MACQUARIE University

# Using plant traits to assess threatened species adaptive capacity under climate change

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**Project overview**

This project aims to assess the adaptive capacity of plant taxa listed under the NSW TSC Act to climate change. Data availability has allowed us to use a trait-based, quantitative framework to classify 342 of NSW's threatened plant species relative to four key areas relevant for response to climate change: dispersal capacity, reproduction, level of niche specialisation and spatial coverage. We have established which of these limiting factors underpin species' vulnerability and adaptive capacity to climate change. We also show where important data gaps in basic ecological information about threatened species need to be addressed. We have used the analysis of adaptive capacity and vulnerability to recommend a suite of management actions which may be most appropriate and effective for increasing the adaptive capacity of threatened species under climate change.

The project objectives and outcomes are to:

**1)** Collate basic ecological data on the traits of threatened plant species in NSW (e.g. dispersal mode, longevity, flowering duration, height). This data is combined with existing outputs from previous NSW Adaptation Hub projects on niche characteristics (soils, climate) and range size;

**2)** Assess the adaptive capacity of threatened plants in NSW to climate change using a quantitative scoring system;

**3)** Categorise NSW threatened plants into climate change vulnerability classes (high, medium, low);

**4)** Recommend appropriate management actions (e.g. weed removal, site manipulation, translocation) based on adaptive capacity and vulnerability;

**5)** Communicate research findings and disseminate outputs.

## Project rationale

Few assessments of species vulnerability to climate change that are used to inform conservation management and planning consider the intrinsic traits that shape species' sensitivity and adaptive capacity and, ultimately, their vulnerability. This omission is problematic as it may result in management actions that are not optimized for the long-term persistence of species under climate change.

Here, we apply a recently developed tool (Butt & Gallagher *in review*) for explicitly linking data on plant species' life history traits to appropriate management actions that maximise their adaptive capacity under climate change. The tool uses data on easily measured traits (e.g. dispersal syndrome, height, longevity) and range characteristics (e.g. range size, climatic/soil niche breadth) to categorise species by their vulnerability as related to four limiting factors affecting adaptive capacity:

- Reproduction
- Movement Capability
- Abiotic Niche Specialisation
- Spatial Coverage

All NSW threatened plant species with sufficient data for each of these traits (*n* = 342 taxa) were allocated vulnerability scores (high, medium, low) for each limiting factor (and overall) using a quantitative scoring scheme (Table 1; see 'NSW_TS_vulnerability.xls' for vulnerability analysis). Vulnerability scores for each limiting factor were then used to make recommendations about which management actions may maximise adaptive capacity under climate change (see 'NSW_TS_vulnerability.xls' for management matrix).

## Project outputs

This project provides the following key resources for OEH:

- A dataset of 11,521 observations across 46 ecological traits for ~600 threatened species in NSW. All sources of trait data for each observation are provided. **This data is provided in the file "threatened_spp_traits_OEH.xls"**;
- An assessment of the vulnerability of 342 NSW threatened plants to climate change. **This data is provided in the file "NSW_TS_vulnerability.xls"**;

- A matrix of potential management actions which account for the limiting factors which shape species vulnerability to climate change. **This data is provided in the file "NSW_TS_vulnerability.xls"**.

## Methods for assessing vulnerability to climate change in NSW threatened plants

### *Trait data collation*

Data were collected by searching the species name (e.g. "*Acacia atrox*") in Macquarie University's Multisearch, Google Scholar and Google and accessing the most relevant of the reputable sources. In many cases, all reputable information available through these searches was screened for useful information. Where little information about the species was available, searches were undertaken using the genus name. Specific terms (e.g. dispersal and flower) were used to narrow these searches in some cases.

Sources consulted include peer-reviewed scientific literature, published books, NSW Scientific Committee documents (e.g. determinations), Threatened Species Scientific Committee documents (e.g. conservation and listing advice), PlantNET, Office of Environment and Heritage threatened species profiles and the Commonwealth Species Profile and Threat Database. Where practical, quotes from sources were included in the notes column to provide context for the data obtained and ensure the original wording was available. Other sources, such as AusGrass, were incorporated into the dataset from Austraits (Gallagher et al. *unpublished*).

Traits and information which may be relevant to the species' adaptive capacity to and management under climate change were included. For instance, hybridisation risk, genetic diversity and gene flow, where available, were incorporated as such genetic factors influence a species' ability to adapt *in situ* (see Christmas, Breed & Lowe 2016, for a review). Fire responses were also recorded as the frequency and severity of fires are projected to increase in Australia, due to climate change (CSIRO & BOM 2015). Habitat considerations, such as alpine, riparian, mesic and ephemeral, were also included. Other factors with no direct link to assessment and management, such as monoecy and dioecy, were nevertheless included for completeness.

The major categories included in the dataset are as follows (see Appendix 1 for a complete user manual for the dataset). General categories of trait information are:

- Relevant habitat information is entered as *habitat_considerations* (e.g. ephemeral or disturbed)
- Species interactions (e.g. parasitic or obligate_mycorrhizae).
- Species' responses to different environmental phenomena include:
  - *drought_considerations* (tolerant or sensitive)
  - *fire_considerations* (e.g. resprouts or regenerates_from_seed)
  - *recruitment_requirements* (e.g. fire or flood)
- Recruitment considerations include:
  - *recruitment_type* (e.g. vegetative)
  - *seed_bank_longevity* (short or long)

- seed_bank_size (e.g. small)
  - *seed_germination_rates* (low, high or conditional)
  - *seed_production* (rare, low, high, variable or none_observed)
  - *seed_predation* (low-high)
  - *seed_set* (very_low, low, moderate or high)
  - *seed_viability* (low – high or variable)
  - *fecundity* (sterile, low, high, increases_with_age or conditional).
- Dispersal information is contained in the categories:
  - *dispersal_appendage* (e.g. pappus)
  - *dispersal_by* (e.g. ants); *dispersal_distance* (m)
  - *dispersal_distance_estimate* (short – long).
- Information about mating systems include:
  - *pollen_distance* (m)
  - *pollen_distance_estimate* (m)
  - *pollination_by* (e.g. native_bees)
  - *pollen_viability* (e.g. sterile)
  - *mating_system* (e.g. outcrossing).
- Flowering information is contained in:
  - *flowering_time* (e.g. 110000000001)
  - *flowering_fruiting_considerations* (e.g. protandry).
- Generation lengths and proxies therein are:
  - *generation_length* (years)
  - *time_reproductive_maturity* (years)
  - *reproductive_maturity* (short or long)
  - *peak_reproductive_maturity_reached* (year)
  - *plant_height* (m)
  - *height_habit* (e.g. decumbent or straggling).
  - Specific genetic considerations are encompassed in:
  - *genetic_considerations* (e.g. hybridisation)
  - *genetic_diversity* (low – high)
  - *gene_flow* (low or high).

## Conducting the climate change vulnerability assessment

A specific subset of traits was used to assess climate change vulnerability in NSW threatened plant species. Note that a trade-off exists between completeness across species and specificity of traits to adaptive capacity. We have chosen traits which relate to limiting factors (*Reproduction, Movement Capability, Abiotic Niche Specialisation, Spatial Coverage*) in a species response to climate change. Justification for each trait choice is as follows:

### *Reproduction*

Species' ability to adapt to changing climatic conditions in situ will be determined, in part, by the rate of population turnover, which is linked to an intrinsic rate of increase (Fordham et al. 2012). Species with shorter generation lengths (time to maturity) are expected to be able to turnover populations at a faster rate, and as a result benefit from greater opportunities for evolutionary or epigenetic change in response to rapid climate change (Bush et al. 2016; Hughes 2000; Franks et al. 2014). We used plant longevity (annual, biennial, perennial or combinations thereof), and maximum height (m) as proxies for generation length. On average, taller species have longer generation times than do shorter species (Moles et al. 2009). We also used duration of the flowering period (months) as a measure of the opportunity for reproductive success, with increasing flowering duration being associated with greater seed set and rate of population increase (Gibson et al. 2011). Species were assigned numerical scores for each trait (Table 1) which were then used to calculate a geometric mean for ranking species by their reproductive capacity, with lower scores conferring lower vulnerability to climate change. We split geometric mean scores across all species into three equal-sized categories (low, medium, and high vulnerability) using the 33rd and 66th percentiles.

### *Movement Capability*

Species' ability to shift distributional range to track optimal conditions for growth and survival is a fundamental limiting factor for their capacity to adapt to climate change. Species whose capacity to range shift is low are at a greater risk of extinction, particularly where their exposure to the effects of climate change is high (Fordham et al. 2012).

We scored species' potential capability for movement based on their dispersal syndrome, assuming that species capable of moving longer distances are more likely to be able to spread to suitable or novel habitats (corresponding to lower vulnerability). The connection between seed dispersal syndromes and species' movement capability has been established across multiple disciplines operating at different temporal and spatial domains, including paleobotany (Eriksson et al. 2000), biogeography (Seidler et al. 2006) and trait ecology (Willson and Traveset 2000).

We allocated species into four categories according to seed dispersal mechanism ((1) wind/water, (2) vertebrate, (3) invertebrate, and (4) localized (seeds with no apparent dispersal appendage which rely on gravity or explosive dehiscence for dispersal); Table 1). For the purposes of assessment, water dispersal was assumed to indicate a similar movement capability to wind.

Species were then assigned to low, medium and high vulnerability to climate change in relation to movement capability (based on scores 1 = low, 2 = medium, 3-4 = high). Species with multiple dispersal syndromes were assigned their lowest potential score (e. g. *Zieria tuberculata* J.A.Armstr. is dispersed locally and by invertebrates and was given a score of 3).

### *Abiotic Niche Specialisation*

Plant species adapted to a narrow suite of abiotic conditions across their realised niche (e.g. infertile soils, ephemeral rainfall) are more likely to be ecological specialists with a lower inherent adaptive capacity to changing conditions (Ackerly 2003; Slatyer et al. 2013). For these species, the combination of rapidly changing climate and relatively stable soil conditions may lead to a mismatch in suitable conditions for populations persistence (Damschen et al. 2012). Species with wider realised niche breadths are expected to have greater ability to cope with diverse abiotic conditions, relative to those species which occupy narrow abiotic niches.

To assess the role of abiotic niche specialisation in vulnerability to climate change we used data on the breath of rainfall (annual precipitation (AP); mm), temperature (mean annual temperature (MAT); °C), soil P content (total P; %), and soil clay content (clay %) in the top 5 cm of the soil profile. The two climate variables are commonly used to summarise broad-scale niche requirements and influence vegetation structure across the strong north-south temperature and east-west rainfall gradients in Australia (Groves 1994). Similarly, low soil fertility – in particular, low phosphorus contents – have driven key ecological adaptations in the Australian flora (e.g. cluster roots, sclerophylly; Beadle 1966; Lambers et al. 2006). In addition, we also assessed how many of Australia's biomes each species occupies as a measure of specialisation, based on the biome classification in Olson et al. (2011).

Species were assigned numerical scores based on the width of their niche and number of biomes occupied (Table 1). These scores were then used to calculate a geometric mean across all niche specialisation scores for ranking species by their specialisation and assigning them to low, medium and high vulnerability categories. Geometric means, used to allow for combination of values across disparate ranges and units, were split into three equal-sized categories at the 33rd and 66th percentiles.

### *Spatial Coverage*

Range size is a well-established surrogate for extinction risk, commonly used in conservation assessments and declarations (Mace et al. 2008). Species with small range sizes are at an increased risk of extinction primarily because singular deterministic or stochastic events are more likely to affect their entire population (IUCN 2016).

To assign species into low, medium and high categories based on their range size across Australia we used a combination of the IUCN thresholds for listing species under the "restricted geographic distribution" clause, and the percent coverage of the species across Australia (Table 1). Specifically, species with a range size small enough to be listed under the threshold for critically endangered, endangered or vulnerable in the IUCN Red List criteria (i.e. 20,000km2) were scored as high vulnerability. Medium vulnerability species were those which had range sizes greater than the IUCN threshold, but occupied less than 1% of the Australian continent by land area (i.e. 70,000km2). All other species were assigned as low vulnerability for the Spatial Coverage category.

**Table 1.** Decision tool for scoring trait and range metrics of sensitivity and adaptive capacity to assess potential vulnerability under climate change. Four factors limiting adaptive capacity are considered: *Reproduction, Movement Capability, Abiotic Niche Specialisation* and *Spatial Coverage*. Lower scores indicate lower potential vulnerability. *(This table was reproduced and altered slightly to reflect changes made in applying the framework to NSW threatened species with permission from Butt & Gallagher, in review.)*

| Limiting Factor | Traits & Range Metrics with Scores (in Parentheses) |
|---|---|
| **Reproduction** | *Longevity:* annual &/or biennial (1); annual/perennial or biennial/perennial (2); perennial (3)<br>*Flowering Duration (months):* 11-12 (1); 9-10 (2); 7-8 (3); 5-6 (4); 3-4 (5); < 1-2, ephemeral/unpredictable or not applicable (e.g. triploid species) (6)<br>*Maximum Height (m):* 0-0.1 or prostrate/straggling etc. (1); > 0.1-1 (2) > 1-10 (3) > 10-100 (4) |
| **Movement Capability** | *Dispersal Syndrome:* wind/water (1); vertebrates (2); invertebrates (3); localised or not applicable (e.g. triploid species) (4) |
| **Abiotic Niche Specialisation** | *Number of Biomes Occupied:* 7 (1); 6 (2); 5 (3); 4 (4); 3 (5); 2 (6); 1 (7)<br>*Thermal Niche Breadth (°C):* > 20 (1); 15-20 (2); 10-15 (3); 5-10 (4); 0-5 (5)<br>*Rainfall Niche Breadth (mm):* > 2,000 (1); 1,000-2,000 (2); 600-1,000 (3); 300-600 (4); 100-300 (5); 0-100 (6)<br>*Clay Content Breadth (%):* > 40 (1); 30-40 (2); 20-30 (3); 10-20 (4); 0-10 (5)<br>*Soil Total P Breadth (mg/kg):* 0.2 (1); 0.1 (2); 0 (3) |
| **Spatial Coverage** | *Range Size (Area of Occupancy, $km^2$):* > 70,000 (1); 20,000-70,000 (2); < 20,000 (3) |

***Overall Vulnerability Classifications***

Overall vulnerability classifications (LOW, MEDIUM or HIGH) were determined using the classifications for each limiting factor for each species. Three methods were used to encompass three possible combinations of vulnerability classifications: consensus, equality or mixed combinations. Where three or more limiting factors shared the same vulnerability classification (n=155 species), consensus was considered reached and that classification was assigned as the overall vulnerability classification (e.g. a HIGH overall vulnerability classification was assigned to *Bossiaea fragrans* K.L.McDougall). Where an equal split of vulnerability classifications occurred across limiting factors (n=69), the higher of those was assigned (e.g. two medium and two high = HIGH [for *Lasiopetalum joyceae* Blakely]; and two medium and two low = MEDIUM [for *Homopholis belsonii* C.E.Hubb.]). In all other cases (n=159), an overall classification of MEDIUM was applied where one limiting factor vulnerability classification was high (e.g. for *Pterostylis despectans* (Nicholls) M.A.Clem. & D.L.Jones).

### Management actions based on climate change vulnerability

We used species' capacity to adapt to climate change – as captured by their vulnerability scores for each limiting factor (Reproduction, Movement Capability, Abiotic Niche Specialisation, Spatial Coverage), to link species with potentially appropriate management actions. To do this, we divided conservation management actions into five groupings accounting for scale, location and biotic interactions: habitat, landscape, interspecific interaction, species-specific, translocation (Figure 1). Conservation actions for plants can be broadly characterized as *in-situ* or *ex-situ*, and a mix of these strategies are represented in the groupings (Figure 1).

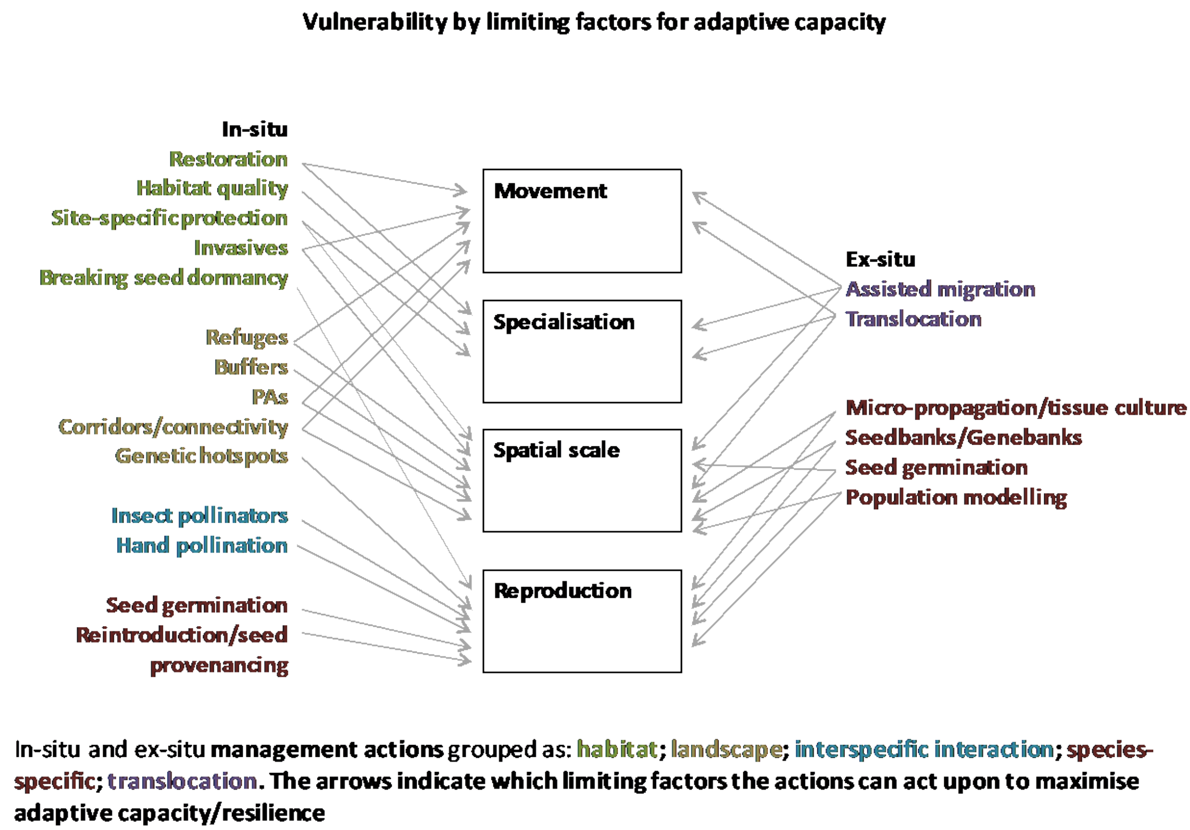


**Figure 1:** Vulnerability by limiting factors for adaptive capacity (as driven by traits and range metrics, Table 1). *In-situ* and *ex-situ* management actions grouped as: habitat; landscape; interspecific interaction; species-specific; translocation. The limiting factors are linked to the actions that can act to maximise adaptive capacity/resilience.

For each species, we examined which limiting factors where assessed as HIGH vulnerability under climate change and assigned the management actions as shown in Figure 1. The table below provides a description of each of the management actions which are being recommended in "NSW_TS_vulnerability.xls".

| MANAGEMENT ACTIONS | TYPE | DESCRIPTION |
|---|---|---|
| RESTORATION | in-situ | Based on focal species/key habitat formation: revegetation; methods range from weed and fire management to re-creating ecosystems from completely denuded landscapes; aims to |

| | | |
|---|---|---|
| | | recover original ecosystem functions and components (related potential risks should be monitored). |
| HABITAT QUALITY | in-situ | Habitat quality preservation methods – cutting, coppicing, mowing, sod cutting, top soil manipulation (often aimed at mitigating runoff/eutrophication effects); maintain edaphic heterogeneity (texture, nutrient composition), managing weeds, managing fire, replanting; reduction of habitat loss, disturbance and modification. |
| SITE-SPECIFIC PROTECTION | in-situ | Either in one place where there is a small population of the target species in a spatially restricted area, or; for scattered populations at different sites across a landscape. |
| INVASIVE SPECIES CONTROL | in-situ | Habitat protection/management to prevent invasive/exotic species by increasing ecological resilience (see also habitat quality actions); removal of invasive weeds. |
| BREAKING SEED DORMANCY IN SITU | in-situ | Assess ecological requirements (light, temperature, fire, etc.), and mimic them on site; scarification methods may include chemical, mechanical, etc. |
| REFUGES | in-situ | Landscape patches/mosaic; could be temporary reserves (seasonal/annual); sequential protection of areas over time to address changes in species distribution may allow for management of gradual range adjustments without protection of the entire projected distribution change. |
| BUFFERS | in-situ | Related to PAs and refuges - protection features that buffer landscape climatic conditions; expansion of protected area/increased connectivity. |
| PROTECTED AREAS | in-situ | Reserves; identify areas crucial for species persistence; investigate formal conservation arrangements such as the use of covenants, conservation agreements or inclusion in reserve tenure; protect known habitat areas from clearing and disturbance; PAs are critical for avoiding (further) habitat loss - analyses incorporating species distribution models can be used to locate/identify optimal additions to PA networks for climate change. |
| CORRIDORS/CONNECTIVITY | in-situ | Increased connectivity to enhance seed and pollen flow between populations, and facilitate (re)colonisation of empty patches; meaningful dispersal scenarios that account |

| | | |
|---|---|---|
| | | for the speed at which species can move, the specificity of species' habitat requirements, and connectivity between current and future suitable habitat, should be included in the consideration of areas of future suitability. |
| GENETIC HOTSPOTS | in-situ | Undertake survey work in suitable habitat and potential habitat to locate and protect any additional populations/occurrences/remnants to account for genetic diversity and variability. |
| INSECT POLLINATORS | in-situ | Protect pollinator species already in place; other species can be brought in/replaced at the location. |
| HAND POLLINATION | in-situ | Periodical/seasonal mixing of on-site genetic material/introduction of genetic material from other populations or sites. |
| SEED GERMINATION | in-situ | Identify appropriate intensity and interval of fire to promote seed germination; introduce seedlings (see also breaking seed dormancy actions). |
| REINTRODUCTION/SEED PROVENANCING | in-situ | Reintroduction/reinforcement: increase population viability by adding plant individuals to an extant population, and replacement of plant material into an area where it previously occurred but is now extinct; using local provenance seed and seedlings for planting is not as relevant when adapting restoration for climate change - use 'composite provenancing', which involves a mixture of seed from populations at increasing distance to mimic natural gene flow patterns, and increases the chance of bringing in climate change-resilient individuals. |
| ASSISTED MIGRATION | ex-situ | Create 'conservation corridors' that span large environmental gradients to ensure species can shift range distributions; increase focus on corridors across latitudinal or elevational gradients to facilitate species tracking suitable climate (see also corridors/connectivity). |
| TRANSLOCATION | ex-situ | Movement of plant material from one or several natural populations to a potentially suitable area/favourable habitat (where it previously hasn't existed); genotype translocation, maximisation of genetic diversity (Targeted Gene Flow). |
| MICRO- | ex-situ | Germination trials; growth trials; glasshouse |

| | | |
|---|---|---|
| PROPAGATION/TISSUE CULTURE | | and lab propagation; create ex-situ populations to maintain genetic material. |
| SEED BANKING | ex-situ | Collection and storage of genetic material: seedbanks, field gene banks, tissue and cell culture, cryopreservation. |
| POPULATION MODELLING | ex-situ | Population modelling/demographic modelling/PVA/minimum available suitable habitat; community level modelling and genomic data can be combined to map population-level genetic response to climate change, and inform planning based on projected vulnerability across landscapes. |

**Results of climate change vulnerability assessment**

***Availability of Data***

Of the 621 extant, threatened NSW plant species, 342 could be assessed using the framework outlined in Butt & Gallagher (*in review*); Figure 2). Of the 279 species which could not be assessed, 47 were plants for which the generalisations the framework is based upon were not applicable (7 epiphytes and 5 aquatic plants with no alternative growth form and height; 14 ferns; 2 mistletoes; 2 cycads; 12 climbing plants; and 5 where data were unavailable at the time of analysis).

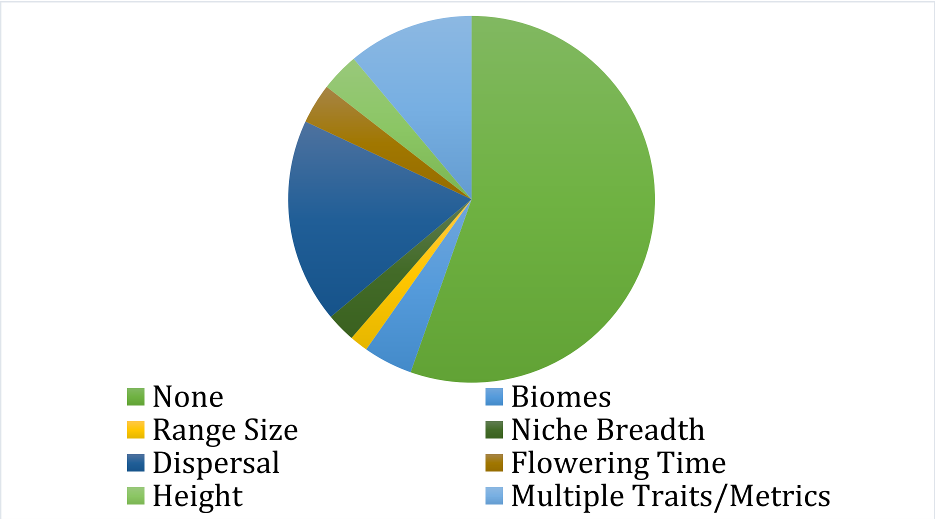


**Figure 2.** The proportions of the 621 extant, threatened NSW species missing data on ecological and range traits needed for vulnerability analyses.

### *Overall Vulnerability Classifications*

Of the 342 species which could be assessed, 52 (15%) were classified as LOW, 187 (55%) as MEDIUM and 103 (30%) as HIGH (Figure 3) vulnerability to climate change.

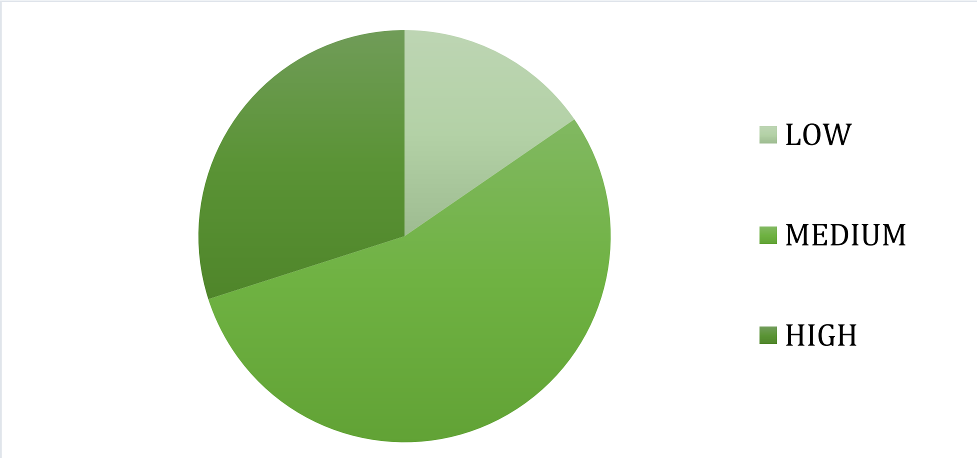


**Figure 3**. The overall vulnerability classifications for the 342 NSW threatened plant species which could be assessed using the framework from Butt & Gallagher (in review).

The three plant families with the greatest representation in each of the overall vulnerability classifications (HIGH, MEDIUM, LOW) are:

**HIGH VULNERABILITY (Figure 4) -**

- Rutaceae (22%)
- Fabaceae (18%)
- Proteaceae (14%)

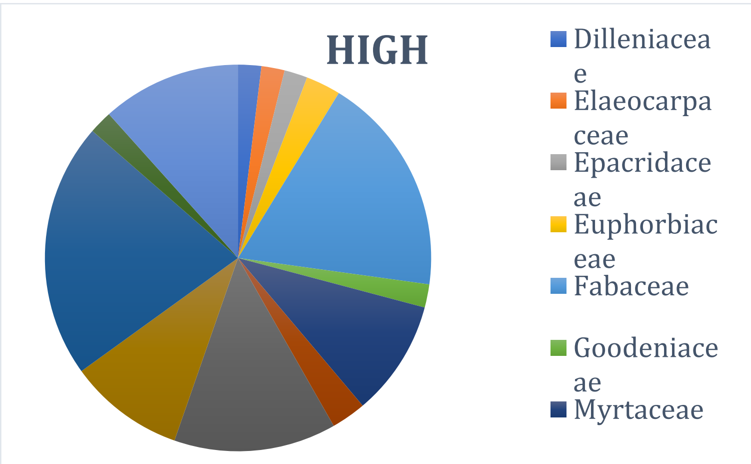


**Figure 4.** The species classified as HIGH vulnerability, presented by family. 'Other' includes the families Apaiaceae, Araucariaceae, Asteraceae, Casuarinaceae, Chenopodiaceae, Davidsoniaceae, Ebenaceae, Haloragaceae, Lamiaceae, Lauraceae, Myrsinaceae and Scrophulariaceae. Each contain one species with HIGH vulnerability.

**MEDIUM VULNERABILITY (Figure 5) -**

- Orchidaceae (19%)
- Fabaceae (13%)
- Myrtaceae (13%)

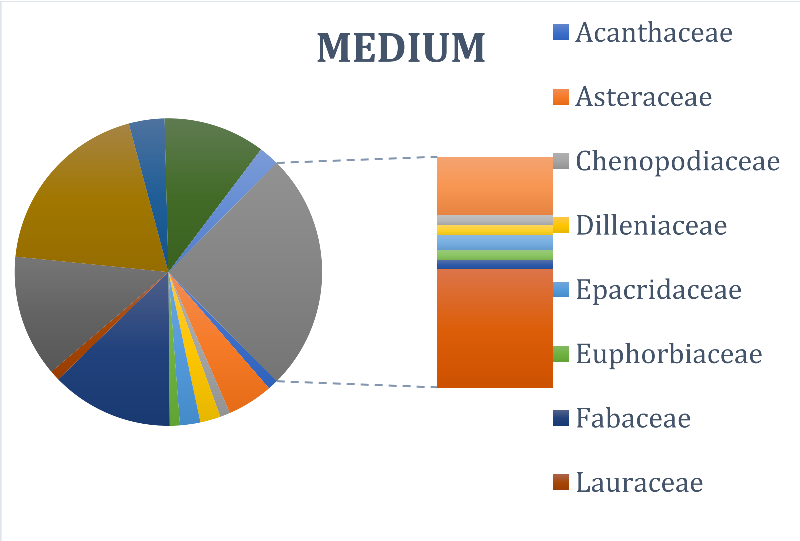


**Figure 5.** The species classified as MEDIUM vulnerability, presented by family. 'Other' includes the families Apocynaceae, Araliaceae, Asteliaceae, Brassicaceae, Capparaceae, Casuarinaceae, Corokiaceae, Doryanthaceae, Ericaceae, Eriocaulaceae, Gentianaceae, Lamiaceae, Malvaceae, Monimiaceae, Olacaceae, Picrodendraceae, Podocarpaceae, Rubiaceae, Santalaceae, Sapotaceae, Sterculiaceae, Symplocaceae, Thymelaeaceae and Tiliaceae. Each contain one species with MEDIUM vulnerability.

**LOW VULNERABILITY (Figure 6) -**

- Orchidaceae (29%)
- Asteraceae (25%)
- Fabaceae (8%)

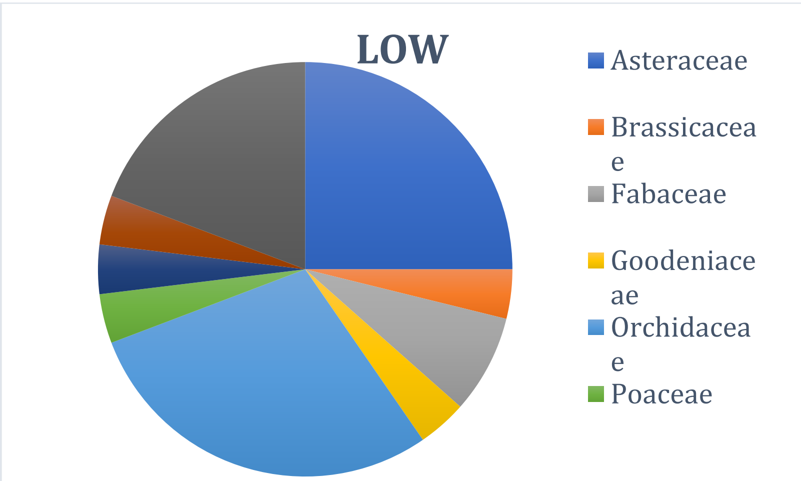


**Figure 6.** The species classified as LOW vulnerability, presented by family. 'Other' includes Casuarinaceae, Convolvulaceae, Dilleniaceae, Euphorbiaceae, Gyrostemonaceae, Polygalaceae, Proteaceae, Santalaceae, Scrophulariaceae and Surianaceae. Each contain one species with LOW vulnerability.

**Listing status of vulnerable species under the BC Act**

Of the species with HIGH vulnerability to climate change, 13 (13%) are listed as Critically Endangered, 50 (49%) are Endangered and 40 (39%) are Vulnerable (Figure 7).

For species classified as MEDIUM vulnerability to climate change, 18 (10%) are Critically Endangered, 90 (48%) are Endangered and 79 (42%) are Vulnerable.

For species classified as LOW vulnerability to climate change, 5 (10%) are listed as Critically Endangered, 30 (58%) are Endangered and 17 (33%) as Vulnerable.

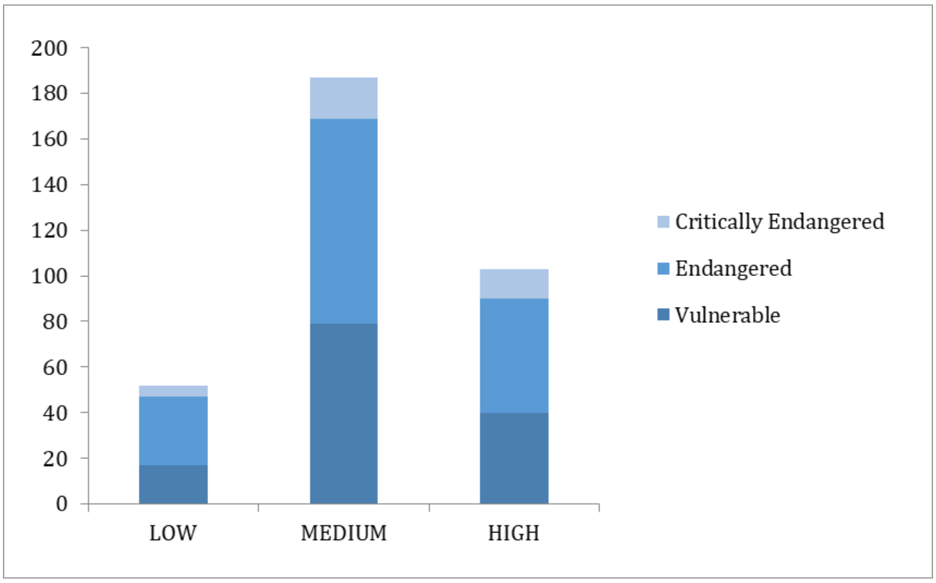


**Figure 7.** The proportions of species classified as having LOW, MEDIUM and HIGH vulnerability to climate change listed as Critically Endangered, Endangered and Vulnerable.

Of the species with HIGH vulnerability, 69 (67%) are listed nationally under the EPBC Act and 34 (33%) are not (Figure 8)

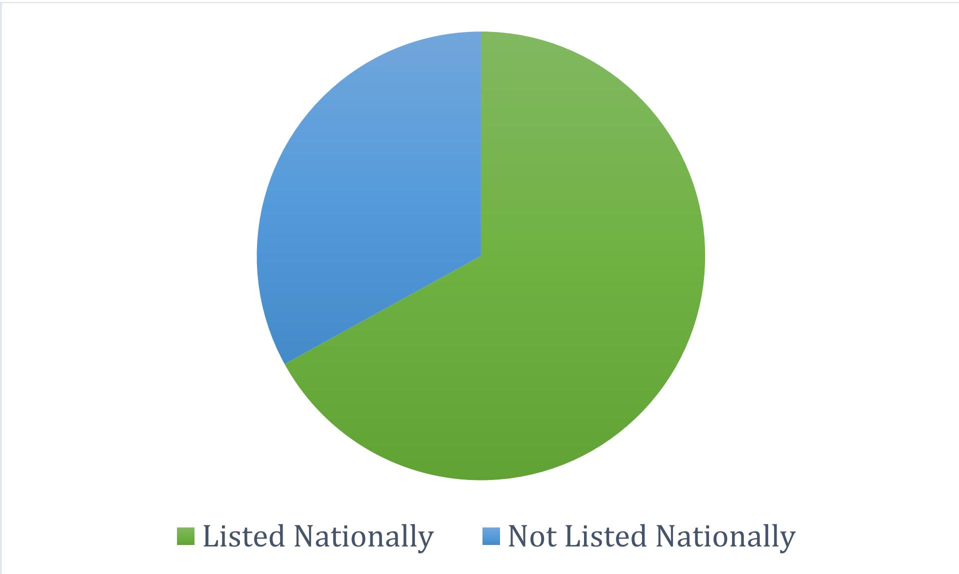


**Figure 8.** The proportions of the HIGH vulnerability species which are and are not listed nationally under the EPBC Act.

### Is climate change mentioned in the determinations for assessed species?

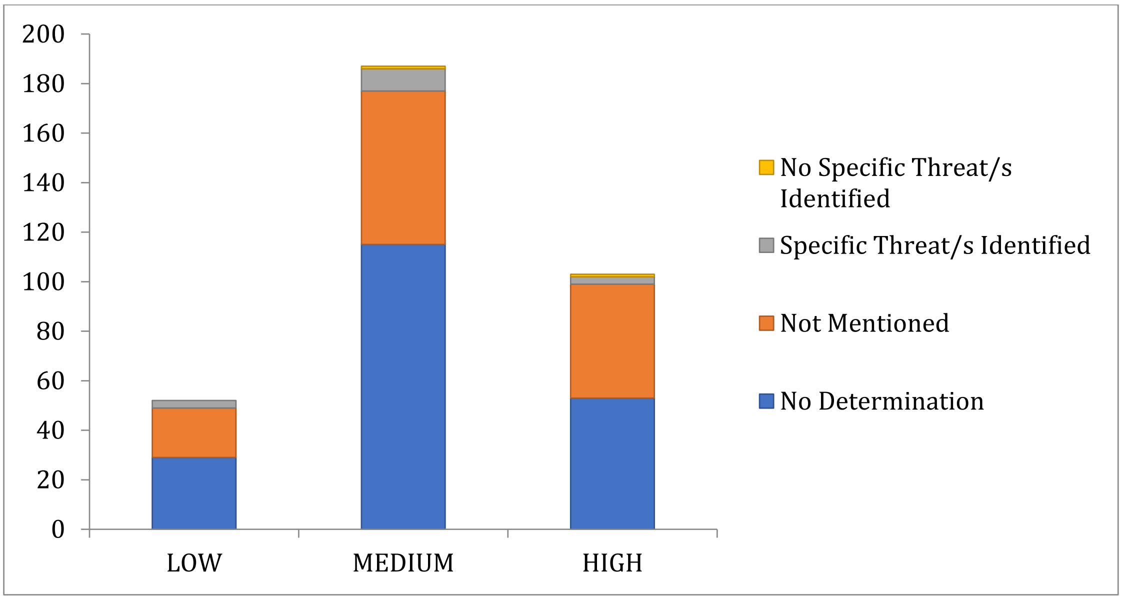


***Figure 9.*** *The proportions of the species classified as LOW, MEDIUM and HIGH vulnerability with either no determination, no mention of climate change, no specific threat/s outlined and threat/s specified in their determination.*

Of the species with HIGH vulnerability to climate change (Figure 9):

- 53 (51%) had no final determination;
- 46 (45%) did not mention climate change;
- 3 (3%) had specific threats form climate change outlined;
- 1 (1%) had no specific threats, beyond climate change.

Of the species with MEDIUM vulnerability to climate change:

- 115 (64%) had no final determination;
- 62 (33%) did not mention climate change;
- 9 (5%) had specific threats from climate change outlined;
- 1 (1%) had no specific threats, beyond climate change.

Of the species with LOW vulnerability to climate change:

- 29 (56%) had no final determination;
- 20 (38%) did not mention climate change;
- 3 (6%) had specific threats from climate change outlined.

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## Appendix 1. Dataset User Manual

### Overview of Categories:

- *habitat_considerations*
  - ephemeral (e.g. ephemeral wetland, floodplain and seasonally waterlogged soils etc.)
  - disturbed (e.g. grazed, roadside, trackside and urban areas etc.; does not necessarily indicate that disturbance is a recruitment requirement)
  - specific (ranges from a specific ecotone to only a few habitat types and/or vegetation communities)
  - wide_breadth (where a wide variety of habitats are specified)
  - soil (details of the soils at the species' locations)
  - mesic (e.g. rainforest, wetland, swamp and permanently damp soil etc.)
  - alpine
  - specific_host (e.g. for parasitic and epiphytic plants)
- *species_interactions*
  - parasitic
  - semi_parasitic
  - obligate_mycorrhizae
  - coextinction_risk (e.g. specialist butterfly etc.)
  - food_resource (e.g. critical food resource for a threatened animal)
- *drought_considerations*
  - tolerant
  - resprouts
  - sensitive (where confirmed or reasonably assumed)
  - sensitive_to_extreme_drought
  - therophyte
  - reliable_rainfall_timing (where the species is tolerant but relies on rainfall at a particular time of year, with details in the notes column)
- *fire_considerations*
  - regenerates from seed
  - resprouts (with organ details in notes)
  - sensitive (e.g. adults are usually killed by fire or the species grows in fire refugia)
- *suggested_fire_interval* (min/max in years; not comprehensive i.e. its absence does not indicate an absence of this information for a particular species)
- *recruitment_requirements*
  - fire (with specific germination requirements in notes, if known)
  - fire_not_required
  - disturbance
  - canopy_gap
  - primary_succession
  - flood
  - rainfall
- *recruitment_type*
  - soil_seed_bank (where confirmed or reasonably assumed)
  - canopy_seed_bank (where confirmed)
  - obligate_seeder (where confirmed or reasonably assumed)
  - vegetative (e.g. stoloniferous or rhizomatous etc.)

    - clonal (e.g. seeds produced are copies of the parent or the source has said 'clonal' without further specification)
    - lignotuber
- *seed_bank_longevity* (short, long)
- *seed_bank_size* (small)
- *seed_germination_rates* (low, high, conditional)
- *seed_mass* (mg)
- *seed_production*
    - none_observed (e.g. fruit is usually aborted before maturity or has not been seen, even in development at the end of the flowering period)
    - rare
    - low
    - high
    - variable (e.g. fruiting is irregular)
- *seed_predation* (low, moderate, high)
- *seed_set* (quotes and/or percentages, if specified, are in notes)
    - very_low (e.g. 3-15% of flowers result in seed)
    - low (e.g. 30%)
    - moderate (e.g. 65%)
    - high
- *seed_viability*
    - low (e.g. 33%)
    - moderate (e.g. 69%)
    - high
    - variable_between_individuals
    - variable_between_populations
    - variable (e.g. 41-100%, with no clear pattern of variation between individual plants or populations)
- *fecundity*
    - sterile (e.g. the species is triploid or otherwise incapable of sexual reproduction)
    - low
    - high
    - increases_with_age
    - conditional (e.g. of two distinct forms of the species, one is entirely clonal)
- *dispersal_appendage* (e.g. winged, hairs, pappus, aril, elaiosome and dehiscent etc.)
- *dispersal_by*
    - ants (where confirmed or reasonably assumed)
    - wind
    - water
    - local (e.g. gravity and ballistic)
    - birds
    - mammals
    - endozoochory
    - vertebrates (when birds, mammals or endozoochory is not specified)
- *dispersal_distance* (min and/or max in m)
- *dispersal_distance_estimate* (short, moderate, long)
- *pollen_distance* (max in m)
- *pollen_distance_estimate* (low)

- *pollination_by*
    - bees (European bees or unspecified)
    - native_bees
    - birds
    - honeyeaters
    - wind
    - self (e.g. autogamy)
- *pollen_viability*
    - sterile
    - no_pollen
    - low
    - high
    - pollen_limited (the mating system is pollen limited)
    - variable
- *mating_system*
    - self_compatible
    - self_incompatible
    - partially_self_compatible
    - outcrossing
    - outcrossing_benefits (e.g. fruit set is greater when outcrossing occurs)
    - autogamy
    - apomixis
    - bisexual_flowers (see the next section for a full explanation of how this is used)
    - dioecious
    - monoecious
    - gynomonoecious
    - andromonoecious
    - gynodioecious
    - polygamodioecious
    - cleistogamous_flowers
    - chasmogamous_flowers
    - spores_only (ferns)
    - heterosporous (some ferns)
- *flowering_duration* (months)
- *fruiting_time* (same metric as *flowering_time*; usually the time fruit is ripe – see notes for details from the source)
- *flowering_fruiting_considerations*
    - rainfall (e.g. flowering is triggered by rainfall)
    - drought (e.g. flowering is heavier following a period of drought)
    - temperature (e.g. flowering is aborted in sustained hot and dry conditions)
    - snowmelt (flowers soon after snowmelt)
    - fire (e.g. flowering is more vigorous following fire)
    - specific (e.g. flowers only open on dry, sunny days or exact requirements were not mentioned by the source)
    - sporadic (see the next section for a full explanation of how this is used)
    - sporadic_during_drought
    - not_vigorous (e.g. not many flowers and/or not all flowers open etc.; see the next section for a full explanation of how this is used)
    - most_of_the_year

- all_year
- rare
- variable_timing (e.g. no definitive flowering period has been identified)
- variable_across_range
- variable_between_populations;
- variable_across_years; highly_variable_across_years
- highly_variable_between_individuals
- protandry
- protogyny

- *fruit_type* (e.g. pod, berry, drupe etc.)
- *fruit_type_botany*
- *fruit_type_function*
- *seedling_recruitment* (none [e.g. triploid spp.], none_observed, very_low – high, variable_between_populations; used to indicate to what extent seedling recruitment is occurring; if low etc., this indicates that the cause has not been identified in the source)
- *seedling_establishment* (very_low, low, high)
- *seedling_survivorship* (low – high, conditional, variable_between_populations)
- *whole_plant_longevity* (min and/or max in years)
- *generation length* (min and/or max in years)
- *time_reproductive_maturity* (min and/or max in years)
- *reproductive_maturity* (used when the exact time in years is unknown but the time period is reasonably suspected to be either short or long)
- *peak_reproductive_maturity_reached* (min and/or max in years)
- *longevity* (e.g. annual)
- *plant_growth_form* (e.g. subshrub)
- *plant_height* (min and/or max in m; some upper/lower_quantile entries remain from Austraits)
- *height_habit* (e.g. prostrate, decumbent, mat-forming etc.; used in analysis as an alternative to height as a proxy for generation length)
- *genetic_considerations* (hybridisation, high_admixture, no_hybridisation, genetic_pollution, inbreeding_depression, diploid, polyploid, triploid and tetraploid)
- *gene_flow* (low and high)
- *genetic_diversity* (none, very_low, low, moderate and high)
- *specific_conservation_advice* (suggestions from scientific papers; e.g. genetic_rescue)
- *woodiness* (herbaceous, semi-woody, woody; entries remain from Austraits; not comprehensive)

**A range of categories were required to adequately capture the information available:**

- Both *recruitment_requirements* (fire) and (fire_not_required) demonstrates that fire will stimulate recruitment but is not a definitive requirement for recruitment.
- The use of *recruitment_requirements* (disturbance) indicates that either the source did not provide details (e.g. whether fire, mechanical disturbance and/or a canopy gap is required) or to indicate that mechanical disturbance is required.

(The details are in the notes column. If this is blank, the source did not specify the exact disturbance requirements.)

- Some of the categories are not mutually exclusive. For instance, there is some overlap between *fecundity, seed_set, seedling_recruitment* and *seedling_establishment*. This is because many of the sources consulted determined that either *fecundity* or *seedling_recruitment* was low but did not link this to *seed_set, seed_viability, seedling_establishment* or any other factor. Fecundity also significantly increases_with_age in some plants, e.g. *Eucalyptus* species.
- To capture variations in flowering, the following conventions are used:
    - When flowering duration is variable and can occur in any season, the two entries *flowering_fruiting_considerations* (all_year) and *flowering_fruiting_considerations* (variable_timing) are used.
    - When plants flower throughout all or most of the year with a peak in a particular season, *flowering_fruiting_considerations* (all_year) or (most_of_the_year) is used in conjunction with *flowering_time*.
    - When plants have only a few flowers throughout the year and a peak in a particular season, *flowering_fruiting_considerations* (all_year) and (not_vigorous) are used, along with *flowering_time*.
    - When plants can flower sporadically throughout the year (or when there is no clear flowering period), *flowering_fruiting_considerations* (sporadic) and (all_year) are used.
    - When plants have a defined flowering period but can also flower sporadically at other times, *flowering_fruiting_considerations* (sporadic) and (variable_timing) are used in conjunction with *flowering_time*.
    - When plants have a flowering period but may flower throughout the year, the entries *flowering_fruiting_considerations* (variable_timing) and (all_year) are used with *flowering_time*.
    - The entries *flowering_fruiting_considerations*(variable_across_years) and (variable_between_individuals) used together indicate that not every individual flowers each year.
- The entry *mating_system* (bisexual_flowers) is used when there is important information in the notes column (e.g. where information about when the male and female parts of the flowers are synchronised). For other, non-monoecious and non-dioecious angiosperms, bisexual flowers are assumed.
- Similarly, it is assumed that seed-producing plants reproduce via seed, unless seeds have never been observed or the species is incapable of seed recruitment. The entry *recruitment_type* (vegetative), for instance, does not necessarily indicate that the species is incapable of reproducing by seed.
- The value moderate is generally used to indicate that the process is occurring but that its extent has not been quantified. For instance, *seed_set* (moderate) and *seed_predation* (moderate) indicate that these processes are occurring. Relevant details, such as the nature of the observation or the seed predator, will be in the notes column.

**Further important caveats on trait data use:**

- The height of the raceme, scape or the single, erect leaf is used as *plant_height* for orchids where a measurement of overall plant height was not available.
- Reasonable assumptions were included, for instance, *pollination_by* (insects) where the assumption was based on an examination of flower morphology and/or key insects were observed visiting flowers. Details as to the nature of the assumption are provided in the notes column.
- While every effort has been made to ensure that the information contained within this dataset is complete, an entry of *fire_considerations* (resprouts) alone, for example, does not necessarily mean that the species is incapable of post-fire regeneration from seed.
- Where it was clear which source a document was referring to, the author and year are provided in notes, with a quote from the document, if required. If it was unclear which source was being referred to or many different sources were cited, the term 'cites various sources' is included in notes.
- Where information specific to the taxon was unavailable, information from different taxonomic levels was used (e.g. genus_level, family_level or species_level, for var. and subsp.), where available and reasonably assumed to be relevant to the taxon. This is denoted in the value_type column.
    - Categorical entries indicate that the information is specific to the species. Some categorical entries have their sources listed as the relevant genus profile in PlantNET. Such entries had more detailed information in the genus profile and this information was confirmed in the species profile.
- The one case of *fruit_type* (mimetic) is not necessarily enough to imply *dispersal_by* (birds). A quote from the source is provided in notes as to why:
    - "mimics fleshy fruit thereby facilitating consumption and dispersal of the seed without providing any nutritional benefit to the seed disperser (usually a bird) (Galetti in Levey et al, 2002)...Galetti notes, in Levey et al (2002), that there is little evidence in the published literature of avian frugivores eating mimetic seeds in the wild...Another possible explanation for the low level of natural recruitment is that the mimetic fruit of White Lace Flower may not be attractive to bird dispersers"
- The entry *drought_considerations* (tolerant) is used where a source explicitly stated this to be the case, although there are other taxa, such as deciduous orchids, which are most likely drought tolerant due to the presence of a tuber. Such information is contained in notes.
- The entries *mating_system* (monoecious) and (dioecious) indicates either that species within the genus are either monoecious or dioecious but the species mating system is not known (if the value_type is genus_level); or that individual plants may be either dioecious or monoecious (if the value_type is categorical).
- Some *flowering_time* entries may be slight over-estimates as many sources simply stated that a species flowers in a particular season or seasons, without specifying weeks or months. Details are provided in notes.
    - Genus_level flowering information is particularly likely to be an over-estimate.

**The species name associated with the schedules of the *Biodiversity Conservation Act 2016* is used in the dataset, with the following exceptions:**

- *Grevillea obtusiflora* is listed as such but consists of two subspecies. It is referred to as the two subspecies within the dataset.
- *Haloragis exalata* subsp. *exalata* has two varieties. If specified in the source, the variety that the entry refers to is provided in notes.

**Other considerations:**

- Commas were replaced with blank spaces so it could be used as a .csv file (including within quotes from sources and source titles).
    - Commas within source URLs, however, could not be removed and remain in the Source_Information sheet.