Rylstone Region Coal Free Community

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Hawkins Rumker PRIA Submission: Aquatic Ecology

Final

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Acknowledgement of Country

The RRCFC acknowledges that we live and work on Wiradjuri Country.

We acknowledge the Wiradjuri peoples as the traditional custodians of the land, and pay our respects to Elders past, present and future.

Executive Summary

2020 Strategic Statement and the PRIA process

The NSW Government June 2020 Strategic Statement on Coal Exploration and Mining outlines the NSW Government's approach to transitioning to renewable energy and supporting the economy and aims to improve certainty about where mining should not occur. It identified 14 potential future coal exploration release areas (NSW Government, 2020). The Hawkins and Rumker potential release areas were identified in this Statement; the Ganguddy-Kelgoola area, which sits adjacent to Hawkins and Rumker, is also identified in this statement.

Following the release of the Strategic Statement, the NSW Government Advisory Body for Strategic Release has requested the Hawkins and Rumker areas be put through the Preliminary Regional Issues Assessment (PRIA) process (Department of Planning, Industry and Environment (DPIE), 2021). Ganguddy-Kelgoola is expected to go through the PRIA process in the near future once further exploration is completed.

The PRIA process, also set out in the Strategic Release Framework (NSW Government, 2020), is an initial assessment of social, environmental and economic matters relating to areas that could be released for exploration. In theory, it involves engaging with interested and potentially impacted stakeholders to identify issues for consideration.

RRCFC's <u>Aquatic Ecology</u> Submission

This report is the Rylstone Region Coal Free Community's (RRCFC's) submission to the PRIA process on *<u>Aquatic Ecology</u>*. Separate submissions for a range of other issues are also being submitted by the RRCFC. The RRCFC recognises that coal exploration is a precursor to coal mining, and therefore it is predominantly the mining phase that is considered in this submission.

Mining is contrary to environmental legislation

This submission clearly demonstrates the high ecological values of the Hawkins and Rumker areas. It shows how the aquatic ecology of the region would be destroyed and lost forever by a short term mine. The RRCFC believes this cost is too high, it is not in line with the principles of ecologically sustainable development and is contrary to the objects of the NSW *Environmental Planning & Assessment Act 1979* (EP&A Act), the NSW *Biodiversity Conservation Act 2016* (BC Act) and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

This is a fragile area which is rich in natural springs and there are important groundwater dependent montane mires. Extensive tracts of riparian meadows of high conservation significance are present. The unique riparian vegetation communities found through Coxs Creek, Reedy Creek and Breakfast Creek are poorly preserved at both local and regional scales.

This submission has established that the montane bogs, montane fens and hanging swamps in Coxs Creek, Reedy Creek and Breakfast Creek are all an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of NSW and are referrable to the Montane Peatlands and Swamps Endangered Ecological Community (EEC) listing under the NSW Biodiversity Conservation Act 2016 and the Temperate Highland Peat Swamps on Sandstone Commonwealth Environment Protection and Biodiversity Conservation Act 1999 listing. The length of montane bogs, montane fens and hanging swamps in Breakfast Creek is 3.4km, in Reedy Creek 4.6km, and in Coxs Creek 13.5km. This is 21.5km in total. It is noted there are a number of other waterways within the Hawkins and Rumker areas where swampy areas are observable on topographic maps. The name of some of these creeks are also indicative of the presence of swamps,

such Dairy Swamp Creek and Greenhills Swamp Creek. While no data is available for the vegetation on these waterways, it is probable EEC could also be present.

Impact of mining on aquatic ecology

Any disturbance from exploration and mining activity would reduce the quantity and quality of water within these waterways. Mines both damage any existing water resources within the affected footprint, as well as requiring a significant amount of water to operate. Regardless of the type of mining proposed – underground or open cut - there will be severe and irreversible impacts on surface water including springs, creeks and rivers. **These groundwater-dependent swamps are scarce and already face a rapidly changing climate; the dead swamps of the Newnes Plateau provide clear evidence of the impacts of longwall mining.** Any mining will lead to the permanent loss of the meadows, sphagnum bogs, wetlands and associated ecosystems as well as a wide range of threatened species, populations and communities. The meadows, sphagnum bogs, wetlands and associated ecosystems of Coxs Creek, Reedy Creek and Breakfast Creek are unique, being at lower elevations and the western extents of these endangered ecological communities. **The impact of mining cannot just be offset through the Biodiversity Offsets Scheme – these communities are not found anywhere else so cannot be offset.**

There is limited data on the range and diversity of fauna present within the waterways of the Hawkins and Rumker areas, however recent survey in a limited area found that the Hawkins, Reedy and Lawsons Creeks support a diverse macroinvertebrate fauna, suggesting relatively rich fauna The assemblage was biologically diverse and the presence of springs supports surface aquatic ecology. There is still a vast area that has not been surveyed and its true value cannot be fully appreciated. As found in the case of the Bowdens Silver aquatic ecology assessment: a*s there has been no stygofaunal officially described and officially named from this area it can be certain that they are new species and highly likely to be endemic.* **The significance of what is in this areas must be better understood before any decisions are made that may impact these areas.**

The impacts to the springs, creeks and rivers in this area and meadows, sphagnum bogs, wetlands and associated ecosystems as well as the wide range of threatened species, populations and communities that are dependent on these features is an unacceptable impact for a short-term exploration and mine project in the Hawkins and Rumker areas.

It is the RRCFC's strongly held view that the PRIA should find that the proposed exploration areas should not be opened for exploration under the Strategic Framework that it recommends against release of the proposed areas, and the Advisory Board should rule that coal exploration should not proceed in the Hawkins and Rumker areas.

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1.1 Preliminary Regional Issues Assessment (PRIA) Process

The NSW Government's Advisory Body for Strategic Release (ABSR) has asked the NSW Department of Planning, Industry and Environment (DPIE) to prepare a Preliminary Regional Issues Assessment (PRIA) (DPIE, 2021) to consider the benefits, opportunities, risks and constraints of releasing two adjacent areas located near Rylstone in the Mid-Western Regional local government area.

These areas are shown in Figure 1 and include:

- Hawkins - an area of 14,900 ha located directly north of Rylstone, and
- Rumker - an area of 17,800 ha located directly northeast of Rylstone.

An initial assessment of resource potential undertaken by the Division of Mining, Exploration and Geoscience within the Department of Regional NSW has identified coal resources within the Hawkins and Rumker areas that could be mined by underground mining methods (DPIE, 2021). It is noted that these areas could just as well be mined using aboveground methods.

In June 2020, the NSW Government released the Strategic Statement on Coal Exploration and Mining (NSW Government, 2020). The Strategic Statement "outlines the NSW Government's approach to transitioning to renewable energy and supporting the economy and aims to improve certainty about where mining should not occur." It identified 14 potential future coal exploration release areas (NSW Government, 2020).

Adjacent to Hawkins and Rumker is the area of Ganguddy – Kelgoola, which is slated to go through the PRIA process once further exploration is completed (NSW Government, 2020).

1.2 PRIA Preparation

The PRIA process is also set out in the Strategic Release Framework (NSW Government, 2020). It is an initial assessment of social, environmental and economic matters relating to areas that could be released for exploration. In theory, it involves engaging with interested and potentially impacted stakeholders to identify issues for consideration.

DPIE has engaged Resource Strategies to undertake 'preparation of a Preliminary Regional Issues Assessment document in relation to a defined area that could be released for coal exploration' for a sum of $167,156 (NSW Government eTendering, 2021).

On its website Resource Strategies (2021) says it facilitates development approvals for major mining and associated infrastructure projects and prepares comprehensive and timely environmental assessment documentation with the assistance of recognised experts across all environmental fields.

The DPIE undertakes the PRIA and submits this to the ABSR, which considers potential release areas, reviews reports and recommends assessment of the release of an area for resource exploration. The ABSR makes recommendations to the Minister for Regional NSW and these are considered by Cabinet and, if approved, the Minister for Regional NSW releases an area for exploration and invites companies to apply for a prospecting title.

1.3 Rylstone Region Coal Free Community

1.3.1 RRCFC

The Rylstone Region Coal Free Community (RRCFC) is a self-funded group of like-minded local residents and supporters, of the Rylstone Region committed to stopping further exploration of coal and approval of mines in our region. Our aim is to protect the land, heritage, culture and community for now and future generations.

1.3.2 Purpose of this report

This report is the RRCFC's submission to the PRIA process on *Aquatic Ecology*. The RRCFC recognises that coal exploration is a precursor to coal mining, and therefore it is predominantly the mining phase that is considered in this submission.

This submission considers the aquatic ecology of the Hawkins and Rumker coal exploration release areas. It clearly demonstrates the high ecological values of the Hawkins and Rumker areas. It shows how the aquatic ecology of the region would be destroyed and lost forever by a short term mine. The RRCFC believes this cost is too high, it is not in line with the principles of ecologically sustainable development and is contrary to the objects of the NSW *Environmental Planning & Assessment Act 1979* (EP&A Act).

It is the RRCFC's strongly held view that the PRIA should find that the proposed exploration areas should not be opened for exploration under the Strategic Framework that it recommends against release of the proposed areas, and the Advisory Board should rule that coal exploration should not proceed in the Hawkins and Rumker areas.

2| Existing Aquatic Environment

Hawkins and Rumker areas both straddle the Great Dividing Range, with each having a portion of their catchments falling east, into the Upper Hunter catchment; and west, into the Cudgegong River and Lawson Creek catchments (Figure 1).

2.1 Location

2.1.1 Hawkins

In the Upper Hunter catchment portion of the Hawkins area, Ginghi Creek and Growee Creek rise in mountainous terrain and flow northeast into the Bylong Valley. In the Upper Lawson Creek catchment portion of the Hawkins area, there are numerous waterways, including: Breakfast Creek and Reedy Creek, which cross Hawkins after rising in Rumker; and Greenhills Swamp Creek, Long Gully, Horse Gully, Hawkins Creek and Lawson Creek, all of which rise in Hawkins. The Lawson Creek catchment waterways flow generally in a westerly direction, where Lawson Creek eventually joins the Cudgegong River below Mudgee.

2.1.2 Rumker

Rumker straddles three upper catchment areas. In the Upper Hunter catchment portion of Rumker, Sapling Creek, Sawyers Creek, Jumper Creek and Spring Log Creek rise in mountainous terrain and flow northeast into the Growee River in the Bylong Valley. In the Lawson Creek catchment portion of Rumker, Breakfast Creek and Reedy Creek rise then flow west into the Hawkins area. In the Cudgegong River catchment, Coxs Creek and Dairy Swamp Creek rise, with their confluence on the southern boundary of Rumker before flowing into Rylstone Dam, a locally important water body and the sole water supply for all towns in this area.

2.2 Waterways

A study of Lawsons Creek and the upper Cudgegong catchments was undertaken for the Cudgegong Catchment Committee (S.J. Landscape Constructions 2002). This section provides a summary of the Coxs Creek, Breakfast Creek and Reedy Creek catchment conditions and the key vegetation communities for these waterways as described in that study.

2.2.1 Coxs Creek

Coxs Creek is approximately 31km in length, from its confluence with the Upper Cudgegong River to Nullo Mountain. Coxs Creek is comprised of three main River Styles: alluvial valley setting, intact valley fill and confined valley setting with occasional floodplains.

The upper reaches of Coxs Creek flow through State Forest and National Park. The remainder of the creek is dominated by mixed grazing with a small amount of cropping in the lower section. Further downstream, the intact valley fill River Style has given rise to a unique vegetation community of Swamp Grassland and Sphagnum Bog. In its natural state, this area would not contain the defined river channel that is present in certain places.

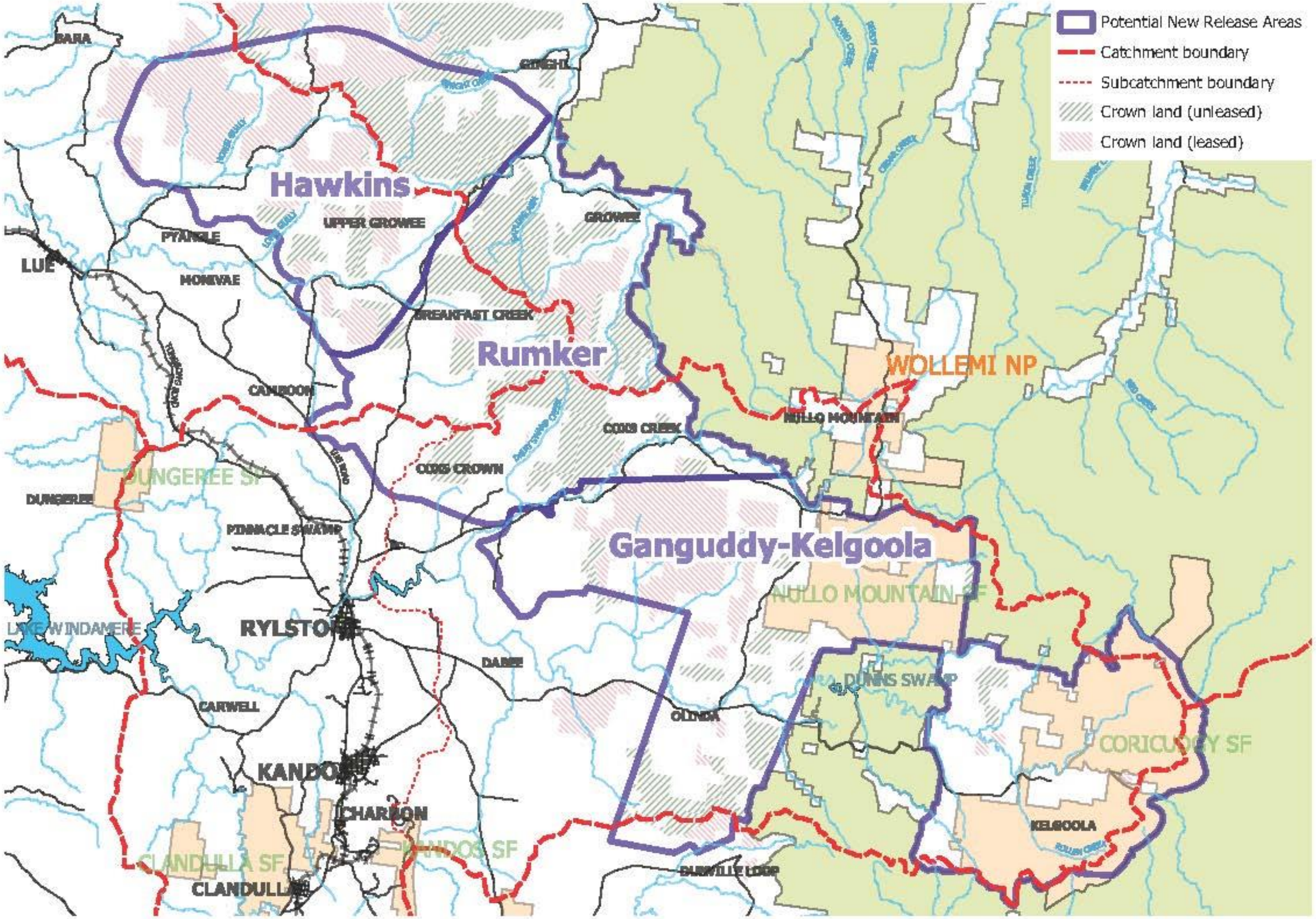

Figure 1 Water catchments within proposed exploration areas

The riparian vegetation consists of four types. A complex sclerophyll forest in the upper reaches of the waterway is dominated by *Eucalyptus viminalis*, *Acacia melanoxylon* and *A. mearnsii*. The system of Sedgeland, Swamp Grassland and Sphagnum Bog below this contains *Leptospermum spp*., *Juncus spp*. and *Cyperus sphaeroides*. The creek then flows through remnants of tall gallery forests and eucalypt forests which contain *Eucalyptus viminalis* and *E. bridgesiana*, and *Callistemon sp*. of shrub. Finally, the lower reach is largely cleared agricultural land that was once dominated by eucalypt forests.

While the Narrabeen sandstone sclerophyll community and the Permian sediments open forests are likely to be similar to that described for the Upper Cudgegong, **the Swamp Grassland and Sphagnum Bog in the central part of Coxs Creek is thoroughly unique**. **This vegetation type warrants detailed botanical survey and will require special attention so that it is managed appropriately to ensure its long-term viability.** The Sphagnum Bog vegetation community is poorly preserved at the local, regional and national conservation levels (Bell 1998 in S.J. Landscape Constructions 2002.

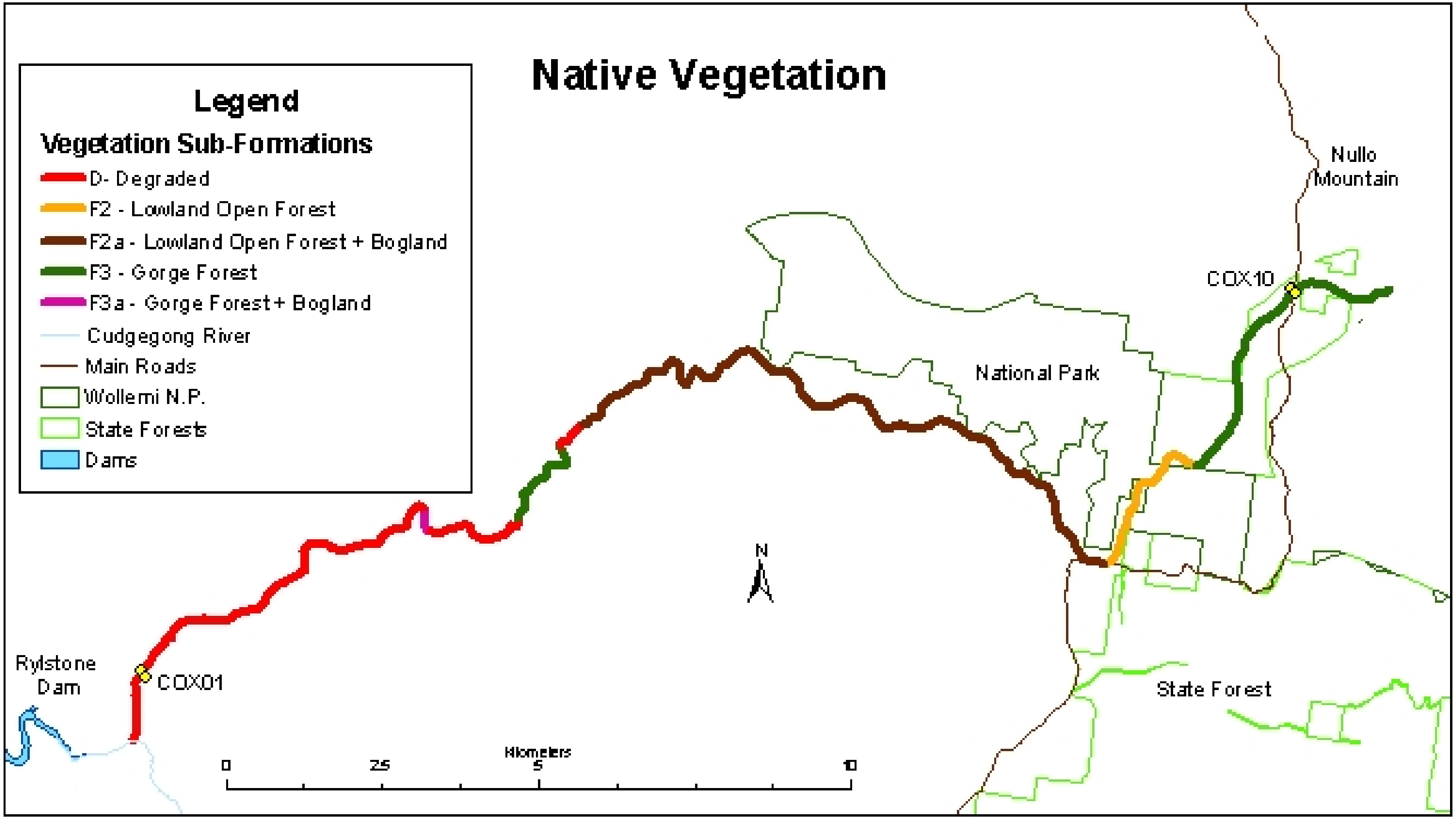

Figure 2 Coxs Creek Native Vegetation

[Source: S.J. Landscape Constructions (2002)]

2.2.2 Reedy Creek

Reedy Creek (upper Lawson Creek) is approximately 13km in length. The upper reach starts in the Great Dividing Range on the southern side of Bald Mountain and ends at the confluence with Lawsons Creek around 11km east of the village of Lue, near the locality of Camboon.

In the upper reach of the creek, limited grazing occurs in small pockets of cleared land and amongst native vegetation. Further downstream, increasing stretches of the creek have been cleared and more extensive grazing of the cleared land occurs. A small section of Meandering Fine Grained River Style occurs in this water, while the remainder of Reedy Creek alternates between Intact Valley Fill and Channelised Fill. In the upper reach, the Intact Valley Fill supports the riparian meadow vegetation formation. The Channelised Fill is a degraded form of Intact Valley Fill and is largely coincident with cleared land.

It is likely that Reedy Creek contains the most intact riparian vegetation types in the entire Lawsons Creek catchment (Figure 3)**.** Significant tracts of the upper reaches are lined by lowland open forest with dominant trees including ribbon gum (*E. viminalis*), Blakely's red gum (*E. blakelyi*) and rough-barked apple (*Angophora floribunda*), as well as several intermediate sections of cleared land where the ground surface is still well-covered by derived pasture.

Occurring primarily to the east of the Bylong Valley Way are extensive tracts of riparian meadows. These meadows are characterised by tussocks of grass (*Poa* sp.), sedge (*Carex appressa*) and rush (*Juncus usitatus*), which occupy the sediment-choked creek bed. The best example of the meadow is located to the south-east of Bald Mountain. Here, an adjacent sandstone outcrop seems to have influenced the presence of low trees in the meadow. The exact nature of the influence is unknown, but the outcrop may trap cool air that has drained from nearby hills, creating a 'cold flat' where the cool air collects overnight. Such locations are typically dominated by grasses and herbs, with small, hardy eucalypts sometimes occurring in certain areas. Here, the flat is dominated by the meadow, with a small patch of mallee eucalypt, identified as broad-leaved Sally (*E. camphora* subsp*. camphora*). **This site is likely to be of high conservation significance.**

West of the Bylong Valley Way, meadows occur intermittently with lowland open forest and cleared pastures. Comparisons with similar vegetation types in other areas have been hard to make, due to a general lack of literature on the subject. The meadows appear to have affinities with the sub-alpine grasslands and sedgelands of alpine and sub-alpine south-east Australia.

Tame suggests that a similar vegetation type occurred on shallow, sandy peat overlying impermeable clays (S.J. Landscape Constructions 2002). A similar situation is probably present with the meadows along Reedy Creek. Bell (1998 in S.J. Landscape Constructions 2002) **this vegetation type in Wollemi National Park is regarded as poorly preserved at both local and regional scales**.

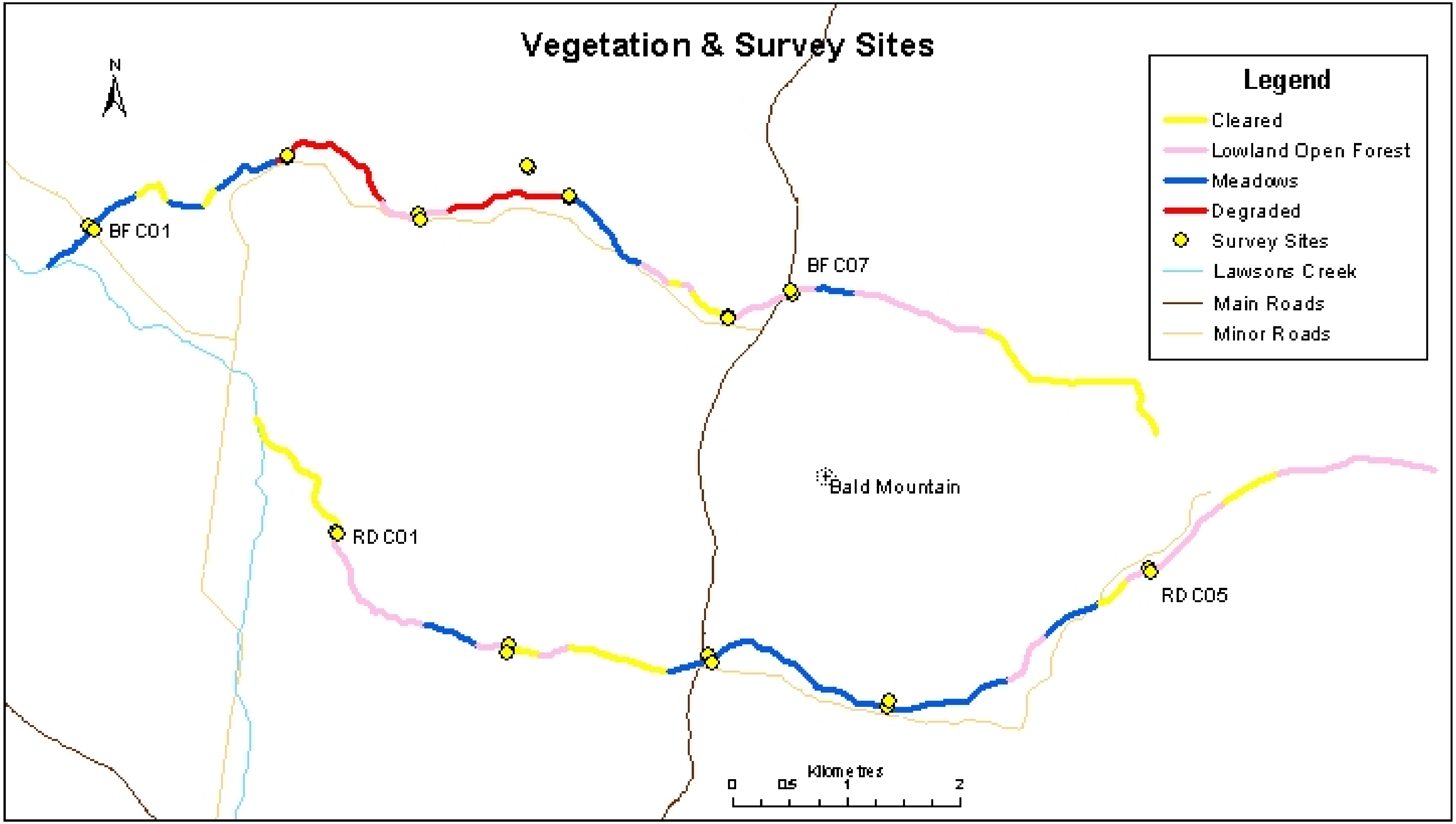

Figure 3 Breakfast and Reedy Vegetation and Survey Sites

[Source: S.J. Landscape Constructions (2002)]

2.2.3 Breakfast Creek

Breakfast Creek is approximately 12km in length and runs on the north side of Bald Mountain to join Lawsons Creek below Reedy Creek, in the vicinity of Pyangle. Aerial interpretation indicates that the creek east of Bylong Valley Way shows few signs of weed infestation or erosion problems.

The predominant land-use along the creek is grazing which occurs on improved pasture and amongst native vegetation. A horse training facility is situated at the corner of Breakfast Creek Road and Bylong Road, and immediately below this are a few small landholdings.

The River Style alternates between Channelised Fill and Intact Valley Fill. The creek meanders through stretches of intact native vegetation and areas that have been cleared of trees for grazing. The majority of the cleared areas have sufficient ground flora in the creek bed; however, this only applies to stretches that have not been channelised. Stands of intact native vegetation are providing the seed source for natural regeneration of native species along the creek.

The upper parts of Breakfast Creek have been cleared although there still remains a high proportion of native groundcover along the creek (Figure 3). Directly north of Bald Mountain the creek is lined by lowland open forest, with dominant eucalypts including ribbon gum (*E. viminalis*) and Blakely's red gum (*E. blakelyi*). Shrubs are sparse, and the groundcover is dominated by natives. A small meadow occurs west of the Bylong Road, dominated by tall sedge (*Carex appressa*) and tussock grass (*Poa* sp.). In this area the creek has been increasingly cleared, with intact lowland open forest being less frequent.

Meadows are still present in some locations with common reed (*Phragmites australis*) being dominant in places. Prior to the junction with Lawsons Creek, meadows occur intermittently with cleared land. **The meadows along Breakfast Creek are most likely simplified versions of the intact example on Reedy Creek**.

2.3 Natural springs

To understand the full extent of springs that may be present in the Hawkins and Rumker areas, use was made of Cardo (2020), which presented some mapping of springs within the Bowden's study area. This report indicated that within an approximately 320ha area, there were 29 springs present. Extrapolating this to the 32,700ha Hawkins and Rumker area, it would be reasonable to conclude that there would be over 3,000 springs within the proposed release area.

2.4 Stream Conditions

Rivers Styles data was sourced from the Bioregional Assessment Program (Earthscapes, 2021). Figure 4 displays stream condition data. Table 1 and Table 2 provide a summary of stream condition and fragility for each of the proposed coal release areas.

Within the Hawkins and Rumker areas, 88% of the waterways are in good or moderate condition and 98% have a moderate or high stream fragility.

Table 1 Stream Condition

Stream Condition (km)	Good	Moderate	Poor
Hawkins	26.1	6.5	7.7
Rumker	16.8	15.3	1.4
Subtotal	42.9	21.8	9.1
% of total waterway	58%	30%	12%

[Source: Earthscapes, 2021]

Table 2 Stream Fragility

Stream Fragility (km)	High	Moderate	Low
Hawkins	26.7	12.1	1.6
Rumker	30.7	2.9	0
Subtotal	57.4	15	1.6
% of total waterway	78%	20%	2%

[Source: Earthscapes, 2021]

2.5 Water quality

There is not readily available water quality data for the small waterways within the Hawkins and Rumker areas. However, given that most of the waterways are in moderate to good condition, that a high proportion of the catchments have native vegetation present, and that much of the riparian corridors of the waterways have native vegetation present, it is reasonable to assume that the water quality within the waterways would be moderate to good. **It is recommended that if the government continues to show an interest in the Hawkins and Rumker areas that it moves to establish independent and comprehensive baselines of the waterways.**

2.6 Fauna

2.6.1 Previous Studies

A NSW Fisheries survey of fish (NSW Fisheries 1997) recorded eleven native and six introduced fish species from the Macquarie River Catchment, including Murray cod and eel tailed catfish (Table 3). Ten native and seven introduced species were recorded in this survey, including Murray cod and silver perch (Llewellyn in Cardno 2020).

A literature review (Goldney et al. 2007) found records for 16 native and seven introduced fish species in the Central West Catchment (Table 3). The review included records held in the NSW Fisheries database of observational results from fish surveys and release sites for their re-stocking programme made available for the study. The review also included an assessment of the regional conservation status of recorded native species based on relative abundances and expert opinion.

Field assessments found that the Hawkins, Reedy and Lawsons Creeks support a diverse macroinvertebrate fauna, suggesting relatively rich fauna (Cardno 2020). While some pollution-tolerant taxa were present, the assemblage was biologically diverse. It also noted the presence of springs which support surface aquatic ecology occurred.

The Lue Action Group commissioned an ecological review of the Cardo (2020) assessment. ABSolution Ecology & Stygoecologia (2020) undertook the review of Cardno's aquatic ecology assessment, and found that that (p11) *the section on stygofauna is completely incorrect as it states that the stygofauna were not endemic to the area as they were typical of fauna found in alluvials. As there has been no stygofaunal officially described and officially named from this area it can be certain that they are new species and highly likely to be endemic. It is obvious that Cardno do not have the expertise to identify or understand the significance of these species or they would not have dismissed this so quickly*.

2.6.2 Desktop assessment

The creeks and rivers within the Hawkins and Rumker areas are classified as Key Fish Habitat by NSW Department of Primary Industries - Fisheries (2021) (Figure 5) . These contain Type 1 – Highly Sensitive Key Fish habitats (native aquatic plants and large wood debris) (Cardno 2020).

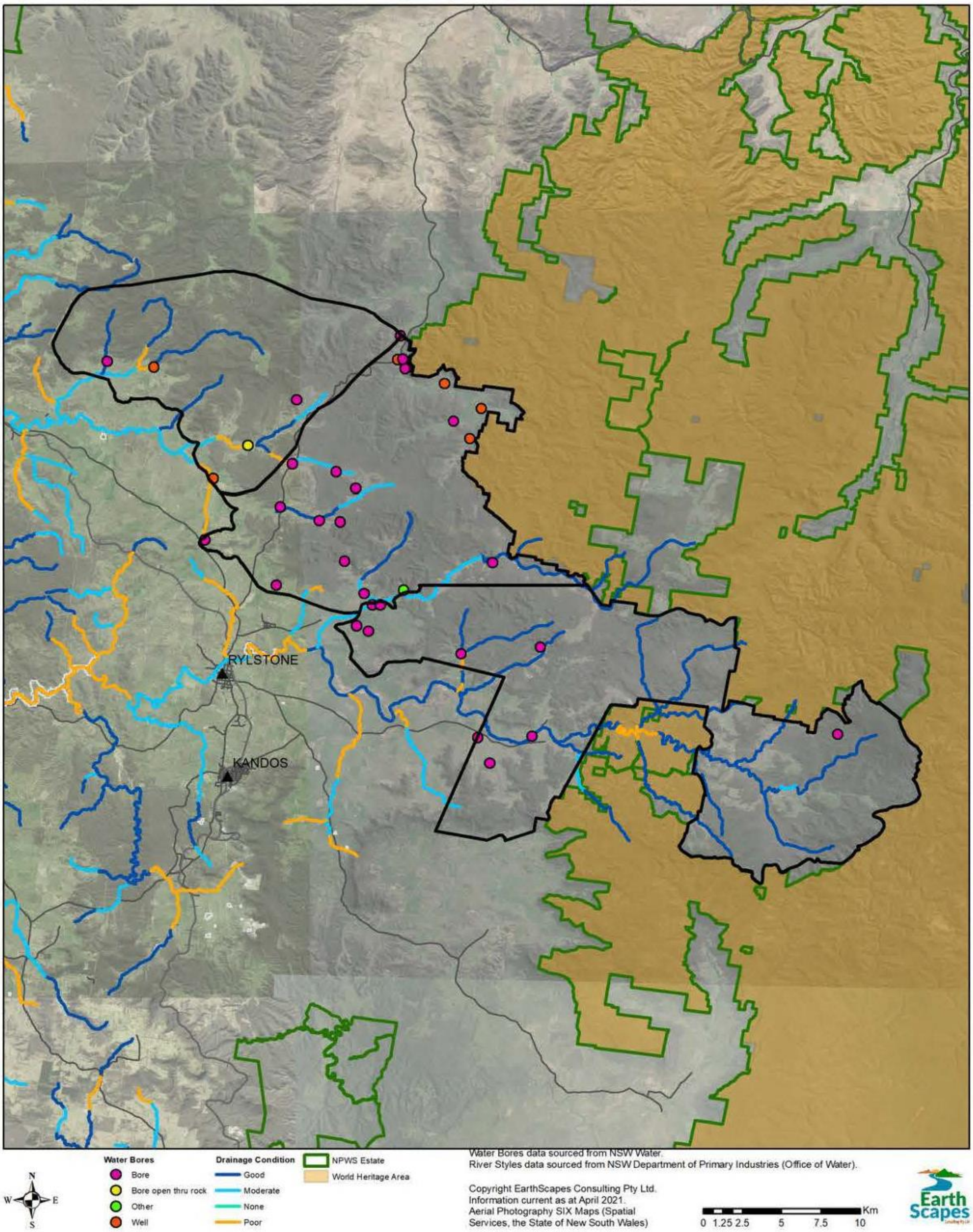

Figure 4 Stream Conditions in the proposed release areas
[Source: Earthscapes, 2021; https://data.gov.au/data/dataset/06fb694b-d2f1-4338-ab65-a707c02f11d7]

Table 3 Species of Fish Recorded Previously in the region

Scientific Name	Common Name	Llewellyn (1983)	NSW Fisheries (1997)	Goldney et al. (2007)	Regional Conservation Assessment (Goldney et al. 2007)
		Macquarie River Catchment		Central West Catchment	
Ambassis agassizii	Olive perchlet	•		•	RE
Bidyanus	Silver perch	•		•	D / RV
Carassius auratus	Goldfish	•	•	•	
Craterocephalus fluviatilis	Murray hardyhead	•			
Craterocephalus stercusmuscarum	Flyspecked hardyhead			•	D / RV
Cyprinus carpio	Common carp	•	•	•	
Gadopsis marmoratus	River blackfish	•		•	RV
Galaxias olidus	Mountain galaxias	•	•	•	D / RV
Gambusia holbrooki	Eastern gambusia	•	•	•	
Hypseleotris spp.	Carp gudgeon	•	•		
Hypseleotris klunzingeri	Western carp gudgeon			•	D
Leiopotherapon unicolor	Spangled perch	•	•	•	RV
Maccullochella macquariensis	Trout cod			•	RE
Maccullochella peelii	Murray cod	•	•	•	RV
Macquaria ambigua	Golden perch	•	•	•	Se
Macquaria australasica	Macquarie perch			•	RE
Melanotaenia fluviatilis	Rainbowfish		•	•	RE
Nannoperca australis	Southern pygmy perch		•		RE
Nematalosa erebi	Bony bream	•	•	•	D / RV
Oncorhynchus mykiss	Rainbow trout	•	•	•	
Perca fluviatilis	Redfin perch	•	•	•	
Philypnodon grandiceps	Flathead gudgeon		•	•	RV
Retropinna semoni	Australian smelt	•	•	•	Se / D
Salmo trutta	Brown trout	•	•	•	
Salvelinus fontinalis	Brook trout	•		•	
Tandanus	Eel-tailed catfish	•	•	•	RE
Grey shading indicates non-native or introduced species					
Se = Secure as a species, D = Declining, RV = Regionally Vulnerable, RE = Regional Endangered.					

[Source: Cardno 2020]

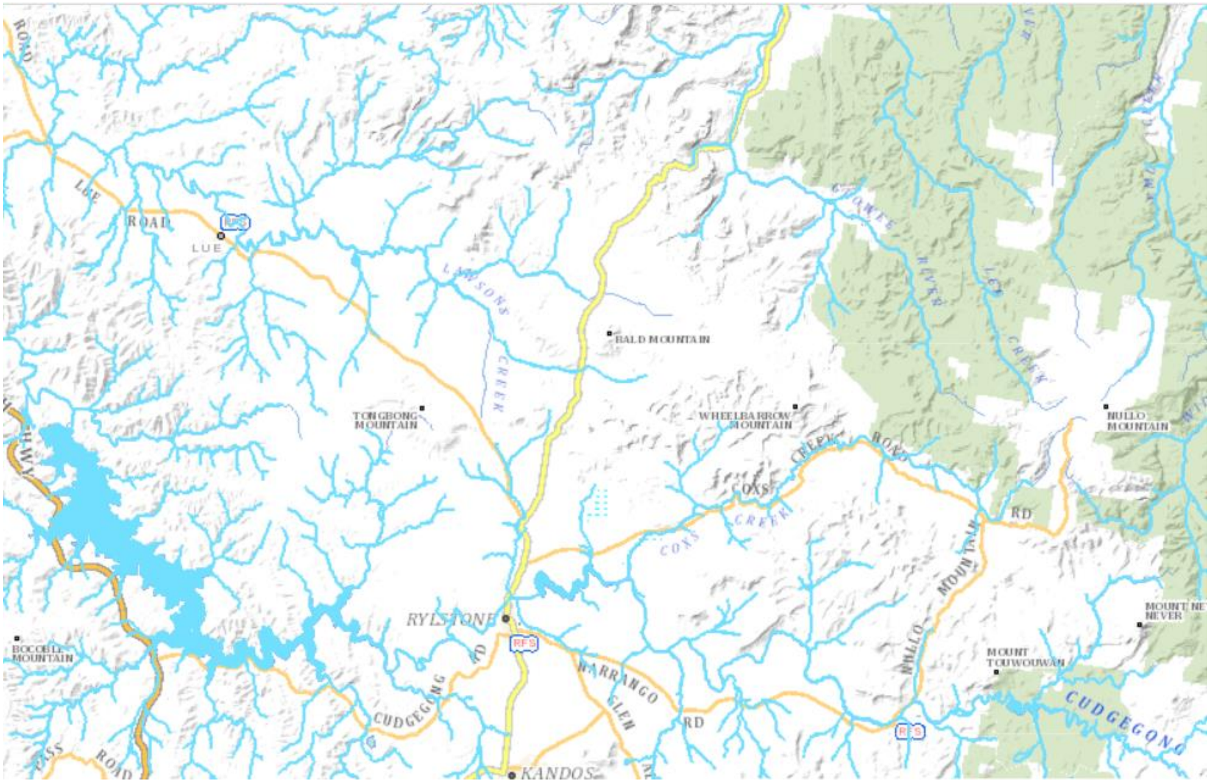

Figure 5 Key fish habitat in the Hawkins Rumker areas

2.7 Flora

2.7.1 Previous Studies

Hawkins Creek, Reedy Creek and Lawsons Creek support several species of native and introduced aquatic macrophytes (Cardno 2020). Numerous springs which support surface aquatic ecology occurred and these may also support sub-surface aquatic ecology.

As discussed in Section 7.1.2, found that extensive tracts of riparian meadows occur, primarily to the east of the Bylong Valley Way (S.J. Landscape Constructions 2002). Here, the flat is dominated by the meadow, with a small patch of mallee eucalypt, identified as broad-leaved Sally (*E. camphora* subsp. *camphora*). **This site is likely to be of high conservation significance.**

Further the Swamp Grassland and Sphagnum Bog in the central part of Coxs Creek is thoroughly unique (S.J. Landscape Constructions, 2002). **This vegetation type warrants detailed botanical survey and will require special attention so that it is managed appropriately to ensure its long-term viability**.

A little-known group of diverse, relatively isolated and largely unprotected mires, in a relatively low rainfall area in the upper Cudgegong River catchment and of their floristic, hydrogeomorphic and typological relationship with other mires of the Blue Mountains has been recently reported (Baird I.R. and Benson, D. 2018). The authors report that these can be broadly divided into montane bogs, montane fens and hanging swamps.

In the Sydney Basin bioregion, Temperate Highland Peat Swamps on Sandstone (THPSS) is listed as an Endangered Ecological Community (EEC) under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. Baird and Benson (2018) concluded that although not specifically included in the description of THPSS, some of the mires of the upper Cudgegong, are clearly referrable to the THPSS EEC, and have been simply overlooked because of lack of documentation. For a similar reason, none of the valley-floor bogs and fens in the upper Cudgegong are specifically identified in the Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions NSW EEC determination. In circumscribing the Montane Peatlands and Swamps EEC, the NSW Scientific Committee referred to swamps above 400–600 m elevation. Baird and Benson (2018) also concluded that the montane bogs and fens of the upper Cudgegong are also referrable to this EEC and are clearly an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of NSW.

Baird and Benson (2018) reported that the montane bogs, montane fens and hanging swamps in the upper Cudgegong are clearly an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of NSW and hoped that highlighting this hitherto unrecognised group of high conservation-value mires will contribute to their improved conservation and encourage further research into mires of eastern NSW Baird I.R. and Benson, D (2018).

The information from the 2002 study on Coxs Creek, Reedy Creek and Breakfast Creek has been provided to Dr Ian Baird for comment as part of the preparation of this submission. He advised that on *"the upper reaches of Reedy and Breakfast creeks, the "riparian meadows" referred to, with some Eucalyptus camphora ssp. camphora, are going to be referable to the same Tableland Swamp Meadows (montane fen) typology we referred to along mid and upper Cox's Creek and referred to also by Tame and noted by Bell in the area. These vary across the catchment, in terms of organic content of the soils, depending on water availability, including groundwater inputs, and in terms of floristics. These are likely to be covered by the NSW Montane Peatlands and Swamps EEC listing, and the presence of E. camphora I think connects many of these occurrences across the upper Cudgegong River catchment east of Rylstone.*

In localised patches along upper Cox's Creek you increasingly find small patches of more groundwater dependent montane bog communities along the edges of the swamp meadows and tributaries. These have distinctive floristics and are the patches where you most likely find E. camphora, Sphagnum, and a suite of bog species not found in the swamp meadows. As Doug and I noted in our paper, the critical factor for development of these peat swamp types is reliable water, and groundwater inputs typically play an important role in these sandstone landscapes, backed up by direct rainfall inputs. The further west you go in the upper Cudgegong catchment there is a reduction in rainfall and suitable conditions for development of peaty wetlands, such as the swamp meadows."

Given this, the montane bogs, montane fens and hanging swamps in Coxs Creek, Reedy Creek and Breakfast Creek are also clearly an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of NSW. The length of montane bogs, montane fens and hanging swamps in Breakfast Creek is 3.4km, in Reedy Creek 4.6km, and in Coxs Creek 13.5km. This is 21.5km in total. It is noted there are a number of other waterways within the Hawkins and Rumker areas where swampy areas are observable on topographic maps. The name of some of these creeks are also indicative of the presence of swamps, such Dairy Swamp Creek and Greenhills Swamp Creek While no data is available for the vegetation on these waterways, it is probable EEC could also be present.

2.8 Threatened Species, Populations and Communities

The aquatic threatened species and populations that could potentially occur, and their likelihood of occurrence was considered as part of the Bowdens Environmental Impact Statement (Cardno, 2020). This report relied on records from:

- NSW DPI Fish communities and threatened species distribution of NSW (NSW DPI, 2016a);
- BioNet the website for the Atlas of NSW Wildlife: http://www.bionet.nsw.gov.au;
- Threatened Species Profile Database: http://www.environment.nsw.gov.au/threatenedspecies;
- NSW DPI Listed threatened species, populations and ecological communities website: http://www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key;
- Department of the Agriculture, Water and Environment (DoAWE) (formerly DoEE and DoE) Protected Matters Search Tool (PMST): http://www.environment.gov.au/epbc/protected-matters-search-tool;
- Atlas of Living Australia: http://www.ala.org.au/;
- The NSW DPI (Fisheries) Threatened and Protected Species Record Viewer (developed by the Threatened Species Unit of the former I&I NSW and now superseded by NSW DPI, 2016a)

The Environmental Impact Statement findings were reviewed, and adjustments made based on published distributions and the information in the table above. Only those considered possible are shown in Table 4.

Table 4 Relevant Aquatic Species, Populations and Communities listed as Threatened under State and Federal Legislation that are likely to occur in the Hawkins and Rumkin areas

Species or Population	BC Act status	FM Act status	EPBC Act status
Species			
Murray cod			Vulnerable
Silver perch		Vulnerable	
Southern Purple Spotted Gudgeon		Endangered	
Invertebrates			
Giant dragonfly	Endangered		
Murray crayfish		Vulnerable	
Populations			
Western population of olive perchlet		Endangered	
Murray-Darling Basin population of eel tailed catfish		Endangered	

[Source: Cardno 2020]

Threatened species searches indicated that several aquatic species or populations (Murray cod, silver perch, southern purple spotted gudgeon, trout cod, Murray crayfish and the Murray-Darling Basin population of eel tailed catfish), or their habitat, may be present in the wider Cudgegong River catchment area. There are also relatively recent records of silver perch existing in the Cudgegong River and it has been stocked in Lake Burrendong and Lake Windamere. Murray crayfish have been recorded from the Cudgegong River.

The Bowdens Environmental Impact Statement (Cardno, 2020) also reported that River blackfish appears to have experienced a reduction in abundance across its range due to anthropogenic disturbance to its habitat. The recent occurrence of purple spotted gudgeon and eel tailed catfish in the Macquarie River catchment (Cardno, 2020) suggests that these species could also be present in the Hawkins and Rumker areas.

3| Discussion

3.1 Discussion

The Hawkins and Rumker areas both straddle the Great Dividing Range, lying in the upper catchments of the Upper Hunter, Cudgegong River and Lawson Creek. Within the Hawkins and Rumker areas, 88% of the waterways are in good or moderate condition and 98% of these waterways have a moderate or high stream fragility.

Stream fragility refers to the susceptibility or sensitivity of certain geomorphic categories to physical adjustments and changes when subjected to degradation or certain threatening activities (Cook and Schneider 2006). Significant adjustment is sometimes seen in geomorphic categories that have higher levels of fragility (that is, streams that are not robust or have lower resilience). This significant adjustment can also result in certain geomorphic categories changing to another one when a certain threshold (level of disturbance) of a damaging impact is exceeded (Cook and Schneider, 2006).

Recognising the fragmented, modular nature of many ecosystems and landscapes today, remaining semi-natural ecosystems must be enhanced, whenever possible, building out from scarce 'natural', 'near-pristine' or 'good condition' remnants. Conservation areas need to be identified and managed in terms of their 'uniqueness' and 'rarity' value, through river health, heritage, and wild and scenic rivers programs (Macquarie University, 2004). Given the fragile rating of 98% of the waterways within the two areas, should the proposed coal mining proceed, it would seem almost certain that the condition of these streams would be degraded irreparably.

Field assessment undertaken recently in a limited area that lies within the Hawkins area found that the Hawkins, Reedy and Lawsons Creeks support a diverse macroinvertebrate fauna, suggesting relatively rich fauna. The assemblage was biologically diverse and the presence of springs supports surface aquatic ecology.

As the majority of the waterways are in moderate to good condition, a high proportion of the catchments and riparian corridors have native vegetation present, it is reasonable to assume that the water quality within the waterways would be moderate to good.

There is a wide range of aquatic threatened species, populations and communities present within the Hawkins and Rumker areas. Further, it is noted that much of the information gathered on aquatic species within these areas is dated. The current situation is likely to now be far more dire for these species considering that higher temperatures, more extreme climatic events, extended droughts and cumulative rainfall deficits (Australian CliMate, 2021) due to climate change combined with anthropogenic disturbance to habitat, have already placed extreme pressure on the water resources and the aquatic ecology they support over the past two decades.

The condition of NSW rivers freshwater habitats) were found to be under intense pressure from historic and current land and water management practices throughout their catchment (Norris et al in DPI 2021. Mining was specifically noted as a key issue affecting rivers in NSW, and that generally water extraction has the most significant impact as it affects the level, frequency and duration of low flows.

3.2 Impacts from underground mining

Impacts can be divided into three broad categories which reflect the time lag between mining and impact (Commonwealth of Australia 2015):

- First order impacts refer to the immediate impacts of subsidence (also called subsidence effects) such as cracking, shearing, tilting and reopening bedding planes and joints.
- Second order impacts refer to the impacts that result from subsidence effects, such as changes to hydrology from altered groundwater or surface water flow paths and water quality impacts.
- Third order impacts are the result of changes to hydrology and water quality, such as streambed erosion and ecological responses.

Third order impacts can lag significantly from the first and second order impacts. Figure 6 shows a conceptual timeline describing the temporal differences in first, second and third order impacts.

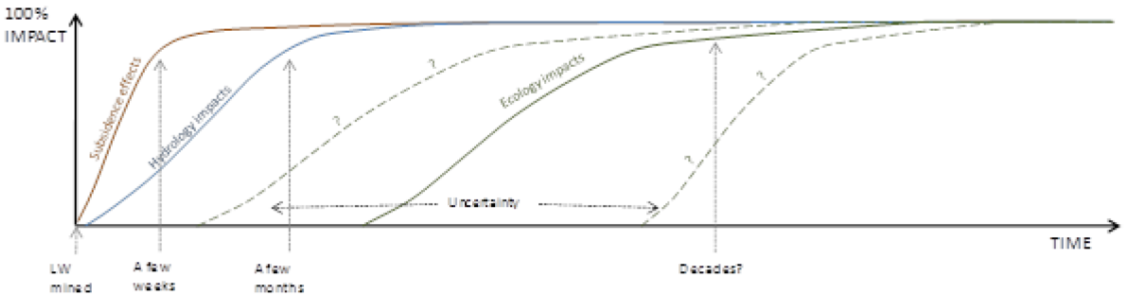

Figure 6 Conceptual timeline showing time lags between first, second and third order impacts

[Source: Commonwealth of Australia 2015]

3.3 Mining destroys riparian habitats and water resources

The surface water systems are such that they should never be disturbed and certainly not dug up. No form of mining is free from risk to the unique ecology of riparian habitats and threatened species found within them. Mining in the nearby Newnes Plateau area has proven this beyond doubt (Gregory, X. 2021). Centennial Coal has admitted its mining operations at its Springvale Mine in the Plateau contributed to the drying out of the Carne West swamp. There is concern that continuing to mine in this area, as is proposed in the Gardens of Stone stage 2 mine, would have a similar outcome for about 300 remaining hectares of swamps, and this could affect the supply of Sydney's drinking water to Warragamba Dam. Centennial Coal's environmental assessment (EA) found "subsidence-related impacts are expected" at several swamps within the catchment area for the Angus Place Mine (Gregory. 2021). The NSW Liberal party is blaming their own government's "erroneous" environmental approvals processes for allowing Centennial Coal to longwall mine below swamps, home to endangered ecosystems and has clearly said there is no social licence for undermining these sensitive areas (Gregory 2021).

These effects have long been recognised by the NSW Government. The NSW Department of Environment and Climate Change (DECC) noted that longwall mining subsidence is frequently associated with cracking of valley floors and creeklines with subsequent effects on surface and groundwater hydrology (2007 in Smith 2009). Of particular concern is the potential for longwall mining to affect upland swamps. Upland swamps, particularly peat swamps, are important to catchment hydrology and ecology because they absorb water and allow runoff for long periods after rainfall has ceased. Surface cracking as a result of longwall mining subsidence can have a variety of impacts on riverine features or attributes. These include:

- Loss of surface flows or water levels

- Loss of aquatic or instream habitats. Complete drying of river pools or wetlands has occurred. The loss of these surface features is potentially irreversible in some cases
- Loss of connectivity between pools as surface water is lost to subsurface flows
- Loss of water quality (Increased iron oxides, manganese, sulphides and electrical conductivity, and lower dissolved oxygen)
- Simplification of remaining instream habitat due to the growth of iron-oxidising bacteria which can also be seen as a rusty-coloured mass in the water

The DECC considered that much of the impact / damage to natural features from longwall mining is unacceptable as many are irreversible and contrary to the principles of ecologically sustainable development. Of key concern to the DECC was that subsidence due to longwall mining has had significant impacts on river health and water dependent ecosystems, including threatened species and endangered ecological communities. Given this, it is inconceivable that the NSW Government should even contemplate the possibility of important riparian habitats in the Hawkins and Rumker areas being destroyed.

Observations of the effect of mining on the Newnes Plateau Swamps post the 2019/20 Black Summer bushfires show the impact of the longwall mining-related lowering of water tables and subsequent fire impacts in these swamps provide dramatic evidence of the irreversible damaging impacts of longwall mining. Unlike the reference swamps, the undermined swamps failed to respond to good rains since January 2020, with almost no resprouting of typical and often long-lived, resprouter sedgeland and shrub species, **destroying any hope that future rainfall might allow some semblance of the pre-mining conditions to return. These groundwater-dependent peat swamps are scarce and already face a rapidly changing climate; the dead swamps provide clear evidence of the impacts of longwall mining. No more swamps should be allowed to be destroyed.** (Baird and Benson 2020)

This submission has established that the montane bogs, montane fens and hanging swamps in Coxs Creek, Reedy Creek and Breakfast Creek are all an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of and are referrable to the Montane Peatlands and Swamps Endangered Ecological Community (EEC) listing under the NSW Biodiversity Conservation Act 2016 and the Temperate Highland Peat Swamps on Sandstone Commonwealth Environment Protection and Biodiversity Conservation Act 1999 listing.

The meadows, sphagnum bogs, wetlands and associated ecosystems of Coxs Creek, Reedy Creek and Breakfast Creek are unique, being at lower elevations and the western extents of these endangered ecological communities. **The impact of mining cannot just be offset through the Biodiversity Offsets Scheme – these are not found anywhere else so cannot be offset.**

The impacts to the springs, creeks and rivers in this area and meadows, sphagnum bogs, wetlands and associated ecosystems as well as the wide range of threatened species, populations and communities that are dependent on these features is an unacceptable impact for a short-term exploration and mine project in the Hawkins and Rumker areas.

No more swamps should be allowed to be destroyed.

3.4 Inconsistency with the Environmental Planning & Assessment Act 1979

3.4.1 Lack of information and Ecologically Sustainable Development principles

It is noted that there is no recent comprehensive information on aquatic species in this area, and that the area has until recently been subject to a prolonged and severe drought. Extensive survey is recommended to document the species and habitat that is present and to better understand this unique and sensitive environment.

Given the current paucity of data, to ensure informed and 'ecologically sustainable development' further information should be gathered to understand the sensitivity of the environment and its true value and that there is conservation of biological diversity and ecological integrity. To not do so fails to meet the principles of ecologically sustainable development.

3.4.2 Contrary to the EP&A Act Objects

Given the sensitivity of the environment, issuing exploration licences, which are the precursor to a mine being approved, it must be concluded that the issuing of exploration licenses within the Hawkins and Rumker areas is contrary to the following objects of the Environmental Planning & Assessment Act 1979:

> (a) to promote the social and economic welfare of the community and a better environment by the proper management, development and conservation of the State's natural and other resources,
> (b) to facilitate ecologically sustainable development by integrating relevant economic, environmental and social considerations in decision-making about environmental planning and assessment,
> (e) to protect the environment, including the conservation of threatened and other species of native animals and plants, ecological communities and their habitats,

4| Conclusion

The Hawkins and Rumker areas are fragile areas, rich in natural springs. There are are extensive tracts of riparian meadows that are of **high conservation significance.** The Swamp Grassland and Sphagnum Bog in the central part of Coxs Creek is **thoroughly unique**. The conservation status of the Sphagnum Bog vegetation community at local, regional and national conservation status is poor. This unique vegetation community would be lost with exploration and mining in proximity to it.

Reedy Creek and Breakfast Creek have extensive tracts of riparian meadows.

This submission has established that the montane bogs, montane fens and hanging swamps in Coxs Creek, Reedy Creek and Breakfast Creek are all an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of and are referrable to the Montane Peatlands and Swamps Endangered Ecological Community (EEC) listing under the NSW Biodiversity Conservation Act 2016 and the Temperate Highland Peat Swamps on Sandstone Commonwealth Environment Protection and Biodiversity Conservation Act 1999 listing. The length of montane bogs, montane fens and hanging swamps in Breakfast Creek is 3.4km, in Reedy Creek 4.6km, and in Coxs Creek 13.5km. This is 21.5km in total. It is noted there are a number of other waterways within the Hawkins and Rumker areas where swampy areas are observable on topographic maps. The name of some of these creeks are also indicative of the presence of swamps, such Dairy Swamp Creek and Greenhills Swamp Creek. While no data is available for the vegetation on these waterways, it is probable EEC could also be present.

Any disturbance from exploration and mining activity would reduce the quantity and quality of water within these waterways. Mines both damage any existing water resources within the affected footprint, as well as requiring a significant amount of water to operate. Regardless of the type of mining proposed – underground or open cut - there will be severe and irreversible impacts on surface water including springs, creeks and rivers. **These groundwater-dependent swamps are scarce and already face a rapidly changing climate; the dead swamps of the Newnes Plateau provide clear evidence of the impacts of longwall mining.** Any mining will lead to the permanent loss of the meadows, sphagnum bogs, wetlands and associated ecosystems as well as a wide range of threatened species, populations and communities. The meadows, sphagnum bogs, wetlands and associated ecosystems of Coxs Creek, Reedy Creek and Breakfast Creek are unique, being at lower elevations and the western extents of these endangered ecological communities. **The impact of mining cannot just be offset through the Biodiversity Offsets Scheme – these communities are not found anywhere else so cannot be offset. No more swamps should be allowed to be destroyed.**

The impacts to the springs, creeks and rivers in this area and meadows, sphagnum bogs, wetlands and associated ecosystems as well as the wide range of threatened species, populations and communities that are dependent on these features is an unacceptable impact for a short-term exploration and mine project in the Hawkins and Rumker areas.

There is limited data on the range and diversity of fauna present within the waterways of the Hawkins and Rumker areas, however recent survey data in a limited area found that the Hawkins, Reedy and Lawsons Creeks support a diverse macroinvertebrate fauna, suggesting relatively rich fauna The assemblage was biologically diverse and the presence of springs supports surface aquatic ecology. There is still a vast area that has not been surveyed and its true value cannot be fully appreciated. As found in the case of the Bowdens Silver aquatic ecology assessment: a*s there has been no stygofaunal officially described and officially named from this area it can be certain that they are new species and highly likely to be endemic*. **The significance of what is in this areas must be better understood before any decisions are made that may impact these areas.**

This submission clearly demonstrates the high ecological values of the Hawkins and Rumker areas. It shows how the aquatic ecology of the region would be destroyed and lost forever by a short term mine. The RRCFC believes this cost is too high, it is not in line with the principles of ecologically sustainable development and is contrary to the objects of the NSW *Environmental Planning & Assessment Act 1979* (EP&A Act).

The RRCFC strongly view that the PRIA should conclude that the environmental constraints in the Hawkins and Rumker areas are insurmountable and cannot be mitigated against by any future mining activity. As such, coal exploration should not proceed in the Hawkins and Rumker areas.

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Appendix A| Appendix A Species Lists for Reedy, Breakfast and Coxs Creek

Coxs Creek

The riparian vegetation consists of four types. A complex sclerophyll forest in the vicinity of Narrabeen sandstone from the headwaters to COX09 is dominated by *Eucalyptus viminalis*, Acacia melanoxylon and *A. mearnsii*. The system of sedgeland, Swamp Grassland and Sphagnum Bog between COX08 and COX03 contains Leptospermum spp., Juncus spp. and *Cyperus sphaeroides*. Remnants of tall gallery forests and eucalypt forests below COX03 contain *Eucalyptus viminalis* and *E. bridgesiana*, and *Callistemon sp*. of shrub. Finally, the lower reach is largely cleared agricultural land that was once dominated by eucalypt forests.

The only vegetation data that exists for this area, is that obtained by Bell for the adjacent Wollemi National Park. While the Narrabeen sandstone sclerophyll community and the Permian sediments open forests are likely to be similar to that described for the Upper Cudgegong, the Swamp Grassland and Sphagnum Bog in the central part of Coxs Creek is thoroughly unique. This vegetation type warrants detailed botanical survey and will require special attention so that it is managed appropriately to ensure its long-term viability.

Breakfast Creek

The upper parts of Breakfast Creek have been cleared although there still remains a high proportion of native groundcover along the creek. Directly north of Bald Mountain the creek is lined by lowland open forest, with dominant eucalypts including ribbon gum (*E. viminalis*) and Blakely's red gum (*E. blakelyi*). Shrubs are sparse, and the groundcover is dominated by natives. A small meadow occurs west of the Bylong Road, dominated by tall sedge (*Carex appressa*) and tussock grass (*Poa* sp.). In this area the creek has been increasingly cleared, with intact lowland open forest being less frequent. **Error! Reference source not found.** shows the vegetation communities identified on Breakfast Creek.

Meadows are still present in some locations with common reed (*Phragmites australis*) being dominant in places. Several lengthy stretches of the stream are highly degraded and have little vegetation (native or exotic), especially in areas currently subject to extensive erosion. Prior to the junction with Lawsons Creek, meadows occur intermittently with cleared land. The meadows along Breakfast Creek are most likely simplified versions of the intact example on Reedy Creek at RDC04.

Reedy Creek

It is likely that Reedy Creek contains the most intact riparian vegetation types in the entire Lawsons Creek catchment. Significant tracts of the upper reaches are lined by lowland open forest with dominant trees including ribbon gum (*E. viminalis*), Blakely's red gum (E. *blakelyi*) and rough-barked apple (*A. floribunda*), as well as several intermediate sections of cleared land where the ground surface is still well-covered by derived pasture.

Occurring primarily to the east of the Bylong Road are extensive tracts of riparian meadows. These meadows are characterised by tussocks of grass (*Poa sp*.), sedge (*Carex appressa*) and rush (*Juncus usitatus*) which occupy the sediment-choked creek bed. The best example of the meadow is located at RDC04 to the south-east of Bald Mountain. Here, an adjacent sandstone outcrop seems to have influenced the presence of low trees in the meadow. The exact nature of the influence is unknown, but the outcrop may trap cool air that has drained from nearby hills, creating a "cold flat" where the cool air collects overnight. Such locations are typically dominated by grasses and herbs, with small, hardy eucalypts sometimes occurring in certain areas. Here, the flat is dominated by the meadow, with a small patch of mallee eucalypt, identified as broad-leaved Sally (*E. camphora subsp. camphora*).

[Source: S.J. Landscape Constructions (2002)]

Appendix B | Baird & Benson paper on hydrogeomorphology, floristics, classification and conservation values of the little-known montane mires of the upper Cudgegong River catchment

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Hydrogeomorphology, floristics, classification and conservation values of the little-known montane mires of the upper Cudgegong River catchment, Central Tablelands, New South Wales

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Abstract: Mires or peat swamps have a restricted distribution in Australia and are limited to areas where hydrological inputs exceed evapotranspiration. In NSW, mires are restricted to the coast, adjacent ranges or tablelands, and along the Great Dividing Range; most are listed as threatened ecological communities under State or Commonwealth legislation. Due primarily to the relatively high rainfall and suitable geology, the Blue Mountains region includes a number of such threatened mire ecological communities. Most of these mire types are largely included within the Greater Blue Mountains World Heritage Area, although there are notable exceptions, such as the endangered Newnes Plateau Shrub Swamps.

This paper reports on a little-known group of diverse, relatively isolated and largely unprotected mires, in a relatively low rainfall area in the upper Cudgegong River catchment, east of Rylstone in the NSW Central Tablelands, and of their floristic, hydrogeomorphic and typological relationship with other mires of the Blue Mountains. They can be broadly divided into montane bogs, montane fens and hanging swamps. Particular attention is focussed on the largest and most diverse one, Rollen Creek swamp, which contains all three types. It is hoped that highlighting this hitherto unrecognised group of high conservation-value mires will contribute to their improved conservation and encourage further research into mires of eastern NSW.

Key words: peat swamp, wetlands, groundwater-dependent ecosystems, *Eucalyptus camphora*, *Petalura gigantea*, National Heritage, Greater Blue Mountains World Heritage Area.

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Introduction

Wetlands encompass a range of vegetated ecosystems, including those referred to as mires, bogs, fens, swamps and marshes (see Gore, 1983; Mitsch & Gosselink, 2007; Mitsch et al., 2009). Wetlands are characterised by a diversity of hydrological regimes, and may be permanently, seasonally or intermittently inundated or saturated (DECCW, 2010). Even in permanent wetlands, water table depth can vary considerably within a particular wetland and between different wetland types. Such spatial heterogeneity, even within a permanent wetland complex, may result in considerable heterogeneity in substrates, vegetation associations and habitat, often across small spatial scales (e.g., Brown et al., 1982; Keith & Myerscough, 1993; Keith et al., 2006). For example, wetland complexes are often characterised by a complex intergrading of fens, bogs, swamps or marshes (Hájek et al., 2006; Kirkpatrick & Bridle, 1998; Rydin & Jeglum, 2013; Wheeler & Proctor, 2000; Yabe & Onimaru, 1997).

Hydrology and water balance (evapotranspiration compared to precipitation and other hydrological inputs) are the critical factors in determining the development of peaty or organic-rich wetland sediments. A basic requirement for peat formation is that plant biomass production (carbon production) exceeds decomposition (ecosystem respiration or carbon output). Consistently high water tables and a relatively anoxic environment generally provide the necessary conditions for peat accumulation in wetlands. Conditions of seasonal drying or widely fluctuating water tables, and/or negative water balance, result in oxidisation and bacterial decomposition of organic matter, and are not conducive to accumulation of peat (Gore, 1983; Rydin & Jeglum, 2013).

In the international context the term *mire* refers to peat-forming wetlands, and includes bogs and fens (Gore, 1983; Joosten et al., 2017; Rydin & Jeglum, 2013), although the terms may be applied somewhat differently in Australia (see Whinam & Hope, 2005). In the Australian context, bogs are typically low nutrient, acidic, dominated by sclerophyllous sedges and shrubs, and mosses, and may have large parts of the surface raised above the water table, while fens are usually more nutrient-rich, less acidic or alkaline, dominated by softer herbaceous and graminoid vegetation, and usually with a near surface water table (Keith, 2004; Whinam & Hope, 2005). Additionally, in Australia, the term *swamp*, as used in this paper, is a generic term which may refer to a wide range of wetland types, including peat-forming wetlands (such as bogs and fens), and wetlands with primarily mineral substrates with environmental conditions unsuitable for peat development, in contrast for example, to its more specific application in the USA (Cowardin et al., 1979) or Europe (Rydin & Jeglum, 2013). While they receive hydrological inputs from precipitation, surface flow and groundwater in varying proportions, most mires (peat swamps) in Australia, including the diverse mire communities across the Blue Mountains of NSW, are considered groundwater-dependent ecosystems (see NSW Government, 2002; Serov et al., 2012; Whinam & Hope, 2005).

Mire ecosystems in the Blue Mountains are captured within the Montane Bogs and Fens and Coastal Heath Swamps vegetation classes of NSW and the ACT of Keith (2004). These are represented by a number of mire vegetation types, including Blue Mountains Sedge Swamps (BMSS), Newnes Plateau Shrub Swamps (NPSS), Coxs River Swamps and Boyd Plateau Bogs (Benson & Keith, 1990; Keith & Benson, 1988). These are characterised by considerable spatial heterogeneity across a number of environmental gradients, within and between individual swamps and swamp types (e.g., Holland et al., 1992a; Holland et al., 1992b). Variation in vegetation across the hydrological gradient (from ephemeral to permanent saturation) is particularly evident within the upland mires developed on sandstone geology (e.g., Benson & Baird, 2012; Holland et al., 1992a). The term *montane*, as used in this paper, follows its usage in various vegetation publications in NSW (e.g., Bell et al., 2008; Hunter & Bell, 2007; Keith, 2004; NSWSC, 2004). In describing the Montane Bogs and Fens vegetation class, Keith (2004) indicated an elevation range of 600–1500 m, which includes the elevation range of the study area. Following Keith (2004), bogs and fens identified in this study are thus referred to as montane bogs and montane fens. In their classification of the native vegetation of southeast NSW, Tozer et al. (2010) attributed higher elevation mire vegetation in the southern half of the Blue Mountains (the northern extent of their study area does not extend beyond Lithgow) to the Tableland Bogs, Tableland Swamp Meadows (in the Montane Bogs and Fens vegetation class) and Blue Mountains-Shoalhaven Hanging Swamps (in the Coastal Heath Swamps vegetation class) types.

The upper Cudgegong River catchment (east of Rylstone) on the NSW Central Tablelands drains an area surrounded by the Great Dividing Range (at elevations over 1000 m) and forms part of the inland flowing Macquarie River catchment (Fig. 1). Part of the upper Cudgegong River catchment (in the Dunns Swamp area) is included in Wollemi National Park in the Greater Blue Mountains World Heritage Area (GBMWHA) (Fig. 2). No comprehensive vegetation or wetland mapping has been undertaken across this catchment, although previous reports have identified and briefly described a range of wetland vegetation types in the Dunns Swamp area (Bell, 1998a, b; Tame, 1997). During doctoral thesis fieldwork on the biology of the endangered mire-dwelling Giant Dragonfly, *Petalura gigantea*, Baird (2012) identified a number of previously undocumented and relatively isolated mires, with disjunct flora and fauna occurrences, in and adjoining the upper Cudgegong River catchment. Baird and Benson (2017) subsequently highlighted the value of one of these mire systems, Rollen Creek swamp, which occurs largely in Coricudgy State Forest, in support of a proposal to add Coricudgy State Forest to the National Heritage list; ultimately a candidate for potential addition to the GBMWHA (GBMWHAAC, 2015). The added inclusion of specific areas on the edges of the GBMWHA, including Coricudgy State Forest, would significantly enhance the currently established biodiversity values of the GBMWHA, and has been recommended (Benson & Smith, 2015).

The aim of this paper is to draw attention to the overlooked mires of the upper Cudgegong River catchment, with a particular focus on the Rollen Creek mire system, the largest and most diverse, to contextualise them in relation to other mires of the Blue Mountains, to contribute to improving their conservation, and to encourage further research on mires in southeastern Australia.

Upper Cudgegong River study area

Location and physiography

The study area is the upper Cudgegong River catchment between the Great Dividing Range and Rylstone, centred approximately on Dunns Swamp, Wollemi National Park (32° 50' 04" S, 150° 12' 21" E). The area is located in the NSW Central Tablelands, in the north-western part of the Blue Mountains and of the Sydney Basin bioregion (Thackway & Cresswell, 1995). The Great Dividing Range forms the watershed of the upper Cudgegong River, which drains inland to the Macquarie River (Fig. 1 & 2). Drainages to the north, east and south of the upper Cudgegong River watershed drain to the coast. Elevation decreases from east to west; from 1256 m on the basalt peak of Mt Coricudgy on the Great Dividing Range, westward to 571 m at Rylstone. Additional high elevation areas (above 1000 m) along the catchment watershed, and associated with the Great Dividing Range, include the remnant basalt-capped plateau of Nullo Mountain, and the isolated basalt-capped peaks of Mt Darcy and Mt Coorongooba.

The geology of the study area consists of underlying Permian sandstone, conglomerate, shale and siltstone; Triassic Narrabeen Sandstone, shale and conglomerate, forming characteristic ‘pagoda country’; and Tertiary basalt-capped peaks and remnant plateaus. The Capertee, Collingwood, Inglewood, Lees Pinch, Munghorn Plateau, Nullo Mountain and Coricudgy soil landscapes dominate the study area (Kovac & Lawrie, 1991). The Inglewood (Yellow Earths), Lees Pinch (Shallow Soils) and Munghorn Plateau (Siliceous Sands) soil landscapes have developed primarily in association with the Triassic Narrabeen sandstone geology, while Nullo Mountain and Coricudgy soil landscapes (Krasnozems) have developed in association with the basalt-capped peaks and remnant plateaus, where *in situ* weathered Tertiary basalt and basalt colluviums overlie the Narrabeen sandstone. Capertee (Yellow Podzolics) and Collingwood (Red Podzolics) soil landscapes have developed in association with the Permian geology (Kovac & Lawrie, 1991). The peaty sediments of the mires in the area were not differentiated in the coarse-scale soil landscape mapping of Kovac and Lawrie (1991).

The study area includes the Dunns Swamp area of Wollemi National Park, a popular tourist site, and parts of Nullo Mountain and Coricudgy State Forests. With the exception of logging of better quality timber from the slopes of Mt Coricudgy, there is no evidence of recent logging activity in the immediate Coricudgy State Forest area which is mainly essentially undisturbed shrubby woodland with little timber value. Variably cleared and farmed freehold lands are mainly concentrated along the Cudgegong River valley and its tributaries, such as Coxs Creek, and in the Nullo Mountain area. The lower Cudgegong valley around Rylstone was explored by the botanist Allan Cunningham in the 1820s, and the area taken up for pastoral settlement soon after. Occupational licences in the upper Cudgegong in the Parish of Kelgoola were offered for sale in 1843 (*Sydney Morning Herald* 18/1/1843).

Climate

Rainfall across the study area is characterised by high inter-annual variability, with average annual rainfall decreasing with elevation and from east to west. Highest mean monthly rainfalls occur between November and March (late spring to early autumn), with lowest mean monthly rainfalls from July to September (winter to early spring). Mean annual rainfall at the Nullo Mountain AWS (1130 m elev.) was 955 mm/annum (1994–2017) (www.bom.gov.au). Mean maximum monthly temperature at Nullo Mountain was 16.7° C (9.2–24.0° C) and mean minimum monthly temperature was 8.0° C (2.5–13.6° C). Mean Annual rainfall at the property “Kelgoola” (747 m elev.) in the upper Cudgegong River valley near Rollen Creek swamp and Mt Coricudgy, was 809 mm (1963–2006), also with high inter-annual variability (486–1235 mm/annum). The higher elevation areas along the Divide, including Mt Coricudgy, Mt Coorongooba and Mt Darcy, can also be expected to have higher rainfall than that of the nearby upper Cudgegong valley at “Kelgoola” due to an orographic effect, and similar to that of Nullo Mountain. Mean annual rainfall at Rylstone (Ilford Rd AWS, 605 m elev.), at the western edge of the study area, is lower, with 655 mm/annum. Mean maximum monthly temperature at Rylstone was 22.6° C (14.4–30.7° C) and mean minimum monthly temperature was 8.2° C (1.2–15.9° C) (www.bom.gov.au).

Previous vegetation studies in the upper Cudgegong

Previous vegetation studies in the upper Cudgegong are mainly confined to the Dunns Swamp area (Bell, 1998a; Gellie & McRae, 1985; Tame, 1997). Gellie and McRae (1985) referred more broadly to the Cudgegong Swamps. Building on a brief report by Tame (1997), and with limited additional fieldwork, Bell (1998a) described Cudgegong River Swamp Grassland, Upper Cudgegong Alluvial Sedgeland, Upper Cudgegong Alluvial Reedland, Upper Cudgegong Alluvial Shrub-swamp and Upper Cudgegong Sphagnum Bog in the Dunns Swamp area of Wollemi National Park.

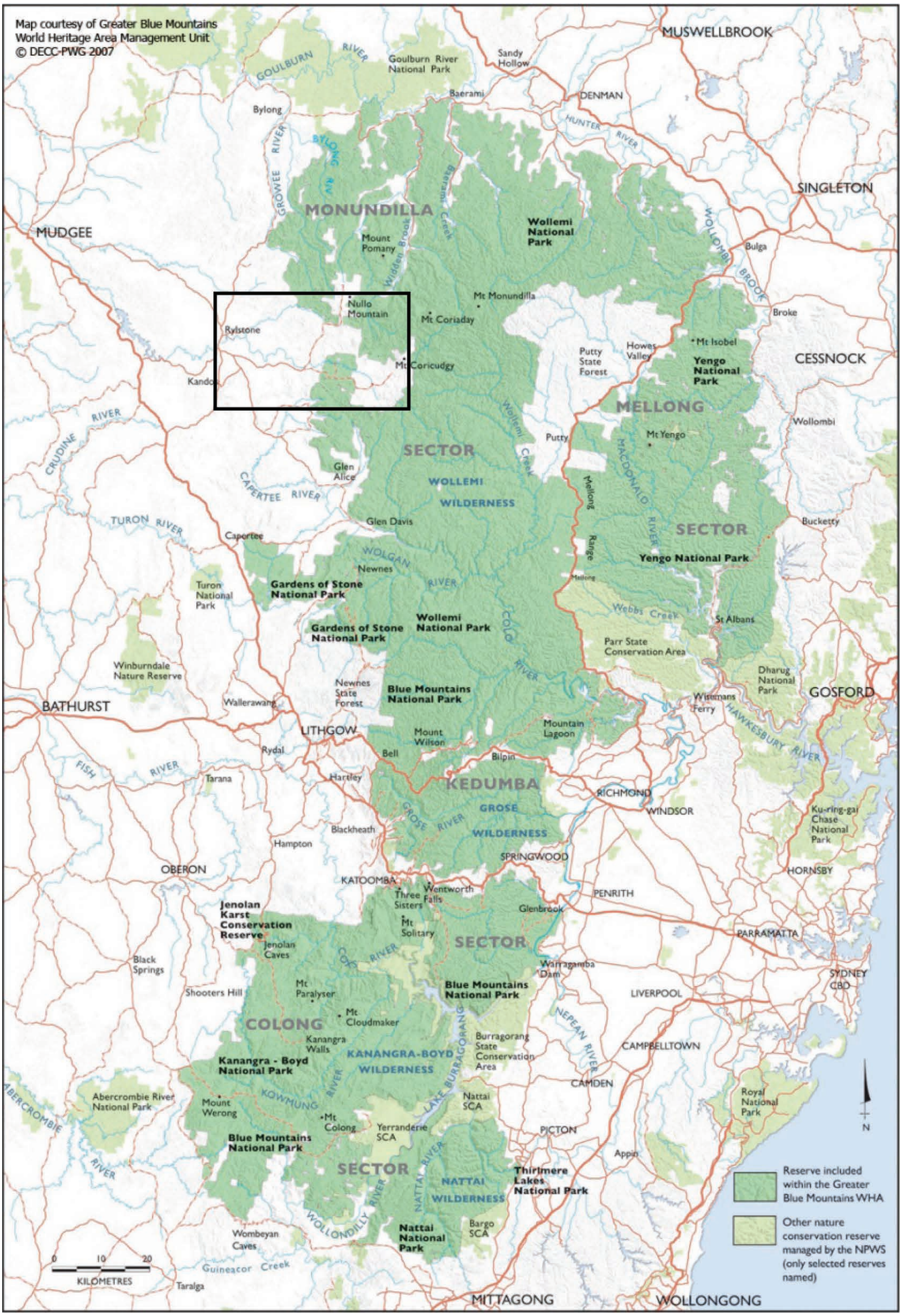

Fig. 1: Map of the Greater Blue Mountains World Heritage Area showing the location of the upper Cudgegong River catchment east of Rylstone (inset box).

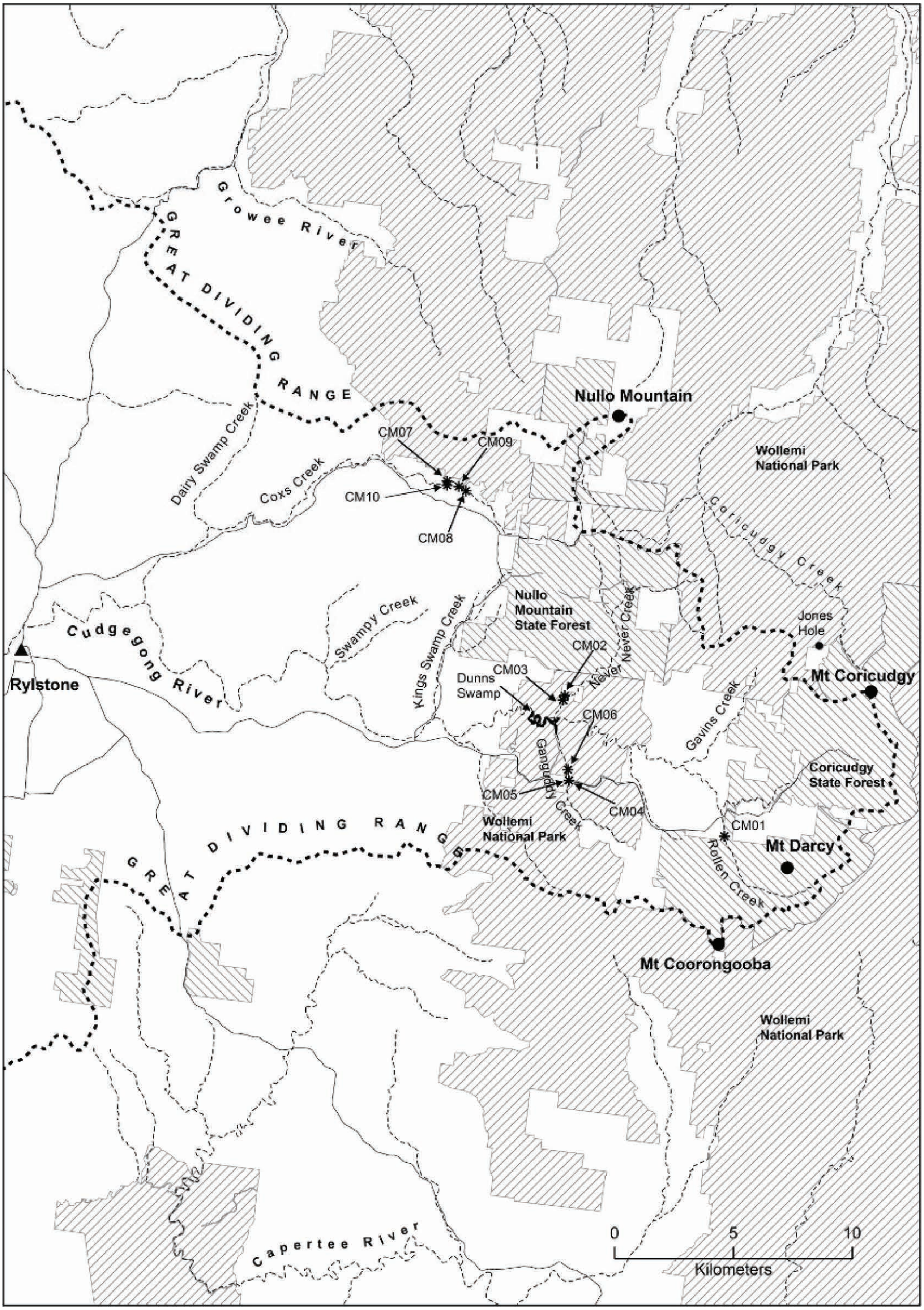

Fig. 2. Map of the Upper Cudgegong River catchment study area and locations of surveyed mires. The site codes in this diagram are explained in Table 1.

Although Bell (1998a, b) did not identify the *Carex* fen vegetation along Never Never Creek and other similar sites, he noted the need for additional survey of wetland vegetation communities across the upper Cudgegong area to clarify their floristic relationships and distributions. Bell (1998a) noted that the Cudgegong River Swamp Grassland vegetation occurred only in waterlogged peaty alluviums and the Upper Cudgegong Alluvial Sedgeland occupied "grassy bogs". Tame (1997) suggested the substrate of this vegetation type was probably a shallow sandy peat overlying impermeable clays. Bell (1998b) noted that Cudgegong Sphagnum Bogs only occurred in limited areas on heavy soils with poor drainage, along creek-lines or in small localised patches, but also referred to it occurring on peaty sands.

Bell (1998a) also noted the mention by Ford (1989) of an area of swamp near Mt Darcy ("along Rollen Creek") with apparent similarities to his Cudgegong River Swamp Grassland. This is the first known reference to a swamp system along Rollen Creek, later described by Baird (2012) and Baird and Benson (2017).

Methods

Reconnaissance fieldwork (by IRCB) was carried out across the upper Cudgegong River catchment and adjoining areas in 2007-2009, searching for evidence of the endangered *Petalura gigantea* and to identify mires with potential breeding habitat for this obligate, groundwater-dependent, mire-dwelling dragonfly (Baird, 2012, 2014). Identification of upper Cudgegong mire sites has been based on a range of sources; aerial photograph interpretation (API, using Google Earth); previous vegetation reports from the Dunns Swamp area (Bell, 1998a, b; Tame, 1997); additional information provided by former NPWS ranger Chris Pavich (pers. comm.); data gathered by Baird (2012) (which included recording mires along 4 creek systems), and the results of a vegetation survey of the swamp system along Rollen Creek in February 2017 (Baird & Benson, 2017); and additional vegetation surveys across the study area in October 2017. Swamps were surveyed across Coxs, Ganguddy, Kings Swamp, Never Never and Rollen creeks (Fig. 2). Swamps on the remaining creek systems are on private property. Vegetation surveys consisted of walking transects targeted to cover as much local variation as possible and to record all readily identifiable plant species (and any evidence of threatened faunal species) across the range of identified floristic and hydrogeomorphic variability within the swamps surveyed. The presence of localised seepage areas or of an emergent water table provided further confirmation of the presence of suitable hydrological conditions for the development of organic-rich substrates. A sediment probe (1.8 m long × 8 mm diameter steel rod) was used to measure depth, and qualitatively assess characteristics, of organic-rich sediments in lower Rollen Creek swamp.

Results

Mires of the upper Cudgegong River catchment

Swamp vegetation in the upper Cudgegong River catchment was identified along the Cudgegong River and its tributary creeks - Coxs, Dairy Swamp, Ganguddy, Gavins, Kings Swamp, Mill, Never Never, Rollen, Sugarloaf and Swampy creeks (Fig. 2). Mire vegetation communities (with persistent high water tables and organic-rich or peaty sediments) were confirmed by survey along Coxs, Ganguddy, Never Never and Rollen creeks. Mire vegetation was identified along the main Cudgegong River valley immediately upstream and downstream of the confluence with Rollen Creek, but was not surveyed due to its location on private property. The presence of mire was not confirmed along the highly degraded Kings Swamp drainage. Details of mires surveyed are shown in Table 1. Occasional small isolated patches of seepage-fed hanging swamp on valley sides are also scattered across the upper study area on Narrabeen Sandstone, particularly in the Rollen Creek catchment. Additional small mire patches can be expected to occur elsewhere across the study area in locations that are difficult to access or identify on Google Earth imagery.

The mires of the upper Cudgegong River and its tributaries above Dunns Swamp, and along upper Coxs Creek, occur primarily in the Munghorn Plateau soil landscape on Triassic geology (see Kovac & Lawrie, 1991). Mire sediments included organic sands, sandy peats, sapric peats and fibrous peats, depending on the hydrological regime and topographic context. Some patches of swamp with sedgeland-heath vegetation, with floristic similarities to the wetter sedgeland-heath bogs, occur on heavier clayey soils (e.g., along lower Ganguddy Creek above Dunns Swamp) and cannot be considered mires. Depths of soft, saturated, organic-rich/peaty sediments throughout the main valley floor along lower Rollen Creek swamp (CM01) were generally >1.8 m, frequently with no major differences in density or texture observed across that depth. Dense sandy-gravel material was encountered, however, below 1.6 m in several locations. In one area near the confluence with a tributary near the Coricudgy State Forest boundary, some narrow bands of sandy-gravel material at different depths indicated historical deposition events, probably associated with post-fire erosion, upstream and/or upslope. Predictably, depth of organic-rich swamp sediment progressively decreased, and sand content increased, towards swamp margins on lower valley side slopes.

Considerable hydrogeomorphic and floristic diversity was observed in the mires across the study area, including montane bogs and montane fens, broadly referable to the Tableland Bogs and Tableland Swamp Meadows typologies, respectively, of Tozer et al. (2010), within the Montane Bogs and Fens vegetation class of Keith (2004), and hanging swamps on valley sides, with similarities to the Blue Mountains-Shoalhaven Hanging Swamps typology of Tozer et al. (2010), within the Coastal Heath Swamps vegetation class of Keith (2004). The rare, swamp-dwelling small tree, *Eucalyptus camphora* subsp. *camphora,* is widely distributed across the upper Cudgegong catchment within each of these mire variants, along associated upstream drainage lines, and in some other swampy areas on heavier soils, including along lower Ganguddy Creek.

The main mire systems

Rollen Creek swamp, most of which occurs in Coricudgy State Forest, is one of only two extensive and relatively undisturbed (based on API, using Google Earth) mire systems in the upper Cudgegong catchment. The Rollen Creek swamp system appears to include the full range of hydrogeomorphic and floristic variation observed within the identified mires in the study area, including montane bogs (Tableland Bogs) and montane fens (Tableland Swamp Meadows) on valley floors, and hanging swamps on valley sides (Figures 3-11). Due to its outstanding diversity, size, condition and its representativeness of the range of mires in the study area, the Rollen Creek swamp system is described in detail below.

In addition to the extensive area of valley-floor sedgeland-heath bog (Tableland Bog) along Rollen Creek, several isolated and very small patches of variably degraded, seepage-fed sedgeland-heath bog (CM08-10) were also identified adjacent to, and intergrading with, the alluvial *Carex*-dominated fen (Tableland Swamp Meadow) (CM07) along upper Coxs Creek (Fig. 13). A narrow band of hanging swamp (CM04) of sedgeland-heath and *Sphagnum*, with conspicuous springs, also occurs just above Ganguddy Creek, near to and upstream of the Coricudgy Road bridge.

The other large mire system in relatively good condition is along Never Never Creek and its lower tributaries above Dunns Swamp (Kandos Weir impoundment) in Wollemi National Park. The Never Never Creek mire system is dominated by *Carex* fen (Tableland Swamp Meadow) along the main valley floor (CM03) with scattered *Leptospermum* shrubs (Fig. 12), although floristic variants occur in some marginal areas and in slightly higher gradient tributary swamp (CM02), in association with *Eucalyptus camphora*. The Rollen Creek and Never Never Creek mire systems are surrounded by high quality, dry sclerophyll eucalypt-dominated woodland on adjoining slopes.

The swamps along the main valley floors of the Cudgegong River (above and below Dunns Swamp) and its tributaries, including Coxs Creek (Fig. 13) are generally low gradient, alluvial swamp meadows. They are generally located on cleared freehold land, with a history of grazing, nutrient enrichment and weed invasion, and mostly range in condition from moderately- to highly-degraded. They range from *Carex*-dominated fens with organic-rich alluvium in wetter areas (Tableland Swamp Meadows) which may be variably inundated with shallow water, to seasonally wet tussock grasslands on largely mineral soils at the drier end of the hydrological gradient. Some of the swamp meadows include small pools along the main drainage line (possible chain-of-ponds system) with reedland (marsh) vegetation of *Typha* sp., *Phragmites australis* and/or *Eleocharis sphacelata*. Along the main Cudgegong River valley above Dunns Swamp, around the confluence with Rollen Creek, areas of highly degraded Tableland Swamp Meadow sometimes also appear to have small remnant patches of sedgeland-heath bog (Tableland Bog) on their margins. Based on API (using Google Earth), additional areas of Tableland Swamp Meadow with possible Tableland Bog were identified along Gavins and Sugarloaf creeks, upper tributaries of the Cudgegong River; these swamps on private properties are mostly surrounded by cleared grazing land and were not visited.

A localised part of the upper Kings Swamp drainage includes some plants which occur in mires elsewhere in the area (e.g., *Callistemon citrinus*, *Eucalyptus camphora*, *Leptospermum obovatum*), with some groundwater seepage evident, but it is highly degraded and occurs on cleared grazing land. Regardless of its potential pre-disturbance state, it is not treated as mire here. A degraded and grazed narrow swamp with *Callistemon citrinus* and *Eucalyptus camphora* subsp. *camphora* also occurs along upper Mill Creek. This small swamp patch on otherwise cleared, private property was observed but not surveyed and it was not possible to determine its substrate or hydrological characteristics. It is also not treated as mire here.

Another large swamp system is in Jones Hole, on Jones Hole Creek (a headwater tributary of Coricudgy Creek), to the northwest of Mt Coricudgy (Fig. 2), in the coastward flowing Hunter River catchment, not the Cudgegong River. It is mostly in Wollemi National Park though partly in Coricudgy State Forest. The vegetation of this difficult-to-access valley-floor swamp system (32° 48' 16" S, 150° 20' 11" E, 720–850 m elev., ~3250 m length) is unknown, but it is reasonable to assume, due to its elevation and proximity to the higher rainfall area of adjacent Mt Coricudgy, that it is characterised by a high water table and variably peaty sediments. API (using Google Earth) suggests that it is predominantly a *Carex*-dominated fen, with areas of intergrading sedgeland-heath bog. The swamps in Jones Hole and along Never Never Creek have some history of cattle grazing prior to National Park gazettal (C. Pavich, pers. comm.). Conspicuous, abundant and structural plant species recorded for each of the identified and surveyed mires in the study area are included in Table 2. This is an incomplete list as some grasses and monocots were not identified, and some seasonal species may not have been evident at the time. Only two conspicuous bryophytes are listed, but the total bryophyte richness is likely to be high.

Other swamps

The study area includes a diversity of swamp vegetation types distributed across the hydrological gradient; much of the swamp area is characterised by only seasonally or intermittently wet sandy alluviums or heavier clayey soils along valley floors and cannot be considered mires. This includes seasonally wet tussock grasslands on largely mineral soils at the drier end of the hydrological gradient, which generally occur in the lower elevation and lower rainfall parts of the catchment. Most of these seasonally wet tussock grasslands are surrounded by cleared grazing areas and occur along the Cudgegong River and its tributaries below Dunns Swamp, and along lower Coxs Creek; they have a history of grazing, nutrient enrichment and weed invasion; and are moderately- to highly-degraded.

Some shrubby swamps on sandy alluviums, including in the Dunns Swamp area and upper Ganguddy Creek, have a scrub of *Leptospermum polygalifolium* (often colonising disturbed sites), and are probably referable to the Upper Cudgegong Alluvial Shrub-swamps of Bell (1998a). Upper Cudgegong Alluvial Reedland (fringing vegetation around the Kandos Weir impoundment) and Upper Cudgegong Alluvial Shrub-swamp of Bell (1998a) in the Dunns Swamp area are not mires and were not considered potential habitat for *P. gigantea* by Baird (2012). Other reedland (marsh) patches, however, occur in association with the *Carex* fens and can be considered part of the mire systems. Swamps in the lower parts of the Cudgegong River catchment (east of Rylstone) below Dunns Swamp and along lower Coxs Creek, occur in the Capertee soil landscape on Permian geology (Kovac & Lawrie, 1991).

Additional seasonally wet swamps occur to the north of the catchment watershed in headwaters of the northward flowing Growee River catchment (e.g., Spring Log Swamp on Spring Log Creek), but these are on primarily mineral sediments and are not mires. Growee Swamp (500 m elevation), which occurs further downstream on the Growee River to the north, was not visited, but it occurs on cleared grazing land in a lower rainfall area, and is also assumed to be on seasonally drying alluvial sediments or heavier clayey soils.

Table 1: Identified mires of the upper Cudgegong River catchment (arranged by decreasing elevation) showing - site code, location, coordinates, approximate elevation range (upper to lower), approximate length or area, mire type and condition. An unsurveyed Cudgegong River mire above Dunns Swamp has been included. Mire types - Tableland Bog (TB), Tableland Swamp Meadow (TSM), and Hanging Swamp (HS). The locations of these mires are indicated in Fig. 2.

Mire site	Location	Coordinates (Google Earth)	Elevation (m) (Google Earth)	Length or area	Mire type	Condition
CM01	Rollen Creek	32° 52' 47" S, 150° 17' 01"E	745-700	3 km	TB, HS, TSM	Good
CM07	Coxs Creek	32° 44' 27" S, 150° 09' 56" E	740-660	10 km	TSM	Poor-Good
CM08	Coxs Creek margins adjoining CM07	32° 44' 43" S, 150° 10' 18" E	724	20 × 20 m	TB	Poor
CM09	Coxs Creek margins adjoining CM07	32° 44' 37" S, 150° 10' 07" E	722	40 × 40 m	TB	Poor
CM10	Coxs Creek margins adjoining CM07	32° 44' 35" S, 150° 09' 48" E	718	150 × 40 m	TB	Poor-Moderate
CM04	Above Ganguddy Creek	32° 51' 22" S, 150° 12' 52" E	680-678	100 × 5 m	HS	Good
CM05	Ganguddy Creek below and adjoining CM04	32° 51' 22" S, 150° 12' 52" E	678	12 × 10 m	TB	Moderate -Good
CM02	Never Never Creek tributary	32° 49' 26" S, 150° 12' 49" E	677-665	200 m	TB/TSM	Good
CM06	Ganguddy Creek tributary at junction with Ganguddy Creek	32° 51' 07" S, 150° 12' 51" E	674	15 × 10 m	TB	Moderate
CM03	Never Never Creek	32° 49' 32" S, 150° 12' 46" E	672-656	1.7 km	TSM	Good
Not surveyed	Cudgegong River above Dunns Swamp, upstream and downstream of the confluence with Rollen Creek	32° 05' 55" S, 150° 17' 04" E (indicative location)	741-719		TSM, TB	Very poor

Table 2: Native plant species (including mosses) recorded for each of the mires surveyed in the upper Cudgegong River catchment. Refer to Table 1 for details.

SPECIES	Family	CM01	CM02	CM03	CM04	CM05	CM06	CM07	CM08-10
Asperula gunnii	Rubiaceae	1							
Baeckea utilis	Myrtaceae	1							
Baloskion fimbriatus	Restionaceae		1						1
Baloskion australe	Restionaceae	1							
Baumea sp.	Cyperaceae	1	1		1		1	1	1
Blechnum nudum	Blechnaceae	1			1	1			
Bulbine bulbosa	Liliaceae	1							
Callistemon citrinus	Myrtaceae	1	1	1	1	1	1		
Carex appressa	Cyperaceae							1	
Carex gaudichaudiana	Cyperaceae	1	1	1	1	1	1	1	1
Centella asiatica (or *cordifolia*)	Apiaceae	1							1
Centrolepis?	Centrolepidaceae	1							
Comesperma retusum	Polygalaceae	1							
Drosera binata	Droseraceae	1			1				1
Drosera peltata/auriculata	Droseraceae				1				
Drosera spathulata	Droseraceae	1							
Eleocharis sphacelata	Cyperaceae			1				1	
Empodisma minus	Restionaceae	1			1				
Epacris microphylla	Ericaceae	1			1				
Epacris paludosa	Ericaceae	1				1	1		
Eriocaulon scariosum	Eriocaulaceae	1							
Eucalyptus camphora subsp. *camphora*	Myrtaceae	1	1	1	1	1	1		1
Eucalyptus pauciflora	Myrtaceae	1							
Gahnia sieberiana	Cyperaceae				1				
Geranium neglectum	Geraniaceae	1	1						1
Gleichenia dicarpa	Gleicheniaceae	1			1	1			
Gonocarpus micrantha	Haloragaceae	1							
Goodenia sp.	Goodeniaceae	1			1				
Gratiola peruviana	Scrophulariaceae						1		
Gymnoschoenus sphaerocephalus	Cyperaceae	1							
Hakea microcarpa	Proteaceae	1							1
Hybanthus?	Violaceae	1							
Hydrocotyle sp. (*sibthorpioides* ?)	Apiaceae	1					1		
Hypericum sp. (*gramineum* ?)	Hypericaceae	1							
Isachne globosa	Poaceae	1							
Isotoma fluviatilis?= Pratia surrepens	Campanulaceae	1							
Juncus spp.	Juncaceae	1		1				1	1
Lepidosperma limicola	Cyperaceae	1							
Leptospermum continentale	Myrtaceae	1	1		1				1
Leptospermum grandifolium	Myrtaceae				1	1	1		
Leptospermum obovatum	Myrtaceae	1	1	1		1	1		1
Lepyrodia sp.	Restionaceae	1			1				
Lythrum salicaria	Lythraceae							1	
Patersonia fragilis	Iridaceae	1							
Phragmites australis	Poaceae		1	1				1	
Polytrichum sp. (*Dawsonia* sp. ?)	Polytrichaceae					1			
Pultenea divaricata	Fabaceae	1							
Pultenea sp.	Fabaceae	1							
Ranunculus sp.	Ranunculaceae	1							
Senecio sp.	Asteraceae	1							
Sphagnum cristatum	Sphagnaceae	1			1	1	1		1
Spiranthes australis	Orchidaceae	1							
Stylidium graminifolium	Stylidiaceae	1							1
Tetrarrhena juncea	Poaceae	1							
Typha sp. (*orientalis* ?)	Typhaceae							1	
Utricularia dichotoma	Lentibulariaceae	1							1
Viola caleyana	Violaceae	1				1			
Xyris ustulata	Xyridaceae	1							
Xyris gracilis	Xyridaceae	1							

Rollen Creek mire system: location and physiography

Because of its size, range of mire variation and good condition, the mire system along Rollen Creek deserves particular attention. Apparently once known as Rotten Creek (G. Summers pers. comm.), Rollen Creek is an upper Cudgegong River tributary about 13 km east of Olinda. The upper swamp is located in Coricudgy State Forest, with the contiguous downstream section of good quality swamp on freehold land ("Inglewood") extending to where the Coricudgy Road crosses (32° 52' 18" S, 150° 16' 59"E). Though cattle have historically had some access to at least parts of the swamp upstream of the Coricudgy Road crossing, it is generally unsuitable for cattle, largely due to its high water table and soft deep peaty soils (G. Summers pers. comm.). A somewhat degraded area of sedgeland-heath bog remnant also occurs downstream of the Coricudgy Road crossing (between the road and cleared grazing land) towards the Cudgegong River junction, but has been impacted by grazing, fire and a previous timber mill with associated sawdust dump which was located below the crossing (G. Summers pers. comm.).

The Rollen Creek mire system (CM01) is narrow and elongate, oriented roughly NNW-SSE along the creek valley, about 3 km long (about 2.5 km in the State Forest) and varies in width from about 10 to 100 m, but is mostly <40 m wide. The catchment is Narrabeen Sandstone with the exception of the isolated peaks of Mt Coorongooba (~1060 m) and Mt Darcy (1079 m), with their residual basalt, Coricudgy soil landscapes. Approximately 20% of the slopes of Mt Coorongooba, and almost 50% of the slopes of Mt Darcy are in the Rollen Creek catchment. The area of the catchment is approximately 18 km², but with the complexity of the hydrogeology of these Narrabeen sandstones, aquifers may be collecting water from a larger area. There is a conspicuous seepage/spring at the head of the main creek and several small drainage lines enter the swamp system along its length; some also have areas of groundwater-fed peaty swamps with sedgeland-heath vegetation along their lower sections where they join Rollen Creek.

The head of Rollen Creek mire is about 2 km from the Divide (to the south); Mt Darcy and Mt Coorongooba are both within 3 km of the head of the mire. Elevation ranges from about 745 m at the source of the mire to 700 m at the road crossing, giving a low overall gradient of 1.5% (15 m per km) and within the range of Newnes Plateau Shrub Swamps (NPSS) (Benson & Baird, 2012). The downstream end lacks a nick-point waterfall, characteristic of NPSS, but grades into a *Carex gaudichaudiana*-dominated fen above the Coricudgy Road crossing, and transitions to cleared grazing land downstream of the Coricudgy Road crossing, with the exception of the patch of remnant sedgeland-heath bog below the Coricudgy Road. The extent of the fen area is likely to have been increased (with conversion from sedgeland-heath bog) by damming associated with the road crossing. The mire system is surrounded by dry eucalypt woodland on poor sandy soils on adjoining slopes.

Rollen Creek mire system: vegetation structure and composition

The Rollen Creek mire system is dominated by extensive, valley-floor, sedgeland-heath bog, referable to the Tableland Bogs typology. In addition to the seepage/spring at the head of the main creek, there are small seepage/spring-fed mire patches adjacent to the main valley-floor mire in at least two other locations further downstream. There is also an extensive valley-side hanging swamp dominated by *Gymnoschoenus sphaerocephalus.*

The Tableland Bog along the main Rollen Creek valley floor includes areas of closed and open sedgeland, with a variable proportion of shrubs forming either sedgeland-heath or with a mallee or tall shrub canopy (Figures 3–10). The swamp is essentially treeless, though much of it is dominated by areas of mallee or multi-stemmed, shrubby *Eucalyptus camphora* subsp. *camphora* plants. Towards the head of the mire system, where the valley narrows, older *Eucalyptus camphora* occasionally reach 6–8 m high. In this area, this mallee/tall shrub canopy (sometimes low open woodland) generally forms dense scrub associated with *Callistemon citrinus* and *Leptospermum* shrubs up to 5 m high. Along the lower parts of the swamp system, however, *Eucalyptus camphora* plants are much smaller and often less than 2 m high. Plants with a range of sizes/ages indicate continual recruitment of these species. Parts of the upper swamp system with a canopy of *Eucalyptus camphora* and other large shrubs also have a wet meadow/forb-land ground-layer, which includes various herbs, *Carex gaudichaudiana*, *Sphagnum cristatum* and unidentified grasses (Fig. 3). A similar vegetation variant was also recorded along a small tributary (CM02) adjoining the *Carex* fen along Never Never Creek (CM03), along lower Ganguddy Creek near the Coricudgy Road bridge (CM05, CM06), and in association with small patches of sedgeland-heath bog (CM08-10) along margins of the *Carex* fen along upper Coxs Creek (CM07).

Throughout the sedgeland-heath dominated valley-floor bog there may be an open or sparse, small-medium height shrub layer, including *Baeckea utilis*, *Comesperma retusum*, *Epacris microphylla, Epacris paludosa*, *Hakea microcarpa*, *Leptospermum obovatum* and *Pultenea divaricata*. The groundcover is generally very dense, mostly >90% cover, predominantly of *Sphagnum* moss, sedges and other graminoids, smaller shrubs and herbs, including carnivorous species such as *Drosera binata* and *Utricularia dichotoma*. Herbs and ferns include *Centella asiatica*, *Geranium* sp., *Gleichenia dicarpa*, *Goodenia* sp., *Isachne globosa*, *Spiranthes australis and Viola caleyana.* Sedgeland species within the sedgeland-heath include *Baumea* sp., *Baloskion australe*, *Empodisma minus*, *Gymnoschoenus sphaerocephalus*, *Juncus* sp., *Lepyrodia* sp., *Tetrarrhena juncea and Xyris ustulata*. There are patches with *Sphagnum* hummocks up to 1 m high and the soil surface is spongy on flat and steeper side slopes (Figures 3, 10). There may also be localised areas of *Sphagnum* bog in shadier, wetter and more fire-protected sites along tributary drainage lines.

Carex gaudichaudiana is scattered throughout the valley floor mire in localised patches of fen amongst sedgeland-heath bog in wetter low gradient areas along the drainage lines (Fig. 6), and as a discrete patch of *Carex*-dominated fen referable to Tableland Swamp Meadow at the downstream end near the Coricudgy Road crossing (Fig. 11).

In hanging swamps on side slopes open patches of sedgeland with few or no shrubs may have *Gymnoschoenus sphaerocephalus* and *Gleichenia dicarpa* dominant, with *Empodisma minus*, *Lepidosperma limicola* and *Xyris ustulata* less abundant (Figures 8–10). *Baeckea utilis* generally occurs as scattered individuals across these *Gymnoschoenus*-dominated hanging swamp areas, with occasional other shrubs present. Upper hanging swamp margins are relatively distinct with a band of *Gleichenia* along the edge of the dry eucalypt woodland; *Eucalyptus camphora* also occurs on swamp margins.

The main woodland dominants adjoining the swamps are *Eucalyptus dives*, *Eucalyptus radiata*, *Eucalyptus rossii* and *Eucalyptus dalrympleana*. In one place (32° 53' 24" S, 150° 17' 24" E), the geographically restricted *Eucalyptus corticosa* was recorded in woodland adjacent to the upper margin of the hanging swamp on the eastern side of the Rollen Creek mire. *Eucalyptus pauciflora* may occur on woodland margins sometimes edging into the swamp, as it does in the higher elevation mires of the Newnes and Boyd plateaus further south.

About 48 native species, including most of the conspicuous, abundant and structural species, were recorded in Rollen Creek mire (Table 2). This is an incomplete list as some grasses and monocots were not identified, and some seasonal species may not have been evident at the time. Appendix 1 includes the list of species recorded in Rollen Creek swamp with reference to species also recorded in NPSS (Benson & Baird, 2012; Benson & Keith, 1990) and Boyd Plateau Bogs (Keith & Benson, 1988; Kodela et al., 1996).

Rollen Creek mire system: hydrology

Given the relatively low average annual rainfall compared to the nearby basalt-capped mounts and the higher elevation parts of the Blue Mountains further south, and its high inter-annual variability at the property "Kelgoola", the presence of the well-developed mire system along Rollen Creek indicates a strong groundwater influence, in addition to rainfall input. This is exemplified by the presence of springs and hanging swamps with groundwater seepage adjacent to the valley floor mire. The Narrabeen Sandstone of the upper Blue Mountains is also characterised by complex groundwater hydrology and the presence of aquifers which support a diversity of groundwater-dependent swamp communities (e.g., Baird, 2012; DLWC, 1999a, b; Marshall, 2005). The expected higher rainfall in the higher elevation areas above 1000 m, around the catchment watershed in the headwaters of the upper Cudgegong River catchment, is likely to contribute significantly to the presence of the groundwater-dependent mires through both direct runoff, and infiltration into the groundwater system in the relatively permeable geology.

The characteristic swamp vegetation and extensive occurrence of peaty/organic-rich mire sediments indicates a permanently high water table in Rollen Creek mire. Peaty sediments include fibrous peats and more highly decomposed sapric peats, which require such hydrological conditions to develop. Depth and characteristics of the peaty/organic-rich sediments can be expected to vary considerably across the swamp system, as occurs in NPSS for example, but the depths recorded in the downstream part of Rollen Creek swamp (>1.8 m) typically exceeded depths recorded in NPSS by Benson and Baird (2012). They are, however, similar to depths recorded in the somewhat similar, low gradient montane bog and fen complex at the head of Long Swamp (part of the Coxs River Swamps of Benson & Keith, 1990) in Ben Bullen State Forest (Baird, 2014; IRCB, unpubl. obs.; Martin, 2017).

The hanging swamps on the valley side, dominated by *Gymnoschoenus sphaerocephalus*, and contiguous with the main valley floor mire (Figures 8-10), are similar to those which occur elsewhere in the Blue Mountains on sandstone geology. These hanging swamps are typically associated with the presence of a low-permeability aquitard (e.g., claystone layer). They develop where groundwater is redirected downslope following the slope of the aquitard to emerge on the valley side as seepage. These hanging swamps along Rollen Creek include groundwater seeps and springs with associated groundwater-dependent species such as burrowing crayfish (*Euastacus* sp.) (Fig. 10).

The predominance of *Sphagnum* in the Rollen Creek mire system is indicative of persistent or permanent wetness. The hummocks are slow growing and the large hummocks were associated with large shrubs with a cluster of basal stems, or large tussocks of sedgeland vegetation, which appear to provide support for the hummock growth and provide moderate levels of shade. Larger *Sphagnum* hummocks in Boyd Plateau Bogs are similarly associated with multi-stemmed shrubs and sedgeland tussocks (IRCB unpubl. obs.). The *Sphagnum* is vulnerable to fire during drought, when the hummocks may dry out (see Hope et al., 2009; Whinam, 1995; Whinam & Chilcott, 2002; Whinam et al., 1989).

Fig. 3: Dense *Sphagnum* cover and hummocks in *Carex* and grass-dominated area in the upper section of Rollen Creek swamp, with *Eucalyptus camphora* subsp. *camphora*. Photo by Ian Baird

Fig. 4: Lignotuberous *Eucalyptus camphora* subsp. *camphora* resprouting after fire along a drainage line through a *Gymnoschoenus*-dominated patch of swamp in the upper Rollen Creek. Photo by Ian Baird

Fig. 5: Dense montane sedgeland-heath bog along the Rollen Creek valley floor. Photo by Ian Baird

Fig. 6: A patch of *Carex gaudichaudiana* fen amongst sedgeland-heath in a low gradient section of Rollen Creek swamp. Note the emergent water table (bottom centre) and *Eucalyptus camphora* subsp. *camphora* in front of adjoining woodland at rear. Photo by Ian Baird

Fig. 7: Valley floor bog with a patch of *Empodisma minus* and *Tetrarrhena juncea*-dominated ground-layer, with low *Eucalyptus camphora* subsp. *camphora* (rear and right). Photo by Ian Baird

Fig. 8: *Gymnoschoenus*-dominated hanging swamp in the upper section of Rollen Creek. The fringing low *Eucalyptus camphora* subsp. *camphora* is in front of adjoining upslope woodland at rear. Photo by Ian Baird

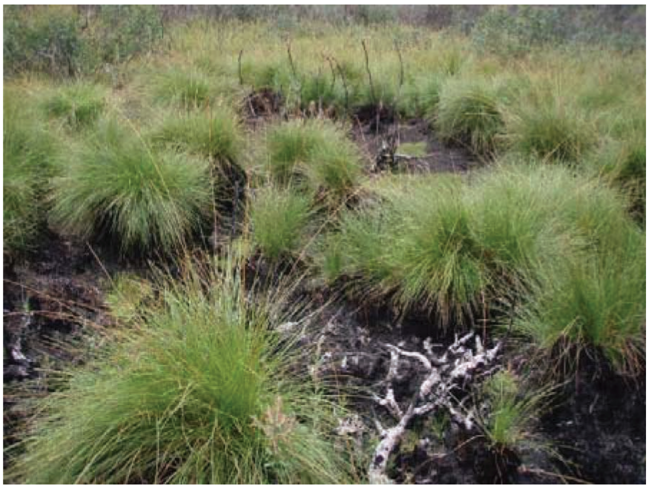

Fig. 9: Resprouting *Gymnoschoenus sphaerocephalus* tussocks post-fire in a hanging swamp in the upper Rollen Creek swamp. Note the large size (and age) of the bases of tussocks, fire-killed shrubs and fringing resprouting *Eucalyptus camphora* subsp. *camphora* (rear). Photo by Ian Baird

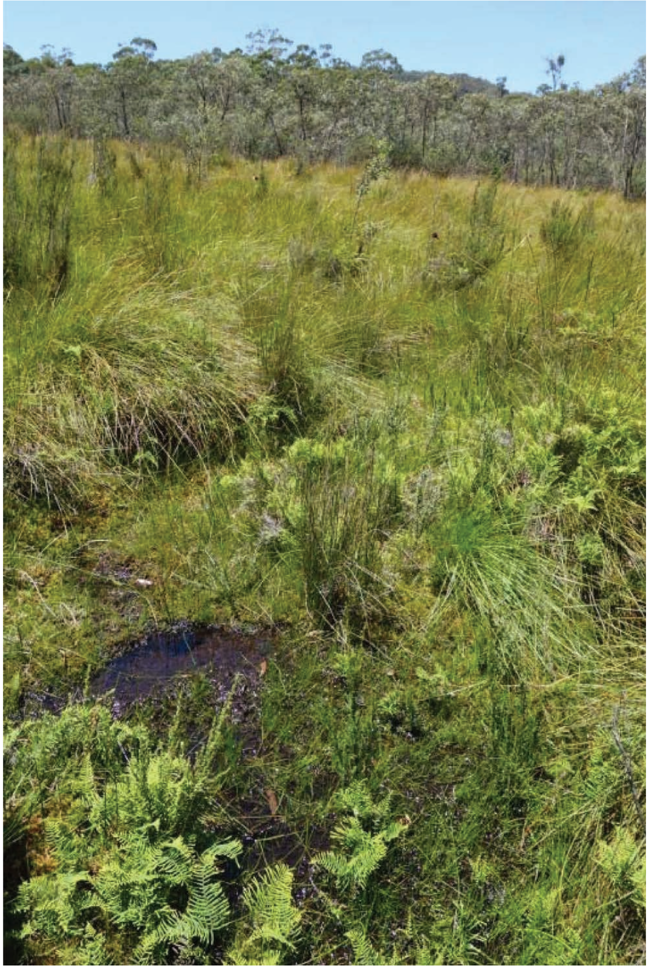

Fig. 10: Seepage in a *Gymnoschoenus*-dominated section of a hanging swamp in the upper Rollen Creek with *Sphagnum*, *Gleichenia dicarpa* and scattered shrubs of *Baeckea utilis* evident. A *Euastacus* sp. crayfish burrow is visible in the pool. Photo by Ian Baird

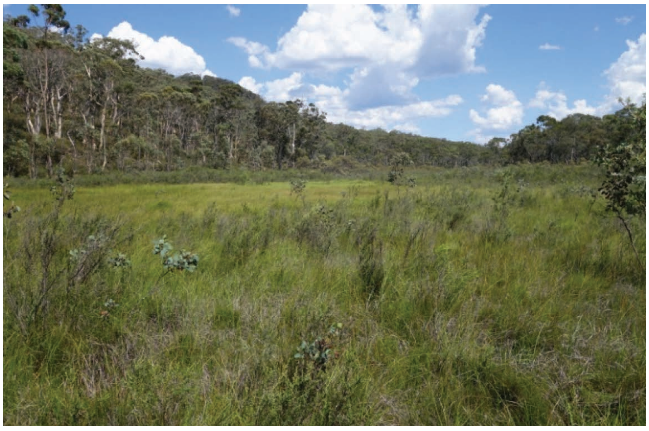

Fig. 11: *Carex gaudichaudiana* –dominated montane fen (centre left) in a low gradient area of the downstream end of the Rollen Creek swamp, with fringing sedgeland-heath bog. Photo by Ian Baird

Fig. 12: Valley-floor *Carex* fen along Never Never Creek above Dunns Swamp, with scattered *Eucalyptus camphora* subsp. *camphora* and *Leptospermum* shrubs. Photo by Ian Baird

Fig. 13: Valley-floor *Carex* fen with flowering *Lythrum salicaria* along Coxs Creek (looking upstream) showing cleared grazing land on private property on right-hand (southern) side and good quality bushland on the left-hand side. Small patches of fringing sedgeland-heath bog, with some *Eucalyptus camphora*, occur in embayments along fen margins at right. Photo by Ian Baird

Discussion

Comparison of montane mires of the upper Cudgegong River catchment with other montane mires of the Blue Mountains

We found a range of mires with considerable floristic and hydrogeomorphic diversity across the upper Cudgegong River catchment. These mires can be broadly divided into montane bogs, montane fens and hanging swamps; all groundwater dependant ecosystems typically found in high rainfall areas. Keith (2004) indicated a rainfall range of 800–1500 mm/year for the Montane Bogs and Fens vegetation class and 1000–1500 mm/year for the Coastal Heath Swamps vegetation class. The Cudgegong mires are at the extreme lower limits of these ranges. The upper Cudgegong montane bogs (Tableland Bogs) and montane fens (Tableland Swamp Meadows) occur in a lower rainfall area, and at relatively lower elevation, compared to similar Blue Mountains mires further south. Mires in Ben Bullen State Forest and on the Newnes Plateau are above 900 m (but most above 1000 m), compared to those at 660–745 m in the upper Cudgegong (Table 1). Mean annual rainfall for these central Blue Mountain mires generally exceeds 1000 mm, and on the Boyd Plateau and nearby areas (above 1100 m elevation) exceeds 1100 mm.

The hanging swamps of the upper Cudgegong River catchment, particularly along upper Rollen Creek, also occur in a lower rainfall area than similar hanging swamps on sandstone in the central Blue Mountains (BMSS), particularly those on the eastern side of the Blue Mountains at similar elevation, where mean annual rainfall also exceeds 1100 mm, compared to mean annual rainfall of 809 mm at “Kelgoola”, near Rollen Creek mire. In upper parts of the Blue Mountains, where the best developed hanging swamps on sandstone occur, mean annual rainfall may exceed 1300 mm. In lower elevation areas with considerably lower rainfall and higher evapotranspiration in the lower reaches of the upper Cudgegong River catchment east of Rylstone (mean annual rainfall <750 mm), to the north of the upper Cudgegong River catchment in the Growee River catchment, and to the south in the Capertee River catchment, suitable conditions for mire development are evidentially absent.

Floristically, the Rollen Creek mire is similar to NPSS with about 65% of the 48 recorded native species in common, particularly shrub species (see Appendix 1), though the predominance of *Eucalyptus camphora*, restricted mainly to these swamps, is a conspicuous point of difference. *Eucalyptus camphora* subsp. *camphora* is geographically restricted to Nullo Mountain and the upper Cudgegong River catchment, with a localised disjunct population in swamps in the Megalong Creek valley near Katoomba. It is also of note in being restricted mainly to swamp habitat; indeed there are very few *Eucalyptus* species that are found in wet or poorly drained sites and *Eucalyptus camphora* appears to be confined to this habitat. The only similar swamp-inhabiting eucalypt in the Sydney Basin bioregion (there are almost 100 eucalypt species in the the GBMWHA; Benson & Smith, 2015) is the closely related *Eucalyptus aquatica*, which is found in analogous montane mires in the Southern Highlands (Penrose State Forest) (Shepherd & Keyzer, 2014).

The abundance of *Callistemon citrinus* along Rollen Creek is another conspicuous difference. This species does not occur in NPSS or Boyd Plateau Bogs, but is the only *Callistemon* found in BMSS (and some transitional to NPSS). Interestingly, *Callistemon pityoides*, the typical montane bog *Callistemon* (found in Boyd Plateau Bogs, some NPSS, and montane bogs elsewhere), was not recorded anywhere in the upper Cudgegong swamps, nor does it occur in BMSS. Other conspicuous NPSS species not so far recorded are *Celmisia* sp. (aff. *longifolia*), *Boronia deanei* subsp. *deanei* and *Grevillea acanthifolia* subsp. *acanthifolia*. *Celmisia* and *Boronia deanei* also occur in Boyd Plateau Bogs. These species may be more drought-sensitive and given the much less extensive swamp areas on the upper Cudgegong, in comparison with the main Blue Mountains area further south, could have been extirpated by past periods of extensive drought, assuming they have been present in the past.

Although *Leptospermum grandifolium* was recorded in the small patch of hanging swamp above Ganguddy Creek (CM04) and a nearby small tributary bog (near and downstream of the bridge on the Coricudgy Road) (CM06), the apparent lack of the species in Rollen Creek swamp and other surveyed sites is noteworthy, considering that it is a common shrub in NPSS, BMSS and Boyd Plateau Bogs (interestingly, single plants of *Epacris paludosa*, which was otherwise only recorded from Rollen Creek swamp, were also recorded in CM05 and the nearby CM06). There is also a general lack of dominance by *Leptospermum* species, compared to their abundance in many NPSS. The only species recorded in Rollen Creek swamp was *Leptospermum obovatum*, which is common in Rollen Creek swamp, occurs in some NPSS, and is common in Boyd Plateau Bogs. *Leptospermum continentalis* also occurs on heavier soils on drier margins of swamps. *Baeckea utilis*, the only *Baeckea* species present, and widely distributed in Rollen Creek swamp, is a typical montane bog and wet heath species which occurs in and around Boyd Plateau Bogs and some higher elevation Newnes Plateau swamps, often on heavier soils, but does not occur in BMSS. *Baeckea utilis* is typically replaced by *Baeckea linifolia* in most NPSS and in the higher elevation Coastal Heath Swamps of the region such as BMSS.

Most other abundant species are similar to those occurring in NPSS, including *Lepidosperma limicola, Empodisma minus, Epacris paludosa* and *Leptospermum obovatum*. Although *Gymnoschoenus sphaerocephalus* occurs in small patches within the main valley floor bog and in upstream areas where the valley narrows, it is mostly restricted to the hanging swamps and seepage/spring-fed mire patches adjacent to the main valley floor mire. Rollen Creek was the only mire in the upper Cudgegong catchment where *Gymnoschoenus* was recorded, although it has been recorded just east of Mt Coricudgy, in a previously undocumented small hanging swamp (990 m elev.) where *Petalura gigantea* was recorded (Baird, 2012: Appendix 1, site PMC01). *Gymnoschoenus* is widely distributed in mires on sandstone elsewhere in the Blue Mountains (in NPSS and BMSS) and the Southern Highlands, and montane bogs of the Northern and Southern Tablelands (mostly on granite), but it appears to be absent from the granite-based Boyd Plateau Bogs. The only occurrence in Tableland Bog on granite in the Blue Mountains region which is known to one of the authors (IRCB) is in a small montane bog south of the Kowmung River near Trailers Mountain, although it may also occur in several small unsurveyed bog patches nearby. Floristically about 58% of the 48 recorded native species in Rollen Creek swamp are shared with the Boyd Plateau Bogs, including herbaceous species such as *Centella asiatica*, *Geranium* sp., *Hypericum* sp., and *Viola caleyana* (Appendix 1).

Areas of hanging swamp dominated by *Gymnoschoenus sphaerocephalus* (Figures 8–10) are not referrable to any of the swamp vegetation types in the upper Cudgegong area identified by Bell (1998a). With the exception of the occurrence of *Eucalyptus camphora* and *Baeckea utilis*, these hanging swamps are more similar floristically and hydrogeomorphically to those occurring elsewhere on Narrabeen Sandstone in the Blue Mountains, such as the BMSS of Keith and Benson (1988).

The presence of extensive areas of *Sphagnum cristatum* along Rollen Creek, often forming large hummocks within the sedges and shrubs, was noteworthy. In comparison with Rollen Creek swamp, *Sphagnum* is either very restricted or absent from NPSS and BMSS (but note the extensive and unusual *Sphagnum* cover in the fen/marsh in Goochs Crater in the upper Wollangambe River catchment and in a BMSS in McCrae's Paddock in Katoomba). The much more extensive *Sphagnum* cover in Rollen Creek swamp (and elsewhere in mires and other parts of the upper Cudgegong catchment) is surprising considering the lower rainfall recorded at nearby "Kelgoola", compared to NPSS and other central Blue Mountains mires. Its persistence is likely to be the result, at least in part, of a sustained groundwater influence and the nearby presence of higher elevation peaks upstream around the catchment watershed contributing additional rainfall inputs as a result of an orographic effect. According to Chris Pavich (pers. comm.), *Sphagnum* was more abundant in the upper Cudgegong before the drought of the 1930-40s, with a subsequent increase in fire and grazing probably contributing to its further disappearance (C. Pavich pers. comm.). Rollen Creek swamp, however, has not been subject to heavy grazing or frequent anthropogenic fire (G. Summers pers. comm.), which may have helped prevent loss of *Sphagnum*. *Sphagnum* is generally much more abundant in montane bogs on granite, such as those of the Boyd Plateau, and nearby areas on metasedimentary geology (e.g., near Mt Werong and in Jenolan State Forest), than in the swamps developed on sandstone in the Blue Mountains, such as the NPSS and BMSS (also see Downing et al., 2007; Whinam & Chilcott, 2002). Differences in fire history and climatic factors between these areas are likely to be contributing factors.

While there are small patches of *Sphagnum* bog in the upper Cudgegong which are broadly consistent with Bell (1998a)'s Cudgegong Sphagnum Bogs, these are treated here as part of a variable upper Cudgegong montane bog type. *Sphagnum* also occurs along various drainage lines (often on heavy soils) and in localised patches within the other swamp types (including areas transitional between *Carex* fen and sedgeland-heath bog) where suitable conditions occur. The Cudgegong River Swamp Grassland and Upper Cudgegong Alluvial Sedgeland of Bell (1998a) are also treated as part of the montane fens identified in this study. As a result of more extensive survey across the study area, and based on their broadly similar floristics and potential organic-rich substrates, as described by Bell (1998a) in the Dunns Swamp area, Baird (2012) noted that there is considerable gradation between these swamp vegetation types.

In summary, the Rollen Creek swamp includes extensive valley floor mire of intergrading bog and fen, with some very small valley-side seepage/spring areas, and extensive valley-side hanging swamp dominated by *Gymnoschoenus*. The valley-side seeps, springs and hanging swamps are most similar to other such groundwater-dependent mire expressions developed on Narrabeen Sandstone in the Blue Mountains, such as the NPSS and BMSS. While these seeps and hanging swamps are hydrogeomorphically similar to similar mires developed on sandstone geology elsewhere in the Blue Mountains, they are characterised by a somewhat distinctive floristic assemblage. BMSS form part of the Coastal Heath Swamp vegetation class (NSWSC, 2007), although most are above the nominal 600 m upper elevation range indicated by Keith (2004) for the Coastal Heath Swamps. NPSS are considered transitional between the Coastal Heath Swamps and Montane Bogs and Fens vegetation classes (NSWSC, 2005b), with that transition occurring between Bell and Clarence. The valley floor mire along Rollen Creek, however, with areas of bog and fen, shows greater affinity, respectively, to the Tableland Bogs and Tableland Swamp Meadows of Tozer et al. (2010), within the Montane Bogs and Fens vegetation class. The valley-floor bogs along Rollen Creek and elsewhere in the upper Cudgegong have floristic and hydrogeomorphic similarities with montane bogs of the Southern, Central and Northern Tablelands (e.g., Hunter & Bell, 2007; Tozer et al., 2010). The *Carex* fens along Coxs Creek and Never Never Creek, at the downstream end of Rollen Creek swamp, and similar areas across the upper Cudgegong River catchment, have affinities with the *Carex* fen vegetation of Northern NSW (Hunter, 2013; Hunter & Bell, 2009), the *Carex-Poa* fen vegetation of Long Swamp in Ben Bullen State Forest and nearby areas (part of the Coxs River Swamps of Benson & Keith, 1990), the swampy meadows of the Central Tablelands (see Mactaggart et al., 2008; Mactaggart, 2008) and the Mountain Hollow Grassy Fens (DEC, 2006). This complexity highlights the value of this and other geographically isolated mires of the upper Cudgegong River catchment.

Conservation value of Rollen Creek swamp and other remaining mires of the upper Cudgegong River catchment

Mires are geographically restricted ecosystems in Australia and their extent and health have been considerably reduced and degraded since European settlement through urban and transport infrastructure development, agriculture, drainage, grazing, and more recently through mining impacts, particularly the impacts of subsidence from longwall coal mining, a Key Threatening Process in NSW (CoA, 2005, 2010; NSWSC, 2005a). Climate change and fire are also recognised as significant threats to these ecosystems (e.g., Baird & Burgin, 2016; CoA, 2010; Keith et al., 2014; Pemberton, 2005).

In the Sydney Basin bioregion, Temperate Highland Peat Swamps on Sandstone (THPSS) is listed as an Endangered Ecological Community (EEC) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (CoA, 2005). THPSS also includes NPSS and BMSS. Under the NSW *Biodiversity Conservation Act 2016* (which replaced the NSW *Threatened Species Conservation Act 1995*) NPSS is also listed as an EEC (NSWSC, 2005b), and Blue Mountains Swamps (including the Blue Mountains Sedge Swamps of Keith and Benson (1988)) is listed as a Vulnerable Ecological Community (NSWSC, 2007). Although not specifically included in the description of THPSS, the authors consider that some of the mires of the upper Cudgegong, particularly the Rollen Creek valley floor mire and hanging swamps, are clearly referrable to the THPSS EEC, and have been simply overlooked because of lack of documentation. For a similar reason, none of the valley-floor bogs and fens in the upper Cudgegong are specifically identified in the Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions EEC determination (NSWSC, 2004). In circumscribing the Montane Peatlands and Swamps EEC, the NSWSC (2004) referred to swamps above 400–600 m elevation. The montane bogs and fens of the upper Cudgegong are also referrable to this EEC and are clearly an important part of the complex of endangered montane mire communities distributed across the tablelands and adjacent ranges of NSW.

Habitat for rare species- flora

The mires of the upper Cudgegong River catchment are isolated from other montane mires. The nearest montane mires to the north occur at high elevation at Barrington Tops (Mort, 1983), although somewhat drier and more floristically impoverished wet heath vegetation, with some floristic affinity to the wet heath in the upper Cudgegong mires, occurs on heavier soils on Coolah Tops (Binns, 1997). The nearest to the south occur on the Newnes Plateau and the adjacent Ben Bullen State Forest.

This isolation contributes to the significance of some rare and restricted plant species in the mires and adjacent woodlands of the upper Cudgegong. For example, the distribution of the mallee *Eucalyptus camphora* subsp. *camphora*, illustrates the disjunct biogeography of many montane species restricted to specialised habitats. This taxon is geographically restricted to higher elevation mires and swampy drainage lines along this part of the Divide, with populations at Nullo Mountain and in the upper Cudgegong River catchment (Rollen Creek swamp in particular has a large population), and a highly localised and disjunct population 90 km further south in the Megalong Creek Valley near Katoomba, where it occurs in swamp patches with different floristics on heavier clayey soil and colluviums on Permian geology (600 m elev.). This locality in the Megalong Creek valley is also noteworthy for the occurrence of the rare and locally endemic *Callistemon megalongensis* (Craven, 2009; Udovicic & Spencer, 2012) and *Callistemon purpurascens* (Douglas & Wilson, 2015).

Another rare eucalypt, *Eucalyptus corticosa*, a locally endemic tree species restricted to the upper Cudgegong valley east of Rylstone, occurs in eucalypt woodland on shallow infertile soils on sandstone ridges and was recorded on the outer edge of the *Gymnoschoenus*-dominated hanging swamp along Rollen Creek. *Veronica blakelyi*, a small shrub restricted to the western Blue Mountains, near Clarence, near Mt Horrible, on Nullo Mountain and in the Coricudgy Range, is listed as Vulnerable under the NSW *Biodiversity Conservation Act 2016* and was recorded in woodland adjoining Rollen Creek swamp. Additional rare plant species are likely to occur in the woodlands adjoining these swamps, including in Coricudgy State Forest.

Habitat for rare species- fauna

The mires of the upper Cudgegong, particularly Rollen Creek, may also provide habitat for specialist mire fauna. Baird (2012) considered that the upper Cudgegong mires, particularly the valley-floor bogs and *Gymnoschoenus*-dominated hanging swamps, provide potential habitat for the endangered dragonfly, *Petalura gigantea.* The record of a single *Petalura* in a small hanging swamp (one of several such previously undocumented swamps in close proximity) east of Mt Coricudgy in Wollemi National Park, a considerable distance from the nearest known populations on the Newnes Plateau (Baird, 2012), strongly suggests that a population occurs somewhere within the complex of mires in the upper Cudgegong. Rollen Creek swamp is the most likely habitat, although surveys on three occasions have not recorded the species.

Rollen Creek swamp also appears to provide suitable habitat for the endangered Blue Mountains Swamp Skink, *Eulamprus leuraensis*, which is only known from mid-upper elevation mires in the central Blue Mountains (BMSS) and the Newnes Plateau (NPSS). This groundwater-dependent species has not been recorded further north than the Newnes Plateau (Gorissen, 2016; LeBreton, 1996). Evidence of foraging and tunnelling activity of Swamp Rats, *Rattus lutreolus*, a common species of BMSS and NPSS, was also observed during fieldwork. Additional obligate mire-dwelling fauna are likely to occur here (e.g., skinks and invertebrate stygofauna), but more detailed surveys will be required to identify them.

A burrowing spiny crayfish, *Euastacus australasiensis,* is widely distributed in Blue Mountains mires (including hanging swamps), and *Euastacus* burrows and partial remains were observed by the authors in the Rollen Creek mire system (including hanging swamps) and (by IRCB) in the small hanging swamp east of Mt Coricudgy where *Petalura gigantea* was recorded. While these are likely to be *Euastacus australasiensis* (see McCormack, 2012), the possibility exists that an unidentified swamp-dwelling taxon is involved. In the forested headwaters of the Cudgegong River in Coricudgy State Forest, below Mt Coricudgy and upstream of Rollen Creek, a large, stream-dwelling, burrowing spiny crayfish species, *Euastacus vesper*, closely related to *Euastacus spinifer* of eastern drainages, has recently been described (McCormack & Ahyong, 2017). The discovery of this apparently highly-localised species provides further evidence of the high conservation value of Coricudgy State Forest and of the opportunities for further research in this area.

Value of mires for palaeo-ecological, evolutionary and climate studies

Previous palaeoecological studies of Blue Mountains mires, based upon pollen and charcoal analysis of radiometrically-dated sediment cores, have greatly increased our understanding of the developmental history of these mires and their past climates and vegetation, particularly since the Last Glacial Maximum (~21 000 years BP). While the oldest sediment core ages suggest some mires may have commenced development around 13 000 years BP, sediment cores from other swamps have maximum ages within the Holocene (e.g., Black et al., 2008; Chalson & Martin, 2009; Fryirs et al., 2014; Martin, 2017). The mires of the upper Cudgegong River catchment can be expected to be a similarly rich source of knowledge related to species distributions, the developmental history of these mires and of climatic change since the Last Glacial Maximum, and expand our existing understanding of vegetation change across southeastern Australia and the Sydney Basin during this period.

The biogeography of the mallee *Eucalyptus camphora* subsp. *camphora,* geographically restricted to localised high elevation patches of suitable habitat along the Divide, is similar to that of many montane species with disjunct populations restricted to specialised habitats. Such disjunct distributions are likely to reflect, or be the result, of past climatic fluctuations to some extent, either during the Last Glacial Maximum or as a result of previous glacial/interglacial cycles. For *Eucalyptus camphora*, two other subspecies have also been recognised; subsp. *relicta*, found further north at Guyra and in Queensland, and subsp. *humeana*, occurring from Wee Jasper south into Victoria. The distribution of these taxa, with their greater morphological and geographic variation, presumably indicates older geographic separation than that within subsp. *camphora,* and provides evidence of past climate-related divergence. Other montane species restricted to specialised habitats, such as mires, have similar biogeographic patterns; understanding these patterns is of considerable scientific interest, particularly in the context of a rapidly changing climate.

Conclusion

The upper Cudgegong River catchment includes a complex of endangered peat swamp or mire types which are geographically disjunct from their nearest neighbours and characterised by some distinctive floristic assemblages. These include areas of montane bog, montane fen and hanging swamp. The presence of rare species such as the mallee *Eucalyptus camphora* subsp. *camphora*, and the potential for endangered fauna such as *Petalura gigantea* to be present, further highlights their value. In the context of the relatively low rainfall where these groundwater-dependent mires occur (and the upper Cudgegong is at their climatic limits), there is a surprising hydrogeomorphic and floristic diversity across these different mire types. With their relatively low rainfall, these mires may be particularly vulnerable to climate change.

Historically there has been considerable loss and degradation of the mires in the upper Cudgegong River catchment through land clearing and agriculture, beginning in the 1840s, and evidence of this damage provides a strong imperative to protect those examples that have survived. Conservation of these mires and their associated flora and fauna will benefit from further survey, mapping and biodiversity census. In addition to improved management of identified mires on private lands, including the possible use of biodiversity conservation covenants and incentives, improved recognition of the inherent values of these mires will be fundamental to their long-term conservation. Rollen Creek swamp is unique in the area, in terms of its size, floristic and hydrogeomorphic diversity, and good condition, and its conservation must be a priority. National Heritage listing of Coricudgy State Forest would provide a substantial foundation to highlight the values of this mire system and its surrounding woodland landscape, including the biodiversity associated with the significant, higher rainfall, basalt-capped island peaks adjoining the GBMWHA. Such listing is a prerequisite for nomination of this and other high biodiversity areas for addition to the GBMWHA and is recommended.

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Appendix 1: Native plant species (including mosses) recorded in Rollen Creek mire (TB=Tableland Bog, TSM=Tableland Swamp Meadow, HS= Hanging Swamp), and whether those species have also been recorded in Newnes Plateau Shrub Swamps (NPSS) (Benson & Baird, 2012) or Boyd Plateau Bogs (Kodela et al., 1996).

PLANT SPECIES	Family	Rollen Creek mire	NPSS	Boyd Plateau Bogs
Asperula gunnii	Rubiaceae	TB	NPSS	BPB
Baeckea utilis	Myrtaceae	TB, HS	NPSS	BPB
Baloskion australe	Restionaceae	TB, HS	NPSS	BPB
Baumea sp.	Cyperaceae	TB, HS	NPSS	BPB
Blechnum nudum	Blechnaceae	TB	NPSS	BPB
Bulbine bulbosa	Liliaceae	TB		
Callistemon citrinus	Myrtaceae	TB, HS		
Carex gaudichaudiana	Cyperaceae	TB, TSM		BPB
Centella asiatica (or *cordifolia*)	Apiaceae	TB		BPB
Centrolepis?	Centrolepiaceae	TB		
Comesperma retusum	Polygalaceae	TB		BPB
Drosera binata	Droseraceae	TB, HS	NPSS	BPB
Drosera spathulata	Droseraceae	TB	NPSS	
Empodisma minus	Restionaceae	TB, HS	NPSS	BPB
Epacris microphylla	Ericaceae	TB	NPSS	BPB
Epacris paludosa	Ericaceae	TB, HS	NPSS	BPB
Epilobium gunnianum	Onagraceae			BPB
Eriocaulon scariosum	Eriocaulaceae	TB		
Eucalyptus camphora subsp. *camphora*	Myrtaceae	TB, HS		
Eucalyptus pauciflora	Myrtaceae	TB	NPSS	BPB
Gahnia sieberiana	Cyperaceae		NPSS	
Geranium neglectum	Geraniaceae	TB		BPB
Gleichenia dicarpa	Gleicheniaceae	TB, HS	NPSS	BPB
Gonocarpus micrantha	Haloragaceae	TB	NPSS	BPB
Goodenia sp. (*bellidifolia*)	Goodeniaceae	TB	NPSS	
Gymnoschoenus sphaerocephalus	Cyperaceae	TB, HS	NPSS	
Hakea microcarpa	Proteaceae	TB	NPSS	BPB
Hybanthus?	Violaceae	TB		
Hydrocotle sp. (*sibthorpioides*?)	Apiaceae	TB	NPSS	BPB
Hypericum sp. (*gramineum*?)	Hypericaceae	TB	NPSS	
Isachne globosa	Poaceae	TB		
Isotoma fluviatilis?= Pratia surrepens	Campanulaceae	TB		BPB
Juncus spp.	Juncaceae	TB, TSM	NPSS	BPB
Lepidosperma limicola	Cyperaceae	TB, HS	NPSS	
Leptospermum continentale	Myrtaceae	TB	NPSS	BPB
Leptospermum myrtifolium	Myrtaceae		NPSS	BPB
Leptospermum obovatum	Myrtaceae	TB, HS	NPSS	BPB
Lepyrodia spp.	Restionaceae	TB	NPSS	
Patersonia fragilis	Iridaceae	TB	NPSS	BPB
Pultenea divaricata	Fabaceae	TB, HS	NPSS	
Pultenea sp.	Fabaceae	TB		
Ranunculus sp.	Ranunculaceae	TB		
Scirpus polystachyus	Cyperaceae			BPB
Senecio sp.	Asteraceae	TB		
Sphagnum cristatum	Sphagnaceae	TB, HS		BPB
Spiranthes australis	Orchidaceae	TB		BPB
Stylidium graminifolium	Stylidiaceae	TB	NPSS	BPB
Tetrarrhena juncea	Poaceae	TB	NPSS	
Utricularia dichotoma	Lentibulariaceae	TB	NPSS	BPB
Viola caleyana	Violaceae	TB	NPSS	
Xyris ustulata	Xyridaceae	TB, HS	NPSS	BPB
Xyris gracilis	Xyridaceae	TB	NPSS	
TOTAL		**48**	**33**	**31**
Number RC shared with NPSS and/or BPB			**31**	**28**
Percentage RC shared with NPSS and/or BPB			**65%**	**58%**