BOTANIC GARDENS OF SYDNEY

Cunninghamia

A journal of plant ecology for eastern Australia

AUSTRALIAN INSTITUTE OF BOTANICAL SCIENCE

Date of Publication: September 2023

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Island treasures: rapid assessment of orchids on Norfolk Island

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***Abstract*:** Islands, because of their small geographic area and tendency for high levels of species endemism, present opportunities for comprehensive biodiversity assessment and conservation. Norfolk Island (35 km^2 in area) is in the South Pacific Ocean, between New Zealand and New Caledonia, approximately 1500 km east of Australia. To assess the conservation and taxonomic status of the orchids of Norfolk Island we analysed historical literature and herbarium records, and then conducted a 10-day field survey. We made 91 records of 11 orchid species, including the first record of *Pinalia rostriflora* (Rchb.f.) Kuntze for the island. The orchid flora of Norfolk Island is relatively species rich, compared to other small oceanic islands.

Because of Norfolk Island's small land area, its endemic orchids may be eligible for listing as Critically Endangered under Australian Government legislation (the *Environment Protection and Biodiversity Conservation Act* 1999), due to their restricted geographic range. Targeted assessments, such as this, raise awareness of the presence and distribution of threatened species, and give confidence to land managers in prioritising conservation management actions.

Cunninghamia (2023) 23: 033–047
doi: 10.7751/cunninghamia.2023.004

Introduction

Biodiversity decline is in the spotlight globally (United Nations 2015, 2023, WWF 2022). As resources for biodiversity conservation are limited (Wintle et al. 2019), prioritisation of conservation actions to achieve the maximum benefit has been advocated (Chades et al. 2008, Joseph et al. 2009). Species that are listed as threatened (at state, national or international levels) are typically prioritised for conservation management (Hoffman et al. 2008), but this can be problematic because many species are yet to be assessed (e.g., plants; Le Breton et al. 2019, Alfonzetti et al. 2020). Taxonomic uncertainty adds further complication to prioritisation, introducing ambiguity in relation to target taxa and actions (Eldridge et al. 2014).

Biodiversity conservation efforts are largely focussed on species (Mace et al. 2008). However, with the advent of genomics technologies and increasing awareness of within-species diversity, our understanding of global biodiversity – and biodiversity declines – is deepening (Des Roches et al. 2021, Formenti et al. 2022). Calls are growing for a more nuanced approach to conservation, one that considers not only species, but the processes that lead to speciation, and the protection of genetic diversity at levels below species level (e.g., subspecies, and genetically and/or geographically distinct populations) (Coates et al. 2018, Des Roches et al. 2021).

Islands provide a valuable environment for advancing our understanding of biodiversity (MacArthur and Wilson 1967). Their discrete area makes comprehensive biodiversity assessment more tractable. Islands represent less than 7% of the world's emergent land but hold 20% of its biota (Sayre et al. 2019). In addition, islands host a high percentage of endemic species (Fernandez-Palacios et al. 2021), and often exhibit a high species-to-area ratio, which combined is hypothesised to offer higher returns for conservation effort (Kier et al. 2009). Islands also offer a particular challenge for managing threats to biodiversity (such as invasive species and disease; Russell and Kueffer 2019, Fernandez-Palacios et al. 2021). Because of their discrete areas and many endemic species, options for dispersal or assisted migration to suitable climates/locations are limited (Courchamp et al. 2014).

Orchids (family Orchidaceae) are among the most threatened plants in the world: globally, more than half the orchid taxa assessed for the IUCN Red List were determined to be threatened; however, <5% have been assessed (Fay 2018). Australia harbours a rich and highly endemic orchid flora with more than 90% occurring nowhere else (Jones 2021). Orchids constitute a large proportion of Australia's threatened flora (16%) and 13% of Australia's orchids are nationally listed as threatened (Australian Government 2023, Jones 2021). Most of Australia's orchids are terrestrial (86%) and exist for part of the year as an underground storage organ only (i.e., they are invisible above ground during this period). Hence, detecting orchids in the field can be challenging. Additionally, terrestrial orchids do not necessarily flower annually (Jones 2021, Shefferson 2004). There are also challenges in effectively surveying epiphytic orchids, which constitute 14% of Australia's orchid flora (Jones 2021), as they occur high in the canopies of trees; indeed, one published survey method for epiphytes states frankly: "not all species will be detected" (Shaw and Bergstrom 1997). The Orchidaceae is also one of the largest and most complex plant families, resulting in many areas of taxonomic uncertainty (Fay 2018). The challenges in taxonomic circumscription of orchids are well known (Bateman 2012, Fay 2018), as are the flow on effects to conservation, especially where there are differing species concepts (Frankham et al. 2012).

Extinction risk assessment typically includes three main elements: geographic distribution, population, and rate of decline (IUCN 2022a). Ninety per cent of the 272 orchids listed as threatened on the IUCN Red List in the past 10 years have been assessed under Criterion B (IUCN 2022b), which focuses on geographic distribution, rather than population. Assessment of whether a species is continuing to decline, in distribution or population, is important in extinction risk assessment, as is identifying the most serious plausible threat most likely to rapidly affect the population (IUCN 2022a). For a species to be eligible for listing as Critically Endangered because it has a restricted geographic distribution, it needs to meet two of three IUCN Red List sub-criteria, these are: existing in one threat-defined location or being severely fragmented; undergoing continuing decline; and/or undergoing extreme fluctuations in population.

Orchids are often threatened, and can be taxonomically difficult. Islands have a high proportion of endemic species, small areas compared to continents, and significant barriers to genetic exchange. For these reasons, the study of orchids on islands is likely to yield information important for taxonomy and conservation. Here, we present Norfolk Island as a case study of a rapid assessment of the taxonomic and conservation status of an island orchid community. We use historical and contemporary data to assess the taxonomic and conservation status of the orchid flora of Norfolk Island, at both the species and population level, to assist with prioritisation of conservation resources. We also make recommendations about on-ground management and further research.

Methods

Study site: geography

Norfolk Island is situated in the South Pacific Ocean, approximately 1500 km east of Australia, between New Zealand and New Caledonia, at approximately the same latitude as Evans Head, NSW. The climate is subtropical and oceanic (Green 1994). Norfolk Island covers an area of 34.6 km^2, with volcanic geology. The highest point is the peak of Mt Bates, at 321 m above sea level. Norfolk Island was formed ~2.3 – 3.1 Mya (Jones and McDougall 1973; DNP 2010); it is younger than New Caledonia (~50 Mya) and Lord Howe Island (~7 Mya), but older than Tahiti (0.6-1.2 Mya) (MacDougall et al. 1981, Neall and Trewick 2008).

Study site: history

Archaeological evidence suggests that Norfolk Island was inhabited by Polynesians, but their settlement ended before Europeans arrived (Power 2022). Norfolk Island was settled by Europeans soon after establishment of a convict settlement in Sydney in 1788. At this time the island was almost entirely covered in subtropical rainforest, with *Araucaria heterophylla* a dominant feature (Hicks 1988). The first botanical collections of Norfolk Island plants (not including orchids) were made in 1774, when Captain Cook landed on the island, and these were described by Georg Forster. It was not until botanical illustrator and collector Ferdinand Bauer visited the island in 1804-1805 that a comprehensive botanical study was undertaken. Bauer's work informed the *Prodromus Florae Norfolkicae* by S.F.L. Endlicher (1833) who described five new orchid species (Table 1). In the years following, there were collections by Allan Cunningham (botanist at the Botanic Gardens in Sydney) in 1830 (Mills 2012) and James Backhouse in 1835, although neither appear to have included orchids. By the end of the convict era in the 1850s, the island had been largely cleared for agriculture, and pigs and goats were introduced. Isaac Robinson, a resident of the island, made at least three orchid collections (1884-1885). Gertrude Purchas, who later records indicate was an artist from New Zealand, made the only collection of the orchid *Nematoceras acuminata* in ~1894, and sent the specimen to Thomas Kirk, a New Zealand botanist, who referred it to Ferdinand von Mueller at the Melbourne Botanic Gardens (Mills 2007a). Further orchid records were made by Captain J.D. McCormish in 1937; in 1947 (date estimated based on a related collection [PDD 5580]) by W. Cottier, and; in 1956 by W. Reginald B. Oliver (later Director of the Dominion Museum, NZ). Additional collections have been made more recently (in the past 70 years) by other collectors.

Table 1. Summary of records for orchid species on Norfolk Island. Abbreviations for other localities to which these orchids extend include Lord Howe Island (LHI), New Zealand (NZ), and New Caledonia (NC). * = Date collected as accessioned herbarium specimen.

	Species	Date first collected	Date last collected*	Number of collections	Records limited to NI/endemism (other locations where species is or may be present are in brackets)	Threatened species listing status	Informal assessment of rarity on NI
1	*Adelopetalum argyropus* (Endl.) D.L.Jones & M.A.Clem.	1804 (Bauer) – type	1996	5	No (Mainland Australia, LHI)	Qld: VU	Very rare
2	*Nematoceras acuminata* (M.A.Clem. & Hatch) Molloy, D.L.Jones & M.A.Clem.	1864 (Purchas)	1864	1	No (NZ)	None	Very rare
3	*Microtis parvifolia* R.Br.	1885 (Robinson)	1885	1	Unclear	None	Uncertain
4	*Microtis unifolia* (G.Forst) Rcbhf.	1937	1956	3	No (Australia, Pacific, Asia)	None	Uncertain
5	*Oberonia titania* Lindl.	1804 (Bauer) – type	2018	3	No (Mainland Australia)	NSW: VU	Rare
6	*Phreatia paleata* (Rchb.f.) Rchb.f. ex Kraenzl.	1975	1975	1	No (Pacific)	EPBC: EN	Common
7	*Phreatia limenophylax* (Endl.) Benth.	1804 (Bauer) – type	2018	2	No (also NC – where it is rare)	EPBC: CE	Very rare
8	*Taeniophyllum norfolkianum* D.L.Jones, B.Gray & M.A.Clem.	1967 (Hoogland) – type	1996	3	Yes	EPBC: VU	Uncommon
9	*Thelychiton brachypus* Endl.	1804 (Bauer) – type	?1804	1	Yes	EPBC: EN	Rare
10	*Thelychiton macropus* Endl.	1804 (Bauer) – type	2018	6	Yes	None	Common
11	*Thelymitra longifolia* J.R.Forst. & G.Forst.	1998	1998	1	No (NZ)	None	Uncertain – Rare
12	*Tropidia viridifusca* Kraenzl.	1997	2016	5	No (Pacific)	None	Common

Study site: vegetation

Remnant native vegetation is found across 425 hectares of Norfolk Island, or 12% of the total land area. Most remnant vegetation is located within the Mount Pitt Section of the Norfolk Island National Park (460 ha) on the northern side of the island (Christian and Mills 2021). The vegetation of Norfolk Island is classified into eight forest vegetation types and six non-forest vegetation types (Christian and Mills 2021). Large areas of Norfolk Island are also covered by non-remnant vegetation including woody weed forest and cleared pastures. Important woody weed species include red guava (*Psidium cattleyanum*), Brazilian peppertree/broad-leaved peppertree (*Schinus terebinthifolius*) and African olive (*Olea europaea* subsp. *cuspidata*). These species form dense thickets, have allelopathic effects and dominate resources such as light and water, making it difficult for other species to compete (DNP 2010).

Data review

We began by identifying which orchid species had been previously recorded on Norfolk Island. First, we downloaded all records of "Orchidaceae" on Norfolk Island from the Atlas of Living Australia (ala.org.au; ALA). To capture additional records without (or with incorrect) coordinates, we manually searched all Orchidaceae records containing the word "Norfolk", crosschecking with other collection information (location, collector, date, habitat and occurrence notes). In this way we gathered 26 verifiable records of 10 species.

We then searched Global Plants (https://plants.jstor.org/), a global database of digitised herbarium specimens, for specimens from Orchidaceae containing the word "Norfolk", to identify additional specimens not included in ALA. Once specimens from other localities had been removed, this revealed seven specimens of five taxa, all from Ferdinand Bauer in 1865. Among these was one species additional to those retrieved from the ALA database: *Thelychiton brachypus* Endl.

A review of key literature (publications focused on or with comprehensive listings of Norfolk Island flora i.e., Green 1994; Mills 2007b; Mills 2010; DNP 2010; Backhouse et al. 2019) revealed one additional species: *Thelymitra longifolia* J.R.Forst. & G.Forst. (de Lange et al. 2005). We then used the Species Profiles and Threats database (http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl; SPRAT) to determine the current threatened species listing status for each of the 12 species (Table 1). For scientific orchid names we use the taxonomy of Jones (2021). Common names of orchids are listed in Appendix 1.

Field survey

Over 10 days in May 2022, we set out to visit the locations recorded for the herbarium specimens, in the literature and known by Norfolk Island National Park staff. We began by visiting areas with the largest number of orchid records. These were largely within Norfolk Island National Park (the Park). The highest concentration of records was on the slopes of Mt Pitt. We then visited Norfolk Island Reserves: Bumboras, Cascade, Cockpit, Crystal Pool, Headstone, Hundred Acres, Selwyn and Two Chimneys, with opportunistic surveys along roadsides during transit. Survey was on foot, using binoculars, with two to eight people in attendance. Orchid locations were recorded using GPS, and voucher specimens were taken where a species was recorded in a new area. Short opportunistic visits (<2 days fieldwork) were also made in October 2022 (M. Clements) and December 2022 (H. Zimmer).

Assessment

Rapid conservation assessment was made based on the IUCN Red List Categories and Criteria (2022a). Using the historical and field survey records, we were able to assess the current conservation status of the orchids of Norfolk Island, largely based on IUCN Criterion B, which has a focus on geographic distribution (i.e., occurrence records with latitude and longitude). Extent of occurrence (EOO) and area of occupancy (AOO) were calculated according to Red List guidelines i.e., EOO as the area of a minimum convex hull encompassing all records, and AOO calculated as the number of 2 x 2 km grid cells occupied by species records (IUCN 2022). EOO and AOO were calculated for Norfolk Island endemic species and distinct populations. We did not explicitly assess IUCN Red Listing subcriteria (i.e., number of locations, continuing decline). We use the term 'Norfolk Island population' for orchid species on Norfolk Island that may be distinct but, as currently circumscribed/delimited, have distributions that extend beyond Norfolk Island (e.g., also present in Australia or New Zealand).

Results

Species list

We detected ten of the 12 species of orchid known from Norfolk Island (Figures 1 and 2) as well as one species not previously recorded from the Norfolk Island Group: *Pinalia rostriflora* (Rchb.f.) Kuntze, Revis. Gen. Pl. 2: 679 (1891).

The two species not seen were terrestrial orchids: *Nematoceras acuminata* and *Thelymitra longifolia. Nematoceras acuminata* has been recorded on Norfolk Island only once, by Gertrude Purchas, who gathered a specimen in about 1894 (Mills 2007). The second species not seen, *Thelymitra longifolia* was recorded in 1998 (de Lange *et al.* 2005).

In addition, two species from the genus *Microtis* were identified as occurring on Norfolk Island. *Microtis aemula* was found in May 2022 and *Microtis unifolia* was identified at a separate location on an opportunistic visit to Norfolk Island (by M. Clements) in October 2022.

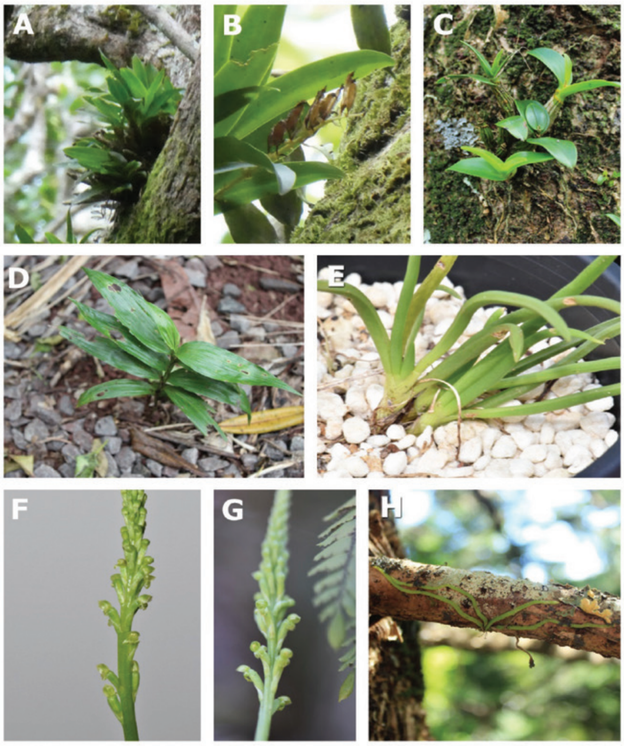

Figure 1. Orchids of Norfolk Island plate 1: (A, B) *Pinalia rostriflora*; (C) *Thelychiton brachypus*; (D) *Tropidia viridifusca*; (E) *Phreatia limenophylax*; (F) *Microtis aemula*; (G) *Microtis unifolia*; (H) *Taeniophyllum norfolkianum*. Photo credits: Mark Clements (A, B, E, F, G), Heidi Zimmer (C, D, H).

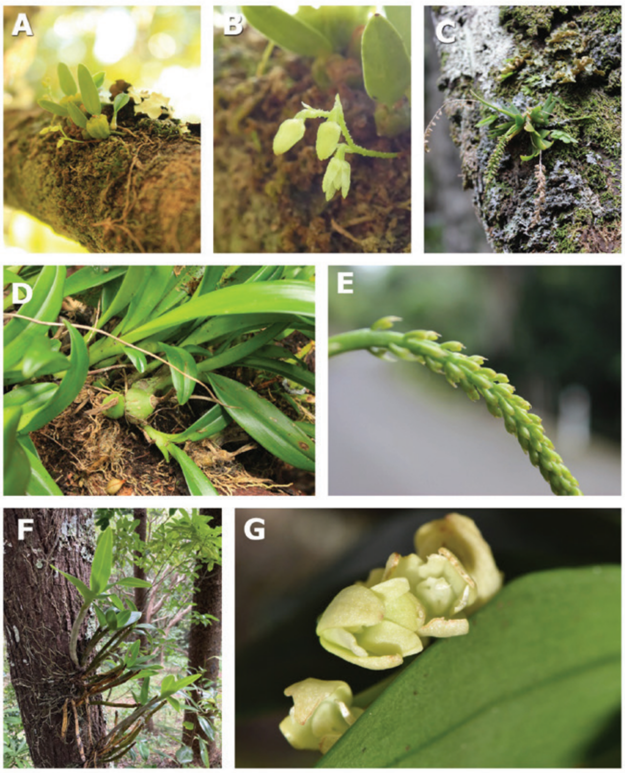

Figure 2. Orchids of Norfolk Island plate 2: (A, B) *Adelopetalum argyropus*; (C) *Oberonia titania;* (D, E) *Phreatia paleata;* (F,G) *Thelychiton macropus*. Photo credits: Mark Clements (B, G), Heidi Zimmer (A, C, D, E, F).

Rapid conservation assessment: distribution

The majority of orchids were recorded within Norfolk Island National Park (Figure 3), consistent with the spatial pattern of previous records. Because of the small geographic area of Norfolk Island, any species (or subspecies or population) endemic to Norfolk Island meets the geographic threshold (EOO <100 km^2) for listing as Critically Endangered (CE) under IUCN Red List Criterion B1. In addition, eight species or populations also met the threshold for listing as Critically Endangered under Criterion B2, having an AOO <10 km^2. Summary data for species and populations restricted to Norfolk Island are given in Table 2. Other thresholds, such as number of locations and decline, must be met, however, before a species can be assessed as CE (IUCN 2022a).

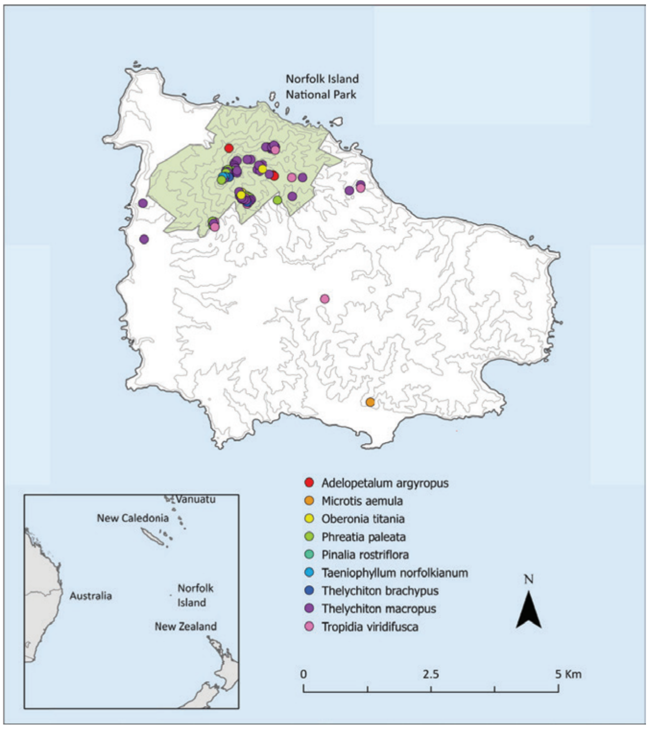

Figure 3. Map of Norfolk Island showing Norfolk Island National Park orchid records. Specific locations of orchid records have been generalised.

Taxonomic assessment

At least one orchid species from Norfolk Island appears to be morphologically distinct from populations of that species on continental Australia. The population of *Adelopetalum argyropus* on Norfolk Island has roughly spherical to inverted-cone-shaped pseudobulbs, which are ribbed or grooved, and flowers that do not open widely, with labellum not protruding. This is distinct from the mainland populations that have egg-shaped to conical pseudobulbs with weakly ribbed and irregularly verrucose surface, and have flowers that open widely, with labellum protruding.

Table 2. Rapid conservation assessment based on geographic range according to the IUCN Red List criteria. Factors considered for listing based on geographic distribution include extent of occurrence (EOO) and area of occupancy (AOO). EOO and AOO were calculated for records on Norfolk Island only. Species for which this does not constitute a global assessment are annotated as 'NI population'. Assessment of continuing decline is based on Norfolk Island occurrences only. Additional abbreviations are: CE, critically endangered; EPBC Act, Environment Protection and Biodiversity Conservation Act (1999); NC, New Caledonia; NZ, New Zealand; NI, Norfolk Island.

Species name	Synonyms	EOO (km^2)	AOO (km^2)	Most important threat causing continuing decline	Conservation assessment (for EPBC Act) recommended	Further taxonomic work recommended (to delimit NI species/populations)
Adelopetalum argyropus NI population	*Bulbophyllum argyropus* NI population	12	12	Restricted habitat and climate change	Yes. New conservation assessment for NI population.	Yes. Delimitation re. continental Australian *Adelopetalum argyropus* populations. Reference phylogenetic framework: Simpson et al. (2022).
Nematoceras acuminata *	*Corybas acuminatus*	NA	NA	Likely extinct	No. Not recorded on NI for >150 years. Species present in NZ.	No
Microtis aemula NI population	none	4	4	Grazing	Further research required.	Yes. Species delimitation in *Microtis.*
Microtis unifolia NI population	none	4	4	Grazing	Further research required.	Yes. Species delimitation in *Microtis*.
Oberonia titania NI population	none	4	4	Restricted habitat and climate change	Further research required.	Yes. Species delimitation in *Oberonia* including Australian populations (conspecifics) and Australian and New Caledonia relatives, especially: *O. crateriformis O. neocaledonica, O. palmicola, O. rimachila.*
Phreatia paleata NI population	none	8	8	Restricted habitat and climate change	Yes. Reassessment. Only Australian occurrence of this species is on NI.	Yes. Compare with conspecifics in the Asia-Pacific.
Phreatia limenophylax NI population	*Pleaxure limenophylax* NI population	4	4	Restricted habitat and climate change	No. Species is listed as CE.	Yes. Compare with conspecifics in New Caledonia.
Pinalia rostriflora NI population	*Eria rostriflora* NI population	4	4	Restricted habitat and climate change	Yes. Only Australian occurrence of this is on NI.	Yes. Compare with conspecifics in New Caledonia and elsewhere in the Pacific.
Taeniophyllum norfolkianum	none	8	8	Restricted habitat and climate change	Yes. Reassessment. The global distribution of this species is on NI.	No
Thelychiton brachypus	*Dendrobium brachypus*	4	4	Restricted habitat and climate change	Yes. Reassessment. The global distribution of this species is on NI.	Delimitation with respect to *Thelychiton macropus*.
Thelychiton macropus	*Dendrobium macropus*	20	20	Restricted habitat and climate change	Yes. The global distribution of this species is on NI	Delimitation with respect to *Thelychiton brachypus.*
Thelymitra longifolia *	none	NA	NA	Grazing	Further research required into species delimitation in *Thelymitra.*	Delimitation with respect to populations of the same species in NZ. Reference phylogenetic framework: Nauheimer et al. (2018).
Tropidia viridifusca NI population	none	16	16	Restricted habitat and climate change	Yes. Only Australian occurrence of this species is on NI.	No

* Species not seen *in situ* for this study (i.e., *Nematoceras acuminatus, Thelymitra longifolia*).

**The type location for this species was recorded as Anson Bay; however, because remnant vegetation has largely been cleared in this area, and we were unable to find any extant *P. limenophylax* here, estimates of EOO and AOO do not include an Anson Bay location.

Spatial correlations among species and vegetation types

Orchids were recorded from four vegetation types on Norfolk Island. The majority of records were moist upland hardwood forest (MUHF) (Figure 4), which has an area of 108 hectares (or 3% of Norfolk Island) (Christian and Mills 2021). MUHF is typically found on the slopes and valleys around the mountains, between the moist palm valley forest and the pine-hardwood ridge forest vegetation types, which cover 42 ha and 163 ha, respectively (Christian and Mills 2021), and are the other two vegetation types where orchids were predominantly recorded.

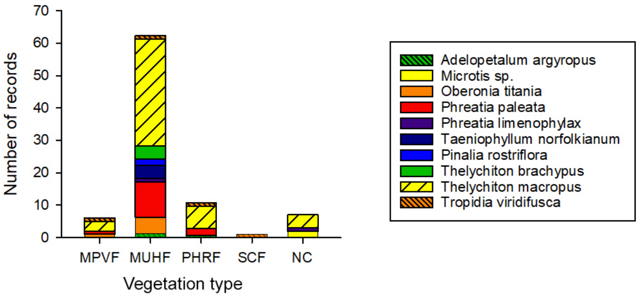

Figure 4. Orchid occurrence according to vegetation type. MPVF, Moist Palm Valley Forest; MUHF, Moist Upland Hardwood Forest; PHRF, Pine Hardwood Ridge Forest; SCF, Sheltered Coastal Forest; NC, not classified.

Discussion

Orchids are often under-represented in oceanic island floras, constituting a mean of 1.2% of plant species richness (Taylor et al. 2019). On Norfolk Island, orchids represent a higher-than-average plant species richness of 6% (11 of 190 indigenous plant species; Mills 2023). While orchids have dust-like seed that can disperse thousands of kilometres (including over oceans), many orchids are also reliant on specific environmental conditions and relationships (i.e., mycorrhizal fungi, pollinators, host trees) to survive and reproduce (Taylor et al. 2019). Both biological and biogeographic factors are likely to have contributed to Norfolk Island's orchid flora.

Biogeographic and biological inferences about Norfolk Island orchids

The unique flora of Norfolk Island comprises elements related to Australia, Lord Howe Island, New Caledonia, and New Zealand (Green 1994). Wind is the most likely mode of dispersal for orchids (Arditti and Ghani 2000), transporting seeds to Norfolk Island from neighbouring landmasses. Prevailing wind direction on Norfolk Island varies across the year. Easterly and south-easterly winds predominate in summer and autumn, shifting to south and south-westerly in winter, and southerly in spring (BOM 2022a, b). New Zealand lies to the southeast of Norfolk Island, and has 130 – 140 mostly terrestrial orchid species, including *Nematoceras acuminata* and *Thelymitra longifolia*. Most weather systems approach the Norfolk Island from the west (Mills 2023), in the direction of Australia, which has 1698 mostly terrestrial orchid taxa (including 27 species of *Microtis*), but also including the epiphytic *Adelopetalum argyropus* and *Oberonia titania*. Lord Howe Island is to the southwest and has 13 orchid species, mostly terrestrial, but also *Adelopetalum argyropus*. To the north of Norfolk Island is New Caledonia, with 209 orchid species (101 endemic) (Endemia 2022), including *Pinalia rostriflora, Phreatia limenophylax,* and *Tropidia viridifusca*. Seeds may have been carried from New Caledonia to Norfolk Island on the northerly winds that drive the cyclones that form in the more tropical waters to the north of Norfolk Island in summer months (BOM 2014).

The epiphytic orchid, *Pinalia rostriflora* was recorded on Norfolk Island for the first time during this survey and constitutes a new species record for Australian territory. *Pinalia rostriflora* is relatively widespread on New Caledonia (Endemia 2022). Eriinae, the subtribe to which *Pinalia* belongs, has been the subject of recent molecular phylogenetic research (Ng et al. 2018), highlighting phylogenetic structure and diversity within this group of orchids, which have been historically grouped together in genus *Eria*. Two other species of *Pinalia* occur in Australia, both in northeast Queensland, these are *Pinalia fitzalanii* (also in the Torres Strait area) and *Pinalia moluccana* (Jones 2021).

Despite the rich terrestrial orchid floras of neighbouring landmasses, only four terrestrial orchid species have been recorded on Norfolk Island (two species of *Microtis*, *Thelymitra longifolia*, not seen in this study; *Nematoceras acuminata*, not seen and likely extinct). The soils of Norfolk Island are basaltic, nutrient rich and well structured, but also friable and porous (DCCEEW 2021), potentially rendering them less able to support seeds of terrestrial orchids. It is also possible that introduced animals, such as cattle and pigs, may have had negative effects on terrestrial orchids, both indirectly, through vegetation degradation, and directly, through grazing, trampling, and rooting. Cattle grazing is still permitted within specific public lands on Norfolk Island, particularly on roadsides. Another explanation for the relative paucity of terrestrial orchids may lie in their requirement for a mycorrhizal symbiont. Orchid seeds are tiny and lacking in nutritive tissue and so they form a relationship with mycorrhizal fungi to provide nutrients during initial seedling development (Dressler 1981). Orchid species that form generalist mycorrhizal associations (i.e., are less species specific and/or with more widespread taxa) could be expected to be more common on islands (Taylor et al. 2019), although this is not always the case (e.g., Hawaii, Swift et al. 2019). *Microtis* species, two of which are recorded on Norfolk Island, form relationships with the relatively widespread *Tulsanella* fungi (Wei Han Lim 2015), possibly contributing to their establishment on Norfolk Island, and nearby Phillip Island. It is possible that seeds of other orchid taxa have dispersed to Norfolk Island but have been unable to establish due to the absence of appropriate mycorrhizal taxa.

Another trait common among island plant species is self-compatibility (Grossenbacher et al. 2017). Norfolk Island's endemic *Thelychiton* species (*Thelychiton brachypus* and *Thelychiton macropus*) are self-pollinating and have flowers that remain closed – they are cleistogamous. In cleistogamous species, the surface of the stigma is covered in tissue from the column, meaning that no pollen can be deposited. Because of this, each flower is self-pollinated from pollen tubes that germinate and grow directly from the anther, down to the stigmatic tissue. *Oberonia titania* is also able to self-pollinate via rain splash (Jones 2021). *Microtis* includes species that can self-pollinate and/or reproduce vegetatively (Swarts and Dixon 2009); where *Microtis* are present on Norfolk Island they occur in colonies, indicative of vegetative reproduction. *Thelymitra* species, including *Theymitra longifolia*, also have the capacity to self-pollinate (Lehnebach et al. 2005).

There were six species on Norfolk Island that had small white or pale yellow-green flowers (i.e., *Adelopetalum argyropus, Phreatia paleata, Phreatia limenophylax, Pinalia rostriflora, Taeniophyllum norfolkianum* and *Tropidia viridifusca*) – these species were also relatively rare and/or were observed to have few seed pods. This floral morphology is hypothesised to be attractive to a diverse array of small insects (Bawa 1990) and suggests pollination by generalist pollinators (cf. self-pollination). Plants can overcome pollinator limitation on islands by selecting floral traits that attract a wider variety of pollinators (Barrett 1996; Taylor et al. 2019). *Adelopetalum* is likely pollinated by flies (as are many Bulbophyllinae, Ridley 1890, Teixeira et al. 2004), while *Taeniophyllum* species are usually pollinated by bees or beetles (short spurred species of Aeridinae, Topik et al. 2005). *Tropidia viridifusca* has the fragrance of decomposing material (M. Clements pers. obs.), so is likely to attract a fly pollinator (Christensen 1994). The insect pollinators of *Phreatia* and *Pinalia* are unknown.

Extinction risk assessments of orchids on an oceanic island

Updated species extinction risk assessments are recommended for three already listed threatened species, where their only occurrence within the jurisdiction of the Commonwealth of Australia's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is on Norfolk Island: *Phreatia paleata* (currently EN), *Taeniophyllum norfolkianum* (currently VU), and *Thelychiton brachypus* (currently EN) (Table 2). Additionally, we recommend threatened species extinction risk assessments for five previously unassessed species/populations: *Adelopetalum argyropus* (Norfolk Island population), *Oberonia titania* (Norfolk Island population), *Pinalia rostriflora* (new, only occurrence on Australian territory), *Thelychiton macropus* (endemic to Norfolk Island, only occurrence on Australian territory), and *Tropidia viridifusca* (only occurrence on Australian territory).

We note that Takhtajan (1969) in his seminal work 'Flowering Plants, Origin and Dispersal' argued that the flora of Norfolk Island differed strongly from that of Australia (and Lord Howe Island). Moreover, the interim biogeographical regionalisation for Australia (IBRA) places Norfolk and Lord Howe Island together, and distinct from continental bioregions (Commonwealth of Australia 2012), while in marine bioregionalization, Norfolk Island is placed on its own (Australian Government 2005). In this study, we emphasise the significance of these orchid species records in the context of Australian Orchidaceae, as Norfolk Island is under the jurisdiction of Australian Government's environmental legislation (the EPBC Act), and one of the intentions of this study is to inform the conservation of these species.

A species or population limited to Norfolk Island, because of the small size of the island, may be eligible to be listed as Critically Endangered under IUCN Red List Criterion B, because the Critically Endangered threshold for extent of occurrence is <100 km^2, and the likelihood of genetic exchange outside Norfolk Island is very low, given its remoteness. Likewise, these populations may be considered severely fragmented, as all individuals are encapsulated by these small populations, isolated on Norfolk Island, and therefore, if they went extinct, there would be no possibility of recolonisation.

Determining which records are associated with which species can be challenging when the morphological and genetic boundaries among species are unclear (e.g., because of taxonomic uncertainty). However, conservation assessments often – and must – continue in the face of uncertainty (Bland et al. 2017, e.g., Melville et al. 2021). In some cases, it may be appropriate to assess populations or evolutionary significant units (*sensu* Coates et al. 2018). As Norfolk Island is clearly delimited by ocean, and orchid populations are unlikely to be undergoing genetic exchange outside Norfolk Island, we suggest assessment of the Norfolk Island populations of *Adelopetalum argyropus* and *Oberonia titania* (which, as currently circumscribed, also exist on the Australian mainland and elsewhere).

Extinction risk assessments of orchids on an oceanic island: threats

The most pervasive threat to orchids on Norfolk Island is decreased rainfall. Mean annual rainfall on Norfolk Island declined 11% between 1970 and 2020 (CSIRO 2020). Current climate change projections for Norfolk Island include a 1.3°C increase in temperature (10th to 90th percentile range, 1.1°C to 1.7°C) and a 6% decrease in rainfall (10th to 90th percentile range, -13% to +4%) by 2050 (CSIRO, Managers of World Heritage Properties in Australia and Indigenous Reference Group 2021), with possible impacts of climate change including changes in seasonal rainfall patterns, and long runs of dry years impacting on the hydrology of Norfolk Island (CSIRO 2020). Hotter, drier conditions may lead to physiological stress on and reduced recruitment of plants, and to an increased risk of fire and consequent impacts on fire-sensitive native plants and wet rainforest ecosystems (DCCEEW 2023).

Climate change poses a particular risk to the biodiversity of oceanic islands because of their many rare and endemic species, low habitat availability and low functional redundancy (Harter et al. 2015). Moreover, epiphytes are particularly vulnerable to climate change because they exist at the vegetation-atmosphere interface (Zotz and Bader 2009). In addition, because they lack direct access to soil water, epiphytes are reliant on moisture that they intercept from the atmosphere (clouds, fog, rain) and stemflow from their host (Mendieta-Leiva et al. 2020). Epiphytes have been identified as possible indicators for floristic response to climate change (Benzing 1998) and in line with this, epiphytic orchids may provide a useful indicator of climate change impacts on the vegetation of Norfolk Island.

The majority of Norfolk Island's epiphytic orchid records were restricted to moist upland hardwood forest. The impacts of decreased rainfall on Norfolk Island's orchid flora, particularly the montane epiphytic orchids, are difficult to predict because of the many factors that influence fine-scale spatial variability in rainfall. The amount of water received by the epiphytic orchids, their forest habitat, and tree hosts, is likely to be affected by duration of cloud immersion (Scholl et al. 2007), which can occur over a longer duration than rainfall. This may result in these higher-elevation areas (including many epiphytes and hosts) receiving more precipitation than lower-elevation areas – although an overall decline may still be experienced. The forest on Norfolk Island is probably important for trapping passing cloud, providing a moist and dense canopy (storage capacity of the canopy is about 2.5 mm), and reducing sunlight and wind (i.e., moist/humid environment) (McJannet et al., 2023). These systems are complex, and while broad-scale trends are known, further research is required for robust predictions of impacts on finer spatial scales (Harter et al. 2015). Moreover, we acknowledge that our search effort was biased towards the mountain slopes of Norfolk Island National Park, which also include the greatest area of moist upland hardwood forest; future systematic survey across all vegetation types would be beneficial.

There are five orchids on Norfolk Island largely limited to moist upland hardwood forest on Norfolk Island: *Adelopetalum argyropus, Oberonia titania*, *Phreatia limenophylax* and *Taeniophyllum norfolkianum* and *Thelychiton brachypus*. The extent to which these species will be (or are already) impacted by desiccation will be influenced by their ability to avoid or tolerate drought. For example, species in the genus *Taeniophyllum* are considered drought resistant, because their leaves have (and hence water loss via stomata has) been radically reduced, with leaves remaining only as tiny papery bracts. Instead, photosynthesis occurs in the roots of *Taeniophyllum,* which contain cortical stomatal complexes enabling controlled gas exchange (Carlsward et al. 2006). *Adelopetalum* species, employing a different tactic for drought resistance, have capacity for water storage via pseudobulbs (Ramesh et al. 2020). Each pseudobulb of *Adelopetalum argyropus* is terminated by a small hard leaf, which can be deciduous, and hence provide a further water saving mechanism. Pseudobulbs of *Adelopetalum argyropus* can also become flaccid with loss of moisture, but they can recover and re-shoot after rain (M. Clements, pers. obs.). *Phreatia limenophylax* similarly stores water, through its thickened/succulent leaves (Zhang et al. 2018). Pseudobulbs and thickened cuticles are two key strategies in epiphytic orchids for maintaining water balance (Yang et al. 2016). *Oberonia titania* comprises a stem covered with succulent, equitant (folded and encasing the base of the next leaf) leaves. Much like *Adelopetalum argyropus*, *Oberonia titania* plants can become flaccid in dry conditions and recover after rainfall (M. Clements, pers. obs.). While each of these five orchids has some capacity for drought tolerance/avoidance, the extent to which this will enable persistence in the face of long-term declines in moisture availability, especially alongside predicted increases in temperature (and evapotranspiration), is unknown.

Recommendations

Investigate the taxonomic status of Norfolk Island's endemic orchids

Morphological and ecological examination indicates that the population of *Adelopetalum argyropum* may constitute a distinct species, endemic to Norfolk Island. Further taxonomic research, guided by molecular analysis, is needed to confirm the identities of the Norfolk Island *Microtis* species. Species in the genus *Microtis* pose a particular challenge for identification and delimitation, not only because of the superficially similar appearance of species and the very small size of their flowers (<5 mm), but also because of limited research to date on their molecular phylogenetics. It is likely that there are many more species of *Microtis* yet to be described (Jones 2021). Molecular taxonomic analysis will also assist in confirming whether the *Thelymitra* species (collected by de Lange in 1998, not seen on during this research) is *Thelymitra longifolia*. Lastly, further research is needed to confirm the taxonomic status of Norfolk Island populations of *Oberonia titania* (Jones 2021) and *Phreatia limenophylax* (Endemia 2016) compared to continental Australian and New Caledonia populations, respectively.

Thelychiton brachypus and *Thelychiton macropus* are endemic to Norfolk Island, though the extent that they are distinct from one another is unclear – as individuals with morphological characters intermediate/between the two species were recorded. Further research into these species is warranted. Recommendations are summarised in Table 3.

Table 3. Summary of management recommendations for conservation of orchids on Norfolk Island.

Objective	Key actions
Resolve the taxonomic and conservation status of the orchids of Norfolk Island	Resolve taxonomic status of *Adelopetalum argyropum* population on Norfolk Island, with respect to populations on Lord Howe Island and continental Australia
	Resolve taxonomic status of *Microtis* species on Norfolk Island
	Resolve taxonomic status of *Thelymitra longifolia* record on Norfolk Island, with respect to other *Thelymitra* species in Australia, New Caledonia and New Zealand
	Resolve taxonomic status of *Oberonia titania* on Norfolk Island, with respect to continental Australian populations
	Resolve taxonomic status of *Phreatia limenophylax* on Norfolk Island, with respect to records on New Caledonia
	Resolve species delimitation of *Thelychiton brachypus* and *Thelychiton macropus* from one another
Increase understanding about the population trajectories of orchids on Norfolk Island population trajectories	Conduct a systematic survey of the Norfolk Island to locate any orchid records missed in this study
	Monitor a subset of permanently marked individuals (abundant species)
	Monitor all individuals (rare species)
	Develop detailed monitoring program with stratified sampling across environmental conditions to identify correlates with decline
Protect and restore Norfolk Island's orchid species	Prioritise moist upland hardwood forest (MUHF) for protection, and MUHF tree species for restoration planting
	Conduct research to determine preferred host tree species and microhabitats for Norfolk Island orchids
	Conduct research to inform *ex situ* conservation of Norfolk Island orchids, such as determining species requirements for germination, cultivation, and transfer from nursery to the field

Monitoring

Establishment of a monitoring program is important to detect decline in Norfolk Island orchid populations, especially for the epiphytic orchids predicted to be affected by climate change. For accurate inference about population decline, a sample of permanently marked individuals should be monitored for survival, growth and recruitment. Monitoring should be undertaken at least annually, but more frequently in response to disturbance including windstorms and severe drought. For many species, it may be possible to monitor all known individuals of the species (e.g., *Adelopetalum argyropus*), giving exact data on the status of the population. For other species with larger populations, a subset of individuals may be monitored. When there are many individuals, consideration should also be given to stratifying the monitored individuals by other variables which may impact survivorship, such as elevation or host tree species. With appropriate experimental design, a diagnostic monitoring program may be established such that the reasons for decline (or increase) may be identified.

Protecting and restoring Norfolk Island's threatened orchid species

Five of Norfolk Island's orchids are epiphytes with distributions centred on moist upland hardwood forest (MUHF), highlighting this vegetation type as a priority for protection and restoration. Key species in MUHF include sharkwood (*Dysoxylon bijugum*), beech (*Myrsine ralstoniae*), ironwood (*Nestegis apetala*), and native oleander (*Pittosporum bracteolatum*). Future research should include the identification of the tree species and associated micro-environments that compose the habitats for the orchid species, such that appropriate conditions for epiphytic orchid establishment can be considered in the ongoing forest restoration work on Norfolk Island.

Management of introduced animals may also assist with orchid conservation. Terrestrial orchids should be protected from grazing during flowering – with careful consideration of issues of competition with other plants, especially exotic grasses, if fencing is erected. Rodent predation of seed has also been hypothesised as a threat to several species, including *Phreatia paleata* and *Thelychiton brachypus* (DCCEEW 2023).

Ex situ conservation may also be used to mitigate extinction risk. However, knowledge of *ex situ* conservation methods for epiphytic orchids is fragmentary, and reports in the scientific literature are few (e.g., Zettler et al. 2007). Moreover, understanding of the requirements for successful translocation of epiphytic orchids from the wild to cultivation and/or new wild sites remains limited (although see Yam et al. 2011, Izuddin et al. 2018, Izuddin et al. 2019). Anecdotally, rescued branch fall epiphytic orchid species are difficult to maintain *ex situ* (M. Clements pers. obs.). Swarts and Dixon (2009) mention the apparent generality of mycorrhizal associations in some epiphytic orchids, allowing them to be grown in large-scale horticulture – although they note that other species appear to be more specific. Nevertheless, the limited information available gives guidance for growing some groups from seed, such as *Thelychiton* species (sometimes placed in the broader genus

Dendrobium) (e.g., Teixeira et al. 2015), whereas others are likely to be more difficult (*Adelopetalum, Oberonia, Phreatia* spp.). Further research is needed, not only in determining germination requirements, but in cultivation through to successful transfer from the nursery to the field. In summary, possible management actions include: the creation and improvement of habitat for orchids, including planting of host trees in suitable locations; seed banking and *ex situ* cultivation (of all species, particularly the rarest species) to create insurance populations and stock for translocations; and translocation, consisting of augmentation and/or population establishment. Further research is needed to determine the relative importance of, and optimal methods and/or locations for implementing, all of these options.

Conclusion

Norfolk Island has at least 11 orchid species, constituting a relatively high proportion of its native plant flora. Potential explanations for this richness are manifold but may include the proximity of multiple, species-rich sources of orchid seed, diversity of microclimates, and the availability of traits such as self-pollination and associations with generalist pollinators and mycorrhizae. Norfolk Island is currently recognised as having three or four endemic orchid species (*Taeniophyllum norfolkianum, Thelychiton macropus*, *Thelychiton brachypus,* and in some assessments *Phreatia limenophylax*); in addition, it has the only occurrences on an Australian territory for at least three more species (*Phreatia paleata*, *Pinalia rostriflora*, and *Tropidia viridifusca*). Because of the remoteness of Norfolk Island, genetic exchange with populations external to Norfolk Island is likely to be limited, hence further investigation of the morphological and genetic distinctiveness of these species is required, along with the Norfolk Island populations of *Adelopetalum argyropus* and *Oberonia titania*. The epiphytic orchids of Norfolk Island are largely centred on the moist upland forests – consideration must be given to the vulnerability of these species to climate changes, especially in the context of the significant decreases in annual rainfall already recorded. A robust monitoring program is essential to further understand the range and population trends of orchid species on the island. *Ex situ* cultivation, translocations to new sites and restoration plantings may assist in ensuring the long-term persistence of Norfolk Island's unique orchid flora.

Acknowledgements

This project was conducted on Norfolk Island, and we acknowledge the people of Norfolk Island, particularly the descendants of the Pitcairn Islanders and their families. We thank the staff of Norfolk Island National Park, particularly Nigel Greenup, Kenny Christian, and Jamie Donaldson for their support and enthusiastic assistance in the field. Thanks to Anne Mackenzie for her assistance in the field, and to Margarita Goumas for assistance with mapping. We thank Margaret Christian, Snowy and Judy Taverner for sharing their knowledge of Norfolk Island with us. We thank the reviewers, Tom Le Breton and Paul Adam, for their detailed and thoughtful feedback, which resulted in several improvements to this manuscript. The study was funded by Director of National Parks and CSIRO.

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Manuscript accepted 4 August 2023

Appendix 1: Orchid scientific names, synonyms and common names.

Species	Synonyms	Local name	Other common names
Adelopetalum argyropus	*Bulbophyllum argyropus*[1]	One Leaf Orchid	Silver Strand Orchid[2]
Nematoceras acuminata	*Corybas acuminatus*[1]	None	Dancing Spider Orchid[2]
Microtis sp.	None	None	Onion Orchid
Oberonia titania[1]	*Oberonia palmicola*, *Oberonia neocaledonica*	Norfolk Island Oberonia	Soldiers Crest Orchid[2]
Phreatia paleata	*Eria paleata*[1]	None	White Lace Orchid[2]
Phreatia limenophylax	*Plexaure limenophylax*[1]	Norfolk Island Phreatia	Norfolk Island Caterpillar Orchid[2]
Pinalia rostriflora	None	None	None
Taeniophyllum norfolkianum[1]	*Taeniophyllum muelleri*	Minute Orchid Taeniophyllum	Norfolk Island Ribbon Root[2]
Thelychiton brachypus	*Dendrobium brachypus*[1]	Short-caned Orchid	Stubby Cane Orchid[2]
Thelychiton macropus	*Dendrobium macropus*[1]	Long-caned Orchid	Norfolk Island Cane Orchid[2]
Thelymitra longifolia	None	None	Sun Orchid
Tropidia viridifusca[1]	None	Ground Orchid	Dark Crown Orchid[2]

[1] Name accepted on the Australasian Plant Census https://biodiversity.org.au/nsl/services/search/taxonomy;

[2] Name sourced from Jones (2021).