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Long delays in identification and publication of naturalized species: a case study of introduced grasses in Hawai‘i

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Abstract
As introduced plants spread across the world, botanists have documented their naturalizations through herbarium specimens and published reports that serve as primary sources for the study and management of biological invasions. Invasion lag time, attracting much attention from both theoretical and applied perspectives, is typically defined as the time between introduction and first reported naturalization. Delays in identifying naturalized specimens in herbaria and publication delays may be a major cause of long reported lag times, but such delays have rarely been quantified. The Hawaiian naturalized grass flora serves as a case study to examine these delays among 269 species introduced after European colonization. From herbarium data, we found the collection date of the fist naturalized specimen, when it was correctly identified, and compared these to the date of the first published naturalization report. There was an average delay of 27 years (median of 17 years) between the first naturalized herbarium specimen and its publication, although this delay has decreased among more recent naturalizations. Among this delay is the time needed for correct identification of specimens, which was an average of 18 years, but a median of 4 years, indicating that most grasses are quickly identified but some identifications required

decades. These delays, when not accounted for, obscure actual temporal trends in invasions. It is also important to understand and account for these delays in order to better characterize the phenomena that contribute to reported lag times for biological invasions. Minimizing identification and publication delays in the future will be important for successful management and control of new invasions. Expanded investment in and support of taxonomic experts at biodiversity institutions is needed to reduce reporting delays for new naturalizations.

Introduction

The study and management of naturalized plant populations and invasions rely on accurate knowledge of species distributions in space and time. For plants, many researchers depend on naturalization information published in journals or botanical checklists (e.g. Seebens et al. 2017, van Kleunen et al. 2019, Seebens et al. 2021, Chen et al. 2022, Egawa & Koyama 2023, Holmes et al. 2023). However, these are secondary sources, as in most cases, preserved specimens in herbaria are the primary sources documenting naturalizations. Because of this, there can be a delay period between when species are first collected and/or documented as naturalized in an herbarium, and when that naturalization becomes recognized to most researchers and policy makers through a publication.

These delays have important repercussions, as they may give false impressions of patterns of naturalization and invasion over time. Publication delays may also contribute to the enigmatic phenomenon of “lag times” (Crooks 2005), where long times have been reported between the first record of introduction and the first report of naturalization. Furthermore, reporting delays hinder on-the-ground eradication activities, which are most effective when populations are small (Reaser et al. 2020), and delays can allow populations to build up to unmanageable levels before the relevant information is available to decision makers. Prior work by Brock (2021) used simulations to examine the effect of delays between collection of naturalized specimens and their publication on perceived patterns of naturalization over time. Simulations showed that these reporting delays can lead to a perceived decreasing number of naturalizations when the number of new naturalizations is constant or even rising (Brock 2021). As such, these delays have the potential to affect our understanding of invasion patterns and processes and our successful management of invasions; yet, the duration of these delay periods has rarely been quantified.

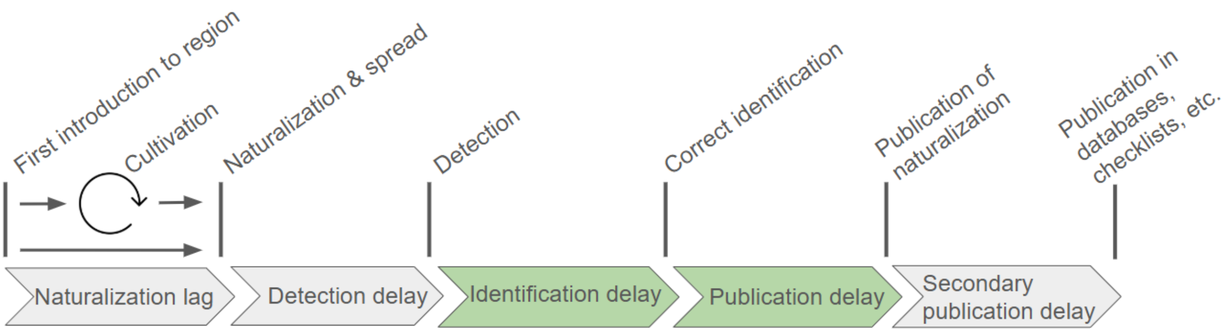

Figure 1 Conceptual diagram showing the lags and delays associated with naturalizations. Delays are associated with human processes, whereas the naturalization lag is associated with biological processes. Components highlighted in green are quantified in this study.

The time between a species' first naturalization and its publication as a new naturalization is determined by the length of time involved in several possible steps leading up to the published report (Figure 1). The first delay is the time between the naturalization of a species and the detection or observation of the naturalized population, this is necessarily unknown (Crooks et al. 1999) and depends on many factors such as search frequency and intensity, conspicuousness of the species, etc. Our study focuses on knowable delays highlighted in green on Figure 1. To illustrate these potential delays, we will use a case study of the naturalization of *Eragrostis superba* Peyr. in Hawaiʻi. When a new naturalization is recognized in the field, typically a specimen is deposited in a herbarium, but this may not be immediate (Marsico et al. 2010), and the species might not be correctly identified. *Eragrostis superba* was first collected as a naturalized specimen in 1985 (E.J. Funk 252 BISH), but it was only identified as Poaceae at the time of collection. The first quantifiable delay, the identification delay, then starts as the specimen awaits correct identification. For *E. superba*, it was nine years before W.D. Clayton attached an annotation label to the specimen with the species identification. Once a specimen is correctly identified, there is then another delay before the species is published as naturalized. For *E. superba*, it was a four year delay (Herbst & Clayton 1998). One could also consider a further possible delay between the primary publication date and the date when the species is incorporated into secondary sources, such as floras, checklists, or databases (Figure 1); however, assessing that delay was beyond the scope of this current work.

The knowable delays discussed above in recognizing additions to a naturalized flora are human caused and are thus under the influence of many cultural and economic factors. This is in contrast to invasion lags, typically envisioned as biological processes associated with naturalization and invasion, including the lag times from introduction to reproduction or dispersal and spread (Crooks 2005), although in practice such invasion lags will also include the human-caused delays unless they are explicitly factored out of invasion lags. Identification delays are likely to be longest for cryptic or non-charismatic taxa, a label many botanists would assign to grasses.

Introduced grasses (Poaceae) of Hawai‘i, which are well-represented in herbaria with over 16700 specimens, were chosen for this case study assessing delays between published records of introduction, collection of a naturalized specimen, identification of the specimen and publication of the naturalized record. The islands of Hawai‘i, located in the tropical Pacific, contain a diverse range of habitats arising from interactions between elevation and the effects of trade winds, including savannahs, dry forest, rainforests, cloud forests, and alpine shrublands. This environmental heterogeneity allows for a high diversity of both native and naturalized grasses in a relatively small area, including 280 species (Faccenda 2025). Grasses have also been well studied in terms of their taxonomy and distribution in Hawai‘i, with many floras documenting naturalized species over time (Hillebrand 1888, McClelland 1915, Hitchcock 1922, Whitney et al. 1939, O’Connor 1990, Faccenda 2022, 2023, Faccenda et al. 2024).

Between 1778, when Europeans first arrived to the Hawaiian archipelago, and 2023, approximately 557 grasses were imported to the islands (Faccenda 2025). The majority of these were deliberately imported by the Hawaiʻi Agricultural Experiment Station (HAES) for pasture use, as native grasses are not adapted to high intensity grazing (McClelland 1915). Numerous grasses also arrived accidentally through shipping, contaminated seed, and massive quantities of hay that were imported during the late 1800s and early 1900s (summarized in Faccenda 2025).

Using grasses in Hawaiʻi as a case study, the primary objective of this study was to quantify delays between documented naturalization and publication of naturalization, and to assess whether these delays have changed over time with increasing interests in naturalization and invasions and shifts in publishing culture. We hypothesized that the delay between first record of a naturalized specimen and identification will be shorter for deliberately introduced species compared to accidentally introduced species, as deliberate introductions may often have at least proposed identities already at their time of introduction. Quantification of these delays can provide new insights into naturalization patterns of invasive species and contribute to invasive species management in Hawaiʻi.

Methods

This study focuses on the first records of presence and naturalization of grass species across the main Hawaiian islands of Niʻihau, Kauaʻi, Oʻahu, Molokaʻi, Lānaʻi, Maui, Kahoʻolawe, and Hawaiʻi, excluding Papahānaumokuākea (northwestern islands) which are largely uninhabited atolls. I focus on the delay periods arising from the first report of a species on any of the islands (new state records), but see Brock & Daeher (2021) for an analysis on interisland spread. The checklist of naturalized grasses used for this work was recently assembled (Faccenda 2025) and includes all grasses recognized as naturalized through the end of 2023. This checklist also identifies each grass species as either deliberately or accidentally introduced. An accidental introduction is defined as the movement of a plant or its propagule to Hawaiʻi when its movement was not intended by the party that transported it. Waif species, those that occasionally appear from bird or crop seed but do not form persistent populations (Nesom 2000), were excluded from this analysis. This includes *Cenchrus americanus* (L.) Morrone, *Oryza sativa* L., *Panicum miliaceum* L., *Phalaris canariensis* L., *Sorghum bicolor* (L.) Moench subsp. *bicolor,* and *Triticum aestivum* L. Grasses hypothesized to be introduced by Polynesian voyagers are excluded from this study due to lack of dated records (Faccenda 2025).

The majority of first naturalization records come from herbaria. Herbarium data have been widely used to document the spread of naturalized plants (Marsico et al. 2010, Lavoie 2013, Osunkoya et al. 2021) and are considered the most comprehensive primary source for studying plant invasions (Brock 2021). Nevertheless, herbarium data are not perfect records of naturalization or invasion, as collecting is not uniform across space, time, or taxonomy (Daru et al. 2018). In addition, determining the naturalization status of old herbarium specimens is not always straightforward. Many specimens from Hawaiʻi collected before the 1930s have little information on their label, often only including a date and place name. Fortunately, labels of this era do frequently note cultivation status using terms such as “cult*”, “garden”, “planted”, “trial”, or “plot”, and these specimens were not considered naturalized. There were also limited stations in Hawaiʻi where grass trials were cultivated, mainly “Pensacola”, “Makawao”, “Poamoho”, “Koele”. Specimens collected from these areas were also not considered naturalized unless the specimen label specifically noted that the collection was made outside of cultivation.

Naturalized species are defined as those which successfully reproduce in the wild (Category C2 or greater, Blackburn et al. 2011). As limited information on older labels made it impossible to apply this criterion precisely, any specimen for which there was no evidence of it being cultivated based on the herbarium label was assumed to be naturalized. This assumption may result in naturalization dates being earlier in time than in reality if a herbarium specimen of a cultivated plant was not labeled as such. The naturalization criteria (Category C2 or greater, Blackburn et al. 2011) could be much more confidently applied to more recent specimens, which tended to have labels specifically mentioning wild reproduction or population sizes.

Extensive collections of naturalized plants in Hawai‘i were made by William Hillebrand when he lived in Hawai‘i from 1851 to 1871, leading up to his *Flora of the Hawaiian Islands* (Hillebrand 1888). Unfortunately, the majority of these were destroyed in the bombing of the Berlin Herbarium in WWII (Hiepko 1987), and the surviving specimens in other herbaria are undated. All species cited by Hillebrand (1888) are therefore assumed to have been collected in 1871 (n=10), which is the latest possible date for these collections. Similar reasoning was used to date specimens made by other early collectors who did not date their specimens; these were dated with the last year that the collector was known to make collections in Hawai‘i (n = 10).

The identification delay is the time between the first naturalized collection of a species and the time at which the species was identified with the correct scientific name at the species level. This delay period ended when any specimen at any herbarium was correctly identified. Species that were identified with a name now recognized as a synonym were considered correctly identified. Synonymy information was obtained from Plants of The World Online (POWO 2024). Welch’s T-test was used to test for differences in identification delays between intentionally and accidentally introduced species on log-transformed lags.

To determine when each grass was first correctly identified, all herbarium specimens of each species were examined, and the earliest label or annotation date with the correct identification was recorded. These specimens were principally examined in the Bishop Museum Herbarium (BISH) and photographed specimens from The Smithsonian Herbarium (US) were also examined.

While modern herbarium convention involves attaching both the date and name of the identifier to an annotation label when identifying a specimen, this has not been consistent through time. Many specimens before the 1930s had identifications penciled in on the label without dates. When a specimen was identified correctly by the collector on a label with no specific identification date given, the identification date is taken to be the same as the collection date, as in most cases, the identification was made in the same handwriting as the rest of the label. This will bias the identification delay shorter as some identifications could have been made by a collector a year or more after collection. On the other hand, if species with undated identifications had instead been excluded from calculations involving identification delays, this would likely add a strong bias toward longer identification delays by excluding many specimens that were immediately identified by collectors while retaining old specimens first identified by modern botanists who consistently dated their identifications.

As grasses have been introduced to Hawaiʻi from across the world, their correct identification in Hawaiʻi has proved challenging. Many species were misidentified and first published as naturalized under a misapplied name. An example is *Themeda villosa* (Poir.) A.Camus, which was first misidentified as *Themeda gigantea* Hack. In these cases, two publication dates were recorded, the date when a misapplied name was published, and the date when the misapplied name was corrected, allowing for the calculation of publication delays excluding or including misapplied names. The identification date was taken as the date when the misapplied name was finally corrected. Several species now known to be introduced after European colonization were initially described as Hawaiian endemic species such as *Garnotia sandwichensis* Hillebr., *Agrostis kauaiensis* Hillebr., *Eragrostis hosakai* O.Deg., and *Syntherisma helleri* Nash. These are also considered misapplied identifications.

Publication delay is defined as the time between correct identification of a naturalized record and its publication in any publicly accessible written medium which describes the grass as naturalized. In the course of this research, naturalization records were found in various sources, including newspapers, agricultural literature, and more traditional botanical sources such as floras and checklists including Reichardt (1877), Hillebrand (1888), Heller (1897), McClelland (1915), Hitchcock (1922), St. John and Hosaka (1932), Ripperton et al. (1933), Whitney et al. (1939), Ripperton and Hosaka (1942), Degener & Degener (1946), Hosaka and Thistle (1954), Rotar (1968), St. John (1973), O'Connor (1990), Staples and Herbst (2005), and Clayton and Snow (2010). Searches were also made in the HathiTrust database (https://hathitrust.org) and Library of Congress's Chronicling America newspaper database (https://chroniclingamerica.loc.gov/) for the scientific and common names of each genus of grass known to be naturalized in Hawaiʻi, using filters to only include sources published in Hawaiʻi. The majority of modern naturalizations were published in the *Bishop Museum Occasional Papers* and were compiled by Imada (2019). Data are available in S1.

Results

A total of 269 naturalized grasses were included in this analysis; however, nine species were excluded from most delay analyses as they were apparently published as naturalized before a herbarium specimen was made. Eight of these are from the late 1890s and early 1900s, before Hawaiʻi had its own herbarium. The 9th is *Cenchrus ciliaris* L. which was published as naturalized by Ripperton & Hosaka (1942) before the first naturalized herbarium specimen was made in 1950.

Table 1. Summary of delay periods. n = 260 unless otherwise noted. Identification delays for grasses first collected after 1930 are separated as the annotation labels after 1930 are usually dated. *Assuming undated identifications were made the same year the specimen was collected.

	Median delay (years)	Mean delay (years)
Identification*	1	18
Identification, specimens after 1930* (n = 149)	4	19
Publication	6	14
Naturalization - publication of any name	17	27
Naturalization - publication	20	32

of correct name		

A total of 103 grasses had specimens bearing correct identifications which were not clearly dated; when these were assumed to be immediately identified and assigned an identification delay of 0 years, the average identification delay across all grasses is 18 years (median 1 year), but this is an underestimation because, some identifications must have been made more than a year after collection, as is known to be the case for more recent naturalized specimens (Table 1). After 1930, most herbarium labels have dated annotations, meaning that undated determinations were likely to have been made immediately by the author. After 1930, only 33 of 149 grasses were assumed to have a 0 year identification delay, with an average of 19 (median 4) years (Table 1). In many cases, identification delays were substantial, with 61 species taking over 30 years to be identified correctly.

Bothriochloa macra (Steud.) S.T.Blake had an unusual identification history as it was published in 1954 (Hosaka & Thistle 1954), yet no herbarium specimens bear this name as they were all misidentified as *Bothriochloa pertusa* (L.) A.Camus until 2022, when the species was independently identified by the author. Only after this 2022 identification was the 1954 original publication located. This was the only case where a publication was used to assign an identification date instead of a herbarium label annotation.

The publication delay tended to be shorter with a mean of 14 (median 6) years, versus the mean identification delay of 18 years (median 1; Table 1). These combine together to give a total delay of 32 years on average between the first naturalized specimen and its correct publication (Table 1).

The distributions of delays found by this analysis have long tails, with most species having relatively short delay periods, but others having substantially longer delay periods (Table 1, Figure 2). The longest delay was 160 years between the first naturalized specimen and the correct publication of *Polypogon fugax* Nees ex Steud., a species whose identity was long confused and published under many misapplied names.

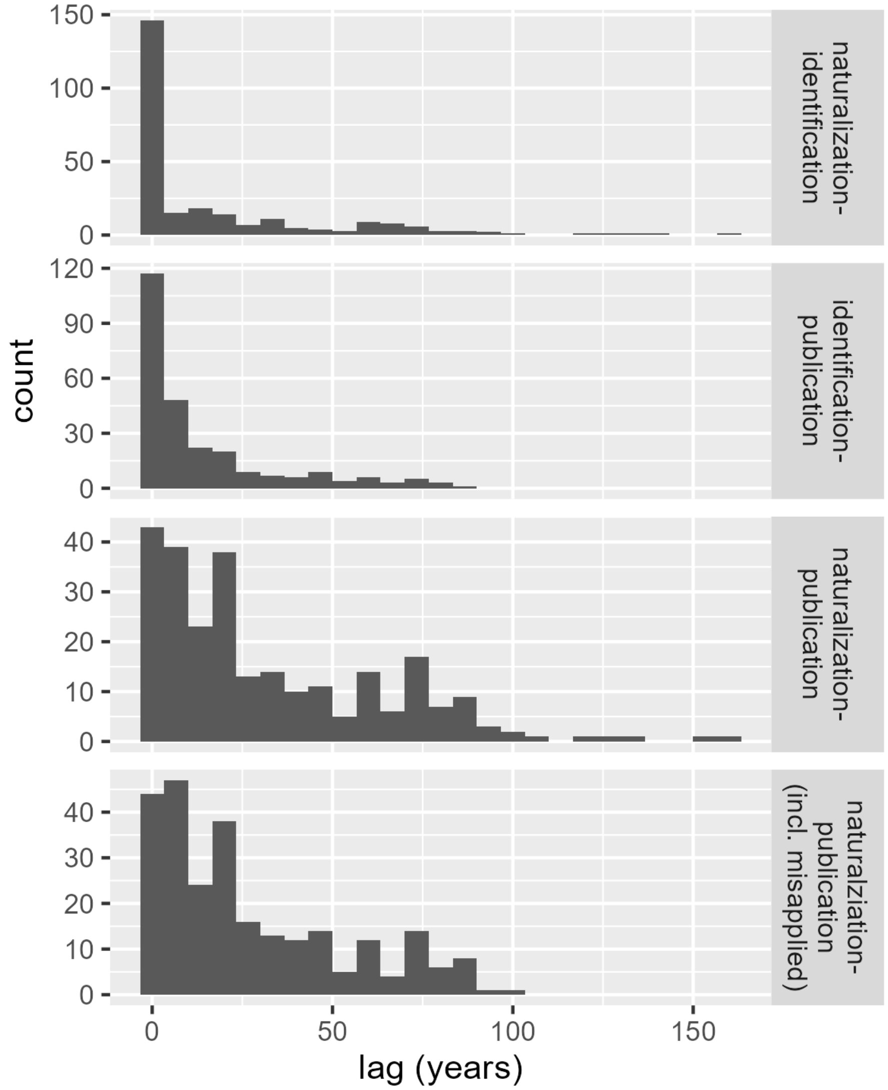

Figure 2. Histogram of various delay periods.

A total of 27 grasses were first published as misapplied names. It took an average of 53 (median 47) years before these misapplied names were corrected. The majority of these misapplied names were published before 1930, with only nine species first published as misapplied names after 1930. No naturalizations are known to be first published under misapplied names after 1998, however, misapplied names continued to be published based on misidentifications of species published before 1998.

The number of naturalized, unpublished grasses present in Hawai‘i has varied over time and peaked at 99 species in 1989 just before publication of the *Manual of the Flowering Plants of Hawai‘i* (O’Connor 1990, Figure 3c). Even after publication of this flora, 58 naturalized species remained unpublished (Figure 3c).

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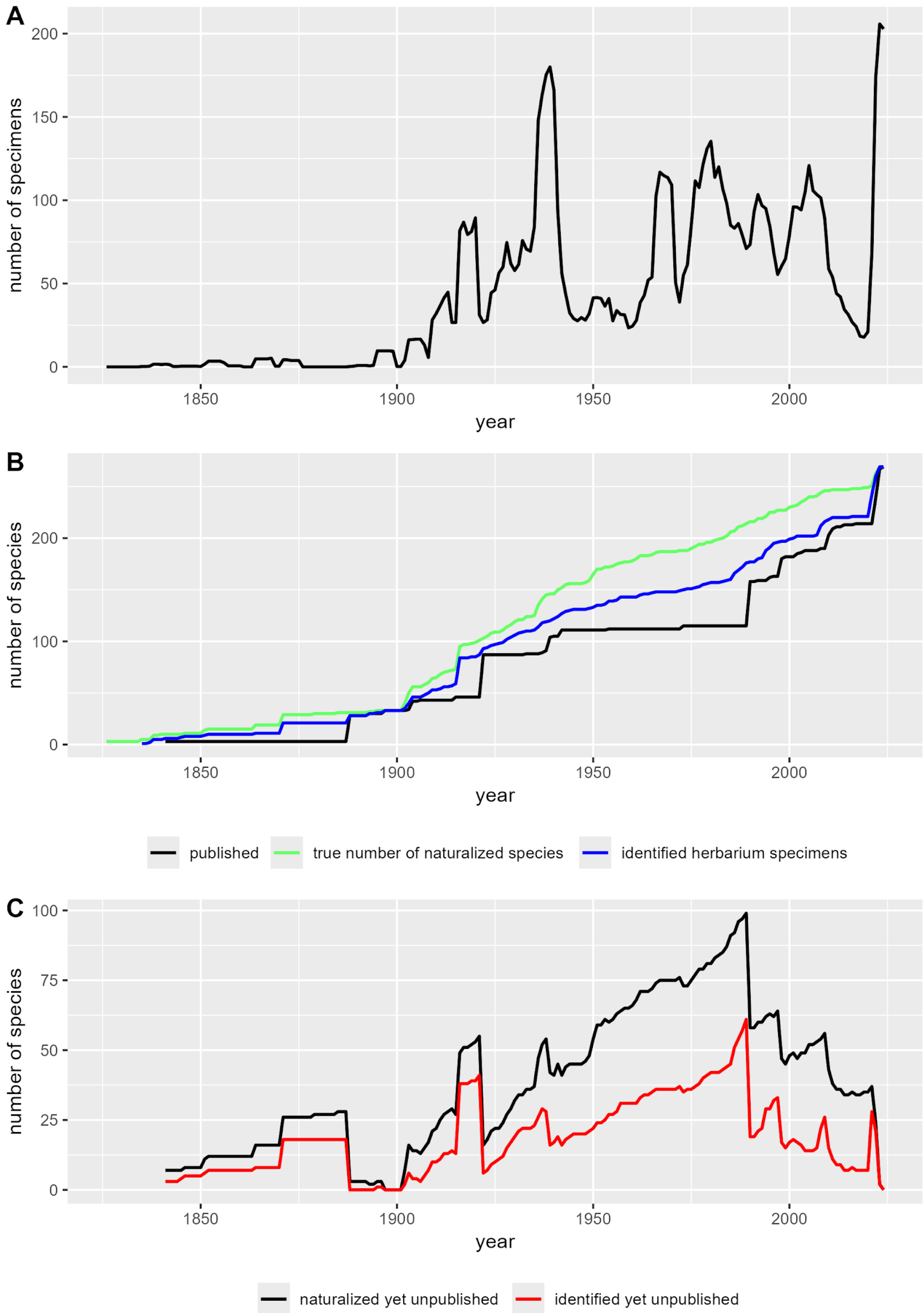

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Figure 3 Number of naturalized species over time as seen from different sources. **A**, Annual number of unique, naturalized grass herbarium specimens collected in Hawaiʻi with a 5 year rolling average. **B**, Number of naturalized species which would be obtained from various sources over time. The true number is based on the modern identifications of all herbarium specimens collected up to each year. **C**, Number of naturalized species omitted from published literature over time.

The delay periods among identification and publication of grasses in Hawaiʻi have decreased over time (Figure 4). The mean publication delay has been under 10 years since the 1970s, and the identification delay has been under 10 years since the 2000s. However, these delays must necessarily decrease towards the present, as the maximum delay for a grass found naturalized in, for example, 2020 would be 3 years, 23 years for 2000, etc. and it is possible that recent published naturalizations may include one or more misidentifications that will be corrected at a distant future date.

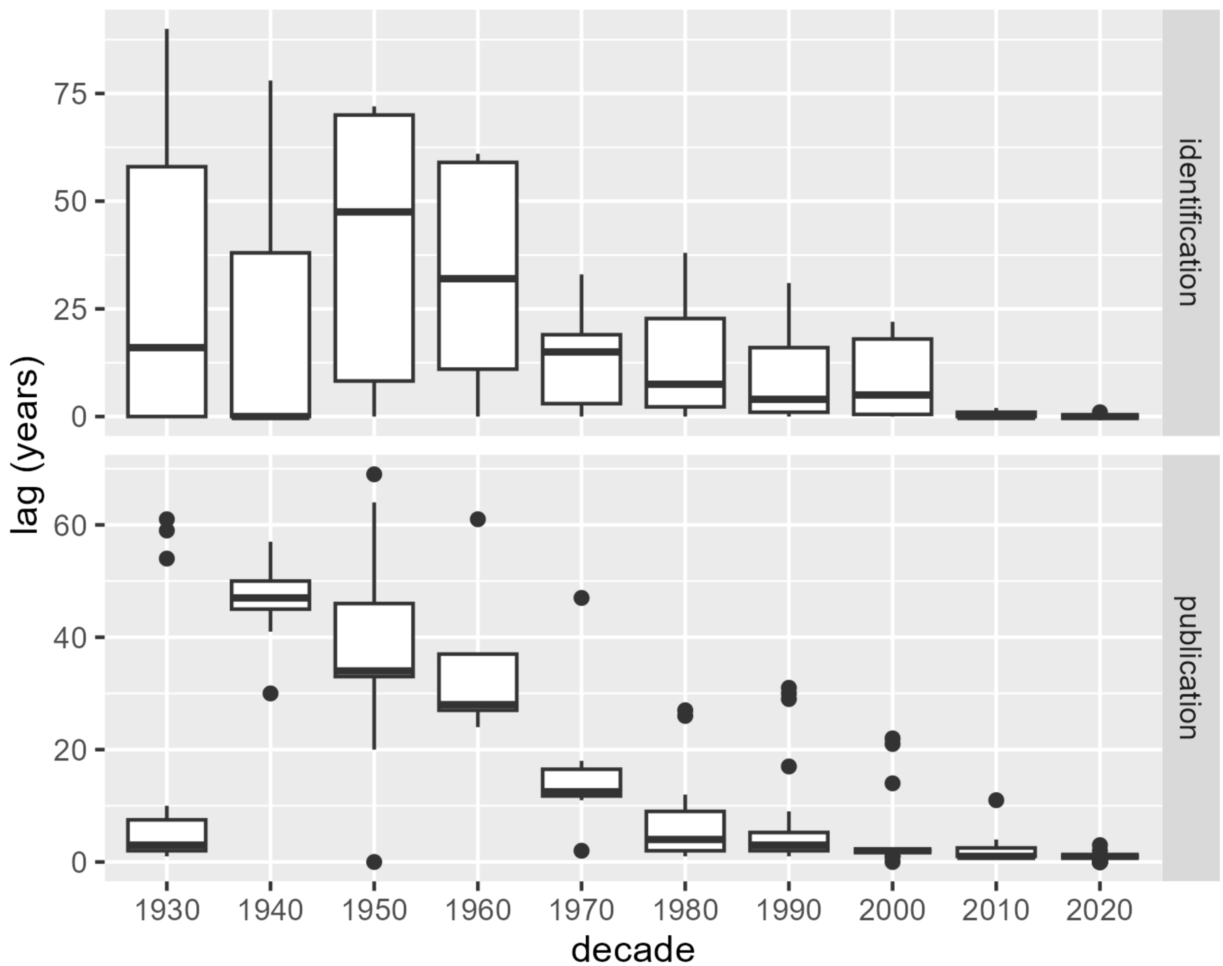

Figure 4 Delay periods for grasses across decades. Species are placed in decades for their identification delay based on what decade they were collected. Similarly, species were placed in decades for their publication delay based on what decade they were identified. Only specimens first collected after 1930 shown as determination dates before then are less reliable.

Discussion

Identification delays

A longer identification delay period was found for accidental introductions compared to deliberately introduced species at 22 vs. 12 years respectively (p=0.02; t=2.35; df=255). This was expected, as plant collectors are often familiar with cultivated plants or with literature which describes cultivated species. In addition, well-identified cultivated herbarium material is typically available to herbarium workers to aid in identifications. In contrast, when a new accidental introduction appears, identified reference specimens are unlikely to exist locally, making identification more difficult.

It is notable how many grasses were first reported under misapplied names, totalling 27 species, or 10% of the grass flora. These misidentifications and long identification delays in general may be explained by the difficulty of grass identification. However, an argument could also be made that tropical plants have high rates of misidentification globally and the findings for grasses in Hawaiʻi are perhaps not unique (Goodwin et al. 2015). Grasses nevertheless comprise a large plant family, totaling about 11,000 species globally (Kellogg 2015) and considering that naturalized grasses in Hawaiʻi have arrived from across all biogeographic realms (Faccenda 2025), some misidentifications are to be expected. One must consult various resources and taxonomic keys from around the world in the hope of making an initial identification, and reference materials must be consulted (often from abroad) to confidently identify a new naturalized species.

Identifications have also been confounded by lack of accessible taxonomic literature at the time when naturalizations were first collected (Pyšek et al. 2013). This is exemplified in the case of *Cynodon aethiopicus* Clayton & J.R.Harlan and *Cynodon nlemfuensis* Vanderyst, species which were described only after they were introduced to Hawaiʻi. Grasses are also often considered a specialist group, and most collectors are not comfortable with their identification and submit herbarium specimens simply identified as “Poaceae” or at the genus level. Thus, specimens often require either a taxonomic expert to visit Hawaiʻi or a duplicate specimen must be mailed to a grass expert outside of Hawaiʻi for identification. The difficulty in identifying grasses and other difficult taxonomic groups has certainly decreased in the internet age due to the sheer quantity of digitized taxonomic and herbarium material now available nearly instantaneously.

To decrease identification delays such that new unwanted naturalizations can be more effectively targeted for management action, investment must be made in training and retaining taxonomic experts at biodiversity institutions, especially herbaria (Pyšek et al.

2013, Goodwin et al. 2015). Forming partnerships between citizen scientists on platforms such as iNaturalist and taxonomic experts will also pay dividends as arrivals of new invasive species are frequently being discovered (though not always identified) by citizen scientists who share photos online (e.g Faccenda 2024). Machine learning and AI tools for plant identification (Hart et al. 2023) may also help decrease identification delays. Investment in floristic inventories is also essential as field botanists and naturalists will have great difficulty recognizing new naturalizations in the field if there are no convenient resources that can be used to check the known naturalized species. This was the case in Hawaiʻi where the latest flora was published in 1990 (Wagner et al. 1990) and it is missing 121 grasses now known to be naturalized. Although one can now find additional resources (Faccenda 2023, www.mauu.net, www.plantsofhawaii.org) that supplement the naturalized species list found in the flora, these resources generally do not include identification keys. Unfortunately, investment in floras and taxonomy generally has been declining across the world (Kim & Byrne 2006, Drew 2011, Löbl et al. 2023), likely further exacerbating identification delays.

Of the delays quantified here, the identification delay is the most likely to bias the data used for calculating presumed biological lags associated with invasion, as most workers now use herbarium data for calculating these lags rather than publication dates (e.g. Aikio et al. 2010, Larkin 2012, Osunkoya et al. 2021). Our study appears to be the first time that the identification delay has been quantified systematically for any taxonomic group, making it unclear how the delays among first reported naturalizations of Hawaiian grasses compare to other taxa in other regions.

Publication delays

Between the 1800s to 1990, the principal vehicles for publication of new plant naturalizations in Hawaiʻi were either floras (e.g. Hitchcock 1922, O'Connor 1990), or agricultural bulletins or extension reports (e.g. Ripperton et al. 1933, Whitney et al. 1939). There was evidently little interest in short notes documenting species spread and, as such, publication delays were longer in the past.

Now, a local journal (the *Bishop Museum Occasional Papers*) has emerged as the principal publication source for new occurrences of naturalized plants. This journal publishes the Hawaiʻi Biological Survey (HBS, Evenhuis & Miller 1995), initiated in 1992 by the Hawaiʻi state legislature and has made substantial contributions, reporting 398 naturalizations over its first 25 years (Evenhuis 2020). Only 4 of 121 grasses reported since 1992 were first reported in other journals. In the 32 years since establishment of the HBS, it has taken an average of 3 years between identification of a grass and its publication (Figure 4). In contrast, in the 32 years preceding the HBS, this delay averaged 13 years. The HBS has likely decreased the publication delay across a diverse range of naturalized taxa. The HBS also likely helps explain the drop in the number of naturalized grass species which were identified yet unpublished ranged from a peak of nearly 60 in 1990 down to a range of 7–22 between 1992–2023, with the lowest number in 2023 (Figure 3c). Other journals such as *BioInvasions Records* also specialize in publishing new naturalizations while many other journals now also publish new naturalization reports without specifically specializing in them. Although there are now various options for publishing naturalization records, local journals can be especially effective for this purpose, especially if they are available online, as they allow researchers and managers to focus on a primary source for information on new naturalizations or emerging invaders.

The average publication delay found here, at 14 years, is much longer than typical publication delays for conservation science. An average delay of 3.2 years was found between data collection and publication among over 7400 conservation and ecological studies across the full tree of life examined by Christie et al. (2021). The shorter delay found by Christie et al. (2021) might be due to the large number of ecology and conservation journals that are available specifically for publishing such work; whereas, limited outlets have been available for publication of naturalizations, and collectors may not always have had access to or awareness of publication outlets. At the same time, workers in conservation science may have greater incentive to publish research findings before another group “scoops” the research question, and because journal publications in conservation science are often important for career advancements (Berenbaum

2019).This delay is also shorter for conservation science due to survivorship bias, as it only includes published works, thus excluding the many studies which will never be published. This is unlike plant naturalizations, where a naturalization can always be published eventually, even if by a different researcher.

After a naturalization has been published, a further delay is associated with the synthesis of new naturalizations into secondary sources such as checklists and databases. While this was not quantified for the Hawaiian grass flora, Brock (2021) compared a database of first occurrences across all plants in Hawaiʻi based on herbarium data to the dataset of Seebens et al. (2017) which was based principally on secondary sources of first naturalizations. The bias due to this secondary source publication delay was substantial, resulting in misleading conclusions about naturalization patterns over time. Seebens et al. (2017) concluded from secondary source data that there was a plateau in plant naturalizations starting in 1980. Whereas the herbarium data showed no plateau in the number of naturalizations (Brock 2021) and revealed twice as many naturalizations after 1980 than were reported from secondary sources used by Seebens et al. (2017).

Naturalization to publication delays

No studies could be found that examine identification delays among naturalized species, and only a few studies could be located that report naturalization-publication delays. A median of 2 years delay is reported among 145 invertebrate plant pests between 1970–2013 in Great Britain, where 97% of establishments were published within 13 years (Smith et al. 2018). Publication dates and first occurrence dates were compiled for 1056 naturalization events among introduced species in Antarctica and the Southern Ocean by Leihy et al. (2023). From these data I calculated an average delay of 7.2 years, median of 5 years, and maximum of 68 years.

Two studies have also examined delays among Mediterranean sea organisms. An average delay of 6 years was found among 776 species with the delay decreasing over time (Zenetos et al. 2019). However, Zenetos et al. (2019) exclude backdated naturalizations where a recent publication revealed that the naturalization date was earlier than the date mentioned in the initial publication, unlike this study which includes backdated reports. Delays between 0 to 38 years were reported among 83 Lessepsian fish species (those that migrated from the Red Sea into the Mediterranean via the Suez Canal). Although summary statistics are not reported, based on their Figure 6 it appears the median delay was around 5 years (Azzurro et al. 2016).

Guedes et al. (2020) report a median of five years between the collection of the holotype specimen of a species, and the publication of a new species among 2661 reptiles described from 1992–2017. Similarly, Goodwin et al. (2020) found an average of 40 years between the collection of the first specimen, and the description of the species in the tropical genus *Aframomum* (Zingiberaceae).

The naturalization to publication delay reported here, averaging 32 years (Table 1) is much longer than those reported by other authors for other taxonomic groups. This may be partially due to inclusion of naturalized specimens in this analysis which are now available due to herbarium digitization and may not have been available to earlier authors. The Hawaiian grass flora was also neglected from 1950–1990, during which few new naturalizations were published, thus increasing delays.

Publication in online databases would be very efficient at reducing publication delays. However, this would not succeed at the ultimate premise of publishing — delivering information to those who seek it, as nobody would notice when a new entry quietly appears in a database. Traditional publication in a journal, newsletter, or extension publication with local readership would both alert its readership to the naturalizations and also include important taxonomic, geographic, or ecological notes which are highly valuable to managers and field botanists. Ultimately, if the goal is to manage and eradicate invasive species, this information must be made available through a traditional publication even if it is technically published first in a database. Neither the Atlas of Living Australia (ALA 2024, Belbin 2021) or Euro+med (2006+) floristic databases directly publish new naturalizations, but rely on external publications or authorities as primary sources of naturalizations.

Synthesis

Despite delays in reporting naturalizations receiving little mention in the literature, these delays have important repercussions for both on the ground management of invasive species and our tracking of invasive and naturalized species. The Convention on Biological Diversity, an international treaty, calls for the reduction in spread of invasive species by 50% in 2030 (CBD 2022). In order to track our progress toward this goal, delay periods must be taken into account as analyses that ignore delay periods can indicate the number of new naturalizations is decreasing when it is, in fact, increasing (Brock 2021). These delays are expected to bias studies which examine accumulations of naturalizations in an area, but they will also bias studies reporting invasion lags presumed to have a biological basis, if the end points for lag times are determined by first publication date, or if herbaria house relevant unidentified or undatabased specimens due to limited taxonomic expertise or resources.

Furthermore, as McGeoch et al. (2023) note, examining the accumulation of naturalized species over time without also having data on collection effort will result in misleading conclusions and Figure 3b demonstrates this well. Between about 2010 to 2020, the number of naturalized grasses plateaus (Figure 3b); however, this is due to the number of specimens made per year, a proxy for survey effort, dropping to the lowest it has been since the early 1900s (Figure 3a). Increased survey efforts beginning in 2020 led to the discovery of many naturalized species and a sharp rise in the number of naturalized species known from Hawaiʻi (Faccenda 2022, 2023, 2024) and eliminating the apparent 2010-2020 plateau (Figure 3b). The species accumulation curve now approximately mirrors that of the Hawaiian flora overall with an approximately linear trend between 1900 and the present day (Brock & Daehler 2021).

Due to publishing delays, data used for analyzing invasion trends should be obtained directly from herbaria and other biodiversity institutions, as that is only biased by the collection to identification delay (Brock 2021) together with a potential detection delay. Consulting herbaria may make analyses more complicated as further data cleaning steps may be needed to remove cultivated, waif, or native specimens along with resolving synonyms which may not be necessary in the case of published data. This further calls for increased funding for herbaria such that these data curation steps can be done by herbarium staff, reducing the workload needed for researchers to use and interpret digitized herbarium data for invasive species management.

Hawaiʻi has been referred to as the “extinction capital of the world”, in part due to the effects of invasive species (Asquith 1995, Wood et al. 2019, Rønsted et al. 2022) on its overwhelmingly endemic biota (Wagner et al. 1990, Roderick & Gillespie 1998). Newly arriving invasive species must be quickly eradicated to prevent further damage to the Hawaiian biota, but delays regarding the identification of these taxa confound management if species are not identified quickly. The ideal time for their identification and assessment is when populations are small because the likelihood of eradication drops exponentially as populations increase in size (Reaser et al. 2020).

Conclusion

There is a substantial delay period between the naturalization of grasses in Hawaiʻi and when they are published. Delays in reporting of naturalization must occur for similar reasons among many taxonomic groups around the world. Delays in identification and reporting of naturalizations hamper the study of the spread of invasions across the world and our ability to track our progress at controlling invasions to meet the agreements set in the Convention of Biological Diversity–a goal of reducing the new number of naturalizations by 50% in 2030. Delays also further hampers on-the-ground management of invasive species. To reduce these delays, investment in and increasing the number of taxonomists at biodiversity institutions must occur (Belbin 2021). Furthermore, the creation of local journals that publish short form notes documenting the spread of invasive species are effective at reducing the time needed for publication of new naturalizations.

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