a reasonable estimate for the entire native vascular flora of the Hawaiian Islands, we estimated AOO, EOO, and number of locations to apply IUCN criterion B for all 1044 native vascular plants of Hawaii included in a previous study of plant species geographic distribution ranges (Price et al., 2012).

The polygon shapefiles available from the previous study (Price et al., 2014) were converted to a 1 × 1 km grid of points with ArcGIS (ESRI, 2011). These points were imported into the R (R Core Team, 2021) package 'ConR' (Dauby et al., 2017) to calculate EOO and AOO. Oceans were excluded in the EOO calculations for multi-island taxa because oceanic islands are an extreme distribution case for terrestrial species (Gaston & Fuller, 2009). Number of locations were estimated automatically by the R function ConR::ConR (Dauby et al., 2017), which differs from the IUCN guidelines, which also require unavailable contextual information about threats (Dauby et al., 2017). Although these status classifications are based solely on estimated AOO, EOO (excluding oceans), and number of locations, they provide a preliminary estimate based on data for 1044 species of the proportion of native vascular Hawaiian plants that can be expected to be assessed as threatened (Appendix S2).

RESULTS

IUCN Red List assessments

The final checklist of Kauai SIE vascular plants included 256 taxa in 47 families (10 pteridophyte, 37 angiosperm) and76 genera (244 species, 19 subspecies, and 21 varieties) (Appendix S1). These 256 taxa represent 38% of the native flora of Kauai (673 taxa) and 46% of the Hawaii endemic taxa that occur on Kauai (554 taxa).

Thirteen taxa (5%) were categorized as EX, 5 of which were from the genus *Cyanea* in Campanulaceae. The remaining 8 taxa were all from different families (Appendix S1). No taxa were categorized as EW, but 12 taxa (5%) were categorized as CR (PE) or CR (PEW), including 3 taxa each of Asteraceae, Campanulaceae, and Lamiaceae. Thus, 25 taxa, corresponding to nearly 10% of the Kauai SIE vascular plants, were categorized EX, CR (PE), or CR (PEW).

Apart from the taxa categorized as EX, all other taxa assessed were categorized in a threatened category: 129 taxa (51%) CR, 106 taxa (41%) EN, and 8 taxa (3%) VU. In other words, we found that 95% of the Kauai SIE vascular flora is threatened with extinction and 5% are already extinct (Figure 3).

The majority of the threatened taxa were placed in a threatened category based on criterion B (geographic range)

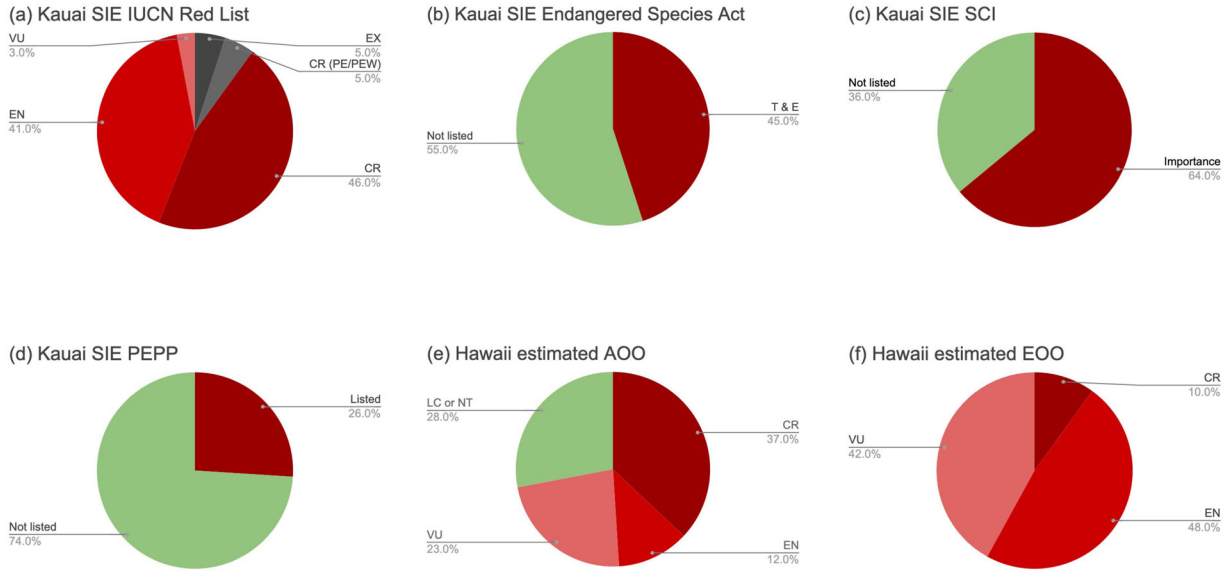

FIGURE 3 Percentage of Kauai Island's single-island endemic vascular plants (a) in 5 International Union for the Conservation of Nature (IUCN) Red List categories, (b) on the U.S. Endangered Species List; (c) listed as species of conservation importance (SCI) by the Hawaii Strategy for Plant Conservation (HSPC), and (d) included in the Plant Extinction Prevention Program (PEPP) (VU, vulnerable; EN, endangered; CR, critically endangered; CR [PE, PEW], critically endangered possibly extinct or possibly extinct in the wild; EX, extinct). Estimated percentage of Hawaiian vascular plants by threat category (VU; EN; CR; LC, least concern; NT, near threatened) based on (e) area of occupancy (AOO) and extent of occurrence (EOO)

using either or both of B1 (EOO) or B2 (AOO) combined with subcriterion a either being severely fragmented or having few locations and subcriterion b an estimated continuing decline in any of EOO (i), AOO (ii), area and extent or quality of habitat or both (iii), number of locations or subpopulations (iv), and number of mature individuals (v) (Appendix S1).

In many cases (77 taxa), placement in a threatened category was further supported by criterion C2a (small population size and decline) (31 taxa), criterion D (very small or restricted population) (6 taxa), or both C2a and D (40 taxa). In some additional cases (20 taxa), an assessment of CR was based solely on criterion C2a or D or both, reflecting small but scattered populations.

Major threats

The major threats to Kauai SIE vascular plants were invasive, non-native species, especially predation and habitat degradation caused by invasive animals such as rats (*Rattus* spp.), pigs (*Sus domesticus*), goats (*Capra hircus*), deer (*Odocoileus hemionus*), and slugs, as well as competition with invasive plants. Invasive plants included naturalized ornamentals, such as Melastomataceae, and introduced edible plants, as well as unintended introductions, such as *Buddleja asiatica*, *Christella dentata*, *Hedychium gardnerianum*, *Juncus planifolius*, *Kalanchoe pinnata*, *Lantana camara*, *Melinis minutiflora*, *Miconia crenata*, *Morella faya*, *Psidium cattleyanum*, *Rubus argutus*, and *Rubus rosifolius*.

All taxa were threatened by habitat loss and modification, extreme weather, and stochastic events, such as landslides and hurricanes, associated with climate change. Vulnerability was highest for taxa already considered rare or endangered and for coastal and mesic habitats.

Use and trade

Nearly 100 taxa (39%) (19 of the 76 genera and 17 of the 47 families) were reported in use either historically or currently (Appendix S1). Plants were often recorded as used for several purposes, including medicines, rituals, building and carving (wood), and weaving (e.g., fibers, leaves). Medicinal uses are often in combination with other plants.

Conservation status

Comparing the IUCN Red List assessments with federal assessments and other lists, 115 (45%) of the 256 taxa were listed as either threatened (3 taxa) or endangered (112 taxa) under the U.S. Endangered Species Act (USFWS, 2021). Sixty-six taxa (26%) were listed by PEPP, generally due to having fewer than 50 individuals left in the wild (PEPP, 2021). Eleven of the PEPP listed taxa had larger populations (e.g., 50–170 individuals) according to their IUCN Red List assessments, but they declined rapidly to under or near 50 individuals in recent years. One hundred and sixty-four taxa (64%) were considered SCI under the Hawaii Strategy for Plant Conservation (Keir & Weisenberger, 2014).

Whether individuals of a taxon occurred in protected areas, such as fenced exclosures, were being systematically monitored over time, or were represented in living ex situ collections, such as seed banks, conservation nurseries, or botanical gardens, was not systematically documented over time. Such information for a taxon, when known, is in the individual IUCN Red List assessments (IUCN, 2022; Appendix S1) and in the reviews conducted by the U.S. Fish and Wildlife Service (USFWS, 2021) for some of the federally listed species. The Hawaii Seed Bank Partnership (HSBP, 2021) also maintains and coordinates lists of ex situ collections.

Preliminary conservation assessment of the native vascular flora of the Hawaiian Islands

Based on the estimated AOO and number of locations for the 1044 native vascular plants of the Hawaiian Islands included in the Price et al. (2014) study (Appendix S2 & Figure 3), 753 (72%) taxa were CR, EN, or VU under criterion B, and 291 (28%) were classified as NT or LC. Of the taxa classified as threatened, 514 (68%) were CR or EN. Using the estimated EOO and number of locations, all 1044 taxa were threatened, but a majority (922 taxa, 88%) were EN or VU.

Differences between the estimated Hawaiian flora-wide category and the published assessments for Kauai SIE taxa were observed. Six of the 8 taxa classified as VU in the Kauai SIE assessment (Appendix S1) were in a higher threatened category (e.g., EN or CR) in the preliminary assessment (Appendix S2). Some of the PEPP taxa classified as CR by the Kauai SIE assessment (Appendix S1) were classified as EN based on EOO and number of locations in the preliminary assessment (Appendix S2). In a few cases (*Melicope knudsenii* and *Panicum niihauense*), threatened categories based on completed IUCN Red List assessments (Appendix S1) were higher than the category placement estimated in preliminary assessments (Appendix S2).

DISCUSSION

Threat level for native flora of the Hawaiian Islands

While many countries have adopted national red lists or red data books, these are often summaries of available knowledge that include incomplete sets of selected species, and in some cases local assessment criteria are being used and translated into IUCN Red List categories. Few studies have been conducted that systematically assess entire endemic floras for the IUCN Red List (Gallagher et al., 2020). In line with global estimates suggesting about 22% of plants are threatened (Brummitt et al., 2015), a partial assessment of the endemic Spanish flora estimated that about 22% of the endemic flora is threatened (Saiz et al., 2015). Partial assessment of the flora of the Chinese island Hainan reported 21% of the endemic flora as CR or EN (Francisco-Ortega et al., 2010). Complete assessment for the IUCN Red List of the endemic vascular plants of Italy (Orsenigo et al., 2018) also showed that 22% were threatened (300 of 1340 taxa). An assessment of the endemic Greek flora (Kougioumoutzis et al., 2021) estimated that 85% of the taxa were threatened based on criteria A and B (67% if only using criterion B). According to the authors, this high proportion might be explained by a large proportion of the Greek endemic flora being isolated mountain or island endemic species.

Other global studies have focused on selected taxonomic groups. For example, Goettsch et al. (2015) showed that 31% of 1478 evaluated species of cacti are threatened, and a global assessment of conifers showed that 34% of the 615 conifer species are threatened (ICCP, 2021), suggesting that cacti and conifers are among the most threatened taxonomic plant groups assessed to date. In Hawaii, 41 of the 134 plant taxa reported extinct by Wood et al. (2019) were members of Campanulaceae and 27 were members of Lamiaceae. The reason is uncertain, but both families are susceptible to rats, slugs, and diseases and may have been affected by loss of specific pollinators and seed dispersers.

The preliminary assessment of the native vascular flora of the entire archipelago of Hawaii based solely on estimated EOO, AOO, and number of locations (Appendix S2 & Figure 3) suggests that the proportion of threatened taxa may be generally high across the archipelago when fully assessed and including SIE and multi-island and nonendemic native vascular plants (72–100% being threatened based on the estimated locations and AOO or EOO, respectively).

However, the preliminary assessments of EOO and AOO are based on suitable abiotic conditions and very coarse climate data (mostly rainfall zones), which could overestimate distribution ranges, whereas AOO and EOO would normally be based on actual occurrence data and include oceans for multi-island taxa, following IUCN guidelines (IUCN, 2019).

In a literature review, Caujapé-Castells et al. (2010) showed that 3500–6800 of the world's estimated 70,000 insular endemic plant species might be highly threatened (CR or EN). Assessments of other oceanic islands show a higher-than-average proportion of the flora being threatened. An assessment (Beech et al., 2021) for the IUCN Red List of 3118 trees of Madagascar, of which 93% are endemic to the island, showed that 63% are threatened (VU, EN, or CR), including 59 species assessed as CR (PEW). An assessment of the endemic vascular flora of Cape Verde showed that 90% of the assessed taxa were classified as CR (Romeiras et al., 2016), in line with the results obtained in the present study of Kauai SIE vascular plants.

It has been suggested (González-Mancebo et al., 2012; Martín, 2009; Romeiras et al., 2016) that application of IUCN Red List criteria to island taxa with small ranges will place them in a higher threat category under criterion B (geographic range), irrespective of whether this range is natural or actively shrinking. This could result in island taxa consistently being classified as more threatened than mainland taxa as well as a lack of differentiation and prioritization ability for conservation.

However, a taxon cannot be assessed using criterion B based solely on EOO (B1) or AOO (B2) or both because at least 2 of the following additional subcriteria must be met: being severely fragmented or occurring in a restricted number of locations (a); having a continuous decline of extent of occurrence (i), area of occupancy (ii), area and extent or quality of habitat or both (iii), number of locations or subpopulations (iv), and number of mature individuals (v) (b); or experiencing extreme fluctuations in extent of occurrence (i), area of occupancy (ii), number of locations or subpopulations (iii), or number of mature individuals (iv) (c) (IUCN, 2019).

It has been suggested that assessors of island taxa should use evidence-based criteria for assessing declines and other trends to avoid overestimation of threatened status (Romeiras et al., 2016). For example, data on continuing range declines or extreme fluctuations are often lacking and judgement of

whether a taxon meets these subcriteria is often associated with uncertainty and based on expert opinion (Cardoso et al., 2011; Romeiras et al., 2016).

However, for the IUCN Red List to be a globally authoritative and comparative list it is fundamental to apply the same criteria to all assessments (IUCN, 2019), and while local subcriteria or practices may provide a better tool for prioritization, such local biases could result in overall trends being neglected on a comparative global scale.

We explored our data to assess whether geographic range could have led to an overestimation of the threatened status in the IUCN Red List assessments of Kauai SIE. Kauai is 1437 km^2 (Stearns & MacDonald, 1960). Due to its small size, any endemic taxon could at least be considered EN according to criterion B, for example, if a decline is detected and populations are severely fragmented or occur in 5 or fewer locations because EOO is <5000 km^2.

Of the 243 taxa classified as threatened, 146 (60%) such classifications were based solely on criterion B and 97 (40%) classifications were based on or also supported by criteria C and/or D (77 taxa), reflecting small but scattered populations. This confirms that the high proportion of threatened plant taxa observed for Kauai SIE vascular plants was not artificially overestimated based on small geographic ranges of island taxa alone, even when a general decline of the flora was estimated or observed.

Usefulness of IUCN Red List assessments for conservation planning in Hawaii

While island systems harbor a high number of narrowly endemic plants with small populations well adapted to a restricted range, these vulnerable island ecosystems are disproportionately threatened by human impact, invasive species, and climate change (Brooks et al., 2002; Caujapé-Castells et al., 2010; Kingsford et al., 2009; Sax & Gaines, 2008). Thus, the high estimates of threatened taxa for the Kauai SIE vascular flora may reflect a very real conservation challenge. For instance, of some 80 plant extinctions in the last 400 years documented by Sax and Gaines (2008), about 50 were island species. Since then, 131 extinctions have been documented in Hawaii alone (Wood et al., 2019). However, information for oceanic island systems other than Hawaii is scarce and plants from the Polynesia–Micronesia hotspot represent a key information gap for IUCN Red List assessments (Caujapé-Castells et al., 2010).

Comparison with the federal listing under the U.S. Endangered Species Act showed that only 45% of the Kauai SIE vascular plants were listed as threatened or endangered (USFWS, 2020). The proportion considered SCI (Keir & Weisenberger, 2014) was slightly higher at 64%. However, our results suggest that the conservation status of the Hawaiian flora is underestimated by these local assessment systems and that a critical look should be taken at the potential need for conducting federal assessments of a higher proportion of the native flora.

With the completion of the assessment of the Kauai SIE vascular plants, there are several next steps to take. The assessment of Hawaiian plants for the IUCN Red List will continue with assessment of nonvascular plants and taxa occurring on multiple islands. For the Kauai SIE, the completed IUCN Red List assessments can now be used to help identify and prioritize local conservation planning and continued monitoring, to seek funding for conservation work, and to petition for state and federal protection. Meta-analysis can also help highlight geographical areas or ecosystems of concern, potentially in parallel with starting IUCN ecosystem assessments (IUCN-CEM, 2021; Murray et al., 2020). The potential impacts of climate change will need to be taken into account in future projections. There are many partners working together in Hawaii that are associated through Laukahi: the Hawaii Plant Conservation Network (www.laukahi.org), which provides a strong basis for protecting and recovering these threatened species and their ecosystems. As conservation and restoration is implemented, the new IUCN Green Status of Species (IUCN-SSC, 2022) can be used to measure how much a taxon has recovered thanks to conservation action and how close it is to being fully ecologically functional across its range (Grace et al., 2021).

Complete assessment for the IUCN Red List of Threatened Species of the SIE vascular flora of Kauai revealed that 95% of the flora is at risk, and 5% is already extinct. Preliminary assessments done here for the vascular plant flora of Hawaii and comparison with assessments done for other islands and island groups suggest that the flora of Hawaii may be one of the world's most threatened, which signals an urgent need for conservation of remote oceanic island floras. The IUCN Red List assessments complement local conservation assessment systems and help highlight conservation needs in a global context.

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