Towards integrating and standardising information on plant invasions across Australia

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Abstract

Over the last decades, terminology to refer to invasion status along the introduction-naturalisation-invasion continuum have been based either on overcome barriers or on impact-based frameworks, generating debates within the scientific community. The lack of agreement with regards to definitions have sometimes hampered combining information from sources based on different criteria. In Australia, information on plant invasions is contributed independently from different jurisdictions, which has led to inconsistencies regarding both, terminology to refer to invasion ecology, and invasion status at the national level, therefore impeding efficient management. In this paper, we review and discuss the steps taken to harmonise the different terminologies used across Australian states, we identify the mismatches in introduction at the jurisdictional and national scales and proposed detailed prioritisation systems to tackle mismatches at both scales and to integrate information into a standardised system at the national scale. This integration exercise has made possible the creation of a standardised dataset at the Australian national scale (the Alien Flora of Australia). In Australia, having an integrated system for referring to and tracking alien flora can, not only aid early warning and prevention of introduced species, but also facilitate decision-making at

the jurisdictional levels, and biosecurity measures at the national scale. We also highlight the opportunities arising from integrating contrasting information into the continental scale.

Introduction

Biological invasions have increasingly gained attention over the past decades within the scientific community (Nuñez et al. 2022), that recognises the importance of having high quality, easy-to-access, standardised and unified data sources (Latombe et al. 2017). Having standardised datasets at large spatial scales allows tracking and monitoring the status of biological invasions, making future predictions and prioritizing invasion-based management actions (Hulme et al. 2009; Le Roux et al. 2020). Despite the increase in the number of publications on biological invasions over the last three decades, within the same period ongoing debates have also taken place. Debates include discussions about the taxonomy of biological invasions (Pyšek et al. 2013), terminology used to refer to invasion status for species that appear outside of their native range (Colautti and Richardson, 2009; Young and Larson, 2011), determinants of invasion success (Daly et al. 2023) and impact (Simberloff et al. 2013), or even about how to delimit and define native range (Guiaşu et al. 2016). Hence, inconsistencies have arisen, subsequently impacting the accuracy and implications of classifying plant species into native and alien (Guiaşu et al. 2016).

There are many terms to refer to 'species occurring in ecosystems to which they are not indigenous', including non-indigenous, non-native, exotic, and alien, among others. The term 'alien' was introduced by the Convention on Biological Diversity (CBD) in Nairobi in 1992 without any specific definition being provided for it (United Nations, 1992). To alleviate the confusion around biological invasion terminology, Richardson et al. (2000) proposed the concept of the introduction-naturalization-invasion continuum, by which a species introduced into a new area received different names according to the barriers it overcame. As such, casual aliens are those that have been transported beyond the limits of their native range; only a fraction of casual aliens become naturalised, that is, forming self-sustaining populations; and only a fraction of the naturalised become invasive, overcoming local dispersal barriers and spreading in the new region. According to Richardson et al. (2000) the subset of invasive species able to impact and change the nature of the environment were called 'transformers', whereas 'weed' was a common term for undesired species regardless of their native or alien origin (Fig. 1a).

The same year, the International Union for Conservation of Nature (IUCN) incorporated the concept of negative impact into the definition of invasive species as "alien species which becomes established in natural or semi-natural ecosystems or habitats, and are an agent of change, threatening native biological diversity" (IUCN, 2000). Two years later, in 2002, the CBD recognises

69 invasive alien species (IAS) as “species introduced outside their native range that have become
70 successfully established and cause substantial impacts on the environment” (Fig. 1b). In 2006, the
71 IUCN Invasive Species Specialist Group (ISSG) developed the Global Register for Introduced and
72 Invasive Species (GRIIS) as a concept and prototype to be subsequently reviewed before
73 implementation across several countries globally. The methods underpinning the GRIIS and the
74 guidelines for the checklists of alien species to be implemented by individual countries were not
75 published until 2018 (Pagdad et al. 2018) and only implemented in the subsequent years. In 2022, a
76 collation of the GRIIS data across 196 countries was published into the country compendium of the
77 GRIIS (Pagdad et al. 2022). The GRIIS follows the impact-based notion of invasive species, to refer to
78 those having a harmful impact in the native community (Fig. 1b).
79 In 2011, a decade after the definitions for invasive species were proposed by Richardson et al. (2000)
80 and the CBD (2002), Blackburn et al. (2011) published a unified framework on biological invasions to
81 address terminology inconsistencies. The framework is very comprehensive and integrative, and
82 successfully reconciliated different synonyms to refer to similar invasion stages along the continuum
83 (Fig. 1c); nowadays it is recognised as the main framework by invasion ecologists.
84 In the last few years, other schemes emerged, such is the case of the Darwin Core (Darwin Core
85 Maintenance Group, 2021a), proposed by the Biodiversity Information Standards (TDWG). The
86 Darwin Core published concepts to refer to biological invasions in 2020; despite being based on
87 Blackburn et al. (2011) and classifying species regardless of their impact, it added a dimension of
88 complexity. According to the Darwin Core, the classification appears split in two dimensions:
89 establishment means (Darwin Core Maintenance Group, 2021b), to refer to origin (i.e., native,
90 introduced or uncertain) and degree of establishment (Darwin Core Maintenance Group, 2021c), to
91 refer to the position along the continuum. However, what Blackburn et al. (2011) had successfully
92 simplified and unified, Darwin Core further divided it into more specific categories introducing new
93 stages such as ‘reproducing’, ‘colonising’, or ‘widespread invasive’ (Fig. 1d).
94 It seems that despite several attempts to harmonise different concepts and ideas, the terminology
95 to refer to further invasion stages within the continuum has not become consistent over time. The
96 need for consensus and the differences between concepts have been further argued and debated
97 considerably in the scientific literature on invasion ecology. More recent attempts to clarify
98 definitions with and without intrinsically including impact, proposed to refer to invasive species with
99 negative impact as ‘harmful invasive’ (Essl et al. 2020).
100 There are currently over 13,000 vascular plant species naturalised outside their native range in the
101 world (van Kleunen et al. 2015, 2019). While the number of high-quality, freely accessible online
102 databases for alien flora at the regional scales have considerably increased in the last decades, their

ultimate value to be applied into management actions depends on the feasibility of integrating the information they contain at larger spatial scales (Latombe et al. 2017; Luo et al. 2011). This is especially important when the data sources to combine follow different criteria.

Australia is a clear example of inconsistencies among plant censuses data sources, making the integration of the recorded information an arduous task. Australia is the sixth largest country in the world, with an overall surface almost comparable to the European continent. It is a unique country in terms of biodiversity and has one of the highest levels of endemism (Gallagher et al. 2021). Despite having one of the strongest biosecurity systems in the world, it does not have a national-wide data on alien species, and taxa introduction in Australia keeps increasing steadily over time (CSIRO, 2020).

Australia's jurisdictions are held by six independent states (New South Wales – NSW; Queensland – QLD; South Australia – SA; Tasmania – TAS; Victoria – VIC; and Western Australia – WA) and two main territories (the Australian Capital Territory – ACT; and the Northern Territory – NT), hereafter referred as 'states' for simplicity. Australia's plant censuses, including information on whether a species is native or introduced, have been developed at a jurisdictional level by government environment departments, therefore there are currently eight plant censuses at the state level. At the national level, there is one existing plant census that provides information for the whole Australia, the Australian Plant Census (APC) (Australian Plant Census, 2022), that provides authoritative data for names and published taxon concepts for native and naturalised taxa in Australia. Despite being federally managed, the APC provides information on a state-by-state basis, without appearing combined at the national scale; as such, there is no way to know if a certain taxon is considered native to Australia or not. In addition, the Global Register of Introduced and Invasive Species (GRIIS) was recently published for Australia (Randall et al. 2022), classifying, among taxa from other kingdoms, the alien flora of Australia into introduced and invasive. However, the criteria for species' inclusion and status are based on impact (Pagad et al. 2018), and for certain species appear unclear.

The different data sources (ten in total) following different criteria has resulted in inconsistencies at the Australian national level (Martin-Fores et al. 2023). To overcome mismatches caused by jurisdictional boundaries and enable efficient management and biosecurity of biological invasions by the Australian federal government, a consensus on clearer definitions, concepts and classifications across Australia is much needed.

To harmonise the different criteria followed by independent jurisdictions, here we: i) propose a framework to refer to plant invasions in Australia, resulting from the combination of all different frameworks used in the data sources to combine; ii) cross-reference the information between

different data sources at the state level and at the national level to identify mismatches, iii) propose a system to address mismatches at the state level and at the national level in order to unify contrasting invasion statuses, iv) provide up-to-date information of the Australian alien flora in numbers.

We developed this harmonisation steps as an integration exercise parallel to a data paper in which we developed a much-needed automated system able to cross-reference and integrate all the existing datasets across Australia. As a result, we recently published the Alien Flora of Australia (AFA) (Martin-Fores et al. 2023), a unified and standardised dataset including invasion status for the Australian flora at the national scale. We hope that both the harmonised framework proposed here, and the standardised dataset we have created in parallel will provide a strong evidence-base for planning and informing actions for prevention and to mitigate risks at the Australian national scale.

Methodology

The terminology used in Australian plant censuses

The APC (Australian Plant Census 2022) displays together information on taxon distribution and introduction statuses contributed by different jurisdictions. It is mostly based on the terminology used by Blackburn et al. (2011) (Fig. 1c) and it classifies taxa as native, naturalised, or with uncertain origin. It follows a system of Boolean flags that are stated together for each state and main territory; therefore, in some instances, a few statuses are displayed for a single taxon in each territory. For example, a taxon recorded in one state as 'native and naturalised and uncertain origin' is a taxon native to such state but naturalised in other areas within the same state but where the taxon was not originally considered native and appearing in other areas of the same state in which it is uncertain whether the taxon was considered native or not.

The Australian GRIIS (Randall et al. 2022) follows the impact-based definition of 'invasive' (Fig. 1b), therefore classifying alien species as introduced or invasive based on evidence of negative impact for those species that are known to be an agent of change and threaten native biodiversity (Pagad et al. 2015,2018). Thus, 'invasive' on the GRIIS should not include native species (although see native-alien category in Pagad et al. (2018)), but only alien ones.

Regarding the plant censuses at the jurisdictional level, the ACT census (Lepschi et al. 2019) classifies taxa as native or exotic, providing information for potential or former (not for current) naturalisation in the territory; the terms employed can be easily translated ones adapted to Blackburn et al. (2011) (Fig. 1c). The censuses for NT (Northern Territory Herbarium, 2015), NSW (PlantNET, 2022) and SA (Department for Environment and Water, 2022) classify taxa in a binary way as either native or introduced, without further information on progression along the continuum. According to the

herbarium keys for the plant censuses of Tasmania (de Salas and Baker, 2022) and WA (Western Australian Herbarium, 2022), the information provided therein refers to the native or naturalised status for plant taxa. Queensland's census (Laidlaw, 2022) follows a structure similar to the one for the APC, stating for each taxon whether it is native, or naturalised (or doubtfully or formerly naturalised); its information is therefore more comparable to the one on APC and easily adapted to Blackburn et al. (2011) (Fig. 1c). Finally, the census for Victoria (VicFlora, 2023), follows the Darwin Core and classifies taxa according to their establishment means and degree of establishment (Fig. 1d).

Terminology integration

We use the concept of the continuum in the harmonised terminology presented here, we therefore kept and selected terms based on an adaptation from Blackburn's framework (Blackburn et al. 2011) that are intuitive and compatible with Australian data sources. We made this decision because we wanted to follow terminology that was not impact-based as closely as possible, and Blackburn's framework is the most recognised internationally and the most directly comparable with the terminology employed on the APC.

We therefore proposed an adapted framework (Fig. 2), by which information about presence (present/extinct), origin (native/introduced/uncertain) and invasion status along the continuum (casual/ naturalised/invasive) are provided in a combined manner for all data sources. Accordingly, we used 'introduced' where information on an alien taxon status along the continuum had not been provided in a given Australian data source (e.g. in the case of binary censuses like SA). We neither included 'casual' nor 'invasive', because most of the censuses lacked detailed information on the spread and dispersal within the introduced range. According to the definitions presented by Essl et al. (2020), we replaced the term 'invasive' used on the Australian GRIIS (Randall et al. 2022) by 'harmful invasive', acknowledging that this definition of invasive explicitly incorporates negative impact. In addition, for native taxa that are also recorded as naturalised or doubtfully naturalised within the same jurisdiction, we used 'native colonising' and 'native potentially colonising' acknowledging a mere reflection of dispersal but not impact. Finally, for taxa no longer present in a given state we used 'presumed extinct' for native taxa and 'formerly introduced' for alien taxa (Fig. 2). Our proposed framework therefore includes the following terms: native (also native potentially colonising and native colonising), introduced (also doubtfully or formerly), naturalised (also doubtfully or formerly), harmful invasive, presumed extinct, and uncertain origin. Certain categories (e.g. doubtfully introduced, doubtfully naturalised, formerly naturalised) specified on the APC, and therefore appearing in this terminology and the one used in the Alien Flora of Australia (AFA), do not

have a direct translation into other frameworks such as the impact-based ones and the Darwin Core concepts. For this reason, and to accommodate to Australian states like Victoria, where its census follows the Darwin Core scheme, we provide equivalences to the Darwin Core for the harmonised terminologies used here. To facilitate understanding of the different terminology when used at both state and national level, we have provided a glossary with specific meanings for each term at both scales and according to different sources of vocabulary for invasion ecology (Table 1).

Identification of mismatches regarding introduction status

We used the system and associated script we developed in parallel to create a unified and standardised dataset of alien flora in Australia, the Alien Flora of Australia (AFA) (Martin-Fores et al. 2023). The script is available on github (https://github.com/MartinFores/AAFSS) and Figshare (https://figshare.com/s/14c1e7eca0e57540cce9). The script allows curating all the data sources and converting the terms used in each of them to the ones we proposed in the harmonised framework above-explained. Afterwards the script automatically detects mismatches at the jurisdictional level by comparing the information on invasion status recorded for each taxon on each of the plant censuses and the taxonomic distribution and invasion status provided on the APC for each of the states. The result of the comparison between the state plant censuses and the distribution information recorded on the APC appears clearly specified in the state-by-state datasets composing the AFA. The script then addresses the mismatches at the jurisdictional level (see next section for details).

In a subsequent step, the script combines the information provided at the state level into a national invasion status and compares such national status with the one provided on the GRIIS. The script automatically detects mismatches at the national level and subsequently address them by combining contrasting statuses into a unified national status (see next sections for details) (see Martin-Fores et al. 2023 for details on methodology related to the steps followed to design the script to detect mismatches in invasion status at the state and territory levels in Australia).

Prioritisation system to unify introduction status at the Australian jurisdictional level in case of contrasting information

We developed a prioritisation system to address mismatches on invasion status at the jurisdictional level in Australia. As such, when a species was not listed on the APC or was recorded on the APC as not present in a given state, we kept the introduction status recorded in the state plant census. For species that appeared in both sources but displayed a mismatch in the introduction status, we developed a prioritisation system in order to be as conservative as possible in terms of potential

implications and undesired effects associated with biological invasions. For example, a taxon recorded as naturalised in one state in one dataset but as introduced in the other dataset can more likely be a source of trouble if it is in fact naturalised; similarly, a taxon recorded as introduced and as native in one state, depending on the data source, can be more problematic if it is introduced. According to this, our system prioritises, for each taxon in each state, the recorded invasion status that has advanced the furthest along the continuum. As such, naturalised, followed by doubtfully naturalised, are prioritised over introduced, formerly naturalised, doubtfully introduced and formerly introduced. Any invasion status recorded within an alien category for a taxon is prioritised over uncertain origin, and those over native statuses, which include, in order of priority, native colonising, native potentially colonising, native, and finally presumed extinct (Fig. 3). In all component datasets developed at the state level as part of the AFA, we incorporated a new column with the unified status for each taxon in each state (See Martín-Forés et al. 2023 to access all the standardised regional datasets for all Australian states).

Prioritisation system to combine introduction statuses at the Australian national level

The prioritisation procedure used to assign national status differed from the one used at state level as follows: if a taxon was native to at least one state, it was considered native to Australia (Fig. 4). If it was not 'native' to any state, but it was a native colonising (or native potentially colonising) in any state, it was considered as native colonising at the national scale; and if it was not native in any possible form to any state but recorded with uncertain origin in at least one state, we kept 'uncertain origin'. If the taxon had not been recorded as native or having uncertain origin in any of the states, then the recorded invasion status that has advanced the furthest along the continuum was prioritise as a precautionary measure for addressing potential invasion and to be as conservative as possible when designing management and eradication programs at the national scale. Only if the species was not present in any state was it then recorded as presumed extinct at the national scale (Fig. 4).

Unifying introduction status at the Australian national level in case of contrasting information

For each taxon, to elucidate the unified invasion status appearing on the AFA, we followed one simple step: for the species that were alien (in any form) to Australia at the national scale according to our system and that appeared recorded as 'invasive' according to the GRIIS, we changed their invasion status to 'harmful invasive' at the national scale.

When other mismatches were identified (e.g. species that are native to at least one Australian state but appeared recorded as introduced or invasive (i.e. harmful invasive) in the GRIIS), we kept the information obtained via our script.

Results

The Australian native and alien flora in numbers

According to the AFA, at the national level, there are 30,527 species, including both native and introduced species outside of cultivation. However, because some of them are only present in external territories and nine species did not have any distribution information recorded; across the six Australian states and two main territories, there are currently a total of 30,287 species listed, from which 3,487 records correspond to alien species (11.4% of the total number of species). From these alien species, 58 species are recorded as introduced (not known to have formed self-sustained populations to date), 3,352 species are recorded as naturalised (able to form self-sustained populations) and 77 as harmful invasive (which accounts for 2.2% of the total of alien plants introduced in Australia). Besides, there are currently 11 species at the national scale for which its origin is uncertain, and 22 species that are presumed to not be present anymore, either because of being extinct (recorded as presumed extinct) or presumed to have been eradicated or extinct (recorded as formerly introduced) (Table 2; Fig. 4). Deliberately introduced alien species for gardening and ornamental purposes that have not become alien outside of cultivation are not listed on the AFA and therefore not reported here.

The number of alien species across the Australian states ranged from 564 in the NT to over 1,900 in NSW, QLD and VIC. However, when considering the percentage of alien species across Australian states, this ranged from 10% in the NT and WA to over 38% in the ACT (Table 2; Fig. 4). Within the alien species in each state, the percentage of harmful invasive species for which there is evidence of negative impact according to the GRIIS, ranged from 2% in Tasmania to 4.4% in the NT (Table 2; Fig. 4). Beyond state and federal use, these data can also be used to report on the global status of Australian biodiversity and to provide indicators of biological invasions.

The mismatches across Australian alien flora data sources

To report the mismatches in a more straightforward way, we grouped introduction status into higher classes. As such, native (any) includes all native, native potentially colonising and native colonising taxa; while alien (any) includes all introduced species regardless of their introduction status; introduced (any) includes all doubtfully introduced, introduced, and formerly naturalised taxa; and naturalised (any) includes all doubtfully naturalised and naturalised taxa. Subsequently, we grouped

the mismatches into several classes as follow: mismatches within groups, across alien groups (when they differ in the invasion status or the degree of establishment reported), and across different groups (native vs. alien). We also identified mismatches related to either taxa presence or origin uncertainty. Finally, the category 'other mismatches' referred to taxa that were either not listed or were an excluded taxon on the APC, taxa recorded as not present in a given state or lacking information about introduction status, and taxa that were pro-parte or pro-parte misapplied and therefore no accurate equivalence of taxonomy and status could be assigned (Table 3).

The degree of mismatches at the national scale between the data obtained by our script integrating unified statuses across Australian states and the GRIIS showed that, for all alien species, only four had similar statuses recorded in both data sources. There were 66 species that appeared as introduced according to the GRIIS despite being native to at least one Australian state (Table 3; although see supplemental table S.1 in Supplementary material for details). The case of *Phragmites australis* (Cav.) Trin. Ex Steud. is somewhat dire as it is native to all the Australian states except WA, but appears recorded as invasive, indeed, harmful invasive, on the GRIIS.

At the state scale, the mismatches detected ranged from 10% in QLD to over 40% for SA (Table 3). The lowest percentage of mismatches detected in QLD is most likely due to the fact that the QLD Herbarium uses the same terminology as the APC and therefore results more easily comparable as species fall within similar categories. On the contrary, the highest percentage was detected in a state that did not provide accurate information about the position along the continuum, and therefore most species could only be assigned to 'introduced'. The highest number of severe mismatches (i.e. those across native and alien groups) were, however, detected in VIC and TAS, with 281 and 115 mismatches falling in this category (Table 3).

Discussion

By means of this integration exercise, we have been able to create the first standardised dataset on alien flora in Australia, to assess the inconsistencies among current data sources, and to provide an updated state-of-the-art of plant invasions across Australia. Having a free easy-to-update Alien Flora of Australia (AFA) standardised dataset at the national scale that combines all up-to-date Australian state and national vascular plant censuses, offers a highly valuable research infrastructure. This national infrastructure creates cost-effective new opportunities to study biological invasions at a large scale at a speed and performance appropriate for a broad range of stakeholders ranging from state and national government entities in Australia, both the national and international scientific community, biosecurity committees, land managers and the society in general.

We would like to clarify that this integration exercise provides a reflection of the diverse information reality existing in Australia. We have developed tools to be able to combine contrasting informtaion, but we have not decided to classify any taxon differently from its statuses recorded in Australian plant censuses. From our point of view, mismatches on differing invasion statuses within groups (e.g. naturalised vs. doubtfully naturalised) are unlikely to be very problematic for management purposes. Nevertheless, mismatches across alien groups (e.g. introduced vs. naturalised) fail to provide accurate information on invasion status along the continuum therefore hampering to develop biosecurity strategies and prioritisation for invasion management or eradication. Finally, mismatches across different groups (e.g. native vs. naturalised) provide contradictory information and pose the highest risk to management and conservation because an alien species could be considered as native and managed as such or vice versa. Due to the high percentage of mismatches detected here, we urge Australian herbaria to adopt a unified scheme in the way they provide information in the state plant censuses. Ideally, the scheme they adopt should provide information on the stage of the plant taxon along the introduction-naturalisation-invasion continuum based on overcome barriers. We recommend herbaria to follow Blackburn et al. (2011) when classifying plant taxa; first, because of being the most internationally recognised framework on biological invasions; and second, because it splits the classification along the continuum in easily recognisable stages. Schemes with intermediate stages such as Darwin Core can be risky to implement, due to the fact that the time lag between consecutive phases (e.g. between a plant considered reproducing or naturalised) can be considerably reduced, therefore being difficult to ensure that a certain taxon is in one stage but not in the next one.

We also advice to limit the use of the term ‘invasive’ to refer to overcome barriers (e.g. Blackburn et al. 2011; Fig. 1c) and use instead ‘harmful invasive’ to refer to invasive taxa with negative impacts. In this sense, if impact wanted to be reported complementary steps in the future could include assessing the environmental and socioeconomic impacts of alien taxa following the EICAT (Hawkins et al. 2015) and SEICAT (Bacher et al. 2018) frameworks, respectively. These frameworks have been adopted by the IUCN to rank introduced species at the national scale (Wallingford et al. 2020) and could be used to inform and address impact in Australia.

One of the strengths of the AFA, is that the information for each plant species is easily comparable among all Australian states and at the national scale, with new opportunities arising from its use. To date, only 32 plant species that are likely to become harmful invaders have been incorporated into the Weeds of National Significance (WoNS) (Thorp and Lynch, 2000). Therefore, National Environmental Biosecurity Response Agreements (NEBRA, 2021) have only been developed for these species. We hope that the AFA resulting from this integration exercise assist predicting invasions

trends and identifying alien plant species introduced to Australia that are already naturalised in several states. For example, there are 77 species from extra-Australian origin that are recorded as naturalised in all Australian states (see supplemental table S.2 in Supplementary material); from them, only *Lycium ferocissimum* Miers is currently considered a WoNS and is included on the GRIIS as a harmful invasive. Even though such distribution can be a result of multiple introduction events, we could expect a species that is already naturalised in almost the whole Australia to become easily invasive. Species that are already recorded as naturalised in several states and that are known to have had negative impacts in other areas worldwide should be rapidly assessed for inclusion in both the GRIIS and WoNS.

In a similar manner, alien plant species that are currently appearing as doubtfully introduced or introduced in only one state, could be more susceptible to be the target of eradication efforts with funding allocated to the relevant state, to prevent further naturalisation and potential expansion into other Australian states.

Native plant species that are naturalised in other areas within the state to which they are native (i.e. recorded in the AFA at national scale as native colonising or native potentially colonising), could be associated with noticeable effects not only within their own region of origin but also in other states in which they might appear as introduced or naturalised. These range-expanding native species require specific attention (Essl et al. 2019). There are currently 103 species falling into the category of native colonising (see supplemental table S.3 in the Supplementary material for details). From these, 41 species are also introduced or naturalised into other Australian states (Supplementary material). This information should be an important consideration for land managers, and when designing conservation strategies. Monitoring those 41 species could also be implemented as part of internal biosecurity procedures in Australia to ensure that these species, despite being native, do not pose any harm to other Australian unique biota (Wallingford et al. 2020). It would be especially useful to monitor and model trends for those species under climate change. For those species expected to shift ranges associated with increasing temperatures or rainfall redistribution, this information would be crucial to apply pre-emptive management procedures.

We would like to highlight that the information provided here on plant invasions in Australia can be easily updated in the future with upcoming releases of the APC or any of the state floras. The script we created to develop the AFA can be used at any time to automatize this process in the future. This can be especially useful to monitor alien flora across Australia under global change, as certain alien taxa are predicted to expand or contract their distribution ranges, whereas others can shift their distribution attempting to track optimal environmental conditions in contiguous states.

References

Australian Plant Census. IBIS database, Centre for Australian National Biodiversity Research, Council of Heads of Australasian Herbaria, https://biodiversity.org.au/nsl/services/export/index (accessed May 2022).

Bacher, S., Blackburn, T. M., Essl, F., Genovesi, P., Heikkilä, J., Jeschke, J. M., ... & Kumschick, S. (2018). Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution, 9(1), 159-168.

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P. *et al.* (2011). A proposed unified framework for biological invasions. *Trends in Ecology and Evolution*, 26, 333–339.

Colautti, R. I., & Richardson, D. M. (2009). Subjectivity and flexibility in invasion terminology: too much of a good thing?. Biological Invasions, 11, 1225-1229.

CSIRO (2020). Australia's Biosecurity Future: Unlocking the next decade of resilience 2020-2030. Melbourne, Victoria, Australia: CSIRO; 2020. csiro:EP206614. http://hdl.handle.net/102.100.100/445389?index=1

Daly, E. Z., Chabrerie, O., Massol, F., Facon, B., Hess, M. C., Tasiemski, A., ... & Renault, D. (2023). A synthesis of biological invasion hypotheses associated with the introduction–naturalisation–invasion continuum. Oikos, 2023(5), e09645.

Darwin Core Maintenance Group (2021a). https://dwc.tdwg.org/

Darwin Core Maintenance Group (2021b). Establishment Means Controlled Vocabulary List of Terms. Biodiversity Information Standards (TDWG). http://rs.tdwg.org/dwc/doc/em/2021-09-01

Darwin Core Maintenance Group. (2021c). Degree of Establishment Controlled Vocabulary List of Terms. Biodiversity Information Standards (TDWG). http://rs.tdwg.org/dwc/doc/doe/2021-09-01

de Salas, M.F. & Baker, M.L. (2022) Census of the Vascular Plants of Tasmania, including Macquarie Island. https://flora.tmag.tas.gov.au/resources/census/, accessed November 2022.

Department for Environment and Water (2022). Biological Databases of South Australia (BDBSA) Vascular Plant BDBSA Taxonomy. https://data.environment.sa.gov.au/Content/Publications/vascular-plants-bdbsa-taxonomy.xlsx, accessed August 2022.

Essl, F., Dullinger, S., Genovesi, P., Hulme, P.E., Jeschke, J.M., et al. (2019). A conceptual framework for range-expanding species that track human-induced environmental change. Bioscience, 11, 908-919.

Essl, F., Latombe, G., Lenzner, B., Pagad, S., Seebens, H. *et al.* (2020). The Convention on Biological Diversity (CBD)'s Post-2020 target on invasive alien species–what should it include and how should it be monitored?. NeoBiota, 62, 99-121.

Gallagher, R. V., Allen, S., Mackenzie, B. D., Yates, C. J., Gosper, C. R., Keith, D. A., ... & Auld, T. D. (2021). High fire frequency and the impact of the 2019–2020 megafires on Australian plant diversity. Diversity and Distributions, 27(7), 1166-1179.

Guiaşu, R. C. (2016). The Troublesome Matter of Subjective Definitions. In *Non-native Species and Their Role in the Environment* (pp. 8-37). Brill.

Hawkins, C.L., Bacher, S., Essl, F., Hulme, P.E., Jeschke, J.M., et al. (2015). Framework and guidelines for implementing the proposed IUCN environmental impact classification for alien taxa (EICAT). Diversity and Distributions, 21, 1360-1363.

Hulme, PE., Roy, DB., Cunha, T., & Larsson, TB. (2009). A pan-European inventory of alien species: rationale, implementation and implications for managing biological invasions. Handbook of alien species in Europe, 1-14.

Laidlaw, MJ. (2022). Census of the Queensland flora and fungi 2022: Vascular Plants (Print). Queensland Department of Environment and Science, Queensland Government. www.data.qld.gov.au/dataset/census-of-the-queensland-flora-fand-fungi-2022, accessed May 2023.

Latombe, G., Pyšek, P., Jeschke, J. M., Blackburn, T. M., Bacher, S., Capinha, C., ... & McGeoch, M. A. (2017). A vision for global monitoring of biological invasions. Biological Conservation, 213, 295-308.

Le Roux, J. J., Leishman, M. R., Cinantya, A. P., Gufu, G. D., Hirsch, H., Keet, J. H., ... & Ossola, A. (2020). Plant biodiversity in the face of global change. Current Biology, 30, R390-R391.

Lepschi, B.J., Cargill, D.C., Albrecht, D.E. & Monro A.M. (Eds.) (2019). Census of the Flora of the Australian Capital Territory. Version 4.1 (30 August 2019). Canberra, ACT, Australia. https://www.cpbr.gov.au/cpbr/ACT-census/vascular-gen-alpha.html, accessed August 2022.

Luo, Y., Ogle, K., Tucker, C., Fei, S., Gao, C., LaDeau, S., ... & Schimel, D. S. (2011). Ecological forecasting and data assimilation in a data-rich era. Ecological Applications, 21(5), 1429-1442.

Martín-Forés, I., Guerin, G.R., Lewis, D., Gallagher, R.V., Vilà, M. et al. (2023). The Alien Flora of Australia (AFA), a unified Australian national dataset on plant invasion (Datasets and R script). Figshare; doi: 10.6084/m9.figshare.23513478.

National Environmental Biosecurity Response Agreement (NEBRA) (2021). Australian Federal Government. Department of Agriculture, Fisheries and Forestry.

Northern Territory Herbarium (2015). FloraNT Northern Territory Flora Online. Department of Land Resource Management. http://eflora.nt.gov.au, accessed August 2022 (version from 2021).

Nuñez, M. A., Chiuffo, M. C., Seebens, H., Kuebbing, S., McCary, M. A., Lieurance, D., ... & Meyerson, L. A. (2022). Two decades of data reveal that Biological Invasions needs to increase participation beyond North America, Europe, and Australasia. Biological Invasions, 1-8.

Pagad, S., Genovesi, P., Carnevali, L., Scalera, R., & Clout, M. (2015). IUCN SSC Invasive Species Specialist Group: invasive alien species information management supporting practitioners, policy makers and decision takers.

Pagad, S., Genovesi, P., Carnevali, L., Schigel, D., & McGeoch, M. A. (2018). Introducing the global register of introduced and invasive species. *Scientific Data*, 5, 1-12.

PlantNET (The NSW Plant Information Network System). Royal Botanic Gardens and Domain Trust, Sydney. https://plantnet.rbgsyd.nsw.gov.au, plant census dataset obtained in June 2022.

Pyšek, P., Hulme, P. E., Meyerson, L. A., Smith, G. F., Boatwright, J. S., Crouch, N. R., ... & Wilson, J. R. (2013). Hitting the right target: taxonomic challenges for, and of, plant invasions. AoB Plants, 5.

Randall J, McDonald J, Wong L J, Pagad S (2022): Global Register of Introduced and Invasive Species - Australia. v1.9. Invasive Species Specialist Group ISSG. Dataset/Checklist. https://cloud.gbif.org/griis/resource?r=griis-australia&v=1.9

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

Simberloff, D., Martin, J. L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J., ... & Vilà, M. (2013). Impacts of biological invasions: what's what and the way forward. Trends in ecology & evolution, 28(1), 58-66.

Thorp J.R. & Lynch R. (2000) The Determination of weeds of national significance. Commonwealth of Australia & National Weeds Strategy Executive Committee. Launceston, Tasmania. 234 pp.

United Nations, I. (1992). Convention on biological diversity. Treaty Collection.

van Kleunen, M, Dawson, W., Essl, F., Pergl, J., Winter, M., Weber, E., Kreft, H., Weigelt, P., Kartesz, J., Nishino, M., Antonova, L.A., Barcelona, J.F., Cabezas, F.J., Cardenas, D., Cardenas-Toro, J/, Castano, N., Chacon, E., Chatelain, C., Ebel, A.L., Figueiredo, E., Fuentes, N., Groom, Q.J., Henderson, L., Inderjit, Kupriyanov, A., Masciadri, S., Meerman, J., Morozova, O., Moser, D., Nickrent, D.L., Patzelt, A., Pelser, P.B., Baptiste, M.P., Poopath, M., Schulze, M., Seebens, H., Shu, W.-S., Thomas, J., Velayos, M., Wieringa, J.J. & Pyšek, P. (2015) Global exchange and accumulation of non-native plants. Nature, 525, pp. 100-103.

van Kleunen, M., Pyšek, P., Dawson, W., Kreft, H., Pergl, J., Weigelt, P., ... & Winter, M. (2019). The global naturalized alien flora (GloNAF) database. Ecology. 2019; 100: 1.

VicFlora (2023). Flora of Victoria, Royal Botanic Gardens Victoria. Available online: https://vicflora.rbg.vic.gov.au, accessed February 2023.

Wallingford, P.D., Morelli, T.L., Allen, J.M., Beaury, E.M., Blumenthal, D.M., et al. (2020). Adjusting the lens of invasion biology to anticipate impacts of climate-driven range shifts. Nature Climate Change, 10, 398–405

Western Australian Herbarium (1998-2022). Florabase—the Western Australian Flora. Department of Biodiversity, Conservation and Attractions. https://florabase.dpaw.wa.gov.au/o plant census obtained in October 2022.

Young, A. M., & Larson, B. M. (2011). Clarifying debates in invasion biology: a survey of invasion biologists. Environmental Research, 111(7), 893-898.

Table 1. Glossary of terms used in the Australian Alien Flora Standardised System (AAFSS) adapted from Blackburn et al. (2011), with equivalent terms used by Darwin Core, the Australian Plant Census (APC) and the Australian Global Register of Introduced and Invasive Species (GRIIS).

		Term used in AAFSS	Darwin Core establishment means [11]	Darwin Core [10] degree of establishment [12]	APC	GRIIS	Definition at the state level	Definition at the national level
	Native (any)	Native	Native	Native	Native	N/A	Native to a given Australian state without being naturalised in other areas of such state	Native to at least one Australian state regardless of being introduced or naturalised into other states
		Native potentially colonising	Native	Native	Native and doubtfully naturalised	Native-alien	Native to a given Australian state being potentially naturalised in other areas of such state	Native to at least one Australian state in which it is also doubtfully naturalised regardless of being introduced or naturalised into other states
		Native colonising	Native	Native	Native and naturalised	Native-alien	Native to a given Australian state although being also naturalised in other areas of such state	Native to at least one Australian state in which it is also naturalised regardless of being introduced or naturalised into other states
Alien	Introduced (any)	Introduced	Introduced	-Casual -Introduced (Not enough information)	NA	Alien	Species that is an alien, and is recorded as introduced into a given state. [7,8]	Species that is not native to any Australian state and is introduced in at least one state. There is not specific information of its naturalisation in the combined data sources, therefore it is not possible to know.
		Doubtfully introduced	NA (we assumed it would still be introduced as casual)	NA	NA	NA	Species for which it is uncertain if it is introduced in a given state.	Species that is not native to any Australian state and is doubtfully naturalised in at least one state, without being known to be naturalised in any state (there are currently no vascular plant species recorded with this status at national scale).
		Formerly naturalised	NA (we assumed it would still be introduced	NA	Formerly naturalised	Alien	Species that was known to have been introduced in the past into a given state. Although it could be presumed to have been eradicated,	Species that is not native to any Australian state and neither introduced or naturalised nor doubtfully introduced and doubtfully naturalised in any other state. It could be

			in a casual form)				it would most likely still be a casual alien.	presumed to have been eradicated although it is likely to still be a casual alien (there are currently 44 species under this category at national scale).
	Naturalised (any)	Naturalised	Introduced	-Reproducing -Established	Naturalised	Alien	Fraction of introduced species that have been able to form unassisted self-sustaining populations [7,8]. The only species that was recoded as 'reproducing' [12] in one of the states has been grouped under this category	Species that is not native to any Australian state and is naturalised in at least one state.
		Doubtfully naturalised	Introduced	NA (unofficially referred to as adventive)	Doubtfully naturalised	Alien	Species that despite being introduced, it is unknown if it is able to form self-sustaining populations. In other sources, sometimes referred to as adventive.	Species that is not native to any Australian state and is doubtfully naturalised in at least one state, without being known to be naturalised in any state.
	Invasive (any)	Invasive	Introduced	-Colonising -Invasive -Widespread invasive	NA	Alien	Naturalised species that have dispersed and spread in the invaded range at a significant distance from the introduction point, regardless of its impact within the invaded community [7,8,12].	
		Harmful invasive	Introduced	NA	NA	Invasive	Invasive alien species that is known to have a negative impact within the invaded range and/or to pose a threat to native biodiversity [7]. In the GRIIS referred to as invasive [32-34].	

	Uncertain	Uncertain origin	Uncertain	NA	Uncertain origin	Cryptogenic Uncertain	Species for which its origin is not known to be native or introduced to a given state	Species of unknown origin that occurs in at least one state.
	Other categories	Presumed extinct	NA	NA		NA	Species that was native to a given Australian state although is now presumed to be extinct	Species that is now presumed to be extinct in at least one Australian state and is not recorded to be present in any other form any other Australian state (there are currently 44 species under this category at national scale).
		Formerly introduced	NA	NA		N/A	Species that was known to have been introduced in the past into a given state, but there is no longer present. It could be presumed extinct or have been eradicated.	Species alien to Australia that has now been eradicated or is extinct in at least one Australian state and is not recorded to be present in any other Australian state (there is currently 1 species under this category at national scale).

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Table 2. Summary showing the number of species within each group (i.e. native, alien, uncertain origin and other categories), and percentage where indicated, regarding introduction status at national and state scales. Alien species at national scale are those for which origin is not Australian, whereas at the state level, alien species refer to those that could be native to other Australian territories. For alien species, the invasion status (e.g. introduced, naturalised and harmful invasive) has also been specified when known. To facilitate understanding, native (any) includes native, native colonising and native potentially colonising; naturalised (any) includes naturalised and doubtfully naturalised; introduced (any) includes introduced, doubtfully introduced, and formerly naturalised, assuming that, most likely, there is still an introduced individual of such species; other categories include species that are presumed extinct and species that were formerly introduced; harmful invasive refers to alien species known to have a negative impact in the native biota. States and main territories have been abbreviated (the Australian Capital Territory, ACT; New South Wales, NSW; the Northern Territory, NT; Queensland, QLD; South Australia, SA; Tasmania, TAS; Victoria, VIC; Western Australia, WA).

							Alien species		
Scale	**Region**	**Total**	**Native total**	**Alien total (% of total)**	**Uncertain origin**	**Other categories**	**Introduced**	**Naturalised**	**Harmful invasive (% of alien)**
National*	Australia	30,557	26,796	3,487 (11.4)	11	22	58	3,352	77 (2.2)
Main territory	ACT	2,034	1,245	785 (38.6)	4	0	120	643	22 (2.8)
State	NSW	9,248	7,296	1,952 (21.1)	0	0	114	1,777	61 (3.1)
Main territory	NT	5,600	5,032	564 (10.1)	4	0	63	476	25 (4.4)
State	QLD	11,812	9,904	1,904 (16.1)	0	4	76	1,769	59 (3.1)
State	SA	5,686	3,940	1,739 (30.6)	3	4	203	1,487	49 (2.8)
State	TAS	3,167	2,181	970 (30.6)	2	14	105	847	18 (1.9)
State	VIC	6,018	3,932	1,989 (33.1)	80	17	121	1,819	49 (2.5)
State	WA	15,001	13,484	1,505 (10)	0	12	1	1,504	51 (3.3)

*There are 29 species that are included in the database because of appearing on the Australian Plant Census (APC) but there are not recorded in any state or external territory. There are also 211 species that are included in the database but only appear in external territories.

Table 3. Mismatches of the status assigned to species between different sources at the national scale (Australian Alien Flora Standardised System, AAFSS, vs. Global Register of Introduced and Invasive Species, GRIIS) and state scale. Mismatches are organised as other (those not listed on the Australian Plant Census, APC, not recorded as present in such state, excluded taxa, pro-parte species for which matching with only one accepted species would be inaccurate without more information, or those with no status specified on the State census), within groups, across alien groups (i.e. different categories of introduced, naturalised and harmful invasive), those related with presence, those related with uncertainty, and those occurring across groups (native vs. introduced, naturalised and harmful invasive). Naturalised (any) includes naturalised and doubtfully naturalised; introduced (any) includes introduced, doubtfully introduced, and formerly naturalised, assuming that, most likely, there is still a casual individual of such species; native (any) includes native, native colonising and native potentially colonising. Not listed on the GRIIS refers only to alien species or those with uncertain origin that do not appear recorded on the GRIIS. States and main territories have been abbreviated (the Australian Capital Territory, ACT; New South Wales, NSW; the Northern Territory, NT; Queensland, QLD; South Australia, SA; Tasmania, TAS; Victoria, VIC; Western Australia, WA).

		National AAFSS vs GRIIS	State or main territory							
			ACT	NSW	NT	QLD	SA	TAS	VIC	WA
	Total	3494	1775	8760	5627	11998	5499	3101	6639	15219
	Similar	4	1094	6297	4587	10740	3264	1900	4493	13145
	Mismatch (%)	3490	681 (38.4)	2463 (28.1)	1040 (18.5)	1258 (10.5)	2235 (40.1)	1201 (38.7)	2146 (32.3)	2074 (13.6)
Across	Native (any) – Introduced (any)	65	3	15	18		16	13	13	
	Native (any) – Naturalised (any)		2	15	19	40	9	123	296	28
	Native (any) – Harmful invasive	1								
Across alien groups	Doubtfully introduced – Doubtfully naturalised		0		0			5		
	Introduced – Doubtfully naturalised	129	21	81	27		149	53	191	
	Formerly naturalised – Doubtfully naturalised		21		0	14		0		0
	Formerly naturalised – Naturalised		17		0	18		0	4	5
	Doubtfully introduced – Naturalised		0		0			2		

	Introduced – Naturalised	1958	368	1583	407		1198	591	157	
	Introduced (any) – Harmful invasive	0								
	Naturalised (any) – Harmful invasive	76								
Within groups	Native – Native colonising		10	56	6	25	10	4	26	66
	Native – Native potentially colonising		0	1	0	1	2	0	2	0
	Native colonising – Native potentially colonising		0	1	0	0	0	0	5	0
	Formerly naturalised – Introduced	13	12	4	6		10	3	6	
	Doubtfully naturalised – Naturalised		9		0	85		0	29	14
Presence related	Formerly introduced – Introduced (any)	0	0		2	0		3	57	
	Formerly introduced – Naturalised (any)		0		0	0		2	24	
	Formerly introduced – Native (any)		0	0	0	0	0	0	1	0
	Presumed extinct – Uncertain origin		0	0	0	0	0	0	1	0
	Presumed extinct – Native (any)		0	10	0	14	20	10	23	16
	Presumed extinct – Alien (any)	0	0	0	0	0	1	0	3	0
Uncertain	Uncertain origin – Native (any)		3		4	0	2	2	74	0
	Uncertain origin – Introduced (any)	3	0		1		0	2	0	
	Uncertain origin – Naturalised (any)		1		1	0	0	0	15	0
	Uncertain origin – Harmful invasive	0								
Other	Not listed on the APC (or the GRIIS)	1306	44	233	399	821	505	153	1004	1773
	Not recorded as present in such State	4*	170	388	144	221	311	195	184	160
	Excluded, no status, or pro-parte and pro-parte misapplied species		0	76	6	19	2	40	31	12

**Only recorded in external territories, therefore not appearing in our AAFSS at Australian national scale*

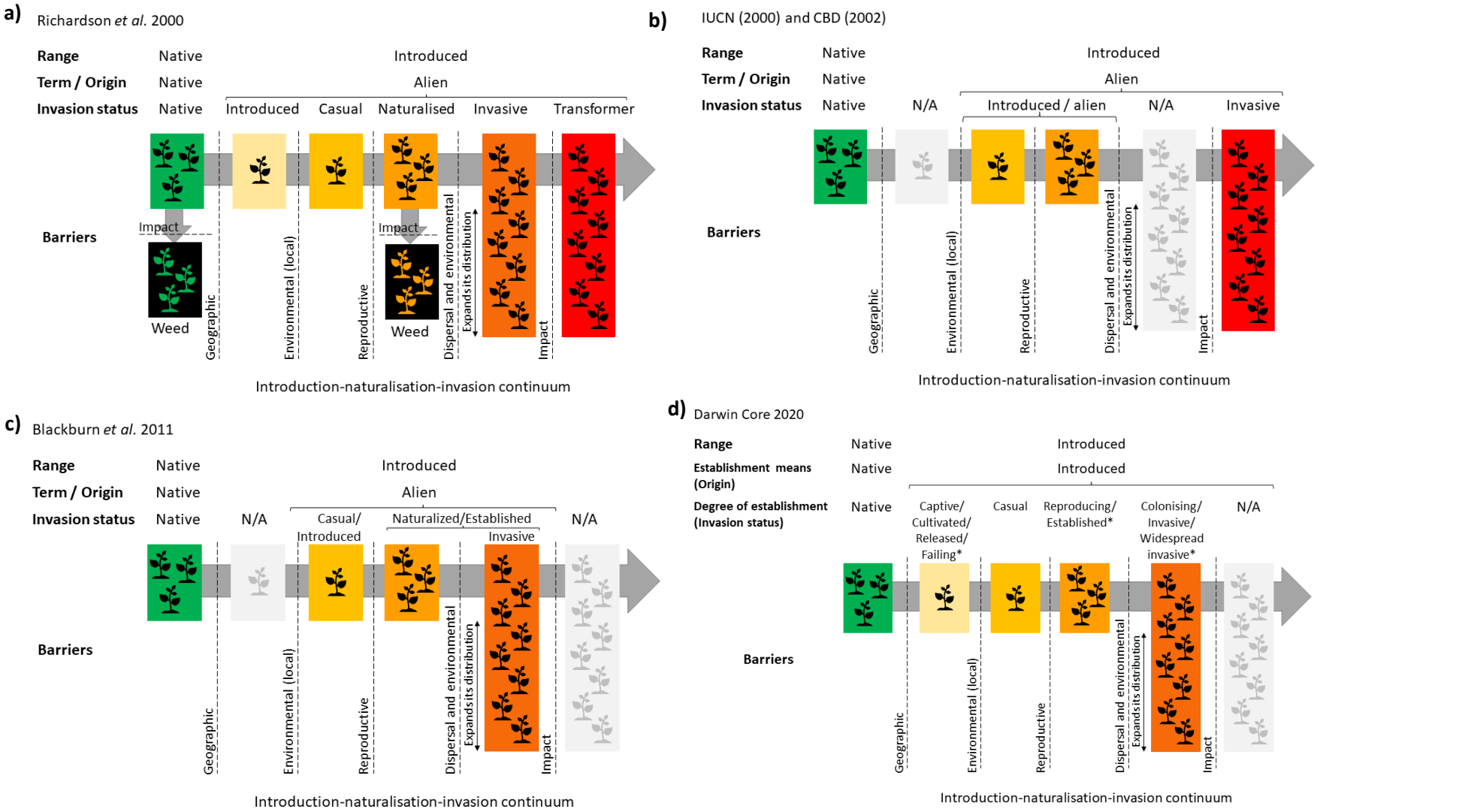


Fig. 1. Frameworks on biological invasions proposed by: a) Richardson et al. (2000), b) CBD and IUCN, c) Blackburn et al. (2011) and d) Darwin Core.

Terminology marked with * in Darwin Core varies according to specific details within the considered barrier; therefore, the terms are not interchangeable.

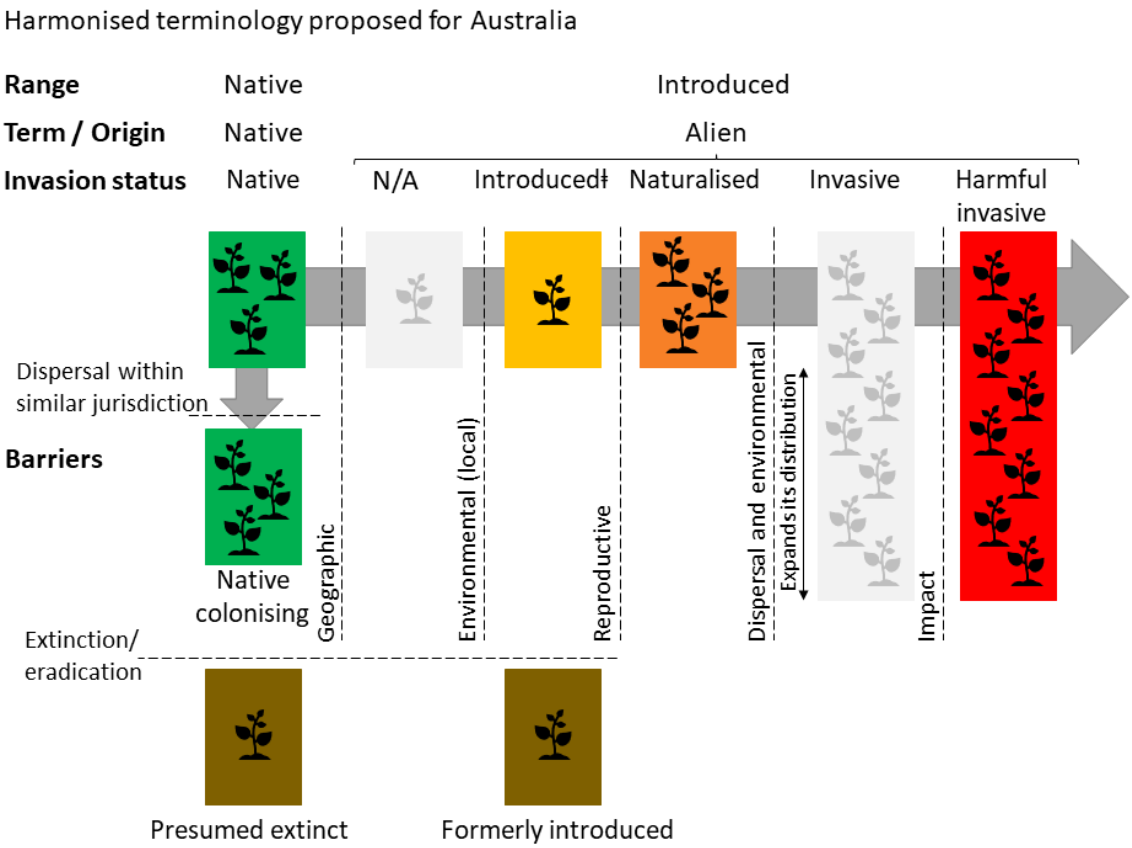


Fig. 2. Harmonised framework to unify terminology on biological invasions across Australian data sources. The unified terminology is based on Blackburn et al. (2011) but incorporating the notion of impact to account for the species recorded as invasive in the Australian Global Register for Introduced and Invasive Species (GRIIS) following the IUCN's guidelines. The term 'introduced' marked with ǂ in our proposed framework does not refer strictly to 'casual' alien species but has been used instead when information on naturalisation was not available in a specific census.

PRIORITISATION PROCEDURE AT THE STATE LEVEL

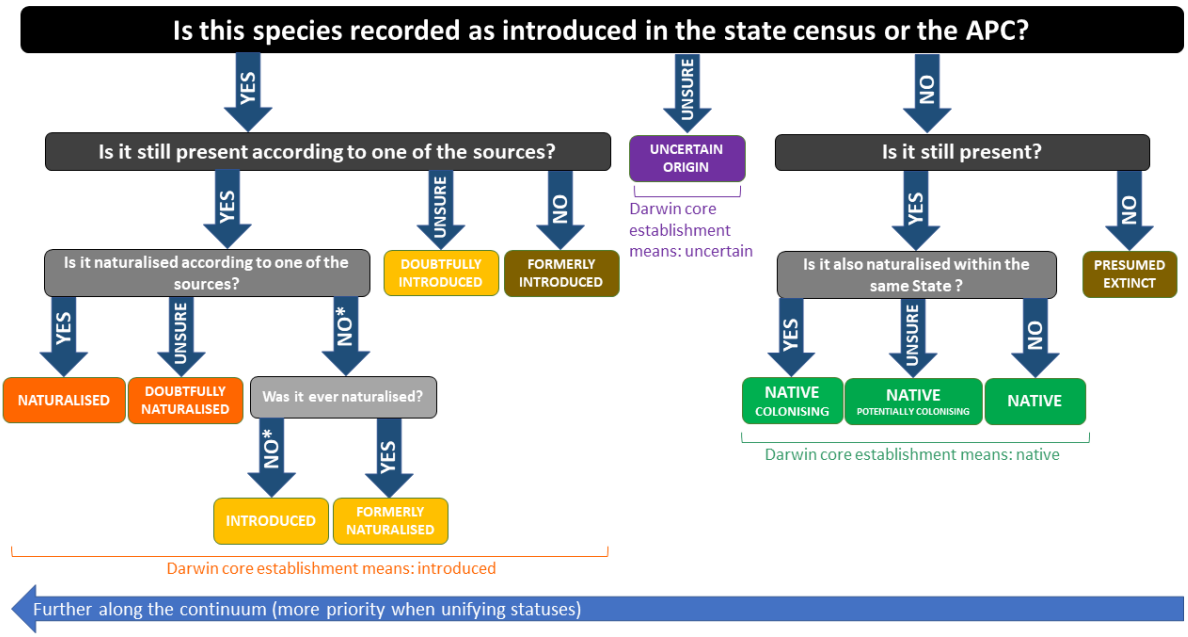


Fig. 3. Prioritisation procedure to assign the most conservative introduction status for a given species in a given Australian state after comparing the records in the corresponding state census and in the Australian Plant Census (APC). The status 'naturalised' refers to introduced species that form unassisted self-sustaining populations. *Indicates that in some cases there is not enough information in the state censuses to respond to these questions; therefore we have assumed that the answer would be no. Darwin Core equivalences with regards to establishment means (native, introduced and uncertain) are also included.

PRIORITISATION PROCEDURE AT THE NATIONAL LEVEL

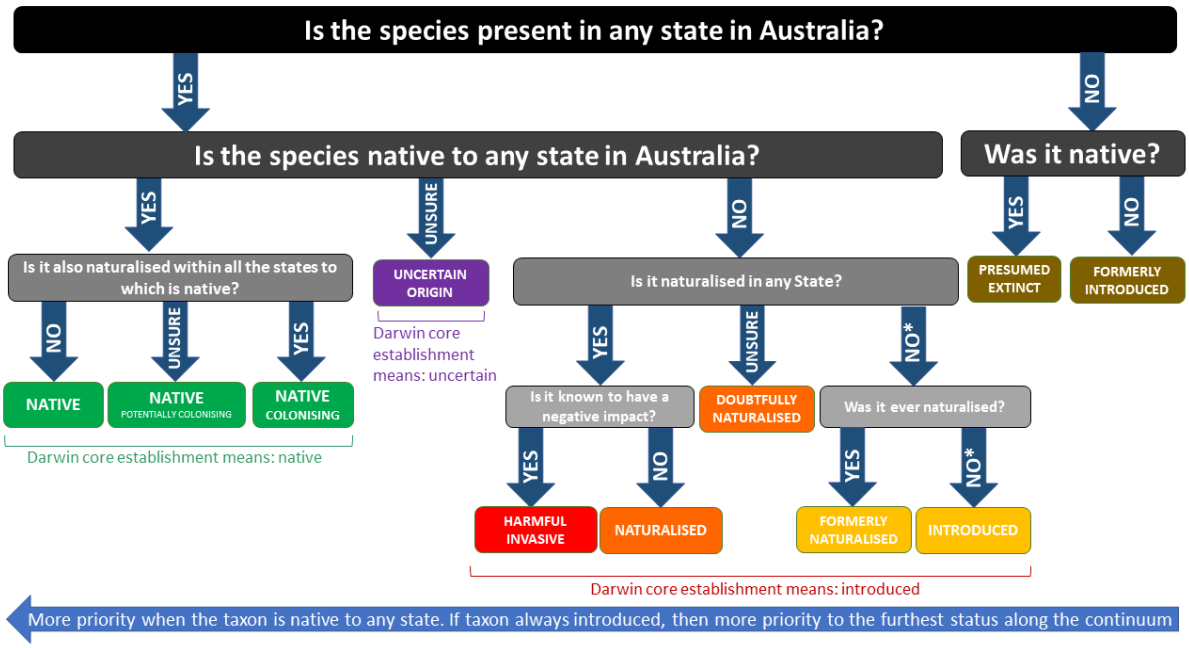
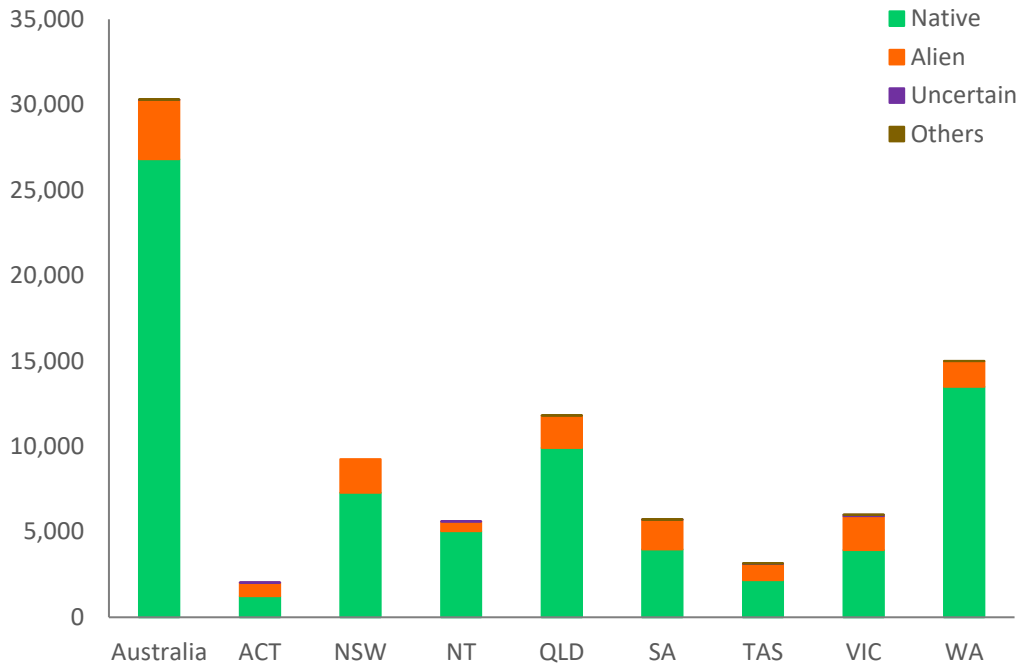


Fig. 4. Prioritisation procedure to assign the national status for a given species after merging the most conservative statuses across all the Australian states. The status 'naturalised' refers to introduced species that form unassisted self-sustaining populations. The status 'harmful invasive' was only assigned for the species that, being introduced at the national level, appeared recorded as invasive in the Australian GRIIS. *Indicates that in some cases there is not enough information in the state censuses to respond to these questions, therefore we have assumed that the answer would be no. Darwin Core equivalences with regards to establishment means (native, introduced and uncertain) are also included.



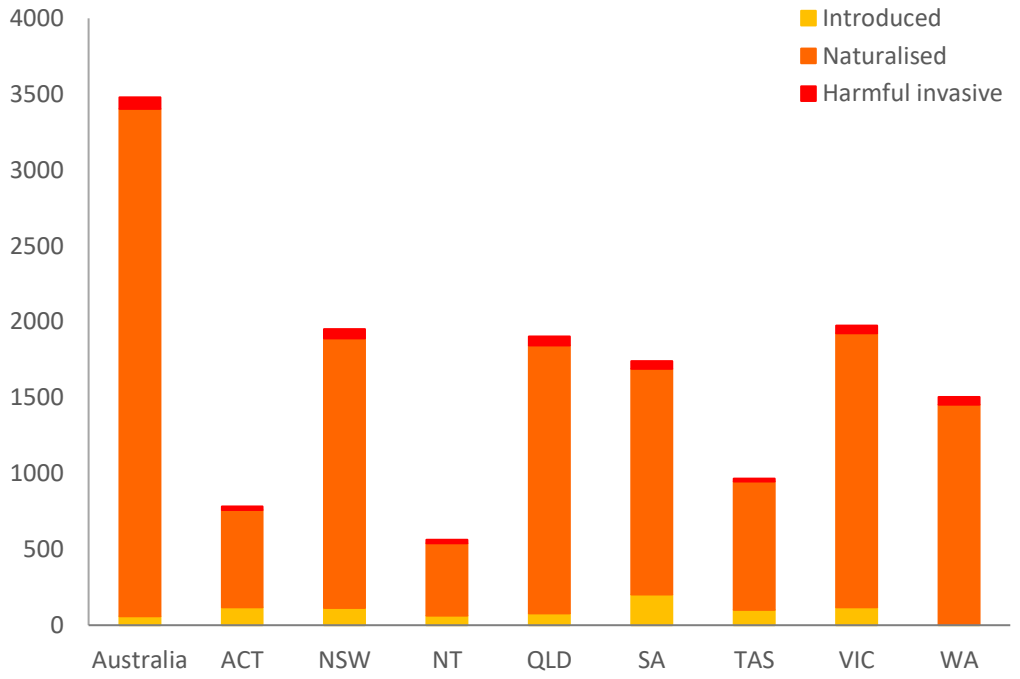


Fig. 4. Summary of the records of Australian flora in AAFSS at both the national and state scales with regards to (top) origin (native, alien, uncertain or other categories), and (bottom) within the alien flora, grouped by introduction status (introduced, naturalised and harmful invasive). States and main territories have also been abbreviated (the Australian Capital Territory, ACT; New South Wales, NSW; the Northern Territory, NT; Queensland, QLD; South Australia, SA; Tasmania, TAS; Victoria, VIC; Western Australia, WA).

Supplementary material

Supplemental Table S.1. Scientific name according to the Australian Plant Census (APC) of the species that are introduced according to the Global Register of Introduced and Invasive Species (GRIIS) despite being native to at least one Australian state according to the Australian Alien Flora Standardised System.

Species scientific name	
Abelmoschus manihot (L.) Medik.	*Ludwigia peploides* (Kunth) P.H.Raven
Aeschynomene brevifolia L.f. ex Poir.	*Lysimachia fortunei* Maxim.
Alchemilla xanthochlora Rothm.	*Lysimachia japonica* Thunb.
Ammannia auriculata Willd.	*Lysimachia vulgaris* L.
Anthyllis vulneraria L.	*Malvastrum americanum* (L.) Torr.
Apluda mutica L.	*Malvastrum coromandelianum* (L.) Garcke
Bidens subalternans DC.	*Melochia pyramidata* L.
Blainvillea acmella (L.) Philipson	*Muehlenbeckia complexa* (A.Cunn.) Meisn.
Brassica fruticulosa Cirillo	*Ocimum tenuiflorum* L.
Cardamine corymbosa Hook.f.	*Oxalis latifolia* Kunth
Cardiospermum halicacabum L.	*Parietaria officinalis* L.
Chenopodium glaucum L.	*Persicaria strigosa* (R.Br.) H.Gross
Clausena excavata Burm.f.	*Phyla nodiflora* (L.) Greene
Cocos nucifera L.	*Phyllanthus tenellus* Roxb.
Corchorus aestuans L.	*Polygonum argyrocoleon* Steud. ex Kunze
Corchorus olitorius L.	*Polyscias scutellaria* (Burm.f.) Fosberg
Corchorus trilocularis L.	*Pteridium aquilinum* (L.) Kuhn
Cucumis melo L.	*Pupalia micrantha* Hauman
Cynodon dactylon (L.) Pers.	*Sagina maritima* Don
Dietes robinsoniana (C.Moore & F.Muell.) Klatt	*Samolus valerandi* L.
Epilobium tetragonum L.	*Sida spinosa* L.
Eriocaulon truncatum Buch.-Ham. ex Mart.	*Sida subcordata* Span.
Erodium aureum Carolin	*Stuckenia pectinata* (L.) Borner
Geranium aequale (Bab.) Aedo	*Symphytum officinale* L.
Gnaphalium polycaulon Pers.	*Torilis arvensis* (Huds.) Link
Heliotropium curassavicum L.	*Tribulus terrestris* L.
Heliotropium europaeum L.	*Utricularia gibba* L.
Indigofera glandulosa J.C.Wendl.	*Vallisneria nana* R.Br.
Isolepis marginata (Thunb.) A.Dietr.	*Verbena officinalis* L.
Juncus bufonius L.	*Vicia cracca* L.
Leucas decemdentata (Willd.) Sm.	*Vigna adenantha* (G.Mey.) Maréchal, Mascherpa & Stainier
Lobelia pedunculata R.Br.	*Vigna radiata* (L.) R.Wilczek
Ludwigia palustris (L.) Elliott	*Vigna vexillata* (L.) A.Rich.

Supplemental Table S.2. Scientific name according to the Australian Plant Census (APC) of the alien species not original from Australia that are naturalised in all Australian states. * indicates that they are recorded as transformers in the Global Register of Introduced and Invasive Species (GRIIS). ǂ indicates that they are included in the Weeds of National Significance (WoNS).

Scientific name of species naturalised in all Australian states	
Aizoon pubescens Eckl. & Zeyh.	*Lolium perenne* L.
Arctotheca calendula (L.) K.Lewin	*Lolium rigidum* Gaudin
Argemone ochroleuca Sweet	*Lycium ferocissimum* Miers *ǂ
Argemone ochroleuca Sweet subsp. *ochroleuca*	*Malva parviflora* L.
Avena barbata Pott ex Link	*Medicago minima* (L.) L. ex Bartal.
Avena fatua L.	*Medicago sativa* L.
Brassica oleracea L.	*Oenothera stricta* Ledeb. ex Link
Briza maxima L.	*Oenothera stricta* Ledeb. ex Link subsp. *stricta*
Bromus catharticus Vahl	*Oxalis corniculata* L.
Bromus diandrus Roth	*Papaver hybridum* L.
Buglossoides arvensis (L.) I.M.Johnst.	*Papaver somniferum* L.
Capsella bursa-pastoris (L.) Medik.	*Paspalum dilatatum* Poir.
Cardamine hirsuta L.	*Plantago coronopus* L.
Carthamus lanatus L.	*Plantago coronopus* L. subsp. *coronopus*
Cenchrus clandestinus (Hochst. ex Chiov.) Morrone	*Plantago lanceolata* L.
Cerastium glomeratum Thuill.	*Poa annua* L.
Chenopodium album L.	*Poa pratensis* L.
Cirsium vulgare (Savi) Ten.	*Polycarpon tetraphyllum* (L.) L.
Cucumis myriocarpus Naudin	*Polygonum aviculare* L.
Cucumis myriocarpus Naudin subsp. *myriocarpus*	*Polypogon monspeliensis* (L.) Desf.
Cyclospermum leptophyllum (Pers.) Sprague ex Britton & P.Wilson	*Rapistrum rugosum* (L.) All.
Datura ferox L.	*Rostraria cristata* (L.) Tzvelev
Dittrichia graveolens (L.) Greuter	*Rumex crispus* L.
Echinochloa crus-galli (L.) P.Beauv.	*Sagina apetala* Ard.
Echinochloa esculenta (A.Braun) H.Scholz	*Salvia verbenaca* L.
Echium plantagineum L.	*Senecio vulgaris* L.
Eleusine indica (L.) Gaertn.	*Setaria italica* (L.) P.Beauv.
Eragrostis cilianensis (All.) Vignolo ex Janch.	*Setaria pumila* (Poir.) Roem. & Schult.
Eragrostis minor Host	*Setaria verticillata* (L.) P.Beauv.
Erigeron bonariensis L.	*Sisymbrium irio* L.
Euphorbia peplus L.	*Sisymbrium orientale* L.
Gypsophila tubulosa (Jaub. & Spach) Boiss.	*Solanum nigrum* L.
Hordeum glaucum Steud.	*Sonchus oleraceus* L.
Hypochaeris glabra L.	*Sporobolus africanus* (Poir.) Robyns & Tournay
Lactuca serriola L.	*Stellaria media* (L.) Vill.
Lactuca serriola L. f. *serriola*	*Triticum aestivum* L.
Lamium amplexicaule L.	*Urtica urens* L.
Lepidium africanum (Burm.f.) DC.	*Vulpia myuros* (L.) C.C.Gmel.
Lepidium bonariense L.	*Xanthium spinosum* L.

Supplemental Table S.3. Scientific name of the native colonising (i.e. those also naturalised in other areas of the state to which they are native). * indicates that they are introduced or naturalised in other states.

Scientific name of species that are native colonising at Australian national level	
Acacia acuminata Benth. *	*Diplolaena dampieri* Desf. *
Acacia amblyophylla F.Muell.	*Diplopeltis petiolaris* Benth. *
Acacia baileyana F.Muell. *	*Echinochloa colona* (L.) Link *
Acacia blakelyi Maiden	*Epipremnum pinnatum* (L.) Engl.
Acacia cardiophylla A.Cunn. ex Benth. *	*Eucalyptus conferruminata* D.J.Carr & S.G.M.Carr *
	Eucalyptus conferruminata subsp. *recherche* D.Nicolle &
Acacia celastrifolia Benth.	M.E.French
Acacia decurrens Willd. *	*Eucalyptus crenulata* Blakely & Beuzev. *
Acacia dietrichiana F.Muell.	*Eucalyptus erythrocorys* F.Muell.
Acacia howittii F.Muell. *	*Eucalyptus gomphocephala* DC. *
Acacia iteaphylla F.Muell. ex Benth. *	*Eucalyptus lane-poolei* Maiden
Acacia lasiocalyx C.R.P.Andrews	*Eucalyptus megacornuta* C.A.Gardner *
Acacia lasiocarpa Benth.	*Eucalyptus utilis* Brooker & Hopper *
Acacia lasiocarpa Benth. var. lasiocarpa	*Grevillea banksii* R.Br.
Acacia macradenia Benth.	*Grevillea curviloba* McGill.
	Grevillea juniperina subsp. *sulphurea* (A.Cunn.)
Acacia mangium Willd. *	Makinson *
Acacia microbotrya Benth.	*Grevillea leucopteris* Meisn.
Acacia podalyriifolia A.Cunn. ex G.Don *	*Grevillea rosieri* McGill.
Acacia pulchella R.Br. *	*Hakea costata* Meisn.
Acacia pulchella R.Br. var. *pulchella* *	*Hakea gibbosa* (Sm.) Cav.
Acacia retinodes Schltdl. *	*Hakea laurina* R.Br. *
Acacia spectabilis A.Cunn. ex Benth.	*Hakea multilineata* Meisn.
Acacia trigonophylla Meisn.	*Hakea pycnoneura* Meisn.
Acacia vestita Ker Gawl. *	*Hakea recurva* Meisn.
Agonis flexuosa (Willd.) Sweet *	*Hakea recurva* Meisn. subsp. *recurva*
Agonis flexuosa (Willd.) Sweet var. *flexuosa* *	*Hibbertia cuneiformis* (Labill.) Sm.
Aleurites moluccanus (L.) Willd. *	*Hibiscus tridactylites* Lindl. *
Allocasuarina huegeliana (Miq.) L.A.S.Johnson	*Kennedia nigricans* Lindl. *
Banksia undata A.R.Mast & K.R.Thiele	*Kunzea baxteri* (Klotzsch) Schauer *
Banksia undata A.R.Mast & K.R.Thiele var. *undata* *	*Labichea lanceolata* Benth.
Bidens subalternans DC. *	*Labichea lanceolata* Benth. subsp. *lanceolata*
Buckinghamia celsissima F.Muell.	*Lagunaria patersonia* (Andrews) G.Don *
Callistemon phoeniceus Lindl.	*Lechenaultia biloba* Lindl.
Callitris canescens (Parl.) S.T.Blake	*Malvastrum coromandelianum* (L.) Garcke *
Callitris preissii Miq.	*Melaleuca diosmifolia* Andrews *
Callitris pyramidalis (Miq.) J.E.Piggin & J.J.Bruhl	*Melaleuca megacephala* F.Muell.
Callitris roei (Endl.) F.Muell.	*Melaleuca nesophila* F.Muell. *
Calothamnus chrysanthereus F.Muell.	*Melaleuca pentagona* Labill.
Calothamnus graniticus Hawkeswood	*Melaleuca pentagona* Labill. var. *pentagona*
Calothamnus graniticus Hawkeswood subsp. *graniticus*	*Paraserianthes lophantha* (Willd.) I.C.Nielsen *
	Paraserianthes lophantha (Willd.) I.C.Nielsen subsp.
Calothamnus quadrifidus R.Br.	*lophantha* *
Calothamnus quadrifidus subsp. *homalophyllus* (F.Muell.)	
A.S.George & N.Gibson	*Piper umbellatum* L.
	Pittosporum bicolor Hook. x *Pittosporum undulatum*
Calothamnus quadrifidus R.Br. subsp. *quadrifidus*	Vent.
Calothamnus quadrifidus subsp. *teretifolius* A.S.George &	
N.Gibson	*Reedia spathacea* F.Muell.
Calothamnus rupestris Schauer	*Solanum hoplopetalum* Bitter & Summerh. *
Calothamnus validus S.Moore	*Solanum hystrix* R.Br. *

Chamelaucium uncinatum Schauer *	*Syzygium paniculatum* Gaertn.
Chionanthus ramiflorus Roxb.	*Terminalia arenicola* Byrnes
Conospermum huegelii R.Br. ex Endl.	*Thryptomene calycina* (Lindl.) Stapf
Corymbia torelliana (F.Muell.) K.D.Hill & L.A.S.Johnson	*Verbena officinalis* L. *
Cynodon dactylon (L.) Pers. *	*Verticordia monadelpha* Turcz.
Dasymalla teckiana (F.Muell.) B.J.Conn & Henwood	*Verticordia monadelpha* Turcz. *var. monadelpha*
Diplazium dietrichianum (Luerss.) C.Chr.	