Received: 30 May 2024 | Revised: 17 November 2024 | Accepted: 26 November 2024

DOI: 10.1002/bod2.12025

ORIGINAL ARTICLE

Ecological dynamics in *Banksia aemula* woodlands following widespread, anthropogenic wildfires on a world heritage listed island (K'gari), Australia

Elizabeth Brunton[1] | **George Anderson**[1,2] | **Grahame Applegate**[3] | **Linda Behrendorff**[4] | **Aaron Brunton**[1,2] | **Rachel Killer**[4] | **Robert Lamont**[1,2] | **Sarah Orchard**[1,2] | **Gabriel Conroy**[1,2]

[1]School of Science, Technology and Engineering, University of the Sunshine Coast, Sippy Downs, Queensland, Australia

[2]Centre for Bioinnovation, University of the Sunshine Coast, Sippy Downs, Queensland, Australia

[3]Tropical Forests & People Research Centre, University of the Sunshine Coast, Sippy Downs, Queensland, Australia

[4]Queensland Government Department of Environment, Science and Innovation, Queensland Parks, and Wildlife Service, K'gari, Queensland, Australia

Correspondence
Elizabeth Brunton.
Email: ebrunton@usc.edu.au

Abstract

The increased severity and frequency of wildfires are a growing threat to biodiversity globally posing a complex challenge for the management of protected areas. K'gari, a World Heritage-listed sand barrier island located off the coast of Australia, was extensively burnt in wildfires in 2019 and 2020. *Banksia aemula* low open woodland (BALOW) is a fire-adapted ecosystem, and *Banksia aemula* is the dominant vegetation type on the island. This research explored interactions between vertebrate fauna and flora species richness and structure after fires in the BALOW habitat. We employed camera trapping and vegetation surveys to estimate species richness and habitat structure. We detected 28 fauna and 56 plant species, including two vulnerable species. Fauna species richness differed between sites; the site with the most intense, extensive, and recent fire had the lowest fauna species richness and mammal species richness. In contrast, the site with lower intensity and more frequent historical fires had the highest fauna diversity. The long unburnt site had higher overall tree diversity and reduced shrub diversity. This research further highlights the need for evidence-based fire management in protected areas and the risk that large-scale and/or high-intensity fires may pose to biodiversity even within fire-adapted ecosystems.

KEYWORDS
camera trap, fire ecology, fire impact, Fraser Island, protected area management, world heritage

Highlights

- We employed camera trapping and vegetation surveys to estimate faunal and floral diversity and structure in *Banksia aemula* low open woodland, following extensive wildfires.
- This research provides an important biodiversity baseline for the dominant ecosystem on World Heritage-listed K'gari, a sand barrier island located off the coast of Australia, identifying 57 flora species and 28 vertebrate fauna species.
- This research further highlights the need for evidence-based fire management in protected areas and the risk that large-scale and/or high-intensity fires may pose to biodiversity even within fire-adapted ecosystems.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2024 The Author(s). Biological Diversity published by John Wiley & Sons Australia, Ltd on behalf of South China Botanical Garden (SCBG), Chinese Academy of Sciences (CAS).

1 | INTRODUCTION

1.1 | Fire and biodiversity in Australia

Biological diversity is diminishing at an alarming rate, largely due to the direct and indirect actions of a rapidly growing human population and the onslaught of the Anthropocene.[1,2] Whilst human-mediated habitat loss, fragmentation and degradation impose significant impacts on biodiversity, the modification of nutrient, hydrological and fire regimes also present substantial threats to biodiversity conservation.[3]

Fire is an important ecological disturbance mechanism in many terrestrial biomes globally, and the importance of fire to many Australian plant species and ecosystems is evident.[4–6] Many Australian plant taxa have life-history aspects relating to the repeated occurrence of fire and other disturbances, and as such, fire regimes play a crucial role in maintaining biodiversity.[7–10] Elements of many plant species' reproductive cycles (e.g. obligate postfire flowering [Lamont and Downes[11]]) or fire-stimulated germination for obligate seeders,[12,13] and thus population recruitment, are dependent on appropriate fire regimes.[14] Fire regimes also influence biodiversity by regulating intra- and interspecific competition and nutrient cycles.[15]

Sclerophyllous taxa, which are high in oil content and hence, flammable, are currently the dominant flora type throughout Australia.[16] However, there is evidence indicating the historical presence of fire in Australia and its influence as a selection pressure on the continent's biota over an extensive period.[17] The anthropogenic manipulation of fire regimes in Australia and the tangible influence of humans on the Australian landscape is generally considered to have commenced approximately 40–50,000 years BP, coinciding with the migration of First Nations peoples to the continent.[18] By the commencement of the Holocene Era (approximately 14,000 years ago), the influence of First Nations peoples on the Australian landscape included an era of increased fire frequency throughout the continent, and it is proposed that this shift towards more frequent burning solidified the dominance of fire-adapted species and ecosystems.[19] During the late Holocene, the intensification of anthropogenic burning along the east coast of Australia including coastal islands such as K'gari and their allied mainland systems (such as the Cooloola sand mass),[20,21] coupled with the progressively deepening aridity of the continent, has had a major influence in shaping the contemporary form of many ecosystems, such as wallum heathlands and associated Banksia woodlands.[19] The fire management strategies historically employed by First Nations peoples in Australia, termed cultural burns, were diverse, dynamic and seasonally determined, resulting in broad patch-mosaic burning patterns. The use of controlled, often smaller fires (often of cooler intensity) created a diversity of habitat types and fire histories throughout the landscape.[22,23]

The predominant fire management ethos on mainland Australia which followed European settlement (approximately 220 years BP), was mostly one of fire suppression to protect human lives, property and livestock/agriculture.[21] This approach was highly detrimental as the resultant build-up of fuel meant that when fires did occur, they were of high-intensity, severity and/or extent.[24] Whilst recent decades have seen increased intention to reintegrate burning regimes that promote biodiversity at a landscape scale and are sometimes more reflective of seasonal cultural burning practices, the legacy of postcolonial fire management through much of the Australian continent can make this challenging to impart on a contemporary landscape. When coupled with severe weather conditions relating to human-mediated climate change, recent years have yielded widespread, catastrophic wildfires, such as the Australian Black Summer megafires in 2019–2020, when 19 million hectares of natural vegetation burnt in hot, large fires.[25–27] The scale and intensity of these fires across affected regions were unparalleled in recorded history.[28] Whilst much of the burnt estate was on mainland Australia, some coastal islands, also experienced large-scale fires, although significant work remains to fully quantify the magnitude of these impacts. As climate change is expected to continue to contribute to exacerbating fire conditions,[29] it is imperative that we further our understanding of the response of Australian species and ecosystems to fire, many of which are understudied.

1.2 | Flora and fauna responses to fire

Vertebrate faunal species' responses to fire regimes can vary in duration and have been observed to contrast widely according to class, life history strategies, population demographics, ecology, habitat structure and variability, and fire regimes.[30–32] A global meta-analysis on the responses of fauna to fire confirmed variations at the class level, and highlights that wildfires can negatively influence the abundance, biomass, diversity, evenness and richness of fauna.[33] However, most of the studies considered in the review were in forests and focused on North America and Europe. In a review on the impact of fire on small vertebrate species in mallee woodland and heathlands of temperate Australia, Friend[30] identified shelter and foraging requirements as key predictors of abundance and distribution of small vertebrates following fires, in the time immediately following the fire and in early succession stages. More recent studies also highlight the importance of habitat structure on the postfire recovery of fauna and flora, including the value of habitat refuges for survival during and postfire.[34–36]

Due to the many factors that influence the response of fauna to fire, land managers of protected areas face a complex task when developing fire regimes that are designed to conserve both flora and fauna and their required habitats. It is evident that more research is needed to inform fire management regimes for protected areas, which consider priority species' life history strategies and adaptations, as well as flora and fauna community interactions under different fire regimes. In a recent global review, Jolly et al.[37] demonstrated that the proportion of wildlife mortality increases during higher intensity fires. Similarly, in a synthesis of fire-driven declines of threatened mammals in Australia,[38] most were threatened by unsuitable fire regimes, particularly in terms of high-intensity, high frequency and large-scale fires.

It has become increasingly acknowledged that a shift back towards fire regimes reminiscent of cultural burning practices can create a patch-mosaic fire landscape with inherent variability, which is somewhat synonymous with the concepts of pyrodiversity and patch-mosaic burning.[39] This approach reduces the risk of higher intensity, widespread fires and thus minimises risk factors whilst

enhancing biodiversity outcomes, although there are logistical, political and bureaucratic barriers that currently compromise widespread readoption of cultural burning practices.[40] in Australia. The benefits of pyrodiversity to create spatiotemporal variability in patch fire history is supported by previous research in Banksia woodlands in the Mediterranean climate (dry summers–wet winters) of southwestern Australia.[36,41] However, Banksia woodlands in subtropical central eastern Australia, which are considered fire-dependent systems, have had little research attention. *Banksia aemula* low open woodland (BALOW—Regional ecosystem 12.2.9) occurs mostly on sand islands off the coast of southern Queensland and supports a variety of threatened plant and animal species.[42] BALOW is well-represented in protected areas, encompassing 16 protected areas in Queensland, including the Great Sandy National Park on World Heritage-listed K'gari.

During the Black Summer megafires in Australia (2019–2020), K'gari experienced widespread wildfires. In 2020, during one single fire event (the 'Duling' wildfire), 46% of the island burnt (essentially the northern half of K'gari) with 82% of the BALOW impacted, and almost 50% experiencing high to extreme relative fire severity.[43] This followed a previous large-scale wildfire (lightning-ignited) on the southern end of the island in the preceding summer (2018/2019). Following these events, in 2021, vegetation survey plots were assessed by the Queensland Herbarium to estimate the vegetation recovery on the island after the 2019/2020 fires. The survey only assessed two BALOW sites, both of which were reported to be in good condition, with slightly lower canopy heights, less coarse woody debris (CWD), and lower shrub species richness than the benchmark for this regional ecosystem.[44] However, there are to date neither published studies assessing the vertebrate fauna composition of this habitat type nor the postfire ecosystem dynamics of BALOW ecosystems and the flora and fauna that they support. This information is vital to refining any fire management strategy for this habitat and informing its conservation within the World Heritage estate on K'gari and in other protected areas.

Therefore, in this study, we aimed to explore interactions of fauna and flora species richness and habitat structure following large-scale fires in BALOW habitat by

i) Assessing the diversity and structure of vegetation of sites with differing fire histories.
ii) Assessing and comparing vertebrate species and class richness at the same sites.
iii) Interpreting flora and fauna species composition and structure, in the context of varying fire regimes.

2 | METHODS

2.1 | Study site and experimental design

K'gari is a coastal barrier sand island, situated within the Great Sandy Strait (Korrawinga) region of southeast Queensland and covers around 160,000 ha.[45] The island constitutes a significant part of the ancestral lands of the Butchulla people, who are the Traditional Custodians of K'gari island who managed the landscape prior to European occupation.[45] The island has a prevailing subtropical climate with a variety of vegetation types including heathlands and wallum, open and closed forests dominated by trees from the Myrtaceae family, mangrove communities on the west coast and vast areas of foredune complexes along the east coast. Climate data taken from the Sandy Cape Lighthouse indicates an average of 1267 mm of rainfall annually mostly occurring during the summer wet season, with an average yearly temperature ranging from a maximum average of 26°C to a minimum average of 19°C.[46]

There are 20 mapped regional ecosystems on K'gari[47] harbouring more than 800 species of flowering plants and ferns.[48] Our focal ecosystem (Regional Ecosystem 12.2.9) is commonly known as '*Banksia aemula* low open woodlands' (BALOW)[42] and is the dominant ecosystem on K'gari covering about 47,000 ha, or 29% of the island. While BALOW also occurs on the mainland from south of Rockhampton in QLD to Newcastle in NSW,[49] the communities on K'gari are significant in terms of their substantial extent at the northern end of the system distribution, alongside high representative protection within national park tenure. BALOW occurs on sandy podzols on recent dune formations as well as those aged in excess of 500,000 years[48,50] and is generally characterised by having an upper tree canopy composed most frequently of *B. aemula* and *Eucalyptus racemosa*. In areas that have been unburnt for a long period of time, *Allocasuarina littoralis*[51] is often also present, whilst the shrub and herb layer is relatively diverse with dominant species including *Ricinocarpos pinifolius*, *Leptospermum trivernium*, *Melaleuca nodosa*, *Aotus ericoides*, *Strangea linearis*, *Platysace linearifolia*, *Pteridium esculentum*, *Xanthorrhoea johnsonii* and *X. fulva*, with some sites also containing fire-dependent threatened species such as *Acacia baueri*.[52,53]

As Traditional Custodians of the island, Butchulla continue to assert their identity and connection with their traditional homelands, with both the land and seascapes being of intrinsic importance to the well-being of Butchulla society. In 2014, the Butchulla Aboriginal Corporation (BAC) became the Registered Native Title Body Corporate for K'gari, and in 2019, the Butchulla Native Title Aboriginal Corporation was also granted native title in adjacent mainland areas, surrounding waters and up to the high-water mark on K'gari. In the BAC's ongoing role as Traditional Custodians, they seek to manage future fire regimes on K'gari in line with their traditional culture and customs.[54] Existing fire management guidelines for BALOW are for mosaic burns of moderate intensity to occur throughout 40%–60% of the current extent every 8–15 years.[47] These fire intervals are aimed at allowing for the survival of obligate seed regenerating species and avoiding a reduction in species richness.[47] Current understanding of this habitat type suggests that ideal management should include reducing the risk of large-scale fires and reducing the extent of high to extreme fire severity.[43,55]

2.2 | Site selection and fire history

From mid-October to late December 2020, an extensive wildfire (hereafter referred to as the 2020 or Duling wildfire) on the northern end of the island burnt 82% of the island's BALOW habitat, 50% of which experienced high to extreme relative fire severity.[43] Approximately 12 months prior to this event (hereafter referred to as the 2019 fire event), approximately 20% of the southern end of the island was burnt, also comprising some areas of BALOW. We therefore

used BALOW sites in the northern and southern regions of the island to represent differing recent fire histories, alongside a long unburnt site as a control, essentially resulting in three distinct fire history treatments (Figure 1, Table 1). Fire history for each site was obtained from FLAME, the Queensland Parks and Wildlife Service (QPWS) fire data recording system.

The sites are latitudinally similar in terms of climatic conditions, and also have the same geologic substrate and soil type. The long unburnt control site (Wanggoolba) was adjacent to Wanggoolba Creek on the central western side of the island and had not burnt for close to 30 years (Table 1). The second site (Yankee Jack) was located in close proximity to Yankee Jack Lake on the southwest of the island and was burnt in the 2019 fire (Table 1). Nearby BALOW vegetation monitoring plots reported moderate fire intensity in the area with more patchy fire than the northern 2020 fires and tree mortality of 5%–25%.[44] The third site was adjacent to Woralie track on the

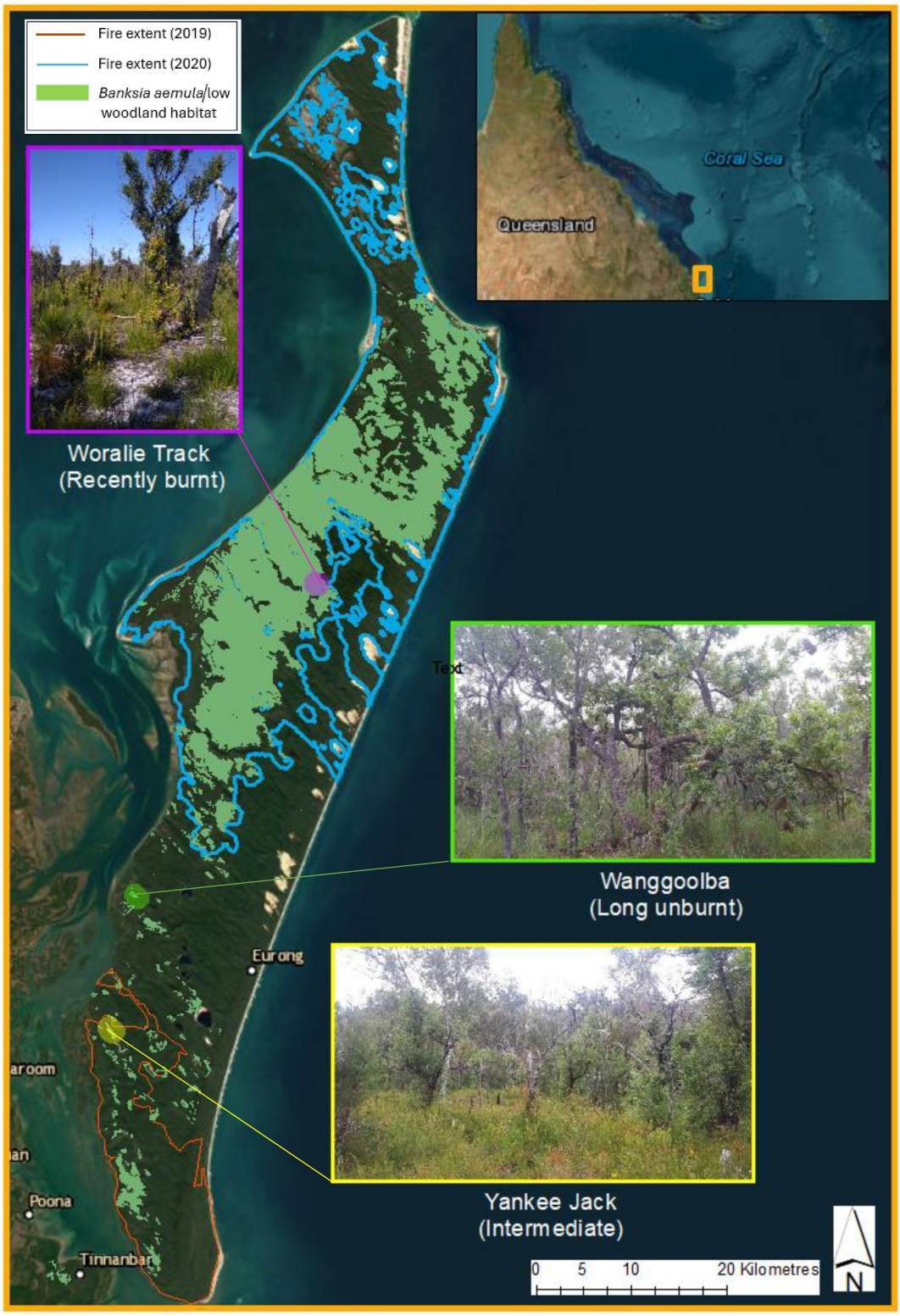


FIGURE 1 Vegetation and camera trap study site locations, fire treatments and approximate extent in *Banksia aemula* low woodland habitat (green shading) on K'gari, Queensland, Australia. Extents of recent wildfires are outlined in orange (2019) and blue (2020).

TABLE 1 Fire history of three study sites on K'gari, showing time since fire (TSF) at two sampling periods and the number of fires in the 20 years prior to initial sampling (T20).

Site location	Most recent fire history classification (timing and intensity)	Date of last fire	TSF in 2021 (months)	TSF in 2022 (months)	T20
Woralie track	Recently/intensely burnt	October 2020	9	21	2 (2020, 2006)
Yankee Jack	Intermediate/lower intensity	November 2019	22	34	3 (2019, 2015, 2009)
Wanggoolba	Long unburnt	August 1992	347	359	0

Abbreviation: TSF, time since fire.

central northern part of the island, and burnt in the most recent, high-intensity fire in 2020.[43] For simplicity, we refer herein to the three sites in terms of their most recent fire history in terms of timing and intensity: long unburnt (control, Wanggoolba), intermediate (last burnt in 2019, lower intensity fire, Yankee Jack) and recently/intensely burnt (last burnt in the 2020 Duling wildfire, Woralie track) (Table 1).

2.3 | Vegetation surveys

2.3.1 | Fire severity, vegetation structure and species richness

Two rounds of vegetation surveys took place, first in September 2021 and again in September 2022. During the first surveys, as a further indicator of fire severity (in addition to QPWS fire records), we measured burn height (m, maximum height at which bark displays burn marks) for each *B. aemula* tree present within our plots at the intermediate and recently/intensely burnt sites.

To assess the diversity and structure of vegetation at both time points and at all sites, we measured attributes commonly collected in a standardised BioCondition survey method using a nested quadrat system around central transect lines.[56] Species richness was recorded at an overall scale of 500 m^2 per site by utilising a 4-m wide belt transect along the first 125 m of overall transect length. Species were classified in situ, using field guides where necessary, and according to descriptions in Applegate.[48] Tree canopy cover and overall shrub cover were measured across 200 m of overall transect length, using the line intercept method.[57] Ground cover was measured using 10 × 1 m^2 quadrats at 10-m intervals along the central transect lines. Percentages were estimated for bare ground, small shrubs (<1 m), litter and grasses/forbs. The magnitude (length) of CWD was measured using a belt transect over a 200-m^2 area as per Eyre et al.,[56] with CWD defined as all fallen timber that was more than 80% in contact with the ground, as well as >0.5 m in length and >10 cm in diameter.

2.4 | Fauna surveys

To assess vertebrate species and class richness, cameras were passively (no bait) deployed across the three sites (Figure 1), with 10–12 camera stations per site, over two trapping periods in two consecutive years (2021 and 2022). Deployment was carried out simultaneously with the vegetation surveys and was not randomised due to several site-based limitations, including avoiding human presence on roads and walking tracks and ensuring placement in BALOW vegetation within proximity to the vegetation survey areas. At each site, camera stations were positioned along two transects, with each station approximately 100 m apart and one camera deployed per station (2 × 5 or 2 × 6 grid). This layout allowed the maximum distance apart that cameras could be positioned, in order to ensure alignment with the vegetation survey areas, which were limited to small spatial extents. Cameras were attached to a tree stem or a log, 40–50 cm above the ground and where possible were focused on a log, tree or area with evidence of animal presence for example, scats or diggings. Cameras were positioned south facing to reduce glare, and vegetation at the station was cleared or restrained to reduce the likelihood of false triggers.

Three types of cameras were used in the study: Bestguarder SG-990, Browning BTC-6PXD and EnduroSwift, and were configured to equivalent settings. Camera brands were spread as close to equal as possible across sites, in order to minimise bias in fauna detection. Cameras were configured to photo mode using an infrared flash, normal PIR trigger, three to five photos per burst and with minimal delay (0–1 s) between triggers. Cameras were deployed at all three sites for an approximately 3-week period, during August/September of 2020 and 2021 (576 and 764 trap nights, respectively).

2.5 | Data analysis

2.5.1 | Camera data management

Following camera collection, images were classified and tagged using digiKam (Version 7.7.0). Where possible, each animal was identified at the species level using taxonomic guide books and online sources. If the animal in the image could not be identified to a species level, identification was made to the lowest possible taxonomic level. At least, two people independently identified each image, and if consensus was not able to be reached on the identification, the image was excluded from analysis. Each image was tagged with the taxonomic metadata, while camera set-up and false trigger (no animal visible) images were tagged accordingly. Five cameras were deployed in video mode instead of photo mode. For the stations with video data, a still image snapshot was taken when an animal was identified and tagged with the relevant metadata. The cameratrapR package[58] and software ExifTool (2016) were used to extract image metadata and merge site and deployment information, summarise trapping efforts and create summary data tables. We classified images as

independent when they were taken more than 15 min apart from any other image on the same camera.

2.5.2 | Statistical analysis

All statistical analyses were conducted using jamovi (Version 2.3.0). We performed Kruskal–Wallis tests (nonparametric) to assess for differences between sites in median fauna species richness, mammal species richness, bird species richness and reptile species richness. We used Dwass-Steel-Critchlow-Fligner pairwise comparisons for multiple comparisons between sites. A Mann–Whitney *U* test was also applied to determine potential differences in burn height between the two burnt sites. Normality was assessed using a Shapiro–Wilks test ($p < 0.01$).

3 | RESULTS

3.1 | Flora surveys

3.1.1 | Fire severity

The mean burn height of trees was significantly higher ($U = 3.135$, $p < 0.01$) at the recently/intensely burnt site ($\bar{x} = 2.4$ m, $s = 1.16$ m), with mean burn height three times greater than at the intermediate site ($\bar{x} = 0.85$ m, $s = 0.5$ m).

3.1.2 | Structure and species richness

Fifty-six flora species were identified across all sites over 2 years (15 trees, 32 shrubs, three grasses and six forbs), including one vulnerable species, *A. baueri*, which was only found at the burnt sites (Table S1). Grass and forb richness were uniformly low for all sites across both years (Table 2). Tree species richness was relatively stable between years, but on a site basis, tree species richness was higher at the long unburnt site than both the intermediate and recently/intensely burnt sites, with the inverse true although less pronounced, for shrub richness (Table 2, Figure 2).

CWD was highest at the long unburnt site, with the recently/intensely burnt site having the least (Table 2, Figure 2). Canopy cover was also highest at the long unburnt site and was fairly uniform between years for all sites and between the two burnt sites (Table 2, Figure 2). Shrub cover had more inter-year variability, increasing at all sites from 2021 to 2022, with a fourfold increase at the recently/intensely burnt and a nearly twofold increase at the intermediate site, which also had the most shrub cover across all sites and years in 2022 (Table 2, Figure 3). In terms of ground cover attributes, overall shrub cover increased within each site between 2021 and 2022, which for the burnt sites resulted in a commensurate decrease in bare ground (Figure 3). Additionally, both burnt sites consistently had higher proportions of bare ground than the long unburnt site, which had negligible bare ground (Figure 3).

The highest cumulative total flora species richness was found at the long unburnt site ($n = 39$), with the burnt sites having lower and similar overall species richness ($n = 26$ and $n = 27$, respectively).

TABLE 2 Summary of vegetation structure and species richness for three sites, sampled in 2021 and 2022, on K'gari, Queensland, Australia.

Site	F_{20}	Survey year	Time since fire (month)	Burn height (m)	CWD (m/ha)	Canopy cover (%)	Overall shrub cover (%)	Ground cover (%)				Species richness (in 500 m^2)				
								Grasses and forbs	Shrubs <1 m in height	Litter	Bare ground	Trees	Shrubs	Grasses	Forbes and vines	Total species
Woralie track	2	2021	9	2.4	90	25.2	15.9	4.5	8.2	57.3	30	4	14	0	0	18
		2022	21	N/A	90	25.5	63.1	0	49.5	37	13.5	3	11	1	2	17
Yankee Jack	3	2021	22	0.85	180	29.9	45.3	5.8	9.3	35	50	3	10	0	0	13
		2022	34	N/A	100	30.3	84.7	0	60	24	16	2	14	0	2	16
Wanggoolba Creek	0	2021	347	N/A	1520	65	39.2	2.5	14.8	82.7	0	10	9	2	2	23
		2022	359	N/A	945	69	49.9	8.5	42	47.5	2	8	6	3	2	19

Abbreviation: CWD, coarse woody debris.

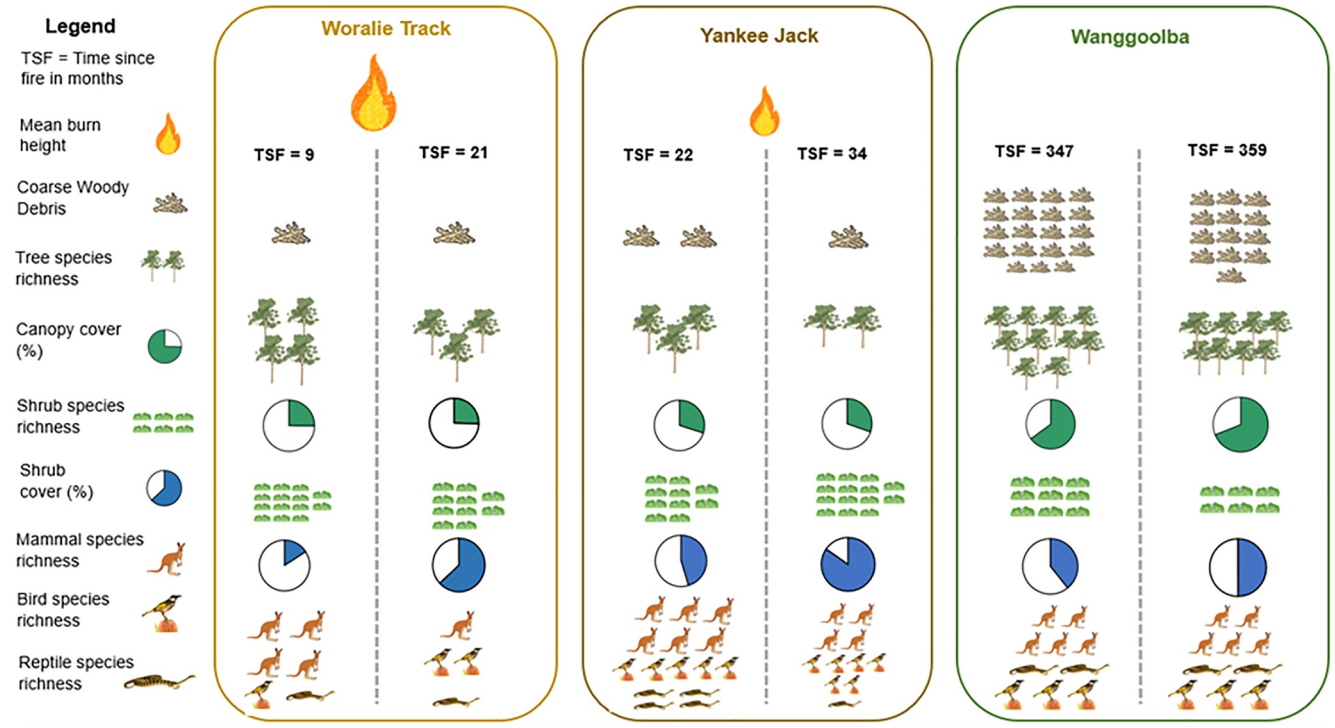


FIGURE 2 Pictographic summary of fauna and flora species richness and structure at three sites of *Banksia aemula* woodland with varying fire histories, sampled in both 2021 and 2022 (recently burnt—Woralie track, intermediate—Yankee Jack and long unburnt—Wanggoolba) on K'gari, Queensland, Australia.

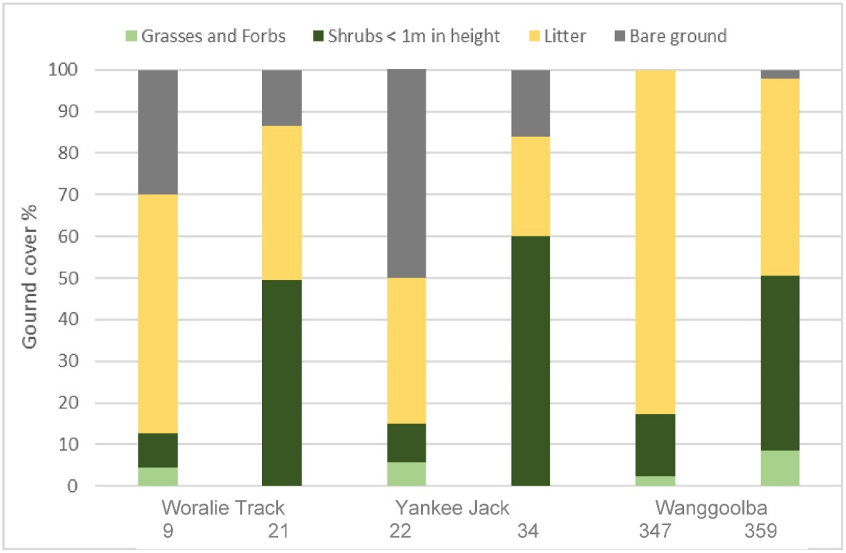


FIGURE 3 Ground cover proportions at three sites of *Banksia aemula* woodland with varying time since fire (months) in 2021 and 2022 on K'gari, Queensland, Australia (recently burnt—Woralie track, intermediate—Yankee Jack and long unburnt—Wanggoolba).

Tree species richness was highest at the long unburnt site, whilst cumulative shrub species richness was similar between sites but lowest at the long unburnt (Figure 2), and grass and forb cumulative species richness was low for all sites (Table 2).

3.2 | Fauna surveys

A total of 1340 trap nights (2021: $n = 576$ and 2022: $n = 764$) across all sites identified 28 vertebrate species in total (10 mammals, eight reptiles and 10 birds) including one vulnerable species, *Potorous tridactylus* (Table 3). One invasive species was detected, *Felis catus*: one cat in 2021 and three cats in 2022, and all were found at the intermediate site only.

At the recently burnt site, 0.032 independent images per trap night of identified species were acquired. The intermediate and long unburnt sites had much higher, and similar, counts of independent images, with 0.152 and 0.157 images/trap night, respectively. The total number of independent images/trap night across all sites was lower in 2022 (0.086) than in 2021 (0.149) and total species richness was higher in 2021 ($n = 21$) than in 2022 ($n = 16$) (Figure 4). Only three species were present at all three sites: *Antechinus flavipes* (10 independent captures), *Colluricincla harmonica* (9 independent captures) and *Wallabia bicolor* (12 independent captures).

TABLE 3 Vertebrate fauna species detected by passive camera traps in 2021 and 2022, at three sites with varying fire histories on K'gari, Queensland, Australia (recently burnt—Woralie track, intermediate—Yankee Jack and long unburnt—Wanggoolba).

			Presence at site (yes or no). Number of stations per site each species was detected at in 2021/2022 shown in brackets		
Class	**Common name**	**Scientific name**	**Recently burnt**	**Intermediate**	**Long unburnt**
Bird	Brown thornbill	*Acanthiza pusilla*	N	Y (0/2)	N
Bird	Australian owlet-nightjar	*Aegotheles cristatus*	N	Y (1/0)	Y (1/0)
Bird	Grey shrike-thrush	*Colluricincla harmonica*	Y (1/1)	Y (1/1)	Y (1/2)
Bird	Bar-shouldered dove	*Geopelia humeralis*	N	Y (2/1)	Y (1/2)
Bird	Painted buttonquail	*Turnix varius*	N	Y (3/3)	N
Bird	Sulphur-crested cockatoo	*Cacatua galerita*	Y (0/1)	N	N
Bird	Eastern yellow robin	*Eopsaltria australis*	N	Y (0/1)	Y (0/1)
Bird	White-cheeked honeyeater	*Phylidonyris niger*	N	Y (0/2)	N
Bird	Eastern whipbird	*Psophodes olivaceus*	N	Y (0/1)	N
Bird	Fairywren	*Malurus* sp.	N	Y (1/0)	N
Mammal	Feathertail glider	*Acrobates phygmaeus*	N	N	Y (1/0)
Mammal	Yellow-footed antechinus	*Antechinus flavipes*	Y (1/0)	Y (1/2)	Y (2/0)
Mammal	Cat	*Felis catus*	N	Y (1/2)	N
Mammal	Northern brown bandicoot	*Isoodon macrourus*	N	N	Y (1/2)
Mammal	Long-nosed bandicoot	*Peramales nasuta*	N	Y (2/0)	N
Mammal	Long-nosed potoroo	*Potorous tridactylus*	N	Y (2/1)	Y (3/3)
Mammal	Bush rat	*Rattus fuscipes*	N	Y (1/0)	Y (3/4)
Mammal	Slender-tailed dunnart	*Sminthopsis murina*	Y (1/0)	N	N
Mammal	Swamp wallaby	*Wallabia bicolor*	Y (1/1)	Y (3/5)	Y (0/2)
Mammal	Fawn-footed melomys	*Melomys cervinipes*	N	N	Y (0/1)
Reptile	Comb-eared skink	*Ctenotus* sp.	N	Y (2/0)	N
Reptile	Green tree snake	*Dendrelaphis punctulatus*	N	Y (1/0)	N
Reptile	Dragon	*Diporiphora* sp.	Y (0/1)	N	N
Reptile	Major skink	*Egernia frere*	Y (1/0)	N	Y (2/1)
Reptile	Garden skink	*Lampropholis* sp.	N	Y (1/0)	N
Reptile	Lace monitor	*Varanus varius*	N	Y (0/5)	Y (5/3)
Reptile	Snake	Unidentified snake 1	N	Y (1/0)	N
Reptile	Snake	Unidentified snake 2	Y (1/0)	N	N
	Total species richness (2021 + 2022)		8	20	13

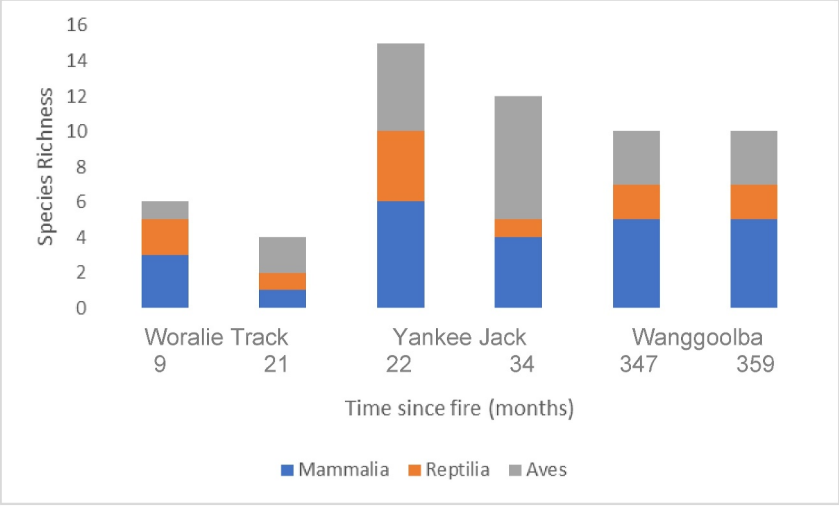


FIGURE 4 Vertebrate fauna species richness by class for three sites with varying fire histories, sampled in both 2021 and 2022 (recently burnt—Woralie track, intermediate—Yankee Jack and long unburnt—Wanggoolba).

Overall median fauna species richness was significantly different between the three sites ($\chi^2 = 14.07$ and $p < 0.001$) (Figure 4), with species richness lower at the recently burnt site than the intermediate ($p = 0.001$) and long unburnt ($p = 0.003$) sites. Total cumulative fauna species richness (i.e. over 2 years) was significantly lower at the recently burnt site ($n = 8$) than at the intermediate ($n = 20$, including one invasive species) and long unburnt sites ($n = 13$). Mammal species richness was lower at the recently burnt than at the long unburnt site ($p = 0.041$). A difference in bird species richness was observed between the recently burnt and long unburnt sites ($\chi^2 = 4.84$, $p = 0.047$). There was no significant difference in reptile species richness observed between sites ($p > 0.15$) (Figure 4).

4 | DISCUSSION

This study provides insights into interactions between fire history and ecosystem dynamics and flora and faunal diversity/assemblage in BALOW habitat that are valuable for guiding management on K'gari and elsewhere. This is of importance, given the World Heritage significance of this landscape and the context of the Duling wildfire being one of many extraordinary fire events throughout Australia during the Black Summer megafires of 2020. One of the challenges of quantifying the impacts of wildfires can be the lack of baseline, prefire data. In our study, while prefire data were lacking in our target ecosystem, we were able to utilise data from a long unburnt BALOW site on K'gari, which provided invaluable context to our results in both burnt sites. The availability of only one 'control' site (unburnt) was a limiting factor and meant that to maintain a balanced survey design without resorting to pseudoreplication, we surveyed only one 'intermediate' site (longer time since the 2019 fire) alongside one recently and intensively burnt site from the Duling wildfire. Despite the imposition of these unavoidable real-world limitations, these sites provided balance in terms of ecosystem type, climate, geology (substrate) and soil type, and our approach yielded illuminating data to underpin management.

Our data presented here (burn height), in field observations and previous research,[43] show that the most recent fire (2020) at Woralie track was of higher severity and scale than the intermediate (Yankee Jack) site's most recent fire (2019). The high severity fire at that site was most likely partly a combination of the prevailing conditions and fire behaviour.[43] It was also potentially influenced by the occurrence of only two fires in the last 20 years, with the most recent fire interval being 14 years. In comparison to this fire regime, the Yankee Jack site had experienced three fires in the previous 20 years, with shorter inter-fire intervals. While fire intensity is the result of many dynamic factors, fire regimes involving longer inter-fire intervals may result in higher intensity fire due to increased fuel load in fire-prone habitats, although these relationships can be complex, variable and influenced by other factors.[59] Of note, the Woralie track site which experienced the high-intensity/severity fire, (partly as a result of the historical fire regime, but also due to fire conditions) also had the lowest amounts of CWD, and the lowest overall vertebrate species richness of all sites at both sampling periods, with mammals being most affected.

The rationale for employing multiple lines of evidence (flora structure and diversity and vertebrate species richness) in our study to examine the impacts of fire is validated, with the long unburnt site showing higher structural complexity and flora species richness yet no significant difference in faunal species richness compared to the intermediate burn site (Yankee Jack). The complexity of fire regime impacts on flora and fauna in BALOW on K'gari is well-illustrated by comparing the outcome from the higher-severity, most recent fire at Woralie track and the lower severity fire at the intermediate site (Yankee Jack) at a similar time since their last fire (21–22 months postfire respectively), whilst using the long unburnt site as a reference point. While the two sites had similar canopy cover, tree and shrub species richness and structure, the overall vertebrate fauna species richness was more than three times lower at Woralie track. Vertebrate species richness was also significantly lower at Woralie track at both time points than at both other sites. This may indicate that fire severity has a stronger influence on vertebrate diversity in BALOW on K'gari than time since the fire, although it is also important to note that the 2020 fire in the Woralie track region was also of far greater extent within BALOW than the 2019 fire at Yankee Jack. Additionally, the recently burnt (Woralie track) site is in a region of K'gari where vast swathes of BALOW dominate the landscape in the northern part of the island (Figure 1). In contrast, both the intermediate (Yankee Jack) and the long unburnt site (Wanggoolba) are smaller pockets of BALOW amongst a more complex ecosystem matrix (habitat diversity), which may also influence vertebrate diversity[60] as a range of feeding and shelter habitats are available in proximity to each of these sites. The differences in the surrounding habitat matrix are typical of the high habitat diversity on K'gari which results from a combination of many factors, such as dune age, topography and fire history.[45] Alongside habitat diversity in the surrounding matrix, the role of predation (from both native dingoes and feral predators such as cats) is worthy of future research on K'gari. These interactions are of particular interest because predation can be a key risk in recently/intensely burnt areas, with cover from predators being reduced immediately following fires[61,62] and the patterns of species richness observed in this study suggest that both fire severity and extent may play a significant role in vertebrate faunal response to fire in BALOW habitat.

There are two broad mechanisms through which depleted wildlife populations can recover from fire impacts: through in situ survival or recolonisation from ex situ populations. The intensity, fire frequency, time since the last fire and extent of current fires can influence both in situ survival of fauna,[63] particularly for species with poor mobility and recolonisation capabilities. Areas undergoing more frequent, larger extent or higher intensity fires are likely to have slower and/or lower levels of fauna recruitment.[37,38] In contrast, fire regimes comprising smaller scale patch-mosaic burning akin to cultural burning practices allow for many species to flee to areas adjacent to the fire for survival. We note the presence of small mammal species at this site which are likely to have survived the fire in situ.[64] However, the lower fauna species diversity at the recently/intensely burnt site may be in part due to the large extent of totally burnt areas and higher severity of the most recent wildfire; it is less likely that animals would have survived in situ, and there is a lower likelihood of recolonisation of animals from nearby areas which had an equivalent habitat type and recent fire history, as all BALOW habitats in this area were burnt.

CWD, provides important microhabitats for a range of terrestrial vertebrates.[65] The lack of CWD at the recently/intensely burnt site may be a product of the high fire severity that occurred in the most recent fire, which reduces the available habitat and shelter for surviving vertebrates postfire, particularly for reptiles and ground mammals. This is reflected in the lower reptile and mammal diversity found at this site than in the long unburnt site. Reptile presence and abundance are known to be affected by foraging and shelter requirements following fire,[30] yet reptile responses can vary widely between taxa.[31] In Banksia woodland in Western Australia, some species of snakes and lizards showed a strong response to fire, with higher abundance associated with a longer, fire-free period.[36] Additionally, in a study of reptile responses to fire in a variety of vegetation types in south-eastern Australia, many species' responses to fire were found to be linked more to vegetation structure and the composition of plant communities, rather than fire history alone,[31] highlighting the importance of a maintaining a structurally complex habitat.

The lower levels of CWD also make the more recently burnt sites in this study more susceptible to negative impacts on reptiles and mammals from future frequent and intense fires, as there will be fewer refuges available to enable in situ survival during, and immediately after large intense fires.[35] This highlights the importance of sufficient fire intervals as well as small-scale patch burns, to maintain habitat and provide refuges during and after fires, which support faunal abundance and diversity in this habitat.

Only two bird species were detected at the recently/intensely burnt site, each with one detection only: *Cacatua galerita* (omnivore) and *C. harmonica* (insectivore). The absence of nectivorous birds detected may reflect the higher percentage of dead Banksia trees (25%), which would result in a reduction in the availability of food for nectarivores, and the surveys were not conducted in key flowering periods. While there were slight differences detected in bird species richness at this site, there were no significant differences in overall bird species richness detected at other sites which may be due to the higher mobility of bird species than other vertebrate taxa. This is supported by previous research in Banksia woodland, which found that bird communities are adaptable to fire regimes, with the density of most bird species studied showing no response to fire regimes.[66] It should also be noted that the camera deployment in this study focused close to ground level and may have been biased towards ground-dwelling bird species. Notably, a study comparing point counts and camera trapping techniques for assessing understorey bird species richness in a variety of habitats found that both survey methods yielded similar results.[67] However, we note that some of the species present on our cameras were not ground dwelling, and predominantly feed in trees for example, white-cheeked honey eaters and sulphur-crested cockatoos, and that an arboreal mammals for example, feathertail glider, was also present. This demonstrates that tree-dwelling species were detected on our cameras, as well as those that feed both on the ground and on trees for example, owlet-nightjar and grey shrikethrush and ground-dwelling species for example, painted buttonquail. In future studies, acoustic recording devices could be deployed to expand the scope of detection for bird and frog species.

Notably, the vegetation surveys also revealed interesting differences between the sites in terms of management priorities, and the long unburnt site in this study provides perspectives into the complexities of managing fire-dependent landscapes. The long unburnt site had the highest overall diversity, but this comprised mainly of tree species, with shrub species richness being higher at both burnt sites. Further, observations by QPWS, combined with the species composition and vegetation structure data indicate that the long unburnt site was transitioning away from type (BALOW), and this was the only site where the threatened, fire-dependent *A. baueri* was not present. The site provided both larger amounts of CWD and canopy cover than recently burnt sites, providing more habitat and refuge from predators for reptiles and small mammals. Similar inter-site canopy cover (largely represented by *B. aemula*) between sampling years confirms the low growth rate for the key tree species, which is typical of *Banksia* species.[68] Higher flora species richness and higher numbers of senescing older Banksia trees noted in a concurrent study[69] indicate more habitat for fauna, particularly arboreal and hollow-dependent species. However, this may also be indicative of the degradation of key flora (e.g. *B. aemula*) and prevent fire-dependent threatened species, such as *A. baueri*[52] from persisting in natural populations in these landscapes, as they have been shown to decline and become vulnerable to localised extinction in the absence of fire.[52,70] Notably, although tree species richness was higher at the long unburnt site, the presence of tree species not usually associated with BALOW (i.e. *Alphitonia excelsa*, *Callitris columellaris* and *Syncarpia glomulifera*), suggest this site may be in the process of transitioning away from BALOW habitat (RE 12.2.9) open woodland towards a more mesic forest type. This typifies the conundrum faced by managers, in that there are often multiple and competing aims—for example, is the management intent to maintain ecosystem integrity versus maximising faunal and/or floral diversity?

5 | IMPLICATIONS FOR EVIDENCE-BASED MANAGEMENT OF BIODIVERSITY IN BALOW HABITAT ON K'GARI

This study provides a crucial baseline understanding of the postfire ecosystem dynamics in the dominant ecosystem on K'gari. Our results not only indicate that the preceding fire regime and fire conditions that led to the high-intensity, widespread Duling wildfire were detrimental to fauna but also that responses of this fire-adapted ecosystem to fire events are dynamic. However, more research is needed that includes sites with stronger representation of intermediate fire frequency and intervals, and replication of fire histories to gain a better understanding of the complexities of postfire processes in BALOW habitat. This is particularly important as fire management on K'gari becomes more reflective of the outcomes of cultural burning practices in broader landscapes and, in recognition of their native title rights, BAC seeks to strengthen its role in planning for and managing K'gari for the benefit of Butchulla people, in the fire management space.[54]

For the management of fire-adapted ecosystems such as BALOW habitat, a trade-off exists between maintaining high fauna species richness and diversity, conserving threatened or priority species and preserving flora health and ecosystem identity. Overall, this trade-off points to the need for pyrodiversity at different scales. For example,

to maintain fauna habitat complexity in BALOW, some long inter-fire intervals are required. Nevertheless, without regular fire, some cryptic threatened flora (e.g. *A. baueri*) will likely decline and be absent in some regions,[70] and key species (e.g. *B. aemula*) may senesce and die back, and the ecosystem may transition away from BALOW. Since these ecosystems are dynamic, and disturbance-driven, management regimes that capture maximum ecosystem, species and habitat diversity are needed for effective conservation, with temporal and spatial variation reflective of historical Traditional Custodian management of fire regimes. Maintaining patch networks of habitat with various fire histories allows for variation in disturbance across the broader landscape, and may improve fauna survival both during and immediately after fire. Given the diverse range of plant and animal species found in BALOW, the need for further research to better understand these relationships is highlighted; to manage the ecosystem effectively.

AUTHOR CONTRIBUTIONS

Elizabeth Brunton: Conceptualization; data curation; validation; formal analysis; writing—original draft; writing—review & editing; methodology; visualization; supervision; project administration. **George Anderson**: Conceptualization; data curation; writing—review & editing; writing—original draft. **Grahame Applegate**: Conceptualization; data curation; validation; supervision; writing—review & editing; methodology; resources. **Linda Behrendorff**: Validation; writing—review & editing; resources; project administration. **Aaron Brunton**: Data curation; visualization; writing—review & editing. **Rachel Killer**: Writing—review & editing; data curation; validation. **Robert Lamont**: Conceptualization; writing—review & editing; data curation. **Sarah Orchard**: Writing—review & editing; data curation. **Gabriel Conroy**: Conceptualization; writing—review & editing; project administration; data curation; validation; writing—original draft; formal analysis; supervision; methodology; resources.

ACKNOWLEDGEMENTS

The authors would like to thank and acknowledge the Traditional Custodians of K'gari, the Butchulla people. Thanks to Christine Bezuidenhout, Dane McMillan, Amanda Monk, Maddison Murrie and Kymberley O'Neill for assistance in the field and/or processing camera images. Thanks to Queensland Parks and Wildlife Service (QPWS) staff on K'gari for their support including Jenna Tapply, Dan Novak, Russ Simpkins, Megan Wilson and Sven Lavender. This work was carried out under DES permit # PTUKI 100065850.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The data used in this study were collected according to relevant ethical guidelines and regulations, and there were no interventions or interactions with living organisms. This work was carried out under Queensland Department of Environment and Science permit # PTUKI 100065850.

ORCID

Elizabeth Brunton https://orcid.org/0000-0003-2982-5439

REFERENCES

1. Frankham, R., S. E. J. D. Ballou, D. A. Briscoe, and J. D. Ballou. 2002. *Introduction to Conservation Genetics*. Cambridge: Cambridge University Press.
2. Johnson, C. N., A. Balmford, B. W. Brook, J. C. Buettel, M. Galetti, L. Guangchun, and J. M. Wilmshurst. 2017. "Biodiversity Losses and Conservation Responses in the Anthropocene." *Science* 356(6335): 270–5. https://doi.org/10.1126/science.aam9317.
3. Catterall, C., and M. Kingston. 1993. *Remnant Bushland of South East Queensland in the 1990's: Its Distribution, Loss, Ecological Consequences, and Future Prospects*. Brisbane: Institute of Applied Environmental Research, Griffith University and Brisbane City Council.
4. Bell, D. T. 2001. "Ecological Response Syndromes in the Flora of Southwestern Western Australia: Fire Resprouters Versus Reseeders." *The Botanical Review* 67(4): 417–40. https://doi.org/10.1007/bf02857891.
5. Enright, N. J., and I. Thomas. 2008. "Pre-European Fire Regimes in Australian Ecosystems." *Geography Compass* 2(4): 979–1011. https://doi.org/10.1111/j.1749-8198.2008.00126.x.
6. Russell-Smith, J., M. R. Gardener, C. Brock, K. Brennan, C. P. Yates, and B. Grace. 2012. "Fire Persistence Traits can be Used to Predict Vegetation Response to Changing Fire Regimes at Expansive Landscape Scales–An Australian Example." *Journal of Biogeography* 39(9): 1657–68. https://doi.org/10.1111/j.1365-2699.2012.02714.x.
7. England, P. R., A. V. Usher, R. J. Whelan, and D. J. Ayre. 2002. "Microsatellite Diversity and Genetic Structure of Fragmented Populations of the Rare, Fire-Dependent Shrub Grevillea Macleayana." *Molecular Ecology* 11(6): 967–77. https://doi.org/10.1046/j.1365-294x.2002.01500.x.
8. Keith, D. A., and R. A. Bradstock. 1994. "Fire and Competition in Australian Heath: A Conceptual Model and Field Investigations." *Journal of Vegetation Science* 5(3): 347–54. https://doi.org/10.2307/3235858.
9. Regan, H. M., and T. D. Auld. 2004. "Australian Shrub *Grevillea caleyi*: Recovery through Management of Fire and Predation." In *Species Conservation and Management: Case Studies*, edited by H. R. Akçakaya, M. A. Burgman, O. Kindvall, C. C. Wood, P. Sjögren-gulve, J. S. Hatfield and M. A. Mccarthy, 23–35. New York, NY: Oxford Academic.
10. Keith, D., J. Williams, and J. Woinarski. 2002. "Fire Management and Biodiversity Conservation: Key Approaches and Principles. Flammable Australia: The Fire Regimes and Biodiversity of a Continent." 401–25.
11. Lamont, B. B., and K. S. Downes. 2011. "Fire-Stimulated Flowering Among Resprouters and Geophytes in Australia and South Africa." *Plant Ecology* 212(12): 2111–25. https://doi.org/10.1007/s11258-011-9987-y.
12. Smith, A. L., D. Blair, L. McBurney, S. C. Banks, P. S. Barton, W. Blanchard, D. A. Driscoll, A. M. Gill, and D. B. Lindenmayer. 2014. "Dominant Drivers of Seedling Establishment in a Fire-Dependent Obligate Seeder: Climate or Fire Regimes?" *Ecosystems* 17(2): 258–70. https://doi.org/10.1007/s10021-013-9721-9.
13. Ooi, M. K. J., R. J. Whelan, and T. D. Auld. 2006. "Persistence of Obligate-Seeding Species at the Population Scale: Effects of Fire Intensity, Fire Patchiness and Long Fire-Free Intervals." *International Journal of Wildland Fire* 15(2): 261–9. https://doi.org/10.1071/wf05024.
14. Foster, C. N., P. S. Barton, C. I. MacGregor, J. A. Catford, W. Blanchard, and D. B. Lindenmayer. 2018. "Effects of Fire Regime on Plant Species Richness and Composition Differ Among Forest, Woodland and Heath Vegetation." *Applied Vegetation Science* 21(1): 132–43. https://doi.org/10.1111/avsc.12345.
15. Driscoll, D. A., D. B. Lindenmayer, A. F. Bennett, M. Bode, R. A. Bradstock, G. J. Cary, M. F. Clarke, et al. 2010. "Fire Management for Biodiversity Conservation: Key Research Questions and Our

Capacity to Answer Them." *Biological Conservation* 143(9): 1928–39. https://doi.org/10.1016/j.biocon.2010.05.026.
16. Rudolph, L. 1993. "Vegetation and Bushfires: Part 1—The Behaviour of Vegetation as Applied to the Landscaping Around Buildings in Bushfire Areas—A Review and Evaluation." *Landscape Australia* 15: 17–23.
17. Gill, A. M., R. H. Groves, and I. R. Noble. 1981. *Fire and the Australian Biota*. Canberra: Australian Academy of Science.
18. Bradstock, R. A., J. E. Williams, and M. A. Gill. 2002. *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. Cambridge: Cambridge University Press.
19. Griffith, S. J., C. Bale, and P. Adam. 2004. "The Influence of Fire and Rainfall Upon Seedling Recruitment in Sand-Mass (Wallum) Heathland of North-Eastern New South Wales." *Australian Journal of Botany* 52(1): 93–118. https://doi.org/10.1071/bt03108.
20. Patton, N. R., J. Shulmeister, Q. Hua, P. Almond, T. M. Rittenour, J. M. Hanson, A. Grealy, J. Gilroy, and D. Ellerton. 2023. "Reconstructing Holocene Fire Records Using Dune Footslope Deposits at the Cooloola Sand Mass, Australia." *Quaternary Research* 115: 67–89. https://doi.org/10.1017/qua.2023.14.
21. Stewart, P. 2017. "Changing Fire Regimes in Tropical and Subtropical Australia."
22. Bowman, D. M. J. S., J. Balch, P. Artaxo, W. J. Bond, M. A. Cochrane, C. M. D'Antonio, R. DeFries, et al. 2011. "The Human Dimension of Fire Regimes on Earth." *Journal of Biogeography* 38(12): 2223–36. https://doi.org/10.1111/j.1365-2699.2011.02595.x.
23. McWethy, D. B., S. G. Haberle, F. Hopf, and D. M. J. S. Bowman. 2017. "Aboriginal Impacts on Fire and Vegetation on a Tasmanian Island." *Journal of Biogeography* 44(6): 1319–30. https://doi.org/10.1111/jbi.12935.
24. Tran, C., and C. Wild. 2000. *A Review of Current Knowledge and Literature to Assist in Determining Ecologically Sustainable Fire Regimes for the Southeast Queensland Region*. Brisbane: Southeast Queensland Fire and Biodiversity Consortium.
25. Filkov, A. I., T. Ngo, S. Matthews, S. Telfer, and T. D. Penman. 2020. "Impact of Australia's Catastrophic 2019/20 Bushfire Season on Communities and Environment. Retrospective Analysis and Current Trends." *Journal of Safety Science and Resilience* 1: 44–56. https://doi.org/10.1016/j.jnlssr.2020.06.009.
26. Wintle, B. A., S. Legge, and J. C. Z. Woinarski. 2020. "After the Megafires: What Next for Australian Wildlife?" *Trends in Ecology and Evolution* 35(9): 753–7. https://doi.org/10.1016/j.tree.2020.06.009.
27. Keith, D. A., S. P. Allen, R. V. Gallagher, B. D. E. Mackenzie, T. D. Auld, S. Barrett, A. Buchan, et al. 2022. "Fire-Related Threats and Transformational Change in Australian Ecosystems." *Global Ecology and Biogeography* 31(10): 2070–84. https://doi.org/10.1111/geb.13500.
28. Samarawickrama, A., G. Conroy, D. Carter, and R. Cristescu. 2023. The Influence of Cultural Burns on the Density and Stress Response of Koalas on Minjerribah, North Stradbroke Island. Queensland: University of the Sunshine Coast.
29. Canadell, J. G., C. P. Meyer, G. D. Cook, A. Dowdy, P. R. Briggs, J. Knauer, A. Pepler, and V. Haverd. 2021. "Multi-Decadal Increase of Forest Burned Area in Australia is Linked to Climate Change." *Nature Communications* 12(1): 6921. https://doi.org/10.1038/s41467-021-27225-4.
30. Friend, G. R. 1993. "Impact of Fire on Small Vertebrates in Mallee Woodlands and Heathlands of Temperate Australia - A Review." *Biological Conservation* 65(2): 99–114. https://doi.org/10.1016/0006-3207(93)90439-8.
31. Lindenmayer, D. B., J. T. Wood, C. MacGregor, D. R. Michael, R. B. Cunningham, M. Crane, R. Montague-Drake, D. Brown, R. Muntz, and D. A. Driscoll. 2008. "How Predictable are Reptile Responses to Wildfire?" *Oikos* 117(7): 1086–97. https://doi.org/10.1111/j.0030-1299.2008.16683.x.
32. Griffiths, A. D., and B. W. Brook. 2014. "Effect of Fire on Small Mammals: A Systematic Review." *International Journal of Wildland Fire* 23(7): 1034–43. https://doi.org/10.1071/wf14026.
33. Moyo, S. 2022. "Community Responses to Fire: A Global Meta-Analysis Unravels the Contrasting Responses of Fauna to Fire." *Earth* 3(4): 1087–111. https://doi.org/10.3390/earth3040063.
34. Bruton, M. J., M. Maron, C. E. Franklin, and C. A. McAlpine. 2016. "The Relative Importance of Habitat Quality and Landscape Context for Reptiles in Regenerating Landscapes." *Biological Conservation* 193: 37–47. https://doi.org/10.1016/j.biocon.2015.11.004.
35. Robinson, N. M., S. W. J. Leonard, E. G. Ritchie, M. Bassett, E. K. Chia, S. Buckingham, H. Gibb, A. F. Bennett, and M. F. Clarke. 2013. "Refuges for Fauna in Fire-Prone Landscapes: Their Ecological Function and Importance." *Journal of Applied Ecology* 50(6): 1321–9. https://doi.org/10.1111/1365-2664.12153.
36. Valentine, L. E., A. Reaveley, B. Johnson, R. Fisher, and B. A. Wilson. 2012. "Burning in Banksia Woodlands: How Does the Fire-Free Period Influence Reptile Communities?" *PLoS One* 7(4): e34448. https://doi.org/10.1371/journal.pone.0034448.
37. Jolly, C. J., C. R. Dickman, T. S. Doherty, L. M. van Eeden, W. L. Geary, S. M. Legge, J. C. Z. Woinarski, and D. G. Nimmo. 2022. "Animal Mortality During Fire." *Global Change Biology* 28(6): 2053–65. https://doi.org/10.1111/gcb.16044.
38. Santos, J. L., B. A. Hradsky, D. A. Keith, K. C. Rowe, K. L. Senior, H. Sitters, and L. T. Kelly. 2022. "Beyond Inappropriate Fire Regimes: A Synthesis of Fire-Driven Declines of Threatened Mammals in Australia." *Conservation Letters* 15(5). https://doi.org/10.1111/conl.12905.
39. Greenwood, L., R. Bliege Bird, and D. Nimmo. 2021. "Indigenous Burning Shapes the Structure of Visible and Invisible Fire Mosaics." *Landscape Ecology* 37(3): 1–17. https://doi.org/10.1007/s10980-021-01373-w.
40. Nolan, R. H., D. M. J. S. Bowman, H. Clarke, K. Haynes, M. K. J. Ooi, O. F. Price, G. J. Williamson, et al. 2021. "What do the Australian Black Summer Fires Signify for the Global Fire Crisis?" *Fire* 4(4): 97. https://doi.org/10.3390/fire4040097.
41. Ritchie, A. L., L. N. Svejcar, B. M. Ayre, J. Bolleter, A. Brace, M. D. Craig, B. Davis, et al. 2021. "A Threatened Ecological Community: Research Advances and Priorities for Banksia Woodlands." *Australian Journal of Botany* 69(2): 53–84. https://doi.org/10.1071/bt20089.
42. Queensland Government. 2021. *Regional Ecosystem Details for 12.2.9*. Queensland Government.
43. Meiklejohn, A. M., R. I. Melzer, H. B. Hines, M. J. Laidlaw, M. Toyne, K. McPherson, L. Behrendorff, and S. MacDonald. 2021. *Post-Fire Assessment Report – Natural Values: 2020 Duling Bushfire, K'gari (Fraser Island), Great Sandy National Park, SouthEast Queensland Bioregion*. Brisbane: Department of Environment and Science, Queensland Government.
44. Neldner, V. J., and M. R. Ngugi. 2021. *Vegetation Recovery After the 2019 and 2020 Bushfires on K'gari (Fraser Island), Great Sandy National Park, Southeast Queensland Bioregion*. Brisbane: Department of Environment and Science. Queensland Government.
45. Walker, K., C. Baldwin, G. Conroy, G. Applegate, C. Archer-Lean, A. Arthington, L. Behrendorff, et al. 2022. "Ecological and Cultural Understanding as a Basis for Management of a Globally Significant Island Landscape." *Coasts* 2(3): 152–202. https://doi.org/10.3390/coasts2030009.
46. Bureau of Meterology. 2024. Climate Statistics for Australian Locations. http://www.bom.gov.au/climate/averages/tables/cw_039085.shtml. Accessed May 1, 2024.
47. Queensland Government. 2022. *Regional Ecosystem Technical Descriptions*. Department of Environment and Science, Queensland Government. https://www.publications.qld.gov.au/dataset/re-technical-descriptions/resource/1771f391-44b9-4d25-8315-f92033610a9b.
48. Applegate, G. 2020. *Vegetation of Fraser Island/K'gari*. South East Queensland: Ingram Book Company.
49. Griffith, S. J., S. Rutherford, K. L. Clarke, and N. W. M. Warwick. 2015. "Water Relations of Wallum Species in Contrasting Groundwater Habitats of Pleistocene Beach Ridge Barriers on the Lower North Coast of New South Wales, Australia." *Australian Journal of Botany* 63(7): 618–30. https://doi.org/10.1071/bt15103.
50. Wardell-Johnson, G., D. Schoeman, T. Schlacher, A. Wardell-Johnson, M. Weston, Y. Shimizu, and G. Conroy. 2015. "Re-Framing Values for a

World Heritage Future: What Type of Icon Will K'gari-Fraser Island Become?" *Australasian Journal of Environmental Management* 22(2): 124–48. https://doi.org/10.1080/14486563.2014.985267.
51. Griffith, S. J., C. Bale, P. Adam, and R. Wilson. 2003. "Wallum and Related Vegetation on the NSW North Coast: Description and Phytosociological Analysis." *Cunninghamia* 8: 202–52.
52. Conroy, G. 2012. "The Effects of Fire and Fragmentation Upon Two Threatened Coastal Heath Species, Acacia Baueri ssp. Baueri (Mimosaceae) and Blandfordia grandiflora (Blandfordiaceae)." MS thesis, Faculty of Science, Health, Education and Engineering. Sippy Downs: University of the Sunshine Coast.
53. Queensland Government Department of Environment and Science. 2021. "Rare or Threatened Plants of Southeast Queensland (SEQ Bioregion, Queensland Government)." https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/wildlife/?AreaID=world-heritage-area-fraser-island&Kingdom=animals&SpeciesFilter=Native.
54. BAC. 2020. *Butchulla Aboriginal Corporation Strategic Business Plan 2020–2030*. Hervey Bay, Queensland: Butchulla Aboriginal Corporation.
55. Melzer, R. I., and H. B. Hines. 2022. *Queensland Parks and Wildlife Service Planned Burn Guidelines. Department of Environment and Science*. Brisbane: Queensland Government.
56. Eyre, T., A. Kelly, V. Neldner, B. Wilson, D. Ferguson, M. Laidlaw, and A. Franks. 2015. BioCondition: A Condition Assessment Framework for Terrestrial Biodiversity in Queensland. Assessment Manual. Version 2.2. Brisbane: Information Technology, Innovation and Arts.
57. Greig, S. 1964. *Quantitative Plant Ecology*. Oxford: Butterworths.
58. Niedballa, J., R. Sollmann, A. Courtiol, and A. Wilting. 2016. "camtrapR: An R Package for Efficient Camera Trap Data Management." *Methods in Ecology and Evolution* 7(12): 1457–62. https://doi.org/10.1111/2041-210x.12600.
59. Gill, A. M., and M. A. McCarthy. 1998. "Intervals Between Prescribed Fires in Australia: What Intrinsic Variation Should Apply?" *Biological Conservation* 85(1–2): 161–9. https://doi.org/10.1016/s0006-3207(97)00121-3.
60. Tagliapietra, D., and M. Sigovini. 2010. "Biological Diversity and Habitat Diversity: A Matter of Science and Perception." *Terre and Environnement* 88: 147–55.
61. Doherty, T. S., W. L. Geary, C. J. Jolly, K. J. Macdonald, V. Miritis, D. J. Watchorn, M. J. Cherry, et al. 2022. "Fire as a Driver and Mediator of Predator–Prey Interactions." *Biological Reviews* 97(4): 1539–58. https://doi.org/10.1111/brv.12853.
62. McGregor, H., S. Legge, M. E. Jones, and C. N. Johnson. 2015. "Feral Cats are Better Killers in Open Habitats, Revealed by Animal-Borne Video." *PLoS One* 10(8): e0133915. https://doi.org/10.1371/journal.pone.0133915.
63. Chia, E. K., M. Bassett, S. W. J. Leonard, G. J. Holland, E. G. Ritchie, M. F. Clarke, and A. F. Bennett. 2016. "Effects of the Fire Regime on Mammal Occurrence After Wildfire: Site Effects vs Landscape Context in Fire-Prone Forests." *Forest Ecology and Management* 363: 130–9. https://doi.org/10.1016/j.foreco.2015.12.008.
64. Hale, S., L. Mendoza, T. Yeatman, R. Cooke, T. Doherty, D. Nimmo, and J. G. White. 2022. "Evidence that Post-Fire Recovery of Small Mammals Occurs Primarily Via In Situ Survival." *Diversity and Distributions* 28(3): 404–16. https://doi.org/10.1111/ddi.13283.
65. Woldendorp, G., and R. J. Keenan. 2005. "Coarse Woody Debris in Australian Forest Ecosystems: A Review." *Austral Ecology* 30(8): 834–43. https://doi.org/10.1111/j.1442-9993.2005.01526.x.
66. Davis, R. A., L. E. Valentine, and M. D. Craig. 2022. "Do Bird Communities Differ with Post-Fire Age in Banksia Woodlands of South-Western Australia?" *International Journal of Wildland Fire* 31(6): 621–33. https://doi.org/10.1071/wf22005.
67. Fontúrbel, F. E., G. B. Rodríguez-Gómez, N. Fernández, B. García, J. I. Orellana, and G. J. Castaño-Villa. 2020. "Sampling Understory Birds in Different Habitat Types Using Point Counts and Camera Traps." *Ecological Indicators* 119: 106863. https://doi.org/10.1016/j.ecolind.2020.106863.
68. Griffiths, E., and J. C. Stevens. 2014. "Managing Nutrient Regimes Improves Seedling Root-Growth Potential of Framework Banksia-Woodland Species." *Australian Journal of Botany* 61(8): 600–10. https://doi.org/10.1071/bt13181.
69. 69 Anderson, G. 2011. The Response of *Banksia aemula* Woodlands to Fire on K'gari. University of the Sunshine Coast.
70. Conroy, G., R. Lamont, G. Applegate, and A. Brunton. 2024. "Population Dynamics and Distribution of the Tiny Wattle (*Acacia baueri* ssp. Baueri) on K'gari." Report. University of the Sunshine Coast.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Brunton, Elizabeth, George Anderson, Grahame Applegate, Linda Behrendorff, Aaron Brunton, Rachel Killer, Robert Lamont, Sarah Orchard, and Gabriel Conroy. 2024. "Ecological dynamics in *Banksia aemula* woodlands following widespread, anthropogenic wildfires on a world heritage listed island (K'gari), Australia." *Biological Diversity* 1(3–4): 180–92. https://doi.org/10.1002/bod2.12025.