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Threat syndromes and conservation of the Australian flora

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ABSTRACT

The status of the Australian flora was reviewed by compiling published information on all critically endangered and endangered species listed federally in 2004. Threatening processes were categorised and their contributions to past, present and future declines were assessed. The information was cross-referenced against State agency information and field knowledge. Land clearance for agriculture (grazing and cropping) and urbanization have been the primary causes of range contractions and habitat loss in the past, responsible for the current status of the majority of threatened Australian plants. In the future, land clearance will remain important but new issues are emerging. Many species are now at risk from demographic and environmental uncertainty alone. Threats growing in importance include disease, salinity, invasive species and changed disturbance regimes. Many species are subject to common, landscape-level threats. A key issue to emerge from our analysis is that most species are threatened by a number of interacting factors – threat syndromes. Several future risks may be mitigated effectively by simple, low-cost changes in policy, such as more stringent controls on land clearance, strategic fire management, and firmer control on the importation of plant species. Other factors will require greater effort and new strategies to mitigate, including social and legal initiatives in urban landscapes and broad strategies for pathogens, climate change and other landscape-level processes.

1. Introduction

Many government agencies use lists of threatened species to allocate recovery resources, design reserve systems, constrain development and report on the state of the environment (Possingham et al., 2002a). Threatened species lists are an important part of decisions about conservation priorities (Lamoreux et al., 2003).

Leigh et al. (1981) compiled and subsequently revised lists of threatened Australian plants (Leigh et al., 1984; Leigh and Briggs, 1992; Briggs and Leigh, 1988, 1996). In several compilations, the most recent in 1996, they included a table summarizing the causes of past, present and future threats to the Australian flora. This table was particularly useful because it provided a continental-scale intuitive overview of the processes affecting the conservation status of numerous vascular plant species. While all lists of threatened species are incomplete and uncertain, Leigh et al.'s summaries represent a substantial sample of species at the threatened end of the conservation spectrum because conservation status reflects the relative likelihood of extinction.

The Australia federal government took up the role of maintaining and publishing the list of threatened Australian plants in 1996. The classification system underpinning the

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federal list is based broadly on the Red List system devised by the International Union for the Conservation of Nature and Natural Resources (IUCN, 2001). In the Red-listing process, species are assigned to categories including extinct, extinct in the wild, critically endangered, endangered, vulnerable, and near threatened.

Effective conservation involves the identification of the causes of environmental change, and the implementation of practices to manage those changes (Caughley and Gunn, 1996). A threatening process is one that may detrimentally affect the survival, abundance, distribution or potential for evolutionary development of a native species or ecological community. The notion of characterizing and managing threatening processes has been a focus for conservation biology for some time (Falk, 1990; Bradstock et al., 1995), and the Australian Federal Government's Environment Protection and Biodiversity Conservation Act (EPBC Act, 1999) makes provision for nominating threatening processes. Threatening pro-

Table 1 – Definitions of threats and threatening processes

Agriculture edge effects: Including most of the local processes found in road/rail verge environments, but with fewer road maintenance and vehicle disturbance effects. Herbicide and fertiliser applications and altered drainage are prevalent.

Clearing for agriculture: Including broad scale clearing for crops and pasture improvement, draining swamps and wetlands (excludes rural residential subdivision, which is included under urban).

Collection/harvesting: Including collecting specimens by rare plant enthusiasts and ornamental plant traders, moss removal, scrub worm collection, collection of fruit for bush food, and root suckers for propagation, seed collection for horticulture.

Extreme environment: Flooding, drought, drought following fire, extreme fires that are a consequence of extended drought.

Feral grazing: Rabbits, goats, pigs, cattle, camels etc, including trampling by feral animals and damage caused by rabbit warrens and pig wallows. Includes grazing by limicid slugs and other introduced invertebrates.

Fire: Changes in components of fire regimes, including season, extent, intensity, or frequency, inhibiting regeneration from seed or by vegetative reproduction. Generally, inappropriate fire regimes lead to the competitive disadvantage of the threatened species against local and introduced species, or represent a future threat if fire recurs before plants are mature and seed is produced (in obligate seeders; e.g., *Persoonia micranthera*).

Forestry: Plantation establishment, native forest harvesting and silviculture, roading for forest management.

Fragmentation: Populations reduced to a few relatively isolated subpopulations between which dispersal is unlikely (e.g., *Prostanthera eurybioides, Tetratheca gunnii*), excluding cases of natural metapopulations (e.g., *Leucopogon gnaphalioides*).

Hydrology: Changed stream flow conditions, altered site characteristics affecting ground water discharge or recharge, dams and weirs, timing and extent of seasonal flooding.

Lack of supportive habitat: Supportive habitat includes co-occurring plants, fungi, animals that provide the niche requirements necessary for long-term survival of the species in question.

Low numbers: Few (generally <250) reproductively mature individuals, sometimes associated with symptoms of genetic effects including low seed set (e.g., *Acacia insolita* subsp. *recurva*) and susceptibility to insect attack (e.g., *Acacia enterocarpa*), making the species susceptible to demographic and environmental stochasticity.

Mining: Including mine site development, gravel extraction, exploration, roading, peat mining.

Narrow habitat: Refers to species restricted to a type of habitat that has limited geographic extent (the area of potential occupancy is small). e.g., *Isoglossa eranthemoides* is restricted to lowland subtropical rainforest on volcanic soils in complex notophyll vine forest.

Native grazing: Includes herbivory of leaves, roots, seeds and whole plants by kangaroos, rats, wombats, slugs, snails, insects (locusts) and other species.

Pollution: Including contaminants from farms (herbicides and pesticides) that enter theair, streams and rivers affecting plants off-site, contaminants in catchments arising from sewage, sediment and nutrients from urban gardens affecting native species (e.g., *Microstrobos fitzgeraldii*), spills, point source and diffuse contamination from industries and transport.

Recreation: Off-road vehicles, bush access tracks, 4-wheel-drive tracks, trail bike riding.

Road/rail verge conditions: This term summarises a range of threats to which plants remaining in these remnants are exposed. They include disturbance during road/rail and fire break maintenance, accidental clearing during road maintenance and farming, frequent fires, incremental road widening, weeds, herbicides to control weeds, reduced fire probability, runoff of herbicides and nutrients from adjacent areas, herbicide and pesticide spray drift, grazing by feral animals and domestic stock, slashing, mowing, construction of drainage channels, power line and optical cable installation and maintenance, gravel extraction and storage for roadworks, mistletoe, disease, grading road reserves, altered drainage, constructing drainage channels (e.g. *Banksia cuneata*).

Roads: Habitat loss resulting from creation of new roads. This term differs from road verge conditions (above) in representing the construction of new roads, rather than summarizing conditions experienced by plants in remnant verge environments.

Small range: The extent of occurrence of a species whose longest axis is <100 km. The distance of 100 km is relatively large; many species have ranges considerably smaller than this. However, this scale is important because it is approximately the scale at which landscape processes such as fire and climate change may be managed.

Trampling: Tourist/recreation foot traffic, orienteering, absailing, camping, hunting, walk trail construction and maintenance. These activities lead to trampling of plants, soil compaction, erosion, and introduction of disease.

Urban and coastal development: The consequences of land development for urban expansion, private and public land development within the limits of existing cities, coastal development.

Weeds/competition: Includes invasive alien species (defined as species originating outside Australia), native Australian species outside their natural range, and local native species that have an unusual competitive advantage against threatened species in modified habitat on road and railway verges and in other modified or disturbed habitat, or under altered climatic or fire conditions.

Definitions are omitted for threats in Figs. 1–5 whose title makes the definition self-evident.

Table 2 – Threats to the endangered and critically endangered Australian flora identified in the federal government list (Department of Environment and Heritage, 2004) and other relevant publications

Demographic factors
Few populations, small range, narrow habitat, low numbers
Agriculture and grazing
Land clearing, domestic grazing, feral grazing, native grazing, agricultural edge effects
Other human activities
Road/rail verges, new road construction, urban and coastal development, mining, forestry, recreation, dams, trampling, collecting, mowing, bush rock removal, rubbish dumping, vehicle damage, pollution, herbicides, fire wood collection
Landscape factors
Weeds, fire, fragmentation, disease, salinity, hydrology, flooding, lack of disturbance, changed disturbance patterns, pollinator disruption, limited sexual reproduction, lack of habitat support, extreme environmental conditions

cesses have been identified in many Australian biomes (temperate woodlands, Yates and Hobbs, 1997; riparian and groundwater ecosystems, Boulton et al., 2003; rangelands, Woinarski, 2001). In most assessments of the Australian flora, land clearing, salinity, disease and urban development are prominent. In other places around the world, land clearance is usually the most serious threat to plants, but other threats such as pollution and over-harvesting are also serious (Wilcove et al., 1998). In the face of the enormous number of species that require attention, it will be effective to focus conservation efforts on broad processes that cause population decline (Caughley and Gunn, 1996).

Butchart et al. (2004) devised a robust measure of change over time in the status of threatened species, based on published lists. The method reports the proportion of genuine changes, that is, the number of changes in classification made up of recent genuine improvement or deterioration in status in the period since the previous assessment. The purpose of this paper is to revisit the list of threatened Australian plants and revise the table of past, present and future threats. We intend to create a benchmark for assessing the conservation status of the Australian flora as a whole, so that in several years, the list may again be evaluated and the number of genuine changes in status documented, so that the process of tracking changes in conservation status of the Australian flora over time may begin. The benchmark that we establish will be based on the most important threats that influence the chances of persistence of each listed species.

2. Methods

The list of critically endangered and endangered species published by the Australian Federal Department of Environment and Heritage in November 2004 contained 524 plant species (Department of Environment and Heritage, 2004). This list differs in part from the latest State lists. All such lists are uncertain, a consequence of observational errors, changes in attitudes to uncertainty and changes in taxonomy (Burgman, 2002). Nevertheless, it contains sufficient taxa for the purposes of the present analysis and represents a sample of relatively highly threatened plant species; the exact composition of the list is not critical for inferring broad threats. The list was accompanied by background information for most species. We used this information and supplemented it with accounts of the biology, distribution, abundance and changes over time of the species documented in the literature. The information for each species was compiled in a spread sheet under headings including names and synonyms, habit, habitat, distribution, mode of dispersal, longevity, population and habitat vulnerability, and past, present and future threats. We were unable to find any information on the reasons for listing, or the past, present or future threats for 100 of the 524 species.

The information compiled in this process from the web and in published sources was reviewed. We classified past threats as the processes primarily responsible for the species being in its current perilous state. Current and future threats were defined as the processes now operating that influence the chances of the persistence of species.

For each threat, we classified its importance in relation to each species in two classes; (1) important process, perhaps not affecting most populations or most individuals, and (2) dominant process, influencing most or all of the populations. The threats fell into four broad classes; demographic factors,

Table 3 – Past and present/future threats for Grevillea caleyi, based on Auld and Denham (2001), Regan et al. (2003), Department of Environment and Heritage (2004), Department of Environment and Conservation (2004)

Threat	Past threats	Present/future threats
Feral grazing (seedlings)	–	1
Seed predation	–	1
Changed fire regime	1	1
Urban development	2	2
Small range	2	2
Low numbers	–	1
Few populations	1	2
Road verge environment	–	1
Fragmentation	–	1

Scores represent (2) dominant processes, influencing most or all of the populations, and (1) important processes, perhaps not affecting most populations or most individuals.

agriculture and grazing, other human activities and landscape factors. Within each broad class, we identified several specific threatening processes.

One of us (CD) compiled the data. To eliminate as much linguistic uncertainty as possible, and to develop an estimate of the repeatability of the assessments, another of us (MB) scored the importance of each threatening process against each species as 0, 1 or 2. Another (DW) scored 50 of the 424 assessed species independently, and compared the results with those of MB. They revised the definitions and interpretations of threats and scores. This resulted in formal definitions of threats and threatening processes that were not considered to be self-evident (Table 1). DW then scored independently an additional 150 species. Differences were recorded and the bases for differences reconciled in a further revision of definitions. The files of scores were then sent to two regional flora conservation experts (DK, SH) who revised the judgments and added or changed values for threats to the taxa that they were familiar with. We then compiled these scores under individual threats within each of the four broad threat classes.

Some threatening processes interact with the biology of many species to generate sets of species that are susceptible to the same set of conditions. We termed these complex interactions 'threat syndromes' and looked for sets of threatening processes that affected relatively large sets of species. The objective is to identify overlaps among threats that may provide a basis for managers to deal with more than one threatening process, improving efficiency. To do this, we calculated Bray-Curtis dissimilarity between threatening processes,

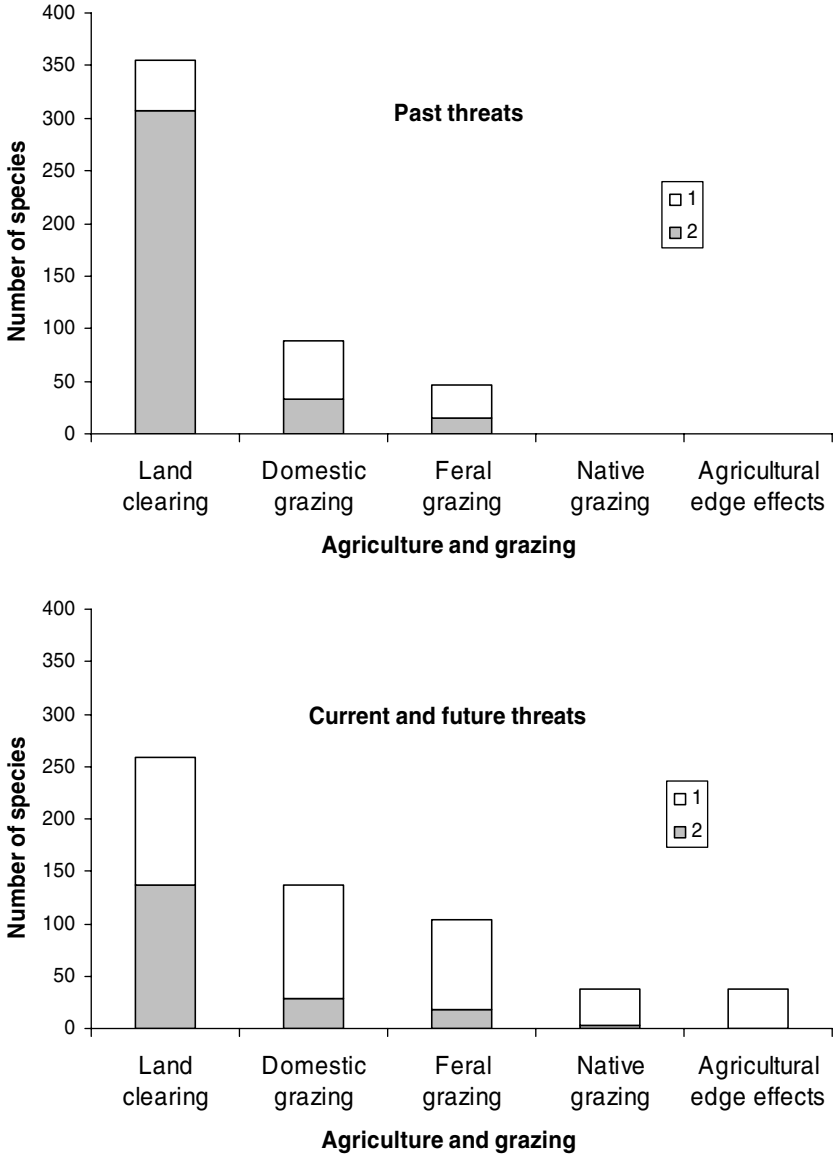

Fig. 1 – The number of species severely (2) and substantially (1) threatened by agriculture and grazing, including land clearing, domestic grazing, feral grazing, native grazing, agricultural edge effects.

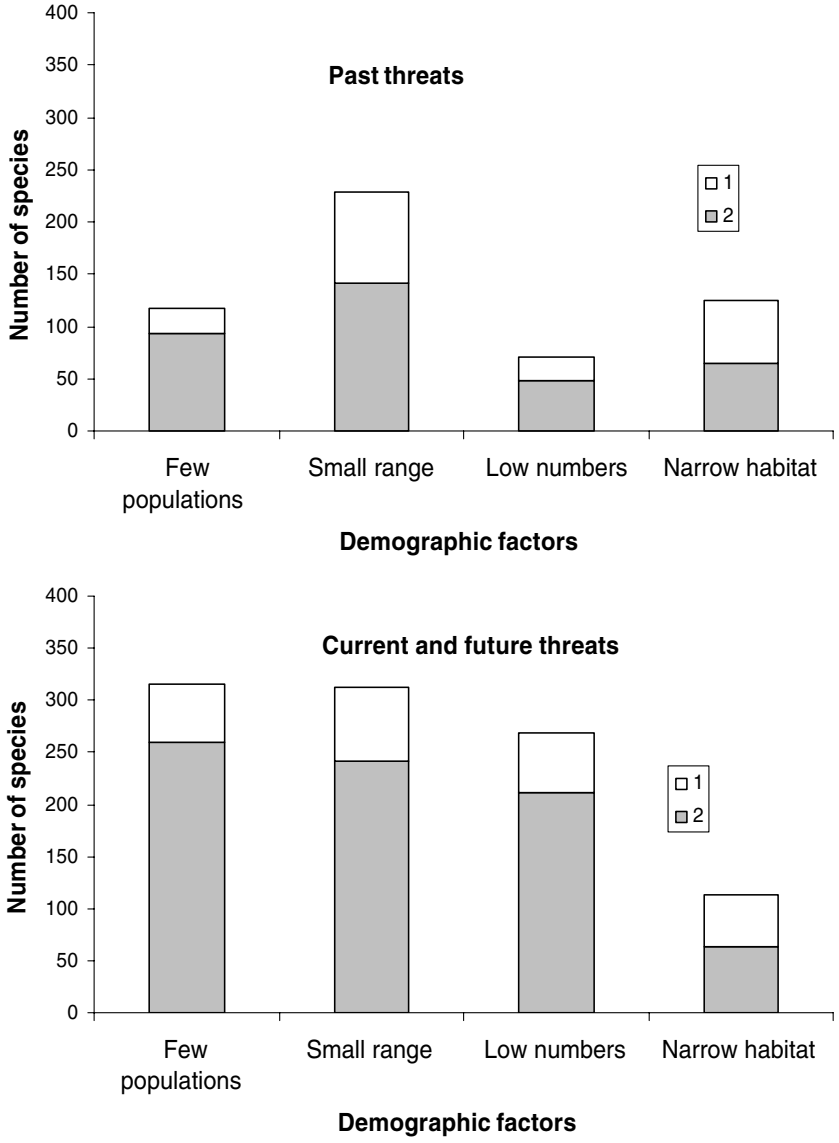

Fig. 2 – The number of species severely (2) and substantially (1) threatened by demographic factors including few populations, small range, narrow habitat, low numbers.

based on the scores (0, 1 or 2) assigned to each process affecting each species. The distance matrix was ordinated using Nonmetric Multi-Dimensional Scaling but stress was high (0.23 in two dimensions and 0.19 in three dimensions) and the result was uninformative. The same matrix was clustered (using UPGMA) to identify sets of threats affecting the species. This analysis generated several clearly delineated groups. These results were used, together with inspection of the raw data and our collective expert judgement, to identify four threat syndromes.

3. Results

The evaluation of the data set and scoring of threats led to explicit definitions for 23 threatening processes (Table 1). After the final iteration, the differences in interpretation between the assessments made by DW and MB were less than 10% of the total number of 1 and 2 scores. Table 2 lists the threats identified in the data supporting listing decisions posted on the federal government web site, and in available publications for the same species. Many of these threats have been identified previously (Falk, 1990; Briggs and Leigh, 1996; Caughley and Gunn, 1996; Yates and Hobbs, 1997; Woinarski, 2001; Sattler et al., 2002; Boulton et al., 2003). For example, *Grevillea caleyi* is a shrub restricted to a few populations in a narrow range in the north-eastern suburbs of Sydney. From the information collated for this study, it has a narrow geographic range but urban expansion and associated processes have increased the risk that the species will be lost. Table 3 lists the past and present/future threats identified from the supporting documentation from the federal list and from other publications that explore the ecology and management of the species.

The federal government maintains a list of 'key threatening processes' defined as processes that threaten or may threaten 'the survival, abundance or evolutionary development of a native species or ecological community' (Department of Environment and Heritage, 2004). A process can be listed if it adversely affects two or more listed threatened species. In 2004, the federal list included the following processes relevant to terrestrial vegetation: grazing and land degradation by feral goats, rabbits and pigs (classified in Table 1 here as feral grazing), dieback caused by *Phytophthora cinnamomi* (Table 1, disease), loss of climatic habitat caused by anthropogenic emissions of greenhouse gases, and reduction in the biodiversity of Australian flora due to the imported red fire ant, *Solenopsis invicta*. These threats are more narrowly defined than those in Table 1. One omission stands out from Table 1. We found no references to loss of climatic habitat among the threat assessments for critically endangered or endangered flora.

The processes that affected the Australian flora in the past were dominated by land clearance for agriculture and urban development (Fig. 1). In the future, land clearance will remain an important threat to Australian plants, but grazing pressures from domestic, feral and native species are expected to become more important, as are the edge effects of farms and farm activities. The importance of demographic factors is expected to increase substantially in the future (Fig. 2). In large part, this change is a consequence of the persistence of many species in conservation reserves, road and rail verges, isolated in-arable land and other vegetation fragments that remain after land clearance activities have slowed or ceased. However, the possibility exists that species vary in their resilience to persisting in small isolated populations due to divergent landscape ages across the continent. For example, rare species on the ancient southwest Australian landscapes (Hopper and Gioia, 2004) may be more resilient than those found on younger southeastern landscapes where more

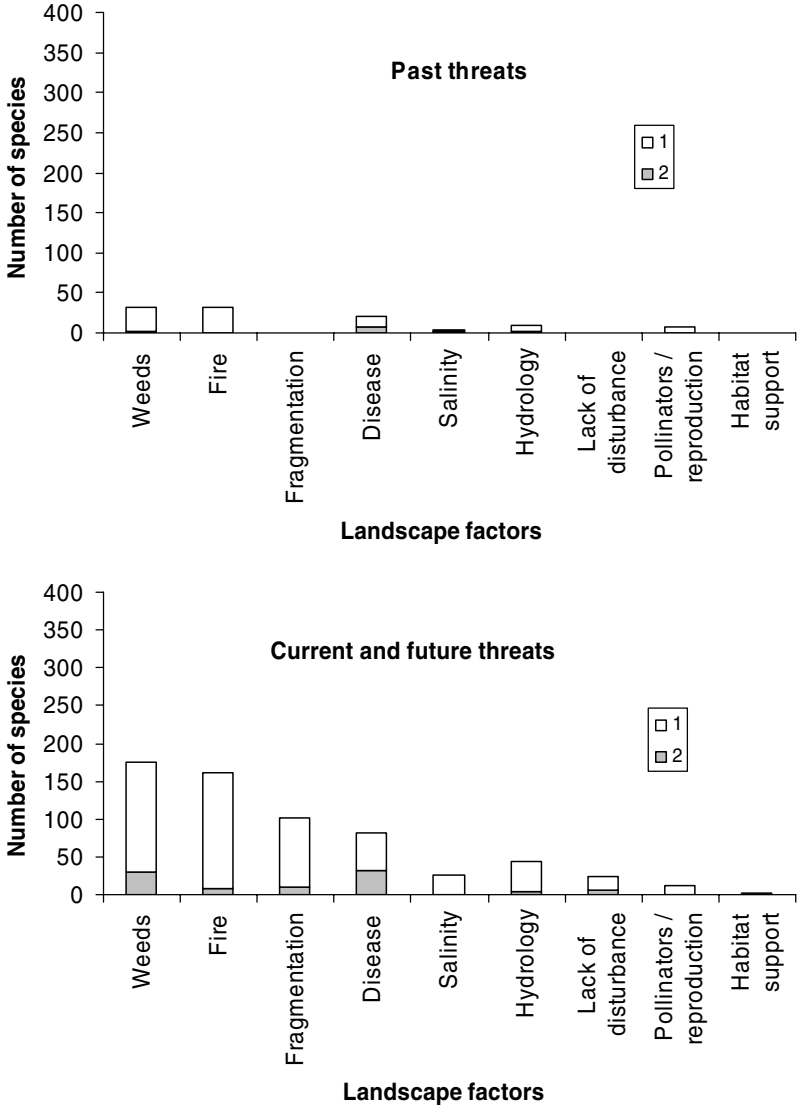

Fig. 3 – The number of species severely (2) and substantially (1) threatened by landscape factors including weeds, fire, fragmentation, disease, salinity, hydrology, flooding, lack of disturbance, changed disturbance patterns, pollinator disruption, limited sexual reproduction, lack of habitat support, extreme environmental conditions.

extensive and continuous population structures are evident in unfragmented vegetation. This hypothesis requires rigorous testing.

Perhaps the greatest changes will occur among the threatening processes classified under landscape factors (Fig. 3). Many of these processes were not a threat in the past, or affected comparatively few species.

It will become increasingly important in the future to manage other human activities with local effects, such as collecting, trampling and recreation (Fig. 4). Like the importance of demographic factors, management of road and rail verge environments will increase in importance over time because of the fact that they harbour many relict populations in otherwise cleared or alienated habitat.

Four threat syndromes (sets of threats that overlap and result in identifiable patterns of decline or response to stress) emerged from our review of the species and classification of their threats (Fig. 5). We used parts of the dendrogram to identify threat syndromes, but also linked like issues together to provide a pragmatic focus.

- Syndrome 1. Species with small to medium geographic ranges (usually <100 km) intersecting regions developed for extensive crops. (e.g., *Verticordia plumosa* var. *pleiobotrya*)
- Syndrome 2. Species with small to medium geographic ranges that intersect urban areas (e.g., *Grevillea caleyi*).
- Syndrome 3. Narrow endemics with specific habitat requirements threatened by fire, weeds, disease, hydrological changes, salinity or other landscape-scale ecological changes. (e.g., *Lambertia echinata* subsp.*occidentalis*).
- Syndrome 4. Species adapted to rock outcrops threatened by grazers (sheep, rabbits, goats), introduced weeds, fires, dams or other human activities (e.g., *Zieria parrisiae*).

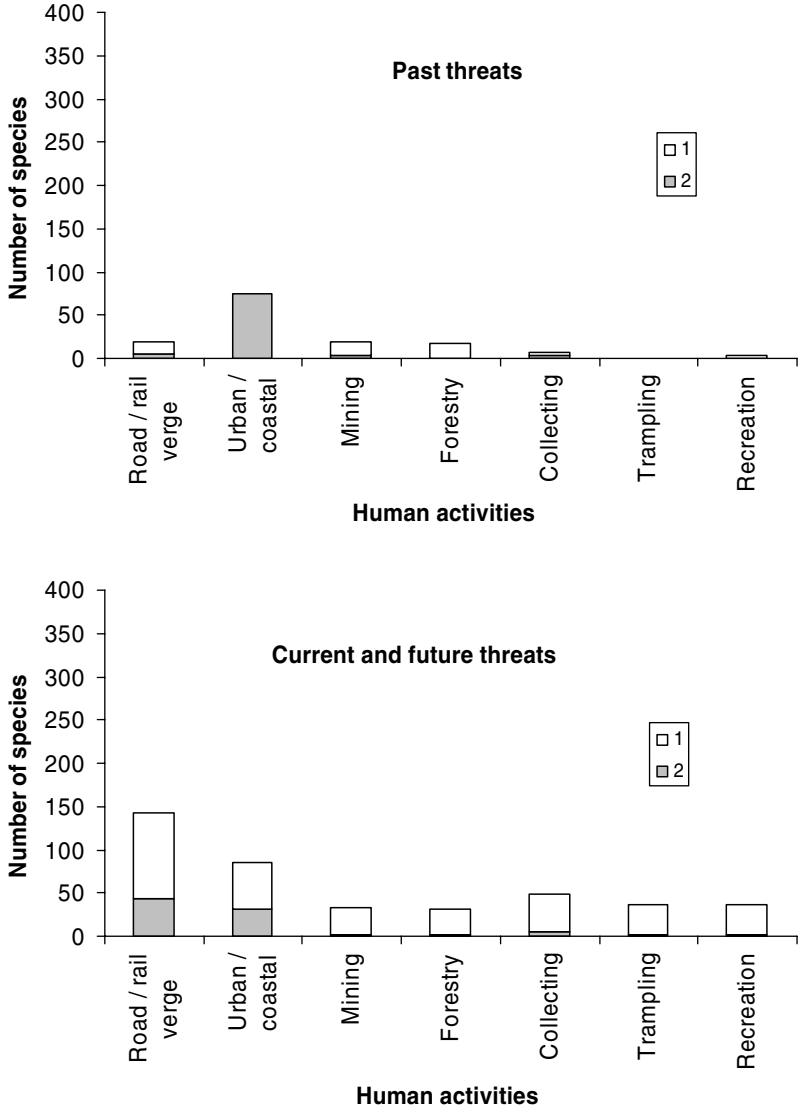

Fig. 4 – The number of species severely (2) and substantially (1) threatened by other human activities including road/rail verge environments, new road construction, urban and coastal development, mining, forestry, recreation, dams, trampling, collecting, mowing, bush rock removal, rubbish dumping, vehicle damage, pollution, herbicides, fire wood collection.

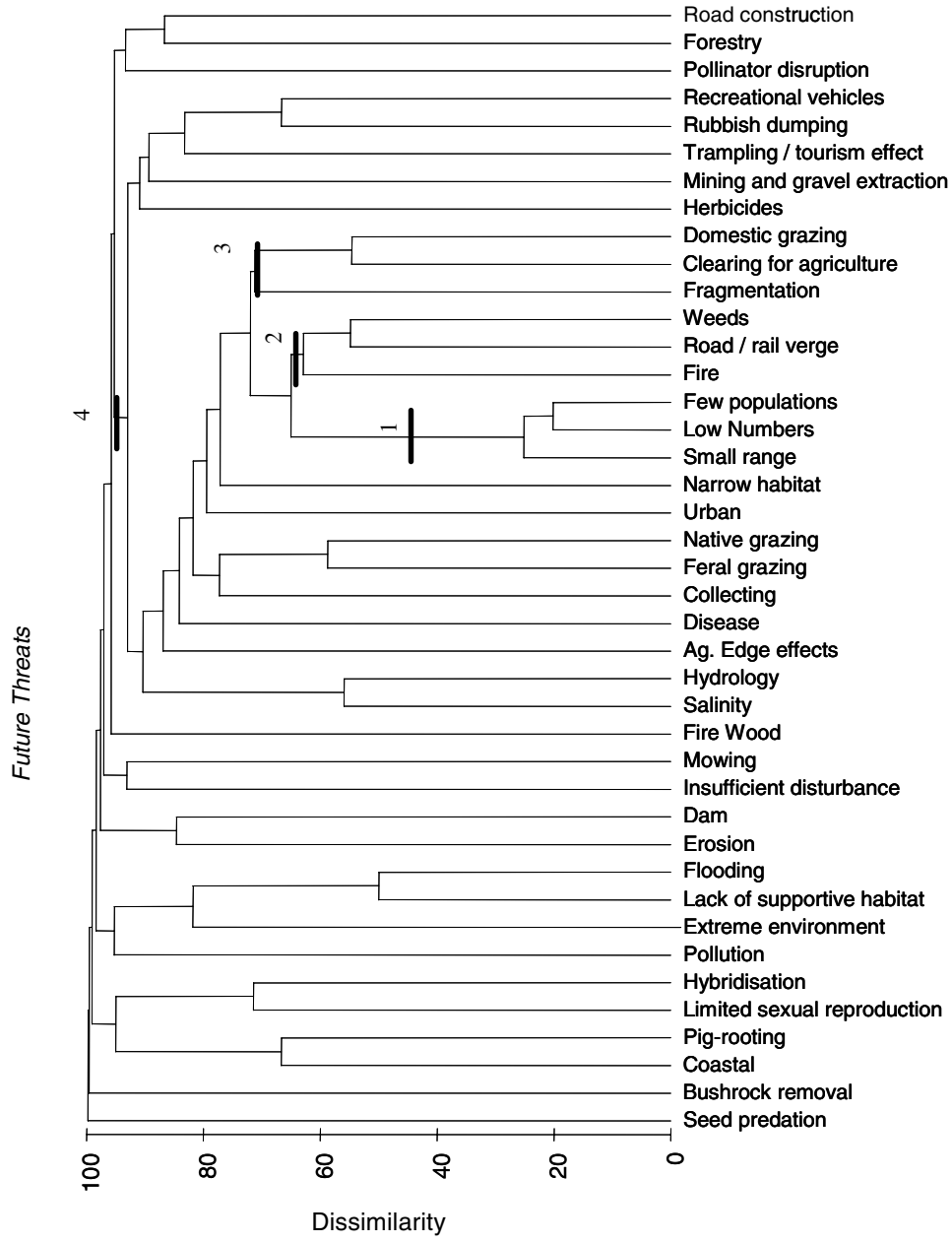

Fig. 5 – The dendrogram relating threats, based on the species they affect and the severity of their effects. Similarities were calculated using Bray-Curtis dissimilarity, and were clustered with UPGMA. Four broad groups of threats include (1) demographic threats; small populations and narrow ranges, (2) road and rail verge environments, (3) land clearing for agriculture, (4) consequences of urban/agricultural activities. This classification was used, together with information on the spatial distribution and habitat requirements of the species, to identify four threat syndromes.

4. Discussion

Sattler et al. (2002) estimated that the most widespread processes threatening Australian ecosystems are vegetation clearing, fragmentation of remnant vegetation, grazing pressure, exotic weeds, feral animals, salinity and changed hydrology, and altered fire regimes. These judgements accord with several of the most important processes in Figs. 1–4 although they omit disease, especially *Phytophthora cinnamomi*.

Issues that did not arise in our review, but that have arisen elsewhere, included climate change (listed federally as a threatening process; Department of Environment and Heritage, 2004), the effects of genetically modified organisms (from genetic introgression or through expansion of the agricultural estate), and changes to environmental flows in rivers and streams. The potential threats posed by climate change and genetically modified organisms to native biota have emerged relatively recently, and are more uncertain than

most other processes. There is an urgent need for research that evaluates their importance.

This study has highlighted several threatening processes that had not previously been considered as significant, including loss of supporting habitat, loss of pollinators, and lack of disturbance, each of which are lagged consequences of habitat fragmentation. 'Emerging issues' that will become more prevalent over time include demographic factors, agricultural edge effects, extreme environmental conditions, and many local human activities (bush rock collection, fire wood collection, plant collection, trampling, 4-wheel-drive vehicles, rubbish dumping, mowing). Some of these have been highlighted elsewhere and there are national plans to deal with them. For instance, Sattler et al. (2002) recognised that firewood collection is a threatening process and cited a national framework for managing its impacts on conservation values and air pollution.

In the future, landscape factors are likely to increase because of the expanding demands of the human population and the diffuse nature and landscape-scale of many threats. Disease, salinity, hydrological change, weeds and the loss of pollinators can rarely be remediated for species on a case by case basis. Their causes are long-term, they may interact with one another, and they operate at locations often far removed from the local populations that managers may be attempting to conserve. Exotic weeds and feral animals have an impact on threatened ecosystems across many bioregions but are difficult and expensive to manage across large areas (Sattler et al., 2002).

National audits of the status of Australia's biodiversity should consider analyzing data to look for sets of threats that overlap and interact to affect large numbers of species (i.e., threat syndromes). This would allow State and National authorities to identify particular habitat or demographic/landscape situations worthy of dedicated effort. If actions are cost-effective, the resulting priorities may result in relatively efficient conservation outcomes.

Maintenance of the list of threatened plants and the data on which assessments are based is a Federal responsibility. If the results presented here are to make a useful benchmark for evaluating the conservation status of the Australian flora as a whole, then the data on which they are based need to be publicly available and the definitions of terms need to be applied consistently.

Several future risks may be mitigated effectively by changes in policy, such as more stringent controls and compliance measures on land clearance, firmer control and surveillance on the importation of plant species and more effective fire management strategies (Possingham et al., 2002b). However, such simple solutions may not apply for many threatened species where interacting processes underpin the decline towards extinction (Hobbs, 2001). Threat syndromes offer one way of characterising complex threats and may provide a basis for setting some management priorities. The need for rigorous experimental research in plant conservation biology to unravel such complexity was never more necessary nor urgent than now.

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