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## Historical and recent observations of male and female cones on specimens of the rare *Pherosphaera fitzgeraldii* (Podocarpaceae), Blue Mountains, eastern Australia

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### ABSTRACT

*Pherosphaera fitzgeraldii* Dwarf Mountain Pine, a rare conifer (Podocarpaceae) restricted to the Upper Blue Mountains in eastern Australia, is described in some sources as dioecious, like its closest relative Tasmanian *Pherosphaera hookeriana*. This review of early collections shows that dioecy was assumed from the first collection, but that monoecy was also recognised at that time. An assessment of 37 herbarium sheets with specimens from Sydney, Melbourne and Kew (UK) herbaria using recently available high-resolution photographs shows that monoecy is common in the species and has been under-reported. This review confirms current field observations of monoecy and provides new information about the reproductive system for those working on conservation of this critically endangered species.

### INTRODUCTION

The Dwarf Mountain Pine, *Pherosphaera fitzgeraldii* (F. Muell.) F. Muell. ex Hook.f., (Gymnosperm family Podocarpaceae) is a small, spreading, relict conifer species associated with waterfalls in the upper Blue Mountains, New South Wales, Australia (Smith 1981). Populations are highly localised and restricted to moist sites in the spray of a limited number of south-facing waterfalls at 600-900 m elevation between Wentworth Falls and Katoomba. Asexual reproduction by layering is common. A recent genetic study showed that the rate of clonality within populations is high and overall genetic diversity is low (McMaster et al. 2024). The species is listed as Endangered under the NSW *Biodiversity Conservation Act* (NSW Office of Environment and Heritage 2020) and recently as Critically Endangered on the schedule of the Commonwealth *Environment Protection and Biodiversity Act* (EPBC Act) (DCCEE 2025).

Many sources currently list the species *Pherosphaera fitzgeraldii* as being dioecious, including the NSW Office of Environment and Heritage (2020), DCCEE (2025), the Atlas of Living Australia (2025), and the IUCN Redlist (2013). The Gymnosperm Database (2025) lists the genus *Pherosphaera* as dioecious, as is the only other species *Pherosphaera hookeriana* from Tasmania (Threatened Species Section 2016). However, recent field observers have found both male and female cones on many reproductive plants of *Pherosphaera fitzgeraldii* across its populations (Richard Delaney pers. comm. 2024, Jan Allen pers. comm. 2024) and raised questions of dioecy versus monoecy, and how this has been reported historically. This paper reviews the original descriptions and collections



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## Observations on male and female cones on *Pherosphaera fitzgeraldii*

(from 1880-2016), now accessible through high resolution scanned images, and provides images of reproductive structures and cone seasonality on fresh material and herbarium specimens.

### Reproductive morphology

The male and female cones of *Pherosphaera fitzgeraldii* may not be particularly conspicuous, especially when immature. Male cones are just 4-6 x 3 mm when mature (Figure 1). Female cones are small, 2-4 mm long (Conifers of the World 2025).

Across the Podocarpaceae both male and female cones change significantly during their development (Figures 2 and 3). In early spring, the male cones resemble a small green ball that subsequently ripens to a red/brown colour at maturity, when the scales open to release pollen. The young female cones are easily mistaken for new leaf growth.

In summer, male cones with their open scales dry off to a woody brown colour. Female cones become more obvious as the light brown seeds swell against the fertile bracts and the cone flares into a star shape (Khan and Hill 2021).

In autumn the male cones disintegrate, sometimes leaving a persistent woody stalk behind after the scales break off (Figure 4). At maturity, the female cones release their seed, sometimes leaving the basal bracts behind. However, sometimes both male and female cones can persist on the plant for some months.

Observations from high-resolution photographs of 59 branchlets on 37 herbarium sheets graphed by month showed that cones of both sexes were present throughout the year. Observations peaked in summer; cones were mostly absent in April to July collections (Figure 5, Appendix 1).



Figure 1. A mature male cone of *Pherosphaera fitzgeraldii* against a human finger. Photo: Richard Delaney.



Figure 2. Female cones of *Pherosphaera fitzgeraldii* at different stages of development, starting top left and progressing to bottom right. Photos: Richard Delaney.

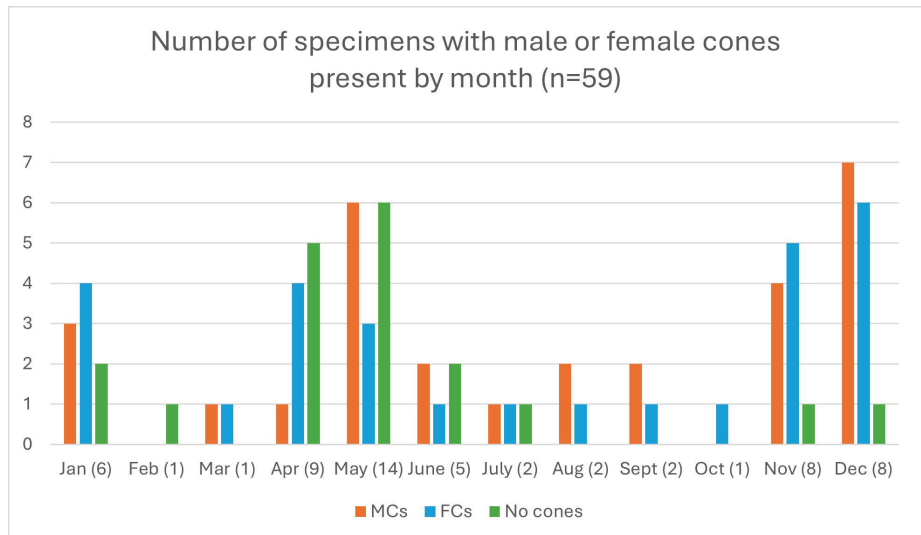


Figure 3. Male cones of *Pherosphaera fitzgeraldii* at different stages of development, progressing from top left to bottom right. Photos: Richard Delaney.





**Figure 4.** A woody stalk remaining after the scales of a male cone have broken off. Photo: Richard Delaney.



**Figure 5.** Cone seasonality - male and female cones present on branchlets by month of collection (collections 1880-2016). Field observations indicate pollen release in Sept/Oct and seed release in April/May (Richard Delaney pers. com. 2025).

### Early collections

*Pherosphaera fitzgeraldii* was described by Victorian botanist Ferdinand von Mueller in 1880 from gatherings collected at Katoomba Falls by Robert D. Fitzgerald, botanical collector, at that time employed in the NSW Surveyor General's Office in Sydney. No single specimen was designated as type, so Fitzgerald's gatherings are all syntypes and are present as four herbarium sheets in the National Herbarium of Victoria in Melbourne. One herbarium sheet (MEL256548) includes letter from Fitzgerald to Mueller, transcribed by the von Mueller Correspondence Project (Home et al.) and reproduced below (with original punctuation).

Surveyor General's Office, Sydney, 12 May 1880.  
Dear Baron

I enclose an extract from the Herald of the 8th which to overcome Reichenbachs objections I have also sent to the Gardeners Chronicle.

I also enclose what I take to be a very interesting specimen obtained under the actual falls at Katoomba water fall on the Blue Mountains.

It is a straggling shrub of about six or seven feet, very like a juniper I could not reconcile it with any of the pines of Tasmania but if it is one of them, it must at least be new to New South Wales I have never seen it before. If you should want them I think I can get specimens of both sexes but I could not see any cones when I found it.

Yours truly

Robt D Fitzgerald

Fitzgerald notes that this plant looked like a juniper, or perhaps one of the Tasmanian pines. These plants are all dioecious but he did not recognise any cones when he collected his specimen. 'I think I can get specimens of both sexes' indicates his intention to collect specimens of both male and female material.

This letter is dated 12 May 1880 and although the herbarium sheets lack a date, it is likely the collection was made in April or early May when female cones have mostly released their seed and bracts. The remnants of female cones can be challenging to identify at this stage and the male cones have also dried off and are likely disintegrating. Some may leave a woody stalk behind. Occasionally young male cone buds may be starting to develop in anticipation of the next spring. It is not surprising that Fitzgerald could not find any cones at this time of year, especially as he was unfamiliar with what to look for.

Examination of images of the four herbarium sheets bearing Fitzgerald's original collections (Figures 6-9) showed cones of both sexes. There are multiple branchlets and while it cannot be guaranteed that these have all been gathered from the same individuals, cones of both sexes are present (although few and difficult to see). This is the original material upon which Mueller based his description of *Dacrydium fitzgeraldii*. In his description, published in the *Fragmenta Phytographiae Australiae*, Mueller (1881a) described the male cones in some detail. He referred to the female "flowers" but did not describe them, beyond saying "*Flores feminei sicut fructus hactenus ignoti*" translating as "The female flowers are, like fruits, hitherto unknown". He used the words "*forsan dioicus*", translating to "perhaps dioecious". This was an acknowledgement of his limited knowledge at that time. He had not observed female cones and as a result could not be sure of the sexuality of the specimens.

Mueller eventually obtained some female material and sent a gathering, which he identified on the label as monoecious to Sir Joseph Hooker, the Director of the Royal Botanic Gardens, Kew, in London. This gathering is preserved as herbarium sheet K000289162, still held at the Royal Botanic Gardens, Kew, with a handwritten accompanying letter by Mueller dated 8 January, 1881 (Figure 10). This gathering may have been collected in late December or early January, when both male and female

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cones are relatively easy to see. The date annotation 3/81 is presumably when the gathering was received at Kew. Most of the letter is transcribed below.

8/1/1881

The fruit of the little *Dacrydium* (*D. fitzgeraldii*) of N S Wales has been found, dear Sir Joseph, and proves it to belong to *Pherosphaera*, if that genus is to be maintained. If so, then *Dacrydium Kirkii* of New Zealand must also be transferred to it. I send you the male and female, thinking that you might wish to figure this exceedingly...[remainder of last sentence of letter is hidden overleaf]

Inspection of the high-resolution image of the sheet with two branchlets reveals many male cones and possible remnants of female cones. The handwritten label identifies the plant as monoecious (Figure 11). On the sheet is a sketch of a female bract with a seed (Figure 12). Presumably this was drawn by Hooker, as was his custom, and it confirms the presence of female cones on the material. It is possible that the original gathering had more female cones on it at the time of collection but these can be fragile and may have been lost.

Hooker agreed with Mueller's suggestion of classifying the species as *Pherosphaera* rather than *Dacrydium* and included the species, with a plate showing a branchlet and details of the male and female cones and a description, in his *Icones Plantarum* (Hooker 1882). The plate drawn by M.S. shows a monoecious plant based on the gathering Hooker received from Mueller (Figure 13) and the Latin description begins with the word "monoica", translating to monoecious.

Mueller then submitted an article to the *Gartenflora*, which was reproduced (translated into English) in the *Gardener's Chronicle* (Mueller 1881b).

'A New Australian Conifer – We extract the following note by Baron Mueller from the *Gartenflora*:-"Recently a representative of the genus *Dacrydium* has been found in continental Australia ... *Dacrydium Fitzgeraldii* has hitherto only been found in small quantity in a single locality in the Blue Mountains, not so very far from Sydney; and it appears to be restricted to the cliffs of a solitary waterfall. So far as we know the species it does not exceed 10 feet in height. The lower part of the stem is creeping and rooting.

This species occurs both monicous and dioicous. When I first defined it for the *Fragmenta* I had neither female flowers nor fruits. These have since been found. And prove that the species belong to the section *Pherosphaera*, which may deserve generic status, though it only differs from the true *Dacrydia* in wanting the cupular disk of the fruit. In *D Kirkii* this organ is so reduced that this species also might be referred to *Pherosphaera*. The fruit of *D. Fitzgeraldii* strongly resembles that of *Pherosphaera Hookeriana*."

In this article Mueller now said the species occurred as 'both monoecious and dioecious', rather than the 'perhaps dioecious' that he used in his first description. However, this contradicts the information he provided to Hooker only a short time before, that the species was monoecious.



Figure 6. Syntype of *Pherosphaera fitzgeraldii* MEL255882. Details added by author. A – young male cone bud, B – young male cone bud, C – closed female cone, D – female cone with seed.





Figure 7. Syntype of *Pherosphaera fitzgeraldii* MEL255885. Details added by author. A – two young male cones buds, B – a young male cone bud, C – stalk of an old male cone, D – disintegrating male cone, E – remnant of a female cone, F – remnant of a female cone.



Figure 9. Syntype of *Pherosphaera fitzgeraldii* MEL256548. Details added by author. A – stalk of an old male cone (middle), remnants of female cone (right). B – closed female cone. C – closed female cone. D – remnants of an old female cone.

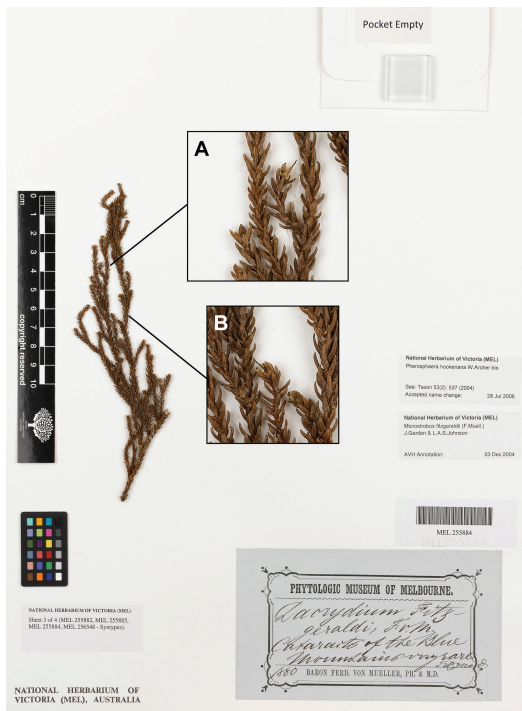


Figure 8. Syntype of *Pherosphaera fitzgeraldii* MEL255884. Details added by author. A – stalk of old male cone, remnants of female cone perhaps with seed. B – stalk of old male cone, and remnants of a female cone below it.

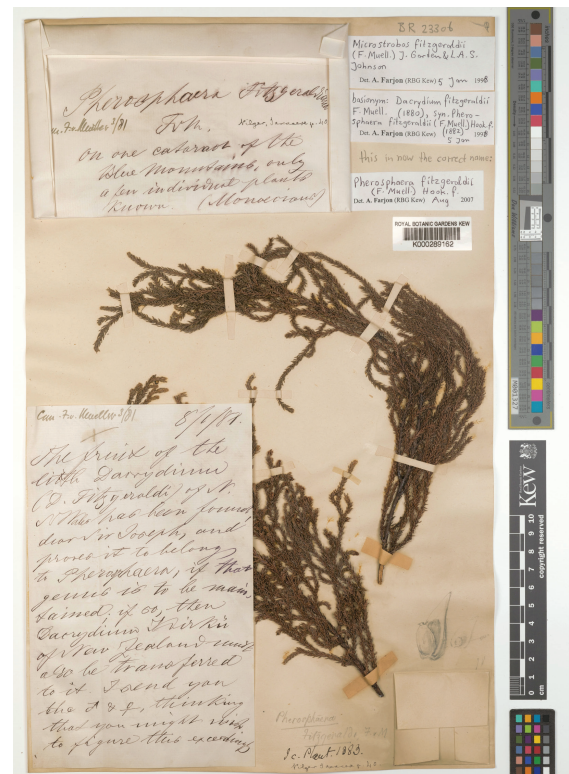


Figure 10. Specimen K000289162 held at Royal Botanic Gardens, Kew © RBG Kew.



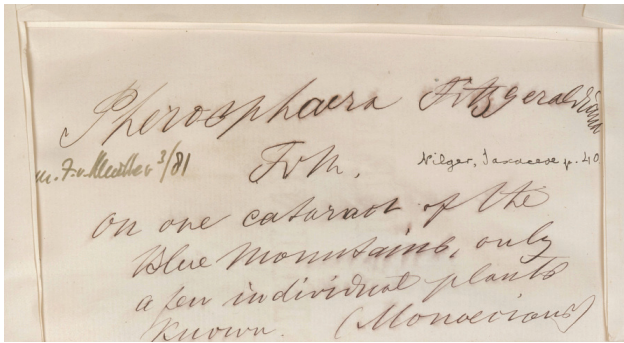


Figure 11. Detail from herbarium sheet K000289162 held at Kew Gardens © RBG Kew.



Figure 12. Detail from herbarium sheet K000289162 showing Hooker's sketch of a female bract with seed © RBG Kew.

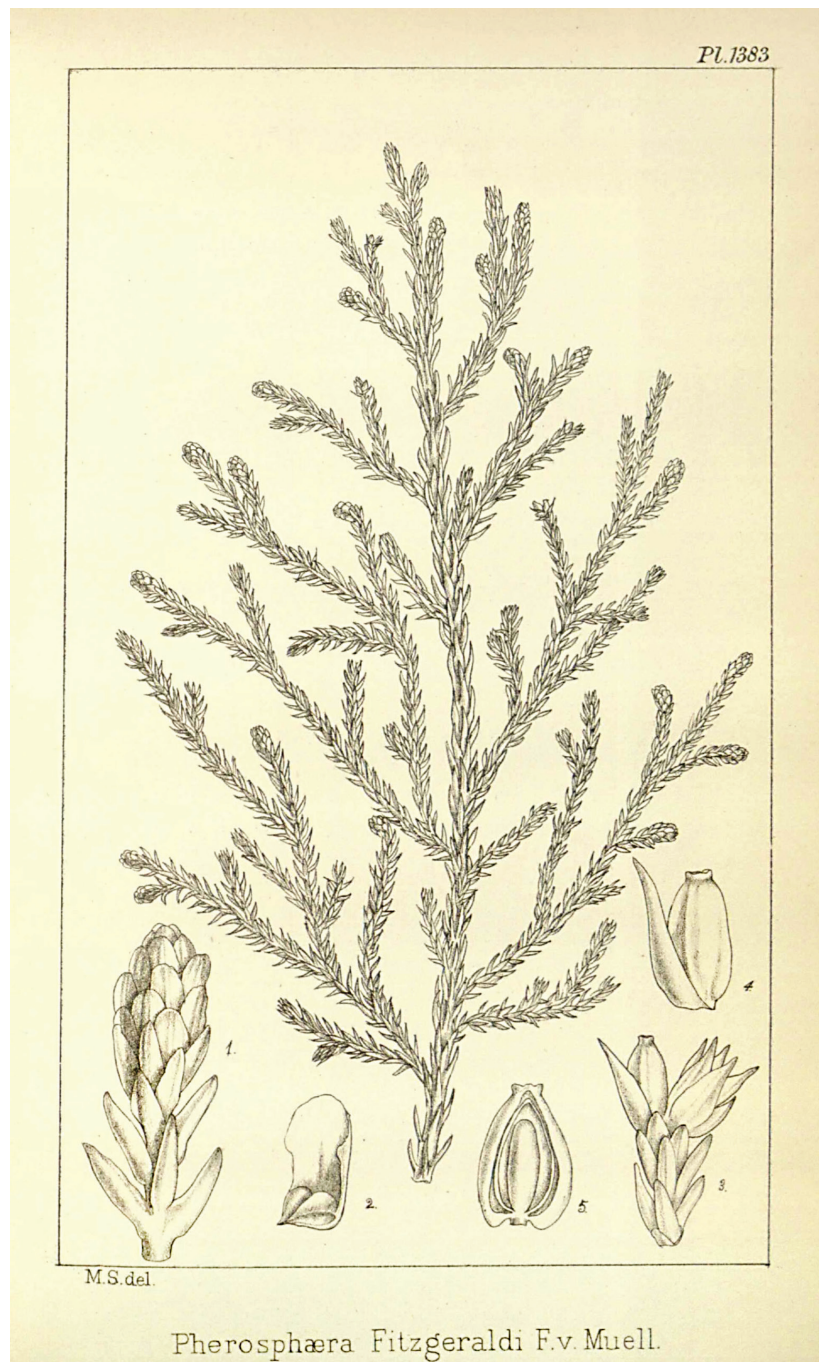


Figure 13. Hooker's plate (Hooker 1882) of *Pherosphaera fitzgeraldii* presenting it as monoecious. 1. Leaves and staminal column. 2. Anther. 3. Leaves and female cone. 4. Scale and young seed. 5. Vertical section of immature seed. All enlarged.



### Collections in the 20<sup>th</sup> Century

Recent programs to provide high quality images of herbarium sheets and make them available worldwide now provide the opportunity for researchers to re-examine and compare specimens in herbarium collections that were previously unavailable. To clarify the monoecious or dioecious state of *Pherosphaera fitzgeraldii*, high-resolution photographs of herbarium sheets held at the National Herbarium of NSW were reviewed.

Some of these herbarium sheets were allocated a single sex by the collector or a subsequent curator, evidently with the assumption of the species being dioecious. An 1899 collection by William Forsyth is labelled as from a female plant (NSW 22552), though there are both male and female cones present. This sheet (Figure 14) holds a collection of different branchlets so there is the possibility that these may have come from different plants, but as they are labelled as from a female plant, Forsyth presumably meant he had collected from one individual.

F.H. Taylor made a collection of two branchlets in 1909 (NSW381499) (Figure 15) and correctly noted that ‘female flowers’ are present, though there are also the remnants of male cones present on each branchlet.

William Blakely’s 1939 collection (NSW22549) (Figure 16) is labelled as from a female plant. There are certainly a lot of female cones present, but there are also very young male cones.

E.F. Constable made four collections in 1959, subsequently annotated by L.A.S. Johnson (K.L. Wilson pers. comm. 2025). He correctly annotated NSW52776 as monoecious, identifying both male and female cones, and NSW52774 as being male with an occasional female. However, NSW48631 and NSW52775 (Figures 17 and 18) were labelled as male, though female cones can also be found on both.

It should be noted that in the 19<sup>th</sup> and 20<sup>th</sup> centuries limited collections of dried specimens were the main resources for botanical study and are more restrictive

than studies with fresh material and access to a population of living plants. In the particular case of *Pherosphaera fitzgeraldii* its limited occurrence and its inaccessible cliff habitat below Blue Mountains waterfalls makes population studies difficult. Most populations have only been located since 1980 (Smith 1981).

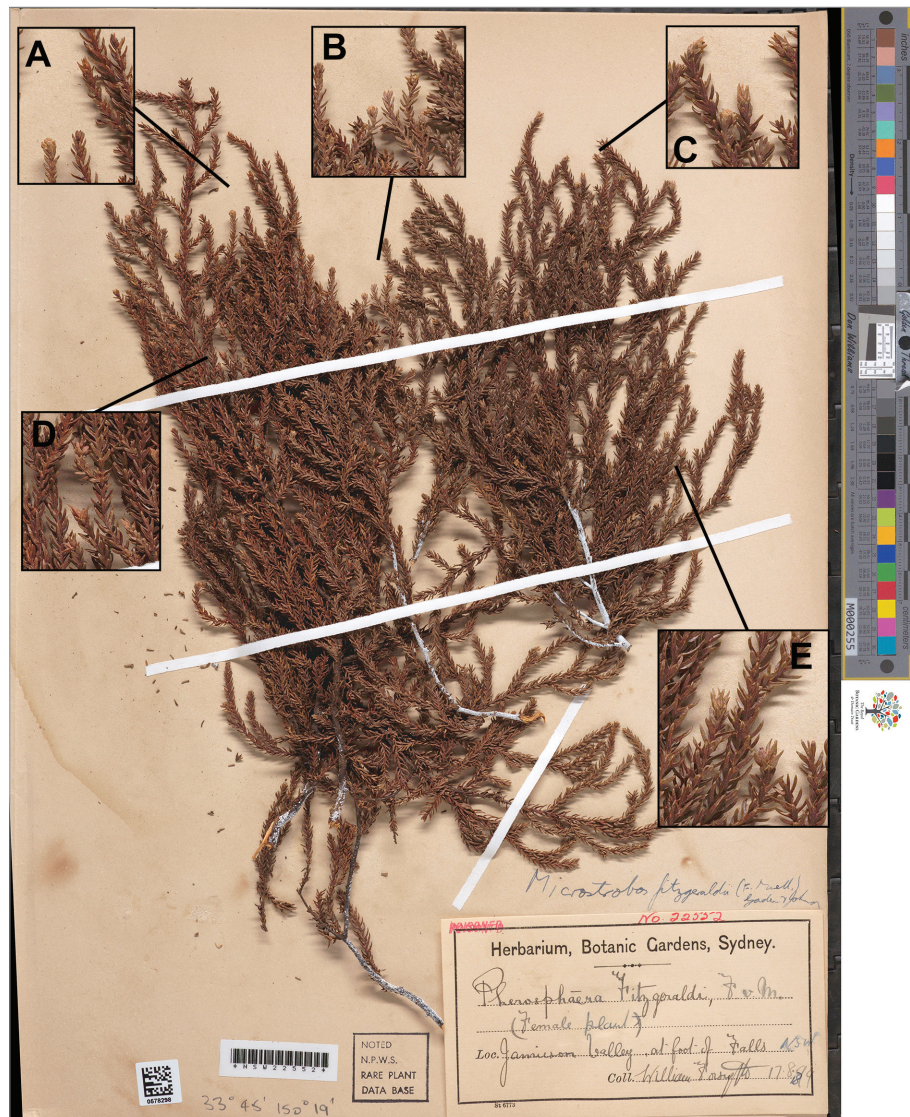


Figure 14. *Pherosphaera fitzgeraldii* NSW22552 annotated as a female plant by L.A.S. Johnson. A – young male cone bud (bottom left), closed female cone (top right). B – young male cone bud (middle), stalk of old male cone (middle right). C – young male cone bud (bottom), closed female cone (middle), remnant of female cone (upper left), closed female cone (upper right). D – remnants of female cones with some bracts still present. E – female cone with seed (bottom right), closed female cone (upper left).



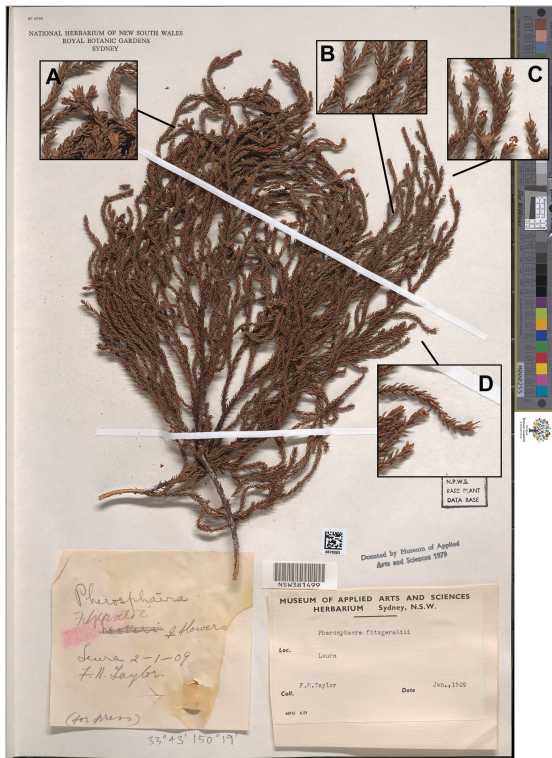


Figure 15. *Pherosphaera fitzgeraldii* NSW381499 annotated as having female flowers. A – multiple female cones, some with seed. B – remains of male cone with lower scales still present (lower left), female cone (upper right). C – four disintegrating male cones some with scales still present. At least two female cones with seed. D – two stalks of old male cones, remnants of a female cone on left.



Figure 17. *Pherosphaera fitzgeraldii* NSW48631 annotated as male. A – closed female cone. B – old male cone (lower right), closed female cone (upper left). C – at least two closed female cones, a young male cone bud (lower right). D – remnants of female cones. E – stalk of old male cone (upper middle), old male cone (lower middle).



Figure 16. *Pherosphaera fitzgeraldii* NSW22549 annotated as a female plant. A – female cone with seed, B – two young male cone buds with remnants of female cone behind the upper one. C – female cone with seed.



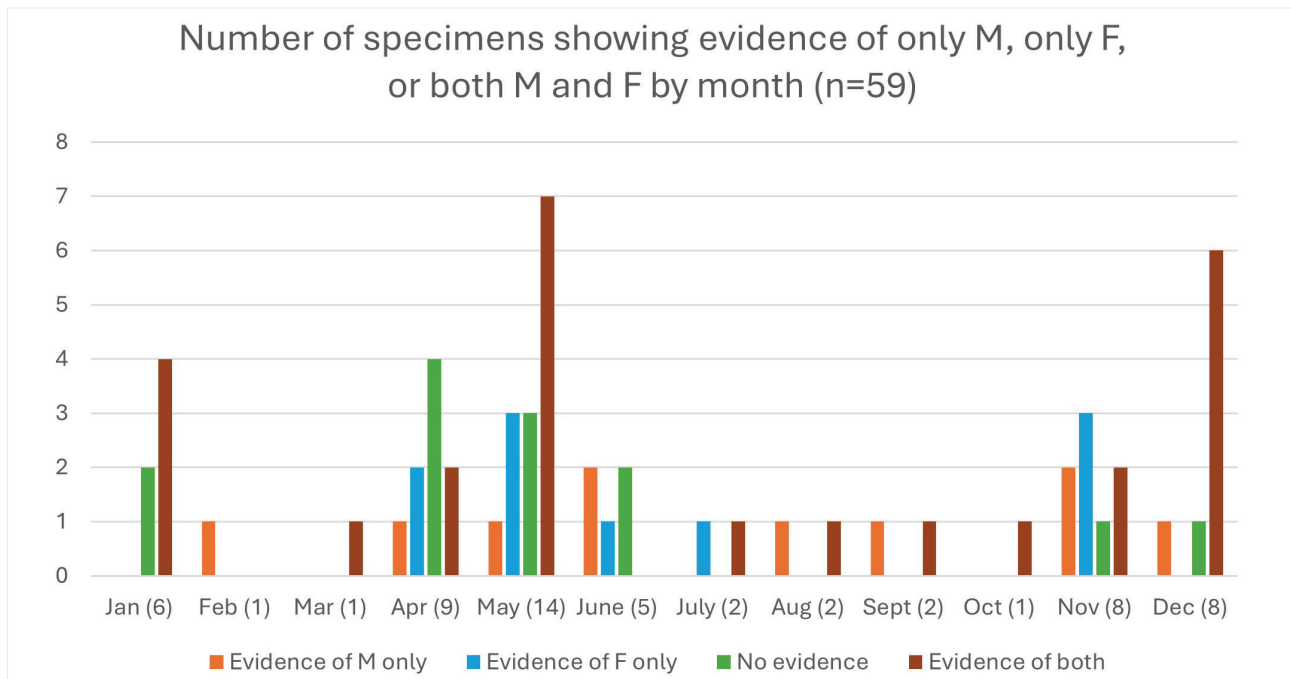
Figure 18. *Pherosphaera fitzgeraldii* NSW52775 annotated as male plant. A – closed female cone (left), female cone with seed (right). B – old male cone. C – closed female cone. D – old male cone.



### Relooking at the specimens

The National Herbarium of NSW has 36 high-resolution images of *Pherosphaera fitzgeraldii* sheets available. All of these were reviewed for reproductive structures alongside five images of the early collections supplied by the Royal Botanic Gardens of Victoria and the Royal Botanic Gardens of Kew giving a total of 41 images. These were reviewed for reproductive structures (Appendix 1). Sixteen of these herbarium sheets held gatherings of multiple branchlets. Each branchlet was assessed separately, as it could not be assumed that they had been gathered from the same individual. Four sheets were omitted as multiple branchlets were overlapping too much in the image to be viewed separately. Two sheets had multiple branchlets overlapping but the text referred to a single plant, so these sheets were included.

Out of the 37 sheets, 59 branchlets were examined. Thirteen of these showed no evidence of cones. On the remaining 46 branchlets, 27 (59%) had evidence of both male and female cones. Monoecy may be higher than this as it is possible that plants may show evidence of male and/or female cones at different times, or on the remainder of the plant not collected. Herbarium sheets, collections at a particular point in time, may therefore be under-representative of monoecy. Graphing the data by month of collection shows that monoecy can be observed throughout the year (Figure 19). Recent images from wild populations of *Pherosphaera fitzgeraldii* (Figures 20-22) confirm monoecy.



**Figure 19.** The number of branchlets that show male and female elements indicating that monoecy in *Pherosphaera fitzgeraldii* can be observed throughout the year. Evidence includes a male cone bud, male cone or a male cone stalk, and female cone (closed or open), remnant bracts of a female cone, or a seed.



**Figure 20.** *Pherosphaera fitzgeraldii* - An old male cone on the left and a female cone with seed on the right. A young male cone can be seen at the top of the frame. Photo: Richard Delaney.



**Figure 21.** *Pherosphaera fitzgeraldii* - Two old male cones with their scales disintegrating and a female cone with seed. Photo: Richard Delaney.



**Figure 22.** *Pherosphaera fitzgeraldii* - A branch with multiple brown male cones and several female cones with developing seed. Photo: Richard Delaney.

### CONCLUSION

The review of early collections and the first descriptions highlight an important knowledge gap around the sexuality of *Pherosphaera fitzgeraldii*. The data gathered from reviewing a range of herbarium sheets shows that plants regularly produce both male and female cones on the same individuals, confirming that monoecy is present in the population and has been under-reported. It was not possible in this review to determine the presence of dioecy as whole plants were not observed.

Nor is it possible from this review to determine the actual nature of monoecy in *Pherosphaera fitzgeraldii*. For example, it does not show if a monoecious individual produces mostly one sex with the other sex appearing sporadically on a branchlet, or if male and female cones are distributed evenly throughout the plant. It also does not show if an individual plant produces the same sex cones from year to year or under different conditions.

However, this study confirms that *Pherosphaera fitzgeraldii* is at least partly monoecious, in contrast with *Pherosphaera hookeriana* which is purely dioecious. Given there are no other members in the genus, it draws attention to the uniqueness of the species and has implications for those working on ecology and conservation in its highly fragmented populations. Genetic analysis shows that while clonality, produced by vegetative asexual reproduction, is present, it is lower in the larger populations (McMaster et al. 2024). Current seed collection efforts confirm that filled seed is being produced by the plants (Richard Delaney pers. com. 2025) and that some sexual reproduction is currently occurring. However, the genetic analysis also shows a high level of inbreeding particularly in smaller populations (McMaster et al. 2024).

It is possible that while monoecy may have helped the species to survive through a range of climatic conditions over time by being able to produce a greater range of male and female cones, it may also be contributing to inbreeding particularly where populations are small and fragmented.

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**Appendix 1. Herbarium specimens of *Pherosphaera fitzgeraldii* indicating herbarium reference number, collection month, herbarium annotations (notes) and observations of Male (MC) and Female cones (FC)**

Herbarium reference	Month	Herbarium notes	MCs, stalks or buds observed on image	FCs, remnants or seed observed on image	Evidence of MC and/or FC	Presence of MC and/or FC
NSW22548 left	Jan				None	None
NSW22548 right	Jan		1 old MC	FCs with seed	M and F	M and F
NSW381499 upper	Jan	Female flowers	MC stalks, old MCs	FCs with seed	M and F	M and F
NSW381499 lower	Jan	Female flowers	MC stalks	FCs with seed	M and F	F
NSW481497 omitted	Jan					
KEW289162 top	Jan	Monoecious			None	None
KEW289162 bottom	Jan	Monoecious	MC, MC stalks	FC remnants, FC sketch	M and F	M and F
NSW381498	Feb		MC stalks		M	None
NSW22549	Mar	Female	MC buds	FCs with seed, FC remnants	M and F	M and F
NSW22544 omitted	Mar					
NSW64658	Apr		1 MC bud, MC stalks	Closed FCs, FC remnants	M and F	M and F
NSW232823 left	Apr	Male			None	None
NSW232823 right	Apr	Male		FC	F	F
NSW22543 top left	Apr		MC stalks		M	None
NSW22543 middle	Apr				None	None
NSW22543 bottom left	Apr				None	None
NSW22543 right hand	Apr		MC stalks	FC	M and F	F
NSW381496	Apr				None	None
NSW851911	Apr	Fruits		FCs with seed	F	F
NSW854462	May	Cones fruiting. Seed collected.	Old MCs, MC buds, MC stalks	FC remnants	M and F	M

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Herbarium reference	Month	Herbarium notes	MCs, stalks or buds observed on image	FCs, remnants or seed observed on image	Evidence of MC and/or FC	Presence of MC and/or FC
NSW381504	May		MC buds, MC stalks	FC remnants	M and F	M
NSW237516	May				None	None
NSW237515	May				None	None
MEL255882 right	May		MC bud		M	M
MEL255882 top left	May				None	None
MEL255882 middle left	May		MC bud	FC	M and F	M and F
MEL255882 bottom left	May			FC with seed	F	F
MEL255884	May		MC stalks	FC remnant	M and F	None
MEL255885 right	May		MC buds, MC stalks	FC remnants	M and F	M
MEL255885 left	May		MC stalks, MC bud	FC remnants	M and F	M
MEL256548 right	May		MC stalks	FC remnants	M and F	None
MEL256548 middle	May			FC	F	F
MEL256548 left	May			FC remnants	F	None
NSW381501 left	Jun		MC buds		M	M
NSW381501 middle	Jun				None	None
NSW381501 right	Jun			FCs	F	F
NSW381503	Jun		MCs		M	M
NSW127697	Jun				None	None
NSW381506	Jul		1 MC bud	FCs	M and F	M and F
NSW381505	Jul			FC remnants	F	None
NSW209213	Aug	Sterile	MC buds, MC stalks		M	M
NSW22552	Aug	Female	MC buds, MC stalk	FCs, FC with seed, FC remnants	M and F	M and F
NSW42289 left	Sep		MC stalks, MC buds		M	M
NSW42289 right	Sep		MC buds	Closed FCs	M and F	M and F



Herbarium reference	Month	Herbarium notes	MCs, stalks or buds observed on image	FCs, remnants or seed observed on image	Evidence of MC and/or FC	Presence of MC and/or FC
NSW22551 omitted	Oct					
NSW381502	Oct		MC stalks	FCs	M and F	F
NSW48631 bottom	Nov	Male			None	None
NSW48631 middle	Nov	Male	MC bud, MC stalks		M	M
NSW48631 top	Nov	Male	MCs, MC stalks	FCs	M and F	M and F
NSW22550 bottom	Nov			FCs	F	F
NSW22550 middle left	Nov			FCs	F	F
NSW22550 middle right	Nov			FCs	F	F
NSW22550 upper right	Nov		MC stalk, old MC	FCs	M and F	M and F
NSW381500	Nov		Old MCs		M	M
NSW52775 left	Dec	Male	MC stalks, MCs	FCs	M and F	M and F
NSW52775 right	Dec	Male	Old MCs		M	M
NSW52776	Dec	Male and female	Old MCs	FCs with seed	M and F	M and F
NSW263770	Dec	Male	MCs	FC	M and F	M and F
NSW941453	Dec	Sterile			None	None
NSW251759	Dec	Male/Sterile	1 old MC	FCs	M and F	M and F
NSW52774 upper	Dec	Male with occasional female	MCs, MC stalks	FCs with seed	M and F	M and F
NSW251760	Dec	Male/Sterile	MCs	FCs	M and F	M and F
NSW22542 omitted	Dec					

