Management of Biological Invasions (2023) Volume 14, Issue 1: 45–62

Research Article

Early detection of alien fern species through the consultation of horticultural catalogues

Emily J. McCulloch-Jones[1,*], Neil Crouch[2,3] and Tineke Kraaij[4]

[1]*Centre for Invasion Biology, School of Natural Resource Management, Nelson Mandela University, Madiba Dr, George Central, George 6530, South Africa*

[2]*South African National Biodiversity Institute, Overport, 4067, Durban, South Africa*

[3]*School of Chemistry and Physics, University of KwaZulu-Natal, Durban, 4001, South Africa*

[4]*Natural Resource Science and Management Cluster, Faculty of Science, Nelson Mandela University; Madiba Dr, George Central, George, 6530, South Africa*

ORCIDs: 0000-0002-4938-5840 (NC), 0000-0002-8891-2869 (TK), 0000-0003-0008-6580 (EM)

**Corresponding author*

E-mail: *emcjones@sun.ac.za*

Citation: McCulloch-Jones EJ, Crouch N, Kraaij T (2023) Early detection of alien fern species through the consultation of horticultural catalogues. *Management of Biological Invasions* 14(1): 45–62, https://doi.org/10.3391/mbi.2023.14.1.02

Received: 2 February 2022
Accepted: 16 August 2022
Published: 5 December 2022

Handling editor: Amy Davis
Thematic editor: Catherine Jarnevich

Abstract

Horticultural trade is a well-documented pathway of introduction for numerous invasive species globally, including ferns. In this study, we analysed trade in terrestrial true ferns (Polypodiophyta) in selected anglophone countries: Canada, the United States of America, the United Kingdom and the Republic of Ireland, South Africa, Australia, and New Zealand. The study provides an overview of fern trade and explored the relationship between trade and alien fern introductions with a view to prioritise risk assessment and ultimately inform management interventions. Through consulting horticultural catalogues, in a period of just six months we identified a total of 382 fern species currently traded by 148 traders. International trade was observed in only three countries with most trade occurring at national scales and e-commerce did not clearly dominate over on-ground trade. Alien species accounted for more than 60% of the total number of traded species in most countries except in Australia and New Zealand. A total of 193 species have not previously been recorded as alien in plant species inventories in their countries of trade and were assigned the status of introduced. Several species (2–10 species per country; 38 species in total) known to be invasive in their country of trade remain actively traded there and are immediate priorities for regulation pending climate, risk and impact assessments. We categorised another 78 species with the status of naturalised or introduced in their trade countries in terms of their priority for risk or climate suitability assessment, and identified 101 potential candidates (approximately 20% of alien species traded per country) for Safe listing. This research constitutes one of few studies that have used horticultural catalogues to identify alien species, and highlights the efficiency of this approach as a tool for the early detection and prioritisation of potentially invasive species for management responses.

Key words: climate suitability assessment, e-commerce, international trade, invasion status, prioritisation, regulation, risk assessment

Introduction

Horticultural trade is an important contributor to agricultural production and economic development but also forms one of the primary introduction pathways of alien plant species globally (van Kleunen et al. 2018). Horticultural trade promotes the continual introduction of species into areas outside of their native ranges which increases propagule pressure (Dehnen-Schmutz and Touza 2008; Simberloff 2009) and exacerbates the likelihood that an alien species (i.e., non-native species) will progress along the introduction-naturalisation-invasion continuum (*sensu* Richardson et al. 2000). Additionally, popular horticultural species generally have traits that also make them successful invaders, such as fast growth rates and resistance to disease (Kolar and Lodge 2001; Hulme 2015). The popularity of ornamental taxa in horticulture is also driven by consumer demand which may be linked to the discovery of new species (historically) or through the desires of horticultural fashions (Müller and Sukopp 2016; van Kleunen et al. 2018).

Ferns are a good example of this – during the nineteenth century ferns flooded the market, most notably in Europe, in a period referred to as the "fern craze" or "pteridomania" (Allen 1969; Whittingham 2010). These terms were coined around the 1850's and capture the fervor with which the public desired ferns and also the extent to which the taxon influenced fashions in art, design and ornamental decoration (Birkenhead 1897). The result was the introduction of some nine hundred species of alien fern to Britain for the purpose of cultivation during the 19th century alone (Smith 1896).

The uses of ferns range from food through to medicine, but it is the ornamental value of ferns that largely underpins their direct economic importance (de Winter and Amoroso 2003; Srivastava 2007). In 2003, ornamental fern production in the US was estimated around 150–300 million USD (de Winter and Amoroso 2003). The popularity of ferns in horticulture is driven by their aesthetic quality where they are used to enhance the scenic beauty of gardens, are popular indoor plants, and are commonly used for cut material in flower arrangements (Kawano 2015). To date, 157 species of ferns are documented as alien somewhere, the majority of which have been introduced for ornamental purposes (Jones et al. 2019).

Market or trade characteristics, such as market presence, marketing time, mode of trade, retail price, etc., influence the invasive potential of alien species in trade (Dehnen-Schmutz et al. 2007a; van Kleunen et al. 2018; McCulloch-Jones et al. 2021). For instance, marketing time has been directly linked to invasion success in multiple ornamental species (Dehnen-Schmutz et al. 2007a; Pemberton and Liu 2009), including ferns, where historically introduced species have extended time periods over which to invade, with long residence time being a known driver of invasion success (Wilson et al. 2007).

Over the last few decades, the horticultural trade industry has changed significantly and evolved to meet the ever-growing demand of the consumer (Dehnen-Schmutz et al. 2010; van Kleunen et al. 2018). E-commerce, also known as online or internet trade, is a clear example of how trade has changed over the years and is a serious concern for biosecurity and alien species management as it encourages competitive pricing and quick access, and promotes the mass production and dissemination of numerous species at great distances across the globe (Humair et al. 2015). Furthermore, e-commerce may avoid certain biosecurity efforts as online traders generally do not have a locatable outlet store and the end destination of the product is difficult to predict, thus rendering regulation problematic (Kikillus et al. 2012; Beaury et al. 2021). Trade via e-commerce also expands the opportunity for global transactions (Lenda et al. 2014) and a greater degree of international trade has been strongly associated with higher numbers of invasive species (Westphal et al. 2008; Hulme 2009; Bradley et al. 2012; Seebens et al. 2015).

On-ground trade (*sensu* McCulloch-Jones et al. 2021), on the other hand, also contributes to invasion success (Hulme et al. 2018). To supply demand, nurseries may harvest from wild populations, source species from dedicated breeders, or simply mass propagate species on-site. Mass production generally favours invasive species as their cultivation is often easier relative to native species and aliens thus commonly comprise the bulk of the market (Hulme et al. 2018). Although it is estimated that only 10 % of alien plant species are likely to escape cultivation (Williamson and Fitter 1996), it is the large number of species cultivated that warrants concern (Hulme 2012; Hulme et al. 2018). For instance, the total number of plant species in cultivation in Great Britain and New Zealand is estimated to be greater than the number of native species existing in the wild (Cubey et al. 2014; Hulme et al. 2018). In addition, commercial nurseries unfortunately often show weak compliance with regulations pertaining to alien or invasive species, and aliens continue to be stocked, propagated and sold regardless of their invasive potential and known negative environmental impacts (Hulme et al. 2018).

Over time, multiple tools have been developed as a means to anticipate and combat current or future invasions, for example, risk assessments (Kumschick et al. 2020a) and impact classification frameworks (Blackburn et al. 2014; Kumschick et al. 2020b). These tools are used to directly inform mitigation efforts pre- and post-introduction (Latombe et al. 2017) and largely rely on understanding the biological, environmental and anthropogenic drivers of invasion success (Leung et al. 2012; Blackburn et al. 2014; Latombe et al. 2017; Kumschick et al. 2020a). Introduced alien species (i.e., species transported into regions outside of their native range and not yet naturalised or invasive; Falk-Petersen et al. 2006; Blackburn et al. 2011) may remain undetected or unmanaged for extended periods of time as their distribution appears limited (Simberloff 2003). Consequently, they are only subjected to control efforts once invasion has already begun – the stage at which management is most challenging (Wilson et al. 2013). Considering this, early detection approaches are needed to effectively identify potentially invasive species introductions and, through appropriate management responses, reduce the impacts of invasive species (Reaser et al. 2020).

Early detection is key to effectively direct pre-border management efforts and can be undertaken using multiple methods including visual detection of wild species, chemical detection, and internet-based detection using automated or manual searches (Martinez et al. 2020). For example, Humair et al. (2015) utilised an automated search algorithm to effectively detect various alien species present in trade through surveying online sales of horticultural plants. The consultation of horticultural catalogues provides a powerful tool for early detection as it considers the pathways of introduction and allows for the easy detection of alien species directly at the source (McGeoch et al. 2016; van Kleunen et al. 2018; Wilson et al. 2018). Despite the effectiveness of this approach, only a handful of studies (Humair et al. 2015; Novoa et al. 2017; Beaury et al. 2021) have made use of trade information such as horticultural catalogues to identify the presence of previously unrecorded alien species.

The representation of ferns and their invasion status in plant species inventories is generally poor and so it is likely that many introduced alien ferns remain unrecorded. Accordingly, Jones et al. (2019) found few alien ferns with the status of introduced as compared to naturalised or invasive, in contrast with other taxa where introduced species are usually most numerous (e.g., Moodley et al. 2013; Jeschke and Pyšek 2018). In addition, studies considering the relationship between trade and invasiveness in ferns are limited, but thus far have shown that market traits such as the selection of species from which multiple cultivars and variants can easily be developed, a high market presence, and trade via e-commerce all drive establishment success (McCulloch-Jones et al. 2021). However, further assessments are required to inform country specific management and regulatory responses to current and future fern invasions that stem from trade. Considering that management responses to newly introduced alien species may be delayed, and that information pertaining to the invasiveness of a species is not always readily available (Simberloff 2003), providing a means of early detection and classifying the invasion potential or invasion risk of a species is crucial in bettering alien species management (van Kleunen et al. 2010; Wilson et al. 2013; Essl et al. 2015).

Accordingly, by consulting horticultural catalogues to develop an inventory of traded ferns for a selection of anglophone countries, this study aimed to, per trade country, i) identify the dominant mode (e-commerce or on-ground) and scale (international or national) at which trade is taking place; ii) establish whether trade is dominated by native or alien fern species; iii) develop a more comprehensive inventory of "introduced" alien ferns; and iv) prioritise species for risk and climate suitability assessments to inform regulatory and other management responses.

Materials and methods

Inventory of traded ferns

To develop a species inventory of traded ferns we closely followed the methods of McCulloch-Jones et al. (2021). We considered e-commerce and on-ground trade where on-ground trade included traders that had clearly identifiable geographic location for an outlet store that allowed for direct hand-to-hand trade, whereas e-commerce trade included online plant traders with no locatable outlet store. To ease our search efforts and avoid issues related to translation and linguistic constraints, we focussed our study on select anglophone countries known to have well-established ornamental plant trade networks (Dehnen-Schmutz et al. 2007b; Humair et al. 2015) namely, Canada (CA), the United States of America (US), the United Kingdom and the Republic of Ireland (abbreviated here as UKI), South Africa (ZA), Australia (AU), and New Zealand (NZ). The approach followed to identify fern traders within the study countries, was rooted in early detection techniques, which implies a swift yet efficient approach (Reaser et al. 2020).

Firstly, Google Maps (https://www.google.com/maps) was searched, at a national scale, for plant traders using terms such as "plant nurseries South Africa" or "ferns for sale Australia" (for a full list of search terms see Supplementary material Table S1). This approach provided websites of frequently searched-for or regularly visited plant traders, and as such, represented the most common or popular traders within a country, a method similar to that adopted by "Google trends" (https://www.trends.google.com/trends/) (Vosen and Schmidt 2011). Google Maps only provides search results for traders with a locatable address or coordinates and largely yielded results for on-ground traders. Thus, additional traders were searched for per country using Google Search (https://www.google.com/search), which yielded results for on-ground and e-commerce traders. Similarly, the immediate results provided through Google Search indicated frequently searched-for or regularly visited traders. Search effort was guided by the principle behind species accumulation curves (Fisher et al. 1943; Soberón and Llorente 1993), whereby search effort was ceased when the cumulative number of recorded traders as a function of the cumulative search effort (~ time) asymptoted. In other words, a slowed influx of information indicated sufficient representation by the sample.

Horticultural trade catalogues for 2019 or 2020 were considered to delimit currently traded species only and were obtained from the traders identified above either through their websites or via email request using a proforma email (Supplementary material Appendix 1). Unfortunately, in some instances, correspondence with the traders was unsuccessful and catalogues for that trader could not be obtained. In keeping with the study approach rooted in early detection, the identified traders provided a sample of nurseries representative of the trade in ferns in each country, rather than an exhaustive inventory of nurseries and species. Data collection took place over a period of six months from August of 2019 to January of 2020. Statistics on global fern trade are challenging to obtain as data on fern production and sales are rarely published, a constraint noted in other studies on ferns in horticulture (de Winter and Amoroso 2003). As such, the current study recorded the presence of a species in the market but could not account for trade volumes and import or export data or routes. Nomenclature of species follows the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/species/search) and is indicated in Table S2, however, due to the taxonomic difficulties associated with ferns (Christenhusz and Chase 2014) and to ensure that no conspecific entities were duplicated in the database, additional sources were consulted to identify synonyms including the Germplasm Resources Information Network (GRIN; https://npgsweb.ars-rin.gov/gringlobal/taxonomybrowse.aspx), and the Catalogue of Life (CoL; http://www.catalogueoflife.org/col/search/all) which is linked to World Ferns (https://www.worldplants.de/world-ferns/ferns-and-lycophytes-list).

Mode and scale of trade

For each species and trader, we recorded the mode of trade as e-commerce or on-ground. The mode of trade for a species was determined by the trader that offered that species. For example, if a species was offered online only, the mode of trade for that species was recorded as e-commerce; if it was offered at an on-ground nursery only, the mode of trade for that species was recorded as on-ground; and if it was offered both online and by an on-ground nursery, or if it was offered by an on-ground nursery with online sales facilities, the mode of trade for that species was recorded as both e-commerce and on-ground. As such, the total species counts per mode of trade contain duplicates. The scale of trade was recorded as international or national. For instance, terms such as "we ship globally" were regarded as international trade; and "trading only in Australia" as national trade. The species offered by each trader was then assigned a scale of trade (according to the trader), and therefore the total species counts per scale of trade, per country, contain duplicates. For each country of trade, we then calculated, i) the total number of fern species traded; ii) the average number of fern species offered per trader; (iii) the percentage of the total number of traders and the percentage of all traded fern species (respectively) per mode of trade and per scale of trade.

Invasion status of species

To establish whether a species is alien to its trade country, the native range of each species was determined using CoL and GRIN. CoL and GRIN provided a descriptive means to determine the native range of a species and is described from a broad to narrow scale distribution, for example, "Native to: Northern America; Northern Mexico; Mexico; Sinaloa". If the trade country fell within the native range of a species, the species was considered as native to that trade country. Species traded in countries which were outside of their native ranges were considered as alien to that trade country. For each alien species in trade, we determined if it had been formally recorded as an alien in its country of trade according to plant species inventories and if an invasion status of introduced, naturalised or invasive had been assigned within its country of trade. For this purpose, we consulted various official plant species inventories that include alien plants at all scales, as well as those contained in published literature, for example, A Global Compendium of Weeds (Randall 2017), and the comprehensive database of 157 alien ferns produced by Jones et al. (2019); as well as online databases such as, GBIF, World Ferns (https://www.worldplants.de/world-ferns/ferns-and-lycophytes-list), and the CABI Invasive Species Compendium (https://www.cabi.org/isc).

To ensure consistency, the invasion status of each species was re-evaluated and potentially modified according to the standard criteria of Falk-Petersen et al. (2006) and Blackburn et al. (2011). For example, if a species was listed as naturalised in a plant species inventory but later described as "spreading beyond the initial site of establishment", the invasion status of that species was modified and recorded in this study as invasive, and if the species was described as exotic or adventive, but no indication of establishment or spread was provided, the species was assigned the status of introduced. Species in trade identified by this study, for which no official records existed in plant species inventories, were assigned the status of introduced and were henceforth referred to as "previously unrecorded introduced species". For each country of trade, we then calculated, i) the number and percentage of traded fern species that are alien; ii) the number and percentage of traded alien fern species that were identified in this study as previously unrecorded introduced species; and iii) the number and percentage of alien fern species that were officially noted as invasive but remain in trade.

Prioritisation of species for further assessment

To prioritise traded alien species for further assessment to inform regulatory and other management responses, we largely followed the approach of Bayón and Vilà (2019) but modified it (see Table S3) to account for discrepancies in data availability between the two studies. This approach of classifying species into so-called Priority~, Attention~, Watch~, Uncertainty~ and Green lists (the latter is more aptly referred to as Safe lists in order to avoid confusion with the IUCN Green lists; Akçakaya et al. 2018) relies on assessing i) the study species' invasion status in its country of trade and elsewhere (a history of successful invasion provides a useful indicator in determining the potential invasiveness of a species, Rejmánek

Table 1. Characteristics of horticultural trade in terrestrial true ferns (Polypodiophyta) in selected anglophone countries. 'Previously unrecorded introduced species' are traded alien species in a particular country of trade for which no official records existed in plant species inventories and for which an invasion status has not previously been determined. Countries of trade: Canada (CA), United States of America (US), the United Kingdom and the Republic of Ireland (UKI), South Africa (ZA), Australia (AU), New Zealand (NZ).

	CA	US	UKI	ZA	AU	NZ
Total number of species	87	196	161	62	163	101
Total number of traders identified	17	47	28	27	21	16
Average number (min, max) of species available per nursery	14 (1, 76)	12 (1, 84)	22 (1, 73)	6 (1, 48)	23 (1, 78)	15 (1, 58)
Number (percentage) of species that are alien	56 (64%)	129 (66%)	142 (88%)	42 (68%)	88 (54%)	46 (46%)
Number (percentage) of alien species that are previously unrecorded introduced species (listed in Table S3)	27 (48%)	42 (34%)	98 (70%)	27 (63%)	51 (58%)	15 (33%)
Number (percentage) of alien species that are invasive but remain in trade (Priority list in Table S2)	2 (4%)	10 (8%)	8 (6%)	10 (24%)	3 (3%)	5 (11%)
Number (percentage) of alien species with limited potential to be invasive (Uncertainty~ or Safe list in Table S2)	10 (18%)	26 (20%)	25 (17%)	10 (24%)	20 (23%)	9 (20%)

et al. 2005; Gordon et al. 2010; Richardson and Rejmánek 2011); ii) the suitability of the climate in its country of trade (bioclimatic or niche distribution modelling can assist to identify where the most problematic traded species pose a high invasion threat, Thuiller et al. 2005; Jiménez-Valverde et al. 2011; Srivastava et al. 2019); and iii) the species' potential environmental and socioeconomic impacts (which we did not have information on). We accordingly screened all species with the status of introduced in their trade country for records of invasion elsewhere (i.e., in regions outside of their country of trade). Based on the rationale outlined in Table S3, we subsequently classified each study species per country of trade into the list types of Bayón and Vilà (2019) and indicated its priority for risk assessment or climate suitability assessment.

Results

Mode and scale of trade

Our search efforts identified a total of 382 fern species currently traded by 148 traders among the countries considered in this study. The US, AU and UKI were most active in trade in terms of total number of traded species (> 160 species each; Table 1). The average number of species offered per trader was highest in AU and UKI and lowest in ZA (Table 1). In all countries, most traders traded at national scales, with international traders (less than 5% of traders across countries) recorded only in the US, UKI, and ZA (Figure 1a). However, for these same countries, a relatively greater proportion of species were traded at international scales (approximately 10% across countries; Figure 1c) with the US showing the highest proportion (25%). The mode of trade differed across the trade countries (Figure 1b, d), where e-commerce traders dominated in UKI, AU, and CA, and on-ground traders dominated in US and ZA, while it was equivalent in NZ (Figure 1b).

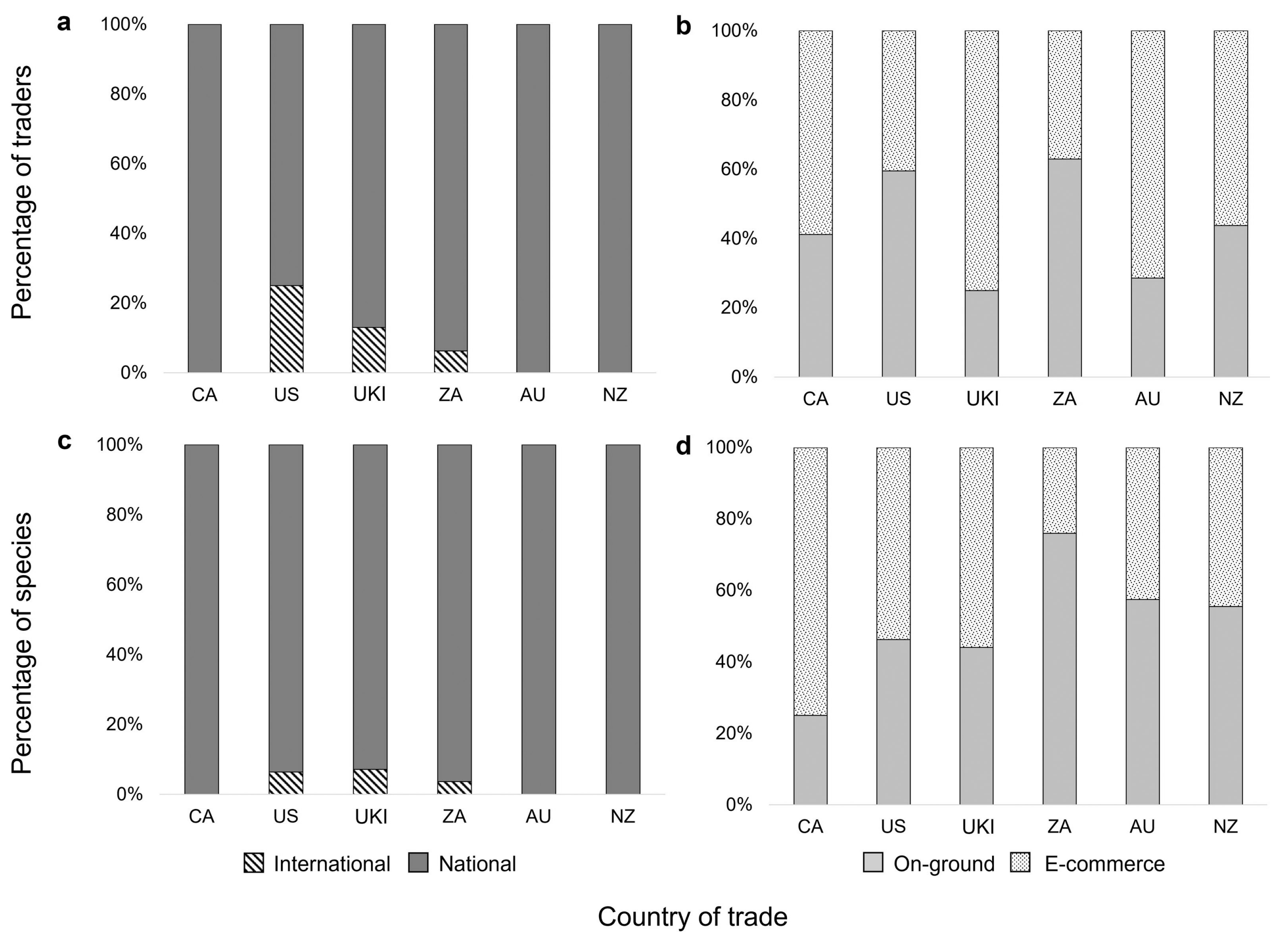

Figure 1. Prevalence of different (a, c) scales and (b, d) modes of trade expressed as proportions of the total number of traders and total number of species recorded per trade country. Treatment of species that were traded both on-ground and via e-commerce is detailed in the methods. Countries of trade: Canada (CA), United States of America (US), the United Kingdom and the Republic of Ireland (UKI), South Africa (ZA), Australia (AU), New Zealand (NZ).

The proportion of species traded via e-commerce differed across countries, with the highest proportion in CA, and the least in ZA (Figure 1d).

Invasion status and prioritisation of species

Trade in alien ferns was prevalent across all countries, although the proportion of alien to native species traded differed. Alien species accounted for more than 60 % of the total number of traded species in UKI, US, CA, and ZA but far less than that proportion in AU and NZ (Table 1). A total of 193 species noted in trade have not previously been recorded as alien in plant species inventories and did not have an invasion status assigned in their countries of trade (Table S4). These previously unrecorded introduced species constituted between 33% and 70% of the total number of alien fern species traded in each country (Table 1). UKI had the highest total number of previously unrecorded introduced species, followed by AU and the US.

The number of fern species that remain actively traded despite being officially noted as invasive ranged between two and ten species per trade country (totaling 38 species across study countries), constituting a quarter of all the traded alien species in ZA but 11 % or less in the other countries (Table 1). These species are classified in the Priority list with regulation of trade being an immediate priority pending climate, risk and impact assessment (Table S3). A total of nine species (between zero and three species per country) were classified in the Attention~ or Watch lists given that they have naturalised in their trade countries and are known to be invasive elsewhere, with these species being a high priority for risk assessment. A total of seven species (between zero and five species per country) were classified in the Uncertainty list given that they have naturalised in their trade countries but are not known to be invasive elsewhere; these species are a medium priority for risk assessment. We identified 62 species with the status of introduced in their trade country that are invasive elsewhere; these species are a high priority for climate suitability assessment to inform the need for risk assessment and whether to be classified in the Watch~, Attention~ or Uncertainty lists. Another 101 species (approximately 20% of alien species traded per country) are introduced in their trade country but are not known to be invasive elsewhere (Table 1). If their respective trade countries are shown to be climatically unsuitable, these species are candidates for Safe listing (Table S3).

Discussion

Mode and scale of trade

This study provided an overview of fern trade in the selected anglophone countries by distinguishing the countries that are most active in trade, the mode via which ferns are being traded and at what scales. The countries trading in the largest number of fern species were the US, AU and UKI. Similarly, these countries were highlighted as dominant in the trade of various angiosperm species on eBay.com (Humair et al. 2015). Contrary to expectation, trade via e-commerce did not clearly dominate over on ground trade. Conversely, some other popular ornamental plant groupings such as cacti (Novoa et al. 2017) and orchids (Hinsley et al. 2016) are more extensively traded via e-commerce. We do, however, recognise that a direct measure of trade volumes was not assessed in this study and that there is a possibility that various species may be traded in higher volumes via e-commerce than what was detected here. One may assume that e-commerce is linked to trade over vast distances (Lenda et al. 2014; Humair et al. 2015), and that e-commerce thus relates with a greater degree of trade at international scales. E-commerce was employed in all countries, albeit not the dominant mode of trade, and only three of the study countries (US, UKI, and ZA) traded in ferns internationally. Although a wider scale of trade may generally be more concerning in how it can facilitate long-distance dispersal of alien species (Levine and D'Antonio 2003; Westphal et al. 2008; Hulme 2009; Lenda et al. 2014), the dominance of trade in ferns at local scales coupled with the prevalence of on-ground trade likely increases propagule pressure at local scales (Dehnen-Schmutz and Touza 2008). This phenomenon is well known to facilitate invasion in various plant taxa (Lockwood et al. 2005; Simberloff 2009).

We postulate that the limited use of e-commerce and international trade noted for ferns in this study may partly be attributed to biological limitations of the taxon. Due to the temperature dependent longevity of fern spores, species that are traded as spore may be difficult to transport as they require specific forms of storage for successful passage (Ballesteros et al. 2011, 2019). Negative effects are most evident after extended exposure periods (Ballesteros et al. 2011) and modern transport technology should, in-theory, be efficient enough to avoid such issues. The sporophyte life phase may likewise be sensitive to temperature fluctuations during transport. For example, the leather leaf fern, *Rumohra adiantiformis*, is a widely traded species that can be shipped at a broader temperature range than other ferns, but it still is reported to be very sensitive to chilling injury, high temperatures or temperature fluctuations that lead to condensation (PPECB 2006). Transportation of this species from South Africa to other countries of import entails a minimum of two weeks for shipping; during this period conditions must be carefully monitored as deterioration of the plant will begin shortly after exposure to unfavorable conditions (PPECB 2006). Considering that this species has a wider tolerance than most ferns, it is reasonable to assume that, to avoid shipping losses, most traded species are propagated on site and traded on-ground. In addition, given that ferns can be difficult to propagate from spores, one may assume that trade is almost exclusively in sporophytes. Since some countries (e.g., NZ) have strict regulations against importing most live plant material, this would also probably severely limit international trade.

Invasion status and prioritisation of traded species

Alien ferns clearly dominated the market with at least 64% of fern species offered in trade being alien in four of the study countries. NZ and AU were exceptions, trading in relatively equal proportions of native and alien ferns, suggesting interest in native fern species or more efficient regulation. In line with this, a recent study conducted in Australia highlighted a positive shift in public perceptions towards the use of native plant species in residential gardens (Shaw et al. 2018). The preference for native or alien species is also likely dependent on various country-specific variables, for example, cultural, legal, economic, or environmental factors which will determine the availability or richness of species offered by traders (Westphal et al. 2008; Singh and Johari 2018). These factors may also determine the scale at which trade can take place. The US, for example, has a strong horticultural economy and a diffuse trade market (i.e., an innovative market that readily adopts new products or services) which permits the country to expand their connectivity to the international market and avoid the seasonal nature of sales (Dehnen-Schmutz et al. 2010). Accordingly, the US was the strongest internationally trading country identified in this study. Greater degrees of international trade have been directly linked to a higher incidence of invasive alien species occurrence (Westphal et al. 2008). Similarly, the countries in this study that were active in international trade also traded in the highest proportions of alien fern species. Countries that trade internationally may furthermore facilitate alien species introductions across the globe through the contribution of their native species to the trade market. This phenomenon has been highlighted in previous studies where the inclusion of native ornamental species in the trade market in Brazil is considered to increase the pool of potentially invasive alien species for other countries (Dehnen-Schmutz et al. 2010).

Our research constitutes one of very few studies (Humair et al. 2015; Beaury et al. 2021) that have used horticultural catalogues to rapidly identify records of alien species that have previously gone undetected in plant species inventories. We identified 193 previously unrecorded introduced species (assigned the status of introduced in this study), evidencing that consultation of horticultural catalogues constitutes a very efficient method for the early detection of alien species (Essl et al. 2015; Humair et al. 2015; van Kleunen et al. 2018), specifically when compared to results obtained through consultation of official plant species inventories which produced few species with the status of introduced (Jones et al. 2019). Furthermore, we detected significantly more alien species at a country scale, for example, official plant species inventories accounted for 15 alien fern species in ZA and 22 in the US (Jones et al. 2019), whereas we detected 42 alien fern species in ZA and 129 in the US. These previously unrecorded introduced species constituted a significant portion (up to 70%) of traded alien ferns in all study countries emphasizing the value of regular screening of horticultural catalogues to directly inform and update alien plant management responses. Our compilation of a list of alien species per country of trade and determination of their invasion status enabled us to prioritise species for further assessment to inform regulatory and other management responses.

NZ and AU are considered world-leaders in biosecurity implementation (Meyerson and Reaser 2002; Simberloff 2009) and have been successful in reducing the rate of alien species introductions through the adoption of a "white list" approach, whereby species not yet cleared for import require evaluation through an official weed risk assessment (Auld 2012; Hulme et al. 2018). In line with this, amongst our study countries, NZ and AU presented with the lowest proportions of alien ferns in trade. Countries that adopt "black list" approaches—whereby any species not listed may be freely imported—have generally shown to be less successful in curtailing invasive species introductions (Simberloff 2006; Hulme et al. 2018). Such countries include various European countries (Essl et al. 2011), the US

(Beaury et al. 2021), and ZA (van Wilgen et al. 2017). In line with this, UKI, the US and ZA traded in relatively high proportions of alien ferns in this study. Moreover, all study countries actively traded in some fern species that are officially noted as invasive, with a quarter of all traded alien fern species in ZA falling in this category (Table 1). These species comprise the Priority list (Bayón and Vilà 2019) and, pending climate, risk and impact assessment, should promptly be included in regulatory lists of species that are prohibited in trade, for example, the National Pest Plant Accord List in NZ or the Alien and Invasive Species Regulations of the National Environmental Management: Biodiversity Act (10/2004) in ZA. In cases where these species may already be included in legislative lists, an increased effort to monitor industry compliance is necessary.

Relatively few (16) species that are naturalised in their trade countries were identified in our study, and were classified into the Attention~, Watch~, or Uncertainty lists (Bayón and Vilà 2019). Depending on their invasiveness elsewhere, these species are high or medium priorities for risk assessment. We furthermore identified numerous (163) species with the status of introduced in their trade countries, of which 62 are invasive elsewhere and thus also classified in the Attention~, Watch~, or Uncertainty lists, and regarded a high priority for climate suitability assessment in their trade countries. A large number (101 species) of traded ferns with the status of introduced are not known to be invasive elsewhere. These constitute approximately a fifth of the alien species traded per country, and are potential candidates for Safe listing, if their countries of trade may be shown to be climatically unsuitable.

Within a global context, our study countries are deemed to have relatively strong regulatory legislation in place (Turbelin et al. 2017). One may thus assume that the number of alien and invasive fern species that are traded may be more pronounced in countries that we have not considered, where lesser or no regulatory systems exist. Countries that are most active in trade, but especially those with a high native fern diversity that also trade in high proportions of alien fern species, should be particularly cognizant of potential trade impacts as these countries are likely more susceptible to invasion (Westphal et al. 2008). In countries not assessed here, a departure point for management of trade in ferns may be to prioritise, for risk assessment, those species that are known to be invasive elsewhere and are also traded internationally (Table S3).

Conclusion

Our study provides an overview of fern trade in selected anglophone countries and found that international trade in ferns appears limited. We suspect this to be linked to biological limitations of ferns, specifically temperature sensitivities that make them poor candidates for extended transit. This research constitutes one of few studies that have adopted an early detection approach by consulting horticultural catalogues to identify previously unrecorded introduced alien species, and is particularly important for alien ferns as they are cryptic and often underrepresented in plant species inventories. The adopted approach allowed for relatively rapid identification of 193 previously unrecorded introduced species of alien ferns in the countries studied and seemed more efficient at detecting alien species than the consultation of official plant species inventories only. Considering that the study countries represent a subset of countries trading in ferns across the globe, and that we assessed a sample of traders rather than a comprehensive list, it is reasonable to assume that numerous fern species introduced through horticultural trade remain undetected. Alien ferns (relative to native ferns) dominated the market in most countries and several species already known to be invasive in their countries of trade remain actively traded there. Among the study countries, we identified a total of 38 species that are prominent candidates for regulatory listing to be prohibited in trade pending climate, risk, and impact assessments, nine species that are a high priority for risk assessment, 62 species that are a high priority for climate suitability assessment, and 101 species that are potential candidates for Safe listing. For several countries, this study constituted a significant first step towards prioritising fern species that require regulation in trade as well as identifying species that pose a low risk of invasion and may potentially be freely traded.

Acknowledgements

We thank all data collection assistants for their time and help with the study. Support and funding for this work was provided through the DSI-NRF Centre for Excellence for Invasion Biology (C•I•B). In addition, constructive criticism of anonymous reviewers enabled the improvement of this manuscript.

Authors' contribution

Research conceptualisation (All); sample design and methodology (All); investigation and data collection (Emily); data analysis and interpretation (Tineke and Emily); primary writer of original draft (Emily); review and editing (Tineke and Neil); final draft (Tineke and Emily).

References

Allen DE (1969) The Victorian Fern Craze. Shire Publications, Bloomsbury, 64 pp

Akçakaya HR, Bennett EL, Brooks TM, Grace, MK, Heath A, Hedges S, Hilton-Taylor C, Hoffmann M, Keith DA, Long B, Mallon DP (2018) Quantifying species recovery and conservation success to develop an IUCN Green List of Species. *Conservation Biology* 32: 1128–1138, https://doi.org/10.1111/cobi.13112

Auld B (2012) An overview of pre-border weed risk assessment and post-border weed risk management protocols. *Plant Protection Quarterly* 27: 105–111

Ballesteros D, Estrelles E, Walters C, Ibars AM (2011) Effect of storage temperature on green spore longevity for the ferns *Equisetum ramosissimum* and *Osmunda regalis*. *Cryo-Letters* 32: 89–98

Ballesteros D, Hill LM, Lynch RT, Pritchard HW, Walters C (2019) Longevity of preserved germplasm: the temperature dependency of aging reactions in glassy matrices of dried fern spores. *Plant & Cell Physiology* 60: 376–392, https://doi.org/10.1093/pcp/pcy217

Bayón Á, Vilà M (2019) Horizon scanning to identify invasion risk of ornamental plants marketed in Spain. *NeoBiota* 52: 47–86, https://doi.org/10.3897/neobiota.52.38113

Beaury EM, Patrick M, Bradley BA (2021) Invaders for sale: the ongoing spread of invasive species by the plant trade industry. *Frontiers in Ecology and the Environment* 19: 550–556, https://doi.org/10.1002/fee.2392

Birkenhead J (1897) Ferns and fern culture, 2ed. John Heywood, Manchester, United Kingdom, 212 pp

Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, Jarošík V, Wilson JR, Richardson DM (2011) A proposed unified framework for biological invasions. *Trends in Ecology & Evolution* 26: 333–339, https://doi.org/10.1016/j.tree.2011.03.023

Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Marková Z, Mrugała A, Nentwig W, Pergl J (2014) A unified classification of alien species based on the magnitude of their environmental impacts. *PLOS Biology* 12: e1001850, https://doi.org/10.1371/journal.pbio.1001850

Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJ, D'Antonio CM, Diez JM, Dukes JS, Ibanez I (2012) Global change, global trade, and the next wave of plant invasions. *Frontiers in Ecology and the Environment* 10: 20–28, https://doi.org/10.1890/110145

Christenhusz MJM, Chase MW (2014) Trends and concepts in fern classification. *Annals of Botany* 113: 571–594, https://doi.org/10.1093/aob/mct299

Cubey J, Edwards D, Lancaster N (2014) RHS Plant Finder 2014. The Royal Horticultural Society, Wisley, United Kingdom, 960 pp

de Winter WP, Amoroso V (2003) Plant Resources of South-East Asia. Cryptogams: Ferns and Fern allies. Backhuys Publishers, Leiden, 264 pp

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007a) A century of the ornamental plant trade and its impact on invasion success. *Diversity and Distribution* 13: 527–534, https://doi.org/10.1111/j.1472-4642.2007.00359.x

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007b) The horticultural trade and ornamental plant invasions in Britain. *Conservation Biology* 21: 224–231, https://doi.org/10.1111/j.1523-1739.2006.00538.x

Dehnen-Schmutz K, Touza JM (2008) Plant invasions and ornamental horticulture: pathway, propagule pressure and the legal framework. In: Teixeira da Silva JA (ed), Floriculture, ornamental and plant biotechnology: advances and topical issues. Global Science Books, Isleworth, UK, pp 15–21

Dehnen-Schmutz K, Holdenrieder O, Jeger MJ, Pautasso M (2010) Structural change in the international horticultural industry: Some implications for plant health. *Scientia Horticulturae* 125: 1–15, https://doi.org/10.1016/j.scienta.2010.02.017

Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C, Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). *The Journal for Nature Conservation* 19: 339–350, https://doi.org/10.1016/j.jnc.2011.08.005

Essl F, Bacher S, Blackburn TM, Booy O, Brundu G, Brunel S, Cardoso AC, Eschen R, Gallardo B, Galil B, García-Berthou E (2015) Crossing Frontiers in Tackling Pathways of Biological Invasions. *The Journal of Biosciences* 65: 769–782, https://doi.org/10.1093/biosci/biv082

Falk-Petersen J, Bøhn T, Sandlund OT (2006) On the numerous concepts in invasion biology. *Biological Invasions* 8: 1409–1424, https://doi.org/10.1007/s10530-005-0710-6

Fisher RA, Corbet AS, Williams CB (1943) The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology* 12: 42, https://doi.org/10.2307/1411

Gordon DR, Mitterdorfer B, Pheloung PC, Ansari S, Buddenhagen C, Chimera C, Daehler CC, Dawson W, Denslow JS, LaRosa A, Nishida T (2010) Guidance for addressing the Australian weed risk assessment questions. *Plant Protection Quarterly* 25: 56–74

Hinsley A, Lee TE, Harrison JR, Roberts DL (2016) Estimating the extent and structure of trade in horticultural orchids via social media. *Conservation Biology* 30: 1038–1047, https://doi.org/10.1111/cobi.12721

Hulme PE (2009) Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology* 46: 10–18, https://doi.org/10.1111/j.1365-2664.2008.01600.x

Hulme PE (2012) Weed risk assessment: A way forward or a waste of time? *Journal of Applied Ecology* 49: 10–19, https://doi.org/10.1111/j.1365-2664.2011.02069.x

Hulme PE (2015) Resolving whether botanic gardens are on the road to conservation or a pathway for plant invasions. *Conservation Biology* 29: 816–824, https://doi.org/10.1111/cobi.12426

Hulme PE, Brundu G, Carboni M, Dehnen-Schmutz K, Dullinger S, Early R, Essl F, González-Moreno P, Groom QJ, Kueffer C, Kühn I (2018) Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *Journal of Applied Ecology* 55: 92–98, https://doi.org/10.1111/1365-2664.12953

Humair F, Humair L, Kuhn F, Kueffer C (2015) E-commerce trade in invasive plants. *Conservation Biology* 29: 1658–1665, https://doi.org/10.1111/cobi.12579

Jeschke J, Pyšek P (2018) Tens rule. In: Jeschke J, Heger T (eds), Invasion biology: hypotheses and evidence. CAB International, Wallingford, pp 124–132, https://doi.org/10.1079/9781780647647.0124

Jiménez-Valverde A, Peterson AT, Soberón J, Overton JM, Aragón P, Lobo JM (2011) Use of niche models in invasive species risk assessments. *Biological Invasions* 13: 2785–2797, https://doi.org/10.1007/s10530-011-9963-4

Jones EJ, Kraaij T, Fritz H, Moodley D (2019) A global assessment of terrestrial alien ferns (Polypodiophyta): species' traits as drivers of naturalisation and invasion. *Biological Invasions* 21: 861–873, https://doi.org/10.1007/s10530-018-1866-1

Kawano T (2015) Pteridophytes as active components in gardening, agricultural and horticultural ecosystems in Japan. *Advances in Horticultural Science* 29: 41–47, https://doi.org/10.13128/ahs-21305

Kikillus KH, Hare KM, Hartley S (2012) Online trading tools as a method of estimating propagule pressure via the pet-release pathway. *Biological Invasions* 14: 2657–2664, https://doi.org/10.1007/s10530-012-0262-5

Kolar CS, Lodge DM (2001) Progress in invasion biology: Predicting invaders. *Trends in Ecology & Evolution* 16: 199–204, https://doi.org/10.1016/S0169-5347(01)02101-2

Kumschick S, Wilson JRU, Foxcroft LC (2020a) A framework to support alien species regulation: the Risk Analysis for Alien Taxa (RAAT). *NeoBiota* 62: 213–239, https://doi.org/10.3897/neobiota.62.51031

Kumschick S, Bacher S, Bertolino S, Blackburn TM, Evans T, Roy HE, Smith K (2020b) Appropriate uses of EICAT protocol, data and classifications. In: Wilson JR, Bacher S, Daehler CC, Groom QJ, Kumschick S, Lockwood JL, Robinson TB, Zengeya TA, Richardson DM (eds), Frameworks used in Invasion Science. *NeoBiota* 62: 193–212, https://doi.org/10.3897/neobiota.62.51574

Latombe G, Pyšek P, Jeschke JM, Blackburn TM, Bacher S, Capinha C, Costello MJ, Fernández M, Gregory RD, Hobern D, Hui C (2017) A vision for global monitoring of biological invasions. *Biological Conservation* 213: 295–308, https://doi.org/10.1016/j.biocon.2016.06.013

Lenda M, Skórka P, Knops JMH, Moroń D, Sutherland WJ, Kuszewska K, Woyciechowski M (2014) Effect of the internet commerce on dispersal modes of invasive alien species. *PLoS ONE* 9: e99786, https://doi.org/10.1371/journal.pone.0099786

Leung B, Roura-Pascual N, Bacher S, Heikkilä J, Brotons L, Burgman MA, Dehnen-Schmutz K, Essl F, Hulme PE, Richardson DM, Sol D (2012) TEASIng apart alien species risk assessments: A framework for best practices. *Ecology Letters* 15: 1475–1493, https://doi.org/10.1111/ele.12003

Levine JM, D'Antonio CM (2003) Forecasting biological invasions with increasing international trade. *Conservation Biology* 17: 322–326, https://doi.org/10.1046/j.1523-1739.2003.02038.x

Lockwood JL, Cassey P, Blackburn T (2005) The role of propagule pressure in explaining species invasions. *Trends in Ecology & Evolution* 20: 223–228, https://doi.org/10.1016/j.tree.2005.02.004

Martinez B, Reaser JK, Dehgan A, Zamft B, Baisch D, McCormick C, Giordano AJ, Aicher R, Selbe S (2020) Technology innovation: advancing capacities for the early detection of and rapid response to invasive species. *Biological Invasions* 22: 75–100, https://doi.org/10.1007/s10530-019-02146-y

McCulloch-Jones EJ, Kraaij T, Crouch N, Fritz H (2021) The effect of horticultural trade on establishment success in alien terrestrial true ferns (Polypodiophyta). *Biological Invasions* 23: 3583–3596, https://doi.org/10.1007/s10530-021-02599-0

McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. *Biological Invasions* 18: 299–314, https://doi.org/10.1007/s10530-015-1013-1

Meyerson LA, Reaser JK (2002) Biosecurity: Moving toward a comprehensive approach: a comprehensive approach to biosecurity is necessary to minimize the risk of harm caused by non-native organisms to agriculture, the economy, the environment, and human health. *Bioscience* 52: 593–600, https://doi.org/10.1641/0006-3568(2002)052[0593:BMTACA]2.0.CO;2

Moodley D, Geerts S, Richardson DM, Wilson JR (2013) Different traits determine introduction, naturalization and invasion success in woody plants: Proteaceae as a test case. *PLoS ONE* 8: e75078, https://doi.org/10.1371/journal.pone.0075078

Müller N, Sukopp H (2016) Influence of different landscape design styles on plant invasions in Central Europe. *Landscape and Ecological Engineering* 12: 151–169, https://doi.org/10.1007/s11355-015-0288-9

Novoa A, Le Roux JJ, Richardson DM, Wilson JRU (2017) Level of environmental threat posed by horticultural trade in Cactaceae. *Conservation Biology* 31: 1066–1075, https://doi.org/10.1111/cobi.12892

Pemberton RW, Liu H (2009) Marketing time predicts naturalization of horticultural plants. *Ecology* 90: 69–80, https://doi.org/10.1890/07-1516.1

PPECB (2006) Handling procedure for sub-tropical leather leaf ferns, plants and palms for seas freight. Perishable Products Export Control Board, South Africa, 6 pp

Randall RP (2017) A global compendium of weeds. RG & FJ Richardson, Melbourne, 905 pp

Reaser JK, Burgiel SW, Kirkey J, Brantley KA, Veatch SD, Burgos-Rodríguez J (2020) The early detection of and rapid response (EDRR) to invasive species: a conceptual framework and federal capacities assessment. *Biological Invasions* 22: 1–19, https://doi.org/10.1007/s10530-019-02156-w

Rejmánek M, Richardson DM, Higgins SI, Pitcairn MJ, Grotkopp E (2005) Ecology of invasive plants: state of the art. Invasive alien species: a new synthesis. Ecology of invasive plants: state of the art. In: Mooney HA, Mack RN, McNeely JA (eds), Invasive alien species. Island Press, Washington, DC, pp 104–161

Richardson DM, Rejmánek M (2011) Trees and shrubs as invasive alien species - a global review. *Diversity and Distribution* 17: 788–809, https://doi.org/10.1111/j.1472-4642.2011.00782.x

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distribution* 6: 93–107, https://doi.org/10.1046/j.1472-4642.2000.00083.x

Roy HE, Peyton J, Aldridge DC, Bantock T, Blackburn TM, Britton R, Clark P, Cook E, Dehnen-Schmutz K, Dines T, Dobson M (2014) Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Global Change Biology* 20: 3859–3871, https://doi.org/10.1111/gcb.12603

Seebens H, Essl F, Dawson W, Fuentes N, Moser D, Pergl J, Pyšek P, van Kleunen M, Weber E, Winter M, Blasius B (2015) Global trade will accelerate plant invasions in emerging economies under climate change. *Global Change Biology* 21: 4128–4140, https://doi.org/10.1111/gcb.13021

Shaw SW, Ranker TA (2018) New and improved leaf terminology for Gleicheniaceae. *American Fern Journal* 101: 117–124, https://doi.org/10.1640/0002-8444-101.2.117

Simberloff D (2003) How much information on population biology is needed to manage introduced species? *Conservation Biology* 17: 83–92, https://doi.org/10.1046/j.1523-1739.2003.02028.x

Simberloff D (2006) Risk assessments, blacklists, and white lists for introduced species: Are predictions good enough to be useful? In: Agricultural and Resource Economics Review. Cambridge University Press, pp 1–10, https://doi.org/10.1017/S1068280500010005

Simberloff D (2009) The role of propagule pressure in biological invasions. *Annual Review of Ecology and Systematics* 40: 81–102, https://doi.org/10.1146/annurev.ecolsys.110308.120304

Singh AP, Johari D (2018) Scope of Ferns in Horticulture and Economic Development. In: Fernández H (ed), Current Advances in Fern Research. Springer, Cham, pp 153–175, https://doi.org/10.1007/978-3-319-75103-0_8

Smith J (1896) Ferns: British & Foreign: The history, organography, classification, and enumeration of the species of garden ferns with a treatise on their cultivation, W.H. Allen & Co., Waterloo Place, London, 412 pp, https://doi.org/10.5962/bhl.title.56289

Soberón MJ, Llorente BJ (1993) The use of species accumulation functions for the prediction of species richness. *Conservation Biology* 7: 480–488, https://doi.org/10.1046/j.1523-1739.1993.07030480.x

Srivastava K (2007) Importance of ferns in human medicine. *Ethnobotanical Leaflets* 11: 231–234

Srivastava V, Lafond V, Griess VC (2019) Species distribution models (SDM): Applications, benefits and challenges in invasive species management. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 14: 1–13, https://doi.org/10.1079/PAVSNNR201914020

Thuiller W, Richardson DM, Pyšek P, Midgley GF, Hughes GO, Rouget M (2005) Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biology* 11: 2234–2250, https://doi.org/10.1111/j.1365-2486.2005.001018.x

Turbelin AJ, Malamud BD, Francis RA (2017) Mapping the global state of invasive alien species: patterns of invasion and policy responses. *Global Ecology and Biogeography* 26: 78–92, https://doi.org/10.1111/geb.12517

van Kleunen M, Weber E, Fischer M (2010) A meta-analysis of trait differences between invasive and non-invasive plant species. *Ecology Letters* 13: 235–245, https://doi.org/10.1111/j.1461-0248.2009.01418.x

van Kleunen M, Essl F, Pergl J, Brundu G, Carboni M, Dullinger S, Early R, González-Moreno P, Groom QJ, Hulme PE, Kueffer C (2018) The changing role of ornamental horticulture in alien plant invasions. *Biological Reviews* 93: 1421–1437, https://doi.org/10.1111/brv.12402

van Wilgen BW, Wilson JRU (2017) The status of biological invasions and their management in South Africa in 2017. South African National Biodiversity Institute, Kirsetnbosch, South Africa, 398 pp

Vosen S, Schmidt T (2011) Forecasting private consumption: Survey-based indicators vs. Google trends. *Journal of Forecasting* 30: 565–578, https://doi.org/10.1002/for.1213

Westphal MI, Browne M, MacKinnon K, Noble I (2008) The link between international trade and the global distribution of invasive alien species. *Biological Invasions* 10: 391–398, https://doi.org/10.1007/s10530-007-9138-5

Whittingham S (2010) The Victorian Fern Craze. Oxford, Shire, 64 pp

Williamson M, Fitter A (1996) The varying success of invaders. *Ecology* 77: 1661–1666, https://doi.org/10.2307/2265769

Wilson JRU, Richardson DM, Rouget M, Procheş Ş, Amis MA, Henderson L, Thuiller W (2007) Residence time and potential range: Crucial considerations in modelling plant invasions. *Diversity and Distribution* 13: 11–22, https://doi.org/10.1111/j.1366-9516.2006.00302.x

Wilson JRU, Ivey P, Manyama P, Nänni I (2013) A new national unit for invasive species detection, assessment and eradication planning. *South African Journal of Science* 109: 1–13, https://doi.org/10.1590/sajs.2013/20120111

Wilson JRU, Faulkner KT, Rahlao SJ, Richardson DM, Zengeya TA, Van Wilgen BW (2018) Indicators for monitoring biological invasions at a national level. *Journal of Applied Ecology* 55: 2612–2620, https://doi.org/10.1111/1365-2664.13251

Supplementary material

The following supplementary material is available for this article:

Appendix 1. An example of the email provided to nurseries to acquire plant catalogues.
Table S1. List of search terms is provided separately in Excel format.
Table S2. Full database with nomenclature is provided separately in Excel format.
Table S3. Species priority lists is provided separately in Excel format.
Table S4. Previously unrecorded introduced species of alien fern is provided separately in Excel format.

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2023/Supplements/MBI_2023_McCulloch-Jones_etal_Appendix_1.pdf
http://www.reabic.net/journals/mbi/2023/Supplements/MBI_2023_McCulloch-Jones_etal_SupplementaryTable.xlsx