Impacts of the Gospers Mountain Wildfire on the flora and fauna of mining-impacted Newnes Plateau Shrub Swamps in Australia's Eastern Highlands

Martin Krogh[1]*, Sarsha Gorissen[2], Ian R.C. Baird[3] and David A. Keith[4,1]

1: New South Wales Department of Planning and Environment, Sydney, NSW 2124, Australia. martin.krogh@environment.nsw.gov.au

2: Independent Wildlife Ecologist, Sydney, NSW 2031, Australia. sgorissen@alumni.sydney.edu.au

3: Independent Conservation Biologist, Katoomba, NSW 2780, Australia. petalurids@gmail.com

4: Centre for Ecosystem Science, UNSW Sydney, NSW 2032, Australia. david.keith@unsw.edu.au

* Corresponding author

ABSTRACT

The Gospers Mountain Fire was the largest wildfire on record in New South Wales. All of the swamps on the Newnes Plateau were burnt, with some areas experiencing fire of very high severity. Despite this severity, the vegetation in all unmined reference swamps recovered relatively quickly, with substantial vegetation cover and biomass returning within 10 weeks. These swamps retained most of their peat and plant species, and both their surveyed endangered fauna species (Blue Mountains Water Skink *Eulamprus leuraensis;* Giant Dragonfly *Petalura gigantea*). This demonstrated the resilience of reference Newnes Plateau Shrub Swamps and their endangered species populations to significant bushfire events.

In stark contrast, after the wildfire there was evidence of extensive combustion and oxidization of peat soils in swamps located above the footprint of prior longwall coal mining operations. Populations of endangered species, which were already in significant decline (due to longwall mining impacts on swamp hydrology), are now vulnerable to localised extinctions in these undermined swamps. Mining is ongoing in these areas and failure to protect the remaining Newnes Plateau Shrub Swamps from the hydrological impacts of longwall mining will likely lead to further ecosystem collapse in undermined swamps, and further localised extinctions of endangered species populations in these swamps.

Key Words: Blue Mountains Water Skink, endangered ecosystem, fire ecology, Giant Dragonfly, groundwater dependent, hydrological disturbance, longwall mining, wildfire, peat swamp conservation, threatened species.

Published: 20 May 2022 DOI: https://doi.org/10.7882/AZ.2022.023

Introduction

Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion (NPSS) is the ecological community dominated by shrubs and sedges occurring on sites with impeded drainage in low slope headwater valleys on the Newnes Plateau in the upper Blue Mountains (OEH 2017). They are a unique example of a peatland ecosystem and because Australia has a marginal climate for peat development, these ecosystems are highly restricted and very sensitive to changes in hydrology (Keith *et al.* 2021). The Shrub Swamps usually occur on long, low gradient, open drainage lines on the Newnes Plateau, extending to altitudes above 1100 m and are the most elevated sandstone swamps on mainland Australia (Keith *et al.* 2021; Fig. 1). The upland swamps of the Newnes Plateau began developing between 9,000-15,000 years ago, after the last glacial maximum (Fryirs *et al.* 2014).

Newnes Plateau Shrub Swamps host a unique biota and provide a highly contrasting habitat to the surrounding landscape matrix of dry sclerophyll forest. The swamps form either a dense, wet heath with an open or closed, tussock sedge understorey, or one dominated by sedgeland. Trees are typically absent, although occasional eucalypts do occur. The main shrub species are *Baeckea linifolia*, *Boronia deanei* subsp. *deanei*, *Grevillea acanthifolia* subsp. *acanthifolia*, *Epacris paludosa*, *Sprengelia incarnata*, and *Leptospermum* species. The consistent feature of the ground cover is the presence of the cyperoid species *Lepidosperma limicola* and *Gymnoschoenus sphaerocephalus*, and species of Restionaceae (e.g. *Empodisma minus*). *Xyris ustulata*, the yellow flag, is also very common in the community (OEH 2017). Several threatened groundwater-dependent biota (plants: *Boronia deanei* subsp. *deanei* and *Dillwynia stipulifera*; the Giant Dragonfly *Petalura gigantea*; and the Blue Mountains Water Skink *Eulamprus leuraensis*) are found in these swamps and are obligate peat swamp dwellers (Benson and Baird 2012; Gorissen *et al.* 2017b).

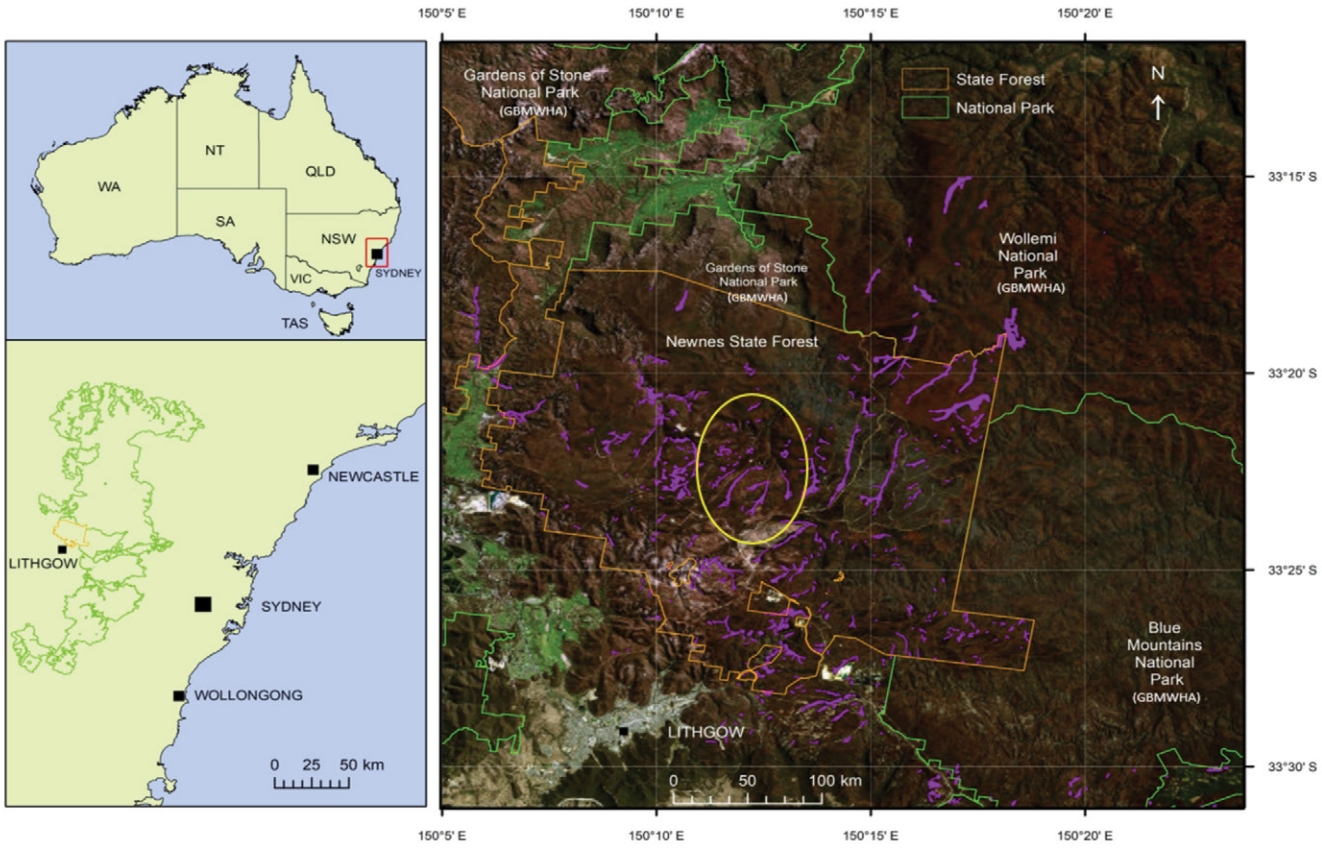

Figure 1: Newnes Plateau Shrub Swamps (shown in purple) on the Newnes Plateau. Major land tenures on and surrounding the Newnes Plateau include the Gardens of Stone, Wollemi and Blue Mountains National Parks which are all part of the Greater Blue Mountains World Heritage Area (GBMWHA). National park boundary (green); State forest boundary (orange); and approximate location of focus swamps (yellow ellipse).

The New South Wales (NSW) Scientific Committee listed Newnes Plateau Shrub Swamps (NPSS) as an Endangered Ecological Community (EEC) under the *Threatened Species Conservation Act* (*TSC Act*) in 2005. They are now listed as an EEC under the NSW *Biodiversity Conservation Act* (*BC Act*) *2016* as well as the Commonwealth *Environment Protection and Biodiversity Conservation Act (EPBC Act) 1999*, as part of the Temperate Highland Peat Swamps on Sandstone (THPSS) EEC.

The relatively poorly studied Newnes Plateau Hanging Swamps (NPHS; MU51; DEC 2006) share many species with the endangered NPSS community but occur in different landscape contexts. The Hanging Swamps occupy gully heads, slopes and ridgetop sites at points of water seepage where percolating groundwater travelling through the sandstone is forced outwards by impermeable shale layers. These more ephemerally wet swamps develop soils with varying organic content and support a range of swamp heath plants (DEC 2006). It is likely that NPHS are simply a different geomorphic expression of the NPSS community. Newnes Plateau Hanging Swamps are also included in the EPBC THPSS listing.

The conservation value of these swamps has long been recognized, including in development applications for mining operations in the area. As early as 1982 (Birds Rock Colliery Proposal), Woodward and Gilpin (Commissioners of Inquiry; 1982) stated:

> *Swamps on the Plateau and adjacent areas play a part in regulating the headwater stream flow. They may also act to filter sediment from surface run-off flowing through them. In effect, they are probably of considerable hydrological importance as well as being of notable floral and faunal value.*

There are approximately 650 ha of NPSS on the Newnes Plateau, of which about 160 ha (25%) are protected in the National Park estate: Blue Mountains, Wollemi and Gardens of Stone National Parks, part of the Greater Blue Mountains World Heritage Area (GBMWHA; Hensen and Mahony 2010; IUCN 2020). Most of the swamps are within Newnes State Forest, including the highest elevation swamps. There are approximately 100 individual NPSS in total, however, the majority occur outside of the National Park estate and are therefore subject to a variety of adverse land use impacts (e.g. NPWS 1981, Hensen 2010, Benson and Baird 2012). In November 2021, the NSW Government announced the creation of the Gardens of Stone State Conservation Area (total 28,944 ha), formed by the transfer of Newnes, Ben Bullen and Wolgan State forests and Crown land to National Parks and Wildlife (NSW DPE 2021a). At the time of writing, this transfer was currently *in progress*.

Because the swamps are groundwater-dependent ecosystems, they are highly susceptible to threats that cause loss of groundwater, the current major threat being the impact and damage from subsidence associated with longwall coal mining (DECCW 2010, Goldney *et al.* 2010, Benson and Baird 2012, Young 2017, Baird and Benson 2020, DPIE BCS 2020). Coal mining remains a permissible activity under the Gardens of Stone State Conservation Area and several mining leases remain active for the Newnes Plateau area (e.g. Springvale, Angus Place and Clarence mines).

Further threats to these swamps include changes to hydrology through damming of creeks, mine wastewater discharges, increased moisture competition from pine plantations, increased fire frequency, recreational motorbike and off-road vehicle tracks and climate change (Benson and Baird 2012; DPIE BCS 2020, Keith *et al.* 2021). Hensen's (2010) review of NPSS found that of the 91 swamps surveyed, ~24% of swamps had no visible impacts (i.e. good condition score). The remaining ~76% of the swamps exhibited varying degrees of degradation with 23% showing minor damage, ~25% showing moderate damage and a further ~28% showing severe damage from one or more sources of degradation (Hensen 2010).

The aim of this paper is to provide a review of what is known about current threats to Newnes Plateau swamps and describe how these swamps and their associated threatened fauna species responded to the 2019-2020 Gospers Mountain Fire.

Hydrogeology of Newnes Plateau Shrub Swamps

The Newnes Plateau is situated on the central western margin of the Sydney Basin. Strata of Permian and Triassic age overlie folded Silurian and Devonian rocks which sit on a Palaeozoic basement, with Quaternary alluvium present in river valleys (McHugh 2014). The Triassic strata of the Banks Wall Sandstone and the overlying Burralow Formation are the only strata in which the NPSS are situated (McHugh 2014). The Banks Wall Sandstone is the primary formation that provides the sheer cliff faces and scenic beauty of the Blue Mountains (e.g. the Three Sisters at Katoomba).

The Burralow Formation consists of medium- to coarse-grained sandstones interbedded with frequent sequences of fine-grained, clay-rich sandstones, siltstones, shales and claystones. The Burralow Formation has a maximum thickness of approximately 110 m, principally in the north-east and the south-eastern area at the headwaters of East Wolgan, Sunnyside, Sunnyside East, Carne West and Gang Gang shrub swamps (McHugh 2014). McHugh (2011, 2014) identified both a lithological and topographic link between the presence of the Burralow Formation and the occurrence of the NPSS and NPHS. Several of the claystone horizons, together with clay-rich, fine-to-medium grained sandstones and shales were found to be acting as aquitards, or semi-permeable layers.

Rainfall percolates through the overlying weathered and semi-weathered strata of the Burralow Formation sandstones until it meets the less permeable clay layers. Water then moves laterally until the clay layers outcrop in the incised drainage lines. The Burralow aquitards provide a permanent or near-permanent water source for the formation and maintenance of the shrub and hanging swamps. Evolutionarily, the permanent waterlogging associated with groundwater from the Burralow aquifers has helped provide the conditions necessary for swamp development and peat formation. Without these aquifers it is highly unlikely that the swamps would survive or persist in the landscape (McHugh 2014).

The majority of NPSS are located within the confines of the Burralow Formation, however, some shrub swamps are situated wholly within the Banks Wall Sandstone, while a smaller population comprises "mixed-type" swamps lying partially within both formations (McHugh 2014). The underlying lithology of each shrub swamp controls its morphology and often, areal extent, but topography can also play an important role, particularly for swamp gradients. The Banks Wall-type and "mixed-type" shrub swamps are generally smaller in area and occur in relatively steep-sided gullies (McHugh 2014). In comparison, the Burralow-type shrub swamps characteristically occur in much broader and gently sloping depressions and are commonly longer and permanently waterlogged in their lower reaches (McHugh 2014).

Important Fauna of Newnes Plateau Shrub Swamps

A wide range of fauna, including threatened fauna, have been recorded in or immediately adjacent to NPSS, including a wide variety of bird species, mammals (e.g. Swamp Rat *Rattus lutreolus*; Eastern Pygmy Possum *Cercartetus nanus*), lizards and snakes (e.g. Blue Mountains Water Skink *Eulamprus leuraensis*; Mountain Copperhead Snake *Austrelaps ramsayi*), amphibians (e.g. Red Crowned Toadlet *Pseudophryne australis*; Stuttering Frog *Mixophyes balbus* ; Giant Burrowing Frog *Heleioporus australiacus*), crayfish (*Euastacus australasiensis*) and insects (e.g. Giant Dragonfly *Petalura gigantea*). Two NSW endangered species, *Eulamprus leuraensis* (Fig. 2) and *Petalura gigantea* (Fig. 3.) are found almost exclusively in these swamps (and in the nearby Blue Mountains Swamps; although the *Petalura gigantea* range does extend to other peat swamp areas of eastern NSW (Baird 2012, Baird and Burgin, 2016).

Eulamprus leuraensis is listed as an endangered reptile species (*BC Act*, *EPBC Act*) and found only in the Blue Mountains and Newnes Plateau regions of NSW, Australia. Its exact distributional extent remains unknown with ~85 populations found to date (Gorissen

Figure 2: Blue Mountains Water Skink *Eulamprus leuraensis*. Photo S. Gorissen

Figure 3: Male Giant Dragonfly *Petalura gigantea*. Photo M. Krogh

et al. 2018b; Gorissen 2021a; unpubl. data). Genetic differences exist between skink populations in swamps of the Blue Mountains and Newnes Plateau regions (Dubey and Shine 2010a, b) which appear to have been isolated from each other for at least a million years (Dubey and Shine 2010a). Dispersal of individuals to nearby swamps is rare, leaving populations of individual swamps genetically distinct from one another (Dubey and Shine 2010a, b). These findings have recently been corroborated by RPS (2021), who identified major genetic differences between individual swamps and groups of swamps on the Newnes Plateau using DArTseq assays.

Eulamprus leuraensis has low annual fecundity and exhibits several other traits predicted to make it vulnerable to disturbance (including the potential effects of future climate change): ectothermy; specialisation to a rare and fragmented habitat type; montane endemicity; small geographic range; low survival rate; and dependence on groundwater (Dubey and Shine 2010b, 2011; Dubey *et al*. 2013; Gorissen *et al*. 2017a). Hydrological degradation to swamps by longwall mining and other threatening processes have led to localised population extinctions in some swamps (Gorissen *et al*. 2017a, Gorissen 2020, 2021b). Ecological research to date has established that long-term protection of the species requires greater protection of its habitat from multiple sources of degradation (Dubey and Shine 2010b, 2011; Gorissen *et al*. 2015, 2017a, b, 2018a, b).

Petalura gigantea is an obligately groundwater-dependent, mire-dwelling dragonfly which is reliant for oviposition and successful larval establishment upon a near surface water-table with surficial moist to saturated, organic-rich or peaty substrates. Larvae excavate and occupy variably groundwater-filled burrows and are reliant throughout their long larval stage on access to groundwater within their burrows, The species has a long larval stage of probably at least 6 years (Baird 2012, 2014). The Blue Mountains (including the Newnes Plateau) populations of *Petalura gigantea* probably represent the stronghold of the species (Baird 2012, Baird and Burgin 2016).

Coal Mining and Longwall Mining Impacts on Newnes Plateau Swamps

Coal mining has occurred under and adjacent to the Newnes Plateau for a considerable amount of time (~160 years). In 1822 William Lawson first collected samples of coal from the slopes of Mt York where Cox's Road descended into the Hartley Valley (Brown 1989). Pells and Hammon (2009) stated that this coal was not 'carbonised wood' but rather torbanite, which was later found in the Wolgan Valley at Newnes, leading to the extensive operations at the Newnes Shale Oil mine under the northern end of the Newnes Plateau (Eardley and Stephens 1974, Brown 1989). A local landowner, Andrew Brown, was reported to have been the first person to mine coal within the general area, with reports indicating that Brown was exploiting the local coal seams to power his flour mill in 1860 (Cremin *et al*. 1987). Since then, numerous coal mines were subsequently opened and worked in the Lithgow Valley and surrounds (Genders 1967, Brown 1989). The most relevant of the mines to the Newnes Plateau today are the Angus Place, Springvale and Clarence collieries.

Angus Place Colliery commenced production in 1979, after being developed as an extension of the Newcom Mine at Kerosene Vale. At this time it was owned by the NSW Government, with Centennial Coal purchasing the mine in 2002 for a reported sum of $306M as part of the 'Powercoal acquisition' (SMH 2002, ACCC 2002). Centennial Coal Company Limited is a wholly owned subsidiary of the Banpu Public Company. Coal was extracted from the Lithgow seam using longwall mining techniques and taken to the Wallerawang and Mount Piper power stations. In March 2015, mining operations at Angus Place Colliery halted due to a "prolonged downturn in international coal markets" and the mine was placed under care and maintenance. There were recent plans before Government to extend Angus Place further under the Newnes Plateau in the vicinity of the Birds Rock Flora Reserve (Centennial 2019). The Amended Angus Place Mine Extension Project has, however, recently been withdrawn. A new proposal for bord and pillar mining under the Upper Coxs River catchment near Long Swamp (Angus Place West proposal) is currently being prepared (NSW DPE 2021b).

Springvale Mine was granted development consent to construct and operate an underground coal mine, overland conveyor and washery in July 1992. Springvale Coal was originally a joint venture company owned by Clutha Coal Pty Ltd and Samsung Co Ltd and awarded a 20-year contract to supply coal to Mount Piper Power Station (SKM 1994). Springvale Mine was subsequently bought by Centennial Coal with coal currently extracted from the Lithgow coal seam using longwall mining techniques. Longwalls were originally proposed at 245 m width but at one stage longwall widths were increased to 315 m (MSEC 2013). Springvale mine is currently extracting coal using 261 m wide longwalls located underneath the headwaters of the Marrangaroo Creek catchment.

Mining began at Clarence colliery in 1979, while coal storage and transport from the site by rail commenced in 1980 and a coal preparation plant came into production in July 1981. Clarence Colliery commenced as a bord and pillar operation in 1980 before turning to longwall mining in 1990. During the mining of longwalls, the mine experienced numerous underground problems and a decision was subsequently made to close the mine in 1998 (Mills and O'Grady 1998). The mine was then bought by Centennial Coal in August 1998 and reopened as a bord and pillar operation less than a year later. Coal at Clarence colliery is extracted from the Katoomba and Lithgow coal seams using modified bord and pillar

methods. Clarence Colliery is currently extracting coal underneath the headwaters of the Bungleboori and Farmers Creek catchments.

In the early phases of mining under the Newnes Plateau, coal was extracted using bord and pillar techniques which produced limited surface subsidence and therefore limited surface impacts on the Newnes Plateau. Longwall mining involves removing a panel of coal by working a face of up to 300 metres in width (or sometimes greater) and up to 2 kilometres long (or sometimes longer; see Krogh 2007). Longwall panels are usually laid side by side with coal pillars, referred to as 'chain pillars', separating the adjacent panels. Chain pillars generally vary in width from 20–50 metres wide (Holla and Barclay 2000). The roof of the working face is temporarily held up by supports that are repositioned as the mine face advances. The roof immediately above the coal seam then collapses into the void (the 'goaf') and a collapse zone is formed above the extracted area. Longwall coal mining can have surface subsidence of up to 2 m or more depending on longwall panel configuration and overlying topography. Numerous recent publications have dealt with the environmental and social impacts of subsidence, particularly the effects it has on streams, swamps, and cliffs and steep slopes (Krogh 2007, NSW Department of Planning 2008, Commonwealth of Australia 2014, IESC 2014, 2020; IEPMC 2019a, b). An illustration of the location of longwall mining in relation to the overlying Newnes Plateau swamps is shown in Fig. 4.

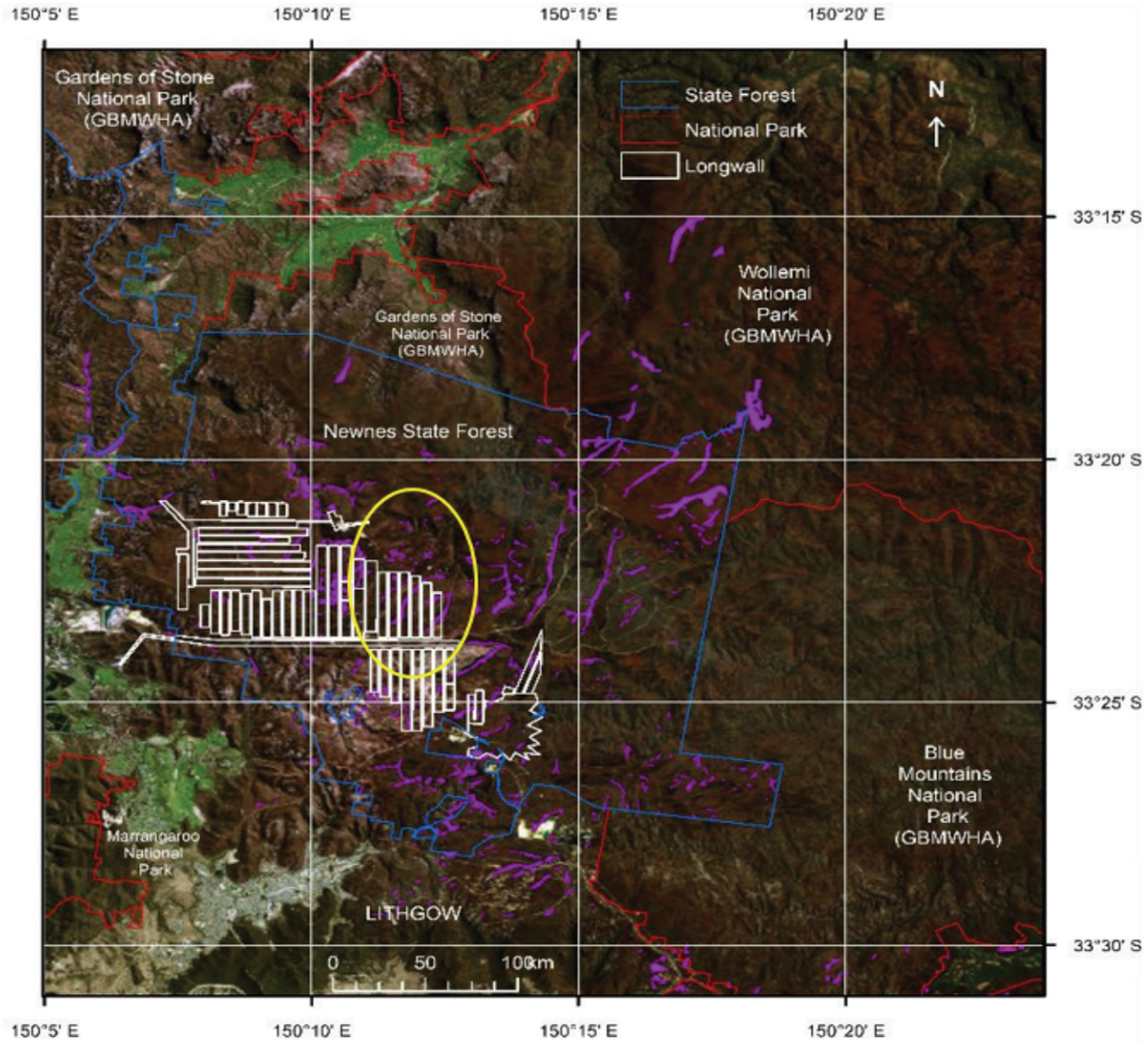

Figure 4: Longwall mining areas (approximated by the white polygons) underneath the Newnes Plateau in relation to the swamps (purple). Areas of bord and pillar mining under swamps have not been illustrated in detail. Most of this mining has occurred underneath the Newnes State Forest, although some may be underneath Crown Land. State forest boundary (blue); National Park boundary (red); approximate location of focus swamps (yellow ellipse).

The NPSS/NPHS/THPSS swamps on the Newnes Plateau above or adjacent to longwall mining can be impacted in three main ways by longwall mining:

- Depressurisation/removal of the aquifer supplying water to the swamp;
- Bedrock fracturing under the swamp and downward aquifer drainage into the fracture network - leading to desiccation and reductions in soil moisture in the swamp; and
- Movement along pre-existing geological structures (faults and lineaments) opening connected pathways leading to aquifer loss within the swamp.

All of these causal mechanisms have played a role in permanent impacts to NPSS/NPHS/THPSS swamps above or adjacent to previous longwall mining on the Newnes Plateau (MSEC 2020, DPIE BCS 2020). A summary of the shrub swamps that have been directly mined beneath by previous longwall mining at Angus Place and Springvale Collieries was provided in MSEC (2019, 2020). An illustration of how longwall mining can impact on swamp aquifer levels is shown in Fig. 5. As longwall mining progressed under the swamps, Sunnyside East Swamp was first impacted in 2013 and Carne West Swamp was impacted a year later in 2014. Once a swamp is impacted, water levels in the swamp usually fall to the bedrock base of the piezometer and whilst rainfall can temporarily lead to rises in water levels, they quickly return to the base of the piezometer. This behaviour is contrasted with a reference swamp that has not been undermined (Sunnyside Swamp), where levels fluctuate but a permanent aquifer is consistently maintained in the swamp. This loss of water in mining impacted swamps is accompanied by significant desiccation of the peat and a reduction in soil moisture (e.g. Mason *et al*. 2021). If surface to seam connective fracturing occurs, surface and swamp aquifer water can move down into the mine itself (IEPMC 2019a, DPIE BCS 2020).

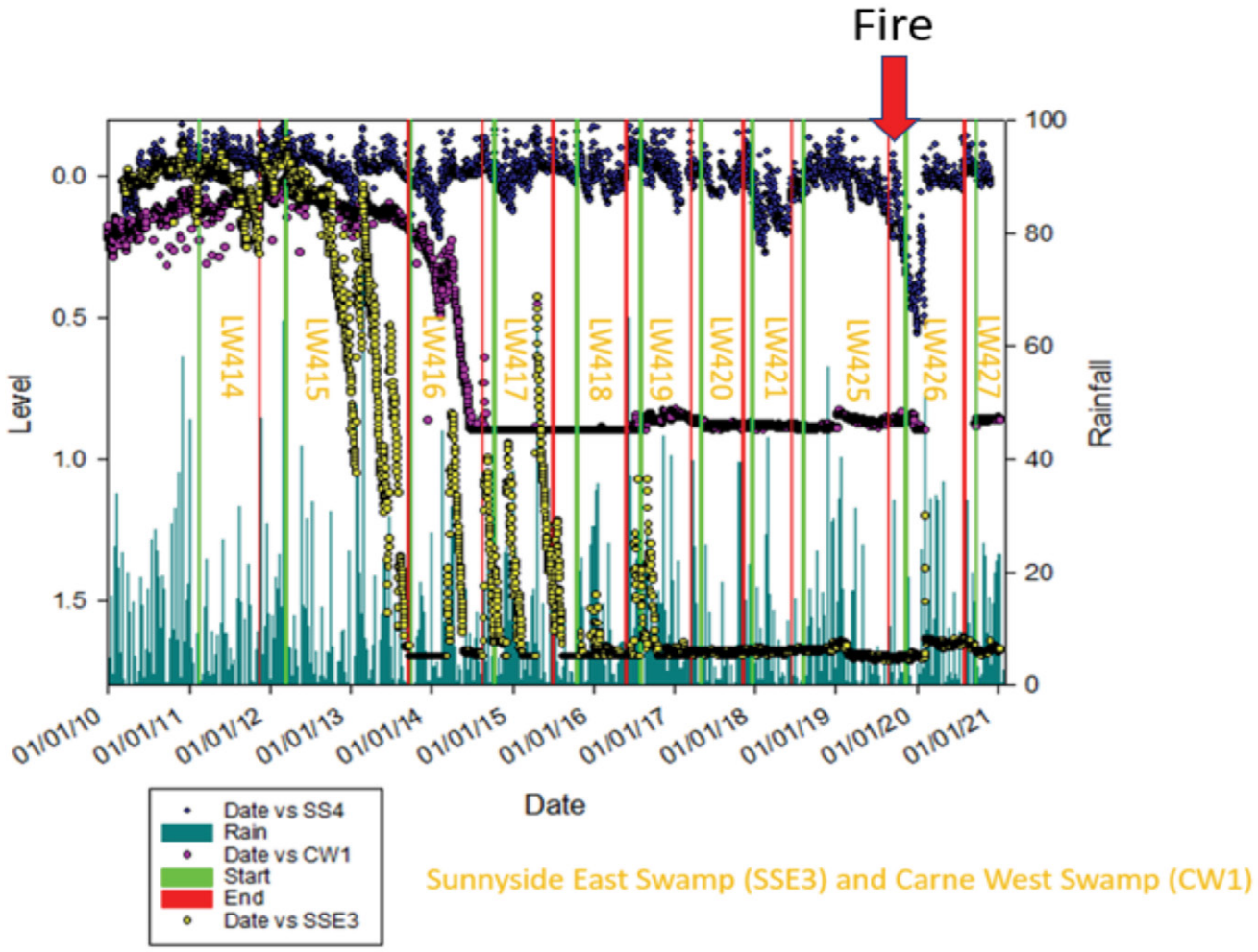

Figure 5: Water levels (in metres) within Sunnyside Swamp (Unmined reference swamp; dark blue circles), Sunnyside East Swamp (Mining impacted swamp; yellow circles) and Carne West Swamp (Mining impacted swamp; purple circles). Daily rainfall in mm shown as vertical bars (cyan). The timing of individual Springvale Mine longwalls (LW414 - LW427) are labelled in yellow. Start = starting date of an individual longwall; End = end date of an individual longwall). Source: Krogh 2021.

Saving our Species *Swamped By Threats* Program

The Save Our Species (SOS) *Swamped By Threats* program is a 10-year project that commenced in July 2016 (LLS 2021). It is a collaboration between State Government agencies (Local Land Services; Department of Planning, Industry and Environment: Biodiversity and Conservation Science and National Parks and Wildlife Service; and Forestry NSW), Local Councils (Lithgow City Council; Blue Mountains City Council) and relevant species experts. It was recognised that due to a range of adverse threats, if these unique swamps were not maintained as healthy ecosystems, there was a real risk that the species that rely on them could decline in numbers and potentially become extinct. The target species for the *Swamped By Threats* program included *E. leuraensis*, *P. gigantea* and *B. deanei*. A summary of the swamps and species monitored and assessed here is detailed in Table 1.

The *Swamped By Threats* Program has monitored *E. leuraensis* and *P. gigantea* over the last six years in selected Newnes Plateau Swamps (Fig.6). *Eulamprus leuraensis* has been monitored each year in three unmined reference swamps (Happy Valley, Broad and Sunnyside Swamps) and three mining-impacted swamps (Carne West, Gang Gang East and Gang Gang West Swamps; lying directly above Springvale Mine longwalls). The methods and conditions for surveying these skinks followed that of a former, long-term research project in this area (Gorissen *et al*. 2017a). Briefly, at each swamp, data related to hydrological change were collected on sunny days including - skink relative abundance and morphometrics; soil moisture; vegetation and other habitat attributes; and toe-clip samples from some skinks (for identification purposes and possible future genetic analyses). Fieldwork was carried out over two 5-day fieldtrips each year during summer with a 3-day trapping period (with funnel and pitfall traps) using mark and recapture techniques. Observational surveys were also conducted post-fire by walking transects in all disturbed swamps (Gorissen 2020).

Building on the work of Baird (2012), *Petalura gigantea* surveys were initially undertaken in January 2017 in Carne West, Gang Gang East, and Gang Gang West Swamps. After the January 2017 surveys, two unmined reference swamps, Budgary Creek Swamp and Dinner Gully Swamp, to the northeast of the Springvale mining lease, were included in the monitoring. Both swamps have recorded populations of the species, support extensive areas of high-quality breeding habitat, are relatively remote from the current approved longwall mining area and are therefore unlikely to be impacted by mining. These five swamps also have a minimum of four years annual monitoring data (up to and including the 2009-2010 flying season) from previous doctoral research (Baird 2012).

The methodology for *Petalura gigantea* monitoring followed that of Baird (2012) and involved walking transects along varying lengths of each of the five swamps, typically for most or all of the length of the swamp containing suitable breeding habitat for the species; Gang Gang East, ~1.5 km; Gang Gang West, ~0.5 km; Carne West, ~1.1 km; Budgary Creek, 1 km; Dinner Gully, ~0.7 km (Baird 2021). Surveys nominally followed the main drainage line, other than when it consisted of dense shrub swamp, in which case the transect route followed the edge of the dense shrub area. The same approximate route was followed each year during the annual survey. All individuals observed were recorded (sex and behaviour) within a distance of ~12 m (estimated) each side of, and 10 m in front of, the observer, taking care to minimise possibility of recounts of individuals which had flown ahead of the observer. All surveys were conducted with temperatures >18° C, with nil precipitation on survey day or on the preceding day, with low wind speed (gusts <15 kph). Sampling at temperatures >23° C with full cloud cover was considered acceptable.

To complement the fauna surveys, piezometers monitoring water levels (at 30-minute intervals) have now been installed in Happy Valley, Broad, Sunnyside, Carne West and Marrangaroo Swamps. Water level data from Gang Gang East and Gang Gang West Swamps are available from

Table 1: Summary of monitoring for E. leuraensis, P. gigantea and piezometer water levels on the Newnes Plateau. Monitoring may not have been continuous on an annual (species) or daily (water level) basis for the entire time period identified (see Gorissen *et al*. 2017a; Gorissen 2020, 2021b, Baird 2012, 2021, DECCW 2010, DPIE BCS 2020).

Species/ Hydrology	Mining Impacted Swamps			Unmined Reference Swamps				
	Carne West Swamp	Gang Gang West Swamp	Gang Gang East Swamp	Sunnyside Swamp	Broad Swamp	Happy Valley Swamp	Budgary Swamp	Dinner Gully Swamp
E. leuraensis	2013-2022	2013-2022	2013-2022	2014-2022	2012-2022	2012-2022	No	No
P. gigantea	2004-2022	2004-2022	2003-2022	No	No	No	2003-2022	2003-2022
Swamp (piezometer) water levels	Mining Company since 2005; DPE since 2014	Mining Company since 2011	Mining Company since 2011	Mining Company since 2005; DPE since 2020	Mining company since 2018; DPE since 2020	Earlier Monitoring by Mining Company now ceased; DPE since 2020	Mining company since 2018	Mining company since 2018

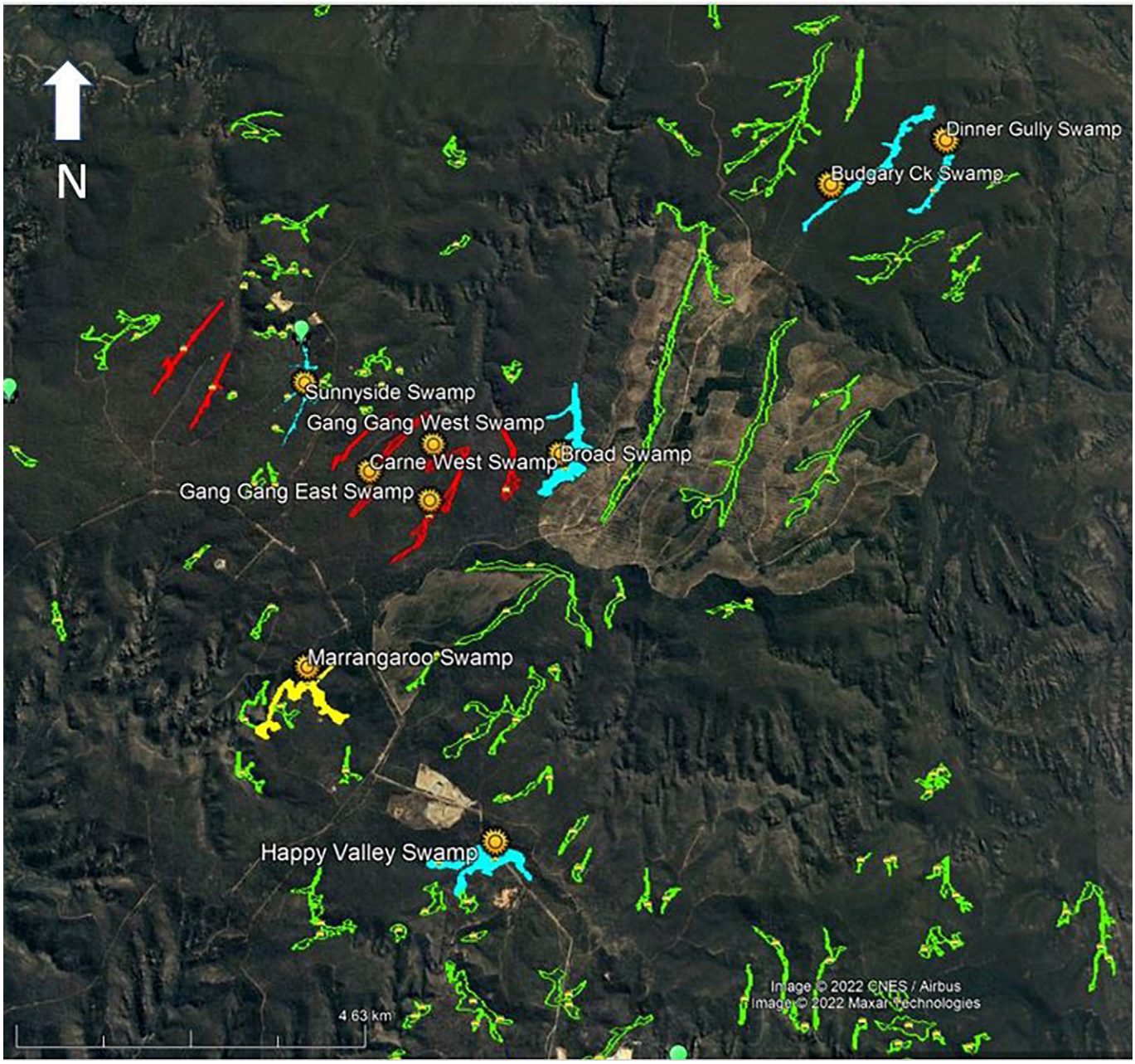

Figure 6: THPSS/NPSS Swamps (green) and swamps monitored as part of the Swamped By Threats program. Unmined reference swamps (light blue); mining impacted swamps (red); and Marrangaroo Swamp, the next swamp proposed to be undermined (yellow).

mining company piezometers installed in those swamps (e.g. Centennial 2021).

The Gospers Mountain Fire and its impacts on swamp flora and fauna - a dichotomy of outcomes

Following an extended period of drought, the first of a series of bushfires in the Greater Blue Mountains Area started from a lightning strike on 26 October 2019 near Gospers Mountain. This large bushfire went on to consume over 1 million ha of land over the following 79 days earning it the title the 'Gospers Mountain Megafire'. It wasn't until February 2020 that torrential rain finally extinguished the fire, which by that stage had extended over 100 km and reached the outskirts of Sydney. During this time, approximately 854,000 ha or ~82% of the World Heritage property was burnt (Fryirs *et al.* 2021). All of the Newnes Plateau was burnt, with some areas experiencing very high severity burns (Figure 7). The torrential rain in February 2020 caused flash flooding across the Greater Blue Mountains Area. These heavy rainfall and storm events resulted in increased sediment, debris and ash runoff and erosion of some watercourses and unsealed access routes across the Plateau.

Vegetation Impacts

The bushfires of the 2019–2020 summer burnt an area more than twice the size of the Australian Capital

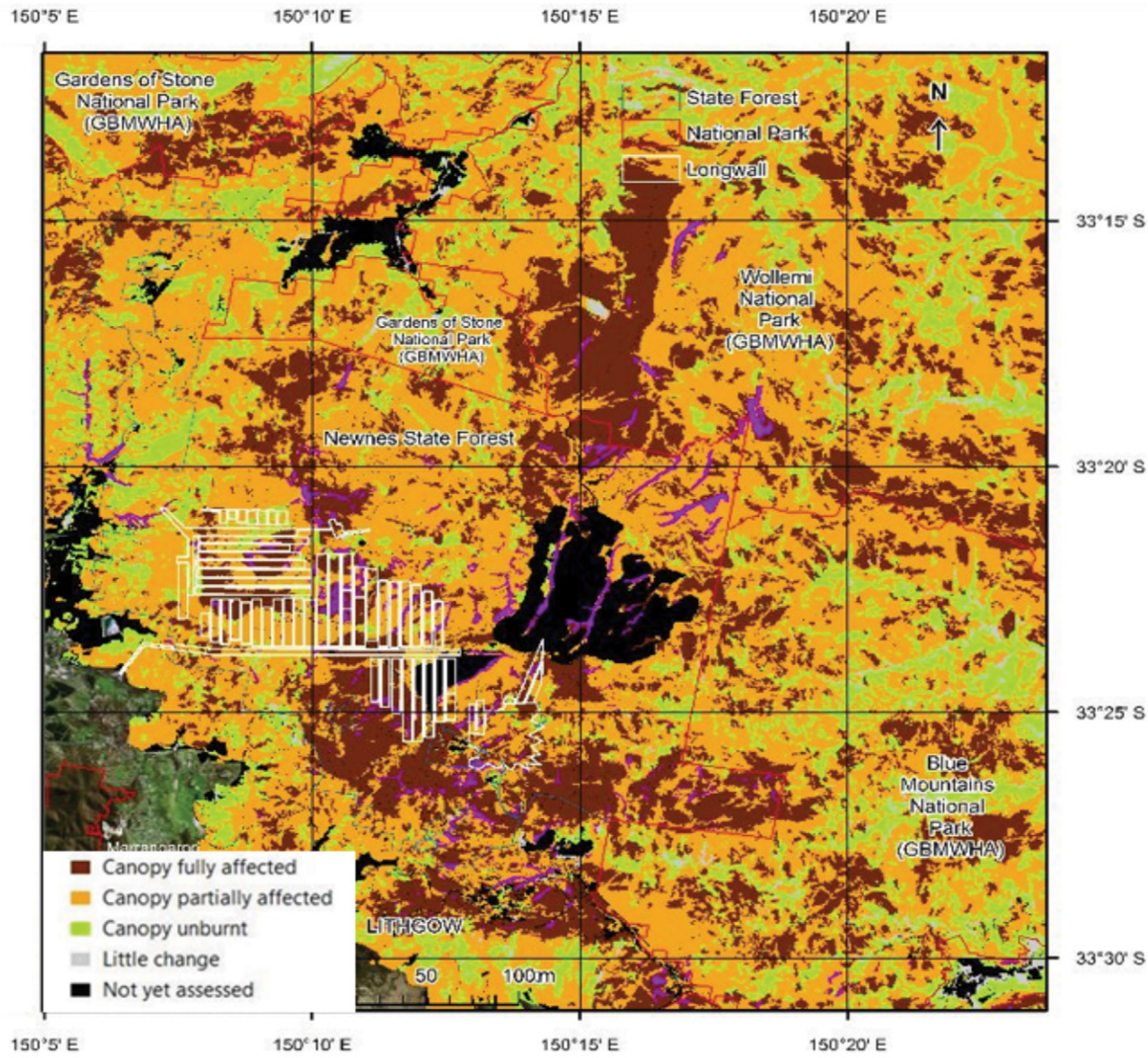

Figure 7: Fire intensity relative to NPSS swamps and underlying longwalls (white polygons). National Park boundary (red); fire intensity (yellow-green = low intensity (canopy unburnt), orange = medium intensity (canopy partially affected), brown = high intensity (canopy fully affected); black = recently harvested (prior to the fires) pine plantation areas or areas not yet assessed; from GEEBAM 2020).

Territory (ACT) and was arguably the costliest natural disaster in Australian recorded history (Fryirs *et al.* 2020). The fires severely affected the THPSS community with ~50% being burnt and many of these by a high severity burn (Keith et al 2022, Fryirs *et al.* 2020). Upland swamps on the Newnes Plateau were the most affected, with 96% burnt and 84% of these with a very high burn severity (Fryirs *et al.* 2020). An appreciable proportion of NPSS have now been burnt twice within the last decade. Baird and Benson (2020) identified that post-fire, vegetation recovery in unmined reference swamps had been rapid with vigorous resprouting of shrubs and sedges, and little evidence of death of plants despite the severity of the fire. There had also been relatively little combustion of surface peat.

In contrast, the impact of the fire on mining impacted swamps has been catastrophic. There were large areas where all lignotuberous resprouter shrubs had been killed or completely combusted, including those with very large and presumably old lignotubers, such as *Leptospermum* and *Baeckea* species. Similarly, large tussock-forming and apparently long-lived sedgeland species such as *Gymnoschoenus sphaerocephalus*, *Xyris ustulata* and *Empodisma minus*, had either been killed, or were barely surviving. With the combustion of the dried-out surface peat, the rooting zone bases of very large old tussocks, which typically survive fire in moist peat conditions, had also been substantially burnt away (Baird and Benson 2020).

Post-fire-vegetation surveys in the swamps was also undertaken by Keith *et al.* (2020, 2021) using quantitative transect counts. The selection of swamp sites complemented the existing *Swamped by Threats* monitoring program and included surveys in Happy Valley, Broad, Sunnyside, Carne West, Gang Gang East, Gang Gang West and Budgary Swamps. Keith *et al.* (2020, 2021) also undertook vegetation surveys in East Wolgan, Carne Central and Marrangaroo Swamps. Two monitoring sites were established within each swamp to monitor any differences in responses between the valley side and the valley floor, which exhibit variation in soils, drainage and vegetation. Monitoring sites were established and first surveyed in the field during March 2020, 10 weeks after the fire event, with repeat monitoring carried out during November 2020. Results indicated that unmined reference swamps exhibited resilience to bushfires, retaining most of their peat and plant species. They exhibited rapid post-fire recovery (see Fig. 8), with substantial vegetation cover returning within ~10 weeks of severe fires that consumed all surface litter, foliage and fine branches (Keith *et al.* 2021). Rapid regrowth and seedling recruitment continued over the first year since fire.

By comparison, peatland swamps exposed to prior longwall extraction of underground coal underwent ecosystem collapse, remaining largely unvegetated 10 weeks after fire, with minor regrowth over the first post-fire year (see Fig. 8). The mining impacted swamps suffered a high level of peat loss, a substantial reduction in species richness and a shift in species composition. These transformational changes are very unlikely to be reversible, as the valleys underwent major hydrological changes associated with the longwall mining and are now no longer suitable for most swamp biota. These heavily impacted swamps also no longer provide any water to the downstream catchment and so the creeks downstream of the swamps have ceased to flow except after very heavy rainfall.

Fauna Impacts

Mining impacts on swamps have been progressive over time. Piezometer water level and soil moisture monitoring identifed the different times at which Carne West (2014-2015), Gang Gang West (2015-2016) and Gang Gang East (2018) Swamps were impacted (Fig. 9; DPIE BCS 2020; Centennial 2021). Unmined reference swamps typically had soil moistures in the 80%-100% range, although soil mositures in these swamps can at times decline below these levels in response to severe drought. Once a swamp is impacted and drained though, swamp soil moistures fall to ~20% (see Fig. 9). While soil moisture may increase temporarily in response to rainfall, mining impacted swamp soils rapidly return to low moisture levels. This effect has previously been investigated in the swamps of the southern coalfields by Mason *et al.* (2020). In that study, longwall undermined wetlands were persistently drier, retained water for shorter durations and exhibited less spatial differentiation than unimpacted wetlands. There was quantitative evidence of severe, persistent hydrological change following coal extraction using the longwall mining method (Mason *et al.* 2020). The same processes are occurring in the mining impacted swamps of the Newnes Plateau.

Shortly after the fires (March 2020), skink numbers in unmined reference swamps fluctuated in accordance with previous years' surveys (Fig. 10; Gorissen 2021b). We also captured and observed an above average number of *E. leuraensis* in Broad Swamp, which is potentially the largest NPSS (~27 ha) on the Newnes Plateau. This data supports the view that Broad Swamp is of particularly high conservation value for the species.

Eulamprus leuraensis populations were already in substantial decline in Carne West, Gang Gang West and Gang Gang East Swamps due to mining induced hydrological impacts prior to the Gospers Mountain Fire (Gorissen *et al.* 2017a; Gorissen 2020, 2021b). After the fires, very few skinks have been captured, with no skinks caught or observed in Carne West Swamp and only one individual observed or caught in Gang Gang East and Gang Gang West Swamps respectively. The lack of recorded *E. leuraensis* in Carne West Swamp suggests the population has most likely been extirpated (Gorissen 2020, 2021b). Although skinks still inhabit two of the three mining impacted swamps (with only one individual captured or observed in each), since the habitat has been severely degraded to sub-optimal conditions, these populations are also likely to be on a trajectory to localised extinction. The loss of the Carne West Swamp population and the marked decline in numbers of the 2 other populations in mining impacted swamps is consistent with the species' dependence on wet swamp habitat with a dense understorey (Gorissen *et al.* 2015, 2017a, 2017b, 2018a).

Petalura gigantea populations have also suffered from the impacts of longwall mining on the hydrology of these swamps (Fig. 11). Baird (2012) confirmed significant differences in annual relative abundance counts of adult dragonflies (and emergence events) among years across the Blue Mountains, and complex patterns of spatial synchrony among nearby swamps, some of which is evident in the results (see Fig. 9). Transect lengths for the *Swamped By Threats* program were essentially the same as described in Baird (2012) for all surveyed swamps except Gang Gang East Swamp. For logistical reasons, a relatively shorter section of wet swamp was originally surveyed by Baird (2012) compared to the full swamp survey for the *Swamped by Threats* program.

Petalura gigantea monitoring results for the 2020-2021 summer flying season for the *Swamped by Threats Project* (Baird 2021) have identified that:

- No *Petalura* were recorded in Carne West Swamp, Gang Gang West Swamp or Gang Gang East Swamp;
- These undermined swamps no longer include any areas of potential breeding habitat for the species;

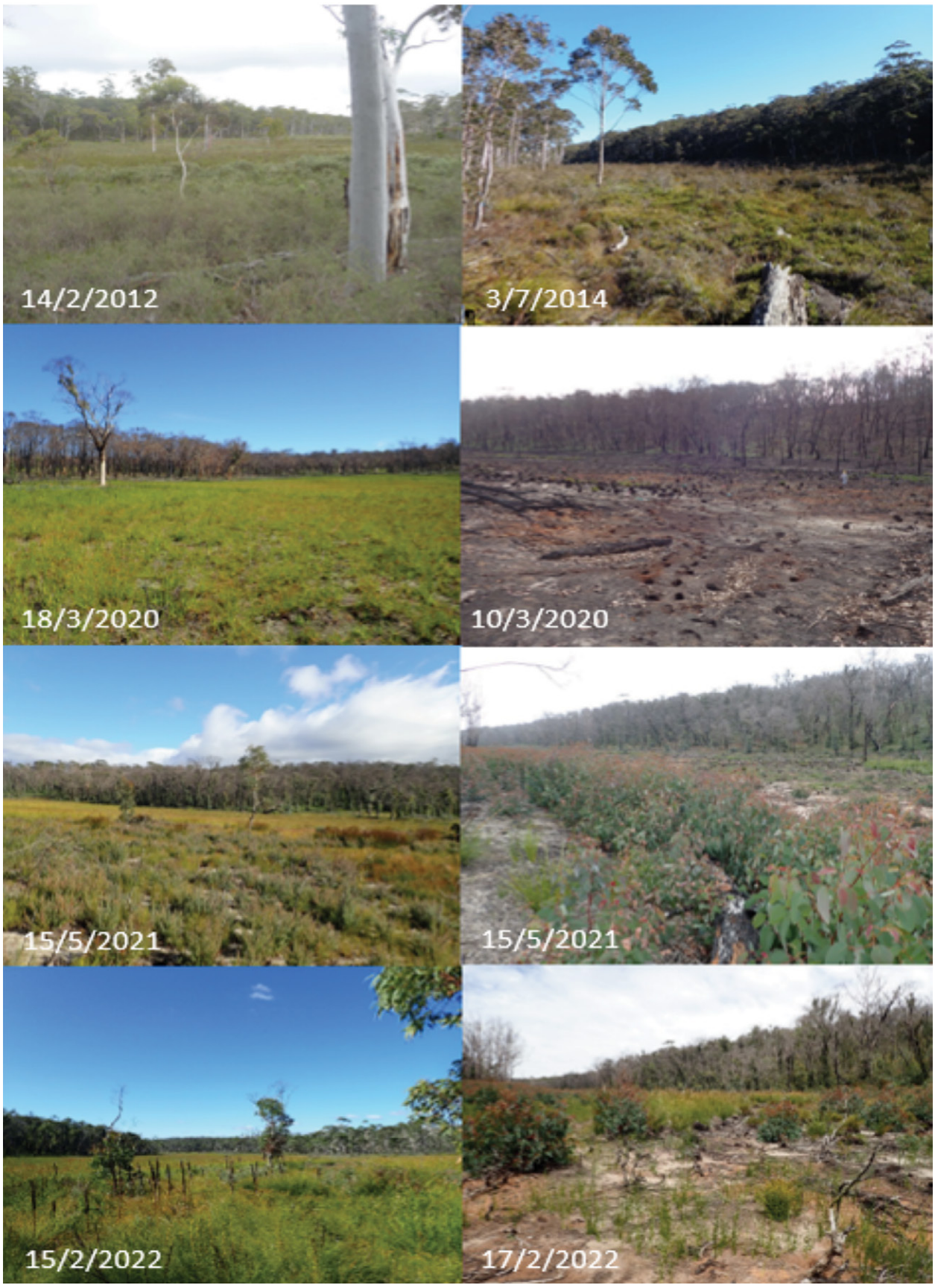

Figure 8: Vegetation changes from before (top) to after (post December 2019 - January 2020) the Gospers Mountain fire in an unmined reference swamp (Broad Swamp; left) and a mining impacted swamp (Carne West Swamp; right). Photographs are labelled with the date the photographs were taken. Note the eucalypt regrowth in what were previously swampy areas of Carne West swamp. Photos M. Krogh.

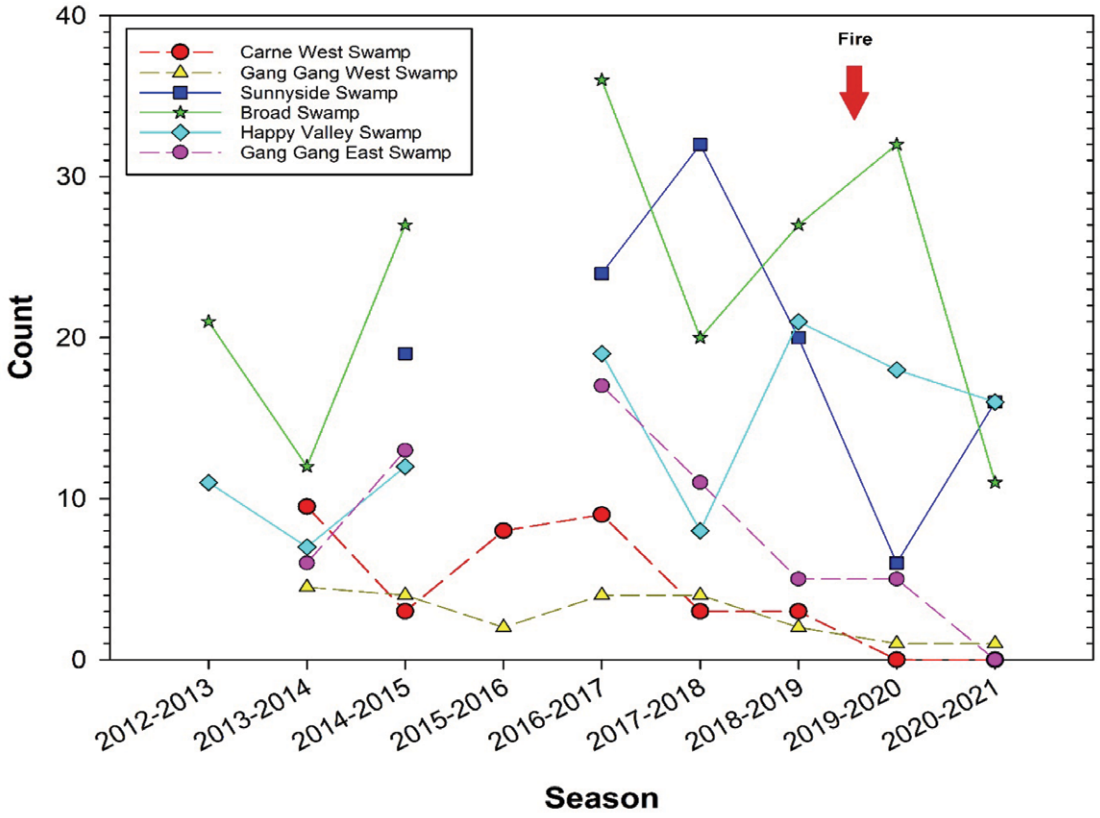

Figure 9: Boxplots of soil moisture levels in monitored swamps for the Swamped By Threats program. Unmined reference swamps are Happy Valley, Broad and Sunnyside Swamps; mining-impacted swamps are Carne West, Gang Gang East and Gang Gang West Swamps. Earlier data come from Dr S. Gorissen's doctoral research (Gorissen 2016, Gorissen *et al.* 2017a).

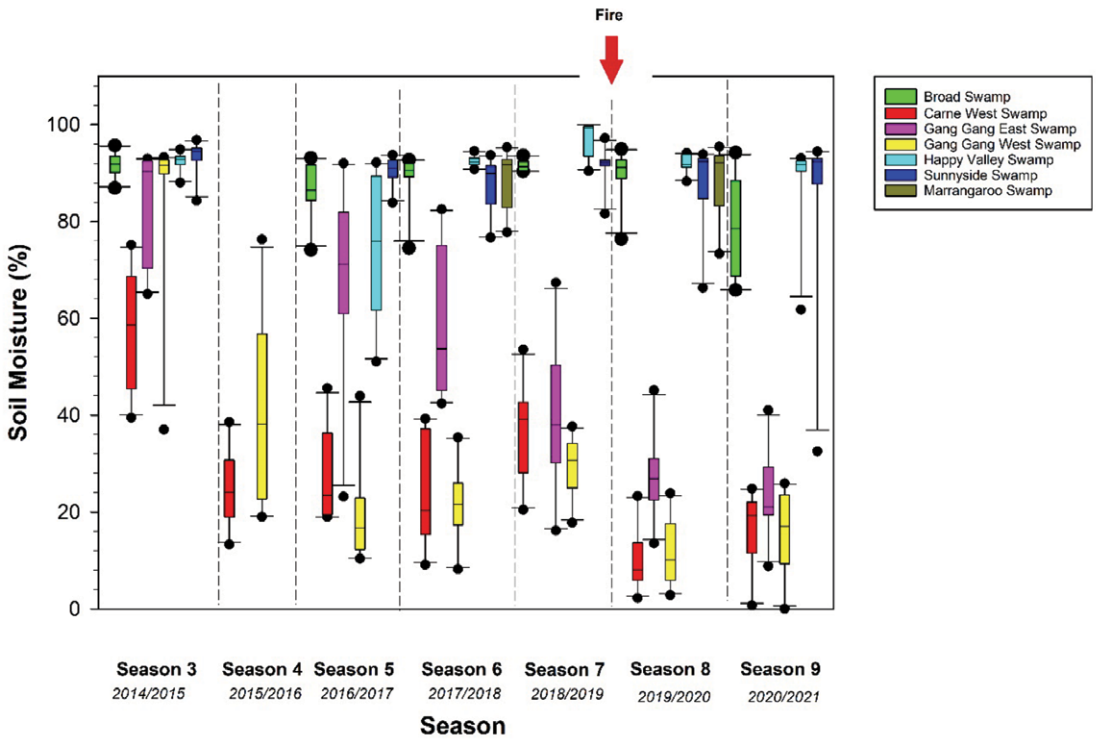

Figure 10: Skink numbers in monitored swamps for the Swamped By Threats program. Unmined reference swamps are Happy Valley, Broad and Sunnyside Swamps (solid lines); mining-impacted swamps are Carne West, Gang Gang East and Gang Gang West Swamps (dashed lines). Earlier data come from Dr S. Gorissen's doctoral research (Gorissen 2016, Gorissen *et al.* 2017a).

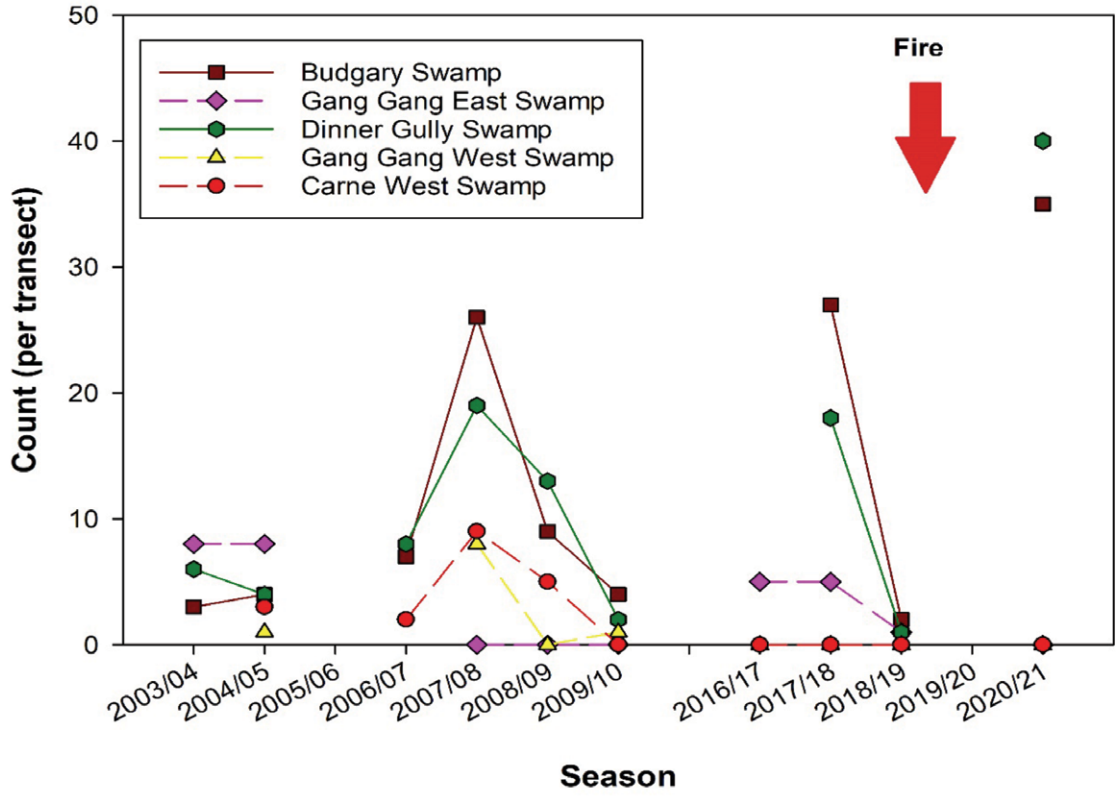

Figure 11: Petalura gigantea numbers from the Swamped by Threats program. Unmined reference swamps are Budgary and Dinner Gully Swamps (solid lines); mining-impacted swamps are Carne West, Gang Gang East and Gang Gang West Swamps (dashed lines). Earlier data (2003-2010) come from Dr I. Baird's doctoral research (Baird 2012). No systematic surveys for giant dragonflies undertaken in 2005/06 or from 2010/11 to 2015/16. Fires prevented safe survey access in 2019/2020.

- There was no evidence of any burrows of crayfish (*Euastacus australasiensis*) persisting, further confirming the loss of groundwater from these systems;
- Budgary Creek (PNP01) and Dinner Gully (PNP04) swamps recorded abundant *Petalura*, including various mating pairs and ovipositing females; and
- Both reference swamps are healthy, with extensive seepage areas and abundant active crayfish burrows.

Conclusion

The Gospers Mountain Fire was the largest single wildfire in NSW in recent times. Despite the magnitude and intensity of the fires, the vegetation in unmined reference swamps is recovering quickly. These swamps retained most of their peat and plant and animal species. demonstrating the resilience of the Newnes Plateau Shrub Swamp Endangered Ecological Community and its endangered species to significant bushfire events.

In stark contrast, there was strong evidence of ecosystem collapse in swamps located above the footprint of prior longwall coal mining operations (Baird and Benson 2020, Keith *et al.* 2020, 2021, Baird 2021, Gorissen 2021b). Endangered species populations (*E. leuraensis*, *P. gigantea*) which had already been catastrophically impacted or were in significant decline due to longwall mining hydrological impacts are now likely to become locally extinct in these mining impacted swamps. To date, 15 swamps or ~13% of the area of the NPSS community on the Newnes Plateau have potentially been irreversibly impacted by longwall mining (DPIE BCS 2020).

The results presented here have serious ramifications for genetic distinctiveness, diversity and population connectivity in *Eulamprus leuraensis*, and metapopulation connectivity of *Petalura gigantea* across the Newnes Plateau and adjoining areas. Protecting the remaining Newnes Plateau Shrub and Hanging Swamps from further hydrological impacts of longwall mining is a prerequisite for the conservation of these swamps and the populations of the endangered species they contain, even when high severity fires occur. Failure to protect these swamps from the damaging hydrological impacts of longwall mining will likely result in further irreversible impacts and localised extinctions of threatened species populations within mining impacted swamps (if not immediately, then following the next major fire event in the area).

Acknowledgments

We thank Huw Evans (Central Tablelands LLS) and Dr Deborah Ashworth (DPE BCD) for their leadership of the *Swamped By Threats* Program. We also greatly appreciate the support and encouragement of the *Swamped By Threats* Program Committee. We thank our many volunteers who have assisted with fieldwork for the various studies. Simon Hunter is thanked for his help with Figures 1, 4 and 7. We thank Dr Michael Hughes and Dr Tanya Mason for their review of an earlier draft of the paper. We thank our 2 anonymous reviewers who also helped improve the paper. Last but by no means least, we thank the NSW Environmental Trust for help in funding the SOS *Swamped by Threats* Program. Fieldwork was conducted under the DPIE/OEH ARA Animal Ethics Committee approval 161018/2; DPIE/OEH NPWS Scientific Licence SL101818; and Forestry Corporation of NSW Research Permit PB55060.

References

ACCC, 2002. Acquirer: Centennial Coal Company Ltd; Target: Powercoal Pty Ltd Australian Competition and Consumer Commission. https://www.accc.gov.au/public-registers/mergers-registers/public-informal-merger-reviews/acquirer-centennial-coal-company-ltd-target-powercoal-pty-ltd Accessed 11/10/2021

Baird, I.R.C. 2012. The wetland habitats, biogeography and population dynamics of *Petalura gigantea* (Odonata: Petaluridae) in the Blue Mountains of New South Wales. PhD thesis. The University of Western Sydney. Available at http://handle.uws.edu.au:8081/1959.7/509925

Baird, I.R.C. 2014. Larval burrow morphology and groundwater dependence in a mire-dwelling dragonfly, *Petalura gigantea* (Odonata: Petaluridae). *International Journal of Odonatology*, **17**: 101-121. doi:10.1080/13887890.2014.932312

Baird, I.R.C. 2021. *Petalura gigantea* monitoring results for Newnes Plateau Shrub Swamps for the 2020-21 summer flying season for the Swamped by Threats Project. Unpublished report to NSW Local Land Services, Central Tablelands and NSW Department of Planning, Industry and Environment, February 2021.

Baird, I.R.C. and Burgin, S. 2016. Conservation of a groundwater-dependent mire-dwelling dragonfly: implications of multiple threatening processes. *Journal of Insect Conservation*, **20**: 165-178. doi:10.1007/s10841-016-9852-3

Baird, I.R.C. and Benson, D.H. 2020. Serious impacts of longwall coalmining on endangered Newnes Plateau Shrub Swamps, exposed by the December 2019 bushfires. *Australasian Plant Conservation*, **20**: 12-15

Benson, D. and Baird, I.R.C. 2012. Vegetation, fauna and groundwater interrelations in low nutrient temperate montane peat swamps in the upper Blue Mountains, New South Wales. *Cunninghamia* **12**: 267-307 https://www.researchgate.net/publication/270761896_Vegetation_fauna_and_groundwater_interrelations_in_low_nutrient_temperate_montane_peat_swamps_in_the_upper_Blue_Mountains_New_South_Wales

Brown, J.W. 1989. Bent Backs. An illustrated social and technological history of the Western Coal field. Industrial Printing Co. Lithgow.

Centennial Coal, 2019. Amendment Report Angus Place Mine Extension Project 6 December 2019 Project No.: 0511056. https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-5602%2120200301T052004.193%20GMT

Centennial Coal, 2021. Centennial Coal Springvale Colliery Annual Review January 2020 to December 2020. Centennial Coal Pty Ltd. March 2021.

Commonwealth of Australia, 2014. Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques, Knowledge report, prepared by the Water Research Laboratory, University of New South Wales, for the Department of the Environment, Commonwealth of Australia.

Cremin, A. 1989. The Growth of an Industrial Valley: Lithgow, New South Wales. Australian *Historical Archaeology*, **7**: 1989

Cremin, A. (ed.) 1987. *Survey of Historical Sites: Lithgow Area*, NSW Heritage Council Sydney.

DEC, 2006. The Vegetation of the Western Blue Mountains including the Capertee, Coxs, Jenolan & Gurnang Areas Volume 1: Technical Report. Information and Assessment Section Metropolitan Branch Environmental Protection and Regulation Division Department of Environment and Conservation July 2006. ISBN 1 920887 44 X

DECCW, 2010. Review of Piezometer Monitoring Data in Newnes Plateau Shrub Swamps and their relationship with Underground Mining in the Western Coalfield. NSW Department of Environment, Climate Change and Water. January 2010.

DPIE BCS, 2020. Amendment report – Angus Place mine extension project (SSD 5602). Biodiversity and Conservation Division. Attachment D – Science Division review. https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=PAE-2357%2120200518T051044.010%20GMT

Dubey, S. and Shine, R. 2010a. Plio-Pleistocene diversification and genetic population structure of an endangered lizard (the Blue Mountains water skink, *Eulamprus leuraensis*) in south eastern Australia. *Journal of Biogeography*, **37**: 902–914 https://doi.org/10.1111/j.1365-2699.2009.02266.x

Dubey, S. and Shine, R. 2010b. Restricted dispersal and genetic diversity in populations of an endangered montane lizard (*Eulamprus leuraensis*, Scincidae). *Molecular Ecology*, **19**: 886–897 https://doi.org/10.1111/j.1365-294X.2010.04539.x

Dubey, S. and Shine, R. 2011. Predicting the effects of climate change on reproductive fitness of an endangered montane lizard, *Eulamprus leuraensis* (Scincidae). *Climatic Change* **107**: 531–547 https://doi.org/10.1007/s10584-010-9963-x

Dubey, S., Sinsch, U., Dehling, M.J., Chevalley, M. and Shine, R. 2013. Population demography of an endangered lizard, the Blue Mountains Water Skink. *BMC Ecology*, **13**: 4. https://doi.org/10.1186/1472-6785-13-4

Eardley, G.H. and Stephens, E.M. 1974. The Shale Railways of NSW. Australian Railway Historical Society ISBN 0 909650 03 9

Fryirs, K., Freidman, B., Williams, R. and Jacobsen, G. 2014. Peatlands in eastern Australia? Sedimentology and age structure of Temperate Highland Peat Swamps on Sandstone (THPSS) in the Southern Highlands and Blue Mountains of NSW, Australia. *The Holocene* **24**: 1527-1538 https://doi.org/10.1177/0959683614544064

Fryirs, K. A., Cowley, K. L., Hejl, N., Chariton, A., Christiansen, N., Dudaniec, R. Y., Farebrother, W., Hardwick, L., Ralph, T., Stow, A. and Hose, G. 2021. Extent and effect of the 2019-20 Australian bushfires on upland peat swamps in the Blue Mountains, NSW. *International Journal of Wildland Fire*, **30**(4): 294-300 https://doi.org/10.1071/WF20081

GEEBAM – Google Earth Engine Burnt Area Map 2020. Newnes Plateau, Swamped by threats Fire impact Map. NSW Department of Planning, Industry and Environment (DPIE) & CT LLS. Accessed 14/5/20. https://data.gov.au/dataset/ds-nsw-60fe872a-daf7-49d4-8a54-49ee414aaed2/details?q=

Genders, B.W. 1967. Coal Mines in the Western Fields. *Lithgow District Historical Society* Occasional Papers No. 5. ISBN 0 858660 03 2

Goldney, D., Mactaggart, B. and Merrick, N. 2010. Determining whether or not a significant impact has occurred on Temperate Highland Peat Swamps on Sandstone within the Angus Place Mine lease on the Newnes Plateau. Report prepared for the Department of the Environment, Water, Heritage and the Arts, January 2010.

Gorissen, S. 2016. Conservation biology of the endangered Blue Mountains Water Skink (*Eulamprus leuraensis*). PhD thesis, University of Sydney, Australia

Gorissen, S. 2021a. Monitoring populations of the Blue Mountains Water Skink – in burnt, disturbed swamps. Report prepared for the Central Tablelands Local Land Services. March 2020, pp. 1-10.

Gorissen, S. 2021b. Enhancing the survival of the endangered Blue Mountains Water Skink *Research Project Report 4: 2020–2021* 18 March 2021

Gorissen, S. 2021. Report 5: 2020-2021, Swamped by threats: conserving threatened species of upland swamps, Monitoring populations of the endangered Blue Mountains Water Skink in peat swamps disturbed by longwall mining. Report prepared for the Central Tablelands Local Lands Services and the Department of Planning, Industry and Environment, March 2021, pp.1–18.

Gorissen S., Mallinson J., Greenlees M. and Shine R. 2015. The impact of fire regimes on populations of an endangered lizard in montane south-eastern Australia. *Austral Ecology*, **40**: 170–177 http://onlinelibrary.wiley.com/doi/10.1111/aec.12190

Gorissen, S., Greenlees, M. and Shine, R. 2017a. A skink out of water: impacts of anthropogenic disturbance on an Endangered reptile in Australian highland swamps. *Oryx*, **51**(4): 610–618. https://doi.org/10.1017/S0030605316000442

Gorissen, S., Greenlees, M. and Shine, R. 2017b. Habitat and Fauna of an Endangered Swamp Ecosystem in Australia's Eastern Highlands. *Wetlands*, **37**(2): 269–276 https://doi.org/10.1007/s13157-016-0865-1

Gorissen, S., Baird, I.R.C., Greenlees, M., Sherieff, A.N. and Shine, R. 2018a. Predicting the occurrence of an endangered reptile based on habitat attributes. *Pacific Conservation Biology* **24**: 12–24 https://doi.org/10.1071/PC17027

Gorissen S., Greenlees, M. and Shine, R. 2018b. The impact of wildfire on an endangered reptile (*Eulamprus leuraensis*) in Australian montane swamps. *International Journal of Wildland Fire*. **27**: 447–456 https://doi.org/10.1071/WF17048

Hensen, M. 2010. Newnes Plateau Shrub Swamp Aerial Assessment Project Report 2010. Save Our Swamps Project, Blue Mountains City Council, Katoomba, Australia.

Hensen, M. and Mahony, E. 2010. Reversing drivers of degradation in Blue Mountains and Newnes Plateau shrub swamp endangered ecological communities. *Australasian Plant Conservation* **18**: 5–6

Holla, L. and Barclay, E. 2000. Mine subsidence in the southern coalfield, NSW, Australia, Mineral Resources of NSW, Sydney.

Independent Expert Panel for Mining in the Catchment (IEPMC), 2019a. Independent Expert Panel for Mining in the Catchment Report: Part 1, Review of specific mining activities at the Metropolitan and Dendrobium coal mines, prepared for the NSW Department of Planning, Industry and Environment.

Independent Expert Panel for Mining in the Catchment (IEPMC), 2019b. Independent Expert Panel for Mining in the Catchment Report: Part 2, Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment, prepared for the NSW Department of Planning, Industry and Environment

IESC, 2014. Advice to decision maker on coal mining project IESC 2014-054: Springvale Mine Extension Project (EPBC 2013/6881; SSD - 5594) http://www.iesc.environment.gov.au/system/files/resources/20efb7df-d3b0-45e1-9ce9-3edb33d32969/files/iesc-advice-springvale-2014-054.pdf

IESC, 2020. Advice to decision maker on coal mining project IESC 2020-113: Angus Place Mine Extension Project (EPBC 2013/6889 and SSD 5602) – Expansion. https://iesc.environment.gov.au/system/files/iesc-advice-angus-place-2020-113.pdf

IUCN, 2020. *Greater Blue Mountains Area - 2020 Conservation Outlook Assessment*. IUCN World Heritage Outlook: https://worldheritageoutlook.iucn.org/

Keith, D.A., Benson, D.H., Krogh, M., Watts, L., Simpson, C.C. and Mason, T.L. 2020. Newnes Plateau Shrub Swamp: Monitoring responses to the 2019-2020 bushfires and interactions with other threatening processes. November 2020. UNSW Centre for Ecosystem Science, Sydney NSW, Australia

Keith, D.A., Benson, D.H., Krogh, M., Watts, L., Simpson, C.C., Baird, I.R.C. and Mason, T.L. 2021. Newnes Plateau Shrub Swamp: Monitoring responses to the 2019-2020 bushfires and interactions with other threatening processes. Update report March 2021. UNSW Centre for Ecosystem Science, Sydney NSW, Australia

Keith, D. A., Allen, S. P., Gallagher, R. V., Mackenzie, B. D. E., Auld, T. D., Barrett, S., Buchan, A., English, V., Gosper, C., Kelly, D., McIllwee, A., Melrose, R. T., Miller, B. J., Neldner, J., Tolsma, A. D., White, M. D., Rogers, D., van Leeuwen, S., Yates, C. J. and Tozer, M. G. 2022. Fire-related threats and transformational change in Australian ecosystems. *Global Ecology and Biogeography*, in press. [doi: 10.1111/geb13500]

Krogh, M. 2007. Management of Longwall Coal Mining Impacts in Sydney's Southern Drinking Water Catchments, Australasian Journal of Environmental Management, vol.14, pp.155– 165.

Krogh, M. 2021. Impacts to Newnes Plateau Shrub Swamps, groundwater aquifers, stream hydrology and biodiversity. BCS presentation to the Springvale Expert Panel. 15 April 2021.

LLS, 2021. Swamped By Threats Conserving Species Reliant On Upland Swamps. NSW Local Land Services. https://www.lls.nsw.gov.au/regions/central-tablelands/key-projects/swamped-by-threats Accessed 11/10/2021.

Mason, T.J., Krogh, M., Popovic, G.C., Glamore, W. and Keith, D.A. 2020. Persistent effects of underground longwall coal mining on freshwater wetland hydrology. *Science of the Total Environment* **772** (2021) 144772 https://doi.org/10.1016/j.scitotenv.2020.144772

McHugh, E. 2011. Hanging Swamps within the Angus Place/Springvale Lease Areas. *Preliminary Report.*

McHugh, E. 2013. The Geology of the Shrub Swamps within Angus Place/Springvale Collieries Preliminary Report July 2013.

McHugh, E. 2014. The Geology of the Shrub Swamps within Angus Place, Springvale and the Springvale Mine Extension Project Areas Sept 2014.

Mills, K.W. and O'Grady, P. 1998. Impact of longwall width on overburden behaviour, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 1998 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019 https://ro.uow.edu.au/coal/277

MSEC 2013. Springvale Colliery Mine Extension Project Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Impact Statement for the Proposed Longwalls 416 to 432 and 501 to 503 in the Lithgow Seam. Report Number MSEC594 Revision A.

MSEC 2019. Centennial Coal: Angus Place Colliery – LW1001 to LW1015. Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Mining of the Proposed LW1001 to LW1015 in Support of the Amended Project. Report Number MSEC1046 Revision A

MSEC 2021. Springvale Colliery – LW428 to LW432 Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Mining of the Proposed LW428 to LW432 in Support of the Extraction Plan Application Report Number: MSEC1090 Revision A. February 2021.

NPWS 1981. Birds Rock Colliery Project. Supplementary Submission by the National Parks and Wildlife Service. September 1981.

NSW Department of Planning, 2008. Impacts of underground coal mining on natural features in the Southern Coalfield: strategic review, New South Wales Government, Sydney.

NSW Department of Planning and Environment (DPE) 2021a. Gardens of Stone and the Lost City Adventures. 13 November 2021 https://www.environment.nsw.gov.au/news/gardens-of-stone-and-the-lost-city-adventures

NSW Department of Planning and Environment (DPE) 2021b. State Significant Development Angus Place West https://www.planningportal.nsw.gov.au/major-projects/project/42631

OEH 2017. Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion – profile. https://www.environment.nsw.gov.au/threatenedSpeciesApp/profile.aspx?id=10974

Pells, P.J. and Hammon, P.J. 2009. The Burning Mists of Time. A Technological and Social History of Mining at Katoomba. WriteLight Pty Ltd. ISBN 978 09775639 6 8

RPS 2021. Blue Mountains Water Skink Research and Management Program: An Overview Presentation to Springvale Expert Panel. 18 March 2021. rpsgroup.com

Sinclair Knight 1994. Springvale Colliery Environmental Management Plan February 1994. Sinclair Knight Consulting Engineers.

SMH 2002. Centennial snaps up Powercoal for $306m. Sydney Morning Herald July 30, 2002. https://www.smh.com.au/national/centennial-snaps-up-powercoal-for-306m-20020730-gdfhv3.html Accessed 11/10/2021.

Woodward, J. and Gilpin, A., Commissioners of Inquiry. 1982. Birds Rock Colliery. An underground coal mine near Birds Rock on the Newnes plateau, near Lithgow, New South Wales. An inquiry pursuant to section 119 of the Environmental Planning and Assessment Act, 1979, into a development application. Report to the Honourable Eric Bedford, B.A., M.P., Minister for Planning and Environment. March 1982.

Young, A. 2017. Upland Swamps in the Sydney Region. ISBN 978 0 9943814 1 5.