Conservation Assessment of *Senecio linearifolius* var*. dangarensis* Belcher ex I.Thomps (Asteraceae)

Vera Wong and Gavin P. Phillips 15/03/2024
Science Economics and Insights Division, NSW Department of Climate Change, Energy, the Environment and Water

***Senecio linearifolius* var*. dangarensis* Belcher ex I.Thomps (Asteraceae)**
Distribution: Endemic to NSW
Current EPBC Act Status: Not listed
Current NSW BC Act Status: Endangered

Proposed listing on NSW BC Act: Endangered

No change to listing.

Summary of Conservation Assessment

Senecio linearifolius var. *dangarensis* Belcher ex I.Thomps. was found to be eligible for listing as Endangered under Criterion B1ab(iii,v) and B2ab(iii,v).

The main reasons for this species being eligible are: (i) *Senecio linearifolius* var. *dangarensis* has a very highly restricted Area of Occupancy (AOO) of 8 km^2 and Extent of Occurrence (EOO) of 23 km^2; (ii) *S. linearifolius* var. *dangarensis* is known from two threat-defined locations; and (iii) continuing decline is inferred in the area, extent and quality of habitat, and the number of individuals of *S. linearifolius* var. *dangarensis* due to the effects of increased frequencies of drought and changes in rainfall patterns resulting from climate change, and invasion and competition from *Opuntia stricta*.

Description and Taxonomy

Figure 1 - Flowers of *Senecio linearifolius var. dangarensis* at the Woodlands site in Wollemi National Park in September 2018. Image: Gavin Phillips.

Senecio linearifolius var. *dangarensis* is conventionally accepted taxon within the Asteraceae family (CHAH 2023). The species *Senecio linearifolius* A.Rich. includes nine varieties and occurs across south-eastern Australia. The species is described as aromatic perennials, often weakly shrubby, to 2 m high, glabrous or nearly so except on lower surface of leaves, sometimes glaucous. Plants becoming many-stemmed from base, branching mostly in upper half. Leaves commonly thin to coriaceous, rarely somewhat fleshy; leaves in middle to upper third of stems narrow to very narrow-elliptic, narrow-ovate, lanceolate, fireor linear, 2–20 cm long, 1–40 mm wide, undivided; base attenuate, truncate, cordate, or variously auriculate, with auricles divided or not, slightly amplexicaul or not; margin entire, denticulate, dentate or serrate; upper surface glabrous, occasionally sparsely appressed-cobwebby, glabrescent, sometimes sparsely and minutely hispid; lower surface glabrous, or variously cobwebby to woolly, with hairs all fine and ± appressed or sometimes spreading; secondary and tertiary venation variably distinct. Unit inflorescences of several to many capitula; peduncles finally to c. 15 mm long. Calycular bracteoles 2–6, 1.5–3.0 mm long; peduncle and margin of bracteole glabrous or cobwebby at anthesis, sometimes glaucous; involucre cylindric to weakly campanulate, 2.5–5.5 mm long, 1.5–3.0 mm diam.; phyllaries 7–12(–14); stereome slightly to moderately convex, usually glabrous. Florets 12–30; ligulate florets 4–8, ligules 3–8 mm long, with nerves commonly 4; disc florets 4.0–5.5 mm long; limb mostly slightly longer than tube. Achenes narrow-obloid or narrow oblong-ellipsoid, 1.3–2.5 mm long, brown, glabrous or with papillose hairs in bands, carpopodium small, slightly exserted. Pappus 4–6 mm long (Thompson 2004).

Senecio linearifolius var. *dangarensis* Belcher ex I.Thomps. is further distinguished from the other varieties of the species by Thompson (2004) as follows:

"Plants glaucous, in parts strongly so, on stems, lower surface of leaves, peduncles and capitula ± glabrous. Upper-stem leaves narrow to very narrow-elliptic, with l:w ratio 5-8; base cuneate to broad-cuneate; auricles absent; margin denticulate; lower surface glabrous; secondary venation ± distinct; tertiary venation distinct. Inflorescences: peduncles glabrous, or rarely cobwebby, at anthesis. Capitula: involucre 3.5-5.0 mm long 2.0-2.8 mm diam.; phyllaries mostly c. 12. Florets 20-31; ligulate florets mostly 7-9; disc florets 13-22. Achenes c. 2.0 mm long, with appressed papillose hairs in bands."

Senecio linearifolius var*. dangarensis* has previously been known as *Senecio* sp. C *sensu* Harden (1992), and *Senecio 'dangarensis'* (a manuscript name that was never published, Thompson pers. comm. in Zimmer 2018)."

Distribution and Abundance

Senecio linearifolius var. *dangarensis* is endemic to the Hunter Valley region in NSW. It has a very highly restricted geographic distribution, found only on two basalt peaks: Mount Dangar in Goulburn River National Park and an unnamed small peak in northern Wollemi National Park referred to as 'Woodlands', located southeast of Woodlands Trig (Bell and Lamrock 2021). The two peaks are separated by approximately 30 km. Originally thought to be restricted to Mount Dangar, the site in Wollemi National Park was discovered in 2017 by nearby residents (Bell 2017). The extent of *S. linearifolius* var. *dangarensis* was mapped in 2017 and found to occupy 9 ha at Mount Dangar and 4.3 ha at Woodlands (Bell 2017).

No additional sites of *S. linearifolius* var. *dangarensis* have been found despite many surveys, including recent aerial surveys of many basalt peaks across central and eastern Goulburn River National Park, northern Wollemi National Park and Manobalai Nature Reserve have been conducted (S. Bell *in litt.* August 2022). The NSW Scientific Committee (2005) state that "Vegetation surveys in the Wollemi (Bell 1998) and Towarri National Parks (Hill *et al.* 2002); the Munghorn Gap (Hill 1999), Manobalai (T. Peake and S. Bell unpublished data), Cedar Brush and Wingen Maid Nature Reserves (Hill *et al*. 2002); on Crown (Bell 1997, Fallding *et al.* 1997, T. Peake and S. Bell unpublished data) and private land (T. Peake unpublished data) in the Hunter Valley have failed to locate any additional populations of the species."

Subpopulations

There are two subpopulations of *Senecio linearifolius* var. *dangarensis*, growing on two separate peaks, Woodlands in Wollemi National Park and Mount Dangar in Goulburn River National Park. If one of these localities became extinct then the probability of recolonisation is low, and so each is considered a separate subpopulation as per the definition in IUCN (2022). Mickaill *et al.* (2020) suggest that it is unlikely (although still plausible) that the subpopulation of *S. linearifolius* var. *dangarensis* present in northern Wollemi National Park was sourced via wind-borne propagules from Mount Dangar (approximately 30 km) under exceptional environmental conditions, such as turbulent and strong winds following a major vegetation structure altering disturbance event like a wildfire. This means that while long-range gene flow may be possible, it is highly likely that each subpopulation experiences very little genetic exchange.

Population Size

Prior to the 2017-2019 drought, the estimated size of the subpopulation at Mount Dangar was 10,000 plants and the subpopulation at Woodlands was estimated to be approximately 15,000 plants (plausible range 11,800 – 23,700 plants), giving a total population size of approximately 25,000 plants (Zimmer 2018). Population size fluctuates widely with the seasons, making an accurate estimate difficult (S. Bell pers. comm. August 2018). The Woodlands site supports more plants than Mount Dangar, despite Woodlands being a considerably smaller hill in size (Bell 2018).

Senecio linearifolius var. *dangarensis* has been monitored at two plots at each of its subpopulations since 2016, recording natural population fluctuations that appear linked to annual rainfall (Bell and Lamrock 2021). In 2016, there were thousands of plants present at the two known sites, which all but disappeared from the above-ground flora through the 2017-2019 drought. New plants returned through multiple seedling recruitment events after the drought broke in 2020 (Bell 2017, 2018; Bell and Lamrock 2020, 2021; S Bell *in litt.* August 2022). Better post-drought recovery was recorded at Woodlands than at Mount Dangar (Bell and Lamrock 2021). The most recent assessment in 2022, found a continuing increase in numbers at Woodlands, and further decline at Mount Dangar (S Bell *in litt*. August 2022). While these short-term trends can also be considered natural population fluctuations, the decline of individuals at Mount Dangar to below pre-drought numbers also indicates that *S. linearifolius* var. *dangarensis* may be influenced by changes in climate and increased occurrences of drought.

Overall, a decline of approximately 50% since 2016 has been recorded in total plant numbers at Mount Dangar, though this has been offset by an increase in total plants

of 150% over the same period at Woodlands (Bell and Lamrock 2021). This means that the current estimate of mature individuals at Mount Dangar is approximately 5,000, and at Woodlands it is 22,500, giving an overall population estimate of 27,500 individuals. While all recorded plants since 2019 have been seedlings, the rapid maturity time of 12-18 months (Bell and Lamrock 2021) means that surviving plants are now also likely to be mature.

Area of Occupancy and Extent of Occurrence

The Area of Occupancy (AOO) is 8 km^2 based on 2 x 2 km grid cells, the scale recommended for assessing area of occupancy by IUCN (2022). The Extent of Occurrence (EOO) is 23 km^2 based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2022). The EOO and AOO were calculated using Kew Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.* 2011).

Number of Locations

When the threat of increased frequency of drought and changes in rainfall patterns resulting from climate change is considered, the two subpopulations of *Senecio linearifolius* var. *dangarensis* can be considered two threat-defined locations, as per the IUCN definition (IUCN 2022). This is due to increased frequency of drought and changes in rainfall patterns resulting from climate change being the most serious plausible threat that results in the lowest number of locations for the taxon. Current long-term rainfall regimes and averages are different for both locations (Bell and Lamrock 2021), and so this means that the effect of changes in local rainfall patterns, and the likelihood and severity of droughts, will also likely differ at each location into the future.

Ecology

Senecio linearifolius var. *dangarensis* is known from only two basalt cap peaks, which are disjunct in a region dominated by underlying sandstone geology. It is unknown why this taxon is restricted to these two basalt peaks (S. Bell *in litt*. August 2022). While a preference for underlying basalt geology is the most plausible explanation for the species' natural distribution, a study of the dispersal potential of this taxon found no morphological impediments that might limit wide dispersal, and it is thought that surrounding vegetation, biotic interactions and/or local wind patterns constrain further spread to other basalt peaks (Mickaill *et al.* 2020).

The NSW Scientific Committee (2005) state *S. linearifolius* var. *dangarensis* "has been recorded growing on an open scree slope (Thompson 2004) and in woodland and rainforest communities on basalt (Hill 1999)". On Woodlands *S. linearifolius* var. *dangarensis* grows in the Plant Community Type (PCT) Western Hunter Basalt Cap Woodland (3512). On Mount Dangar, the species grows in the PCTs Hunter-Peel Dry Rainforest (3120), Mount Dangar Wattle Scrub (4121), Western Hunter Basalt Cap Woodland (3512) and Western Hunter Rocky Scrub (3784).

Flowering occurs in some individuals as early as seven months post-emergence, but more commonly between 12 and 18 months after germination (Bell and Lamrock 2021). Seedling recruitment events have been recorded when there has been a preceding annual rainfall >70% of the annual average (Bell and Lamrock 2021). Severe drought causes aboveground parts of *S. linearifolius* var. *dangarensis* to die off and appear absent from the vegetation (Bell and Lamrock 2021). When rainfall

returns, *S. linearifolius* var. *dangarensis* resprouts from woody stems after partial dieback and many seedlings germinate. As *S. linearifolius* var. *dangarensis* is quick to flower and fruit, the seed bank is continually replenished.

A study of seed ecology by Mackenzie and Auld (2020) found that the seeds of *S. linearifolius* var. *dangarensis* have a high level of fill and viability (~70%), which was found to decline >50% after one year of burial. The magnitude of decline suggests a relatively short-lived seed bank in the absence of regular inputs of new seeds. Field observations suggest the soil seedbank can still retain high numbers of viable seeds over several years at least, with seedlings germinating abundantly after a severe three-year drought in 2017–2019 (S. Bell *in litt.* August 2022). *Senecio linearifolius* var. *dangarensis* has also remained on Mount Dangar despite numerous other major droughts (>3 yrs) since at least 1825, suggesting the soil seedbank can retain enough viable seeds to provide for significant germination events across a period of several years of drought. However, moisture must remain available over the successive years to prevent desiccation and allow continued growth of emergent seedlings (Bell and Lamrock 2021). This early emergent stage, where plants transition from the seedbank to seedlings, has been shown to be a highly sensitive period in other shrubby Asteraceae that exhibit similar life history traits (e.g., *Olearia flocktoniae*; Gross and Mackay 2014), and *S. linearifolius* var. *dangarensis* may be similarly sensitive at this stage.

For plants with seedbanks, juvenile period plus the half-life of seeds in the soil seedbank can be used to calculate generation length (IUCN 2022). The juvenile period of 12 to 18 months (Bell and Lamrock 2021) and seedbank half-life of one year (Mackenzie and Auld 2020) mean that the generation length of *Senecio linearifolius* var. *dangarensis* is therefore estimated to be 2–3 years.

Mackenzie and Auld (2020) found that fresh and buried seed are apparently non-dormant and have a germination that is strongly temperature dependant, faster and greater in winter and independent of fire cues. Germination and emergence were also found to occur at other times given sustained soil moisture. As in some other species of *Senecio* (e.g., *S. macrocarpus*; Davies 2009), fire does not appear to be a necessary stimulant to promote germination.

Senecio species are typically adapted to disturbance, including fire (Lawrence 1985), although the specific response of *S. linearifolius* var. *dangarensis* to fire remains uncertain. Given other related *Senecio* species respond positively to fire (Wapstra *et al.* 2008), it is considered that *S. linearifolius* var. *dangarensis* will respond in a similar manner (Bell 2016).

Pollination and seed dispersal

Asteraceae species are typically pollinated by many insects (Vanparys *et al*. 2011; Lachmuch *et al.* 2017). Observations of ex situ garden plantings of this species indicate that fertilisation of flowers is readily affected, and there are no limiting factors to pollination (Bell 2016). Hover Flies (possibly *Chalcosyrphus* spp.) have been frequently observed visiting flowers and extracting pollen and/or nectar in this garden situation, as well as being recorded at the wild sites (Bell 2017). Observations suggest that flowering and fruiting is prolific throughout most of the year (Bell 2016).

Seeds of *Senecio* are wind dispersed. The seeds are very light and enclosed within a dry, one-seeded fruit called an achene. The achene possesses an apical pappus of slender, predominantly deciduous bristles arranged in a three-dimensional cone-

shaped structure which, when fully expanded, aids wind dispersal (Mickaill *et al*. 2020). The achene and pappus are together known as a propagule and its size affects its dispersal ability. The larger the propagule, the faster the settling velocity and vice versa. *Senecio linearifolius* var. *dangarensis* has relatively small propagules, suggesting an ability to spread widely that conflicts with its restricted distribution. Mickaill *et al*. (2020) suggest that the apparently poor dispersal ability of *S. linearifolius* var. *dangarensis* indicates that rare disturbance events, such as wildfire, may be required to open up habitat and encourage successful establishment over a wider area.

Threats

The NSW Scientific Committee (2005) stated that environmental and demographic stochasticity due to low population numbers, a low number of individuals and a highly restricted distribution, as well as high abundances of weeds, were the main threats to *Senecio linearifolius* var. *dangarensis.*

More recently, the threat of environmental and demographic stochasticity has been somewhat abated by the subsequent discovery of the Woodlands subpopulation, and an increase in known numbers from 500-1000 to the current estimate of 27,500 plants across both subpopulations (Bell and Lamrock 2021). Additionally, weeds such as *Opuntia stricta* (Zimmer 2018), are no longer considered to be a serious threat following recent systematic surveys and successful weed management at the *Senecio linearifolius* var. *dangarensis* sites (Bell and Lamrock 2021; S. Bell *in litt.* August 2022, S. Bell *in litt*. November 2022), although are likely to still be contributing to declines in habitat extent and quality.

However, the increased knowledge of the demography and ecology of *Senecio linearifolius* var. *dangarensis* is also revealing that increased drought events, and changes in rainfall driven by climate change may be causing continuing decline in the number of mature individuals, especially at Mount Dangar (Bell and Lamrock 2021). This is now considered the most serious plausible threat to *S. linearifolius* var. *dangarensis* and future climate projections indicate that decline through this threat may become exacerbated over the long-term.

Increased frequency of drought and changes in rainfall patterns resulting from climate change

Increased frequency and duration of drought and changes in seasonal rainfall patterns are contributing to continuing decline in the *Senecio linearifolius* var. *dangarensis* population. During the 2017-2019 drought, there was a dramatic decline in mature individuals at both known locations of *S. linearifolius* var. *dangarensis*, with all adult plants dying off by September 2018 at Mount Dangar (Bell and Lamrock 2021). Mature plants continued to resprout at Woodlands until at least March 2019 (Bell and Lamrock 2021), although significant dieback was evident by September 2018, with most mature individuals only bearing foliage on reshooting stems after this time (G. Phillips pers. obs. September 2018). Seedlings were observed to sporadically emerge through the drought, however survivorship was minimal with tagged seedlings at Mount Dangar dying out repeatedly up until May 2020, and very few seedlings persisted throughout the same period at Woodlands (G. Phillips pers. obs. September 2018; Bell and Lamrock 2021).

While numbers of *Senecio linearifolius* var. *dangarensis* appear to be rebounding at Woodlands to replenish pre-drought numbers, even following recruitment events plant

numbers at Mount Dangar had reduced by approximately 50% of pre-drought numbers by 2021 (Bell and Lamrock 2021) with further declines noted in 2022 (S. Bell *in litt.* August 2022). These differences in recovery between sites appear to be related to the persistence of mature plants to replenish the soil seedbank, with mature plants persisting through resprouting for at least 17 months longer at Woodlands. Flowering and fruiting were also still apparent at Woodlands in September 2018 (G. Phillips pers. obs. September 2018), the point all mature plants at Mount Dangar had succumbed to the drought (Bell and Lamrock 2021). This indicates that the species is sensitive to drought and changes in rainfall, given that Mount Dangar received substantially less rainfall over the course of 2018 and 2019 compared to Woodlands (Bell and Lamrock 2021).

The Hunter Region in which *S. linearifolius* var. *dangarensis* occurs is projected to become hotter, have fewer colder nights under 2°C annually, and more hot days over 35°C annually (CSIRO and BOM 2022; AdaptNSW 2023). Additionally, the time spent in drought is projected to increase on the East Coast through the 21st century (CSIRO 2023). Therefore, it is highly plausible that more frequent and severe droughts driven by these changes in climate will impact the *S. linearifolius* var. *dangarensis* population in the future. That *Senecio linearifolius* var. *dangarensis* possesses a relatively short-lived soil seedbank, that germination is highly dependent on temperature and is strongest in winter (Mackenzie and Auld 2020), and that seedlings require moisture over successive years to prevent desiccation (Bell and Lamrock 2021), means that currently observed declines may become exacerbated into the future if drought increases in frequency and/or intensity due to these projected changes.

The Hunter Region is also projected to see changes in the seasonality of rainfall into the future, which may influence the germination rates and seedling survivorship of *Senecio linearifolius* var. *dangarensis.* Cool season rainfall from April to October has decreased by 10% since the late 1990's and this trend is projected to continue (CSIRO and BOM 2022; AdaptNSW 2023; CSIRO 2023). While annual rainfall totals are projected to increase to 2079 (AdaptNSW 2023), this is expected to be due to increases in extreme weather events in warmer months, with cool season rainfall, particularly in winter, projected to continue to decrease across the same period (CSIRO and BOM 2022; AdaptNSW 2023; CSIRO 2023). This presents a problem for *S. linearifolius* var. *dangarensis* as it germinates most strongly in winter (Mackenzie and Auld 2020) and is likely to have early seedling stages that are sensitive to desiccation as in related species (Gross and Mackay 2014). Furthermore, increases in extreme rainfall events during flowering and fruiting in Asteraceae can result in rapid degradation of seed as it develops, resulting in poor dispersal and lowered input to the soil seedbank (Gross and Mackay 2014). This means that not only are projected changes in seasonality of rainfall likely to exacerbate drought impacts (CSIRO and BOM 2022) but are also likely to exacerbate already observed declines in recruitment and seedling survivorship, and consequently the number of mature individuals, of *S. linearifolius* var. *dangarensis* into the future by limiting moisture at key stages of the species' lifecycle.

Altogether, it is considered that *Senecio linearifolius* var. *dangarensis* is sensitive to drought and changes in rainfall seasonality. It has been observed that *Senecio linearifolius* var. *dangarensis* is currently undergoing continuing decline in the number of mature individuals due to these mechanisms, particularly at Mount Dangar, with that trend inferred to continue given projected changes in climate for the region.

'Anthropogenic Climate Change' is listed as a Key Threatening Process under the *NSW Biodiversity Conservation Act 2016*.

Invasion and competition from Opuntia stricta

Previously, *Opuntia stricta* (Prickly Pear) was considered one of the most important threats to *Senecio linearifolius* var. *dangarensis*, particularly at Mount Dangar (NSW Scientific Committee 2005; Zimmer 2018). However, the current understanding of the population dynamics of *S. linearifolius* var. *dangarensis* indicates that weed infestations, including *O. stricta*, do not hamper germination or persistence *of S. linearifolius var.* dangarensis as much as first thought (S. Bell *in litt.* August 2022, S. Bell *in. litt*. November 2022). Additionally, in 2017 and 2018 a species of Cochineal (*Dactylopius opuntiae*) was introduced at Mount Dangar as a biological control for *O. stricta* (Bell and Lamrock 2021). The Cochineal population substantially expanded following the release and *Opuntia* biomass declined significantly. By 2021, *O. stricta* was considered to have reached a natural level of stabilisation (Bell and Lamrock 2021). Currently, no other species of weeds are considered a threat to this species (S. Bell *in litt.* August 2022).

However, it is inferred that *Opuntia stricta* is contributing to continuing decline in the quality and extent of habitat for *Senecio linearifolius* var. *dangarensis.* While the Cochineal appear to have stabilized the infestation of *O. stricta* at Mount Dangar, the weed is still present in reasonable numbers (over 300 cladodes in a 10 x 10 m plot) at that site (Bell and Lamrock 2021) and is similarly notable at Woodlands (G. Phillips pers. obs. September 2018). The Cochineal introduction is unlikely to ever eliminate *O. stricta* from Mount Dangar, and so the current levels of infestation are likely to persist without additional management effort (Bell and Lamrock 2021). Additionally, Cochineal are highly susceptible to heavy rainfall events which may detach the sessile organisms from the *O. stricta* cladodes so they cannot return to the cladode and perish (A. McConnachie pers. comm. 2019 in Bell and Lamrock 2021). This means that increased incidences of heavy rainfall as projected for the NSW North Coast (CSIRO and BOM 2022) may diminish the abundance of Cochineal and their impacts on *O. stricta*, while the weed biomass increases again with increased soil moisture (Bell and Lamrock 2021). This means that while *O. stricta* is currently unlikely to be significantly impacting numbers and/or persistence of *S. linearifolius* var. *dangarensis*, it is inferred to be contributing to declines in habitat extent and quality, and the possibility of this threat increasing once again in the future cannot be dismissed so long as the weeds persist at the sites.

Adverse Fire Regimes

The response to fire of *Senecio linearifolius* var. *dangarensis* is uncertain, although other *Senecio* species respond positively to disturbance, including fire (Wapstra *et al.* 2008). The most likely threat from fire would therefore be multiple, short interval fires that could potentially kill mature plants and deplete the seed bank. However, the species' short time to maturity of 7-18 months confers a level of tolerance to shorter fire intervals and reduces the risk of this threat.

Additionally, neither of the two known sites of *Senecio linearifolius* var. *dangarensis* has a history of high fire frequency. The known fire history of Mount Dangar consists of a patchy hazard reduction burn in 2010 on the slopes below the mountain, that did not affect the *Senecio* populations, and a wildfire that affected the entire peak in 1957–58 (NPWS Fire History Spatial Layer; Bell *et al.* 2022). The known fire history of the

Woodlands site only consists of hazard reduction burns in 2003 and 2013 (NPWS Fire History Spatial Layer).

Therefore while climate change projections indicate larger, more frequent fires covering the distribution of *Senecio linearifolius* var. *dangarensis* into the future (Abatzoglou *et al*. 2019; AdaptNSW 2022; Clarke *et al.* 2011; Jones *et al.* 2022), the tolerance to fire conferred by the species' ecology and the previous fire history of the area indicates that it is unlikely that projected changes will result in continuing decline in the habitat or abundance of *S. linearifolius* var. *dangarensis* with any certainty.

Lack of fire in the surrounding landscape may also restrict successful seed dispersal and establishment of *S. linearifolius* var. *dangarensis. Senecio linearifolius* var. *dangarensis* is very highly geographically restricted, despite its small seeds having potential for wide dispersal by wind, suggesting that a disturbance to the surrounding vegetation such as fire is needed to open up habitat for successful seed establishment (Mickaill *et al.* 2020).

Therefore, adverse fire regimes are only considered a plausible future threat given the unknown response of *S. linearifolius* var. *dangarensis* to fire and the fact the taxon has not historically encountered frequent fire of any severity. Adverse fire regimes are also not a threat that is likely to rapidly drive the species to extinction in a rapid timeframe.

Assessment against IUCN Red List criteria

For this assessment it is considered that the survey of *S. linearifolius* var. *dangarensis* has been adequate and there is sufficient scientific evidence to support the listing outcome.

Criterion A Population size reduction

Assessment Outcome: Not met.

Justification: While *Senecio linearifolius* var. *dangarensis* has suffered an approximate 50% population reduction at Mount Dangar since monitoring began in 2016, no overall population reduction is yet evident across the population of the taxon. This is due to large increases in the Woodlands subpopulation following the breaking of the 2017–2019 drought offsetting losses at Mount Dangar (Bell and Lamrock 2021). Furthermore, despite projections of future climate scenarios that will likely exacerbate the localised declines seen at Mount Dangar as rainfall patterns and drought occurrences change, the overall magnitude of any future population reductions due to these causes are uncertain in magnitude and cannot be confidently calculated across a 10-year timeframe. Therefore, *S. linearifolius* var. *dangarensis* does not meet the thresholds for listing under Criterion A.

Criterion B Geographic range

Assessment Outcome: Endangered under Criterion B1ab(iii, v) and B2ab(iii, v)

Justification: *Senecio linearifolius* var. *dangarensis* has a very highly restricted geographic distribution. The Extent of Occurrence (EOO) has been calculated as 23 km^2, which meets the threshold for listing as Critically Endangered. The Area of Occupancy (AOO) has been calculated as 8 km^2, also meeting the threshold for Critically Endangered.

In addition to these thresholds, at least two of three other conditions must be met. These conditions are:

a) The population or habitat is observed or inferred to be severely fragmented or number of locations equals 1(CR), ≤5(EN), ≤10(VU).

Assessment Outcome: Endangered due to having two threat-defined locations.

Justification: *Senecio linearifolius* var. *dangarensis* is found at two threat-defined locations when considering the most serious plausible threat of of increased frequency of drought and changes in rainfall patterns resulting from climate change.

Senecio linearifolius var. *dangarensis* is not considered severely fragmented as all although both subpopulations are isolated and have a low chance of recolonization in the case of a localized extinction, both subpopulations are relatively large in number and are considered viable.

b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals.

Assessment Outcome: Met for continuing decline inferred in (iii) area, extent and quality of habitat, and (v) number of mature individuals.

Justification: Continuing decline is inferred in the area, extent and quality of habitat, and the number of individuals of *Senecio linearifolius* var. *dangarensis.* This is due to the effects of increased frequencies of drought and changes in rainfall patterns resulting from climate change, and invasion and competition from *Opuntia stricta*. During the 2017-2019 drought, there was a dramatic decline in mature individuals at both known locations of *S. linearifolius* var. *dangarensis* (Bell and Lamrock 2021). While numbers of *Senecio linearifolius* var. *dangarensis* appear to be rebounding at Woodlands to replenish pre-drought numbers, plant numbers at Mount Dangar had reduced by approximately 50% of pre-drought numbers by 2021 (Bell and Lamrock 2021) with further declines noted in 2022 (S. Bell *in litt.* August 2022). This indicates that the species is sensitive to drought and changes in rainfall, given that Mount Dangar received substantially less rainfall over the course of 2018 and 2019 compared to Woodlands (Bell and Lamrock 2021). Given that the Hunter Region in which *S. linearifolius* var. *dangarensis* occurs is projected to become hotter, have fewer colder nights under 2°C annually, and more hot days over 35°C annually (CSIRO and BOM 2022; AdaptNSW 2023) and the time spent in drought is projected to increase on the East Coast through the 21st century (CSIRO 2023), it is highly plausible that more frequent and severe droughts driven by these changes in climate will impact *S. linearifolius* var. *dangarensis* in the future. Furthermore, the Hunter Region is also projected to see changes in the seasonality of rainfall into the future, which may further influence the germination rates and seedling survivorship of *Senecio linearifolius* var. *dangarensis.* Cool season rainfall from April to October has decreased by 10% since the late 1990's and this trend is projected to continue into the future (CSIRO and BOM 2022; AdaptNSW 2023; CSIRO 2023), limiting moisture at key stages of the species' lifecycle. Habitat quality and extent is also adversely affected by the presence of *O. stricta* at both sites. While *O. stricta* is currently unlikely to be significantly impacting numbers and/or persistence of *S. linearifolius* var. *dangarensis*, it

is inferred to be contributing to declines in habitat extent and quality by limiting dispersal opportunities, and the possibility of this threat increasing once again in the future cannot be dismissed if the current biocontrol agent was to be negatively impacted through increased rainfall (Bell and Lamrock 2021). Therefore, continuing decline is inferred to continue in the area, extent and habitat, and the number of mature individuals of *S. linearifolius* var. *dangarensis.*

c) Extreme fluctuations.

Assessment Outcome: Not met.

Justification: *Senecio linearifolius* var. *dangarensis* is unlikely to undergo extreme fluctuations. The species maintains a soil seedbank and has the ability to reshoot in times of stress (Bell and Lamrock 2021). Recent cycles of mortality and recruitment from the soil seedbank also appear to be natural fluctuations in line with rainfall patterns (Bell and Lamrock 2021). This means that observed fluctuations are more likely to be part of long-term regeneration cycles, and so do not constitute extreme fluctuations as per IUCN (2022).

Criterion C Small population size and decline

Assessment Outcome: Not met.

Justification: The current estimated population of *S. linearifolius* var. *dangarensis* is approximately 27,500 mature individuals, exceeding the threshold for Vulnerable.

At least one of two additional conditions must be met. These are:

C1. An observed, estimated or projected continuing decline of at least: 25% in 3 years or 1 generation (whichever is longer) (CR); 20% in 5 years or 2 generations (whichever is longer) (EN); or 10% in 10 years or 3 generations (whichever is longer) (VU).

Assessment Outcome: Not met.

Justification: While *Senecio linearifolius* var. *dangarensis* has suffered an approximate 50% population reduction at Mount Dangar in the seven years since monitoring began in 2016, no overall population reduction is yet evident across the population of the taxon. This is due to large increases in the Woodlands subpopulation following the breaking of the 2017–2019 drought offsetting losses at Mount Dangar (Bell and Lamrock 2021). Furthermore, despite projections of future climate scenarios that will likely exacerbate the localised declines seen at Mount Dangar as rainfall patterns and drought occurrences change, the overall magnitude of any future population reductions due to these causes are uncertain in magnitude, and cannot be confidently calculated across a 10-year timeframe.

C2. An observed, estimated, projected or inferred continuing decline in number of mature individuals.

Assessment Outcome: Met.

Justification: Continuing decline is inferred in the number of individuals of *Senecio linearifolius* var. *dangarensis.* This is due to the effects of increased

frequencies of drought and changes in rainfall patterns resulting from climate change.

However, at least 1 of the following 3 conditions also must be met:

a (i). Number of mature individuals in each subpopulation ≤50 (CR); ≤250 (EN) or ≤1000 (VU).

Assessment Outcome: Not met.

Justification: Both subpopulations of *Senecio linearifolius* var. *dangarensis* have >1,000 mature individuals. Currently, Mount Dangar is estimated to have 5,000 mature individuals, and there is estimated to be 22,500 mature individuals at Woodlands.

a (ii). % of mature individuals in one subpopulation is 90-100% (CR); 95-100% (EN) or 100% (VU)

Assessment Outcome: Not met.

Justification: Current knowledge suggests the largest subpopulation of *Senecio linearifolius* var. *dangarensis* is the Woodlands subpopulation, which contains an estimated 81% of the total population, exceeding the thresholds for this criterion.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Not met.

Justification: *Senecio linearifolius var. dangarensis* is unlikely to undergo extreme fluctuations. The species maintains a soil seedbank and has the ability to reshoot in times of stress (Bell and Lamrock 2021). Recent cycles of mortality and recruitment from the soil seedbank also appear to be natural fluctuations in line with rainfall patterns (Bell and Lamrock 2021). This means that observed fluctuations are more likely to be part of long-term regeneration cycles, and so do not constitute extreme fluctuations as per IUCN (2022).

Criterion D Very small or restricted population

Assessment Outcome: Not met.

Justification: *Senecio linearifolius var. dangarensis* is currently estimated to have a minimum population of at least 27,500 mature individuals.

To be listed as Vulnerable under Criterion D, a species must meet at least one of the two following conditions:

D1. Population size estimated to number ≤50 (CR), ≤ 250 (EN), or ≤1,000 (VU) mature individuals.

Assessment Outcome: Not met.

Justification: *Senecio linearifolius var. dangarensis* is currently estimated to have a minimum population of at least 27,500 mature individuals.

D2. Population with a very restricted area of occupancy (typically less than 20 km^2) or number of locations (typically five or fewer) such that it is prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and is thus capable of becoming CR or even EX in a very short time period.

Assessment outcome: Not met.

Justification: *Senecio linearifolius* var. *dangarensis* has an AOO of 8 km^2 and it occurs at only two locations. However, the currently identified threats of increased frequency of drought and changes in rainfall patterns resulting from climate change, invasion and competition from *Opuntia stricta*, and adverse fire regimes are all unlikely to drive *S. linearifolius* var. *dangarensis* to CR or EX in a very short time period of one to two generations based on current observations, and so Criterion D2 is not met.

Criterion E Quantitative Analysis

Assessment outcome: Data Deficient.

Justification: Currently there is not enough data to undertake a quantitative analysis to determine the extinction probability of *S. linearifolius* var. *dangarensis*.

Conservation and Management Actions

Senecio linearifolius var. *dangarensis* is currently listed on the NSW *Biodiversity Conservation Act 2016* and a conservation project has been developed by the NSW Department of Planning and Environment under the Saving our Species program. The conservation project identifies priority locations, critical threats and required management actions to ensure the species is extant in the wild in 100 years. *Senecio linearifolius* var. *dangarensis* sits within the Site-managed species stream of the SoS program.

Activities to assist this species currently recommended by the SoS program (OEH 2019; DPE 2023) include:

Habitat loss, disturbance and modification

- Biological, chemical and physical control of weeds. Biological control agents to include cochineal and/or cactoblastis.
- Implement appropriate fire regime for the species.

Ex situ conservation

- Maintain viable ex-situ seedbank and/or living collection.

Survey and monitoring

- Monitor mortality, reproduction and threats within the population.
- Undertake surveys to identify unrecorded subpopulations.
- Maintain permanent monitoring plots in known sites and record information on plant numbers, recruitment, weed species and general condition and health of plants. In case of wildlife increase frequency of monitoring regime.
- Monitor species response to wildfire and/or hazard reduction burning to determine appropriate fire regime.
- Conduct aerial survey when the species is in flower and take high resolution digital images. In conjunction with aerial survey conduct ground truthing to

determine the extent of occurrence and obtain information on population size, density and age class structure.
- Quantitative assessment of pest animal abundance/density/activity using appropriate methodology or qualitative estimate, including motion detection camera trapping.
- Monitor species recruitment and adult condition immediately post fire event and subsequently every 6 months for 3 years.
- Mapping of weeds (specifically *Opuntia*) through the use of walked transects into pre-prepared grids, and notes recorded on weed presence, density and evidence of biological control agents (Cochineal and/or Cactoblastis).

Information and Research Priorities

- Research ecological requirements and fire ecology of the species.

References

Abatzoglou JT, Williams AP, Barbero R (2019) Global emergence of anthropogenic climate change in fire weather indices. *Geophysical Research Letters* **46**, 326–336.

AdaptNSW (2023) Interactive climate change projections map. Available at: https://www.climatechange.environment.nsw.gov.au/projections-map?region=south-east-and-tablelands&climateprojection=tasmean&range=0 (accessed on 26 September 2023)

Bachman S, Moat J, Hill AW, de la Torre J, Scott B (2011) Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool, in Smith V & Penev L (eds) e-Infrastructures for data publishing in biodiversity science. *ZooKeys* **150**, 117–126. (Version BETA)

Bell SAJ (1997) Vegetation survey and mapping of Crown land, south of Manobalai Nature Reserve, Upper Hunter Valley. Report to the Department of Land and Water Conservation and the NSW National Parks and Wildlife Service, Upper Hunter District.

Bell SAJ (1998) Wollemi National Park vegetation survey. A fire management document. Report to the NSW National Parks and Wildlife Service, Upper Hunter District.

Bell SAJ (2016) Research plan: Ecology and management of threatened flora species at Mt Dangar, Hunter Valley, New South Wales. October 2016.

Bell, SAJ (2017) Mt Dangar Multi-species Saving our Species Project: Year 1 (2016-2017) Summary Report. Unpublished Report to NSW National Parks and Wildlife Service. June 2017. Eastcoast Flora Survey.

Bell, SAJ (2018) Mt Dangar Multi-species Saving our Species Project: Year 2 (2017-2018) Summary Report. Unpublished Report to NSW National Parks and Wildlife Service. October 2018. Eastcoast Flora Survey.

Bell, SAJ, Lamrock P (2020) Mt Dangar Multi-species Saving our Species Project: Year 3 (2018-2019) Summary Report. Unpublished Report to NSW National Parks and Wildlife Service. January 2020. Eastcoast Flora Survey.

Bell SAJ, Lamrock P (2021) Mt Dangar Multi-species Saving our Species Project: Year 5 (2020-2021) Summary Report. Unpublished DRAFT Reportv2 to NSW National Parks and Wildlife Service. August 2021. Eastcoast Flora Survey.

Bell SAJ, Lamrock P, Haines HA, Turney C (2022). Multiple lines of evidence infer centurial-scale habitat change and resilience in a threatened plant species at Mount Dangar, Hunter Valley, New South Wales. *Australian Journal of Botany* **70(6)**: 432–446.

CHAH (Council of Heads of Australian Herbaria) (2023). Australian Plant Name Index. URL: https://biodiversity.org.au/nsl/services/rest/name/apni/191823/api/apni-format (accessed 18 October 2023).

Clarke HG, Smith PL, Pitman AJ (2011) Regional signatures of future fire weather over eastern Australia from global climate models. *International Journal of Wildland Fire*, ***20*(4)**, 550-562.

CSIRO (2023). Climate Change in Australia: East Coast South projection summaries. URL: https://www.climatechangeinaustralia.gov.au/en/projections-tools/regional-climate-change-explorer/sub-clusters/?current=ECSC&tooltip=true&popup=true (Accessed 26 September 2023).

CSIRO and the Bureau of Meteorology (BOM) (2022). State of the Climate 2022. CSIRO and the Bureau of Meteorology, Commonwealth of Australia. URL: http://www.bom.gov.au/state-of-the-climate/2022/documents/2022-state-of-the-climate-web.pdf (Accessed 26 September 2023).

Davies RJP (2009). *The Monitoring of the Impact of Fire and Hydrological Change on the Nationally Threatened Daisy* Senecio macrocarpus *in Messent Conservation Park in the Upper South East of South Australia, 1992-2009.* Consultants report prepared for South East Region, Department for Environment & Heritage, South Australia.

DPE (Department of Planning and Environment) (2023). Project: *Senecio linearifolius* var. *dangarensis*. Extracted from Saving Our Species database 4.9.0. NSW Department of Planning and Environment (Accessed 26 September 2023).

Fallding M, Bell S, Murray M (1997) Myambat vegetation and fauna management. Guidelines for Landscape Management at the Myambat Logistics Company Site. Report by Land and Environment Planning to the Department of Defence.

Gardner DR, Thorne MS, Molyneux RJ, Pfister JA, Seawright AA (2006) Pyrrolizidine alkaloids in *Senecio madagascariensis* from Australia and Hawaii and assessment of possible livestock poisoning. *Biochemical Systematics and Ecology* **34**, 736–744.

Gross CL, Mackay D (2014). Two decades of demography reveals that seed and seedling transitions limit population persistence in a translocated shrub. *Annals of Botany* **114**: 85-96.

Harden GJ (1992) Flora of New South Wales. Volume 3. (University of NSW Press, Kensington.)

Hill L (1999) Goulburn River National Park and Munghorn Gap Nature Reserve vegetation survey for fire management purposes. Report to the NSW National Parks and Wildlife Service, Upper Hunter District.

Hill L, Peake T, Bell S, Raine A (2002) Vegetation survey and mapping of Towarri National Park, Cedar Brush Nature Reserve and Wingen Maid Nature Reserve. Report to the NSW National Parks and Wildlife Service, Upper Hunter District.

IUCN Standards and Petitions Subcommittee (2022) Guidelines for Using the IUCN Red List Categories and Criteria, Available at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf (accessed on 8 August 2022)

Jones MW, Abatzoglou JT, Veraverbeke S, Andela N, Lasslop G, Forkel M, Smith A JP, Burton C, Betts RA, Werf GR, Sitch S, Canadell JG, Santín C, Kolden C, Doerr SH, Le Quéré, C (2022). Global and regional trends and drivers of fire under climate change. *Reviews of Geophysics*, https://doi.org/10.1029/2020rg000726

Lawrence ME (1985) *Senecio* L. (Asteraceae) in Australia: reproductive biology of a genus found primarily in unstable environments. *Australian Journal of Botany* **33**: 197–208.

Lachmuth S, Heinrichmann C, Horn J, Pagel J, Schurr FM (2017) Neighborhood effects on plant reproduction: An experimental-analytic framework and its application to the invasive *Senecio inaeqidens. Journal of Ecology*, **106(2)**, 761–773.

Mickaill LN, Bell SA, Beranek CT (2020) Dispersal potential in two restricted and five wide-ranging *Senecio* (Asteraceae) taxa from central eastern New South Wales, Australia. *Australian Journal of Botany*, **68(5)**, 333–344.

Mackenzie BDE, Auld TD (2020) Seed Ecology of *Senecio linearifolius* var. *dangarensis:* Year 1 Progress Report (Oct 2018-Dec 2019).

NSW Scientific Committee (2005) *Senecio linearifolius* var. *dangarensis* (a shrub) – endangered species listing. Available at https://www.environment.nsw.gov.au/Topics/Animals-and-plants/Threatened-species/NSW-Threatened-Species-Scientific-Committee/Determinations/Final-determinations/2004-2007/Senecio-linearifolius-var-dangarensis-a-shrub-endangered-species-listing (accessed 8 August 2022).

OEH (Office of Environment and Heritage) (2019). Senecio linearifolius var. dangarensis – profile. URL: https://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=20041# (accessed 26 September 2023).

Thompson IR (2004) Taxonomic studies in Australian *Senecio* (Senecioneae - Asteraceae). II. The shrubby discoid species and the allied radiate species *Senecio linearifolius*. *Muelleria* **20**, 67–110.

Vanparys V, Cawoy V, Mahaux O and Jacquemart AL (2011) Comparative study of the reproductive ecology of two co-occuring related plant species: the invasive *Senecio inaequidens* and the native *Jacobea vulgaris. Plant Ecology and Evolution* **144**: 3–11.

Wapstra M, Thompson IR, Buchanan AM (2008) An illustrated and annotated key to the Tasmanian species of Senecio (Asteraceae). *The Research Journal of the Tasmanian Museum and Art Gallery*, ***3*(2)**, 49.

Zimmer H (2018) Conservation Assessment of *Senecio linearifolius* var. *dangarensis.* Office of Environment and Heritage.

Expert Communications

Bell, Stephen. Consulting Botanist, East Coast Flora Survey. Newcastle, NSW.

APPENDIX 1

Assessment against *Biodiversity Conservation Regulation 2017* criteria
The Clauses used for assessment are listed below for reference.

Overall Assessment Outcome:
Senecio linearifolius var. *dangarensis* Belcher ex I.Thomps. was found to be Endangered under Clause 4.3 (b)(d)(e i,iii).

Clause 4.2 – Reduction in population size of species
(Equivalent to IUCN criterion A)
Assessment Outcome: Not met

(1) - The species has undergone or is likely to undergo within a time frame appropriate to the life cycle and habitat characteristics of the taxon:			
	(a)	for critically endangered species	a very large reduction in population size, or
	(b)	for endangered species	a large reduction in population size, or
	(c)	for vulnerable species	a moderate reduction in population size.
(2) - The determination of that criteria is to be based on any of the following:			
	(a)	direct observation,	
	(b)	an index of abundance appropriate to the taxon,	
	(c)	a decline in the geographic distribution or habitat quality,	
	(d)	the actual or potential levels of exploitation of the species,	
	(e)	the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.	

Clause 4.3 - Restricted geographic distribution of species and other conditions
(Equivalent to IUCN criterion B)
Assessment Outcome: Endangered under Clause 4.3 (b)(d)(e i,iii)

The geographic distribution of the species is:			
	(a)	for critically endangered species	very highly restricted, or
	(b)	for endangered species	highly restricted, or
	(c)	for vulnerable species	moderately restricted,
and at least 2 of the following 3 conditions apply:			
	(d)	the population or habitat of the species is severely fragmented or nearly all the mature individuals of the species occur within a small number of locations,	
	(e)	there is a projected or continuing decline in any of the following:	
		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	habitat area, extent or quality,

		(iv)	the number of locations in which the species occurs or of populations of the species,	
	(f)	extreme fluctuations occur in any of the following:		
		(i)	an index of abundance appropriate to the taxon,	
		(ii)	the geographic distribution of the species,	
		(iii)	the number of locations in which the species occur or of populations of the species.	

Clause 4.4 - Low numbers of mature individuals of species and other conditions (Equivalent to IUCN criterion C)
Assessment Outcome: Not met

The estimated total number of mature individuals of the species is:						
	(a)	for critically endangered species		very low, or		
	(b)	for endangered species		low, or		
	(c)	for vulnerable species		moderately low,		
and either of the following 2 conditions apply:						
	(d)	a continuing decline in the number of mature individuals that is (according to an index of abundance appropriate to the species):				
		(i)	for critically endangered species	very large, or		
		(ii)	for endangered species	large, or		
		(iii)	for vulnerable species	moderate,		
	(e)	both of the following apply:				
		(i)	a continuing decline in the number of mature individuals (according to an index of abundance appropriate to the species), and			
		(ii)	at least one of the following applies:			
			(A)	the number of individuals in each population of the species is:		
				(I)	for critically endangered species	extremely low, or
				(II)	for endangered species	very low, or
				(III)	for vulnerable species	low,
			(B)	all or nearly all mature individuals of the species occur within one population,		
			(C)	extreme fluctuations occur in an index of abundance appropriate to the species.		

Clause 4.5 - Low total numbers of mature individuals of species (Equivalent to IUCN criterion D)
Assessment Outcome: Not met

The total number of mature individuals of the species is:			
	(a)	for critically endangered species	extremely low, or
	(b)	for endangered species	very low, or
	(c)	for vulnerable species	low.

Clause 4.6 - Quantitative analysis of extinction probability
(Equivalent to IUCN criterion E)
Assessment Outcome: Data deficient

The probability of extinction of the species is estimated to be:			
	(a)	for critically endangered species	extremely high, or
	(b)	for endangered species	very high, or
	(c)	for vulnerable species	high.

Clause 4.7 - Very highly restricted geographic distribution of species–vulnerable species
(Equivalent to IUCN criterion D2)
Assessment Outcome: Not met

For vulnerable species,	the geographic distribution of the species or the number of locations of the species is very highly restricted such that the species is prone to the effects of human activities or stochastic events within a very short time period.