

# NSW Threatened Species Scientific Committee

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## Conservation Assessment of *Carex klaphakei* K.L.Wilson (Cyperaceae)

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### *Carex klaphakei* K.L.Wilson (Cyperaceae)

Distribution: Endemic to NSW

Current EPBC Act Status: Not listed

Current NSW BC Act Status: Endangered

Proposed outcome of Conservation Assessment: List as Endangered

### Summary of Conservation Assessment

*Carex klaphakei* is found to be eligible for listing as Endangered under Criterion B1ab(i)(ii)(iii)(iv)(v) + B2ab(i)(ii)(iii)(iv)(v) and C2a(i)

The main reasons for this species being eligible are:

- (i) it has a highly restricted geographic distribution,
- (ii) it is severely fragmented and has six locations,
- (iii) it has a small population size, and
- (iv) there is an estimated continuing decline in the geographical range, the area, extent and/or quality of habitat, the number of locations and the number of subpopulations due to changes in hydrological regimes as a result of longwall coal mining, sand mining, damage by feral pigs and off-road vehicles and habitat loss from ongoing climate change.

### Description and Taxonomy

*Carex klaphakei* K.L.Wilson, also known as Klaphake's Sedge, is a perennial herb that was originally described in 1996. No synonyms or phrase names were found after a search of Australian taxonomic databases (PlantNet, APNI, APC; access date 14 March 2022), however, the species has previously been collected under other names. A 1999 collection was re-determined in 2018 as *C. klaphakei*, having previously been misidentified as *C. inversa* (K. Wilson *in litt.* June 2018). According to Wilson (1996), the species is not easily identifiable without mature inflorescence.

*Carex klaphakei* was formally described by Wilson (1996) as a "slender perennial, with shoots at 2–6 cm intervals along rhizomes. Culms 45–160 cm long, to 1.2 mm diam., smooth or slightly scaberulous. Leaves with reduced flat blades to 7 cm long, c. 1.5 mm wide; ligule white- to brown-membranous, rounded, c.0.3 mm wide. Inflorescence 0.8–1.5 cm long, composed of a single spike or up to 3 spikes in a small cluster; lowest 1 or 2 leafy involucral bracts shorter than the inflorescence or rarely slightly exceeding it. Spikes androgynous, with upper male portion often half-hidden by the female portion, 6–10 mm long, 1–3 per inflorescence, few-flowered. Male bracts ('glumes') c. 4 mm long, pale yellow- to pale red-brown with acute apex and mucro c. 0.3 mm long. Female bracts 3–4 mm long, pale yellow- to pale red-brown, with acute apex and mucro 0.5–1 mm long. Perigynia (utricles) ovate in outline, planoconvex, thickened near base, strongly 8–10-nerved abaxially, not or faintly few-nerved adaxially, 5.5–7 mm long, 1.7–2 mm diam. in broadest part, green to yellow-brown, eventually grey-

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brown; beak long-tapering, more or less excurved eventually, slightly hispidulous on margins, with 2-fid or split apex. Stamens 3; anthers c. 2 mm long. Style 2-fid. Nut narrow-elliptical to obovate in outline, with obtuse apex, plano-convex, 2–2.5 mm long, 1.3–1.5 mm diam., pale brown.”

Wilson (1996) notes that *C. klaphakei* is distinctive for its “long rhizome, extremely long slender culms, [and] short leaf-blades.”

## **Distribution and Abundance**

*Carex klaphakei* is endemic to NSW. It is found from the Newnes Plateau in the greater Blue Mountains in the north, south to Penrose in the Southern Highlands. The NSW Scientific Committee (2000) state that “*Carex klaphakei* grows with other native sedges and rushes in swamps on sandstone at altitudes of greater than 600 m. It is locally common over a small area in a very restricted habitat.”

## Known Sites

There are seven known sites of *C. klaphakei* located across the greater Blue Mountains and Central and Southern Tablelands of NSW. Three of these, the Rhododendron Gardens in Blackheath, Ruby Creek near Mt Werong, and Hanging Rock Swamp near Penrose, were described in the NSW Scientific Committee Final Determination (2000). A fourth site was found in the catchment for the Cascade Dams at Katoomba when a specimen labelled *C. inversa* (collected 1999) was determined as *C. klaphakei* (K. Wilson *in litt.* June 2018; RBG Herbarium Specimen 643899). A fifth site was defined by the collection of an additional specimen from Marrangaroo Creek in the Newnes Plateau near Lithgow in 2013. The sixth and seventh sites were discovered on the Newnes Plateau in 2019 and are two separate swamps near Sunnyside Ridge Road, Tristar Swamp and Twin Gullies Swamp. These two swamps are located approximately 7 km from the Marrangaroo Creek site. The shortest distance between the sites outside of the Newnes Plateau is 16 km, and the greatest 140 km.

The precise locations of the Katoomba and Marrangaroo sites are uncertain. The Marrangaroo Creek site occurs in a shrub swamp on a “tributary in the upper catchment of Marrangaroo Creek”. Aerial imagery (Department of Finance, Services and Innovation 2016) suggests that the most likely location is in the Marrangaroo Creek Swamp system, although there are also smaller, unnamed hanging swamps that are potential candidates (see Figure 9, page 11 in Centennial Coal Company Ltd 2016). This Katoomba site occurs on a tributary to the Cascade Dam. The exact location of the collection is not known (M. Sherring *in litt.* July 2018) The most likely area is a tributary of the upper Cascade Dam. The middle and lower Cascade Dams have few creeks draining into them, however, there are several swampy areas in tributaries to the upper dam.

The current distribution is based on a cleaned set of 39 unique records compiled from the Atlas of Living Australia, NSW Bionet Atlas and herbarium collections and includes both herbarium specimens and human observations with georeferences that could be verified based on their location descriptions. The georeferences of seven records were revised based on their descriptions.

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## Extent of Occurrence and Area of Occurrence

The extent of occurrence (EOO) of *C. klaphakei* is 2,616 km<sup>2</sup> and the area of occurrence (AOO) is 32 km<sup>2</sup>. The AOO is based on 2 x 2 km grid cells, the scale recommended for assessing area of occupancy by IUCN (2022). The EOO is based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2022). The EOO and AOO are based on the cleaned dataset and calculated using Kew Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.* 2011).

The scattered nature of the sites, the specialized knowledge required to identify the species, and recent discoveries on the Newnes Plateau suggest that it is likely to occur more widely (K. Wilson *in litt.* January 2018). A number of possible sites for survey have been identified. Near Penrose, these include Stingray Swamp on the eastern boundary of the Penrose State Forest (Douglas 2018), Long Swamp to the north of Hanging Rock Swamp, several other unnamed swamps which drain into Paddys River (S. Douglas pers. comm. July 2018), the upper Cudgegong catchment, other swamps on the Newnes Plateau and near Cascade Dam (K. Wilson *in litt.* May 2018; Hammill 2018). At Mt Werong, there is additional swamp habitat located both upstream and downstream of the collection locality that may be less disturbed than areas near the road (Hammill 2018).

Another large montane peat swamp, Long Swamp, abuts the proposed Sutton Forest Quarry site. Long Swamp may contain suitable habitat for *C. klaphakei* (S. Douglas pers. comm. June 2018). Environmental impact assessments for the Sutton Forest Quarry did not find *C. klaphakei* in Long Swamp, however, all surveys were undertaken during September when *C. klaphakei* is not in flower (Kevin Mills & Associates 2018) and is difficult to detect.

Surveys were conducted between 2017 and 2022 at Blackheath, Mt Werong, and Hanging Rock Swamp.

Blackheath: A 2020 survey found that the *C. klaphakei* was in flower and widespread throughout the Rhododendron Garden swamp, an area of about 650 m<sup>2</sup> (Jones 2020). This is greater than the 20–30 m strip at the edge of the swap previously reported (V. Klaphake *in litt.* October 1999). Surveys were undertaken in three other wetland areas in Blackheath: 1) the creek below the known population in the Rhododendron Garden swamp; 2) Victoria Creek to the west of the garden; and 3) Popes Glenn Creek to the east (Hammill 2018). No further specimens were found. The edges of the Blackheath site were burnt in December 2019, affecting 15% of the swamp (Jones 2020). Post-fire monitoring conducted in February and April 2020 found no reduction in the extent of the species.

Mt Werong: The original observation of *C. klaphakei* at Mt. Werong was made in 1994. Surveys in 2022 and 2018 were not able to confirm the presence of *C. klaphakei* (Hammill 2018; M. Jones pers. comm. April 2022). In 2018 a “few” potential *C. klaphakei* plants were found, but these could not be positively identified without fertile material. There was evidence of damage from off-road vehicles and feral pigs (Hammill 2018). The population may have decreased or been extirpated since 1999, when it was reported to occur on both margins of the creek for ~50 m (V. Klaphake *in litt.* October 1999). However, the species may also have gone undetected. It can be

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cryptic when not in flower, and both surveys took place at the end of the flowering window.

Hanging Rock Swamp: In 2018 at Hanging Rock Swamp two clumps of the species were found in an approximately 500 m search along the creek line (Douglas 2018). This appears to be less extensive than reported by Klaphake in 1999: “Initially found over a 120 m x 8 m area, but later found scattered through quite big sections of the swamp in a patchy distribution for about 1 km” (V. Klaphake *in litt.* October 1999). In 2019, a new location in the swamp was found 20 m upstream from the reference location with an estimated 50 plants (Douglas 2019). The NSW Scientific Committee (2000) found that this was “the largest known site” and the survey results indicate that this population has declined since listing, with the extent of the species as surveyed in 2018 apparently less than that described at the time of nomination (Douglas 2018). It may no longer be the largest population. It is also possible that Douglas (2018, 2019) may have missed patches because he may have sampled a smaller area than Klaphake (*in litt.* October 1999), however the precautionary principle is applied here to assume that two years of searches would have covered a similar area.

## Population Estimates and Trends

*Carex klaphakei* is a clonal plant and for clonal organisms, IUCN guidelines (2022) suggest a pragmatic approach, estimating the number of mature individuals from the area covered, then dividing by size believed to correspond to a single self-sustaining patch. An individual patch or clump of a clonal species is known as a ramet. The colony of genetically identical individuals in a given location is known as a genet

The total cover for *C. klaphakei* across all sites is estimated to be between 2,750 – 4,750 m<sup>2</sup>. At Blackheath the extent of the total area occupied was reported in 2020 to be 650 m<sup>2</sup> (Jones 2020). At Mt Werong, “a few possible plants were sighted” in 2018 (Hammill 2018) and none in 2022 (M. Jones pers. comm. April 2022). Based on these surveys the species appears to have been extirpated from Mt Werong. At Penrose, “two clumps” of the species were seen (Douglas 2018) plus an estimated 50 plants (Douglas 2019). Based on the density of *C. klaphakei* at the Blackheath site of one ramet per 10 m<sup>2</sup> (V. Wong pers. obs. April 2022), this is estimated to correspond to a patch size of approximately 500 m<sup>2</sup>. No size estimate was available for the site at Marangaroo Creek, but *C. klaphakei* is described as being “occasional to locally common” indicating that there are multiple patches at this site. This patch is estimated to be similar in size to initial reports for the Penrose Hanging Rock Swamp (~800–2000 m<sup>2</sup>). At Twin Gully and Tristar Swamps, an estimated 2 m<sup>2</sup> area was found in survey plots at each swamp, with no searches for the species conducted outside of the plots but is suspected to occur elsewhere around the edges of the swamp. The size of patches at these sites is estimated to be smaller in size to the Marangaroo Site, possibly similar in size to the Blackheath population (~100–800 m<sup>2</sup>). No investigation of the total patch size was made at the Katoomba Cascade Dam at the time of collection (M. Sherring, *in litt.* July 2018). Associated notes indicate the plant was “Inconspicuous. Tangled through the undergrowth”. This may suggest a smaller population; it is estimated to be similar in size to the Blackheath population (~100–800 m<sup>2</sup>).

The total population size of mature individuals (ramets) is estimated to be 275–475. The estimate was made using the density of ramets per m<sup>2</sup> from a 2022 survey of the Blackheath site (V. Wong pers. obs. April 2020). At Blackheath the ramets of *C.*

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*klaphakei* were estimated to be between 0.5 to 1 m<sup>2</sup>, or on average 0.75 m<sup>2</sup> and there were approximately 80 ramets found in the 650 m<sup>2</sup> area occupied by the species. This gives a density estimate of approximately one ramet per 10 m<sup>2</sup>.

## Land Tenure

The three *C. klaphakei* sites on the Newnes Plateau are in the recently gazetted Gardens of Stone State Conservation Area, formerly Newnes State Forest. Two *C. klaphakei* sites are partly in conservation reserves. The Mt Werong population occurs along Ruby Creek which forms one of the boundaries between Kanangra-Boyd National Park and a freehold inholding of ~45 ha. The Katoomba population occurs in a no-access Sydney drinking water catchment Special Area managed by WaterNSW (WaterNSW 2022). The Katoomba Special Area may be considered a reserve from the perspective of disturbance, however hydrological regimes in the area are unlikely to be managed with the aim of protecting the species. The Hanging Rock Swamp population occurs on the boundary of Penrose State Forest and freehold land (Penrose Quarry). The Blackheath population occurs on council-owned land which is managed as a garden by a volunteer organization.

## **Ecology**

*Carex klaphakei* is relatively recently described (Wilson 1996) and many aspects of its ecology are not known specifically. These include flowering timing and flowering cues, lifespan of ramets, rate of propagation, the age of colonies, minimum self-sustaining patch size, tolerance to changes in water level, and interactions with animals. However, the genus *Carex*, with its worldwide distribution and large number of species, has a mostly uniform life history (Schutz 2000).

*Carex klaphakei* is a colony forming plant with a long creeping rhizome. The species is described as being decumbent on the surrounding plants or occasionally erect. *Carex klaphakei* requires permanently wet swamp habitat (Hammill 2018). It occurs in undisturbed or lightly disturbed swamps on sandstone with other native sedges and rushes (Wilson 1996). It grows tangled amongst other sedges and swamp understory plants or occasionally forms dense stands. Herbarium notes depict a slender species that can be somewhat hidden among its neighbours

Associated species from herbarium locality and habitat notes include *Eucalyptus aquatica*, *Gahnia grandis*, *Gahnia sieberiana*, *Gleichenia dicarpa*, *Grevillea acanthifolia* subsp. *acanthifolia*, *Isolepis inundata*, *Juncus falcatus*, *Juncus planifolius*, *Lepidosperma limicola*, *Leptospermum emarginatum*, *Leptospermum grandifolium*, *Leptospermum myrtifolium*, *Lepyrodia anarthria*, *Olearia quercifolia*, *Pteridium esculentum*, *Restio australis*, and *Tetrarrhena turfosa*.

Four of five of the swamp habitats of *C. klaphakei* are listed as Threatened Ecological Communities (TEC) under the EPBC Act and/or the NSW BC Act. Hanging Rock Swamp is part of the EPBC Act-listed Temperate Highland Peat Swamps on Sandstone TEC. The swamps containing the species on the Newnes Plateau are recognised as Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion TEC, listed as Endangered under the BC Act and also are part of the EPBC Act-listed Temperate Highland Peat Swamps on Sandstone TEC. The swamps near Mt Werong are part of the Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps Bioregion TEC, listed as Endangered under the BC Act. Habitat at the

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Katoomba site may be part of the Blue Mountains Swamps TEC listed as Vulnerable under BC Act and is recognised as being part of the EPBC Act-listed Temperate Highland Peat Swamps on Sandstone. The Blackheath site is not in a threatened ecological community.

The plant community types (PCTs) surrounding swamps where *C. klaphakei* occurs are Central Tableland Peppermint Shrub-Grass Forest (3735) at Mt Werong, Shoalhaven Escarpment Peppermint Silvertop Ash Forest (3689) at Penrose, Upper Blue Mountain Ridgetop Woodland (3694) at Katoomba, Upper Blue Mountain Moist Forest (3692) at Blackheath, and Newnes Plateau Peppermint Ash Tall Forest (3687) and Newnes Plateau Rockplate Heath (3862) at Newnes Plateau (Department of Planning and Environment 2022).

## Pollination, seed dispersal and gene flow

Fragmentation of swamps in the landscape reduces the capacity of dispersal and genetic exchange between swamp dependant species (Middleton *et al.* 2006). *Carex* sedges are near-exclusively wind pollinated (Friedman and Barrett 2008), which limits the distance that gene-exchange can occur between sites. Tristar and Twin Gully swamps are located 1.5 km apart, so it is possible that pollination may occur between sites. These two swamps are approximately 7km from the Marangaroo Creek site and it is unlikely that wind pollination occurs between these sites. The other four *C. klaphakei* sites are beyond the distance of wind pollination, located between 16 km and 140 km apart.

It is not known how *C. klaphakei* seeds are dispersed, however, animals, wind and water are all possible agents, with the seeds of many wetland species having morphological adaptations to float on water (Middleton *et al.* 2006). In almost all *Carex* species, seed dormancy is broken by stratification at low temperatures followed by germination in warmer conditions, although a few species germinate at temperatures <10 °C (Schutz 2000). There is evidence that long-term physiological changes and changes in the structure of seed coats can play a role in delaying germination (Schutz 2000). These dormancy and germination traits not only enable the accumulation of seeds in the soil, but also constitute seasonal seed regeneration strategies that rely on the high longevity of seeds and the formation of persistent seed banks. Temperate *Carex* spp. are mainly adapted to exploit the temporally and spatially infrequent occurrence of canopy gaps that become available only in late spring or early summer, whereas the colonization of gaps at the beginning of the vegetation period is largely prevented by a high temperature requirement for germination (Schutz 2000).

## Subpopulations

All *C. klaphakei* sites, except the Newnes Plateau sites, can be considered separate subpopulations because they are geographically and genetically isolated and unable to be recolonised from another site if extirpation occurs. On the Newnes Plateau, Tristar and Twin Gully swamp sites are located 1.5 km apart and can be considered one subpopulation, with pollination and seed dispersal possible. The Marangaroo site is located 7 km from the other Newnes Plateau sites and could be either considered a separate subpopulation, or the same subpopulation if there are undiscovered *C. klaphakei* sites in between.

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## Threats

The NSW Scientific Committee (2000) state that “The small area of occupancy and the great distance between populations (c. 50 km) makes these populations susceptible to extinction from human activities or stochastic events.” In addition, each site faces distinct threats, and all sites face the threat of habitat loss through climate change. Some of the site-specific threats were identified at the time of listing in 2000; others have emerged more recently. These are detailed by site below.

Blackheath: The NSW Scientific Committee (2000) state that this site is “subject to runoff from urban areas and the highway.” However, the Blackheath *C. klaphakei* site is next to a small walking track in the Rhododendron Gardens and not near the highway or any road, which makes runoff from the highway not a threat. Runoff from an adjacent property is a potential source of future exotic invasive species (Hammill 2018) and pesticide and fertilizer runoff from the surrounding horticultural gardens is a suspected ongoing threat to the site. Invasive weeds, specifically blackberry (*Rubus* spp.) and willow (*Salix* spp.), were identified as a threat at the Blackheath site in 2001 (specimen notes, OEH Default Sightings/Royal Botanic Gardens Herbarium Specimen Register SKDT03053005). Survey in 2018 found that blackberry remained present at the site, and also honeysuckle (*Lonicera japonica*) and exotic grasses (Hammill 2018). In 2020, invasive weeds were controlled at the site (M. Jones pers. comm. April 2022) but remain a potential ongoing threat if management is not continued. The 2018 survey found that the outlet of the swamp at this site was unstable and may collapse, which could lead to a change in hydrology as the creek bed drops approximately 2 m at this point (Hammill 2018). Swamp stabilisation works were carried out in 2019, but additional works are required to be effective (Jones 2020).

Ruby Creek near Mt Werong: The NSW Scientific Committee (2000) considered land tenure and stocking to be the primary threat at this site, which “is partly on freehold land and may be subject to future grazing of livestock.” As noted above, Hammill (2018) was not able to positively confirm the species at this site but did find a limited number of potential non-flowering individuals. Extensive damage by feral pigs was reported. In addition, vehicles use the area near the creek as a traverse to cleared areas downstream, leaving deep wheel ruts and erosion along the main creek line in the area previously identified as habitat (Hammill 2018). Erosion and degradation of swamp habitat should be considered a suspected, ongoing threat at this site.

Hanging Rock Swamp in Penrose State Forest: The NSW Scientific Committee (2000) found that this site was likely the most threatened due to “nearby sandmining activities and clear felling of the surrounding pine forest.” Impact from sandmining is a current ongoing threat at this site. Penrose Quarry, a friable sandstone mine, is adjacent to the swamp and although the mine is not currently operating, there remains a risk of sediment runoff. In 2001, a spill of sand from the mine blocked water flow from to the lower regions of the swamp for two months (12 Oct 2001 to 20 Dec 2001) and led to the death of some vegetation (Lloyd 2003). It is not known whether this is related to the marked population decline observed at this site. Another concern is the proposal for a large sand mine, the Sutton Forest Quarry, located approximately 2 km north of Hanging Rock Swamp (RW Corkery & Co 2018). As of 2022, this project is in consultation stages and has not yet been approved. Hydrological modelling for the project does not extend into Hanging Rock Swamp, but projects changes to the water

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table of 0.1 m at the edge of the Hanging Rock Swamp catchment (Larry Cook Consulting Pty Ltd 2018).

Forestry activity is a current ongoing threat to this site. Hanging Rock Swamp forms the border between freehold land associated with the Penrose Quarry and Penrose State Forest. An asset protection zone (APZ) is maintained by slashing around Penrose State Forest, adjacent to and occasionally impinging on Hanging Rock Swamp. Slashing may cause direct mechanical damage to the species as the heath-like vegetation provides the swamp with a protective buffer (Douglas 2018). Sediment runoff occurs in association with unsealed forestry roads (Douglas 2018). Surveys in 2018 showed that some of the sediment control fences associated with these roads had failed and were in need of maintenance (Douglas 2018). Invasive species from the plantation are also a suspected ongoing threat. Pine wildlings are found in the swamp; these are generally well-controlled on the State Forests side of the swamp, but poorly controlled on the freehold land where the Penrose Quarry is located (Douglas 2018). Blackberry (*Rubus* spp.) and honeysuckle (*Lonicera japonica*) were found in the plantation during a previous survey (S. Douglas pers. comm. June 2018). In addition, forestry activities may result in altered hydrology, pesticide drift, and eutrophication due to fertilizer runoff.

Feral pigs are a suspected future threat to the site. Both feral pigs and recreational activities possibly associated with hunting have caused damage to nearby Stingray Swamp, though neither has been observed in Hanging Rock Swamp (S. Douglas pers. comm. June 2018).

Highway runoff and the potential for hazardous spills are a suspected future threat at this site (S. Douglas pers. comm. June 2018). The Hume Highway is adjacent to the upper part of Hanging Rock Swamp and carries heavy vehicle traffic between Sydney and Melbourne. Environmental impact assessments found that ~5000 heavy vehicles pass the site on a weekday (Transport and Urban Planning Pty Ltd 2018).

Commercial extraction of mineral water by Coca Cola-Amatil and other operators (Larry Cook Consulting Pty Ltd 2018) is a suspected ongoing threat to the hydrological regime at Hanging Rock Swamp. This is thought to have the potential to affect groundwater flows (Douglas 2018).

Cascade Dam catchment at Katoomba: Of the seven known populations of *C. klaphakei*, this may have the fewest site-specific threats, as it falls within a no-access drinking water catchment Special Area. Hazardous spills, highway runoff and invasive species are potential ongoing threats to this population, as the upper Cascade Dam catchment is bordered on one side by the Great Western Highway, which carries heavy vehicle traffic through the Blue Mountains. The exact collection locality is not known, but all three areas fitting the locality description fall within 100–700 m of the highway.

Marangaroo Creek on Newnes Plateau: Loss of groundwater from longwall mining is a severe, observed threat to this subpopulation that is projected to continue. The Marangaroo Creek swamps are above approved long wall mines from the Springvale Mine Extension and associated extension modifications (NSW Planning and Environment 2015; NSW Planning Assessment Commission 2017). Undermining of upland swamps by longwall mining results in the permanent loss of groundwater and long-term transition to woodland habitat (Baird and Benson 2020; Mason *et al.* 2021).

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Should this occur in the area where *C. klaphakei* is present, it would lead to the loss of this population. In NSW, 'Alteration of habitat following subsidence due to longwall mining' and 'Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands' have been listed as a Key Threatening Processes under the BC Act.

Twin Gully and Tristar Swamp on Newnes Plateau: These two swamps are not threatened by longwall mining (Krogh *et al. in litt.* 2021). Disturbance by illegal off-road vehicles is a widespread problem in Newnes, however the 2022 reservation of Newnes State Forest as the Gardens of Stone SCA will minimise future threat as future management proposes to substantially reduce the impact of vehicles and the trail network on the swamps (D. Taylor *in litt.* June 2022). Both swamps burnt at very high intensity in the 2019/20 summer fires, and *C. klaphakei* was recorded from Twin Gully swamp before and after this fire indicating that the species successfully resprouts after fire.

## Habitat loss from ongoing climate change

Anthropogenic climate change is an inferred, projected threat to all *C. klaphakei* swamp habitats. Modelling of the effect of climate change of Coastal Uplands Swamps, which include the Newnes Plateau, Blue Mountains and Penrose *C. klaphakei* sites, forecast a progressive contraction of swamp habitat (Keith *et al.* 2014). By 2070, Keith *et al.* (2014) predicted that Coastal Upland Swamps, using five global climate models for three different emissions scenarios, would decline in both area and suitability of environments by 11–97%. Current CO<sub>2</sub> emission level trajectories (Intergovernmental Panel on Climate Change 2022) suggest that the medium emission scenarios in Keith *et al.* (2014) is most likely. Upland Swamps in NSW are predicted to contract markedly and shift in a SSW-SW direction, with the northern margin moving south more rapidly than the southern margin. Under a medium emissions scenario, swamp losses would be 31-92%. The modelling of Keith *et al.* (2014) did not incorporate potential effects of groundwater abstraction, longwall mining or inappropriate fire regimes, and is thus likely to be conservative. 'Anthropogenic climate change' is listed as a Key Threatening Process under the BC Act

## Assessment against IUCN Red List criteria

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

### *Criterion A Population Size reduction*

#### Assessment Outcome: Data deficient

Justification: The species is clonal in nature, so population size reductions may be measured as decrease in the size of colonies according to IUCN guidelines (IUCN 2022). Clonal organisms can be considered at either the level of the genet (in this case, a colony) or ramet (clump of tillers capable of producing further offshoots). In this assessment, ramets are used to estimate generation time, as ramets are born, reproduce, and decay independently. Ramet generation time is not known in *C. klaphakei* but has been measured as approximately 2.2–3.2 years in another *Carex* species (Wikberg *et al.* 1994; Carlsson and Callaghan 1994). This would make three generations approximately 6-10 years.

*Carex klaphakei* was first recorded in 1991 and measurements of colony sizes were made in 1993–1994, 2018, 2020, 2021 and 2022 for Blackheath, Mt Werong and

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Penrose (V. *Klaphake in litt.* October 1999; Hammill 2018; Douglas 2018, 2019; Jones 2020; W. Vile *in litt.* 2022; M. Jones pers. comm. 2022). The surveys suggested that there was an increase in colony size at Blackheath and a decrease at two sites, Hanging Rock Swamp and Mt Werong (Table 1). However, both Douglas (2018) and Hammill (2018) note that the species may have been undetectable or may occur in areas of habitat which were relatively inaccessible. Further surveys would be needed to verify the magnitude of any reduction to meet this criterion.

## *Criterion B Geographic range*

Assessment Outcome: Endangered under B1ab(i)(ii)(iii)(iv)(v) + B2ab(i)(ii)(iii)(iv)(v).

Justification: The extent of occurrence (EOO) of *C. klaphakei* is 2,616 km<sup>2</sup> and the area of occurrence (AOO) is 32 km<sup>2</sup>. The AOO is based on 2 x 2 km grid cells, the scale recommended for assessing area of occupancy by IUCN (2022). The extent of occurrence (EOO) is based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2022). Both the EOO and AOO meet the thresholds for Endangered.

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

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

Assessment Outcome: Subcriterion met at Endangered threshold

Justification: *Carex klaphakei* is found at six threat-based locations, meeting the threshold for Vulnerable. Population health and persistence at each site depends on the integrity of the swamp, with each site subject to separate hydrological regimes. The threats identified are loss of groundwater by longwall mining, sand mining, changes in hydrological regimes, urban runoff, grazing, damage by feral pigs, damage by off-road vehicles, sediment runoff, invasive weeds and habitat loss from ongoing climate change. Each threat occurs in distinct ways at each site, though many of these occur at more than one site.

*Carex klaphakei* is severely fragmented because >50% of its total AOO, comprising five or six subpopulations over seven sites, are spatially and genetically isolated. The *C. klaphakei* sites are widely separated by 16–140 km, except the sites on the Newnes Plateau which are separated by 1.5 and 7 kms. Several of the sites are under active threats that make the disappearance of the site possible. Were any existing site to be lost, recolonization from the other sites is unlikely, except on the Newnes Plateau, given dispersal mechanisms of the species and patterns of land use. The species meets the definition of severely fragmented.

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

Assessment Outcome: Subcriterion met for (i)(ii)(iii)(iv)(v)

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Justification: A decline is projected in the extent of occurrence, area of occupancy, area, extent and/or quality of habitat and number of locations, concurrent with a decrease in the number of mature individuals. Two locations have shown declines in population size that may be as large as 50-100%. These are Mt Werong (possible decline from 200 m<sup>2</sup> to a 'few' or no plants over 1994–2018) and Hanging Rock Swamp (possible decline from widespread colonies up to 10 m wide to 50 plants plus two clumps over 1993–2018.) Continuation of either trend could lead to the loss of the associated site. A further location, Marangaroo Creek in Newnes State Forest, is above an approved longwall mine which is highly likely to result in the permanent loss of the swamp habitat. Because of the highly restricted and poorly connected distribution of the species, loss of any site will lead to a decrease in AOO and EOO.

A decline is projected in the extent and quality of habitat from loss of groundwater by longwall mining, sand mining, changes in hydrological regimes, urban runoff, grazing, damage by feral pigs, damage by off-road vehicles, sediment run-off, invasive weeds and habitat loss from ongoing climate change. There are six threat-defined locations, with some threatening processes occurring at more than one location and climate change affecting all of them.

The Blackheath site is located in a volunteer-run public garden and under the current management regime no short-term decline is expected. However, the habitat is located downstream of an artificial lake created as part of the garden landscape, and alterations to landscaping would lead to changes in the hydrology of the area where *C. klaphakei* is growing. A collapse of the swamp outlet would also alter the hydrology. A decline is projected if management of invasive species does not continue.

The Mt Werong site is located on the border of Kanangra-Boyd National Park and leasehold land. A continuing decline is projected in the quality of habitat at this site due to feral pig activity, off-road vehicle activity, uncertainty of land tenure, and the potential for the site to be grazed.

The Hanging Rock Swamp site is located between a commercial sand mine and Penrose state forest. A decline is projected in the quality of habitat due to the close proximity of pine plantations, which pose the threat of chemical drift, altered hydrological flows and invasion by exotic species. Although the Penrose Quarry is not currently operating, there is still the potential for sediment spills from retaining pools and storage areas. A decline is also projected in the quality of habitat due to altered hydrology as a result of the proposed nearby Sutton Forest Quarry.

Under current climate change emission trajectories and future projection models (IPCC 2022), Keith *et al.* (2014) predicted that Coastal Upland Swamp habitat, which includes all *C. klaphakei* sites except Mt Werong, will decline by 31-92%.

c) Extreme fluctuations.

Assessment Outcome: Subcriterion not met.

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Justification: There has been no formal long-term monitoring of the species at any site. However, the genus is clonal and thought to persist over long time periods.

*Criterion C Small population size and decline*

Assessment Outcome: Endangered under C2a(i).

Justification: Based on estimates of population size from total cover and the size and density of ramets at the Blackheath site, which averaged ramets of 0.75 m<sup>2</sup> every 10m<sup>2</sup> (V. Wong pers. obs. April 2022), the 2022 population is estimated as 275 to 475 which meets the threshold for Endangered.

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

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

Assessment Outcome: Data deficient.

Justification: *Carex klaphakei* was first recorded in 1991 and measurements of colony sizes were made in 1993–1994, 2018, 2020, 2021 and 2022 for Blackheath, Mt Werong and Penrose (V. Klaphake *in litt.* October 1999; Hammill 2018b; Douglas 2018, 2019; Jones 2020; W. Vile *in litt.* 2022; M. Jones pers. comm. 2022) The surveys suggested that there was an increase in colony size at one site (Blackheath) and a decrease at two sites (Hanging Rock Swamp and Mt Werong). However, both Douglas (2018) and Hammill (2018) note that the species may have been undetectable or may occur in areas of habitat which were relatively inaccessible. Further surveys would be needed to verify the magnitude of any reduction to meet this criterion.

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

Assessment Outcome: Subcriterion met for Endangered

Justification: A decline is projected in the number of mature individuals due to a variety of threats, including changes to hydrology related to mining, forestry, and vehicular traffic, uncertainty of land tenure and potential grazing, feral pig activity and habitat loss from ongoing climate change.

Two locations have recorded declines in population size of up to 50-100%. As the species can be cryptic, further individuals may be found during future surveys, however, a precautionary approach takes trends as observed. At Mt Werong, a possible decline from 200 m<sup>2</sup> to a 'few' or no plants was observed over 1994–2022. These declines are attributed to feral pig activity and vehicle traffic. Continuing declines are projected at this site due to these factors, as well as uncertainty of land tenure and management practices.

At Hanging Rock Swamp, a possible decline from widespread colonies up to 10 m wide to two clumps was observed over 1993–2018. The causes for the decline are unknown, but in 2001 a spill of sand from a nearby mine blocked water flow from the lower regions of the swamp for two months (12 Oct

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2001 to 20 Dec 2001) and led to the death of other nearby vegetation (Lloyd 2003). A decline is also projected due to sediment run-off from forestry in the adjacent Penrose State Forest.

A further location, Marangaroo Creek in Newnes State Forest, is subject to approved undermining by long wall coal mining, which causes loss of the permanent swamp habitat. (Baird & Benson 2020; Mason *et al.* 2021).

Under current climate change emission trajectories and future projection models (IPCC 2022), Keith *et al.* (2014) predicted that Coastal Upland Swamp habitat, which includes all *C. klaphakei* sites except Mt Werong, will decline by 31-92%.

In addition, at least 1 of the following 3 conditions:

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

Assessment Outcome: Subcriterion met at under Endangered.

Justification: All but one estimated populations of *C. klaphakei* fall beneath the Endangered threshold. Only Marangaroo Creek may exceed this threshold, but this estimate has very low confidence, and is equally likely to fall beneath it.

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

Assessment Outcome: Subcriterion not met.

Justification: None of the subpopulations of *C. klaphakei* are thought to contain  $\geq 90\%$  of all individuals.

- b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Subcriterion not met.

Justification: There has been no formal long-term monitoring of the species at any site. However, the genus is clonal and thought to persist over long time periods.

## *Criterion D*      *Very small or restricted population*

Assessment Outcome: Criterion met under Vulnerable.

Justification: The estimated 2022 population size of *C. klaphakei* is 275 to 475 mature individuals which is below the threshold for Vulnerable under Criterion D1. Species with AOO  $< 20 \text{ km}^2$  or number of locations  $\leq 5$  are also eligible for listing under Criterion D2, if a plausible future threat is present which could drive the species to CR or EX in a very short time. *Carex klaphakei* has an AOO of  $32 \text{ km}^2$  and six threat-defined locations which are both above the thresholds for D2. In addition, while it is plausible that current threats could extirpate a single site, it is unlikely that there is a plausible future threat that could drive this taxon to extinction in a very short time.

## *Criterion E*      *Quantitative Analysis*

Assessment Outcome: Data deficient.

Justification: No quantitative modelling of extinction probability has been undertaken.

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## Conservation and Management Actions

This species is currently listed on the NSW BC Act and a conservation project has been developed by the NSW Department of Planning and Environment under the Saving our Species program. The conservation project identifies priority locations, critical threats and required management actions to ensure the species is extant in the wild in 100 years. *Carex klaphakei* sits within the Site-managed species stream of the SoS program and the conservation project can be viewed here: <https://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10148>.

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## APPENDIX 1

### Assessment against *Biodiversity Conservation Regulation 2017* criteria

The Clauses used for assessment are listed below for reference.

#### Overall Assessment Outcome:

*Carex klaphakei* was found to be eligible for listing as Endangered under Clauses 4.3(b)(d)(e)(i)(ii)(iii)(iv) + Clause 4.4(b)(e)(i)(ii)(A)(II)

#### Clause 4.2 – Reduction in population size of species

(Equivalent to IUCN criterion A)

Assessment Outcome: Data deficient

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

#### Clause 4.3 - Restricted geographic distribution of species and other conditions (Equivalent to IUCN criterion B)

Assessment Outcome: Endangered under Clause 4.3(b)(d)(e)(i)(ii)(iii)(iv)

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

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

**Clause 4.4 - Low numbers of mature individuals of species and other conditions**

**(Equivalent to IUCN criterion C)**

**Assessment Outcome: Endangered under Clause 4.4(b)(e)(i)(ii)(A)(II)**

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

**Clause 4.5 - Low total numbers of mature individuals of species**

**(Equivalent to IUCN criterion D)**

**Assessment Outcome: Vulnerable under Clause 4.5(c)**

<b>The total number of mature individuals of the species is:</b>		
(a)	for critically endangered species	extremely low, or
(b)	for endangered species	very low, or

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	(c)	for vulnerable species	low.
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**Clause 4.6 - Quantitative analysis of extinction probability  
(Equivalent to IUCN criterion E)**

**Assessment Outcome:** Data deficient

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

**Clause 4.7 - Very highly restricted geographic distribution of species—  
vulnerable species**

**(Equivalent to IUCN criterion D2)**

**Assessment Outcome: Clause not met**

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