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Indigenous cultural burning had less impact than wildfire on the threatened Backwater grevillea (*Grevillea scortechinii* subsp. *sarmentosa*) while effectively decreasing fuel loads

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Abstract. Indigenous self-determination, land rights and caring for Country programs are enabling Indigenous peoples across the world to re-establish customary roles in biodiversity conservation and cultural fire management. In Australia, Indigenous-controlled lands form the majority of the protected area estate, harbour almost 60% of listed threatened species and maintain high levels of biodiversity. This study used cross-cultural (Indigenous and Western academic) methods to monitor the impact of Indigenous cultural burning *v.* wildfire on the threatened plant, Backwater grevillea (*Grevillea scortechinii* subsp. *sarmentosa*). Cultural burning resulted in lower mature grevillea mortality and less impact on reproductive output than wildfire. Both fires stimulated a mass germination but the cultural burn preserved a multi-aged population while the wildfire killed 99.6% of mature shrubs. Comparison of fuel load changes resulting from cultural burning, hazard reduction burning and wildfire indicated that fuel loads were reduced by all fire treatments, although the cultural burn was less severe than other fires. Our case study of the Backwater grevillea and its Banbai custodians provides an example where Indigenous rangers have adopted a plant into their cultural management framework. They are conserving this threatened species using culturally driven, holistic management that is locally focused and supported by cross-cultural knowledge.

Keywords: Indigenous knowledge, fire ecology, threatened species, prescribed fire management, cultural fire, cross-cultural knowledge and practice, Aboriginal rangers, southeast Australia.

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Introduction

Indigenous peoples have adapted to their environment in ways that conserve both ecosystems and livelihoods in integrated social–ecological systems (Folke 2004). Colding and Folke (1997) shared examples of traditional communities that have co-evolved over long periods with species now identified as 'threatened', 'endemic' and 'keystone', and developed social restraints that resulted in Indigenous-led biological conservation. However, biocultural diversity (interlinked biological and cultural diversity, as per Potts *et al.* 2016; Maffi 2018; Hughes and Vadrot 2019) is threatened by human population growth, increasing consumption and globalisation (Loh and Harmon 2014). Ongoing declines in biocultural diversity have prompted initiatives to increase opportunities for Indigenous people to engage in managing their 'Country' (ancestral Indigenous lands) using cultural practice (Leiper *et al.* 2018). Globally, formal recognition of Indigenous peoples in conservation is increasing, leading to multiple benefits to communities, and contributing to national and international biodiversity goals and obligations (Ens *et al.* 2016; Garnett *et al.* 2018; Fa *et al.* 2020). One example is the revival of Indigenous cultural fire management practices world-wide (Russell-Smith *et al.* 2009; Lake *et al.* 2017; Bilbao *et al.* 2019; Mistry *et al.* 2019; Moura *et al.* 2019; McKemey *et al.* 2020*a*). Fire is a powerful tool that Indigenous communities use for subsistence purposes as well as a wide variety of social, cultural, spiritual and practical reasons (Boyd 1999; Trauernicht *et al.* 2015; Ens *et al.* 2017; Ansell and Evans 2020).

From the 1990s in Australia, the establishment of community ranger groups and Indigenous Protected Areas (IPAs) facilitated many Indigenous peoples to reconnect to, and participate in, cultural and natural resource management activities (Altman and Kerins 2012). IPAs are voluntarily protected areas of land and sea managed by Indigenous groups and contribute over 100 million ha or 54% of Australia's National Reserve System (Department of Environment and Energy 2019). Leiper *et al.* (2018) found that at least 59.5% of threatened species occur on Indigenous peoples' lands and several studies have concluded that genuine cross-cultural partnerships are an essential underpinning for collaborative work and conservation outcomes (Ens *et al.* 2015; Renwick *et al.* 2017; Lindenmayer *et al.* 2020). Case studies include the Pintupi people's partnership with ecologists to manage bilby (ninu or *Macrotis lagotis*) and great desert skink (tjalapa or *Liopholis kintorei*) at Kiwirrkurra IPA (Crossing and Thomas 2015); the Nawarddeken's care of the rainforest tree Anbinik (*Allosyncarpia ternata*) (Warddeken Land Management Limited 2018; Ansell and Evans 2020); and the Bundjalung people's conservation of the Byron Bay orchid (*Diuris byronesis*) at jointly-managed Arakwal National Park (CSIRO *et al.* 2019). Ridges *et al.* (2020) and Hooper (2019) discussed Aboriginal[1] core values in relation to the conservation of the threatened malleefowl (yungadhu or *Leipoa ocellata*) and Australian brush turkey (*Alectura lathami*), respectively. Garnett and Woinarski (2007) linked the decline of many species in recent decades to the cessation of traditional Indigenous stewardship and concluded that Indigenous management of fire and other threats at a landscape scale benefits several threatened species.

In south-east Australia, a revival of Aboriginal cultural burning is occurring. 'Cultural burning', defined as 'burning practices developed by Aboriginal people to enhance the health of the land and its people' (Firesticks Alliance Indigenous Corporation 2019), is used to describe the application of fire, while 'cultural fire management' encompasses broader cultural practices, values, heritage and land management activities (Office of Environment and Heritage 2016; McKemey *et al.* 2020*b*). An emerging field of academic research aims to monitor and evaluate the outcomes of Indigenous cultural burning activities (Maclean *et al.* 2018). Concurrently, Indigenous cultural fire managers are seeking support to produce ethical research that translates and communicates the holistic benefits of cultural fire management (Firesticks Alliance 2020). The majority of studies to date have taken a qualitative approach. For example, several papers have claimed that cultural burning protects threatened species and reduces wildfire risk (Maclean *et al.* 2018; Robertson 2019), but there is limited empirical evidence to support these claims in south-east Australia (McKemey 2020). Research into cultural fire management provides an opportunity to explore cross-cultural (or two-way) techniques, which are described as 'using combinations of Indigenous and non-Indigenous knowledge and methods and with the involvement of both Indigenous and non-Indigenous people towards a common goal' (Ens 2012; for examples, see Hill 2003; Ens *et al.* 2012; Hoffmann *et al.* 2012; Walsh *et al.* 2013).

On the New England Tablelands of New South Wales (NSW), the Indigenous Banbai rangers manage the 480 ha Wattleridge IPA (Fig. 1) for the conservation of biodiversity and cultural heritage (Patterson and Hunt 2012). Sixteen species of threatened fauna and flora have been recorded in the dry sclerophyll forest communities of Wattleridge IPA (Hunter 2005; Milledge 2016). Despite disruptions to their traditional cultural practices (Sonter 2018), the Banbai rangers started to renew their cultural burning practices from 2014. The Banbai rangers initiated a cross-cultural monitoring program alongside academic (Western) scientists (McKemey *et al.* 2019) to monitor the impact of cultural burning on Backwater grevillea (*Grevillea scortechinii* subsp. *sarmentosa*, also known as black or toothbrush grevillea). The Backwater grevillea is a low spreading shrub that occurs in dry sclerophyll forest, restricted to granite country on the New England Tablelands (Threatened Species Scientific Committee 2013). The subspecies is listed as Vulnerable in NSW under the *Biodiversity Conservation Act 2016* (BC Act) (Department of Planning Industry and Environment 2020*a*). It was previously listed as Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) but was de-listed in 2013 due to localised high abundance (Department of the Environment 2020) with up to 20 000 individuals found in Wattleridge IPA and the surrounding Backwater area (Hunter 2005). Threats include cattle grazing, vegetation clearing, roadworks, inappropriate fire regimes, weed invasion and feral animals, and the grevillea's restricted distribution increases its vulnerability to local extinction (Minister for the Environment 2008). Further work is needed in the areas of cultural fire management and cross-cultural monitoring, due to escalating threats associated with increasing frequency and intensity of wildfire under climate change (Bureau of Meteorology and CSIRO 2020; Mullins *et al.* 2020). An example of this was the 2019 Crown Mountain wildfire during Australia's catastrophic 2019–2020 wildfire season, which burnt 9091 ha in the region encompassing the range of the Backwater grevillea (Filkov *et al.* 2020).

The fire response syndrome of a plant species, based on its vital attributes and fire response traits, has profound effects on post-fire population dynamics and community composition (Noble and Slatyer 1980; Gill and Bradstock 1992; Clarke *et al.* 2009). Some shrubs are killed by fire and depend on seed germination and a sufficient inter-fire period to survive and reproduce (obligate seeders), whilst others resprout following fire (Croft *et al.* 2006). The maturation time has been given the term 'primary juvenile period' (PJP), which refers to the time taken for seedlings to flower and produce viable seed. 'Secondary juvenile period' (SJP) is the time to flowering after resprouting (Gill and Bradstock 1992; Clarke *et al.* 2009). Maturation times of new recruits for plants killed by fire is a critical biological variable in the context of fire regimes because this time sets the lower limit for fire intervals that can cause local population decline or extirpation (Keith 1996; Clarke *et al.* 2009). As such, 'High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition' has been listed as a Key

[1]While the term 'Indigenous' is used in a global context, 'Aboriginal' is often used to describe the Indigenous peoples of Australia, not including Torres Strait Islanders.

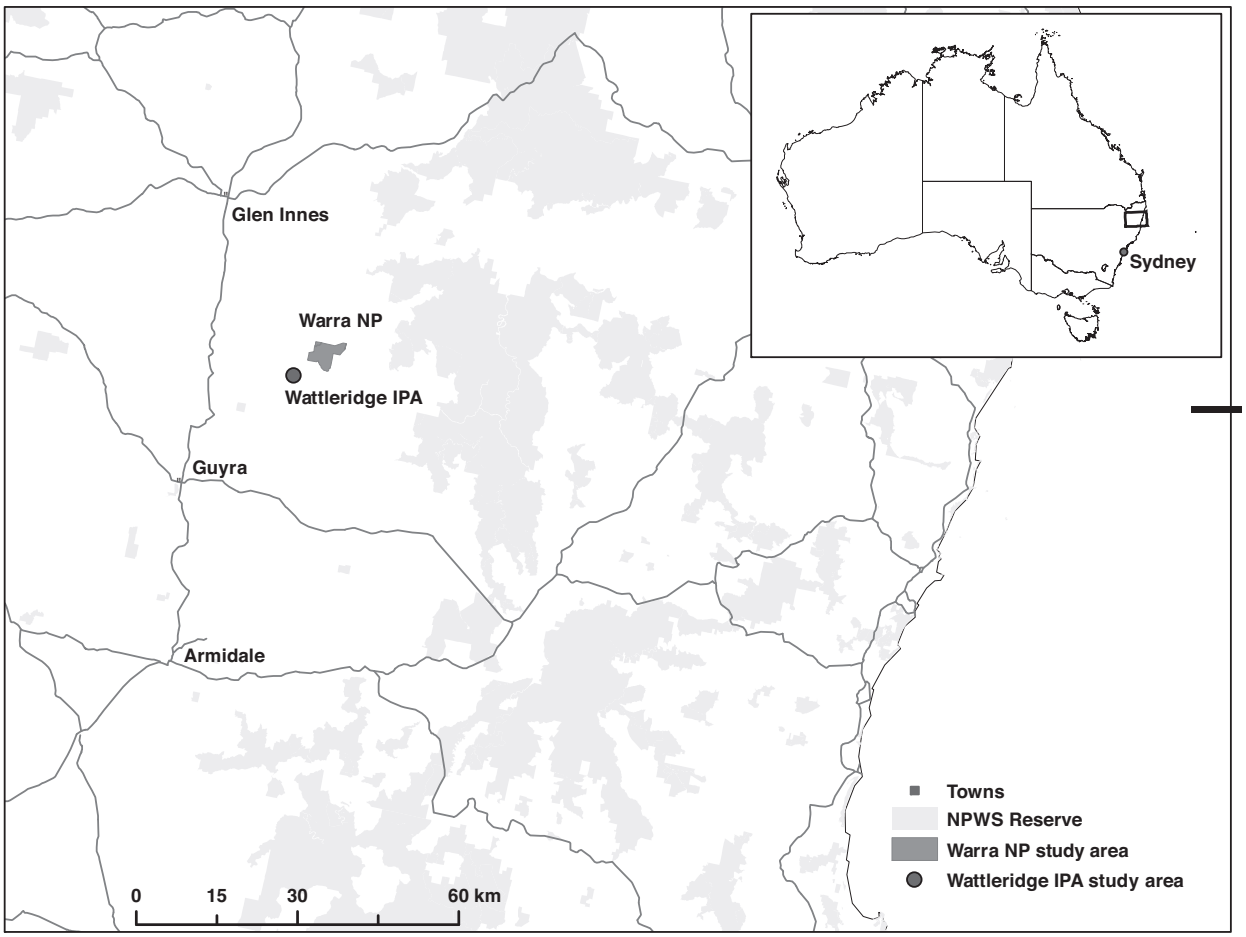

Fig. 1. Location of the study area (Wattleridge Indigenous Protected Area) and adjoining Warra National Park (NP) in northern New South Wales, Australia.

Threatening Process under the BC Act (Department of Planning Industry and Environment 2020*d*). On the New England Tablelands, Kitchin (2001) found that dry sclerophyll forest communities subjected to frequent fire displayed reduced shrub species abundance (including the seed bank), richness and simplified structure. Various fire response traits have been suggested for the Backwater grevillea including resprouting from basal buds (Clarke *et al.* 2009), killed soil-stored seed bank (P. Clarke unpubl. data), and 'occasionally resprouting but largely an obligate seeder with a high germination rate' (Hunter 2003). Populations at Warra National Park (NP) and Wattleridge IPA were noted to germinate *en masse* after fire (Hunter 2005). The PJP is not known (Clarke *et al.* 2009) and SJP was observed to be 3 years (Hunter 2003). Fire management recommendations for the Backwater grevillea were 'no fire more than once every 11 years' (Hotspots Fire Project 2016).

The Conservation Advice for the Backwater grevillea identified research priorities including assessments of the species' response to fire, more precise total population size, distribution, ecological requirements, and the relative impacts of threatening processes (Minister for the Environment 2008). Coupled with the need for quantitative research related to contemporary cultural burning, cross-cultural monitoring of the Backwater grevillea provided an opportunity to address these key research gaps. The aims of this study were to: (1) undertake cross-cultural monitoring of the Backwater grevillea, through interviews and on-ground monitoring with Banbai rangers, and academic research techniques of experimental design, analysis and scientific writing; (2) compare the fire effects of Aboriginal cultural burning, NPWS hazard reduction burning and the 2019 Crown Mountain wildfire; (3) investigate changes in mortality, recruitment, reproduction and fire response traits of the Backwater grevillea following cultural burning and a wildfire; and (4) use this information to make recommendations for effective fire management and conservation of the Backwater grevillea based on the Banbai rangers' Indigenous knowledge, and academic science, and discuss the role of Indigenous landholders and rangers in threatened species conservation.

Materials and methods

The cross-cultural monitoring of the Backwater grevillea (*Grevillea scortechinii* subsp. *sarmentosa*) employed socio-cultural and ecological monitoring techniques. Throughout the study period (2014–2020), the Banbai rangers, Indigenous fire practitioners and non-Indigenous scientists collaborated to codevelop the research project, collect data, share observations,

Fig. 2. Cross-cultural monitoring of Backwater grevillea. (*a*) Measuring a large, old shrub before fire in 2015, (*b*) cultural burning of the treatment plots in 2015, (*c*) mass recruitment of juvenile shrubs and (*d*) monitoring following the Crown Mountain wildfire in 2020.

Table 1. Banbai participants in interviews and grevillea monitoring

Initials of Banbai participant	Gender	Role	Ranger experience	Interview years
LP	Female	Elder and Ranger	12 years	2015, 2016, 2017, 2018, 2020
MT	Male	Elder and Ranger	10 years	2015, 2016, 2018, 2020
CP	Male	Ranger supervisor	11 years	2015, 2016, 2017
TP	Male	Ranger supervisor	11 years	2015, 2016, 2017, 2018, 2020
DC	Male	Ranger	10 years	2016, 2018
KP	Male	Ranger	9 years	2015, 2016, 2017, 2018
JJ	Male	Ranger	4 years	2018
PA	Male	Ranger	4 years	Not interviewed, participated in monitoring

discuss the findings of the research, develop the manuscript for publication and share the findings with a broader audience.

Socio-cultural research

An inductive approach to qualitative socio-cultural research was adopted, using participatory action research and semi-structured interviews (Babbie 2013). For the participatory action research, a non-Indigenous scientist (MM) and the Banbai Indigenous rangers participated in two activities (Fig. 2): (1) implementing a cultural burn; and (2) monitoring the Backwater grevillea population before and after the burn. Semi-structured interviews were undertaken during the cultural burn and grevillea monitoring over a period of 5 years. Interviews were recorded audio-visually, transcribed and later coded and qualitatively analysed around the themes (Schwandt 2014) of cultural burning, significance of the Backwater grevillea, impact of fire on backwater grevillea, threats and management related to backwater grevillea, and collaborative monitoring (Appendix S1, available on the journal's website). Eight Banbai rangers with varying levels of experience participated (Table 1). Five Banbai rangers were interviewed before the cultural burn in 2015, four during the burn and seven after the burn. Three Banbai rangers were interviewed following the Crown Mountain wildfire in 2020. Eight Banbai rangers (including two Elders who were also

rangers) participated in data collection and monitoring Backwater grevillea. The participation of rangers depended on their availability and willingness to be interviewed.

Collaborative ecological monitoring

A collaborative ecological monitoring program was undertaken to assess fuel loads, fire effects and grevillea population dynamics. Nomenclature follows that of the PlantNET Information System (National Herbarium of NSW 2020). Pre- and post-burn assessments based on a Before–After–Control–Impact (BACI) experimental design were undertaken (Underwood 1991). In 2015, 30 monitoring plots (15 each of control and impact plots) were established across the two study sites (12 at Wattleridge IPA; 18 at Warra NP). Control and impact plots had similar vegetation type, soil, geology, climate, slope, aspect and location (Hunter 2005). Plots were randomly placed in each zone. Plot dimensions were 20 × 20 m (400 m^2, 'large plots') (akin to Department of Environment Climate Change and Water 2011) and each plot included four nested transects of 5 m^2 (totalling 20 m^2 of 'transects' per plot) and five quadrats of 1 m^2 ('small plots').

A cultural burn was undertaken at the Wattleridge IPA on 16 August 2015 by the Banbai rangers (with the NSW Rural Fire Service present). This fire was a small (4 ha), low-severity, mosaic burn in dry sclerophyll forest. Time since last fire was ~30 years (Rural Fire Service NSW 2015). A hazard reduction burn was also undertaken in 2015. This fire was a large (685 ha) moderate-intensity burn on 20 October 2015 by NPWS and RFS at Warra NP and adjoining private land. The planned burn area was 351 ha; however, another fire started nearby and met with the planned burn to increase the total burnt area to 685 ha. Time since the last fire was 16 years (National Parks and Wildlife Service NSW 2015). For both planned burns in 2015, only the impact plots were burnt, control plots remained unburnt. In December 2019, the very large (9091 ha) Crown Mountain wildfire burnt all of the control and impact BACI plots at Wattleridge IPA and Warra NP. Time since the last fire was 4 years.

We measured indicators of fire effects (impact on variables before and after fire) across 30 large plots before and after (6 weeks, 1 year, 3 years) cultural (Wattleridge IPA) and hazard reduction (Warra NP) burning, and after (0.5 year) wildfire at both locations. Overall fire severity (broadly defined as ecosystem impact of fire; Keeley 2009) was determined based on mean indicative fuel load decrease (t/ha) (measured using overall fuel hazard assessment, as per Hines *et al.* 2010), mean bark char height (m) (mean height of scorch on tree bole bark, visually estimated in large plots), mean percentage of plot burnt (percent bare ground after fire in all small plots), fire plan optimum intensity (intended fire intensity, recorded in prescribed fire plans as per National Parks and Wildlife Service NSW 2015; Rural Fire Service NSW 2015; Department of Planning Industry and Environment 2020*b*), total fire size (ha) and estimated canopy scorch (%) (recorded in prescribed fire debrief reports and Google Earth Engine Burnt Area Map, see Department of Planning Industry and Environment 2020*c*).

At Wattleridge IPA, each large plot was measured four times: before (2015), after cultural burning (2016, 2018), and after wildfire (2020). We measured the total number (count) and size (height and width of plant) of mature (>20 cm height) Backwater grevillea. For each plant, the following details were noted: burnt/unburnt, alive/dead, reproductive stage (none/flower/fruit), fire response (resprouting/seeding). In all transects, all grevillea individuals (seedlings and mature plants) were counted and measured. A representative sample of grevillea seedlings were dug up and assessed to determine if they were individual plants or suckers from a larger plant.

Seven response variables (count of seedlings and mature grevilleas, reproduction, fuel load, fuel load decrease, bark char height and percentage plot burnt) were analysed in relation to time (2015, 2016, 2018, 2020) and fire treatment (control *v.* impact) with R statistical software (R Core Team 2014). For exploration of counts of both seedlings and mature grevilleas, we used mixed models with treatment (i.e. control and impact), year and the interaction of these two factors as fixed effects, and individual plot as a random effect. A Fisher's Exact Test was used to test for differences in reproduction affected by treatment and year. A two-way ANOVA model was used for the fuel load data and a one-way ANOVA to assess change in fuel load. For both of these fuel load analyses ANOVA model assumptions of normality of residuals and heterogeneity of variances were satisfied. Due to differences in group variance values, a Welch's ANOVA was used to assess bark char height. Categories of percentage of plot burnt were analysed using a Chi-squared test of independence.

Results

Socio-cultural research

Before they began work at the Wattleridge IPA, many of the Banbai rangers were not familiar with the Backwater grevillea or its traditional values. In 2015, before cultural burning, the rangers indicated that the grevillea had become important to them, as it was a declared threatened species that was only found in the Wattleridge IPA region. They felt a responsibility to look after this plant. They were interested to learn if cultural burning would benefit the grevillea. One ranger predicted that '*Having a winba* [Banbai word for fire] *will push the seed out and create more of it*' (TP). The rangers said that mitigation of wildfire risk was one purpose of cultural burning: '*The difference to the way we burn is … we set it up so it's not just gonna fly for the bush. And so we just slowly move through the bush and don't … burn everything … A wildfire would just kill everything and start crown fires, so we just try to keep it low*' (KP).

In 2016, the year following the cultural burn, the Banbai rangers noted that a lot of Backwater grevillea came up after the cultural burn. They stated that the cultural burn '*went well*' and benefited the grevillea by stimulating establishment of new plants. Some of the rangers said that leaf litter was inhibiting grevillea growth and the fire reduced the ground cover to allow it to establish. Ranger and Elder LP expressed that '*We know now that it comes back really strong after a good winba*' and '*the grevillea down here has come back 10-fold. We've proven that every fire we do, that grevillea will regenerate after a winba*'.

In 2017, the Banbai rangers continued to say that cultural burning is a good tool for the management of Backwater grevillea. In 2018 (3 years after the cultural burn), LP said that the grevillea recruitment was so dense '*it came back like a carpet*'. While the cultural burn killed some of the large, old

Table 2. Fire effects (mean ± s.e., sample size in parentheses) and overall fire severity in impacted plots after the Wattleridge IPA cultural burn (2015), Warra NP hazard reduction burn (2015) and Crown Mountain wildfire (2019)

Mean fuel load decrease did not differ significantly between the three types of fire. For bark char height and proportion of the plot burnt, means followed by a different lowercase superscript letter differed significantly at $P < 0.05$

Indicator	Wattleridge IPA cultural burn 2015	Warra NP hazard reduction 2015	Crown Mountain wildfire 2019
Mean fuel load decrease (t/ha)	8.9 ± 1.59 (6)[a]	7.8 ± 1.49 (9)[a]	10.8 ± 0.81 (30)[a]
Mean bark char height (m)	3.8 ± 0.65 (6)[a]	5.8 ± 1.25 (9)[a]	12.2 ± 1.18 (30)[b]
Mean percentage plot burnt (%)	59 ± 8.0 (6)[a]	81 ± 5.1 (9)[b]	98 ± 1.18 (30)[c]
Total fire size (ha)	4	685	9091
Fire plan optimum intensity[A]	Low	Moderate–high	Unplanned
Estimated crown scorch (%)	0	10	90
Overall fire severity	Low	Moderate	Very severe

[A]Fire plan optimum intensity uses the definitions in Rural and Land Management Group (2012). *Australasian Fire Authorities Council Bushfire Glossary* of low intensity fire as 'a fire which travels slowly and only burns lower storey vegetation, like grass and lower tree branches, with an average intensity of less than 500 kW.m^{-1} and flame height less than 1.5 m. Usually causes little or no crown scorch and is easily controlled' and high intensity fire as 'fires with an average intensity greater than 3000 kW.m^{-1} and flame heights greater than 3 m, causing complete crown scorch or possibly crown fires in forests'.

shrubs, fire had awakened the seeds, and the new plants were mostly seedlings, not suckers. Mature shrubs in the unburnt control plots and those left unburnt by the patchy cultural burn were reproducing: '*The unburnt areas had a lot of bigger ones through them so they were starting to flower a lot more*' (DC). They felt that the population was healthy because '*they reproduce flowers and seeds every year. Some of them might need a bit of winba to reinvigorate them but it is a very healthy population here*' (LP).

The rangers listed threats to the Backwater grevillea as severe fire, kangaroos, feral animals, pigs, drought and humans. They described their preferred management actions for the grevillea as cultural burning to reduce wildfire risk, feral animal management and educating people to look but not touch. LP described the variable outcomes of burning on the grevillea, which are dependent on '*where you've got them in the landscape and what sort of winba you are using*'. From their observations, the rangers agreed that patchy, low severity burning was best, and it worked well at Wattleridge IPA. Cultural burning leads to '*healthy Country and healthy people*' (LP and TP). The rangers wanted to continue the monitoring. '*I can say it has worked really well, the winba with the grevillea, it has come a long way and to keep doing it would be great*' (TP).

Following the Crown Mountain wildfire in 2020, the Banbai rangers observed that the mature Backwater grevillea plants had died, and young plants were emerging. The rangers noted that many Australian native plants need fire, but cool burns were preferable to hot burns. They were concerned that the wildfire had '*burnt everything right out*' and several months later *'there is still nothing coming back*' (MT) where the fire was very hot. TP noted that cultural burning had slowed down two wildfires that came into Wattleridge IPA in 2019, but the combination of drought and severe fire meant that the Crown Mountain wildfire '*hit us pretty hard*'. LP spoke about the frequency of fire: '*Native* [plants] *love winba but not on a regular basis. You have got to give the time for everything to settle, move onto the next burn patch, then come back in another two or three years. Don't let your Country get sick again, but not burning too frequently. If you burn too much you will make it sick too, killing all the nutrients*.' The rangers intend to continue their cultural burning program, noting '*Us Banbai rangers have got the knowledge and the know-how to do it on our own property. Cultural burning is the way to go, you know your canopy and the old trees are going to survive if you do low-intensity* [low severity] *burns. It does the Country better, it doesn't take as long to come back, as it would with a wildfire*' (LP).

Collaborative ecological monitoring

The cultural burn undertaken by the Banbai rangers in 2015 was smaller, patchier and less intense than the hazard reduction burn undertaken by NPWS on neighbouring Warra NP in 2015 (Table 2). The cultural burn had negligible impact on the canopy, while the hazard reduction burn scorched 10% of the canopy. The overall fire severity of the cultural burn was low, while the hazard reduction burn was moderate. In comparison to the 2015 fires, the effect of the Crown Mountain wildfire was very severe. The wildfire was large and impacted 90% of the canopy. The bark char was higher and the fire effects were more uniform (98% burn coverage across all plots). In general, the three fires resulted in a similar decrease in fuel load (mean 10 t/ha) and the change in fuel load was significantly affected by time and treatment ($P < 0.001$; Fig. 3).

In 2016, 43% of the mature shrubs that were alive in pre-burn monitoring had died in the plots that were impacted by cultural burning (Fig. 4). In 2018 (3 years after cultural burning), the count of mature shrubs had increased 5-fold in the impact plots. The control plots showed negligible change. All plots were burnt by the Crown Mountain wildfire, after which (2020) mortality of mature shrubs was 99.6%: the total number of mature shrubs across all 400 m^2 plots was 277 in 2018, falling to 1 in 2020 after the wildfire. Mature shrub count was significantly affected by year, after wildfire ($P < 0.001$).

One year after cultural burning, grevillea seedlings increased from a mean count of 1.7 to 79.0 per 20 m^2 transect, but there was little germination in unburnt transects (Fig. 5; treatment × year interaction, $P = 0.017$). Three years after cultural burning, the mean count of grevillea seedlings had decreased to 29.8 per 20 m^2 in the impact transects, which was

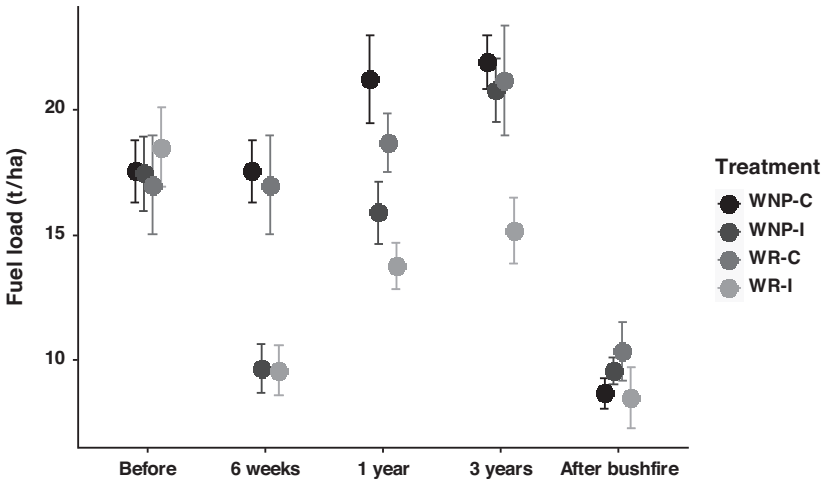

Fig. 3. Fuel load (t/ha) before and after (6 weeks, 1 year, 3 years) cultural and hazard reduction burning, and after wildfire in Wattleridge IPA (WR) and Warra NP (WNP) control (WNP-C and WR-C) and impact (WNP-I and WR-I) plots. Error bars indicate 95% confidence intervals.

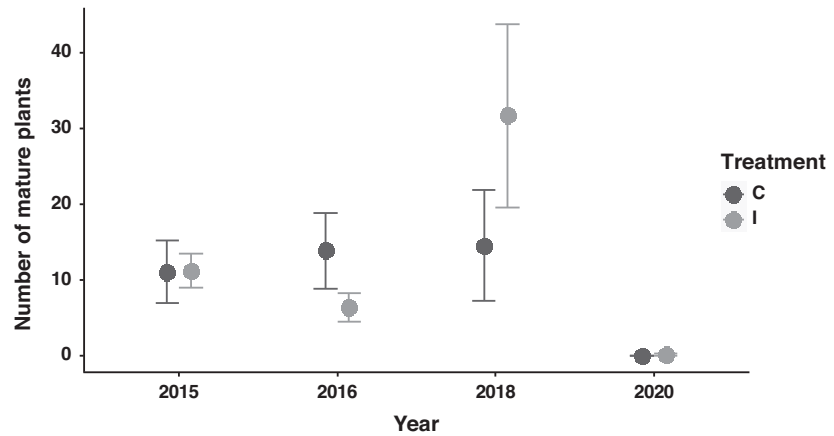

Fig. 4. Mean count of mature Backwater grevillea before (2015) and after (2016, 2018) cultural burning, and after wildfire (2020) in Wattleridge IPA control (C) and impact (I) plots. Error bars indicate 95% confidence intervals.

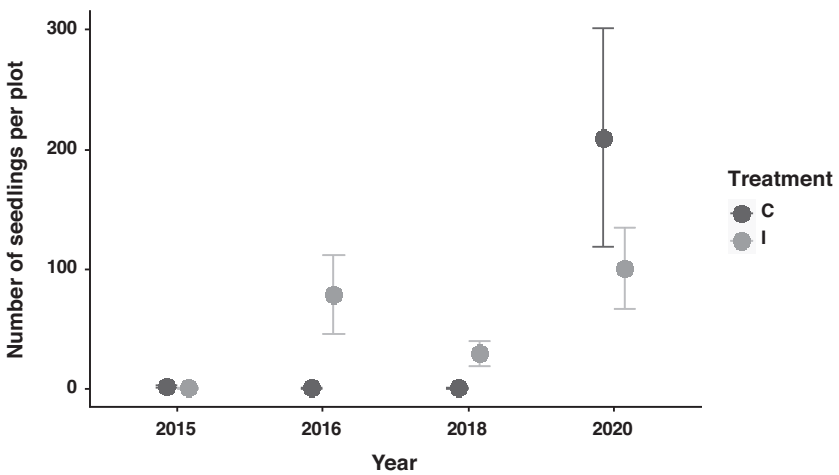

Fig. 5. Mean count of Backwater grevillea seedlings before (2015) and after (2016, 2018) cultural burning, and after wildfire (2020) in Wattleridge IPA control (C) and impact (I) transects. Error bars indicate 95% confidence intervals.

still an 18-fold increase from the pre-fire population. The control transects had negligible change with an average of 1.2 plants per 20 m^2. After all plots were impacted by the wildfire of 2020, the mean count of seedlings in control transects increased to 210.0 per 20 m^2 in the control transects, and to 100.8 in the impact transects (year, $P < 0.01$).

Prior to cultural burning, there were similar numbers of mature reproductive grevillea in the pre-burn impact (17 of 67 plants bore flowers or fruit, or 25% of the total number of mature plants) and control plots (18 of 66 plants bore flowers or fruit, or 27% of the total number of mature plants) (Fisher's Exact Test, $P = 0.85$). In the year after the cultural burn (2016), there was a significantly lower percentage of grevillea with flowers or fruit in the impact plots (3% of 38 mature plants) compared to the control plots (59% of 83 mature plants) ($P < 0.001$). Three years after cultural burning (2018), there was still a significantly lower percentage of mature shrubs reproducing in impact plots (27% of 190 plants) than in control plots (90% of 87 plants) ($P < 0.001$). After all plots were burnt in the wildfire, only one mature shrub remained in 2020 and it was re-sprouting and not reproductive. Across all transects in all plots in 2020, there were 1865 new seedlings (these were not suckers).

Discussion

In this study, we compared the fire effects of Indigenous cultural burning to a nearby hazard reduction burn, followed by an unforeseen wildfire. Results showed that the cultural burn was smaller, patchier (a mosaic of burnt and unburnt patches), less intense and less severe than the hazard reduction burn and wildfire. All fires resulted in a similar decrease in fuel load. We found that the cultural burn had a lower impact on mature Backwater grevillea survival compared to wildfire. The cultural burn created a multi-age population, with mature shrubs contributing to the seed bank and seedlings providing the next generation of grevilleas. While mass recruitment was observed following the fires, the high fire frequency (two fires in 4 years) is likely to have affected the seed bank. The cultural burn germinated many seeds, depleting the number available for germination after the subsequent wildfire, resulting in half as much recruitment in impact plots as control plots following the wildfire.

This study addressed several previous Backwater grevillea knowledge gaps. We found that obligate seeding was a far more prevalent fire response than resprouting. The wildfire stimulated more seedling recruitment in previously unburnt plots than the cultural burn, which may be due to heat penetrating deeper into the soil profile during the wildfire (Tangney *et al.* 2020). We also found that 3 years after the cultural burn, some of the grevilleas in the impact plots were able to complete their secondary or primary juvenile period, while others were not yet reproductive. However, the percentage of grevilleas reproducing was still minimal compared to the 90% in the control plots and we predict it will take longer for seedling maturation and to achieve a similar 'normal output' of seed rain after cultural burning. Recovery of the seed bank may have been depressed for longer than 3 years. We suggest that at least 50% of the grevillea population should be reproductive before the population is considered to have completed the secondary or primary juvenile period. Future research could include measuring the seed bank before and after fire, tagging plants to closely monitor fire response, maturation (PJP and SJP) periods and reproductive capacity (e.g. output of young plants cf. old-growth shrubs), as well as mapping and monitoring of grevillea populations in Warra NP, Mann River Nature Reserve and on private land. The findings of this study have parallels in other international contexts, such as in the US where rare, fire-dependent plants such as the Tecate cypress (*Hesperocyparis forbesii*) are vulnerable due to immaturity risk and fire–climate interactions that may impact their persistence in a future of climate change and altered fire regimes (Brennan and Keeley 2019).

The Backwater grevillea has a restricted distribution, which makes it vulnerable to one-off catastrophic events, although it was recently de-listed as a threatened species under the EPBC Act 1999. The Crown Mountain, Pinkett, Kangawalla and other wildfires (part of the 'Black Summer Fires' of 2019–2020) that burnt almost 19 million ha of south-east Australia (Filkov *et al.* 2020) had a catastrophic ecological impact across the majority of the grevillea's range. Future cultural burning regimes implemented by the Banbai rangers will need to be carefully timed to avoid depleting the seed bank of the grevillea while also balancing the mitigation of wildfire risk. The data collected through this study will guide the Banbai rangers in their adaptive management of Wattleridge IPA and should inform threatened species and protected area management plans. We recommend: identifying and protecting Backwater grevillea populations as a high priority; continued cross-cultural monitoring to inform adaptive management; a re-assessment of the conservation status of the Backwater grevillea; taking a more precautionary approach to the conservation of restricted and rare species; and consideration of compounding impacts such as climate change, drought and fire, as per the *Blueprint for a conservation response to large-scale ecological disaster* in Dickman *et al.* (2020).

The Banbai rangers concluded that cultural burning was the best fire management for conservation of the Backwater grevillea as the low severity burning stimulated establishment of new seedlings but did not kill all of the mature shrubs. Following the cultural burn, the Banbai rangers said that the grevillea population was healthy because 'they reproduce flowers and seeds every year'. They noted that cultural burning slowed down the wildfire, but due to drought and extreme fire conditions, Wattleridge IPA was still impacted. The Banbai rangers compared the low-intensity, patchy nature of cultural burning to the severe, destructive nature of wildfire. While these are early findings and continued evaluation may lead to different understanding, our initial collaborative ecological monitoring results concurred with the Banbai rangers' observations. As research in northern Australia has shown (Ansell and Evans 2020), the Banbai cultural burn resulted in a decrease in fuel load but was less severe than the hazard reduction burn and wildfire.

Prior to the extreme wildfire weather of 2019–2020, the Banbai rangers were only able to implement a few cultural burns on Wattleridge, which although beneficial, were inadequate to provide landscape-scale wildfire risk mitigation. In future, an expanded cross-tenure cultural burning program could evaluate whether cultural burning reduces wildfire risk. Brazil's Integrated Fire Management program commenced in protected areas and Indigenous territories in 2014 and has already changed fire regimes in some areas, reducing wildfires and helping to protect fire-sensitive vegetation (Schmidt and Eloy 2020).

This study provided an opportunity to share the journey of the Banbai rangers as they care for their Country and the Backwater grevillea. Prior to the project, the Banbai rangers considered that they had limited knowledge about the grevillea and they were not aware of any traditional use or cultural significance for this plant. Their interest in the grevillea emerged because it was brought to their attention as a threatened species. When the Banbai rangers applied a cultural burn, they observed that it had some benefit for the grevillea, which they confirmed through cross-cultural monitoring. Through their monitoring of the grevillea, the Banbai rangers have become more confident with the application of cultural burning and concluded that cultural burning is the best fire management approach at Wattleridge IPA. It is sometimes assumed that Indigenous conservation requires application of traditional practices (Berkes *et al.* 1994; Colding and Folke 1997) or extensive biocultural, traditional ecological or Indigenous ecological knowledge, discussed in Thomassin *et al.* (2019). However, this assumption overlooks the revitalisation and/or evolution of cultural knowledge and how this contributes to cultural renewal (Bessarab and Ng'andu 2010). While interest in the grevillea may have been triggered by its scientific listing as Vulnerable, and the project progressed within a Western positivist-science framework, the decision to assume stewardship of the grevillea and apply a low-intensity fire regime was a *cultural* decision made by the Banbai based on burning having traditionally been part of a cultural approach to land management (even if it is not known how that was implemented). Through that process and through participating in an academic monitoring approach as a community, the Banbai have reconnected with the grevillea. They are now observing and understanding the grevillea's lifecycle (i.e. they are understanding its kinship), interacting with its needs and applying cultural burning (i.e. as part of their responsibilities for Country) and making decisions about the rule sets they will apply in future management (i.e. they are relearning and applying Backwater grevillea lore). As the Banbai learn more about the grevillea, the short-beaked echidna (spiny anteater or *Tachyglossus aculeatus*) (McKemey *et al.* 2019) and all other biophysical and cultural aspects of managing their Country (McKemey *et al.* 2021), they are re-awakening the Dreaming in that landscape. This project therefore documents an important part of cultural burning, which is cultural renewal. While this process may have been triggered and motivated by science, it nonetheless will be continued through a cultural paradigm that is motivated by the connection of Banbai with Country and the grevillea. This is a culturally driven approach (Hooper 2019; Ridges *et al.* 2020) to managing threatened species that benefits from management that is local and affords attention to detail and is based on a deep spiritual connection (similar to the basis of Indigenous fire management described in McKemey *et al.* 2020*a*; also see Mistry and Berardi 2016). This contrasts with the government-managed Warra NP, which is managed according to fire regimes determined centrally rather than locally, and managed by agency officers who are spread thinly, often under-resourced, time-poor and present onsite for only short periods as they work across the region-wide public park and reserve estate.

The relationship between biodiversity conservation and Indigenous land management is nuanced and complex (Garnett and Woinarski 2007; Nursey-Bray 2009; Leiper *et al.* 2018). Garnett and Woinarski (2007) explained that biodiversity in Australian law is a modern concept and threatened species conservation may be a collateral benefit of Indigenous landscape-scale land management. Some threatened species may appear to be insignificant to Indigenous people due to their rarity, lack of practical function or lack of spiritual significance in Indigenous culture. However, as noted here and by Garnett and Woinarski (2007), culture is ever-changing and it is conceivable that some threatened species have become important parts of Indigenous land management and cosmology. Our case study of the Backwater grevillea and its Banbai custodians provides an example where the Aboriginal community has adopted and integrated a plant into their cultural framework. By employing cross-cultural methods, they are conserving a threatened species using culturally-driven, holistic management, characterised by its local focus and attention to detail.

Conclusion

Through the use of a cross-cultural monitoring model, we accessed a dual (Indigenous and academic) toolbox (Hill 2003) to provide insight into the conservation of a threatened species. Comparison of fuel load changes resulting from cultural burning, hazard reduction burning and wildfire indicated that fuel loads were reduced by all fire treatments, although effects of the cultural burn were less severe than other fires. Cultural burning resulted in lower mature grevillea mortality and lesser impact on reproductive output than wildfire. Both fires stimulated a mass germination event, but the cultural burn preserved a multi-aged population while the wildfire killed 99.6% of mature shrubs. Our study concluded that cultural burning was the best fire management for conservation of the Backwater grevillea, ongoing cross-cultural monitoring is required to inform adaptive management and, in the aftermath of severe wildfire, management to protect Backwater grevillea populations is a high priority, as is a re-evaluation of the conservation status of the Backwater grevillea. The Banbai custodians play an important and ongoing role in the protection of this threatened species. Indigenous caring for Country projects are generally under-resourced (Hill and Williams 2009; Strelein *et al.* 2020) and their outcomes are ill-acknowledged (United Nations 2019; McKemey 2020). Yet, considering that Indigenous peoples manage 40% of the world's ecologically intact landscapes (Garnett *et al.* 2018), effective monitoring and adaptive management is critical to the ongoing survival of biological and cultural diversity.

Ethics statement

Research was conducted under the University of New England Human Ethics approval HE14–182 and 19–068.

Conflicts of interest

The authors declare no conflicts of interest.

Declaration of funding

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