

1 **Population trends and effects of weedy bulbs on a highly restricted and critically**
2 **endangered clay pan endemic**

3

4 Carl R. Gosper^{A,*}, Kate Brown^B, Anne Harris^C, Tanya M. Llorens^A and Grazyna
5 Paczkowska^D

6

7 Author affiliations

8 ^ABiodiversity and Conservation Science, Department of Biodiversity, Conservation and
9 Attractions, Locked Bag 104, Bentley Delivery Centre, WA 6983, Australia

10 ^BAlbany, WA 6330, Australia

11 ^CSwan Coastal District, Parks and Wildlife Service, Department of Biodiversity,
12 Conservation and Attractions, 5 Dundobar Rd, Wanneroo WA 6065, Australia

13 ^DSwan Region, Parks and Wildlife Service, Department of Biodiversity, Conservation and
14 Attractions, Cnr Australia II Drive and Hackett Drive, Crawley WA 6009, Australia

15 * Correspondence to: Carl R. Gosper

16 Email: carl.gosper@dbca.wa.gov.au

17

18

19 Word Count: Abstract - 250 Main text (incl Refs) - 4272

20

21 Number of Tables: 0

22 Number of figures: 4

23

24

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

25 **Abstract**

26 **Context.** Conservation management of threatened flora is best underpinned by dedicated and
27 structured monitoring and experimental programs that provide an understanding of
28 population trends, demographic responses to threats, and the effectiveness of threat
29 mitigation actions. Obtaining this information can be particularly challenging for species with
30 extremely small population sizes or extents where larger-scale adaptive management
31 approaches may be deemed too high-risk. **Aims.** To understand population trends in the
32 critically endangered *Ptilotus pyramidatus* in the context of weed threats, in what at the time
33 was the only known population. **Methods.** Fixed quadrat ramet counts were conducted over
34 six years in a 'before-after-control-impact' design of three treatments: a largely weed-free
35 Reference; a Weedy treatment with high cover of *Sparaxis bulbifera*; and a Weeded
36 treatment with manual *S. bulbifera* removal. In a glasshouse, the impact of exposure of *P.*
37 *pyramidatus* to the herbicide metsulfuron methyl was tested. **Key results.** Abundance of *P.*
38 *pyramidatus* ramets did not differ with treatment and remained similar over time. Hand
39 weeding maintained low cover of *S. bulbifera*, while *S. bulbifera* cover in Weedy plots also
40 decreased over time without management. Glasshouse *P. pyramidatus* was susceptible to
41 metsulfuron methyl. **Conclusions.** The population of *P. pyramidatus* appears stable.
42 Application of metsulfuron methyl for *S. bulbifera* control will need robust testing on
43 potentially sacrificial *P. pyramidatus* individuals in a field context before it could be
44 considered for wider use in *P. pyramidatus* habitat. **Implications.** Understanding the impacts
45 of threats and effectiveness of threat mitigation actions can assist in prioritising management
46 resources.

47
48 **Keywords:** herbicide; off-target impact; population monitoring; *Ptilotus pyramidatus*; south-
49 west Australia; threat mitigation; threatened flora; weed management

51 **Introduction**

52 Conservation management of threatened flora is best underpinned by ecological monitoring
53 that provides an understanding of temporal population trends, demographic responses to
54 natural ecological and anthropogenic threatening processes, and the effectiveness of threat
55 mitigation actions (Lindenmayer *et al.* 2012). Obtaining this information requires dedicated
56 and structured monitoring and experimental programs, especially as most threatened flora are

57 affected by multiple co-occurring and likely interacting threats (Burgman *et al.* 2007). In
58 jurisdictions with numerous threatened flora, prioritisation among potentially competing
59 priorities may also be required, adding to the need for decision making based on evidence
60 (Bottrill *et al.* 2008). Particular challenges can arise in obtaining the information required to
61 inform management for species with extremely small population sizes or extents. In these
62 cases, large-scale adaptive management approaches may be deemed too high risk, or it may
63 be logistically and technically difficult to obtain independent and replicated experimental
64 units to test different management approaches.

65 Conservation management of the critically endangered *Ptilotus pyramidatus* (Moq.) F.Muell
66 is a case in point. The species was described based on a specimen collected by Drummond
67 from an uncertain location in the 1840s. The species was then not collected for over 160
68 years and was presumed extinct until 2012, when taxonomic research clarified that a newly
69 described species was synonymous with *P. pyramidatus* (Davis and Tausch 2011; Davis 2012).
70 The only population of *P. pyramidatus* known at this time occurred in an ephemeral clay pan
71 (winter-wet) on the eastern Swan Coastal Plain, within the city of Perth, Western Australia
72 (Fig. 1a). While a range of putative threats to the species have been identified (DPaW 2016),
73 there has previously been no long-term monitoring of the population, nor quantitative
74 assessment of the impact of specific threats, nor of the effectiveness of threat mitigation
75 actions.

76 The Interim Recovery Plan for *P. pyramidatus* (DPaW 2016) listed threats of weed invasion,
77 hydrological changes, inappropriate fire regimes, disturbance by recreational activities and
78 waste dumping, browsing by rabbits, disease (particularly *Phytophthora*), poor genetic
79 diversity and off-site impacts in a rapidly industrialising and urbanising landscape. Land
80 managers have historically applied some weed management in the area, particularly using the
81 herbicide metsulfuron methyl to control southern African geophytes such as *Sparaxis*
82 *bulbifera* (L.) Ker Gawl. and *Moraea flaccida* (Sweet) Steud., which can exclude native flora
83 through forming dense populations in ephemeral clay pans (Brown and Brooks 2003; Gibson
84 *et al.* 2019). However, it is not known whether *P. pyramidatus* is susceptible to the herbicide,
85 and hence whether metsulfuron methyl can be used in *P. pyramidatus* populations with
86 acceptable levels of off-target impact (i.e. any deleterious effects of the herbicide are lesser
87 than the effects of ongoing weed invasion; Gosper *et al.* 2025).

88 The aims of this study were to:

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

- 89 i) Monitor temporal trends in abundance and flowering in the Perth population of *P.*
90 *pyramidatus*.
- 91 ii) Determine if the abundance of weeds, particularly the key threats of *S. bulbifera*
92 and *M. flaccida*, changes over time in plots with *P. pyramidatus*.
- 93 iii) Determine if greater weed abundance is associated with lower *P. pyramidatus*
94 abundance, and alternatively, if weed removal (through hand weeding) increases
95 *P. pyramidatus* abundance.
- 96 iv) In a controlled glasshouse environment, test the susceptibility of *P. pyramidatus*
97 to metsulfuron methyl.

98

99 **Materials and methods**

100 *Study species and ecosystem*

101 *Ptilotus pyramidatus* is a rhizomatous perennial herb that is plausibly clonal, hence the
102 number of genetically and physically distinct individuals in the population is unknown (Fig.
103 1e, 2b). Based on the small extent of occurrence, area of occupancy and number of
104 individuals, combined with a single subpopulation being known at the time, *P. pyramidatus* is
105 considered critically endangered under the Western Australian *Biodiversity Conservation Act*
106 *2016* (B1ab(iii)+2ab(iii); D) and the Australian *Environment Protection and Biodiversity*
107 *Conservation Act 1999* (B1, B2(a)(b)(iii), C2(a)(ii)) (DPaW 2016; TSSC 2016; WA
108 Government Gazette 2025). After the initiation of this study, a second subpopulation of *P.*
109 *pyramidatus* was discovered in 2022, geographically far removed from the Perth
110 subpopulation (Paczkowska and Davis 2022;
111 <https://florabase.dbca.wa.gov.au/browse/profile/2753>).

112 Ephemeral clay pans on the Swan Coastal Plain are characterised by an extremely rich and
113 endemic flora, with high rates of species turnover both within and between clay pans (Gibson
114 *et al.* 2005, 2019). The eastern Swan Coastal Plain, in which the Perth population of *P.*
115 *pyramidatus* occurs, supports an exceptionally high number of threatened and priority flora
116 species and populations (Gosper *et al.* 2021). Many ephemeral clay pans that are putatively
117 similar to that in which the Perth population occurs have been cleared for agricultural, urban
118 and industrial development (Gibson *et al.* 2005, 2019), contributing to *Clay pans of the Swan*
119 *Coastal Plain* being federally listed as a critically endangered ecological community (TSSC

120 2012) and *Shrublands on dry clay flats* being listed under state legislation as endangered
121 (WA Government Gazette 2023). Whether *P. pyramidatus* occurred (or occurs) at any other
122 extant clay pans on the Swan Coastal Plain is unknown, but targeted searches have been
123 unsuccessful.

124

125 *Field monitoring of Ptilotus pyramidatus and weed populations with weed control treatments*

126 The density of *P. pyramidatus* ramets (defined in the field as separate above-ground entities)
127 was monitored from 2016-2021 in thirty 50 x 50 cm plots in which *P. pyramidatus* was
128 present. These plots were distributed equally among three treatments: (i) 10 plots in
129 'Reference' condition, having little to no bulbous weed cover at the start of the sampling
130 period and in native vegetation of good or better quality (Fig. 1a); (ii) 10 plots in 'Weedy'
131 condition, having moderate to high initial cover of *S. bulbifera* and no weed management
132 over the sampling period (Fig. 1b); and (iii) 10 plots in 'Weeded' condition, having moderate
133 to high initial cover of *S. bulbifera* and with annual hand removal of *S. bulbifera* under wet
134 soil conditions (winter) from 2017-2021 (Fig. 1c,d).

135 Corners of plots were marked with metal pegs and each plot was divided into 100 5 x 5 cm
136 subsamples through the overlay of a fixed metal grid (Fig. 1c,d). The gridded subsamples
137 were used to achieve accurate counts of the number of leaf rosettes (ramets) and flowering
138 stems of *P. pyramidatus*, with counts aggregated at the plot level for analysis. Plot cover of
139 the weeds *S. bulbifera*, and aggregated weedy annuals (including the grasses *Briza maxima*,
140 *B. minor*, *Aira caryophyllea*, *Vulpia* sp., and the herbs *Heliophila pusilla*, *Bellardia viscosa*,
141 *Hypochaeris glabra*, *Petrorhagia dubia*, *Sonchus oleraceus*, *Lotus* sp.) was visually
142 estimated in 7 classes (0, <1%, 1-5%, 5-25%, 25-50%, 50-75% and >75%; with midpoints of
143 these classes used in statistical analyses) across the whole plot. Signs of disturbance within
144 plots and grazing of *P. pyramidatus* by mammals were noted. Plots were established and
145 sampled in October 2016 prior to weed removal from Weeded plots in August 2017, and then
146 the Weeded plots were weeded in August and all the plots sampled annually in October from
147 2017 to 2021, in a before-after-control-impact design.

148

149 *Glasshouse trial of herbicide effects on Ptilotus pyramidatus*

150 *Ptilotus pyramidatus* was propagated from cuttings in the Kings Park and Botanic Garden
151 accredited nursery, from collections in November 2017. Multiple individual plants were
152 propagated from six different accessions, collected from spatially separate locations in the
153 natural population. The six accessions likely represent genetically independent individuals,
154 but this is not definitively known, with above-ground plants potentially connected through
155 below-ground rhizomes (DPaW 2016). Individual cuttings were placed in a separate cell in
156 trays, then potted up to tubes as they grew and then to pots 125 mm diameter. Ample water
157 and fertiliser were provided. In September 2019, plants were transferred to a glasshouse at
158 CSIRO Floreat, where plants were watered for 5 minutes daily.

159 *Sparaxis bulbifera* plants were transplanted from an invasive wild-growing population near to
160 the *P. pyramidatus* population. Collections were made in July 2019, after winter rains had
161 waterlogged the soil and leaves growing from corms had emerged from the ground. A trowel
162 was used to dig underneath the corm (or corms, as sometimes multiple individuals could not
163 be separated and were transplanted together) to collect the growing shoots, corm and
164 surrounding soil. Commercial potting mix was added to fill 125 mm diameter pots, and the
165 plants transferred to the CSIRO glasshouse. Pots of both species were randomly intermingled,
166 with placement within the glasshouse rotated fortnightly.

167 Each accession of *P. pyramidatus* was represented by 10 plants, which were divided equally
168 between herbicide and control treatments (i.e. total n per treatment of 6 accessions x 5
169 replicates). The 34 *S. bulbifera* pots were also divided between herbicide and control
170 treatments. The herbicide treatment was applied on 11 September 2019 by a professional
171 weed control contractor. All plants of both species were removed from the glasshouse and
172 divided into treatment and control groups. Treatment plants were sprayed with metsulfuron
173 methyl 0.2 g 15 L⁻¹ + Pulse® (penetrant polydimethylsiloxane 100 g L⁻¹) + dye; a formulation
174 known to be effective in controlling *S. bulbifera* at this stage of the growing season in the
175 field, with application timed for corm exhaustion at flowering (Brown and Brooks 2003).
176 Plants of both treatments were returned to the glasshouse after four hours.

177 From week three after treatment onwards, plants were monitored weekly, recording whether
178 plants were alive or dead. The experiment was terminated on 19 December 2019.

179

180 *Growth form*

181 On termination of the herbicide experiment, the below-ground plant structure of several of
182 the surviving *P. pyramidatus* control treatment plants was examined by carefully removing
183 the surrounding potting mix.

184

185 *Statistical analysis*

186 The number of *P. pyramidatus* ramets and cover of annual weeds from the field plot data was
187 analysed using the repeated measures ANOVA module in Statistica 7.1
188 (<https://docs.tibco.com/products/tibco-statistica-14-0-0>), with a repeated measures factor of
189 year (six levels; 2016, 2017, 2018, 2019, 2020 and 2021) and a between-group factor of
190 treatment (three levels; Reference, Weedy and Weeded). As weed control occurred between
191 2016 and 2017 samples, an effect of weed control would be represented by a time \times treatment
192 interaction. Annual weed cover was \log_{10} transformed. Change in cover of *S. bulbifera* over
193 time was assessed in the two treatments where *S. bulbifera* cover was not systematically
194 manipulated (Weedy and Reference) by linear regression, fitted using the polynomial
195 standard curves regression module of Sigmaplot 10.0 (<https://grafiti.com/>). The absence of
196 flowering *P. pyramidatus* from some treatment and year combinations precluded robust
197 analysis of effects of treatments on reproduction.

198 Two-factor ANOVA was used to test the effect of herbicide treatment (treated vs. control)
199 and accession (considered a random factor) on *P. pyramidatus* survival at the end of the
200 experiment. The effect of herbicide treatment on survival in *Sparaxis* was tested with a *t*-test
201 based on data at week 8 post-spraying, beyond which seasonal withering confounded
202 treatment effects.

203

204 **Results**

205 *Field monitoring of Ptilotus pyramidatus and weed abundance and flowering*

206 The abundance of *P. pyramidatus* ramets did not significantly differ with treatment (Weeded,
207 Weedy and Reference), suggesting limited impacts of *S. bulbifera* on *P. pyramidatus*
208 populations, notwithstanding that *P. pyramidatus* abundance tended to be lower in Weedy
209 plots (Fig. 3a). Nor was there an interaction of treatment and year, indicating no effect of
210 hand weeding on *P. pyramidatus* abundance. *Ptilotus pyramidatus* ramet abundance did

211 differ between sample years, peaking in 2019, but with no consistent increase or decrease
212 over the entire sample period, nor an obvious relationship with precipitation (Fig. 3d).

213 Flowering was infrequent, precluding robust statistical analysis, but there was an indication
214 of a difference between treatments and over time (Fig. 3b). No flowering was recorded in any
215 of the ten Weedy plots in any of the six sample years. Flowering was recorded in a single
216 Weeded plot, not in the single pre-weeding year, but in four of the five post-weeding years.
217 Half of Reference plots had flowering stems in at least one year, and in all years some
218 flowering was recorded in Reference plots. Minimal flowering was recorded in 2018 and
219 2021, which were the wettest years over the sample period.

220 Approximately 15% of the 180 plot \times year combinations were affected by putative mammal
221 diggings, most likely either indigenous quenda (*Isoodon obesulus*) or invasive rabbits
222 (*Oryctolagus cuniculus*). Noticeably browsed foliage of *P. pyramidatus* was recorded in ~3%
223 of plot \times year combinations.

224 Annual hand weeding of *S. bulbifera* earlier in the growing season kept cover of *S. bulbifera*
225 low at the time of plant sampling in Weeded plots (Fig. 4a). In Weedy plots, there was a
226 significant trend for declining cover of *S. bulbifera* over the monitoring period (Fig. 4a). In
227 contrast, in Reference plots, cover of *S. bulbifera* increased over the monitoring period,
228 noting that even with this increase, cover of *S. bulbifera* in Reference plots remained very
229 low (Fig. 4b). Annual hand removal of *S. bulbifera* did not lead to replacement by other
230 weeds, with annual weed cover not showing a time \times treatment interaction, although there
231 was a pronounced increase in annual weed cover in Weeded plots in the first year of weeding
232 but this increase was not maintained over subsequent years. Unsurprisingly, given that
233 Reference plots were chosen because of their better condition, cover of annual weeds was
234 less in Reference than either Weeded or Weedy plots (Fig. 3c). There was no evidence for a
235 trend in annual weed cover over time.

236

237 *Effect of herbicide on glasshouse-housed Ptilotus pyramidatus*

238 The metsulfuron methyl herbicide treatment caused high mortality in *P. pyramidatus* housed
239 in the glasshouse, with 83.3% of treated plants dead by the end of the experiment. Control
240 plants not exposed to herbicide had significantly lower mortality (10%; Treatment $F_{1,5} =$
241 55.0, $P < 0.0001$). Clone identity had no effect on survival (Accession $F_{5,48} = 0.91$, $P = 0.48$;

242 Treatment \times Accession $F_{5,48} = 1.26$, $P = 0.30$). As expected, the herbicide treatment was
243 effective in killing *S. bulbifera* housed in the glasshouse ($t_{1,32} = -3.65$; $P < 0.001$).

244

245 *Growth form*

246 Single cutting-derived individuals grown in the glasshouse developed multiple above-ground
247 shoots over the course of the experiment (Fig. 2a). When these were excavated, the shoots
248 diverged above tubers (Fig. 2b). At the time of excavation, new above-ground shoots were
249 not developing separate tubers to the parental shoot, although multiple tubers developing
250 below shoot divergence were recorded on some individuals. Unlike the wild population
251 where plants are dormant over the hot, dry summer period, there was no evidence that above-
252 ground parts of individuals housed in the glasshouse under conditions of plentiful water were
253 withering by early summer, suggesting water limitation rather than photoperiod cues for
254 seasonal dormancy.

255

256 **Discussion**

257 Invasive plants are frequently cited as threats to native flora (Kearney *et al.* 2019). Our
258 experimental manipulations of *S. bulbifera* cover suggests that *P. pyramidatus* ramet
259 abundance was not strongly affected by invasive bulb occurrence, with little evidence that
260 high invasive bulb cover depressed *P. pyramidatus* populations over the monitoring period,
261 nor that invasive bulb removal increased *P. pyramidatus* abundance. While many studies
262 have shown that abundant invasive plants can have strong suppressive effects on native
263 species (Davies 2011; Pyšek *et al.* 2012), other studies have concluded that invasive plants
264 have marginal impacts on native plant diversity (Meffin *et al.* 2010; McDougall *et al.* 2025).
265 *Ptilotus pyramidatus* appears to be able to persist with *S. bulbifera*, at least under the
266 conditions experienced over the period of monitoring. Case-by-case variation in the degree of
267 impact by invasive plants, likely associated with traits of the invader, native plants and
268 recipient ecosystems, and chance historical factors, emphasises the value in directly
269 measuring weed impacts on conservation assets.

270 Further, there was a declining trend in *S. bulbifera* cover at Weedy (unmanaged) plots over
271 time, contrasting with a slight increase in cover at Reference plots and other studies that have

272 recorded increased weed occurrence in local clay pans over time (Gibson *et al.* 2019). The
273 mechanism underpinning this outcome is not known, illustrating the lack of data and
274 understanding of the ecological processes regulating the demography of seasonally active
275 flora (native and invasive) in ephemeral clay pans. Important avenues for further research
276 include the effects of changing hydrological regimes associated with long-term declining
277 rainfall in south-western Australia (Delworth and Zang 2014) and rapid and recent urban and
278 industrial development of the catchment of the specific clay pan under study.

279 Hand removal of invasive bulbs had no detectably deleterious impact on *P. pyramidatus*
280 ramet abundance, nor on the cover of other weeds. This finding indicates that hand weeding,
281 which is admittedly labour-intensive, is a risk-free approach for *S. bulbifera* management
282 amongst *P. pyramidatus* for broader conservation of ephemeral clay pans where *S. bulbifera*
283 and other weeds are having substantial impact (Brown and Brooks 2003; Gibson *et al.* 2019).

284 Although flowering was sparse across all plots, there was an indication that Reference plots
285 supported more flowering, and Weedy plots notably had no flowering recorded at all over the
286 six years sampled. Established *P. pyramidatus* ramets may be able to persist in the presence
287 of invasive bulbs, but this possible difference in flowering performance suggests that weeds
288 may be compromising long-term persistence through reducing sexual reproductive output.
289 However, there are two caveats with this finding. First, there are no data on rates of seedling
290 recruitment or ramet turnover to provide context for these possible impacts on reproductive
291 output. Second, it is possible that differences in flowering between Reference and both
292 Weedy and Weeded plots are associated with environmental factors, rather than levels of
293 weed invasion. A plausible explanation for differences in flowering output across years is that
294 flowering occurred later in those years of longer inundation over winter-spring, as there was
295 no or minimal flowering in October in the two wettest years of the sample period.

296 The finding that metsulfuron methyl caused extensive mortality in glasshouse-housed *P.*
297 *pyramidatus* indicates that substantial caution is needed in using this herbicide to control *S.*
298 *bulbifera* where the two species co-occur. Herbicide effectiveness is typically greater in
299 actively growing plants, and for resprouting perennials when the herbicide is translocated to
300 and kills the underground buds (Sosebee and Dahl 1992). It is possible that greater tolerance
301 of *P. pyramidatus* to metsulfuron methyl would occur in management scenarios. Glasshouse-
302 housed *P. pyramidatus* with unlimited water reached greater stature (greater leaf area to
303 intercept herbicide; Fig. 1,2), had higher rates of flowering (C. Gosper pers. obs.) and

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

304 retained leafy shoots later in the season than individuals in the natural population, which is
305 highly suggestive that individuals in the glasshouse were more actively growing than those in
306 the field would be at the time of optimal herbicide application for *S. bulbifera* control. The
307 relative allocation of resources to tubers between glasshouse and field individuals is also
308 unknown, but may mediate differential responses to herbicide. Any field metsulfuron methyl
309 application near *P. pyramidatus* would need testing of effects on a small sample of
310 potentially sacrificial individuals (as per Gosper *et al.* 2025).

311 The population monitoring conducted in this study suggests that the Swan Coastal Plain
312 subpopulation of *P. pyramidatus* is stable. Continuation of population monitoring is
313 recommended – although perhaps a lower frequency of monitoring could be accommodated
314 but remain informative under resource limitations – to detect any change in population
315 trajectory. The effects of a range of putative threats to the species (DPaW 2016) remain to be
316 explored and it is plausible that the effects of geophyte weed management may become more
317 apparent in particular circumstances. After fire may be one such time. Fires are expected to
318 instigate enhanced flowering and recruitment potential in invasive geophytes through adults
319 that persist as dormant bulbs through fire events, whilst long-term adult removal may lead to
320 effective control following fire as these invasive geophytes have a short-lived seed bank (Le
321 Maitre and Brown 1992; Keeley and Bond 1997; Brown and Paczkowska 2008). More
322 broadly, this study provides an example of the value of regular monitoring of populations of
323 threatened flora with consistent methods, and integration with experimental manipulations to
324 test the effects of putative threats and threat mitigation actions, as an approach for informing
325 management priorities.

326

327 **Permits.** The research was conducted under Section 40 Authorisations DRF 156-1617 and
328 TFL 168-1920.

329 **Data availability.** Raw data will be made publicly available through the Department of
330 Biodiversity, Conservation and Attraction's Data Catalogue
331 (<https://data.bio.wa.gov.au/about>) on article acceptance.

332 **Conflicts of interest.** The authors declare they have no conflicts of interest.

333 **Declaration of funding.** This work received no specific funding.

334 **Acknowledgements.** We thank Bruce Webber, Kathryn Batchelor and Jenny Reidy-Crofts of
335 CSIRO Health and Biosecurity for access to glasshouse facilities and for providing
336 equipment for undertaking the herbicide experiment. The conservation nursery at Kings Park
337 and Botanic Garden grew on propagated *P. pyramidatus* used for the herbicide experiment, at
338 which we acknowledge the work of Amanda Shade and the nursery team. Malcolm Barker of
339 Environmental Weed Management provided the glasshouse herbicide treatment free of
340 charge. We thank Fiona Felton, Veronica Wilson and Aimee Connell for field assistance.

341 **Author contributions.** Conceptualisation, field – KB, AH, GP; Data collection, field – all
342 authors; Conceptualisation and data collection, glasshouse – CRG; Data analysis and writing
343 lead – CRG; Writing, review and editing – all authors.

344

345 **References**

346 Brown K, Brooks K (2003) *Sparaxis bulbifera* (Iridaceae) invading a clay based wetland on
347 the Swan Coastal Plain – control methods and observations on the reproductive biology.
348 *Plant Protection Quarterly* **18**, 26–29.

349 Brown K, Paczkowska G (2008) Seed biology of two invasive South African geophytes and
350 implications for natural area management. *Ecological Management & Restoration* **9**,
351 232–234. <https://doi.org/10.1111/j.1442-8903.2008.00425.x>

352 Bottrill MC, Joseph LN, Carwardine J, Bode M, Cook C, Game ET, Grantham H, Kark S,
353 Linke S, McDonald-Madden E, Pressey RL, Walker S, Wilson KA, Possingham HP
354 (2008) Is conservation triage just smart decision making? *Trends in ecology & evolution*
355 **23**, 649–654. <https://doi.org/10.1016/j.tree.2008.07.007>

356 Davies KW (2011) Plant community diversity and native plant abundance decline with
357 increasing abundance of an exotic annual grass. *Oecologia* **167**, 481–491.
358 <https://doi.org/10.1007/s00442-011-1992-2>

359 Davis RW (2012) *Ptilotus christineae* is synonymous with the previously Presumed Extinct
360 taxon *P. pyramidatus*. *Nuytsia* **22**, 335. <https://doi.org/10.58828/nuy00647>

361 Davis RW, Tauss C (2011) A new and rare species of *Ptilotus* (Amaranthaceae) from a
362 suburban wetland of the eastern Swan Coastal Plain, Western Australia. *Nuytsia* **21**,
363 97–102. <https://doi.org/10.58828/nuy00614>

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

- 364 Delworth T, Zeng F (2014) Regional rainfall decline in Australia attributed to anthropogenic
365 greenhouse gases and ozone levels. *Nature Geosciences* **7**, 583–587.
366 <https://doi.org/10.1038/ngeo2201>
- 367 Department of Parks and Wildlife (DPaW) (2016) ‘Pyramid mulla-mulla (*Ptilotus*
368 *pyramidatus*) interim recovery plan 2016–2021.’ Interim Recovery Plan No. 360.
369 (Department of Parks and Wildlife: Western Australia)
- 370 Gibson N, Brown K, Paczkowska G (2019) Temporal changes in threatened ephemeral
371 claypans over annual and decadal timescales in south-west Australia. *Australian Journal*
372 *of Botany* **66**, 609–617. <https://doi.org/10.1071/BT18067>
- 373 Gibson N, Keighery GJ, Lyons MN, Keighery BJ (2005) Threatened plant communities of
374 Western Australia. 2 The seasonal clay-based wetland communities of the South West.
375 *Pacific Conservation Biology* **11**, 287–301. <https://doi.org/10.1071/PC050287>
- 376 Gosper CR, Coates DJ, Hopper SD, Byrne M, Yates CJ (2021) The role of landscape history
377 in the distribution and conservation of threatened flora in the Southwest Australian
378 Floristic Region. *Biological Journal of the Linnean Society* **133**, 394–410.
379 <https://doi.org/10.1093/biolinnean/blaa141>
- 380 Gosper CR, Cullity J, Paczkowska G (2025) Control of African lovegrass by flupropanate in
381 a flora conservation context. *Australian Journal of Botany* **73**, BT25005.
382 <https://doi.org/10.1071/BT25005>
- 383 Kearney SG, Carwardine J, Reside AE, Fisher DO, Maron M, Doherty TS, Legge S, Silcock
384 J, Woinarski JCZ, Garnett ST, Wintle BA, Watson JEM (2019) The threats to Australia’s
385 imperilled species and implications for a national conservation response. *Pacific*
386 *Conservation Biology* **25**, 231–244. <https://doi.org/10.1071/PC18024>
- 387 Keeley JE, Bond WJ (1997) Convergent seed germination in South African fynbos and
388 Californian chaparral. *Plant Ecology* **133**, 153–167.
389 <https://doi.org/10.1023/A:1009748603202>
- 390 Le Maitre DC, Brown PJ (1992) Life cycles and fire stimulated flowering in geophytes. In
391 ‘Fire in South African mountain fynbos’ (Eds BW van Wilgen, DM Richardson, FJ
392 Kruger, HJ van Hensbergen), pp. 145–160. (Springer-Verlag: Berlin)
- 393 Lindenmayer DB, Gibbons P, Bourke M, Burgman M, Dickman CR, Ferrier S, Fitzsimons J,
394 Freudenberger D, Garnett ST, Groves C, Hobbs RJ, Kingsford RT, Krebs C, Legge S,
395 Lowe AJ, McLean R, Montambault J, Possingham H, Radford J, Robinson D, Smallbone
396 L, Thomas D, Varcoe T, Vardon M, Wardle G, Woinarski J, Zerger A (2012) Improving

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

- 397 biodiversity monitoring. *Austral Ecology* **37**, 285–294. <https://doi.org/10.1111/j.1442->
398 [9993.2011.02314.x](https://doi.org/10.1111/j.1442-9993.2011.02314.x)
- 399 McDougall KL, Miles J, Wright GT (2025) Ox-eye daisy (*Leucanthemum vulgare* Lam.)
400 invasion has only a small effect on the diversity of a subalpine grassland. *Australian*
401 *Journal of Botany* **73**, BT24059. <https://doi.org/10.1071/BT24059>
- 402 Meffin R, Miller AL, Hulme PE, Duncan RP (2010) BIODIVERSITY RESEARCH:
403 Experimental introduction of the alien plant *Hieracium lepidulum* reveals no significant
404 impact on montane plant communities in New Zealand. *Diversity and Distributions* **16**,
405 804–815. <https://doi.org/10.1111/j.1472-4642.2010.00684.x>
- 406 Paczkowska G, Davis R. (2022) A second lifeline for the critically endangered pyramid
407 mulla-mulla, *Ptilotus pyramidatus*. *Bushland News* **121**, 5-6.
408 <https://library.dbca.wa.gov.au/static/Journals/080662/080662-121.001.pdf> (accessed 31
409 January 2025)
- 410 Pyšek P, Jarošík V, Hulme PE, Pergl J, Hejda M, Schaffner U, Vilà M (2012) A global
411 assessment of invasive plant impacts on resident species, communities and ecosystems:
412 the interaction of impact measures, invading species' traits and environment. *Global*
413 *Change Biology* **18**, 1725–1737. <https://doi.org/10.1111/j.1365-2486.2011.02636.x>
- 414 Sosebee RE, Dahl BE (1992) Timing of herbicide application for effective weed control: a
415 plant's ability to respond. In 'Noxious range weeds' (Ed LF James) pp. 115–126. (CRC
416 Press: Boca Raton)
- 417 Threatened Species Scientific Committee (TSSC) (2012) 'Commonwealth listing advice on
418 Clay pans of the Swan Coastal Plain.' Department of Climate Change, Energy, the
419 Environment and Water. (Canberra: ACT). Available from:
420 <http://www.environment.gov.au/biodiversity/threatened/communities/pubs/121-listing->
421 [advice.pdf](http://www.environment.gov.au/biodiversity/threatened/communities/pubs/121-listing-advice.pdf) (accessed 15 August 2025)
- 422 Threatened Species Scientific Committee (TSSC) (2016) 'Conservation advice *Ptilotus*
423 *pyramidatus* pyramid mulla-mulla.' Department of Climate Change, Energy, the
424 Environment and Water. (Canberra: ACT). Available from:
425 <http://www.environment.gov.au/biodiversity/threatened/species/pubs/18216->
426 [conservation-advice-05052016.pdf](http://www.environment.gov.au/biodiversity/threatened/species/pubs/18216-conservation-advice-05052016.pdf) (accessed 15 August 2025)
- 427 WA Government Gazette (2023) 'Biodiversity Conservation (Threatened Ecological
428 Communities) Order 2023.' Friday 26 May 2023, No. 62. (Perth:WA). Available from:

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.

429 [https://www.legislation.wa.gov.au/legislation/prod/gazettestore.nsf/FileURL/gg2023_062.pdf/\\$FILE/Gg2023_062.pdf?OpenElement](https://www.legislation.wa.gov.au/legislation/prod/gazettestore.nsf/FileURL/gg2023_062.pdf/$FILE/Gg2023_062.pdf?OpenElement) (accessed 17 October 2025)

431 WA Government Gazette (2025) 'Biodiversity Conservation (Listing of Native Species) (Flora) Order 2025.' Tuesday 1 July 2025, No. 78. (Perth: WA). Available from:

432 [https://www.legislation.wa.gov.au/legislation/prod/gazettestore.nsf/FileURL/gg2025_078.pdf/\\$FILE/Gg2025_078.pdf?OpenElement](https://www.legislation.wa.gov.au/legislation/prod/gazettestore.nsf/FileURL/gg2025_078.pdf/$FILE/Gg2025_078.pdf?OpenElement) (accessed 21 November 2025)

435

436

Preprint

437 **Figure captions**

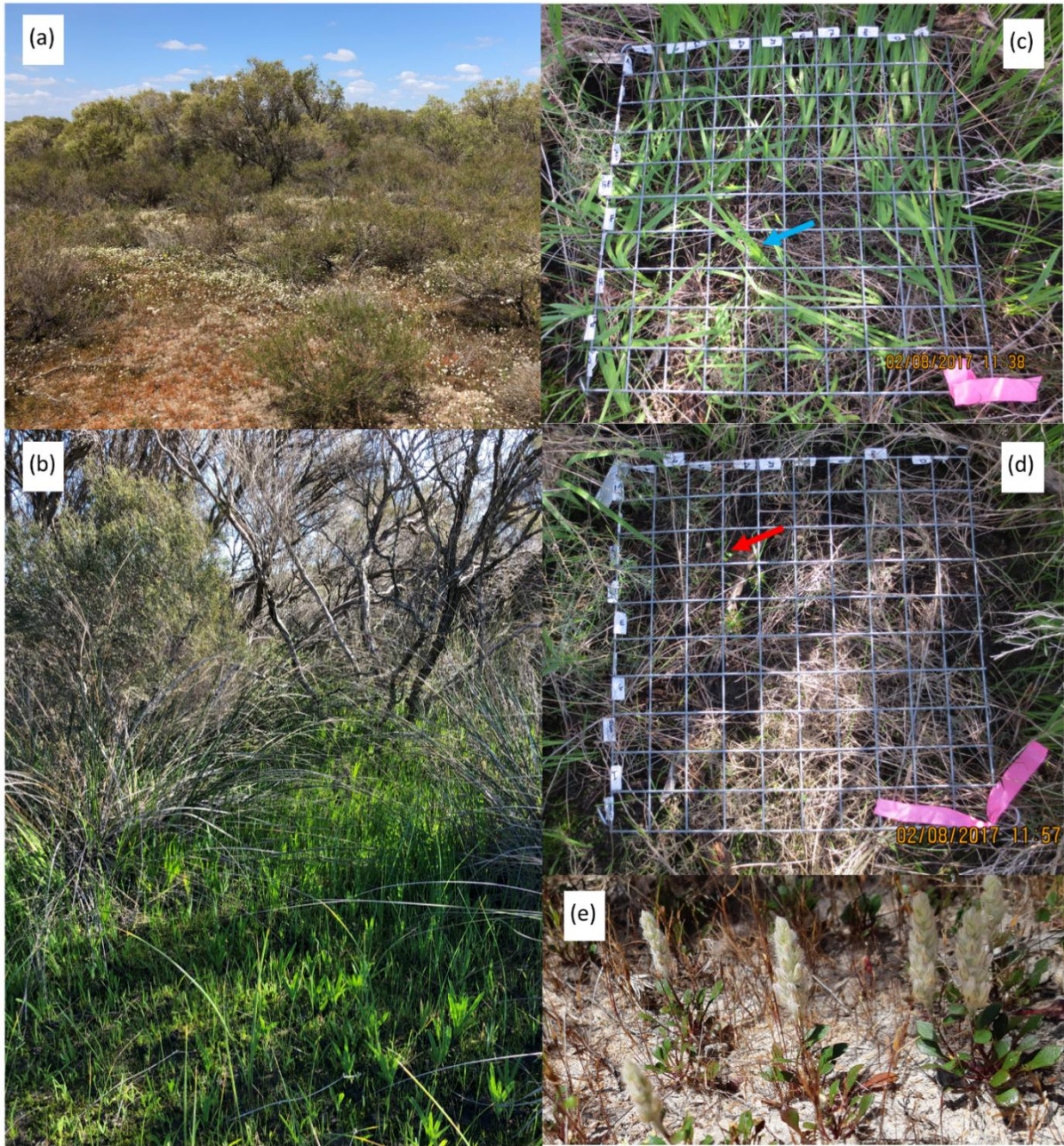
438 **Fig. 1.** (a) Winter-wet clay pan shrubland habitat, in very good condition, in which the Perth
439 population of *Ptilotus pyramidatus* occurs; (b) clay pan shrubland habitat, in degraded
440 condition, with extensive *Sparaxis bulbifera* invasion; (c) plot sampling grid over a Weeded
441 plot prior to the first experimental hand weed removal, with location of example *S. bulbifera*
442 (blue arrow) shown; (d) plot sampling grid over a Weeded plot immediately after the first
443 experimental hand weed removal, with location of example *P. pyramidatus* (red arrow)
444 shown; and (e) *P. pyramidatus* growing and flowering *in-situ* in vegetation of a condition
445 equivalent to Reference plots, showing plant growth form. Photos: G. Paczkowska (a, b), A.
446 Harris (c, d), C. Gosper (e).

447 **Fig. 2.** Cutting-propagated and glasshouse-grown individual of *P. pyramidatus* showing
448 development of multiple ramets (a); and (b) this individual after removal of potting mix,
449 showing development of storage tubers and ramet branching pattern, with approximate soil
450 level shown by a dashed pink line. Photos: C. Gosper.

451 **Fig. 3.** Effects of treatment (Weedy – high initial invasive bulb abundance, no weed removal;
452 Weeded – high initial invasive bulb abundance, annual hand removal of invasive bulbs from
453 2017 onwards; Reference – good condition vegetation with minimal invasive bulb abundance
454 in 2016) and time (Year) on (a) mean (\pm SE) number of *Ptilotus pyramidatus* ramets per plot,
455 with repeated measures ANOVA results; (b) mean (\pm SE) number of flowering *P.*
456 *pyramidatus* ramets per plot; (c) untransformed % cover (\pm SE) of annual weeds per plot, with
457 repeated measures ANOVA results based on log₁₀-transformed data; (d) annual precipitation
458 at the nearby Perth Airport (station number 009021; Bureau of Meteorology,
459 <http://www.bom.gov.au/climate/data/>, accessed 7 February 2025) over the sample period, in
460 the context of the long-term average. *** P<0.001, ** P<0.01, * P<0.05.

461 **Fig. 4.** Temporal trends in the cover of the invasive *Sparaxis bulbifera* under the three
462 experimental treatments: (a) Weedy – high initial invasive bulb abundance, no weed removal,
463 and Weeded – high initial invasive bulb abundance, annual hand removal of invasive bulbs
464 from 2017 onwards; (b) Reference – good condition vegetation with minimal invasive bulb
465 abundance in 2016. Linear regression models are shown for Weedy and Reference plots.
466 Note different scales in (a) and (b). *** P<0.001, ** P<0.01, * P<0.05.

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.



467

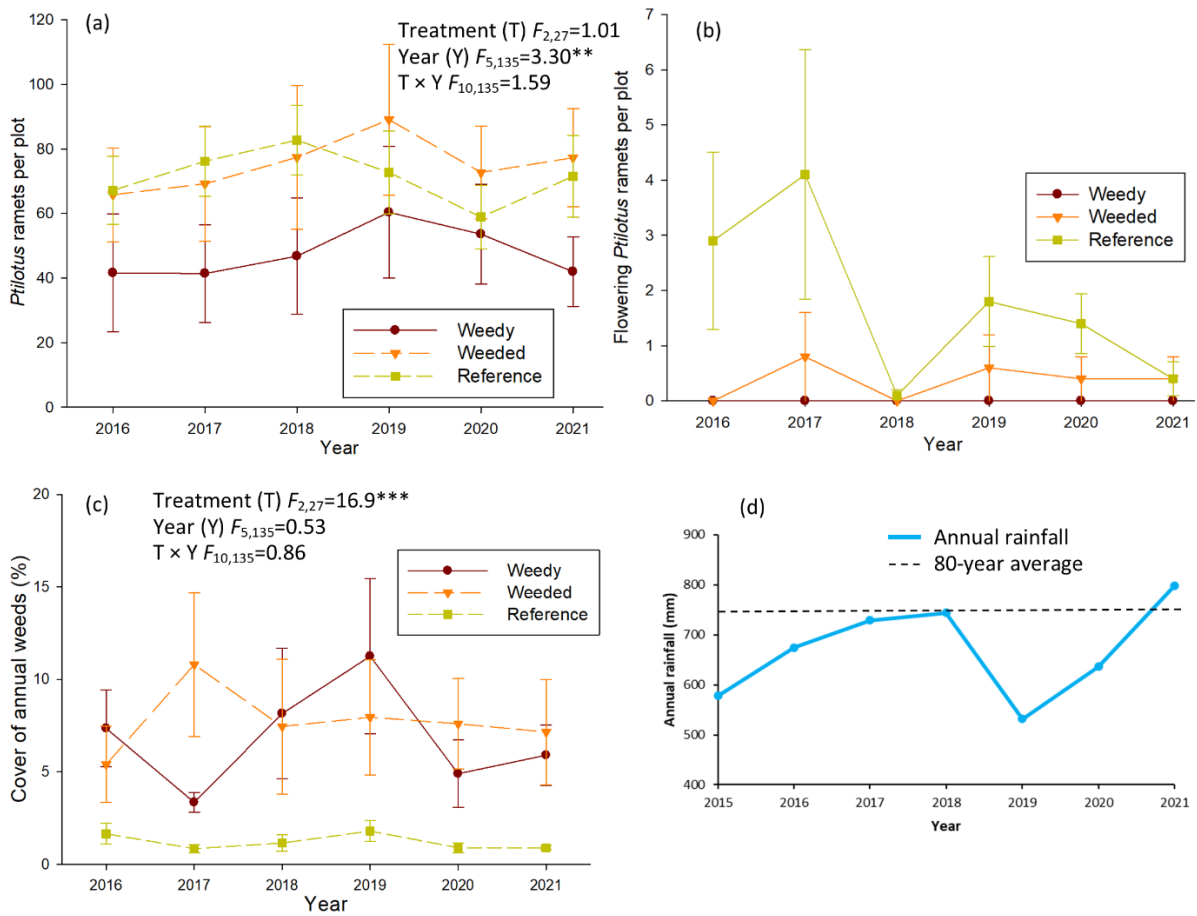
468 Fig. 1

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.



469

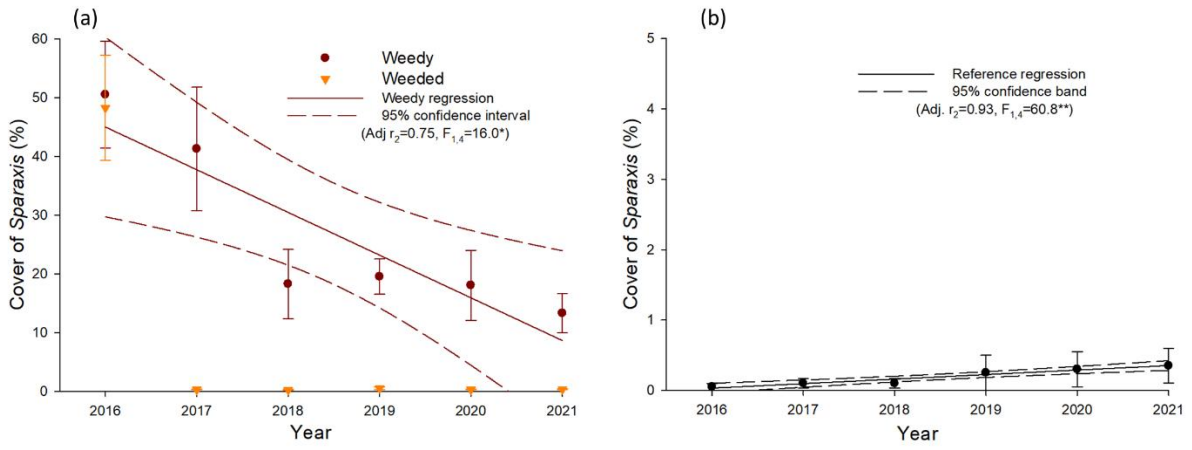
470 Fig. 2



471

472 Fig. 3

This version, posted 24 November 2025, is a **PREPRINT**. The copyright holder for this author's original manuscript (which has not been certified by peer review) is the author/Department of Biodiversity, Conservation and Attractions.



473

474 Fig. 4

475

476

477

478

Preprint