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ORIGINAL PAPER

Using IUCN criteria to perform rapid assessments of at-risk taxa

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Abstract

The IUCN Red List criteria are a globally accepted method of assessing species extinction risk, and countries around the world are adapting these criteria for domestic use. First, we compared trends in IUCN Red List criteria used in threatened plant species listings in Australia and globally. Second, using the state of New South Wales (NSW), Australia, as a study region, we conducted two complementary analyses: (1) An assessment of ~5000 currently unlisted NSW plant species against the thresholds for the geographic range criterion (Criterion B) to identify species which may require full assessment; and (2) A rapid assessment of currently listed threatened plant species, applying the IUCN Red List Critically Endangered thresholds for all criteria, to identify species likely to be at the highest risk of extinction from further decline. Impacts on these species could be considered to be "serious and irreversible impacts" (SAII). Geographic range size was the most common criterion used in Australia and globally for plant listings. Our assessment of unlisted NSW plant species revealed 92 species (75 endemic to NSW) met the geographic range thresholds for Critically Endangered. Our rapid assessments of currently listed NSW threatened plant species identified 53.5% as having an extremely high risk of extinction should further decline occur. Of these, most were flagged under Criterion B (88.8%). Geographic range and the other IUCN Red List criteria thresholds for Critically Endangered provide a useful framework to identify species at an extremely high risk of extinction from ongoing decline.

Keywords Australia · Geographic range · IUCN Red List · Plant conservation · Threatened species · Habitat loss

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Introduction

Prioritisation is essential for effective conservation management as the number of threatened species, and the actions required to conserve them, typically outweigh the resources available (Possingham et al. 2002). Traditional conservation prioritisation is usually based on three factors (benefit, cost and likelihood of success), with species extinction risk or "threat category" used as a surrogate for the potential benefit that can be obtained from conservation actions (Bottrill et al. 2008). Similarly, extinction risk is commonly used to identify those species to be offered the highest protection under regulatory frameworks such as policy settings for development and land clearing (e.g. Department of Sustainability, Environment, Water, Population and Communities 2012). The global standard for assessing extinction risk are the International Union for the Conservation of Nature (IUCN) Red List criteria (IUCN 2012). Under this system, species are assigned a ranked threat category, such as critically endangered (CR), endangered (EN) and vulnerable (VU) through assessment against quantitative criteria based on indicators of extinction risk (Collen et al. 2016). Assessing species according to the IUCN Red List criteria provides a globally accepted metric of extinction risk and can inform conservation prioritisation and conservation measures such as offsetting (Maron et al. 2012).

The three main components of an IUCN extinction risk assessment are: decline (Criteria A and E), geographic range (Criteria B and D2) and population size (abundance) (Criteria C and D). Decline rate is intrinsically bound to extinction risk; all else being equal, if death rate exceeds birth rate, extinction risk increases (Mace et al. 2008). Decline can be difficult to detect (Staples et al. 2005), especially declines which are: small; occur in rare species (Wilson et al. 2011); or associated with variable or cyclic climatic conditions and nomadism (Runge et al. 2015). Indeed, many monitoring programs for assessing decline are ineffective or fail completely (Lindenmayer and Likens 2010). Decline can be direct, through losses of mature individuals, or indirect through habitat loss and fragmentation (IUCN 2017). The effect of habitat loss is particularly important in sessile organisms with limited dispersal ability, such as many plants (Keith 1998). The second component, geographic range size, is also a strong predictor of extinction risk (Gaston and Fuller 2009). Species with larger range sizes are buffered against local losses of individuals and habitat, and are less likely to experience catastrophic or range-wide losses (Payne and Finnegan 2007; Brook et al. 2008). Third, the probability of extinction is higher when population size is small (Mace et al. 2008). Small populations generally suffer reduced genetic variation which can impact on breeding systems (Frankham 2005), and very small populations are susceptible to demographic stochasticity (Lande 1993).

As elements of extinction risk, the three main components of the IUCN criteria can be used to prioritise species that are most at risk from further decline (including via habitat loss). IUCN threat categories are often used as a direct measure of the degree to which species are at risk from extinction, despite this constituting a somewhat incomplete conservation prioritisation (Possingham et al. 2002; Collen et al. 2016). However, as data collation and assessment are time- and resource-intensive activities, an approach which identifies at-risk species based on threshold elements (or a subset) of IUCN Red List criteria has the potential to increase the speed of conservation assessments and prioritisation. Importantly, rapid assessments—preliminary coarse-scale assessments which help prioritise taxa by flagging the potential for significant increases in extinction risk—facilitate a precautionary approach to conservation actions (i.e. What would the threat status of a species be *if* there was further loss of known sites? What species cannot tolerate further loss without significantly increasing their extinction risk?).

Precautionary approaches, which can identify extinction risk across large cohorts of species, minimise risk to species in the long-term, due to the increased potential for appropriate planning and protection (Pressey et al. 2007; Walls 2018). By contrast, reactive approaches prioritise protection and recovery actions for species closest to extinction (i.e. high vulnerability and high threat; Brooks et al. 2006). If CR species are strongly prioritised at the expense of EN, VU or declining unlisted species, this may increase the impact of ongoing extinction drivers (e.g. development pressure, land-clearing) on species that are not currently categorised as CR, potentially moving more species closer to extinction (Possingham et al. 2002; Wilson et al. 2011). For example, CR species receive on average approximately 50% more funding, per species, compared to either EN or VU species (NSW Saving our Species data, 2016–2017: http://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-program/conservation-projects-database, accessed 21 January 2018). In terms of direct savings, a German study, comparing the costs of implementing proactive conservation actions with waiting for legal requirements (i.e. formal listing as a threatened species) to trigger conservation actions, found that the proactive approach led to savings of between €17.2 and 36.4 million (Drechsler et al. 2011).

Quantifying geographic range size in species yet to have their extinction risk formally assessed, constitutes an important first-step for identifying species at risk and prioritising conservation actions. Examples include the rapid assessment of large numbers of unassessed and or data deficient species (Brummitt et al. 2008), identification of geographic areas that are “hotspots of threat” (Darrah et al. 2017) and identification of threatened plant taxonomic groups (Brummitt et al. 2015a). Rapid assessments of geographic range are particularly important for identifying species meeting CR thresholds which can then be prioritised for full assessment. Currently 23,074 plant species have undergone extinction risk assessments using the IUCN Red List criteria (www.iucnredlist.org, accessed 26 October 2017). This accounts for just 5.7% of current estimates of the number of described plant species globally (403,911 species; Lughadha et al. 2016) and a recent audit of one of the key goals of the Global Strategy for Plant Conservation showed that only 21–26% of accepted plant species have had a threat assessment completed (Bachman et al. 2018) underscoring the need for new methods which can accelerate the identification of at risk taxa. The enormity of the challenge of comprehensively assessing the world’s biodiversity has not gone unnoticed, and the adaptation of IUCN criteria to flag extinction risk has been proposed as a solution. Assessments of area of occupancy (AOO) and extent of occurrence (EOO) can also help to objectively identify potential CR species which may otherwise not have been nominated for protection in legislative systems which rely heavily on public nominations, such as in New South Wales (NSW), Australia.

The need for conservation policy makers to move away from a model solely focusing on the species with the highest threat status (such as already listed CR species) and towards a more balanced proactive approach, which also seeks to identify and protect potentially at risk species at an early stage, has been highlighted in a number of recent studies (Cardillo and Meijaard 2012; Walls 2018). This is especially relevant where there are likely threatened species which have not been formally assessed or listed, and species with listings that are out of date. We suggest that rapid assessments, using the major components of the IUCN criteria to identify species most at risk of further declines, are a particularly useful tool for prioritising species that are: (1) unassessed but which may qualify as CR; (2) have out-of-date assessments; and (3) VU and EN species which already meet some (but not all) thresholds for CR and may move to a higher threat category with further loss. For currently unlisted species, focusing on identifying those which are closest to extinction is the most proactive approach; waiting for them to be assessed under the current system it may be too late to effectively conserve them. For those species which have already been assessed and which we know are threatened, the imperative is then to identify those species which are potentially being pushed towards extinction faster than others, regardless of their current threat status. This method of rapid assessment could serve as a tool which conservation policymakers can begin to incorporate a more proactive and preventative approach to conservation.

In this study, we use the flora of the Australian state of NSW as a case study for the deployment of precautionary, rapid assessments of extinction risk. To do this, we follow a theoretical workflow which can be employed across varying geographic scales and taxonomic groups to streamline the prioritisation and assessment process. The first step was to examine, within our study group (plants), which of the IUCN criteria are most prevalent in threatened species listings, and are therefore likely to be most useful for a rapid assessment. Secondly, we quantify the geographic range (AOO and EOO) of plants in NSW which are currently unlisted under IUCN criteria, to ascertain the range of species that may meet thresholds for threatened status (VU, EN, CR). Finally, we assess whether IUCN criteria and/or the subcriteria at the CR threshold can be used to prioritise protection of currently listed threatened species that are unlikely to tolerate further decline (in population size or geographic range), through land clearing and habitat degradation, as any decline will likely result in them having an extremely high extinction risk. We do this by identifying species that meet some, but not all, criteria and subcriteria for listing as CR. Under IUCN Red List Criteria one of the key subcriteria for listing a species as threatened is "continuing declines" which can be difficult to show are continuing, even if there have been declines in the past. Further losses resulting from land clearing for EN and VU species, which already meet some of the thresholds and criteria for CR, would be considered continuing declines as IUCN (2017) stress that such continuing declines can be at any rate. Consequently, in addition to any CR criteria thresholds they already meet, they would also meet one of the key subcriteria (continuing declines) and they would therefore have a high chance of being listed as CR. We can then prioritise protection of those species, defined as species with potential to trigger a "serious and irreversible impact" (SAII). SAII assessment is undertaken in the context of proposed impacts on species through development impacts, hence decline is predicted to occur if the development is not prevented.

The concept of SAII is fundamentally about protecting threatened species that are most at risk of extinction from development impacts and is provided for as part of a legislative framework for protection and conservation of threatened species (the *NSW Biodiversity Conservation Act 2016;* hereafter *NSW BC Act*). Any declines in these SAII species' populations or habitat is expected to increase extinction risk; species listed as VU or EN under the *NSW BC Act* could then become eligible for listing as CR if further losses occur. Species listed as CR are "considered to be facing an extremely high risk of extinction in the wild" (IUCN 2017). Flagging that a threatened species is at risk of a SAII triggers additional assessment requirements and further consideration of proposed impacts under the *NSW BC Act* (OEH 2017). Hence, rapid assessment in the SAII framework, identifies and therefore seeks to protect (through SAII listing) species near IUCN criteria thresholds, attempting to prevent them from reaching those thresholds. Together, the rapid assessments of unlisted species based on geographic range, and of currently listed species based on CR thresholds of IUCN criteria (geographic range, population size and decline), aim to address the resource limitations that constrain the process of identifying and listing threatened species, and then prioritise conservation investment and management for those species that either are or become listed as threatened.

We applied the IUCN Red List criteria, using data from existing species extinction risk assessments and occurrence data to conduct a rapid assessment of extinction risk in plant species either currently listed as threatened, or unassessed in NSW. We addressed the following specific questions:

1. Which IUCN criterion is most prevalent in existing threatened plant species listings?
2. How many currently unassessed flora species in the state of NSW meet the thresholds for restricted geographic range size (IUCN Criterion B)?
3. How many currently listed threatened plant species in NSW would meet the thresholds for Critically Endangered if there were further losses of known sites? Such species would be considered to be at risk of serious and irreversible impact (SAII), as defined under provisions in the *NSW Biodiversity Conservation Act 2016*.

Methods

Relative contribution of IUCN Red List criteria to listings at national and global scales

Three sources of information were used to determine which IUCN Red List criteria are most prevalent in listings of threatened plant species in Australia compared to the global IUCN Red List. For each species, we used only the most recent IUCN-compliant assessment from either: (1) assessments for plants listed under the *New South Wales Biodiversity Conservation Act* 2016 (NSW State Government 2017), (2) assessments for plants listed under the *Environment Protection and Biodiversity Conservation Act 2000* (Australian Government 2000; hereafter *EPBC Act*), or (3) IUCN Red List assessments for globally threatened plant species.

(1) The *NSW BC Act* list of threatened plants is comprised of a mixture of listings prior to (56%) and since (44%) the full consideration of IUCN Red List criteria in listing criteria. (Prior to 1995 a modified version of the IUCN Red List criteria were used for listing). Some 634 species from 97 families are on the list, however, species which are endemic to NSW (and hence represent a global assessment), and also had IUCN-compliant listing data, only account for 104 species from 44 families. The *NSW BC Act* data set was downloaded from https://www.legislation.nsw.gov.au/#/view/act/2016/63/sch1
(2) The Australian national list of threatened plants listed under the *EPBC Act* is similarly comprised of assessments from before (79%) and after (21%) the full consideration of the IUCN Red List criteria. Of the IUCN-compliant assessments, 268 plant species (across 64 families) are extant and endemic to Australia (and hence represent a global assessment). The *EPBC Act* data set was downloaded from the Species Profiles and Threats Database (http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=flora; accessed 24/07/2017).
(3) The IUCN Red List of threatened flora contains some 12,102 species of plants which have been globally assessed as threatened (CR, EN or VU) under the IUCN Red List

criteria. The list covers 326 families of plants. The IUCN Red List data set was downloaded from the IUCN Red List website (http://www.iucnredlist.org/search; accessed 25/09/2017).

We considered only those listings which were global assessments using IUCN criteria, or their equivalents, and, after removing duplicates which were assessed under both Australian Acts, we compiled all assessment data (*NSW BC Act*, $n=104$; *EPBC Act,* $n=243$) into one list for threatened Australian plant species. For the 15 species assessed under both the *NSW BC Act* and the *EPBC Act* only the most recent assessment was included. Considering only global assessments meant that the data set was not confounded by the application of IUCN Red List criteria in regional assessments.

For each species with an IUCN-compliant assessment, we identified the criterion or criteria that determined its listing outcome (i.e. IUCN Criterion A, B, C, D, or E, Table 1). Criterion A is based on population size reduction; Criterion B on geographic range size; Criterion C on population size. Criterion D was broken up into two parts as IUCN sub-criterion D2 is based on spatial distribution information, while population data informs IUCN sub-criterion D (CR, EN) or D1 (VU). Lastly, Criterion E relates to quantitative estimates of extinction risk such as population viability analysis. The number of species listed under each criterion were tallied.

Potential threat status of unlisted NSW plants based on AOO and EOO thresholds

To determine how many currently unassessed flora species (including subspecies and varieties) in NSW met VU, EN or CR thresholds for restricted geographic range size (IUCN Criteria B1 and B2) we calculated their AOO and EOO as specified under the IUCN Red List guidelines (Table 1). Although other methods for calculating geographic range size have been advocated [e.g. alpha-hull (Burgman and Fox 2003); species distribution modelling (Syfert et al. 2014); incorporation of other geospatial data (Ocampo-Peñuela et al. 2016)] these differ from the standard IUCN method which is used as an initial basis for assessment under Criteria B1 and B2 and are beyond the scope of this study. AOO and EOO offer two complementary measures of geographic range: AOO approximates the likely resistance of the species to stochastic and deterministic threats and approximates population size, whereas EOO captures the overall geographic spread of known species occurrences (Gaston and Fuller 2009). EOO is measured using a minimum convex polygon (the smallest polygon in which no angle exceeds 180 degrees, and which contains all the sites of occurrence, IUCN 2017). AOO is measured by calculating the cumulative area of 2 km × 2 km grid cells occupied by the species across its range (IUCN 2017).

AOO and EOO estimates were calculated from cleaned herbarium occurrences for 4976 higher-plant (angiosperm and gymnosperm) and fern species occurring in NSW, including 779 species endemic to NSW and 4197 occurring in other states and territories. These 4976 species were chosen based on three criteria: (1) they were taxonomically valid across multiple sources, (2) they were native to Australia, and (3) they were not already listed as threatened under the *NSW BC Act*. As a basis for this analysis, we extracted a list of all plant taxa present in NSW based on occurrence records in the *Atlas of Living Australia* (ALA) portal in October 2017 (http://spatial.ala.org.au/webportal//; $n=16{,}501$ taxa). Records for 1980 (12%) of species in this preliminary list were not identified to species level and these were removed. We also removed all species not part of the major plant subclasses (*Cycadidae*, *Magnoliidae*, *Pinidae*) according to the ALA or the fern families

Table 1 The IUCN Red List criteria thresholds

Thresholds for IUCN Red List criteria						
Criteria			Critically Endangered	Endangered	Vulnerable	No thresholds met
(A)	Population size reduction		≥80% population reduction over the longer of 10 years or 3 generations			
(B)	Geographic range size	1. EOO	<100 km^2	<5000 km^2	$<20{,}000$ km^2	$>20{,}000$ km^2
		2. AOO	<10 km^2	<500 km^2	<2000 km^2	>2000 km^2
(C)	Small population size and decline		<250 Mature individuals			
(D)	Very small populations		<50 Mature individuals			

The Critically Endangered thresholds for all criteria were used for flagging species that would face increased extinction risk following further loss (referred to as serious and irreversible impacts (SAII)). While the geographic range criteria thresholds, extent of occurrence (EOO) and area of occupancy (AOO), for each threat category (Critically Endangered – Vulnerable) were used to assess non-listed species across Australia listed in the NSW Herbarium's PlantNET application (http://plantnet.rbgsyd.nsw.gov.au/; $n = 4763$; 29% of taxa removed). Note that we report the number and percentage of affected species in the original ALA download flagged for removal at each cleaning step, and that the same species may be affected by more than one flag (i.e. % removal does not necessarily add to 100).

To create a species list to meet our three criteria, we began by eliminating all species whose name in the ALA could not be matched to an accepted name appearing in both the Australian Plant Census (APC; $n = 4552$; 28% of species removed) and the NSW Herbarium's PlantNET application (http://plantnet.rbgsyd.nsw.gov.au/; 52% of species removed). From this list we removed species not native in NSW by merging with information on their naturalised status in the APC ($n = 9977$; 60% of species removed) and the introduced status on PlantNET ($n = 1663$; 10% of species removed). Finally, we eliminated all species which are currently listed as threatened under the *NSW BC Act* (http://www.environment.nsw.gov.au/committee/schedulesthreatenedspeciesconservationact.htm; ($n = 608$; 4% of species removed).

To assess geographic range (AOO and EOO) we downloaded raw occurrence data points associated with vouchered herbarium specimens ($n = 1{,}716{,}009$ records) for the 4976 species in our final dataset from the ALA. We used only vouchered herbarium specimens as this is the standard used by the NSW Threatened Species Scientific Committee who undertake assessments under the *NSW BC Act*. We thoroughly cleaned occurrences to prepare the data to an acceptable standard for comparative analysis. Specifically, we removed records which: (1) were collected prior to 1950 or missing a year of collection ($n = 332{,}654$; 19% of records), (2) did not have latitude and longitude coordinates ($n = 101{,}805$; 6% of records), (3) were of cultivated origin ($n = 27{,}062$; 2% of records), and (4) fell outside the terrestrial boundary of Australia ($n = 117{,}102$; 7% of records). Records collected pre-1950 (between 1770 and 1950) are likely to have less-precise location details, on average, than more recent collections. After cleaning, the final dataset contained 1,203,517 records for 4976 species with a median of 121 records per species and a range of 1–2536 records per species. There were 162 species (3%) with less than 10 cleaned occurrence records.

We calculated AOO and EOO from cleaned occurrence records in R (R Core Team 2013; see Supplementary Appendix 1 for AOO and EOO calculations for all taxa; R script available on request). Using these estimates, and the thresholds under IUCN Criterion B1 and B2 for threat categories, we assigned species to either potentially threatened (CR, EN, VU; Table 1) or 'No Threshold Met' groups.

Critically Endangered thresholds as flags for sensitivity to further habitat loss

In order to identify which currently listed threatened species in NSW would be potentially at risk of serious and irreversible impacts should they experience further declines in geographic range or population size, we assessed currently listed threatened species endemic to NSW (n = 342; see Supplementary Appendix 2 for full list of species and assessment data) against the IUCN Red List criteria thresholds and subcriteria for CR (Table 1). The nature of species extinction risk assessments according to the IUCN Red List Criteria is that species only qualify for a threat category (CR, EN or VU) if they meet both the criteria threshold (e.g. EOO < 100 km^2) and additional subcriteria (e.g. only one location, continuing decline) (Tables 1, 2), except for Criteria A and D where there are no subcriteria. As a result, some species may meet the threshold for a higher threat category in a criterion, but

Table 2 Definitions of IUCN Red List Subcriteria for criteria B and C and how and why they were modified and applied for a rapid precautionary assessment

Criteria	Subcriteria	Definition	Modified application	Justification
B	Severely fragmented OR Number of Locations	Populations are relatively isolated, unlikely to recolonise and too small to persist OR the species occurs in one location	Severe fragmentation was assumed Data Deficient. Number of locations was applied as defined with the threshold increased to three	Severe fragmentation is data intensive, requiring both long term dispersal distance averages and minimum viable population estimates. Number of locations was increased from one to three because: (1) a species with one location qualifies as Critically Endangered and should not be impacted; (2) if a species with two locations, lost one location, it would therefore qualify as Critically Endangered; three locations was therefore chosen as a precautionary threshold
B & C	Continuing decline	A recent, current or projected future decline, in number of mature individuals, populations, area, extent or quality of habitat, which is liable to continue unless measures are taken	Assumed	The context of severe and irreversible impact is that species are being assessed because of their presence in an area proposed for development or land clearing. It is reasonable to assume continuing decline (direct impacts on population and distribution, or indirect impacts on habitat) if the proposal is allowed. IUCN (2017) state that "Continuing declines at any rate can be used to qualify taxa under criteria B or C2. This is because taxa under consideration for criteria B and C are already characterized by restricted ranges or small population size."

Table 2 (continued)

Criteria	Subcriteria	Definition	Modified application	Justification
	Extreme fluctuations	Where population size or distribution area varies widely, rapidly and frequently, typically with a variation greater than one order of magnitude	Assumed if species had an ephemeral life history	Long-term population data is rare for individual threatened plant species. For this reason, species were grouped by life cycle. Having an ephemeral life cycle means species are more likely to experience extreme fluctuations and so where assumed to meet this subcriteria based on a precautionary approach
C	Mature individuals per population	The number of mature individuals in each population is ≤ 50	Applied as defined	Species with sufficient population data were assessed. Species with insufficient data were deemed Data Deficient for this criterion
	% of mature individuals in one population	90–100% of the mature is contained within a single population	Applied as defined	Species with sufficient population data were assessed. Species with insufficient data were deemed Data Deficient for this criterion

be listed in a lower threat category because they do not meet the associated subcriteria in that threat category.

The IUCN CR thresholds were chosen to indicate risk of SAII because it is reasonable to assume that the species meeting these thresholds are the group of species that are at the highest risk of extinction and will be the least likely to be able to tolerate further loss.

In order to assess species against the CR thresholds, we collated data on decline (Criterion A), geographic range (AOO, EOO) and number of locations (Criterion B), and population size (Criteria C and D), according to the IUCN Guidelines (2017). As population reduction often requires population estimates taken over three generations or at least 10 years, only limited relevant data were available (published either in a NSW Scientific Determination, Commonwealth Conservation Advice or in the scientific literature). Species already listed as CR under the *NSW BC Act* were not re-assessed (hence all species listed as CR under the *NSW BC Act* are also listed as SAII).

Geographic range size (AOO and EOO) estimates were taken from published sources (as above), or from the online Nichefinder Tool (http://www.nswthreatenedspecies.net/species_search.php; accessed 26 October 2017), which uses cleaned herbarium data to assess the EOO and AOO of species in Australia. Specifically, Nichefinder (1) uses records with preserved specimens, (2) excludes occurrences outside Australia, (3) excludes records missing latitude or longitude and (4) excludes records flagged as cultivated. Distinct from the unlisted species assessments, species with records pre-1950 are included. When geographic range size estimates were unavailable in Nichefinder, EOO and AOO were calculated from vouchered specimens records available in online databases: the Atlas of Living Australia (ALA; https://www.ala.org.au/; accessed 26 July 2017). The cleaning process for these datasets involved manually investigating outlying records (i.e. which had large effects on EOO), by comparing the point with written location descriptions. Records were then included (if the co-ordinates aligned with the location description), corrected (if the co-ordinates did not align with the description but the description was detailed enough to allow the relocation of the point) or excluded (if the co-ordinates were clearly wrong and the description was too vague to relocate). Close attention was paid to species that were near to the CR thresholds (i.e. EOO of 100 km^2 or AOO of 10 km^2; Table 1) to ensure correct assignment. Number of locations was calculated according to the IUCN Guidelines (2017), that is "a geographically or ecologically distinct area in which a single threatening event can rapidly affect all of the individuals present… location should be defined by considering the most serious plausible threat". Information on the most serious plausible threat was sought from published sources. If the most serious plausible threat to the species was not documented then it was derived from species' life history, ecology and habitat combined with most likely threats operating within the species range. Where this information was not available no estimate of locations was made. Population size was only used if available from published sources otherwise it was considered to be data deficient.

Geographic range, population and decline data were then assessed against the CR thresholds for each IUCN Red List criterion, and if a species met the threshold for one or more criteria it was deemed at risk of SAII (e.g. if a species had a population of 170 mature individuals it would fall below the CR threshold for Criterion C ($<$ 250 mature individuals) and be considered at risk of SAII). In addition, we compared the number of species that met *only* the CR criteria thresholds to the number that met the thresholds for the criteria *and* the subcriteria that could be addressed in this study (under Criteria B and C). The subcriteria were applied using a precautionary approach (e.g. all species with ephemeral life cycles over periods ranging up to two decades were assumed to potentially undergo extreme fluctuations; refer to Table 2 for details for each subcriterion). Data were collated for the subcriteria from the same sources as for the criteria, and if no data were available, and an accurate generalisation (e.g. based on life cycle) was not possible, the subcriterion was considered data deficient.

We added an additional criterion for inclusion into SAII: species with three or fewer locations would automatically be flagged as a species at risk of a SAII. We did this because, in the IUCN guidelines (2017), a location is defined as an area in which all individuals of a species may be impacted by a single threat, clearly illustrating the relationship between extinction risk and threatening processes. Given that the SAII provision in the *NSW BC Act* was intended to flag species for which any impact is likely to contribute significantly to the risk of the species becoming extinct, a change from three to two remaining sites for a species would often result in the species shifting to be below the CR threshold under IUCN Criterion B for AOO. This approach was precautionary to minimise the risk of extinctions occurring without a priori assessment of impacts on species in any development approval process.

The principles for assessing a species as potentially at risk of SAII in the *NSW BC Act* also include the possibility of flagging species if their losses cannot be effectively offset based on habitat irreplaceability and the inability of a species to respond to management (OEH 2017). Assessment according to this principle is on-going and as data on all flora species was unavailable, it is not included in this analysis.

Results

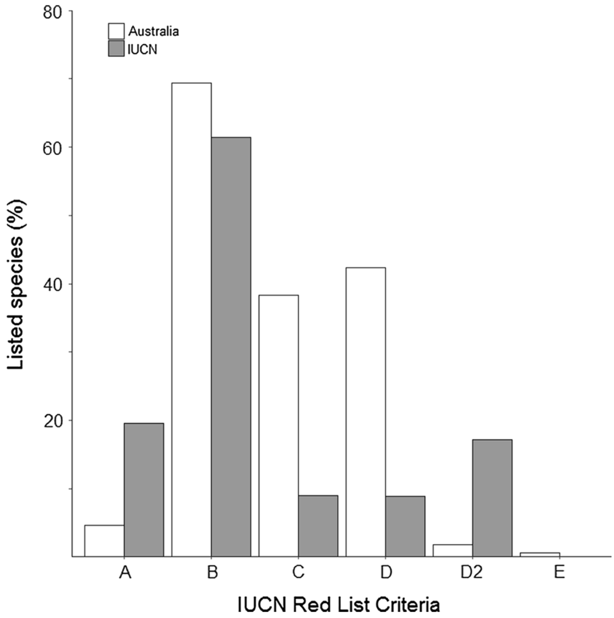
Relative contribution of IUCN Red List criteria to listings at national and global scales

Geographic range (Criterion B) was the most frequently used criterion for listing a plant species as threatened in both Australian and IUCN listings (61.4% of IUCN listings and 69.5% of Australian listings; Fig. 1). Of the other criteria, C and D were used much more often in Australian listings than in IUCN listings, while the converse was true of Criterion A and D2. IUCN criterion D2 was used much more often in global IUCN assessments than in Australia (17.2% compared to 1.7%, respectively). This likely reflects that the *EPBC Act* does not currently allow for listings under D2. Finally, Criterion E appears to be used rarely, if ever, globally and within Australia. Species may be listed under more than one criterion, however, the majority in both Australia (60%) and the IUCN (86%) listings were listed under a single criterion. Of the species that were listed under one or more criteria the most common combinations were Criteria B and C in Australia (47.5%) and Criteria B and A in IUCN listings (46.4%); these numbers reflect the first and second most common criteria for listing at each scale.

Potential threat status of unlisted NSW plants based on AOO and EOO thresholds

Of the 4976 currently unlisted NSW plant taxa assessed, 92 (2%) met AOO and/or EOO thresholds for CR under Criteria B of the IUCN Red List Guidelines (Fig. 2). In addition, 2711 (55%) met the EOO and/or AOO thresholds for EN, and 1756 (35%) for VU. For 695 species, both AOO and EOO were assigned to the same threat category, while for 4236 species, AOO met the thresholds of a higher threat category than EOO and

Fig. 1 Percentage of globally-assessed plant species listed as threatened under each IUCN Red List criterion within Australia (n = 347) and IUCN (n = 12,102). Species can be listed under more than one criterion



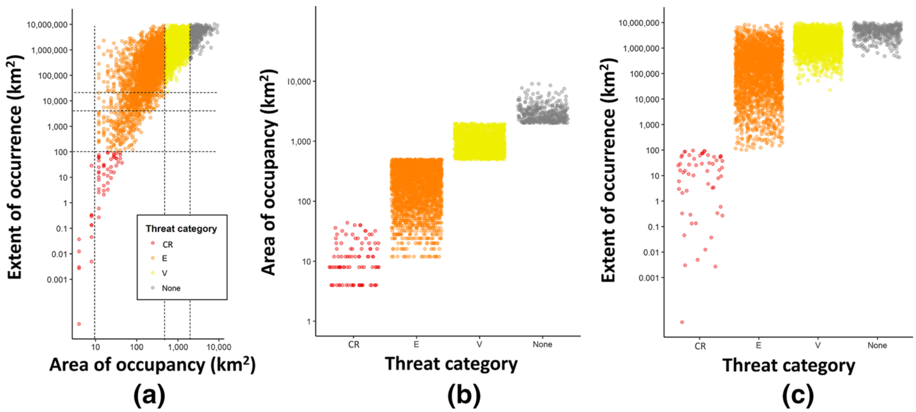


Fig. 2 Geographic range sizes calculated from IUCN AOO and EOO guidelines for 4976 NSW plant species which are yet to have a full extinction risk assessment. Colours represent the highest threat category species qualified for based on either AOO or EOO. The dotted lines in (a) correspond to the AOO and EOO thresholds for CR, EN and VU under IUCN Red List Criteria

for 45 species EOO met a higher threat category than AOO. Despite only accounting for 16% of the species assessed, all 779 NSW-endemic species met the thresholds for threatened under Criterion B. Furthermore, endemic species accounted for the majority (82%, 75 species) of plants assessed as meeting the geographic range thresholds for CR. Endemic species also accounted for 25% of those species meeting the EN thresholds with a total of 683 species, while only 21 (1%) of the species meeting the VU thresholds were endemic. The remaining 417 taxa (8%) have AOO and EOO estimates which exceed Criteria B thresholds. Occurrence records for all 92 taxa meeting thresholds for CR were re-examined to detect potential outliers.

Critically Endangered thresholds as flags for sensitivity to further habitat loss

Of the 342 threatened plant species endemic to NSW, which were assessed against the IUCN Red List criteria thresholds (and subcriteria) for Critically Endangered (Table 1, Table 2), 183 species were identified as meeting the thresholds for one or more criteria (without consideration of the subcriteria) (Fig. 3). When the subcriteria were also included (Table 2), a slightly smaller number of 167 species met the IUCN Red List criteria for CR. The assumption of continuing decline occurring was made on the basis of widespread and ongoing threats to species and biodiversity in general. The most commonly met IUCN Red List criterion was Criterion B (restricted geographic range), where 46.2% of all species met criterion thresholds (vs. 43.6% with thresholds and subcriteria). Criterion C (small population size) was met less frequently (18.7% with only criterion thresholds), and there was little difference when subcriteria were included (16.7% with criterion thresholds and subcriteria).

Of the species that met the IUCN criteria CR thresholds without subcriteria, 42.1% met the thresholds of two or more criteria. The remainder, 57.9% of the species, met only one criterion. Five times more species met Criterion B alone (24.1%) than the next most frequently met criterion, population size (5.2%) (Criterion C). Very few species were flagged by either Criterion D (1.2%) or Criterion A (0.9%) alone.

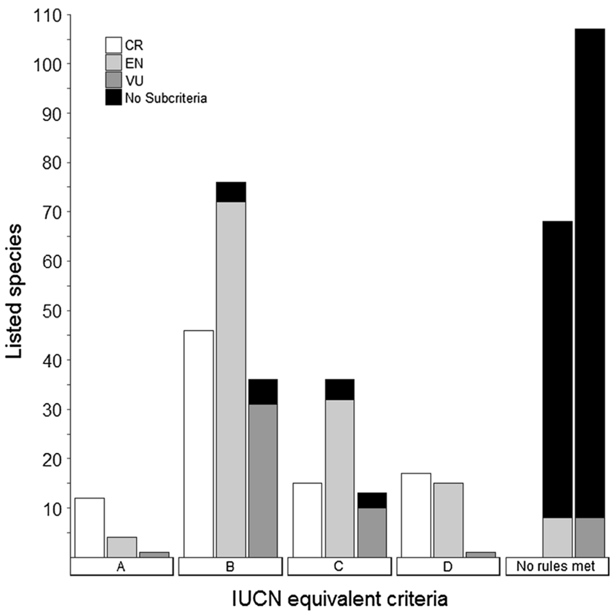


Fig. 3 The number of listed threatened NSW endemic plant species (n = 342) in each threat category (Critically Endangered (CR), Endangered (EN) and Vulnerable (VU)) that met each IUCN thresholds for Critically Endangered criteria A, B, C and D and those that met no criteria (with or without consideration of subcriteria). Species can meet more than one criterion

Discussion

This study illustrates the utility of rapid assessments for informing conservation policy development and prioritising species for formal extinction risk assessment. We have shown that IUCN geographic range size is the primary foundation for listing of threatened plant species in Australia. Using a rapid assessment of vouchered herbarium specimens to quantify the proportion of unassessed flora in the state of NSW which would meet IUCN geographic range size thresholds for CR, EN and VU, we found most species, and all NSW endemics, met at least the Vulnerable thresholds. More importantly, 92 currently unlisted plant species (75 of which are endemic to NSW) meet the geographic range size thresholds for CR and can now be prioritised for further, more formal assessment of threats and population decline. Objectively identifying these small-ranged species which meet CR thresholds and progressing these to full assessment is crucial for expanding the geographic and taxonomic breadth of taxa which are listed for protection in NSW. Restricted range size was also an important basis for identifying species with the potential for SAII under the *NSW BC Act*.

Relative contribution of IUCN Red List criteria to listings at state, national and global scales

Geographic range size (IUCN Criterion B) was the most frequently used criterion for listing Australian plants as threatened. This result is consistent with trends in IUCN listings of plant species worldwide (e.g. Sweden, Gärdenfors et al. 2001; Italy, Foggi et al. 2015; and southern Africa, Golding 2004). Geographic range is important to the listing of many taxa, not only plants—approximately half of the species on the IUCN Red List were listed on the basis of *only* geographic range criteria (Gaston and Fuller 2009). Extinction risk is increased in species with small range sizes because there is a greater likelihood that all populations can be affected by a single threat.

A key driver of the prevalence of listings based on geographic range is data availability (Golding 2004). This is particularly the case for plants where data are often primarily from herbarium records which commonly include location, but less commonly include population data. Herbarium and other incidental records are increasingly including accurate georeferenced location data improving the ability to identify species ranges (Gärdenfors et al. 2001; Golding 2004; Foggi et al. 2015). In contrast, population data are often reported in relative terms (e.g. abundant, common, rare), making it difficult to extrapolate to population size estimates. Moreover, occurrence records may refer to single plants or thousands of individuals (Golding 2004). Nevertheless, the use of geographic range data requires careful preparation and the application of a priori rule-sets. For example, we disregarded 512,412 records of geographic range (occurrence points) which did not meet cleaning procedures prior to assessing AOO and EOO in unlisted NSW plants. We acknowledge that a proportion of geo-references may be incorrect or misleading (Wieczorek et al. 2004), however the taxonomic breadth and ecological knowledge embedded in digitised vouchered collection records has become an accepted and essential part of modern biodiversity analysis (Graham et al. 2004; Brummitt et al. 2015b).

Methods for calculating geographic range used by IUCN continue to be the subject of debate with common problems including methodological discrepancies, misinterpretations of EOO and AOO and scaling (Gaston and Fuller 2009; Collen et al. 2016; Keith et al. 2017; Akçakaya et al. 2018). The most common errors in georeferencing tend to be locality generalisations, resulting in outliers, and which may artificially inflate EOO or AOO (Wieczorek et al. 2004). Hence, calculated geographic ranges are likely to be overestimated rather than underestimated, (Wieczorek et al. 2004). In this study we used only vouchered specimens (cf. unvouchered or human observations), and acknowledge that this more precautionary approach may have decreased estimates of EOO and AOO; hence estimates of EOO and AOO in this study are considered to be lower estimates, a trade off with increasing the risk of overestimation. We closely scrutinised outlying/range-edge records in this study because of their potential to significantly impact EOO (erroneous records within the established bounds of EOO typically cause only small changes to AOO). In addition, a focus on only species with restricted geographic ranges while a useful starting point, may see biases in threatened species listings against species with high rates of decline or low population numbers, independent of their range size. We note that a range of alternate techniques have been proposed for assessing geographic range size of species, including the use of additional geospatial data and species distribution modelling, however we deliberately adhered to the use of IUCN guidelines for assessing AOO and EOO in this study as they represent the current global standard methodology.

Trends in the listing of Australian plant species on the basis of population data differed from listings under the IUCN Red List. Our analysis shows that a much smaller proportion of plants were listed as threatened under Australian legislation due to rapid population decline, relative to IUCN listings (Criterion A; 4.6% of Australian plants, compared to 19.6% of IUCN-listed plants). In contrast, a relatively high number of plant species were listed according to small population size (Criterion C; 38.3% for Australia, 8.9% for IUCN; Criterion D, 42.4% for Australia, 8.9% for IUCN).

The relative scarcity of listings under Criterion A is surprising given Australia's relatively recent European colonisation and associated environmental impact (Kirkpatrick 1999) and a recent history of rapid and extensive land clearing (Evans 2016). The scarcity of rigorous, multi-year population monitoring datasets or a reluctance to use other metrics of change permitted in Criterion A (e.g. decline in EOO/AOO or habitat quality) may contribute to the low frequency of decline-related listings in Australia. A similar pattern exists for Australian birds, where Criterion A is used one-third less often in Australia than in the IUCN Red List (Garnett et al. 2011) (Supplementary Appendix 3). Bird assessments in Australia typically focus on Criterion D and D2. However, in Australian mammal listings, Criterion A is used more frequently than in IUCN listings; indeed, it is the most commonly used criterion (Woinarski et al. 2014) (Supplementary Appendix 3). Assessments of plants in Australia focus instead on the use of population size data in Criteria C and D. This may be attributed to a higher availability of population size estimates stemming from single population estimates, rather than repeat monitoring.

Potential threat status of unlisted NSW plants based on AOO and EOO thresholds

Our analysis shows that there is a large potential pool of NSW plant species which meet IUCN AOO and EOO thresholds for threatened status which are currently afforded limited protection under threatened species legislation (*NSW BC Act*). We acknowledge that our analysis forms only the preliminary step in an full IUCN assessment of extinction risk under Criterion B. To complete a full assessment, all subcriteria need to be quantified (e.g. evidence of decline, threats, severe fragmentation, restricted number of locations, extreme fluctuations). Our analysis will help to accelerate the process of threat assessments by demonstrating how large numbers of species can be rapidly considered and prioritised. This has been identified as a crucial part of meeting the Goals of the Global Strategy for Plant Conservation (Bachman et al. 2018).

A related limitation of the geographic range size calculations in this study is that while the data cleaning procedures we have addressed false-presences, they may underestimate geographic range of poorly collected species. The estimates in this study (of EOO and AOO, based only on verified records) are considered minimum estimates of the true geographic range (IUCN 2017) and as the role of rapid assessment is to act as a guide for where full assessments and conservation efforts may best be prioritised, therefore, a precautionary approach is warranted. Full IUCN Red List assessment would be required for any IUCN or legislative listing and this will address survey adequacy.

Our systematic examination of AOO and EOO across most native higher-plant and fern species in NSW will allow for the prioritisation of species which should then be considered for a full IUCN assessment, a prerequisite to the legal protection of threatened species. In particular, the 92 species which met thresholds for CR under Criteria B1 and B2 are obvious targets for formal assessment of their threat status under the *NSW BC Act*. Additional analysis could be conducted to further prioritise species (especially those in the larger groups which meet the EOO/AOO thresholds for EN and VU) based on elements such as where species occur (urban fringe vs. conservation reserves). A benefit of this method is that it utilises widely available data directly applicable to the IUCN Red List assessment criteria. Formal assessment on a species-by-species basis involves a time-consuming process of data collation, verification, analysis and discussion (e.g. 17 workshops with 300 experts were required to formally assess extinction risk of the world's sharks and rays; Dulvy et al. 2014). This level of expert engagement may prohibit the systematic assessment of large numbers of species within a taxonomic group, such as the NSW flora.

Similar applications of geographic range data for rapid preliminary assessments have proven successful with Brummitt et al. (2008) reporting a 74% agreement between the preliminary and final assessments of species within the plant family Cupressaceae. Likewise, a study testing the effectiveness of using coarse-scale distribution data to predict extinction risk in bulbous monocotyledons achieved 91% classification accuracy (Darrah et al. 2017). While these applications differ in their execution and goals, they highlight that geographic data alone can provide accurate rapid assessments of extinction risk. That AOO consistently resulted in species meeting a higher threat category than EOO is not entirely unexpected in a study area such as NSW with high levels of land clearing and habitat fragmentation resulting in geographically dispersed records. However, it could also be a consequence of under sampling of these species, emphasising the need for species to be thoroughly assessed once they are flagged under this type of rapid assessment.

Species are listed in NSW via nomination (typically from members of the public) and formal assessment by the NSW Threatened Species Scientific Committee against Clauses in the *NSW BC Act* which are aligned to the IUCN Red List criteria. The nomination process, whilst rigorous and considered, has potentially led to bias in the types of organisms which are being protected in NSW. This is problematic because formally listed threatened species are subject to statutory requirements for their protection (e.g. via the NSW Biodiversity Offsets Scheme) and therefore will typically gain more funding for management and baseline research (e.g. via the NSW Saving our Species program). However, arresting biodiversity losses is not only about protection of currently listed threatened species, and planning and conservation actions should encompass a broad suite of species to be representative and comprehensive—an outcome more likely using a systematic approach, such as broadscale rapid assessment, to prioritise comprehensive assessment.

Critically Endangered thresholds as flags for sensitivity to further loss

We found that applying the IUCN Red List criteria thresholds for CR alone resulted in 53.5% of threatened species being flagged as highly sensitive to further decline (what is termed serious and irreversible impact (SAII) in the *NSW BC Act*). A number of species currently listed as EN or VU in the *NSW BC Act* were flagged as SAII as they met either the IUCN CR criteria thresholds (183 species) or both the IUCN CR criteria *and* subcriteria (167 species). This suggests that a large number of threatened species listings on the *NSW BC Act* may need urgent review. Many listings in the *NSW BC Act* were made before 2005, prior to which the legislation did not provide for the listing of CR species (only EN and VU categories existed at that time).

The number of threatened species sensitive to further loss was comparable with (48.8%) and without IUCN subcriteria (53.5%). One explanation for this result is the precautionary approach that was taken in assessments. All species were assumed to have continuing decline in Criteria B and C, as this assessment was undertaken within the context of proposed loss (including habitat loss). While a biodiversity offsetting mechanism may be used to potentially mitigate the loss of habitat, usually losses occur immediately and offsetting gains are realised at a later time (Gibbons and Lindenmayer 2007; Maron et al. 2012), meaning that extinction risk will increase, at least in the short to medium term, as a result of the loss.

Those species sensitive to further loss, facing a high or very high risk of extinction in the wild, require effective protection and conservation management actions to prevent them from becoming CR or Extinct. The majority of species flagged as SAII have some parts of their distributions that are not protected in formal reserves, while some 54 species (29.5% of total species flagged) have no records within protected areas. Only 17 of the species flagged (9.3% of flagged species) occur wholly within reserve tenure. Of the species on reserved tenure, most have only 1 or 2 locations and, or populations <250 or <50 mature individuals, and therefore are at increased risk from stochastic disturbance events or threats within the reserves.

Additionally, this study shows that identifying species according to CR criteria thresholds has only limited overestimation in the absence of the much stricter, more data-intensive subcriteria. Most species met IUCN Red List Criterion B, while the inclusion of the other Criteria (A, C and D) captured an additional 7.3% of species.

Conclusion and applications

Our intention in this work was to highlight the utility of rapid assessments and precautionary approaches in conservation prioritisation. Precautionary approaches are fundamentally about acting to prevent or reduce the impacts of activities that would result in increased extinction risk. Reactive approaches to conservation, focussing only on those species most at risk of extinction, do not address the processes underlying widespread continuing declines in biodiversity worldwide (Butchart et al. 2010; Ceballos et al. 2017). In short, a more effective approach to conservation in terms of likelihood of species recovery and financial investment as well as regulatory measures, would be to prevent species from becoming CR in the first place.

The vast number of species yet to be assessed for extinction risk combined with the limited resources available for such work necessitate rapid assessments as a first step toward identifying where conservation efforts should be prioritised. By taking a precautionary approach to these rapid assessments, utilising verifiable data (such as cleaned and vouchered specimens) we can establish, based on a minimum known range, which species are more likely to meet IUCN thresholds and therefore should be prioritised for full assessment. The 92 unlisted species flagged in this study as having geographic range under the CR thresholds serve as the obvious start point for further investigation. The rapid assessment used to flag listed species most sensitive to decline (SAII species) aims to capture species currently listed as EN and VU that face significant increases in extinction risk should further losses occur. These species should, therefore, be afforded the highest protection under regulatory frameworks. Utilising these two rapid assessment methodologies together allows for a holistic approach to the identification and prioritisation of threatened species that is proactive and preventative. While still built around risk categories, this study attempts to remedy the focus on CR species by considering the increased extinction risk (and therefore increased recovery costs and reduced likelihood of success) incurred by permitting future loss of EN and VU species.

The rapid assessment methodology presented here, using IUCN Red List Criteria CR criteria thresholds only and/or focussing on geographic range size, may be usefully applied to flag heightened extinction risk in other jurisdictions, particularly those with limited resources available for conservation assessment. This study provides evidence that the use of the geographic range criteria (Criterion B) alone is a useful tool to identify the majority of at-risk plant species, but care should be taken not to ignore other risk elements. This method is not intended to be a substitute for listing species as threatened, but rather a method for highlighting those species which there may be an increase in extinction risk if they undergo further declines. Through these approaches we are aiming for proactive conservation, rather than the "fire-fighting" which is characteristic of short term thinking and great optimism about the future (as described by Wilson et al. 2011). If we are to effectively curb the impending wave of extinctions widely predicted, rapid assessments and effective, proactive prioritisation will be crucial.

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