Published online: 7 July 2020 ISSN (online) 2376-3191

Records of the Hawaii Biological Survey for 2019. Edited by Neal L. Evenhuis. *Bishop Museum Occasional Papers* 129: 109–124 (2020)

Recommendations for reporting records of nonnative plant species in the Hawaiian Islands[1]

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Abstract Reports of nonnative plants found outside of cultivation or human-contained areas for the first time are crucial for invasive species research and management, allowing compilation of species checklists that document the naturalization and rough geographical distribution of Hawai'i's nonnative flora. However, the naturalization status of plants can be difficult to assess in the field and little guidance exists on what criteria are needed to fit the definition of "naturalized". Moreover, disappearances of nonnative plants from Hawai'i's floras are generally not reported even though multiple eradication programs exist. Over time these issues may artificially inflate the number of naturalized species on checklists, confounding biodiversity research and distracting management from problematic species. We reviewed the literature on terminology and the invasion process to provide Hawai'i-specific guidelines on reporting nonnative plant statuses without requiring major changes to current reporting or data collection practices. These guidelines are intended to help authors of reports contribute information needed to update statuses on naturalized species checklists and aid management decisions.

INTRODUCTION

Collectors have been vouchering nonnative plants in the Hawaiian Islands for over 200 years, increasingly integrating data about nonnative species into our knowledge of Hawai'i's natural history (Funk *et al.* 2005; Wester 1992). The long-term curation of voucher specimens combined with effective communication of noteworthy finds has numerous applications. This information has been most prominently used in floristic studies (Funk 2003; Souza & Hawkins 2017; Stern & Eriksson 1996) and collection of nonnative plant data has focused on identifying which species form an established component of Hawai'i's flora (Imada 2012, 2019; Palmer *et al.* 1995; Wagner *et al*. 1999, 2005). However, the past few decades have seen a significant increase in efforts to understand the biogeography and behavior of nonnative plants from the perspective of invasive plant management (Antunes & Schamp 2017; Munekata *et al*. 2016). Today, Hawai'i possess-

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es a well-established network of agencies that fund, conduct research, and enact strategies with diverse and complementary goals, relying on species-specific data to direct their management actions (Munekata *et al*. 2016). Methods for consistently reporting biodiversity data therefore need adjusting to bridge the gap between natural history collections and invasive species managers while maintaining traditional uses.

The *Records of the Hawai'i Biological Survey* provides an effective forum for communicating the taxonomy, status, and basic distribution of nonnative plants in Hawai'i. This forum was officially initiated in 1995 and encourages authors to report records of naturalization in the *Bishop Museum Occasional Papers,* although new weed reports date back to 1911 (Forbes 1911). The vast majority of new records since 1995 have been reported through this system, supported by specimens deposited in herbaria (Evenhuis & Miller 2015), and have subsequently been compiled into species checklists (Imada 2019; Wagner *et al*. 2005). Furthermore, the utility of this system has been leveraged in recent years by the digitization of herbarium vouchers (Allison 2003). At least three herbaria with significant collections of nonnative plants from Hawai'i maintain searchable databases of voucher information, including the Bernice Pauahi Bishop Museum's *Herbarium Pacificum* (BISH) in Honolulu, Hawai'i; the National Tropical Botanical Garden herbarium (PTBG) in Kalāheo, Hawai'i; and the Smithsonian's United States National Herbarium (US) in Washington, D.C. Additionally, many of these data are available globally through free online data platforms that consolidate information from multiple herbaria, such as the Global Biodiversity Information Facility (GBIF) and the Integrated Digitized Biocollections (iDigBio). Field collections are critical for providing a verifiable physical specimen to accompany field observations of invasive plant distribution and behavior. In combination with tools that aggregate data and make them accessible, herbarium vouchers and associated field observations provide the foundation for a taxonomically sound information system to improve invasive plant management strategies.

The basic informational needs of floristic studies and invasive plant management are largely overlapping, although invasion control programs often require more detailed observations of population structure, distribution, and arrival time. However, the terminology used by invasion biologists and invasive species managers to describe the introduction-naturalization-invasion continuum has varied on a global scale since the field emerged (Blackburn *et al*. 2011; Pyšek *et al*. 2004; Richardson *et al*. 2000, 2011). The use of these terms is oftentimes inconsistent with floras and checklists compiled by taxonomists, hindering our ability to apply data collected from taxonomic projects to invasive plant management and vice versa (Pyšek *et al*. 2004). Data submitted to the *Records of the Hawai'i Biological Survey* are likely no exception. In particular, the term "naturalized" may have various definitions amongst contributing authors, and records must be further scrutinized when compiling new information into research projects.

It is our hope that this summary will increase the utility of nonnative plant data in Hawai'i and promote synergisms between future invasive plant research, management, and floristic studies. In particular, we highlight two means of improving Hawai'i's data infrastructure, including: 1) recommendations to local botanists for reporting field data such that it informs invasive plant research/management and is consistent across collectors, and 2) a description of how terminology and statuses should be applied in reports of new records, such that they align with globally recommended frameworks for tracking nonnative plant species. We focus on naturalization and extirpation, as accurate reports of these events are vital for curating a checklist of nonnative plant species existing outside of cultivation.

TERMINOLOGY

Given the immense value of tracking the fate of nonnative species introductions across the Hawaiian archipelago, it is important that nonnative plant records use consistent terminology to ensure that the data generated by numerous individuals is easily understood and comparable. Robust records of nonnative plants are required to prevent misappropriation of conservation resources, as errors in recording invasive behavior can lead managers to address species that are unlikely to pose a threat or miss opportunities to prevent spread before it is too late. Much progress has been made to standardize terminology between taxonomists and invasion biologists within the last two decades alongside several publications that provide broad guidelines to track nonnative plant species in any region (Blackburn *et al*. 2011; Pyšek *et al*. 2004; Richardson *et al*. 2000, 2011; Wilson *et al*. 2014). Thus, the purpose of this paper is not to propose new definitions, but to provide a Hawai‘i-specific guide that aligns with these generalized frameworks while avoiding major changes to current data collection practices.

Definition of Terms Concerning Naturalized Status

Nonnative **(synonyms: alien, exotic, introduced):** any species that is present in Hawai‘i as a result of intentional or accidental human action or has arrived in Hawai‘i without the help of humans from a region where it was also nonnative (Blackburn *et al*. 2011; Pyšek *et al*. 2004). This term can be applied in both a statewide and an island-specific manner (Pyšek *et al*. 2004). For instance, if a plant is native to one island, but is introduced by humans to a second island, it can be said to be nonnative to the second island (e.g., the purposeful introduction of *Sphagnum palustre* L. to O‘ahu from Hawai‘i Island, where it is indigenous; Karlin *et al*. 2012).

Naturalized **(synonym: established)**: nonnative species that reproduce sexually or vegetatively to form self-replacing populations outside of human cultivation or containment (i.e., in the wild), as evidenced by multiple wild-growing individuals of different ages classes, indicating that the population has undergone many reproductive cycles (Blackburn *et al*. 2011; Pyšek *et al*. 2004; Richardson *et al*. 2000; Wagner *et al*. 2005, 2012). This does not include casuals (see below) or species that have so far produced only a single-few generations of offspring. Accidental introductions of seed contaminated soil giving rise to multiple generations in pots or greenhouses are not considered naturalized because although populations may be self-sustaining, they have not yet escaped human containment. Invasive plants are considered a subset of naturalized plants.

Casual*:* nonnative plants that survive and reproduce occasionally outside of cultivation but do not form self-sustaining populations, thus requiring repeat introductions to persist (Pyšek *et al*. 2004; Richardson *et al*. 2000). These plants are difficult to distinguish from cultivated remnants or plants that are just beginning to naturalize because time is needed to determine their behavior. No synonyms are consistently used in the literature, although casuals are sometimes referred to as “spontaneous”, “waifs” or “occasional escapes” (Pyšek *et al*. 2004). The term “adventive” originated as a synonym for casual (De Candolle 1855), but has been used more broadly in the past to include naturalized (Wester 1992, Provost 1999).

Definition of Terms Concerning Extirpation

***Extirpation* (synonyms: local/regional extinction)**: a species that has entirely disappeared from a specific geographical area (e.g., statewide or island-wide) by natural or anthropogenic means, but still persists elsewhere in the world (Riddle *et al.* 2011). Extirpations are more thoroughly discussed in relation to native species but can be applied to nonnative species that previously formed (or were forming) self-sustaining populations outside of their native range (naturalized), where the very last individual within that population has died (Simberloff & Gibbons 2004; Panetta 2015). Akin to the IUCN Red List status "Extinct in the Wild" where captive individuals remain but wild populations no longer exist, nonnative plants that are entirely absent from a region may be considered totally extirpated whereas species with cultivated individuals remaining are considered extirpated in the wild (with wild referring to areas outside of actively maintained cultivation sites). Reports of extirpation should be accompanied by sound reasoning based on time since last sighting, seed bank longevity, and adequate search effort.

Eradication: a subcategory of extirpated referring to a species whose removal was the result of purposeful human intervention (Panetta 2007, 2015; Larson *et al.* 2019). This term may be used in the explanatory paragraph that accompanies record submissions (Evenhuis & Eldredge 2010) to distinguish purposeful extirpations from natural extirpations (occurring without intentional human involvement).

STATUS DESIGNATIONS

Because Hawai‘i is an archipelago (i.e., naturally discrete land areas), opportunity exists to prevent inter-island introductions and accomplish island-wide eradications, requiring language that can distinguish between island and statewide populations. Additionally, studies have established Hawai‘i as a global hotspot for naturalized plant species, many of which have been, and continue to be, introduced purposefully for cultivation (Pyšek *et al*. 2017; Staples & Herbst 2005; Wester 1992). Recent introductions require extra scrutiny and the application of precise terminology to describe the phase of a plant's establishment (Blackburn *et al*. 2011). For instance, plants outside of cultivation are often encountered in Hawai‘i, although it may not be immediately obvious whether a self-sustaining naturalized population exists. Reports of reproduction outside of cultivation should be encouraged because early detection of invasive behavior is valuable for management. However, it is necessary to clearly communicate any uncertainty of naturalization and describe field observations that distinguish these reports from fully naturalized records.

We also encourage vouchering cultivated species and plants in human contained areas (e.g., aquatic plants in a man-made pond) because an accurate tally of these is lacking in Hawai‘i, representing a critical knowledge gap for invasive species management. However, significant improvements in monitoring and data infrastructure are needed to track cultivated species. Unlike naturalized plants (Imada 2019), there is no up-to-date resource listing all known cultivated species statewide, let alone at the island level, making the determination that a species is "new" infeasible. Updates and verification of partial lists compiled for book projects (Staples & Herbst 2005) provide a good starting point, but given the low collection rate for cultivated species, dates attached to new reports are likely to be inaccurate and not useful. Furthermore, thousands of cultivated species exist

in Hawai‘i that have not been vouchered, and an unknown number of others are not documented in any way. Rather than opportunistically reporting these plants through the *Hawai‘i Biological Survey*, a curated working list first needs to be assembled that could expand as new records are vouchered. Thus, we do not recommend reporting cultivated plants in the same manner recommended here for naturalized ones, although we recognize that publishing notes on new arrivals of pest species or accidental seed contaminants could be of immediate value to managers.

Guidelines for reporting to the *Records of the Hawai‘i Biological Survey* were established by Evenhuis & Eldredge (2010), with the inclusion of headings that denote establishment statuses for all organisms. These headings are aligned to the right of each species name in bolded font and indicate whether each record represents a first observation for an island or the entire state. The use of headings and terminology are further described here and in Table 1 to encourage consistent usage for nonnative plant records among all contributing authors. As an interim solution to a tracking system that addresses plant species of all statuses in Hawai‘i, these guidelines encourage accurate reporting to inform the addition or removal of plants from naturalized species checklists.

Applying Naturalized Status Headings

New State Record: the first report of naturalization for a nonnative species within the Hawaiian archipelago that has no documented history of cultivation in Hawai‘i or is thought to be very rarely cultivated (e.g., previously reported from one botanical garden specializing in rare or unusual plant species).

New Naturalized Record: the first report of naturalization for a nonnative species within the Hawaiian archipelago that has been previously observed in cultivation.

New Island Record: the first report of naturalization for a nonnative species on a particular Hawaiian island, where naturalization has already been recorded for at least one other island in the Hawaiian archipelago.

Correction: a heading applied to reports that provide new evidence or arguments to justify the correction of past records. This may include the discovery of misidentified species, analyses showing that previous reports of new naturalized records do not fit the current definition of “naturalized”, and other corrections that may improve the accuracy of Hawai‘i’s checklists and other records.

Distinguishing completely unknown from previously cultivated species as “New State Record” and “New Naturalized Record”, respectively, has been used for over two decades in the *Records of the Hawai‘i Biological Survey* and we have included this distinction for consistency (Table 1). Differentiating reports in this manner is valuable for examining the role of multiple introductions or history of planting in producing invasions (i.e., propagule pressure) and assessing the feasibility of eradication (Colautti *et al*. 2006; Imada *et al*. 2000; Lockwood *et al*. 2009; Panetta 2015). A drawback of this distinction is that it relies heavily on one’s knowledge of Hawai‘i’s cultivated flora. As no comprehensive list of cultivated plants is currently available, a thorough review of available sources is necessary to assign these statuses, minimally including searches of herbaria databases (BPBM 2018;

Table 1. Decision matrix for reporting plant statuses.
Orange boxes indicate status changes for naturalized species checklists. Blue boxes highlight helpful information for invasion management that do not correspond to status changes on any checklist curated in Hawai‘i.

		In cultivation or somehow human contained		Outside of cultivation or containment	
		Intentional	Unintentional	Insufficient evidence of population longevity	Sufficient evidence of population longevity
First Record of Presence	For the Entire Archipelago	Deposit Voucher in Herbaria	Publish Note + Deposit Voucher	Report Status as **Potentially Naturaliz(ed/ing)** + Deposit Voucher	Report Status as **New State Record** or **New Naturalized Record*** + Deposit Voucher
	For an Island	Deposit Voucher in Herbaria	Publish Note + Deposit Voucher	Report Status as **Potentially Naturaliz(ed/ing)** + Deposit Voucher	Report Status as **New Island Record** + Deposit Voucher
First Record of Absence**	For the Entire Archipelago	N/A	N/A	Report Status as **Possible Extirpation**	Report Status as **State Extirpation Record**
	For an Island	Publish Note	Publish Note	Report Status as **Possible Extirpation**	Report Status as **Island Extirpation Record**

* Plants with well-documented cultivation histories are reported as New Naturalized Records while those absent or uncommon in cultivation are reported as New State Records. However, both are simply reflected as naturalized on species checklists.

** Eradication campaigns should voucher their targets throughout the process to allow identifications to be verified after removal.

NMNH 2018; NTBG 2018), publications of species commonly found in Hawai‘i’s gardens (Staples & Herbst 2005), and checklists such as the Bishop Museum’s *Annotated Checklist of Cultivated Plants of Hawai‘i* (Imada *et al*. 2000).

Describing Naturalized Status

As outlined in the guidelines for submissions to the *Records of the Hawai‘i Biological Survey*, status reports should be accompanied by a short note (Evenhuis & Eldredge 2010). Despite attempts to standardize the use of terminology and statuses commonly associated with nonnative plants outside of cultivation, interpretation of data from the field remains subjective and species-specific. Detailed reasons for why species should be designated as naturalized are helpful for placing species along the introduction–naturalization–invasion continuum and predicting future behavior (Blackburn *et al*. 2011; Pyšek *et al*. 2004; Richardson *et al.* 2000). Authors can greatly increase the value of their submissions by providing estimates of the following:

1) The area covered by noncultivated individuals, their density, and a description of the habitat;
2) The number of noncultivated individuals observed, or, for vegetatively reproducing species, evidence that many, disconnected individuals are present s (even if propagules are vegetative and/or dispersal is human assisted);
3) The number and type of life stages present (mature, seedlings, etc.); and
4) The source of naturalization, if apparent (e.g., seed contamination, cultivated plants), or whether it appears to have naturalized a significant distance from its likely introduction site.

Additionally, a search for previously collected vouchers within the geographic area of interest, if available, can be included in a "material examined" section to provide additional distribution information and a timeline of establishment (Pyšek *et al.* 2004).

Potentially Naturalized or Naturalizing Species

Contributors are encouraged to provide first reports of nonnative species existing outside of cultivation without direct human assistance, especially those reproducing (sexually or vegetatively), even if the long-term survival of self-sustaining populations is not apparent (Pyšek *et al*. 2004; Richardson *et al*. 2000; Wagner *et al*. 2005). These reports may alert managers to eradication opportunities by identifying species that are possibly beginning to naturalize while not assuming that they will definitely naturalize in the future. Examples of species that may be reported include observations of multiple, widely distributed immature plants for which no mature individuals have been located, or a small number of mature, similarly aged individuals outside of cultivation. Although this information can be used to identify would-be invaders before they spread, species that are beginning to naturalize are often indistinguishable in the field from plants exhibiting a variety of other behaviors, such as 1) casual species, which may also produce offspring outside of cultivation, 2) remnants from cultivation where overgrown adjacent vegetation masks evidence of its cultivated history, and 3) species that have already naturalized but only a few individuals have been detected.

Various terms have been used in the literature to denote species with ambiguous statuses, but either they cause confusion due to inconsistent global use or are somewhat presumptuous of a species' fate. This includes species often described as "adventive", which is variously used both in Hawai'i and worldwide (Pyšek *et al*. 2004; Wester 1992), and "emerging invaders" or "sleeper weeds", which imply that populations will persist and eventually expand. The problem of status uncertainty (whether arising from poorly surveyed populations or from insufficient passage of time to determine behavior) illuminates a pressing need to re-examine terminology and provide guidelines for adapting regional species checklists to existing nonnative species tracking systems. A tracking scheme with 11 population status categories was developed by Blackburn *et al*. (2011) that describe the phases preceding naturalization, but adapting Hawai'i's checklist to these fine-grained statuses would require data that has not been collected for all species, as well as a higher site revisitation rate. Despite the fine scale of Blackburn *et al*.'s (2011) system, it too does not account for uncertainty, and thus, modifications to solve these issues are still needed before implementation (Brock & Daehler, *in press*).

In light of these challenges, we do not recommend any one specific term or status heading to accompany reports of these data-deficient species. Instead, we propose that these records be listed in a section separate from new naturalized records entitled "Potentially Naturalized or Naturalizing", allowing these species to be prioritized for revisitation and monitored for status changes.

Applying Extirpated Status Headings

Eradication programs have been implemented on most of the main Hawaiian Islands (Kraus & Duffy 2010), and some reports in the *Bishop Museum Occasional Papers* mention actions for the immediate removal of recently established plant species with small populations. Determining whether a nonnative plant has been extirpated can be costly and difficult because extensive field monitoring and reconnaissance are required to provide evidence of a species' absence (Butchart *et al*. 2006; Pluess *et al*. 2012). Cases where disappearances have occurred naturally without purposeful removal by humans are especially problematic, as population distributions and declines are less likely to have been documented. Some previously naturalized species appear to have been eradicated from entire islands in Hawai'i (Penniman *et al.* 2011), and these events are occasionally alluded to in outreach materials and progress reports to funders (e.g., DLNR 2009). However, such instances are rarely reported in archived scientific publications and do not contain the information necessary to update plant checklists, likely because no guidance exists on how to report them. This is problematic because the following are all dependent on an accurate account of extirpations: preventative checklists for border biosecurity, quantitative analyses of plant biodiversity, feasibility estimates of species eradications, and determinations of control program success.

To encourage reports of extirpation events, we propose applying aspects of the IUCN guidelines to report extinctions of endangered species (IUCN 2017). In the IUCN system, assignment of species to the official "Extirpated" or "Extinct" categories requires exhaustive surveys to justify, beyond reasonable doubt, that the last individual has died. Consequently, the IUCN allows the additional descriptor of "Possibly Extinct", which, although still evidence-based, explicitly acknowledges uncertainty. This status is especially applicable to recent apparent extinctions where a substantial timeline of disappearance has not been established (IUCN 2017). We recommend applying the following status headings, which are modeled on the IUCN's (2017) Red List criteria, to be formatted in the same style as when describing naturalized taxa (bolded and located to the right of species names). As described in the definition section above, it is useful to report species that are extirpated in the wild but remain in cultivation. However, we do not include separate status headings for species that are entirely extirpated versus those only extirpated from the wild, because reports of both result in losing naturalized status. Nonetheless, it is valuable to indicate whether cultivated individuals are thought to remain because this may be useful when evaluating sources of future invasions, or implementing all-species tracking systems in the future (e.g., demotion from naturalized to either "no longer present" or "in cultivation only").

State Extirpation Record: a report providing evidence to declare that a naturalized or potentially naturalized/naturalizing species is no longer present in the wild in the Hawaiian Islands. Contributors should apply this heading to records of species that

have totally disappeared, as well as those that no longer have populations in the wild, but still exist in cultivation. Presence of remaining cultivated individuals should be described in the report text alongside an account of surveying efforts and time elapsed since last sighting. Criteria to apply this heading versus "Possible Extirpation" are discussed below.

Island Extirpation Record: a report providing evidence to declare a nonnative species as no longer present in the wild on a specific island.

Possible Extirpation: a report providing evidence that a formerly naturalized species is likely to have been extirpated from an island or statewide, but where reduced confidence is appropriate due to missing information or the species is very likely to be reintroduced (e.g., common in cultivation on other islands). Most nonnatives that have been targeted by recent extirpation programs will likely fall into this category because such cases often do not allow for high confidence due to a short time since last sighting (less than several plant generations), a long-lived or uncertain seedbank, or lack of comprehensive searches across the area being reported (i.e., island or Statewide). Further discussion of scenarios and criteria is presented below.

Rediscovery: a heading applied to reports of species that were previously thought to be extirpated, but where individuals have subsequently been found outside of cultivation or areas of human containment. This may include individuals that have likely arisen from the original infestation or from reintroductions of that species, which should be described in the report text. The application of this heading does not necessarily imply a species status should be updated to "Naturalized", as the status of the population may be uncertain or just beginning to naturalize. Thus, authors reporting a rediscovery should communicate field observations that allow assessment of whether the rediscovered species should or should not be considered naturalized or potentially naturalized/naturalizing.

Two scenarios may be commonly encountered when reporting extirpations: 1) recently observed species for which eradication programs have monitored population decline, resulting in the disappearance of the species, and 2) apparently natural extirpations of species previously known from a single or few sites for which there are no recent observations. No single rule exists for how much time must pass before nonnative plants can be reported as extirpated, as these events are highly scenario-specific and dependent on a species' biology (Panetta 2015). However, a general timeline used by the IUCN for endangered organisms, referring to whether a species has disappeared from known sites for ten years or three generations, whichever is longer, is useful for our purposes (IUCN 2017). With regards to seed plants, one generation includes the amount of time necessary for a new seed to develop into a mature, reproductive individual (Moravcova *et al*. 2018). As this period is affected by seed dormancy and factors that may slow maturation (e.g., shade), it may be beneficial to consider a range of generation times that may exist within a single species when proposing extirpation status or implementing control programs.

It is important to note that some plants have propagules that can persist for a very long time in the soil; however, seed longevity data is sparse, and dormancy is affected by

numerous site-related factors including soil moisture, nutrients, pH, and texture (Baskin & Baskin 1998). Relying on seed survival data collected from seed preservation labs, which deliberately maintain humidity and temperature-controlled environments that are improbable in nature, may vastly overestimate time needed for eradication programs and delay the optimal time to report possible extirpations. Thus, in purposeful eradication scenarios where population decline has been carefully monitored, a status of "Possible Extirpation" may be suggested within the timeframe of ten years or three generations (whichever is longer) if detailed distribution and time since last observation data are described (Dodd *et al*. 2015; Panetta 2015). A species' status may later be updated to "Statewide/Island Extirpation Record" if the species is not found after a longer period of time, taking into account the species' biology (e.g., seed bank persistence).

In scenarios where extirpations appear to have occurred naturally, the status of "Possible Extirpation" should be applied if the historic locations have been surveyed recently and at least ten years or three generations (whichever is longest) has elapsed since last voucher collection. As precise distribution and population decline data are usually absent in these cases, the status may be upgraded to "Statewide/Island Extirpation Record" after more extensive surveys have been conducted over multiple years (IUCN 2017). Surveys in support of extirpation reports should consider all adequate habitat within the possible dispersal area while accounting for factors that affect detectability (e.g., phenology, terrain; Dodd *et al*. 2015; Panetta 2015).

RESOURCES USED FOR SPECIES DETERMINATIONS

Plant taxonomy is a difficult, dynamic science where incorrect identifications are common, even amongst specialists, and species circumscriptions are constantly being revised as new research is conducted (Pyšek *et al*. 2013; Rouhan & Gaudeul 2014). Compounding this difficulty is that nonnative plants in Hawai'i arrive from all over the world, and few dichotomous keys compare morphologically similar species across broad geographical regions (Carter *et al*. 2007). We recommend that contributors cite the taxonomic resources and specific traits used to identify a new record to provide a helpful logical pathway that can be examined during the verification of vouchers and taxonomic checklists. Furthermore, reporting these resources can assist those identifying other specimens in the field. A system to periodically review and verify identifications is central to invasive species management in Hawai'i, especially for programs that rely on observations of invasive behavior and impacts from elsewhere in the world (Daehler *et al*. 2004; Munekata *et al*. 2016; Tunison & Zimmer 1992). Incorrect identifications immediately decouple the organism from its life history information, resulting in missed opportunities for rapid response if potentially high impact species are misidentified as relatively innocuous ones, or misdirection of funds if a low-impact nonnative is misidentified as a damaging invader.

PROVIDING VOUCHER SPECIMENS

Voucher specimens are often the primary documentation of a species' presence and should represent the diagnostic characters necessary for accurate identification. When vouchering nonnative plants in support of naturalization records, material should be collected from plants belonging to the naturalized population rather than cultivated plants in the vicinity, in order to decrease the likelihood of false naturalization records (Carter *et al*. 2007; Morais & Reichard 2018). Reports of new records that reference vouchers collect-

ed from multiple areas provide convincing evidence that species should be included in floristic works (Wagner *et al*. 1999). Additionally, eradication programs should collect representative voucher specimens to provide a verifiable taxonomic record of plants they control and potentially eradicate to definitively document the species being reported. Repeat collections of the same population, especially newly naturalized or possibly naturalized species, provide a lasting record of visitation that, in combination with adequate field notes, documents mode of dispersal and changes in population size.

Whenever possible, the collection of duplicate specimens is strongly recommended because 1) a specimen may need to be dissected and effectively destroyed during the identification process, 2) material may be sent to specialists for identification, and 3) duplicates deposited at other herbaria may assist in the verification of specimens from other areas (Carter *et al*. 2007). At least three duplicates are ideal even when identification is simple, as this allows specimens to be sent to institutions with experts in the Hawaiian flora (BISH, PTBG, US). If vouchers are intended to be deposited at PTBG or US, collectors should ensure that a duplicate is sent to BISH, the official state repository for biological specimens. Deliberate collection of reproductive propagules and detailed notes are particularly helpful for nonnative species, whose methods of reproduction and dispersal may be unclear outside of their native ranges (Richardson *et al*. 2000). Photographs to supplement vouchers are extremely valuable to add to reports; close-up shots of diagnostic characters, especially those that do not preserve well (e.g., flower/fruit color and shape, plant habit) can assist with identification, while landscape-level shots are helpful accompaniments to descriptions of population density, structure, and habitat type. Biodiversity data repositories, including those curated by local herbaria, are increasingly integrating the ability to upload photographs when depositing voucher specimens.

CONCLUSIONS

Consistent use of terminology is necessary to accurately track nonnative plant biodiversity and increase communication between botanists, invasion researchers, and on-the-ground conservationists. These improvements will additionally allow for easier analysis/synthesis and review of the current statuses of nonnative plants present in Hawai‘i. When combined with ongoing detection programs, this informational network stands to prevent large ecological and societal costs resulting from delayed or inappropriate responses to invasions.

ACKNOWLEDGMENTS

Many thanks to Warren Wagner and David Lorence for their thoughtful comments on the manuscript. We also thank David Richardson and John Wilson for sharing their experience about tracking species established outside of cultivation, but whose potential to naturalize is uncertain. Additionally, we are grateful for the ideas and wisdom accumulated from years of early detection botany shared by Danielle Frohlich and Alex Lau. Our sincerest gratitude is extended to the hard-working field botanists of Hawai‘i, past and present, who deposit specimens in herbaria and report new species records. Without this small group of industrious people to advance knowledge of Hawai‘i’s flora, our hopes of better informing invasive plant management would be baseless.

LITERATURE CITED

Allison, A. 2003. Biological surveys–new perspectives in the Pacific. *Organisms Diversity & Evolution* **3**(2): 103–110.

Antunes, P.M. & Schamp, B. 2017. Constructing standard invasion curves from herbarium data – Toward increased predictability of plant invasions. *Invasive Plant Science and Management* **10**(4): 293–303. doi:10.1017/inp.2017.38.

Baskin, C.C. & Baskin, J.M. 1998. *Seeds: ecology, biogeography, and, evolution of dormancy and germination*. Academic Press, Cambridge, UK. 680 pp.

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarosik, V., Wilson, J.R.U. & Richardson, D.M. 2011. A proposed unified framework for biological invasions. *Trends in Ecology & Evolution* **26**(7): 333–339. doi:10.1016/j.tree.2011.03.023.

BPBM [Bernice Pauahi Bishop Museum]. 2018. Bernice Pauahi Bishop Museum–Botany Database. Honolulu.

Brock, K.C. & Daehler, C.C. *In press.* Applying an invasion and risk framework to track non-native island floras: a case study of challenges and solutions in Hawai‘i. *NeoBiota.*

Butchart, S.H., Stattersfield, A.J. & Brooks, T.M. 2006. Going or gone: defining ‘Possibly Extinct’ species to give a truer picture of recent extinctions. *Bulletin of the British Ornithologists’ Club* **126**: 7.

Carter, R., Bryson, C.T. & Darbyshire, S.J. 2007. Preparation and use of voucher specimens for documenting research in weed science. *Weed Technology* **21**(4): 1101–1108. doi:10.1614/wt-07-007.1.

Colautti, R.I., Grigorovich, I.A. & MacIsaac, H.J. 2006. Propagule pressure: A null model for biological invasions. *Biological Invasions* **8**(5): 1023–1037. doi:10.1007/s10530-005-3735-y.

Daehler, C.C., Denslow, J.S., Ansari, S. & Kuo, H.C. 2004. A risk-assessment system for screening out invasive pest plants from Hawai‘i and other Pacific Islands. *Conservation Biology* **18**(2): 360–368. doi:10.1111/j.1523-1739.2004.00066.x.

De Candolle, A. 1855. *Géographie Botanique Raisonnée: ou, Exposition des faits principaux et des lois concernant la distribution géographique des plantes de l’epoque actuelle*, vol. 2. V. Masson, Paris, France. doi: 10.5962/bhl.title.62718

Dodd, A.J., Ainsworth, N., Burgman, M.A. & McCarthy, M.A. 2015. Plant extirpation at the site scale: implications for eradication programmes. *Diversity and Distributions* **21**(2): 151–162. doi:10.1111/ddi.12262.

DLNR [Department of Land and Natural Resources]. 2009. Report to the twenty-fifth legislature regular session of 2009: budgetary and other issues regarding invasive species. State of Hawai‘i, Department of Land and Natural Resources, Division of Forestry and Wildlife. Honolulu, Hawai‘i.Available at: https://dlnr.hawaii.gov/hisc/files/2013/02/2009-HISC-Legislative-Report.pdf (Accessed June 2020)

Evenhuis, N.L. & Eldredge, L.G. 2010. Guidelines for contributors. *Records of the Hawai'i Biological Survey*. Bishop Museum, Honolulu. Available at: http://hbs.bishopmuseum.org/guidelines.pdf (Accessed March 2018).

Evenhuis, N.L. & Miller, S.E. 2015. Twenty years of the records of the Hawai'i Biological Survey. *Bishop Museum Occasional Papers* **117**: 1–2.

Forbes, C.N. 1911. Notes on the naturalized flora of the Hawaiian Islands. *Occasional Papers of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History* **4**: 23–34.

Funk, V.A. 2003. 100 Uses for an herbarium: well at least 72. *American Society of Plant Taxonomists Newsletter* **17**(2):17–19.

Funk, V.A., Hoch, P.C., Prather, L.A. & Wagner, W.L. 2005. The importance of vouchers. *Taxon* **54**(1): 127–129.

Munekata, M., Oishi, D., Ho, J., Wong, R., Atwood, J., Kramer, S., Conry, P., Ansari, S., Loope, L.L., Miyashiro, M., Spencer, G., Merk, J., DeBruyn, J., Marcotte, M., Chang, D., Hookano, S., Kealalio, K. & Hill, R. 2016. Hawaii Interagency Biosecurity Plan 2017–2027. Hawai'i Department of Agriculture, Hawai'i Department of Land and Natural Resources, H.T. Harvey & Associates, Kuiwalu LLC, and Richard Hill & Associates. 114 pp. Available at: https://hdoa.hawaii.gov/wp-content/uploads/2016/09/Hawaii-Interagency-Biosecurity-Plan.pdf. (Accessed 1 December 2018).

Imada, C.T. 2012. Hawaiian native and naturalized vascular plant checklist. *Bishop Museum Technical Report* **60**: 29 pp. + 27 appendices.

Imada, C.T. 2019. Hawaiian naturalized vascular plant checklist. *Bishop Museum Technical Report* **69**: 23 pp.

Imada, C.T., Staples, G.W. & Herbst, D.R. 2000. Annotated checklist of cultivated plants of Hawai'i, Bernice Pauahi Bishop Museum. Available at: http://www2.bishopmuseum.org/HBS/botany/cultivatedplants. (Accessed November 2018).

IUCN [International Union for the Conservation of Nature]. 2017. Guidelines for using the IUCN Red List categories and criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Available at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf. (Accessed March 2018).

Karlin, E.F., Hotchkiss, S.C., Boles, S.B., Stenoien, H.K., Hassel, K., Flatberg, K.I. & Shaw, A.J. 2012. High genetic diversity in a remote island population system: sans sex. *New Phytologist* **193**(4): 1088–1097. doi:10.1111/j.1469-8137.2011.03999.x.

Kraus, F. & Duffy, D.C. 2010. A successful model from Hawai'i for rapid response to invasive species. *Journal for Nature Conservation* **18**(2): 135–141. doi:10.1016/j.jnc.2009.07.001.

Larson, E.R., Kreps, T.A., Peters, B., Peters, J.A. & Lodge, D.M. 2019. Habitat explains patterns of population decline for an invasive crayfish. *Ecology* **100**(5): e02659. https://doi.org/10.1002/ecy.2659

Lockwood, J.L., Cassey, P. & Blackburn, T.M. 2009. The more you introduce the more you get: the role of colonization pressure and propagule pressure in invasion ecology. *Diversity and Distributions* **15**(5): 904–910. doi:10.1111/j.1472-4642.2009.00594.x.

Morais, P. & Reichard, M. 2018. Cryptic invasions: a review. *Science of the Total Environment* **613**: 1438–1448. doi:10.1016/j.scitotenv.2017.06.133.

Moravcova, L., Pyšek, P., Krinke, L., Mullerova, J., Perglova, I. & Pergl, J. 2018. Long-term survival in soil of seed of the invasive herbaceous plant *Heracleum mantegazzianum*. *Preslia* **90**(3): 225–234. doi:10.23855/preslia.2018.225.

NMNH [National Museum of Natural History]. 2018. Department of Botany Collections Search Engine. National Museum of Natural History, Smithsonian Institution, Washington, D.C. Available at: https://collections.nmnh.si.edu/search/botany/ (Accessed March 2018).

NTBG [National Tropical Botanical Garden]. 2018. National Tropical Botanical Garden–Herbarium Search Engine Database. Kalaheo, Hawai‘i. Available at: https://ntbg.org/database/herbarium (Accessed March 2018).

Palmer, M.W., Wade, G.L. & Neal, P. 1995. Standards for the writing of floras. *Bioscience* **45**(5): 339–345. doi:10.2307/1312495.

Panetta, F.D. 2007. Evaluation of weed eradication programs: containment and extirpation. *Diversity and Distributions* **13**(1): 33–41.

Panetta, F.D. 2015. Weed eradication feasibility: lessons of the 21st century. *Weed Research* **55**(3): 226–238. doi:10.1111/wre.12136.

Penniman, T.M., Buchanan, L. & Loope, L.L. 2011. Recent plant eradications on the islands of Maui County, Hawai‘i, pp. 325–331. *In:* Veitch, C.R., Clout, M.N. & Towns, D.R. (eds), *Island Invasives: Eradication and Management*. IUCN, Gland, Switzerland. http://www.issg.org/pdf/publications/island_invasives/pdfhqprint/3penniman.pdf

Pluess, T., Cannon, R., Jarosik, V., Pergl, J., Pyšek, P. & Bacher, S. 2012. When are eradication campaigns successful? A test of common assumptions. *Biological Invasions* **14**(7): 1365–1378. doi:10.1007/s10530-011-0160-2.

Provost, M. 1998. *Flore vasculaire de Basse-Normandie.* Vol. 2. Presses Universitaires de Caen, Caen, France.

Pyšek, P., Richardson, D.M., Rejmanek, M., Webster, G.L., Williamson, M. & Kirschner, J. 2004. Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. *Taxon* **53**(1): 131–143. doi:10.2307/4135498.

Pyšek, P., Hulme, P.E., Meyerson, L.A., Smith, G.F., Boatwright, J.S., Crouch, N.R., Figueiredo, E., Foxcroft, L.C., Jarosik, V., Richardson, D.M., Suda, J. & Wilson, J.R.U. 2013. Hitting the right target: taxonomic challenges for, and of, plant invasions. *AoB Plants* **5**. doi:10.1093/aobpla/plt042.

Pyšek, P., Pergl, J., Essl, F., Lenzner, B., Dawson, W., Kreft, H., Weigelt, P., Winter, M., Kartesz, J., Nishino, M., Antonova, L.A., Barcelona, J.F., Cabezas, F.J., Cardenas, D., Cardenas-Toro, J., Castano, N., Chacon, E., Chatelain, C., Dullinger, S., Ebel, A.L., Figueiredo, E., Fuentes, N., Genovesi, P., Groom, Q.J.,

Henderson, L., Inderjit, Kupriyanov, A., Masciadri, S., Maurel, N., Meerman, J., Morozova, O., Moser, D., Nickrent, D., Nowak, P.M., Pagad, S., Patzelt, A., Pelser, P.B., Seebens, H., Shu, W.S., Thomas, J., Velayos, M., Weber, E., Wieringa, J.J., Baptiste, M.P. & van Kleunen, M. 2017. Naturalized alien flora of the world: species diversity, taxonomic and phylogenetic patterns, geographic distribution and global hotspots of plant invasion. *Preslia* **89**(3): 203–274. doi:10.23855/preslia.2017.203.

Richardson, D.M., Pyšek, P. & Carlton, J.T. 2011. A compendium of essential concepts and terminology in invasion ecology, pp. 409–420. *In:* Richardson, D.M. (ed.), *Fifty Years of Invasion Ecology: the Legacy of Charles Elton*. Wiley-Blackwell, Chichester, UK.

Richardson, D.M., Pyšek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D. & West, C.J. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* **6**(2): 93–107.

Riddle, B.R., Ladle, R.J., Lourie, S.A. & Whittaker, R.J. 2011. Basic biogeography: estimating biodiversity and mapping nature, pp. 45–92. *In:* Ladle, R.J. & Whittaker, R.J. (eds), *Conservation Biogeography*. Wiley-Blackwell, Hoboken, New Jersey. doi:10.1002/9781444390001.ch4

Rouhan, G. & Gaudeul, M. 2014. Plant taxonomy: a historical perspective, current challenges, and perspectives, pp. 1–37. *In:* Besse, P. (ed.), *Molecular Plant Taxonomy*. Methods in Molecular Biology (Methods and Protocols) 1115. Humana Press, Totowa, NJ.

Simberloff, D. & Gibbons, L. 2004. Now you see them, now you don't! – population crashes of established introduced species. *Biological Invasions* **6**(2): 161–172. https://doi.org/10.1023/B:BINV.0000022133.49752.46

Souza, E.N.F. & Hawkins, J.A. 2017. Comparison of herbarium label data and published medicinal use: herbaria as an underutilized source of ethnobotanical information. *Economic Botany* **71**(1): 1–12. doi:10.1007/s12231-017-9367-1.

Staples, G. & Herbst, D. 2005. *A Tropical Garden Flora: Plants Cultivated in the Hawaiian Islands and Other Tropical Places*. Bishop Museum Press, Honolulu. 908 pp.

Stern, M.J. & Eriksson, T. 1996. Symbioses in herbaria: recommendations for more positive interactions between plant systematists and ecologists. *Taxon* **45**(1): 49–58. doi:10.2307/1222584.

Tunison, J.T. & Zimmer, N.G. 1992. Success in controlling localized plants in Hawai'i Volcanoes National Park, pp. 506–524. *In:* Stone, C.P., Smith, C.W. & Tunison, J.T. (eds), *Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research*. Cooperative National Park Resources, University of Hawai'i Press, Honolulu.

Wagner, W.L., Herbst, D.R. & Sohmer, S.H. 1999. *Manual of the Flowering Plants of Hawai'i.* Revised edition. University of Hawai'i Press, Honolulu. 1,918 pp.

Wagner, W.L., Herbst, D.R. & Lorence, D.H. 2005. Flora of the Hawaiian Islands website. Smithsonian Institute, Washington, DC. Available at: http://botany.si.edu/pacificislandbiodiversity/Hawaiianflora/index.htm. (Accessed March 2018).

Wagner, W.L., Herbst, D.R., Khan, N. & Flynn, T. 2012. Hawaiian vascular plant updates: a supplement to the Manual of the flowering plants of Hawai‘i and Hawai‘i’s ferns and fern allies. Smithsonian Institute, Washington, DC. Available at: https://naturalhistory2.si.edu/botany/hawaiianflora/supplement.htm. (Accessed March 2018).

Wester, L. 1992. Origin and distribution of adventive non-native flowering plants in Hawai‘i, pp. 99–154. *In:* Stone, C.P., Smith, C.W. & Tunison, J.T. (eds), *Alien Plant Invasions in Native Ecosystems of Hawai‘i: Management and Research.* Cooperative National Park Resources, University of Hawai‘i Press, Honolulu.

Wilson, J.R.U., Caplat, P., Dickie, I.A., Hui, C., Maxwell, B.D., Nuñez, M.A., Pauchard, A., Rejmánek, M., Richardson, D.M., Robertson, M.P., Spear, D., Webber, B.L., van Wilgen, B.W. & Zenni, R.D. 2014. A standardized set of metrics to assess and monitor tree invasions. *Biological Invasions* **16**(3): 535–551. doi.org/10.1007/s10530-013-0605-x.