Bushfire Recovery Program 2020–2022:

Priority actions for threatened species in the Cooloola section of Great Sandy National Park

South East Queensland

2023

Queensland Government

Prepared by: Threatened Species Operations, Queensland Parks and Wildlife Service and Partnerships, Department of Environment and Science

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Front cover: Regenerating heath plants after the 2019–2020 bushfires in the Cooloola section of Great Sandy National Park. (Photo: T.B. Churchill)

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Executive summary

The bushfires of late 2019 to early 2020 had extensive ecological impacts across Australia. The most fire-impacted threatened species in Queensland were prioritised for recovery efforts through an expert evaluation process led by the Department of Environment and Science (DES), in collaboration with the Australian Government's 'Wildlife and Threatened Species Bushfire Recovery Expert Panel'. In March 2020, the Queensland Bushfire Recovery Program was established with assistance from the Australian Government's Bushfire Recovery for Wildlife and their Habitats initiative, to implement recovery projects across strategic locations, including the Cooloola section of Great Sandy National Park.

At Cooloola, eight threatened fauna species were identified as the most fire-impacted: ground parrot *Pezoporus wallicus wallicus*; southern emu-wren *Stipiturus malachurus*; wallum froglet *Crinia tinnula*; wallum sedgefrog *Litoria olongburensis*; wallum rocketfrog *Litoria freycineti*; Cooloola sedgefrog *Litoria cooloolensis*; Oxleyan pygmy perch *Nannoperca oxleyana*, and the honey blue-eye *Pseudomugil mellis*. Four plant species were also prioritised, along with endemic invertebrate taxa that may be fire-impacted. Fire impacts across the diverse ecosystems of Cooloola were also evaluated to prioritise recovery efforts and ongoing monitoring.

Recovery actions were undertaken between May 2020 and October 2022, including:

- **Post-fire assessment**—detailed spatial evaluation of fire extent and severity, and the associated ecological impacts, to guide the survey of priority species and on-ground efforts to reduce threats to their recovery.
- **Monitor priority species**—field assessment of species' status by experts using best-practice techniques to set a baseline to track recovery and to compare to pre-fire data, where available.
- **Reduce threats to recovery**—implementation of actions to reduce the risk to priority species and their habitats from future unplanned fires, invasive weeds and pest animals.
- **Recommendations and guidance**—assessment of the information and insights gained from the previous actions to provide recommendations for reducing threats, ecological monitoring and research.

The post-fire assessment measured a total of 14,608 hectares (ha) that burnt across the Cooloola section of Great Sandy National Park (Meiklejohn *et al*. 2020). A quarter of this area was at a low fire severity level, where fire did not scorch the canopy, but fire-sensitive low shrubs were lost. A similar proportion was burnt at a moderate, high and extreme level of fire severity. At the extreme level, a total of 3,817ha of vegetation was completely consumed. For a given level of fire severity, the ecological impacts can vary across different vegetation types based on their fire-tolerance. Fire severity was therefore incorporated with the fire-sensitivity of vegetation to spatially quantify the 'potential ecological impact' (PEI) (Laidlaw *et al*. 2022). This revealed high to catastrophic PEI levels for the fire sensitive foredune vegetation, with its recovery of concern (Meiklejohn *et al.* 2021).

The eastern ground parrot was monitored across 32 sites of suitable burnt and unburnt habitat using standardised listening for calls and bio-acoustic recorders with subsequent call analyses. Ground parrots were recorded at 84% of surveyed sites, with their post-fire presence not impacted by the 2019–2020 fires. The post-fire population size in the Cooloola–Noosa North Shore area is consistent with previous estimates from 1989. Recommendations to support and promote ground parrot populations include protecting burnt areas from fire for seven to 10 years and maintaining a planned burn program that sustains a diversity of heath seral stages.

Southern emu-wrens were surveyed across 27 sites of suitable habitat. Across both burnt and unburnt sites, the level of detectable occupancy was low, hence interpreting fire impacts was not possible. Southern emu-wrens have been regularly recorded in a core area that was not burnt during the 2019–2020 fires, and they continued to be sighted during 2020 outside of the formal surveys. For eastern ground parrot and southern emu-wrens it is recommended that monitoring continue, as well as ecological research to improve the understanding of their ecology and fire impacts. Reducing the threat of predation from feral cats and foxes and reducing impacts from pigs through appropriate controls is also advised.

The Oxleyan pygmy perch and honey blue-eye were surveyed across 23 wetland sites using standardised box traps and electrofishing methods. These species were absent from some sites where they had previously been recorded, although this did not appear to be fire related. Water chemistry variables were measured, and except for dissolved oxygen at some sites, all variables were within acceptable ranges. Recommendations to support the priority fish species include monitoring, protection from the impacts of frequent or severe fires and reducing impacts from invasive fish, plants and pigs. Research into how fire, drought, flooding and invasive species impact these freshwater fish species and their habitats is advised.

The wallum sedgefrog, wallum rocketfrog, wallum froglet and Cooloola sedgefrog were surveyed across a total of 59 sites in 2020 and 33 sites in 2021, which included both burnt and unburnt sites. All four wallum acid frogs were detected at both unburnt and burnt sites, with most present across a spectrum of appropriate habitat types in the landscape, both burnt and unburnt. This indicates that the 2019–2020 fires did not cause a detectable impact.

However, with most sites containing no frogs in 2020 and >50% of sites recording no frogs in 2021, the recommendations remain applicable. The recommendations include ongoing monitoring of the four acid frog species and protecting habitats from the impacts of pigs, frequent and severe fires, sedimentation or local hydrology changes and water extraction to fight fires. Ecological studies into how fire severity and frequency affect acid frog species is encouraged, as well as understanding the interactions between fire, weeds and cane toads *Rhinella marina*.

Of the 15 species initially flagged as priority invertebrate taxa, only two dragonfly species were recorded during post-fire surveys and two additional species worthy of ongoing monitoring were recorded. Survey results confirmed that all four species persisted at Cooloola following the 2019–2020 bushfires. The fire impacts on these species were difficult to assess. Ongoing monitoring of the four detected species is recommended, as well as research to improve the understanding of their distribution, abundance and ecological requirements. Control of pigs is advised as this will help protect invertebrates and their habitats.

Threatened plant species and species of conservation concern were included in post-fire surveys. Of these, 12 species were confirmed as not being within the fire extent and six species were fire-impacted but had a post-fire response such as resprouting, germinating or flowering. A new native species for Queensland was recorded in a burnt area: *Trachymene composita* var. *composita*, which germinates after fire or disturbance. Protecting threatened plant species and their habitats from high fire frequency and ecosystem-transforming weeds is a priority.

An assessment of 52 regional ecosystems identified 40 as fire impacted and of these, nine are fire-sensitive, including one listed as ‘Endangered’, and three as ‘Of concern’ under the *Vegetation Management Act 1999*. All burnt fire-sensitive ecosystems experienced at least moderate ecological impacts. Over 1,800ha of fire-sensitive ecosystems were burnt, leaving them at risk of biodiversity loss and a transition to a more fire-tolerant ecosystem. For both fire-sensitive and fire-tolerant ecosystems, the increased risk to their post-fire recovery from invasive animals and fire-promoting weeds makes control of these threats a high priority. It is recommended that the additional ongoing threats of myrtle rust, recreational vehicles on foredunes and the use of fire retardants in emergency fire response are also addressed to protect the ecosystems of Cooloola.

During 2020 and 2021, a range of actions was undertaken to reduce threats to the initial post-fire recovery of priority species and ecosystems. To reduce the risk of subsequent unplanned fires in the short term and to support broader landscape-scale fire management, critical firelines were upgraded and the fire strategy and planned burn program were revised. To reduce the impacts of habitat damage and predation by pigs, feral cats and foxes, these species were targeted for control using suitable techniques and in collaboration with local government. Ecosystem-transforming weeds, such as invasive grasses and Singapore daisy, were a priority for control given their colonisation of burnt areas. The pest strategy was revised to accommodate the increased threat from weeds and pest animals, including invasive freshwater fish.

A range of project lessons is outlined with forward recommendations, including applying the National Disaster Risk Reduction Framework for protecting life and property to the context of protecting wildlife and to sustain ongoing investment to reduce the key threats to the recovery of threatened species, and to mitigate the increasing risk of extinctions due to climate change. To more effectively prioritise and guide conservation and threat management actions, there is an urgent need to improve the availability of high-quality ecological data. To enhance the ability to provide recovery actions for wildlife, especially amidst a broad-scale natural disaster, it is important to build capacity in the relevant specialist ecological and technical skills and maintain relationships with external specialists to expedite assessment of wildlife impacts to implement the most appropriate recovery actions following the next natural disaster. Ongoing investment is necessary to sustain best-practice methodologies and embrace more cost-effective technologies to support ecological monitoring.

1 Context

1.1 2019–2020 bushfires

The Australian bushfire season of 2019–2020 was extraordinary in terms of its extent, duration and intensity. The year of 2019 was the hottest and driest on Australian records and the Forest Fire Danger Index exceeded all previous values (Bureau of Meteorology 2020). Over 24 million hectares (ha) burned, impacting at least 37 ecological communities and 330 species listed as nationally threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) (Binskin *et al*. 2020) and almost three billion mammals, reptiles, birds and frogs (WWF 2020). Fire-sensitive communities such as rainforests experienced an historic increase in fire severity (Collins *et al*. 2021) with associated wildlife having limited capacity to recover. At least 20 nationally threatened species have been pushed closer to extinction and the long-term ecological consequences of these fires are of serious concern (Woinarski *et al*. 2020).

Quantifying the impact on invertebrates is difficult given inadequate knowledge of their taxonomy, distribution and ecology. Only a third of species are considered described, yet an analysis of the fire impacts on known taxa found that they contributed 95% of fauna species with a distributional overlap of 50% or more with the fires (Marsh *et al*. 2021). Moreover, 382 invertebrate taxa had their entire known range burnt (Marsh *et al*. 2022). The fires are estimated to have caused the extinction of 700 invertebrate species (Lee 2020) and fire impacts can persist for many decades (Henry *et al*. 2022).

In Queensland, over 7.7 million ha were burnt (Queensland Reconstruction Authority 2020) which included more than 1.6 million ha of protected areas and 12,000ha of Ramsar wetlands (Threatened Species Operations 2020). A total of 648 threatened species was impacted, including 631 listed as threatened under the state's *Nature Conservation Act 1992* (NCA) and 266 listed under the EPBC, of which 21 were Critically Endangered (Threatened Species Operations 2020). In southern Queensland, the preceding extensive drought (Bureau of Meteorology 2019) had already reduced habitat condition and the availability of water and food resources, exacerbating fire impacts on wildlife. Normal refugia of gullies, rocky outcrops and rainforests were unpredictably burnt (e.g., Hines *et al*. 2020), which would have significant consequences for wildlife during the fire, as well as for their post-fire recovery.

1.2 Queensland Bushfire Recovery Program

In January 2020, the Department of Environment and Science (DES) initiated a desktop process to evaluate the spatial extent of the fires relative to the likely habitat for species listed as threatened under the NCA. For species with the greatest area of burnt habitat, experts interpreted the potential fire impacts and the main threats to their recovery. These outcomes were then compared to a broader scale study by the Commonwealth's Wildlife and Threatened Species Bushfire Recovery Expert Panel for species listed as threatened under the EPBC. An agreed list of priority species and ecological communities then qualified for emergency support under Phase 1 of the Australian Government's $200 million 'Bushfire Recovery for Wildlife and their Habitats package'.

In March 2020, the Australian Government supported DES through Phase 1 'Emergency Response' funding of $1.5 million for the delivery of prioritised actions through to June 2021. The Department established the Queensland Bushfire Recovery Program, led by Threatened Species Operations unit within the Queensland Parks and Wildlife Service (QPWS). The first phase of the program included four projects representing strategic locations of fire-impacted threatened species: Gondwana Rainforests of Australia World Heritage Area; Coastal wallum-heath of the Cooloola area; Oakview and Nangur National Parks; and Bulburin National Park.

By March 2021, the Australian Government provided further support through 'Phase 2 Recovery and Resilience' funding of $2.35 million to sustain efforts across the Gondwana Rainforests of Australia World Heritage Area and the Cooloola section of Great Sandy National Park through to October 2022. This phase of the program included three projects to continue to reduce threats to the recovery of prioritised species: i) pest animal control; ii) fire management actions; and iii) strategic weed control. Ecological monitoring of a revised set of priority threatened species and priority ecosystems was incorporated into each project.

This report documents the implementation of recovery actions for priority threatened species in the Cooloola section of Great Sandy National Park (hereafter referred to as Cooloola) between May 2020 and October 2022 for Phases 1 and 2 of the Queensland Bushfire Recovery Program.

1.3 Prioritisation of threatened species and ecological communities

The species classified as threatened under the NCA and/or EPBC were prioritised for recovery efforts based on the spatial overlap of their modelled habitat with fire extent, alongside expert evaluation of likely fire impacts and post-fire threats (Threatened Species Operations 2020). A total of eight fauna and four flora species was prioritised for recovery efforts at Cooloola in Phase 1 of the program (Table 1). A reduced suite of priority species was identified by the Commonwealth for ongoing monitoring efforts in Phase 2 (Table 1).

Table 1: Vertebrate fauna and plant species prioritised for recovery actions at Cooloola, with the area of their modelled habitat burnt in the 2019–2020 fires, their conservation status under state (NCA) and Commonwealth (EPBC) legislation (NT – Near Threatened; V – Vulnerable; E – Endangered) and selection for Phase 1 and 2 of the program.

Group	Common name	Species	Impacted Habitat (Ha)	% Habitat Impacted	NCA	EPBC	Phase 1	Phase 2
Birds	Eastern ground parrot	*Pezoporus wallicus wallicus*	5,533	18	V		✓	✓
	Southern emu-wren	*Stipiturus malachurus*	658	13	V		✓	
Fish	Oxleyan pygmy perch	*Nannoperca oxleyana*	3,757	22	V	E	✓	✓
	Honey blue-eye	*Pseudomugil mellis*	2,440	19	V	V	✓	✓
Frogs	Wallum sedgefrog	*Litoria olongburensis*	26,501	18	V	V	✓	✓
	Cooloola sedgefrog	*Litoria cooloolensis*	14,965	15	NT		✓	
	Wallum rocketfrog	*Litoria freycineti*	27,721	15	V		✓	
	Wallum froglet	*Crinia tinnula*	33,570	12	V		✓	
Plants	Mt. Emu she-oak	*Allocasuarina emuina*	4,593	20	E	E	✓	
	Durringtonia	*Durringtonia paludosa*	1,374	38	NT		✓	
	-	*Gonocarpus effusus*	4,676	23	V		✓	
	Fraser Island creeper	*Tecomanthe hillii*	771	27	NT		✓	

The Commonwealth's Expert Panel acknowledged that the conservation status of invertebrate fauna was poorly documented, and that many endemic taxa were likely impacted by the 2019–2020 fires and worthy of recovery efforts. In collaboration with experts from the Queensland Museum, invertebrate species with restricted distributions and other attributes that can make them vulnerable to fire were identified as priority species for this project (Table 2).

Table 2: Invertebrate species prioritised for post-fire surveys during Phase 1 at Cooloola.

Order	Common name	Species
Coleoptera	Earth-boring beetle	*Australobolbus masneri*
	Native dung beetles	*Onthophagus cooloola*, *O. yarrumba* and *O. beelarong*
	Christmas beetles	*Anoplognathus debaari*, *A. hilleri* and *A. storeyi*
	Ladybird beetle	*Sticholotis cooloola*
Diptera	Crane flies	*Molophilus cooloola*
		Paralimnophila cooloola
Odonata	Wallum vicetail	*Hemigomphus cooloola*
	Wallum darner	*Austroaeschna cooloola*
Orthoptera	King cricket	*Cooloola propator*
	Fraser Island katydid	*Tinzeda fraserensis*
Strepsiptera	Twisted-wing parasite	*Triozocera cooloolaensis*

The vegetation communities that burnt in the 2019–2020 fires were assessed during Phase 2 of this project to identify the most fire-impacted ecological communities. As a result of this evaluation process, the foredune vegetation with spinifex grassland and she-oak canopy was prioritised for the establishment of monitoring sites, where key attributes were measured to set a post-fire baseline and support future assessments of post-fire recovery (section 8).

1.4 Priority recovery actions

This project aimed to deliver a range of actions that aligned to expert advice to protect and support the ongoing recovery of priority threatened species at Cooloola:

- **Post-fire assessment**—detailed spatial evaluation of fire extent and severity, and the associated ecological impacts, to guide the survey of priority species and on-ground efforts to reduce threats to their recovery.
- **Monitor priority species**—field assessment of species' status by expert ecologists using best-practice techniques to set a baseline to track recovery and to compare to pre-fire data, where available.
- **Reduce threats to recovery**— implementation of actions to reduce the risk to priority species and their habitats from future unplanned fires, invasive weeds and pest animals.
- **Recommendations and guidance**—assessment of the information and insights gained from the previous actions to provide recommendations for ecological monitoring and research and for reducing threats.

This report documents the implementation of these actions across the Cooloola section of Great Sandy National Park (NP) between May 2020 and October 2022 for the Queensland Bushfire Recovery Program.

2 Post-fire assessment

A post-fire assessment was undertaken by DES to document the 2019–2020 bushfires, clarify the fire extent and evaluate the patterns of fire severity and ecological impacts across Great Sandy and Noosa NPs (Meiklejohn *et al*. 2020). Three different fires burnt across Cooloola between 8 September 2019 and 7 January 2020. Summary results from the post-fire assessment report have been reproduced below, and additional data specific to Cooloola utilised, to provide background context for this report (refer to Meiklejohn *et al*. 2020 for the full analysis, and the details and caveats of the remote sensing methodology).

2.1 Fire extent and severity

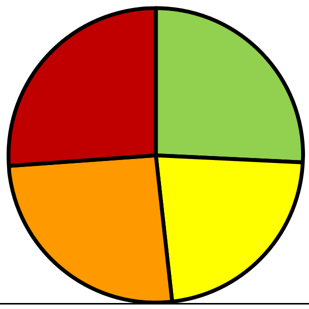
Overall, 14,608ha burned across Cooloola (Figure 1; Meiklejohn *et al.* 2020).

Fire severity was analysed by comparing remote satellite imagery before and after the 2019–2020 fire events and using the scientifically derived difference to create fire severity classes from low to extreme, which were then field validated (Meiklejohn *et al.* 2020). These classes reflect the level of impact to vegetation strata, which were then quantified (Table 3) and mapped (Figure 1).

Across Cooloola, a quarter of the area burnt was at a low level of fire severity, where fire did not scorch the canopy, but fire-sensitive low shrubs were lost. A similar proportion of the landscape (22–26%) was burnt at a moderate, high, and extreme level of fire severity. At the extreme level, a total of 3,817ha of vegetation was completely consumed, including the canopy layer (Table 3; Figure 1).

Table 3: The area burnt at Cooloola across four classes of fire severity, and the relative proportion of each class of the total area burnt (colour coded by fire severity class). Data derived from Meiklejohn *et al*. (2020).

Fire severity class	Description of effect on vegetation	Area (ha)
Low	Canopy and subcanopy unscorched, shrubs may be scorched, fire-sensitive low shrubs may be killed.	3762
Moderate	Partial canopy scorch, subcanopy partially or completely scorched, and/or fire-sensitive tall shrub or small tree layer mostly killed.	3281
High	Full canopy scorch to partial canopy consumption, subcanopy fully scorched or consumed.	3747
Extreme	Full canopy, subcanopy and understorey consumption.	3817



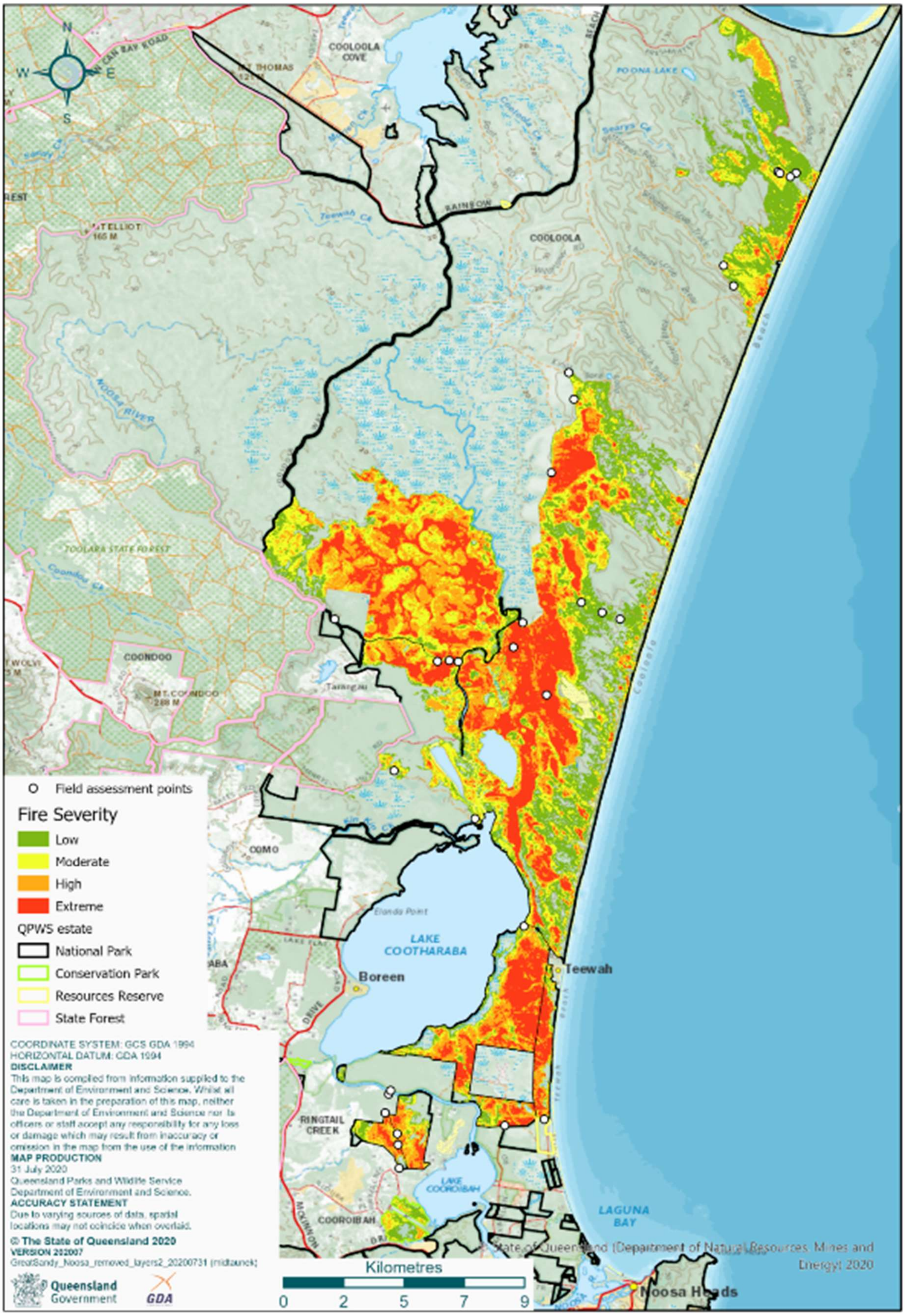


Figure 1: Distribution of the 2019–2020 bushfires at Cooloola, based on four classes of fire severity (low to extreme). Reproduced from Meiklejohn *et al*. (2020).

2.2 Potential ecological impacts

The ecological consequences of a fire, at a given level of fire severity, can vary across different plant communities according to their fire sensitivity. For example, eucalypt woodlands, which are fire tolerant, have plant species that can quickly recover from a low or moderate severity fire that consumed the understorey. In contrast, fire-sensitive ecosystems, such as rainforest or coastal foredunes, can be significantly impacted by loss of the understorey and be slow to recover. The native fauna of these different communities has typically evolved a comparable level of fire tolerance, with those endemic to fire-sensitive ecosystems more at risk from fires. To map this ecological context, the fire tolerance of plant communities was combined with fire severity class to predict the 'Potential Ecological Impacts' (PEI) across burnt landscapes (Laidlaw *et al*. 2022). This classification process incorporates other ecological considerations, such as the critical loss of food resources and habitat structures, and the risk from invasive plants (for Cooloola, see Meiklejohn *et al*. 2020). As a result, efforts to monitor priority species and reduce threats to recovery actions across Cooloola were better directed to where they were most needed.

The diverse vegetation across Cooloola includes heath, coastal foredunes, swamps, rainforest, forests and woodlands. Due to their variable fire tolerance, these communities experienced relatively different proportions of PEI following the 2019–2020 fires (Figure 2). The fire-tolerant ecosystems, such as eucalypt woodlands, were predicted to mostly have low to moderate ecological impacts. However, where fire-sensitive species occurred, such as cypress pine *Callitris columellaris*, high to catastrophic PEI was likely, with a loss of canopy removing key habitat features for fauna. The burnt fire-sensitive foredune vegetation had PEI at high to catastrophic levels (Figure 3). The beach she-oak *Casuarina equisetifolia* and pandanus *Pandanus tectorius* are characteristic of this plant community and readily killed by fire, with a slow recovery, enhancing the risk of coastal erosion (Meiklejohn *et al*. 2020).

Over 2,000ha of wet heath burned, mostly at high fire severity. Whilst the extent of the fire is of concern, this habitat is fire adapted and the PEI low or moderate, given that the flammable peat layer was not notably ignited. For the grass and sedge swamps, approximately 180ha was burnt with minimal ignition of the peat layer (despite preceding drought conditions) and PEI low to moderate. The tea-tree swamps dominated by paperbarks were burnt over an estimated 2,500ha, and whilst considered fire tolerant, some areas lost the canopy and hence, had moderate to high PEI. An area of 600ha of fire-adapted dry heath with wallum banksia *Banksia aemula* burned with a moderate to high PEI, given the loss of some mature trees (see Section 8 and further detail in Meiklejohn *et al*. 2020).

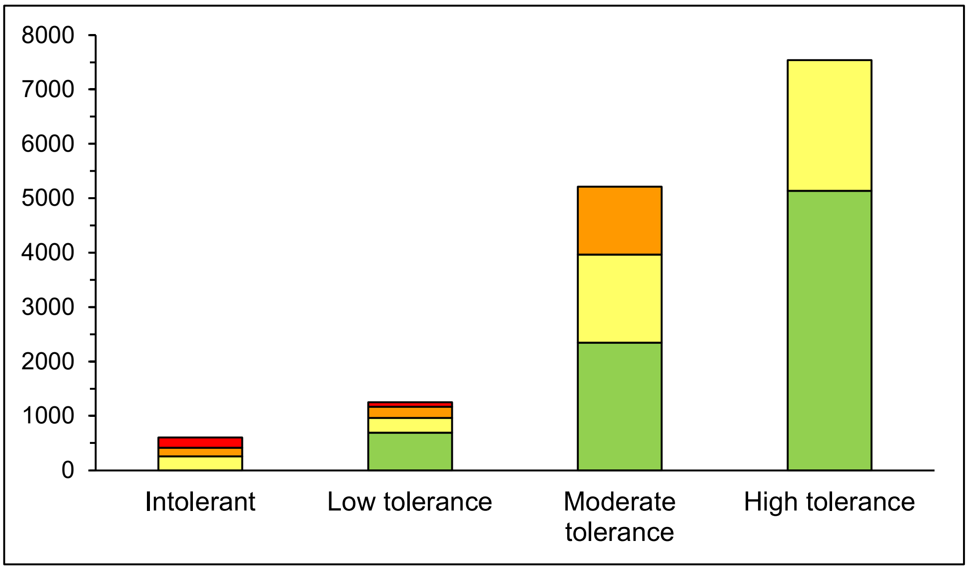


Figure 2: The area (ha) that was burnt with a limited (■), moderate (■), high (■) or catastrophic (■) level of PEI across four vegetation types, based on their fire sensitivity or tolerance.

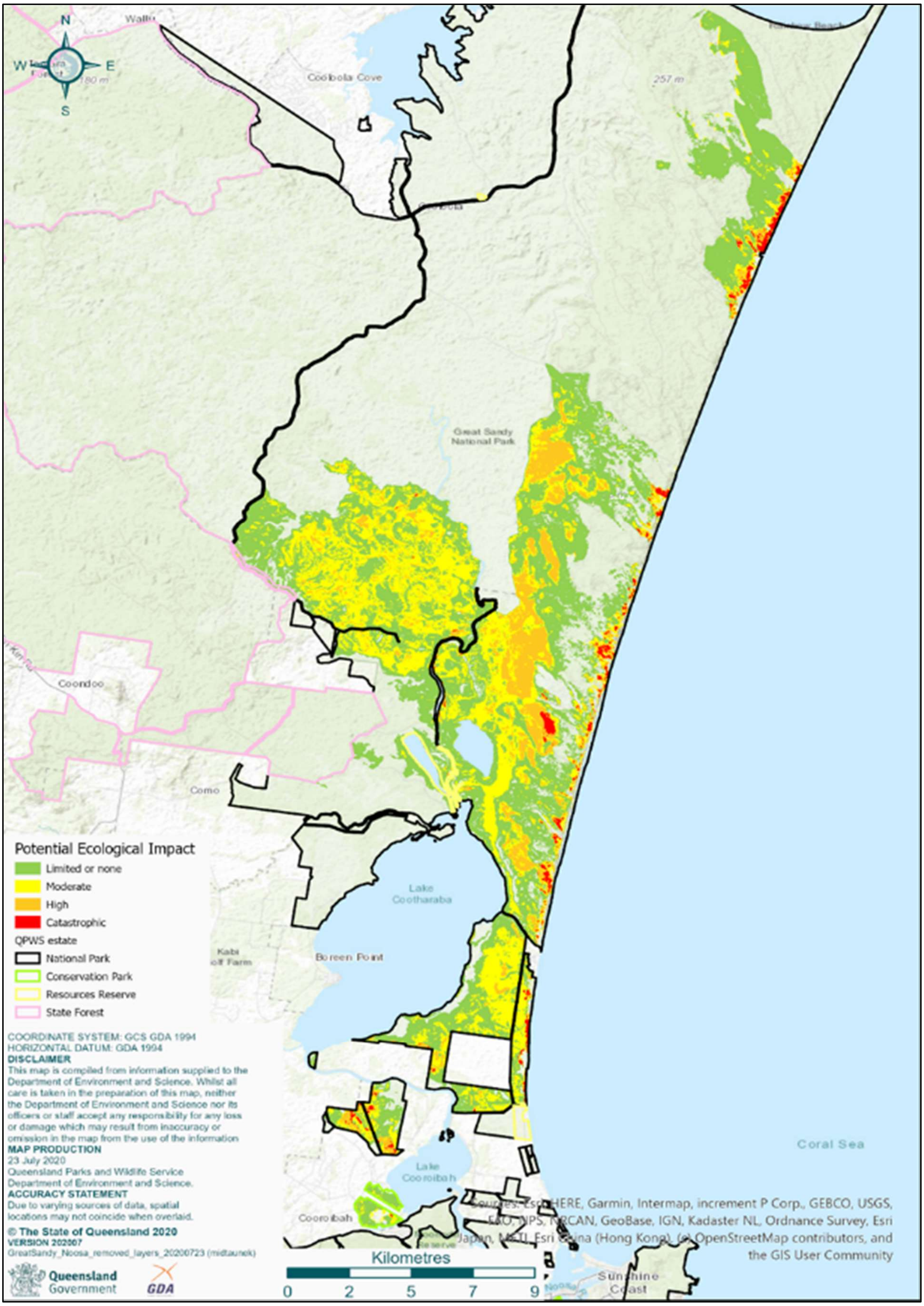


Figure 3: PEI of the 2019–2020 fires at Cooloola across four classes (limited/none to catastrophic). Reproduced from Meiklejohn *et al*. (2020).

3 Priority birds

3.1 Eastern ground parrot

3.1.1 Conservation context

The eastern ground parrot *Pezoporus wallicus wallicus* is listed as Vulnerable under the NCA. The South East Queensland population is at the northern end of the subspecies' range and represents a significant population in the Australian context (McFarland 1989). In Queensland, they can be found in closed graminoid-heathlands (specifically *Caustis–Empodisma* and *Ptilothrix* heathlands; Spearritt & Krieger 2007) and sedgelands between Maryborough and Coolum on the mainland, and along the west coast of K'gari (Fraser Island; McFarland 1991c).

Studies at Cooloola have shown that ground parrots feed on seeds from at least 40 different species of plants, notably curly sedge *Caustis recurvata*, variable smoke-bush *Conospermum taxifolium*, ground parrot berry *Pseudanthus orientalis* and *Sprengelia sprengelioides* (McFarland 1989, 1991a; Spearritt & Krieger 2007). The seeds of *Eurychorda complanata*, *Schoenus paludosus*, *Lepyrodia scariosa* and species of native fuchsia *Epacris* spp. are also eaten seasonally (Spearritt & Krieger 2007). Seed selection appears to be based on availability, accessibility, and size. Across the heathlands, ground parrots use dry and wet microhabitats but rarely sedgelands and shrub- or tree-dominated areas. Birds visit dry microhabitats between late autumn and early summer and use wet microhabitats mostly in summer, with these shifts corresponding to changes in seed availability and accessibility (McFarland 1991a). Spatial variability of habitat appears to be crucial to survival of the subspecies, with vegetation age-since-burning a known factor affecting the availability of resources and presence of eastern ground parrots.

In a previous study, McFarland (1991b) found that ground parrot calling activity was predominantly restricted to 25 minutes (mins) before sunrise and 19 mins after sunset. Calling activity varied little with time of the year or with years since fire, and only the duration of dawn calling changed significantly during the year (McFarland 1991c). Within a site, parrot numbers increased with the time since fire, peaking after 5–8 years (due to changes in vegetation structure and seed availability) and varied seasonally due to dispersal and breeding activities (McFarland 1991c).

Threats to the persistence of eastern ground parrots at Cooloola include woody thickening of the heath, inappropriate fire regimes that alter habitat structure and composition, and predation by foxes and feral cats (Threatened Species Operations 2020). The 2019–2020 fires impacted a significant proportion (>15%) of ground parrot habitat across Great Sandy NP and Noosa NP (Meiklejohn *et al*. 2020). Since these fires occurred in wet heaths early in the summer of 2019–2020, mortality of ground parrots may have been minimal. However, fire-impacts to seeding plants could have led to critical food shortages, presenting a challenge to the post-fire recovery of ground parrot populations.

3.1.2 Survey sites and methods

Survey area

Field surveys were undertaken in 2020 and 2021 to assess the rates of occupancy and number of ground parrots across Cooloola, Noosa North Shore (between Teewah Village and the Noosa River) and Noosa NP. These areas contain the primary ground parrot habitat of heath and sedgeland communities (McFarland 1989). Within this study area, ground parrots have been previously surveyed systematically by McFarland (1989) and Spearritt & Krieger (2007), using the listening survey methods described by McFarland (pers comm. and unpublished reports from 1989, 2001a and b, 2003 and 2004) over a period of approximately 20 years.

Survey methods

Listening surveys and deployment of Bioacoustic Recorder (BAR) units were undertaken between July and September 2020, and BARs again deployed between July and October 2021. The BAR sampling rate was 16-bit samples at 44.1 kHz, with a gain of 50 dB. Microphones attached to the units had wide frequency responses (±2dB from 80Hz to 20kHz or ±3dB from 10Hz to 15kHz) with built-in 20dB class A pre-amp. The BARs were timed to record evenings for one hour, commencing 10 minutes prior to civil sunset, and mornings for one hour, finishing 10 minutes after civil sunrise (Hines *et al*. 2017). Recordings from BARs were analysed using Raven Lite™ and Raven Pro™ software to obtain sonograms of ground parrot calls (Figure 4). The sonogram window was adjusted so that the area between 2 and 7 kHz on the vertical axis was maximised and the Fast Fourier Transformation adjustment set variably to 2,000–8,000 to sharpen images. Listening surveys were conducted at similar times, such that both automated units and listeners were able to record start and finish times of calling around the dusk–dawn periods and the number of calls heard.

McFarland (1991b) recognised seven different call types: four that could be heard throughout the year; and three only heard during the breeding season, associated with the nest. Chan & Mudie (2004) suggested that 11 call types could be identified from mainland Queensland. In the field, calls were easily identified by observers, with minor possible confusion with other species (e.g. scarlet honeyeater *Myzomela sanguinolenta*). Individual calls were identified using Raven software as a series of ascending notes and syllables, with monotone notes within syllables, mostly within the 4–6 kHz range (Figure 4). Individual notes and syllables were not tallied, but it was sometimes difficult to discern when the calls of individual birds started and finished, further confounded by individual bird calls occurring simultaneously. As a result, subjective decisions were sometimes required to differentiate individual calls.

For each morning and evening survey, the number of individual calls (trains of syllables and notes comprising a call), irrespective of type (e.g. single note rising, double note ascending, and others; McFarland 1991c; Chan & Mudie 2004; Hines *et al*. 2017) were tallied to produce a total value for each listening/detection period. If acoustic conditions were suitable, the number of calls, combined with the duration of calling, provided a call index (number of calls per 10 mins), a probable range for the number of birds calling and an absolute number estimate (according to the formula: ground parrot number = 0.127 x Call Index + 1.62) (McFarland 1991c; McFarland in Spearritt & Krieger 2007).

Survey sites

All sites monitored for ground parrot were selected on the basis that the habitat was considered suitable, as described by McFarland (1989, 1991a) and Spearritt & Krieger (2007), and that historical comparison sites were located nearby. Ground parrot records were obtained from the Queensland WildNet database for wildlife (WildNet) and historical sites were mapped using the associated WildMap application.

In 2020, a total of 32 sites was monitored for ground parrot calls (Figure 5), including 19 sites at which observers listened for calls and recorded in both a dusk and dawn session as a minimum. At the other 13 sites, BARs were deployed for varying periods (9–31 days) between July and September. Two sites (one listening, one recorder) were surveyed on one evening only in Noosa NP. Burnt areas were monitored at 15 sites and unburnt at 17 sites. One burnt site was a result of a management burn in 2020, after the 2019–2020 fires and before monitoring began.

In 2021, a total of 19 sites was monitored only at Cooloola using BARs for varying periods of time (22–112 days) between July and October. Eleven of these sites were previously surveyed in 2020. Five sites were located in burnt areas and 14 in unburnt areas, with the intent to optimise capture of the variability in site occupancy across the Cooloola landscape. A selection of recording sessions was analysed from each recording unit.

Because BARs were deployed over extended periods, they produced multiple estimates of the numbers of calls/birds at each site. Comparisons between burnt and unburnt treatments were based on the maximum number of calls recorded for a recording session, as the use of averages could significantly underestimate population occupancy.

Whilst ground parrot vocalisation can be heard up to 500–800m away dependent on weather and terrain (McFarland 1989), a radius of 350m accounts for acoustic interference (following Spearritt & Krieger 2007). The maximum effective listening area based on the 350-metre radius was up to 38.4ha, but this was calibrated by available habitat within the theoretical detection area to calculate maximum densities of individual ground parrots per 10ha using the formula of McFarland (in Spearritt & Krieger 2007).

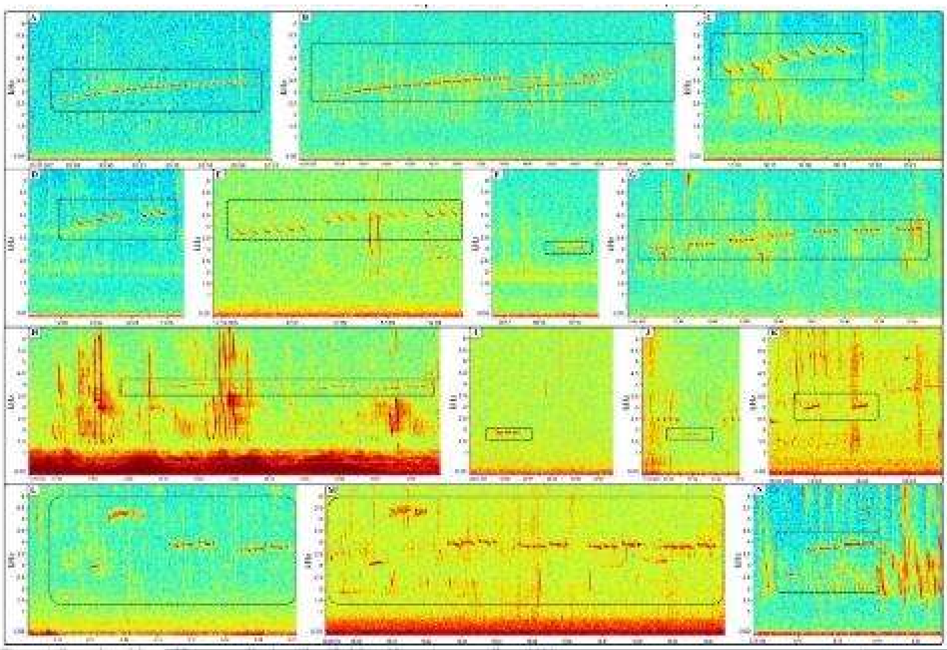


Figure 4: Sonograms of the range of ground parrot calls from Cooloola 2020, plotted as frequency (Kilohertz) against time in seconds.

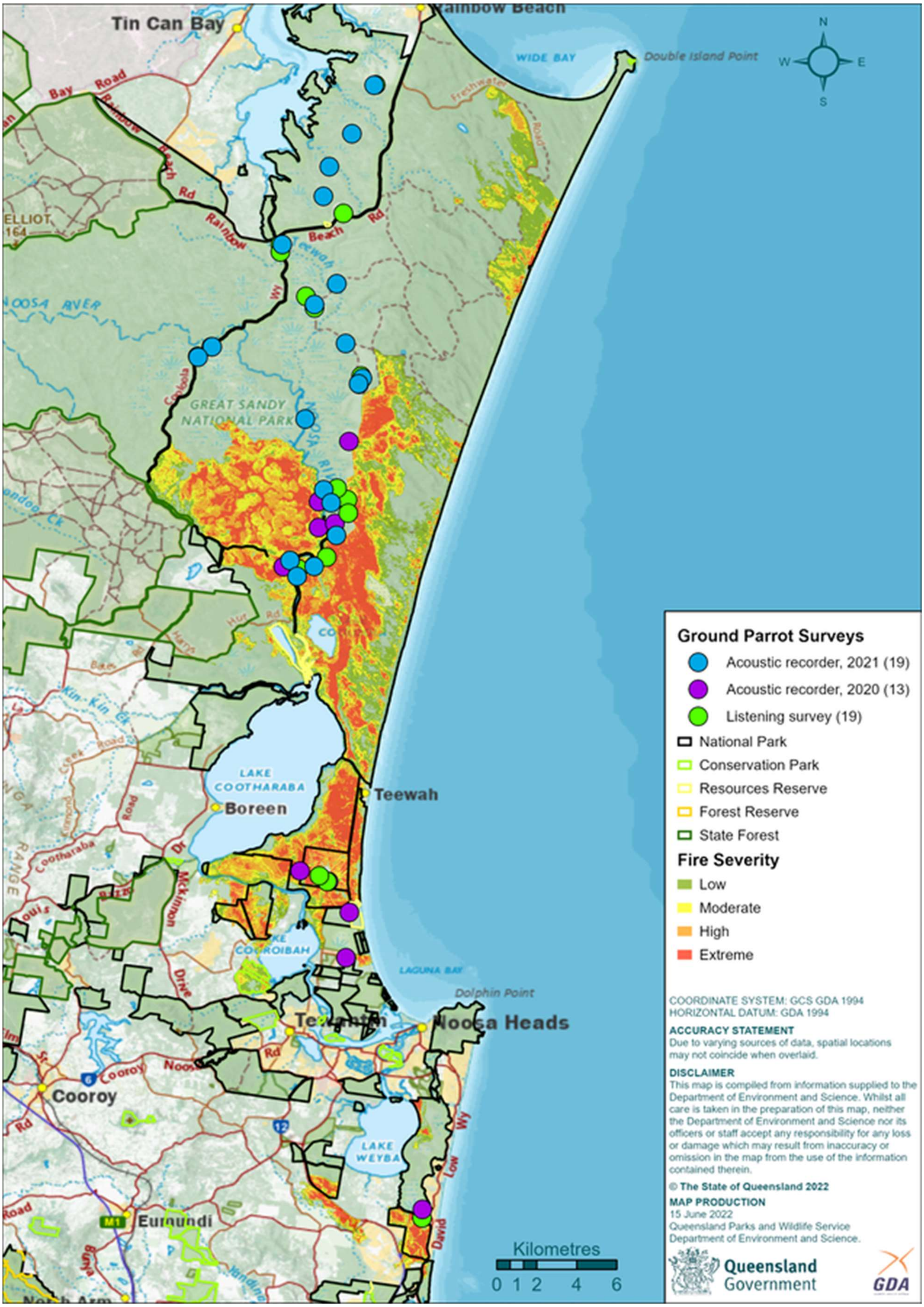


Figure 5: Location of monitoring sites for ground parrot calls at Cooloola, Noosa NP and Noosa North Shore.

3.1.3 Survey results

Approximately 728 hours of recordings (both morning and evening at 32 sites) from BAR recordings and observer listening sessions in 2020, and 166 hours from BAR recordings in 2021 (at 19 sites) were analysed. Ground parrots were recorded in 323 (44%) and 119 (72%) sessions in 2020 and 2021, respectively (Appendix 1, Table A1.1).

Across all sites, the number of calls ranged from 0–211 for a listening session, and 0–532 using acoustic recordings. The maximum number of calls (532) was recorded from a site that burnt in 2019 on the Noosa North Shore, adjacent to an airfield, during a calling session that lasted approximately 52 minutes. Whilst the site was burnt, birds occurring within unburnt habitat would have been within detection range.

Diel call rhythms

Ground parrots can be heard calling at any time of the day, particularly when overcast, albeit not commonly. Almost all calling occurs within limited time periods at dawn and dusk. Hines *et al*. (2017) tapped into sound windows of one hour around civil sunrise and civil sunset to assess the practicability of using acoustic recorders to detect ground parrots. To further investigate the distribution of calling across these hour windows, data recordings were pooled from seven sites surveyed in 2020: five sites contributed data to the analysis for mornings and all seven sites contributed to the analysis for evenings. For each site, the number of ground parrot calls recorded in each minute of the recording session was noted, tallied across recording sessions, and then pooled from each of the sites to provide vocalisations per minute for each minute of the 60-minute recording sessions (Figure 6). A total of 355 calls at dawn and 1,698 calls at dusk were used in these analyses.

The dawn peak in calling occurred at 48–49 minutes into the recording session, just prior to civil sunrise which was at 50 minutes. The dusk peak in calling occurred at 9–10 minutes into the recording session, which aligned with civil sunset at 10 minutes. The spread of calling across the dawn detection window was greater than for dusk calls. From the data it appears that morning calls could occur before recording began, but this was considered unlikely. It is more likely that calls could occur after the dawn recording sessions, which was substantiated by the occurrence of calling throughout the day. Calling may also occur prior to the dusk recordings; however, given the decline in the number of calls around the 30-minute mark, calling after the recording period was deemed unlikely; no calls were recorded after the 39th minute into the hour-long recording session at dusk.

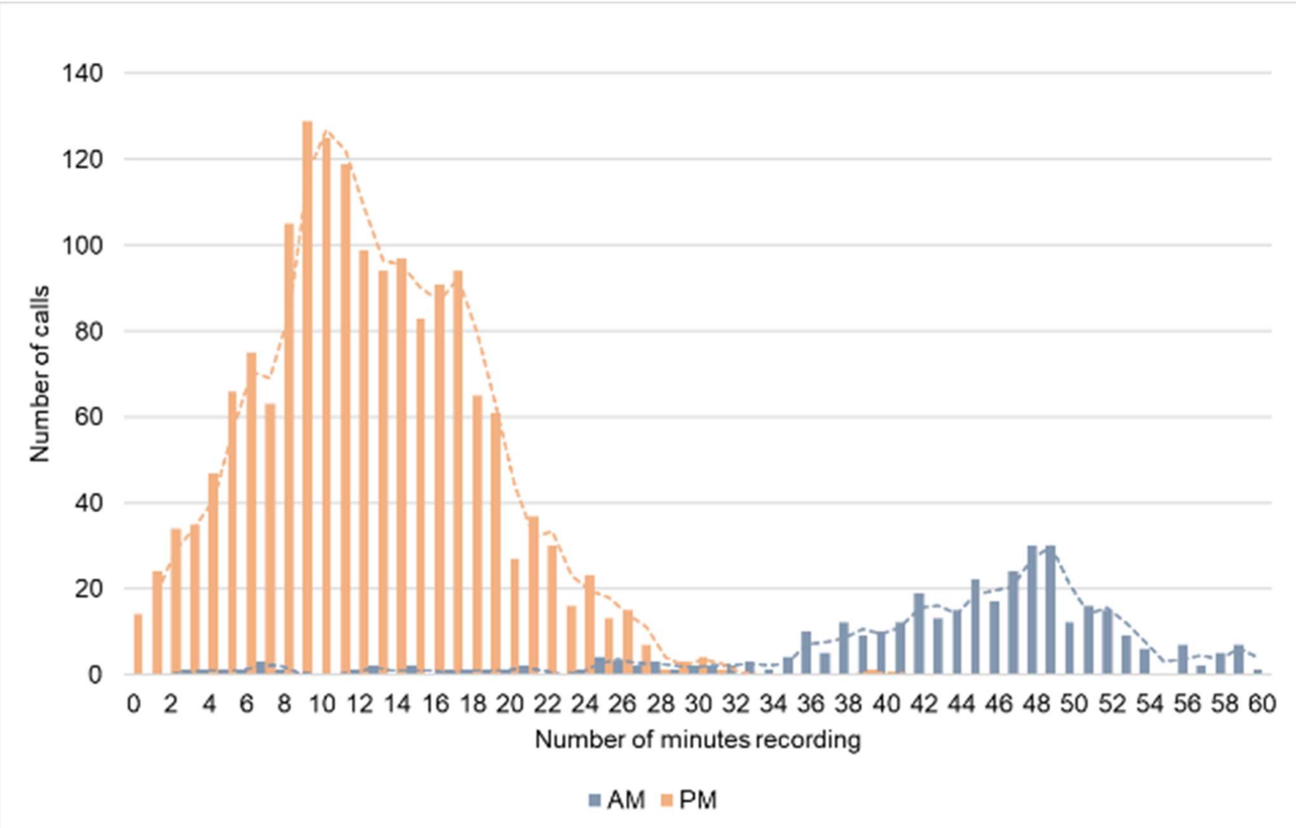


Figure 6: Total number of calls detected per minute of each one-hour bioacoustic recording pooled across seven sites (AM=5 samples, PM=7 samples) in 2020.

Call detection

Mean call indices (McFarland 1991c; Spearritt & Krieger 2007) recorded at BAR sites were higher and had higher variability compared with listening sites (Figure 7). Since BARs operated over extended periods, this increased the likelihood of recording higher numbers of birds. It also increased the sample size for each site leading to greater variability in recorded numbers, as demonstrated by the larger standard error bar for BARs compared to listening sites (Figure 7). For the purposes of this study, statistical difference between means was not significant (t= 0.8, df=30, P>0.05). It is acknowledged, however, that one-off surveys may underestimate the occurrence and abundance of ground parrots given the high variability that occurs in detection between sampling days.

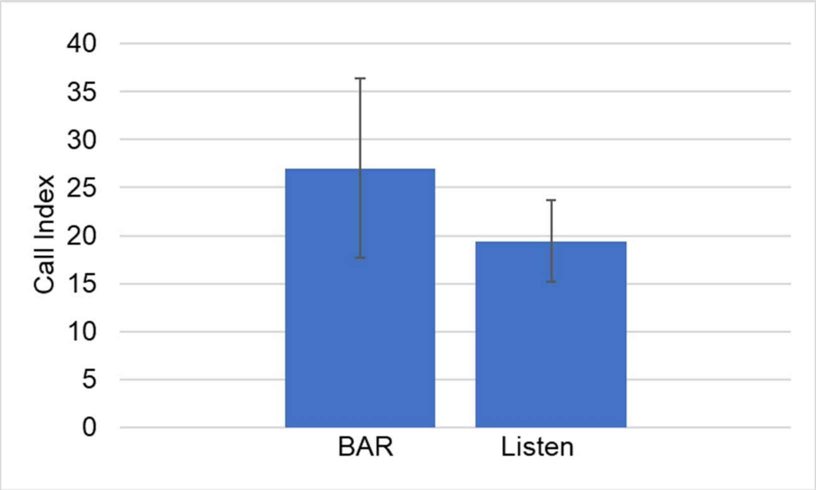


Figure 7: The mean call index per site according to detection either by bioacoustic recorder (BAR) or by physical listening in 2020, ± one standard error of the mean. Call indices per site were based on the maximum number of calls recorded in a session from the recording period for each site.

Across the breeding period (July–September), the number of calls heard at dusk and dawn was variable between days, as illustrated across pooled listening sites (Figure 8) and at one acoustic monitoring site where recording occurred every day over the set recording period (Figure 9). In general, there were fewer calls heard during dawn surveys than at dusk. The total numbers of calls heard through the breeding period in 2020 at 11 BAR sites were 2,387 calls during dawn recordings and 8,741 calls during dusk recordings, with this disparity also reflected at one site (Figure 9). Nevertheless, more calling was recorded at dawn than dusk for some acoustic recorders.

Analysis of sites over equivalent periods indicated that call duration was slightly longer during the dawn chorus by four minutes on average (means: July = 19 mins, Aug = 21 mins, Sep = 11 mins) than during dusk (means: July = 15 mins, Aug = 15 mins, Sep = 7 mins).

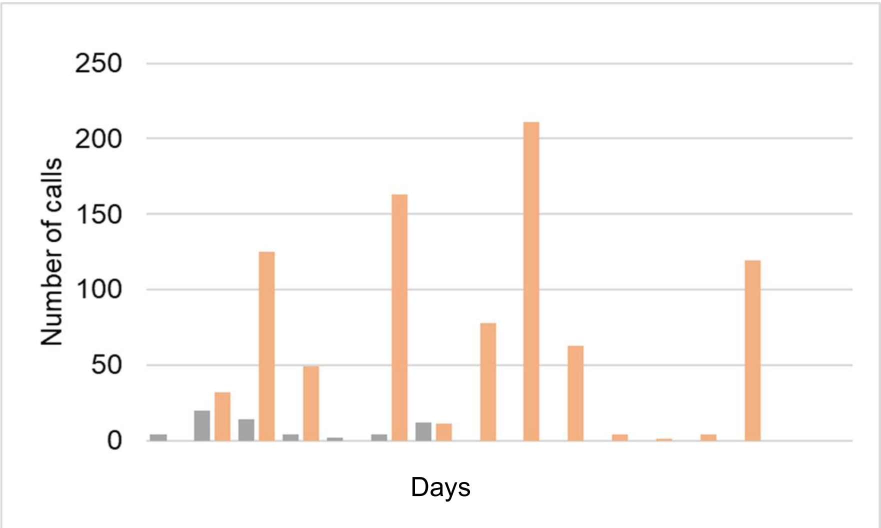


Figure 8: Number of ground parrot calls heard in the dawn (■) and dusk (■) listening session for pooled sites between 2 July and 16 August 2020.

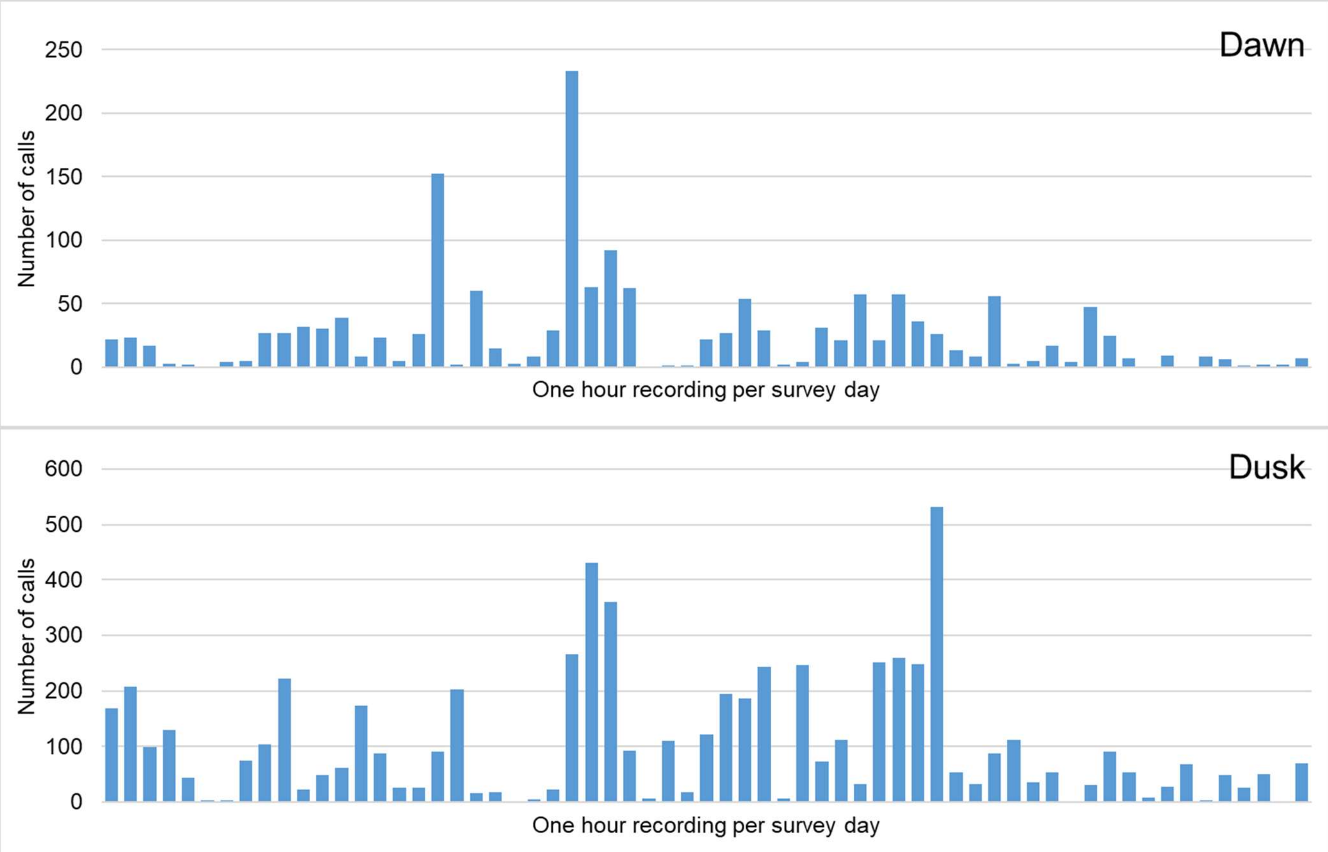


Figure 9: Number of calls recorded in each hour of recording between 2 July and 3 September 2020 for an unburnt site adjacent to an airfield on the Noosa North Shore.

Unburnt versus burnt sites

In 2020, ground parrots were detected at all sites that were not burnt in the 2019–2020 fires but were absent from almost a quarter (four sites) of all sites that did burn (Figure 10). However, the actual status of ground parrots at one burnt site is unclear because of the proximity to unburnt habitat, which would have been within detection range of the recorder. Birds were observed feeding on burnt ground at this site during the calling period. A lack of calls recorded at another site was possibly compromised by a brown falcon *Falco berigora* hunting in a burnt area during the listening session. The calculated mean maximum number of birds per site was also, on average, higher in the unburnt sites, and showed less variation in size among sites (Figure 11).

In 2021, ground parrots were present at all five burnt sites, albeit in very low numbers, except for a site in the northern section of Cooloola on the Old Pump Station Rd (PBR0024, maximum of 49 calls recorded), which was not burnt in the 2019–2020 bushfire but which was burnt in a management burn in 2020 and which had recorded zero calls immediately post-burn in 2020. Ground parrots were recorded in all sites unburnt in 2019 except for one, also in the northern section of Cooloola along the Roy Weber firebreak (PBR0025). However, low calling rates were experienced at two other sites unburnt in 2019 (a site just to the north of Dutgee near the Noosa River, PBR0032, and at Joe's Gully on the Flood Plain firebreak, PBR0005).

Four of the 15 sites that were burnt in 2019 and monitored in 2020 were resampled in 2021 (Appendix 1, Table A1.2). One site increased in the maximum number of calls (Old Pump Station Rd site, PBR0024 – from zero to a maximum of 49 calls [as detailed above]); one site stayed approximately the same (Eurobi Rd, PBR0027, PBR0028 – from 17 to a maximum of 20 calls); and two sites decreased (Camp 2 Site, PBR0001 – from 78 to 14 calls; and the Heli Pad Site, PBR0006 – from 79 to a maximum of 16 calls).

Historical record of burnt sites and present numbers

Calculated numbers of individuals from McFarland's formula (in Spearritt & Krieger 2007) were compared with historical records available from the Queensland Government WildNet database (Appendix 1, Table A1.2). Sites from the historical record were selected on the basis that they were no greater than 800m distant from sites surveyed during this study; given that calls could sometimes be heard over approximately 800m if conditions were good (McFarland 1989). Most of the comparison sites were derived from McFarland's surveys, but there were a few that were made by Cecily Fearnley, Jim Porter, the Conservation Resources Unit, WA Museum, DEH SEQ Database and one during an EIS, as identified in the WildNet database. It is possible that many of abundance of ‘1’ records were records of presence rather than a real estimate of the number.

Forty sites were monitored across the 2020–2021 period. Four sites burnt in 2019 and one site unburnt in 2019 recorded absences of ground parrots. All sites recorded previous occupation by ground parrots, some dating back over approximately 20 years. Sites that picked up ground parrots where previously unrecorded could not be ascertained since WildNet does not store absences. High abundances (>3 individuals) were historically detected at 21 out of 32 sites (66% of sites), while high abundances were detected at 25 out of 40 sites (63% of sites). Four of the historically high abundance sites had declined in abundance by more than one individual per site (10% of sites) in 2020–2021. One of the declining sites occurred in the area burnt in 2019–2020, and the rest were unburnt. Five of the historically abundant sites had increased by more than one individual per site in 2020–2021 (12% of sites). Two of the increasing sites occurred in the area burnt in 2019–2020, and the rest were unburnt. On balance, recent bushfire did not appear to affect the abundance of ground parrots in high-use areas.

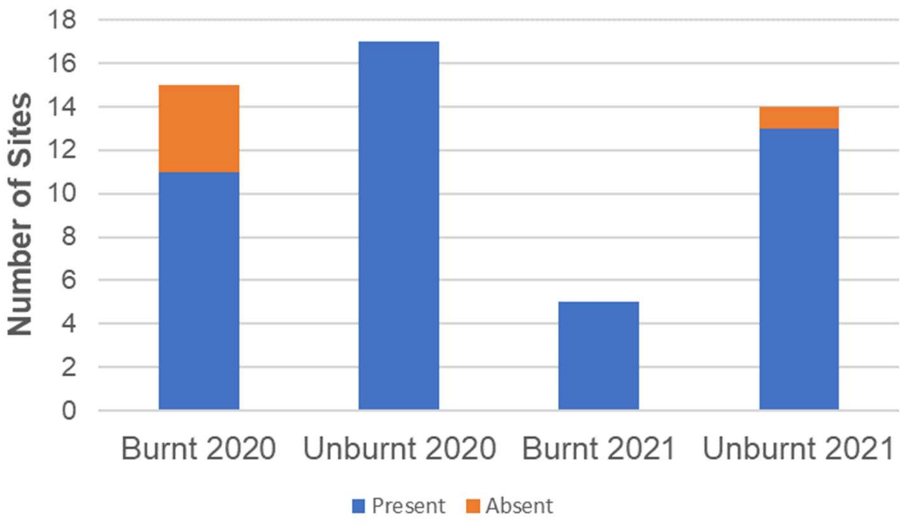


Figure 10: Detected occurrences and absences of ground parrots from burnt and unburnt sites, irrespective of method of detection and numbers detected. 2020: n = 15 sites burnt and n =17 sites unburnt. 2021: n = 5 sites burnt and n = 14 sites unburnt.

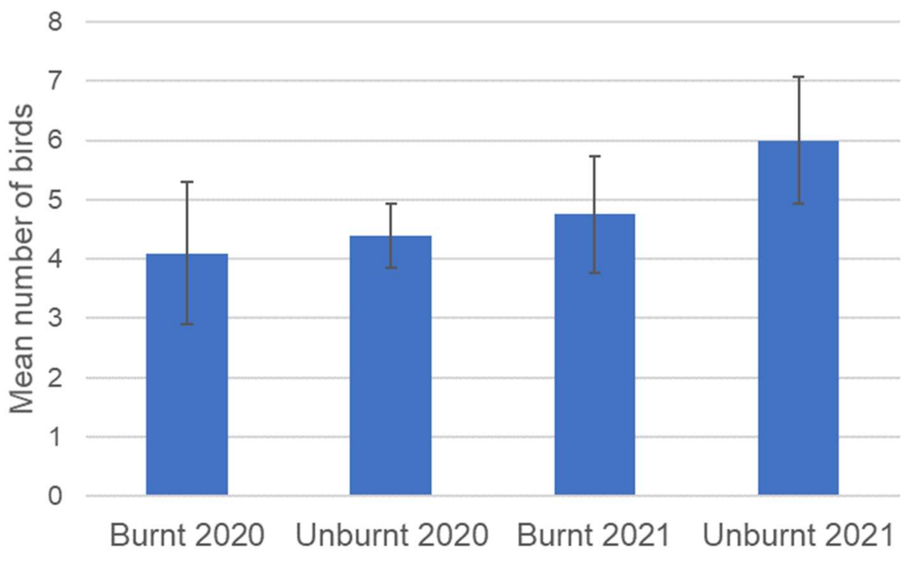


Figure 11: Mean maximum numbers (±1 standard error) of ground parrots per site, calculated for burnt and unburnt sites. Calculations used a formula from McFarland (1991c) and is based on the maximum number of calls recorded per session for each site and duration of calling.

Occupied–unoccupied sites in the landscape

Across the sites surveyed, 84% were occupied by at least one ground parrot, with levels of occupancy varying considerably in the landscape. High calling indices were recorded mostly in the north of Cooloola where there was no impact from the 2019–2020 fires. There was a mix of burnt and unburnt habitat in the south of Cooloola adjacent to the airstrip on Noosa North Shore, with a high amount of calling from the unburnt area. A low calling rate and an absence of calling were recorded in Noosa NP in the south of the study area; noting that these responses were based on a single night of recording at each site.

Historical records indicate that the abundance of ground parrots has typically been higher in the northern section of Cooloola, with lower numbers toward the south in the vicinity of the 2019–2020 fires (Appendix 1, Table A1.2).

Density calculations based on the maximum numbers of ground parrot detected at each site per 10ha were averaged across sites. The mean density was 2.4 per 10ha (s.e. ± 0.3, n= 40) and ranged from 0 to 8.6 birds per 10ha across the whole study area. For Cooloola and Noosa North Shore only, mean density was 2.5 per 10ha (s.e. ± 0.3, n= 38) and 95% confidence limits of 1.9–3.1 individuals per 10ha.

3.1.4 Discussion

Ground parrots exist within fire-tolerant habitats, and relationships have been drawn between their occurrence and fire frequency. Habitat preference by ground parrots changes with time since fire (due to temporal changes in vegetation structure and seed availability) peaking at five to eight years after burning, and changes at a seasonal level with dispersal and breeding (McFarland 1991c). Ground parrots can also be found in their preferred habitats soon after fire and up to at least 20 years post-fire. This broadly corresponds with the peak of plant seed abundance between two-and-a-half and eight years post-fire. Breeding too appears to be influenced by age of vegetation post-fire, with breeding recorded within patches of dry coastal heath not burnt for at least three or four years. McFarland surmised that habitat 8–10 years since fire provided best on offer, but others have suggested that older seral stages are also important (e.g. Baker & Whelan 1994; Baker *et al*. 2010).

To date, few studies have utilised automated recording of vocalisations of ground parrots to study the bird's behaviour and ecology in relation to fire. Automated acoustic recorders were utilised in this project as a cost-effective sampling technique. The results showed that calling rates differed between mornings and evenings, with higher calling rates in the evening. There may have been masking of morning calls due to dawn choruses. Across the breeding season calling rates varied considerably across days, particularly at sites where bird numbers and calling rates were highest. Ground parrots were recorded at most sites surveyed and presence–absence was not noticeably affected by the bushfire, approximately six months later. The 2019–2020 fires primarily impacted only a section of the preferred habitat of ground parrot in Cooloola and on the Noosa North Shore. Whilst the highest densities of ground parrots appeared to occur north of the fire extent, this was not considered to be due to the 2019–2020 fires. Based on the estimates of ground parrot density across the sites, and of suitable habitat, the population of the Cooloola–Noosa North Shore area has maintained a size consistent with previous estimates by McFarland (1989).

Sampling and sampling biases

It is likely that most calls are captured by the hour windows of recording that has been established as the most suitable for detecting ground parrots (McFarland 1991b; Hines *et al*. 2017). However, sampling during early morning and late afternoon revealed that calling rates vary across the window of investigation. The link with civil twilight at dawn and dusk is extremely useful, and while calling was detected throughout the hour recording windows (for dawn recording sessions at least), peaks occurred at civil dawn and dusk. There are distinct differences between morning and afternoon calling rates, with calling rates in the afternoon generally better than in the morning (cf. McFarland 1991b), and this has important implications for targeted sampling.

On a seasonal timeframe, calling rates varied considerably between days, even at the most used sites. While it is likely that weather conditions contribute to variability in the rate of calling and the ability to detect calls, environmental factors (such as ground wetness, night light) and biological factors (such as plant food availability, movement of birds between areas seeking food or escaping predators, differences in motivational states associated with breeding, and number of birds present) may also contribute to such variability.

Considering the role of biological factors affecting calling rates, McFarland suggested that within season or over short time periods ground parrots are sedentary, but habitat use changes seasonally (McFarland 1989). McFarland's (1991a) tagged birds in Cooloola changed their foraging sites every few days, sometimes revisiting areas. It is likely then that parrots move around within their home ranges and travel over distances that preclude detection by acoustic recorders. Alternatively, movement by subadult individuals may also affect calling rates between days. Jordan (1987) found that young birds move over larger areas than adults and that birds occasionally 'disappear' from areas, returning several days later. Whatever the reason for daily variation, this is likely to lead to false negative occupancy assessments in the short term, so care is required when interpreting results from 'one-off' listening surveys.

The choice of maximum calling rates to measure occupancy was made because of the variability that occurs in calling rates, even daily, which could lead to underestimation of bird numbers. It assumes that on lower calling days birds are present but are either beyond the detection range of recorders or are poorly motivated to call. The decision was therefore made to err on the side of capturing abundance on days when it was apparent that all birds were vocalising, although this approach fails to recognise that maxima may sometimes be overestimated due to juvenile/subadult birds that are highly mobile in the landscape. Nevertheless, the effects of fire on ground parrots after the 2019–2020 fires were analysed by examining presence–absence of calling and maximum rates of calling at sites that were burnt and unburnt. Maximum calling rates were used to calculate and analyse calling indices and potential abundances for each site.

The impacts of fire, pests and people

As wildlife managers, it is valid to be concerned about direct mortality and the indirect effects from fire on ground parrots through habitat alteration in the short and long term (Lindenmayer *et al*. 2016). However, eastern ground parrots appear to be resilient to fire, having been recorded in most seral stages of habitat post-fire (McFarland 1989; Spearritt & Krieger 2007). Birds may disappear immediately post-fire, but it has been argued that if fires burn patchily and if habitat has the capacity to regenerate then effects on the subspecies will be minimised.

This study was hampered by a lack of pre-fire data from sites sampled across the area burnt by bushfire. Data on presence of ground parrots across the study area for pre-fire comparison were available from the State database (WildNet) but was not structured by the fire footprint. The WildNet database does not contain absences and nor does it hold records from a consistent sampling strategy. The WildNet data, supplemented by data collected from 2020–2021, suggest that most of the core areas for ground parrot currently exist outside of the footprint of the 2019–2020 fires, except on Noosa North Shore. It seems, therefore, that a large part of the population is likely to have avoided being impacted by these fires.

In sampling, sites burnt in 2019–2020 were not distributed randomly through the landscape but were primarily distributed along the lower Noosa River, while the sites unburnt were distributed widely across the landscape. In comparing occupancy within burnt and unburnt sites there may be bias introduced by the distribution of sites. Of the sites that were burnt in 2019–2020, two-thirds of sites had ground parrots present, albeit at typically low numbers. It was also noted that an area burnt in a management burn after the 2019–2020 fires in the north of Cooloola was quickly recolonised by ground parrots in the breeding season. Given that most of the area in the vicinity of this site was unburnt, a source of birds was available for reoccupation. These observations fortify the idea that ground parrots can live with fire if a heterogeneity of seral stages in the landscape is maintained.

Pigs were detected on bioacoustic recorders at and near monitoring sites. Habitat disturbance by pigs was also observed in ground parrot habitat. Whilst this project did not document evidence of direct interference or competition with pigs, nor declines in populations due to pigs, impacts to habitat and hydrology from pig foraging behaviour, as well as possible predation on nesting birds or chicks, presents a threat to this subspecies. Equally, foxes and feral cats present a threat of predation to ground parrots, with a greater risk likely in Noosa NP given the proximity to urban zones.

In addition to listening surveys undertaken by the Queensland Herbarium and QPWS, BirdLife Sunshine Coast have been recording ground parrots on unburnt sites at Pump Station Road, where passing vehicles have readily flushed ground parrots from vegetation (Col Lawton pers. comm.). This highlights a further threat to ground parrots from recreational vehicles driving off tracks, a situation observed on the Pump Station Rd (G.C. Smith and M. Mathieson pers. obs.). In conclusion, it is noted that McFarland (1991c) detected a general decline in parrot distribution, which raised concerns for the long-term survival of this threatened subspecies, now exacerbated by the increasing risks associated with more frequent and intense fires due to a changing climate.

Impacts, population densities and population size

McFarland (1989) noted that the distribution of ground parrots across the Cooloola–Noosa-Sunshine Coast landscape occurred more within the common *Caustis–Empodisma* heathlands than in the less plentiful *Ptilanthelium* heathlands. He found parrots in most heathlands in Cooloola NP and on K'gari (Fraser Island). The most suitable habitat mapped by McFarland (1989) is considered to include Regional Ecosystems (Queensland Herbarium 2019) that include, but are not limited to, RE 12.2.12 (Closed or wet heath ± stunted emergent shrubs/ low trees on poorly drained coastal dunes and sand plains), RE 12.2.15 (Closed sedgeland in coastal swamps and associated water bodies, but not RE 12.2.15a or RE 12.2.15f), RE 12.3.13 (Closed heathland on seasonally waterlogged alluvial plains near coast) and RE 12.9-10.22 (Closed sedgeland to heathland with emergent trees). Spearritt & Krieger (2007) also suggested that these were favoured ecosystems on the Sunshine Coast.

Habitat for ground parrot has also been modelled in Maxent (Phillips *et al.* 2006; DES 2019) as outlined in Appendix 5 of Meiklejohn *et al.* (2020), but it is suggested that it overestimates the available amount of habitat. The model used records of precision better than 2000m post-1975 that had been compiled for the purpose of Biodiversity Assessments by the Queensland Department of Environment and Science and additional records held in WildNet. A mask of Queensland's roads network was used to down-weight subspecies records collected along roads to have half the value of records collected away from roads. Models were constrained within an occurrence mask, defined by a buffer of 200km around a convex hull encompassing all records. Models were based on seven variables: annual mean temperature, temperature seasonality (coefficient of variation), annual precipitation, mean moisture index of the lowest quarter moisture index, broad vegetation group (BVG 1:1M), land zone and a terrain ruggedness index (after Riley *et al.* 1999). Land zone and pre-clearing broad vegetation group were derived from the pre-clearing Regional Ecosystem mapping. Land zone provides a high-level classification of substrate and geomorphology into 12 groups (Neldner *et al.* 2019a), and broad vegetation group is a high-level classification of vegetation composition at the 1:1M scale (Neldner *et al.* 2019b). Broad vegetation group is classified at a coarser scale than Regional Ecosystem and so by definition is not as refined a measure of preferred habitat.

Based on the density estimate of ground parrots across the Cooloola landscape (including the Noosa North Shore), population estimates were derived using the habitat area approximations of McFarland (1989) and the Maxent model. Based on McFarland's estimate of 9,350ha of habitat across Cooloola and the estimate of density, a population of approximately 2,337 (95% confidence limits: 1,776–2,898) individual ground parrots was calculated. Maxent modelling estimated an area of some 33,444ha. Combined with the density estimate there is a suggestion that the number of individuals could be up to approximately 8,361 (95% confidence limits: 6,354–10,367) individual birds, which is likely to be an overestimate.

As a comparison with the estimates, McFarland (1989) estimated a population size of approximately 2,900–4,900 birds in SEQ, with the majority in Cooloola, Wide Bay and on K'gari (Fraser Island). McFarland's (1989) estimates for Cooloola alone were 1,668–2,418 individual parrots based on mean values from heathland habitat where parrots were recorded and 2,165–3,131 individual parrots based on the inclusion of all potential habitat. McFarland (1991c) has previously referred to a general decline in eastern ground parrot distribution and abundance, which poses a concern for the long-term welfare of the subspecies. However, the estimate provided by this study suggests that the population is currently stable.

3.2 Southern emu-wren

3.2.1 Conservation context

The southern emu-wren *Stipiturus malachurus* is listed as Vulnerable under the NCA. The species' range extends from Tin Can Bay, Queensland, along the New South Wales (NSW) and Victorian coasts to Eyre Peninsula, South Australia. It also occurs in the south-west of Western Australia between Israelite Bay and Shark Bay, and in Tasmania. Declines have been recorded in Queensland and NSW populations due to habitat loss.

In Queensland, southern emu-wren are restricted to a population at Girraween National Park (Mathieson & Rintoul 1991) and the Teewah–Noosa Plain in Great Sandy National Park (Cooloola section). The species is known to occur in heath and swampland situations within Cooloola but is possibly under reported (Hobson 2008).

A significant proportion (>15%) of potential emu-wren habitat within Cooloola and Noosa NP was impacted by the 20192020 bushfires. Surveys were undertaken to assess the southern emu-wren population after these fires.

3.2.2 Survey sites and methods

A combination of listening surveys and acoustic playback of southern emu-wren calls was undertaken across 27 sites between July 2020 and March 2021 (Figure 12). Sites were selected in habitat suitable for southern emu-wrens, and in the vicinity of Pump Station Road into Teewah Creek, and the locations recorded on eBird (https://ebird.org/australia/species/souemu1/L1408971, accessed 17 December 2020). The exact location of survey sites remains confidential in order to protect the species.

Of the 27 sites, 10 searches for southern emu-wren using listening surveys, with call playback, were conducted at seven sites: five in Cooloola (which overlapped with acoustic recording sites); one in Noosa NP, and one in Toolara State Forest, adjacent to Cooloola. Three repeat searches occurred at one of the search/playback sites at Cooloola.

At 21 sites, BARs were deployed to monitor for calls: 20 sites in Cooloola and one site at the Teewah Landing Ground. These BARs were set utilising similar recording parameters to those deployed to detect eastern ground parrots (Section 3.1), except that the schedule of recording was set to listen/record for one hour at civil sunrise. Recordings from BARs were analysed using Raven Lite and Raven Pro software. Sonograms derived from published calls (e.g. Xeno Canto, Bird Observation and Conservation Australia) using Raven software (Figure 12) indicated that typical calls of southern emu-wren occur mostly above 8 kHz.

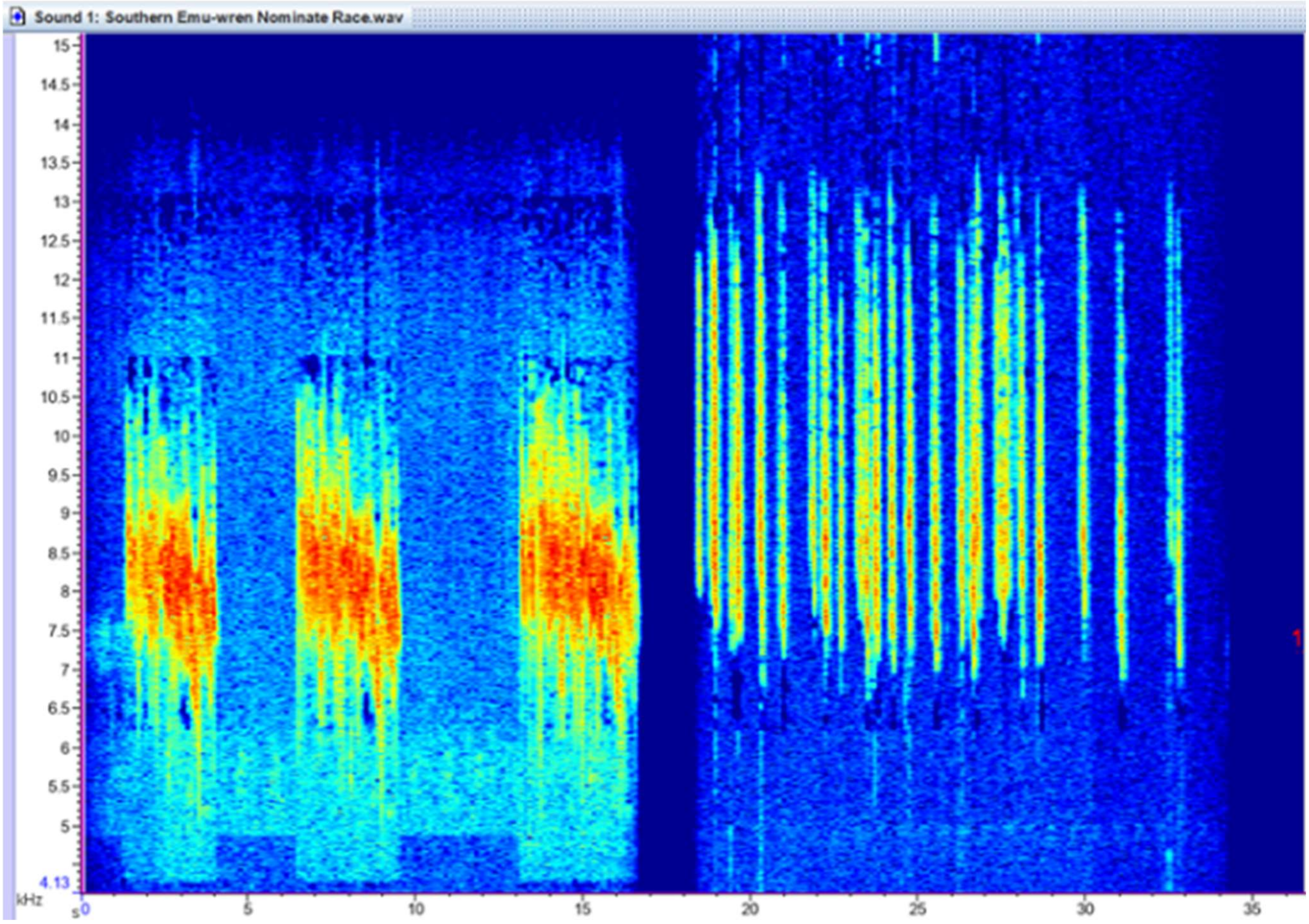


Figure 12: Sonogram of southern emu-wren calls derived from calls recorded elsewhere. (Image: Bird Observation and Conservation Australia)

3.2.3 Survey results

A total of 1,799 acoustic recording sessions of one hour each were conducted from July 2020–March 2021 across 21 sites. Given the extensive amount of data, the analyses will continue beyond this project. Initial results from listening surveys and analyses of acoustic recordings are presented here.

Southern emu-wrens were not detected from most sites surveyed across both burnt and unburnt terrain (Figure 13). No birds were detected during the listening surveys with playback of southern emu-wren calls, including the site where they are commonly seen in the upper Teewah Creek catchment (Moyra McCrae pers. comm.). However, this highly cryptic species was recorded at this site by other parties, indicating that sightings can be dependent on time of day and weather conditions.

During the studies, a southern emu-wren was incidentally recorded south-west of the main population in the upper Teewah Creek catchment (T. Eyre pers. comm.). The vegetation at this site is mapped as Regional Ecosystem 12.5.12 and consisted of *Eucalyptus racemosa*, *Corymbia intermedia* and *Lophostemon confertus* open forest with a subcanopy dominated by *Acacia disparrima*, *Alphitonia excelsa* and *Allocasuarina littoralis*; the ground layer varied from grass to areas dominated by patches of dense sedge/rushes and *Gahnia aspera.* The bird was seen in an area dominated by thick *Gahnia* 0.7 to 1.3 m tall. The numerous senescing *Allocasuarina* and *Acacia* subcanopy trees suggested that the location had not been burnt for some time, with the state-based fire scar mapping system having recorded the last fire scar for the area in 1990. Whilst this is the first record from this site, a nearby historical record in WildNet suggests that the species has utilised this general area for some time.

The use of acoustic recorders across 21 sites resulted in the detection of southern emu-wren calls at only two sites (one burnt site and one unburnt site; Figure 13). Neither of these detections was in an area where southern emu-wren had been commonly reported by the birding community. At the site in the upper Teewah Creek catchment where southern emu-wrens have been commonly seen, the acoustic recorder did not detect the species. This emphasises that southern emu-wrens are likely to be highly habitat specific and that their calls can be difficult to detect if the birds are not near the acoustic recorder.

It was not possible to identify any fire effects from the data analysed. The population occurring in the northern area of Cooloola is likely to be intact as it was not affected by the 2019–2020 fires. The extent of occurrence across the Cooloola landscape is not well known nor whether subpopulations of the species intersected with the 2019–2020 fires.

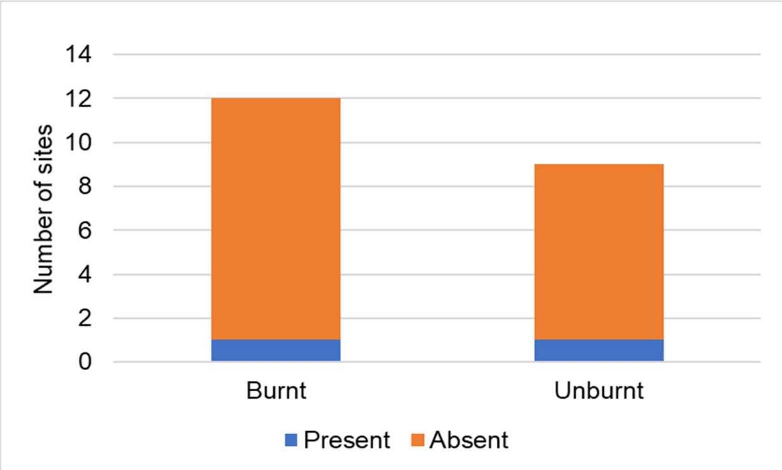


Figure 13: Number of burnt and unburnt sites in which southern emu-wren were present, as detected by automated bioacoustics recorders.

3.2.4 Discussion

The southern emu-wren is highly cryptic and difficult to detect. Across both burnt and unburnt sites, the level of detectable occupancy was low. The species has been regularly recorded outside of this project in a core area within the upper reaches of Teewah Creek that was not burnt during the 2019–2020 fires.

Southern emu-wrens continued to be sighted during 2020 in wet heath where previously recorded, with sightings of up to five birds on 30 August 2020 (Michael Daley unpublished data; Moyra McCrae pers. comm.), including an image captured (C. Lawton pers. comm.). On 2 November, one female adult and two juveniles were observed in tall timbered vegetation (Warren Bennet pers. comm.), although this locality was adjacent to more suitable habitat (Col Lawton pers. comm.) and the area was not impacted by the 2019–2020 fires.

Records of southern emu-wren from elsewhere within Cooloola (Hobson 2008; T. Eyre pers. comm.) and outside of the core area centred on the upper Teewah Creek catchment indicate that the species could occur more broadly across the Cooloola landscape and in vegetation other than low heath.

3.3 Recommendations

Reducing ongoing threats

- Reduce the risk of frequent, extensive and/or severe bushfires

  Eastern ground parrots require patches of heath and sedgeland at different post-fire ages (up to eight or ten years) across the landscape to ensure ongoing availability of suitable habitat and food resources. This can be achieved through rotational planned burning when the ground is moist, shortly after the wet season and at the beginning of the dry season, creating possibilities for further staged burning. Planned burns at the lower end of fuel hazard build-up that only cover 50 to 60% of the treatment area will provide the best opportunity for creating a diverse range of age-class structure and suitable plant life cycle diversity. The aim should be to create patchiness within the heath, both within and among burn blocks.

  The burning program underway at Cooloola aims to protect assets from bushfire and achieve ecological outcomes. It is conducted across blocks, which are scheduled to burn in any one burn season, depending on when fire management was last implemented. This program is appropriate for maintaining a diversity of seral stages for ground parrots in the landscape and to limit future threats of widespread bushfire.

- Protect unburnt habitat from fire

  For ground parrots, it is important to protect specific unburnt refugia until the burnt habitat has sufficient time to recover. Any planned burns east of Noosa River south of campsite 3 (Blocks 1, 2, 2b) for at least 5–8 years (McFarland 1991c) should be limited to a small percentage of the area to break up country and reduce any further risk of bushfire. Blocks 6a, 12a, b, c and d, unburnt in the 2019–2020 fires, should remain primary refugia for ground parrots in the short term. These areas have not burned since 2016 and could remain unburnt for at least a further three years to adopt the upper limit of the preferred burning regime for ground parrot (McFarland 1991c). It will also be critical to continue to preserve areas in a long-unburnt condition throughout the landscape and ensure protection from bushfire. The important areas for ground parrots appear in the north of Cooloola and in the Noosa Northshore area. Surveys have indicated that good sites are a rarity in the Sunshine Coast area, but at least two sites are well utilised around the Maroochydore airport (K. Aland pers. comm.).

  For southern emu-wrens, fire should be excluded from Pump Station Rd into the Teewah Creek pump station (park blocks 12a, b, c, d) and the status of the population should be assessed prior to any future planned burn.

- Reduce impacts of feral pigs

  Control of feral pigs is a priority, given the extensive impacts they can have on habitats and food resources.

- Reduce the risk of predation from cats and foxes

  Monitoring of cats and foxes is advised with appropriate control measures to reduce the risk to both southern emu-wrens and ground parrots, especially when these birds are breeding.

Ecological monitoring

- Continue to monitor ground parrots to track post-fire recovery changes in populations/site occurrence.

  Minimal requirements are to record presence/absence across sites used in this report every 2–5 years and/or prior to and following fire management activities.

- Monitor ground parrot populations to assess the effect of planned burns.

  Presence of ground parrots should not preclude burning activities (except as outlined below). Monitoring would aim to determine the bird's presence or absence before and after fire, to understand its spatial use of the landscape as a result of a fire. Follow-up monitoring can then clarify if eastern ground parrots do re-establish and utilise mosaic burn areas.

- Continue to monitor southern emu-wren populations.

  Minimal monitoring requirements are a continuation of the current survey methodology. Optimally, the number of locations surveyed would include more sites across the bird's preferred habitats.

Ecological research

- Ground parrot population dynamics.

  Aim to identify indicators and critical thresholds of population decline to guide conservation actions. Population modelling may be necessary with data from a highly structured sampling strategy.

- Investigate how fire and fire frequency might influence the distribution and abundance of southern emu-wrens.

4 Priority fish

4.1 Conservation context

Oxleyan pygmy perch

Oxleyan pygmy perch *Nannoperca oxleyana* is listed as Vulnerable under the NCA and Endangered under the EPBC.

Oxleyan pygmy perch has a restricted and fragmented distribution along the central region of Australia's east coast, with an area of occupancy of only 292km^2 (Butler 2019). It occurs in coastal swamps, streams and lakes in lowland wallum heathlands from Tin Can Bay in South East Queensland, south to Corindi in northern NSW (Pusey *et al*. 2004; Knight 2016). Habitat loss and degradation is regarded as the most immediate and ongoing threat for Oxleyan pygmy perch. Sand-mining, drainage and re-channelling of natural waterways, in-stream infrastructure, pollution and bushfires have also increased fragmentation of local populations. The only relatively safe populations are those present in protected areas; however, an increasing frequency of droughts and bushfires as a result of climate change will enhance the risk of extinction for localised populations (Knight 2016; Butler 2019).

Honey blue-eye

Honey blue-eye *Pseudomugil mellis* is listed as Vulnerable under the NCA and the EPBC and Endangered on the IUCN Red list (Brooks & Arthington 2019). Honey blue-eye has a restricted and highly fragmented distribution, with the area of occupancy estimated to be only 64km^2 (Brooks & Arthington 2019). An isolated population is known from Dismal Swamp, south of Shoalwater Bay, and approximately 390km to the south, it occurs in streams, lakes and coastal dune wetlands from Tin Can Bay, south to Mellum Creek, near Beerwah. It is also present on K'gari (Fraser Island) (Pusey *et al*. 2004; Brooks & Arthington 2019). The distribution of this species has been fragmented by residential development, forestry plantations and agriculture, and the spread of the invasive mosquitofish *Gambusia holbrooki*, as well as over-collecting for the aquarium trade, are key threats to the persistence of this species (Brooks & Arthington 2019).

Ornate rainbowfish

The ornate rainbowfish *Rhadinocentrus ornatus* is not currently listed as threatened under the NCA or EPBC, and therefore was not considered during the bushfire recovery prioritisation process. However, as it is classified as Vulnerable under the IUCN Red List (Arthington & Butler 2019) and is surveyed using the same methodology as that for the priority fish species, it was included in this report.

Ornate rainbowfish has a fragmented distribution within coastal catchments of eastern Australia from Rockhampton, south to Coffs Harbour, NSW. This species is also found on sandy islands off southern Queensland, including K'gari (Fraser Island), Moreton Island and North Stradbroke Island. The area of occupancy is estimated to be less than 2,000km^2, with threats to this species similar to those for the Oxleyan pygmy perch and honey blue-eye.

4.2 Survey sites and methods

Across Cooloola, priority fish species were sampled at 23 riverine, lacustrine or palustrine wetland sites from February 2021–May 2022 (Figure 14, Table 4). In total, 39 samples were taken, with 13 sites resampled up to three times. Sites were located within both fire-impacted and non-fire-impacted areas and were within the known ranges of the Oxleyan pygmy perch, honey blue-eye and ornate rainbowfish. To evaluate the potential for localised extinctions, sites were resampled if a species of interest was not recorded and the site contained historic records.

Fish sampling methodology was based on a standardised protocol described Knight *et al*. (2007) to align with the sampling efforts of prior records. At each site, 20 unbaited collapsible box traps (Figure 15) were set in a variety of habitat types at varying depths (ranging between 20 and 100cm) for 30 minutes. Box traps measured 250 x 250 x 450mm with 3mm nylon mesh and inverted funnel entrances at each end with 40mm openings. Traps were retrieved and fish removed and placed in buckets of aerated water. Electrofishing (Figure 15) was conducted with a Smith-Root model LR24, battery-powered, backpack electrofisher, using a 280mm diameter aluminium anode ring attached to a fibreglass handle, and a steel cable cathode. The electrofisher was set to pulsed direct current (DC) at 120Hz, with outputs of 250 to 400 volts depending on water conductivity. Multiple 150 second on-time shots were conducted in all accessible habitats, up to a maximum of eight shots (total 1200 seconds on-time). After electrofishing, all fish collected from both sampling methods were identified, counted, measured, and then released unharmed at the location of capture.

To measure water quality at each site, a YSI ProDSS instrument was used to sample physiochemical variables: temperature (°C), dissolved oxygen (DO; mg/L and % saturation), pH, conductivity (µS/cm) and turbidity (NTU). For sites sampled in 2021, water samples were also collected at each site to assess nutrient concentrations using pre-rinsed 50mL tubes. Samples for dissolved inorganic nitrogen (DIN; NO_3-N and NH_4-N), phosphate (PO_4-P), total dissolved nitrogen (TDN) and phosphorus (TDP) analysis were filtered through 0.45μm filters. An unfiltered water sample was also collected at each site for the measurement of total nitrogen (TN) and phosphorus (TP) concentrations. All water samples were kept refrigerated at 4°C while transported and stored frozen at -20°C in the laboratory prior to analysis at the DES chemistry centre. These samples will be analysed, and records will be available from late-2022.

Mean fire severity score was calculated for each study site sub-catchment derived from the Australian Hydrological Geospatial Fabric (AHGF) Geofabric dataset (Figure 16). An on-ground rapid-fire impact assessment of both the aquatic and riparian zone was undertaken at each site to provide ground-truthing of mapped fire severity and complementary data (Southwell *et al.* 2022). For riparian zone vegetation degradation and loss, bankside erosion, vertebrate pest damage and invasive plant encroachment were scored between 1 (none) and 4 (high). Aquatic zones were scored from 1–4 for ash and sediment deposition, vertebrate pest damage and invasive plant encroachment.

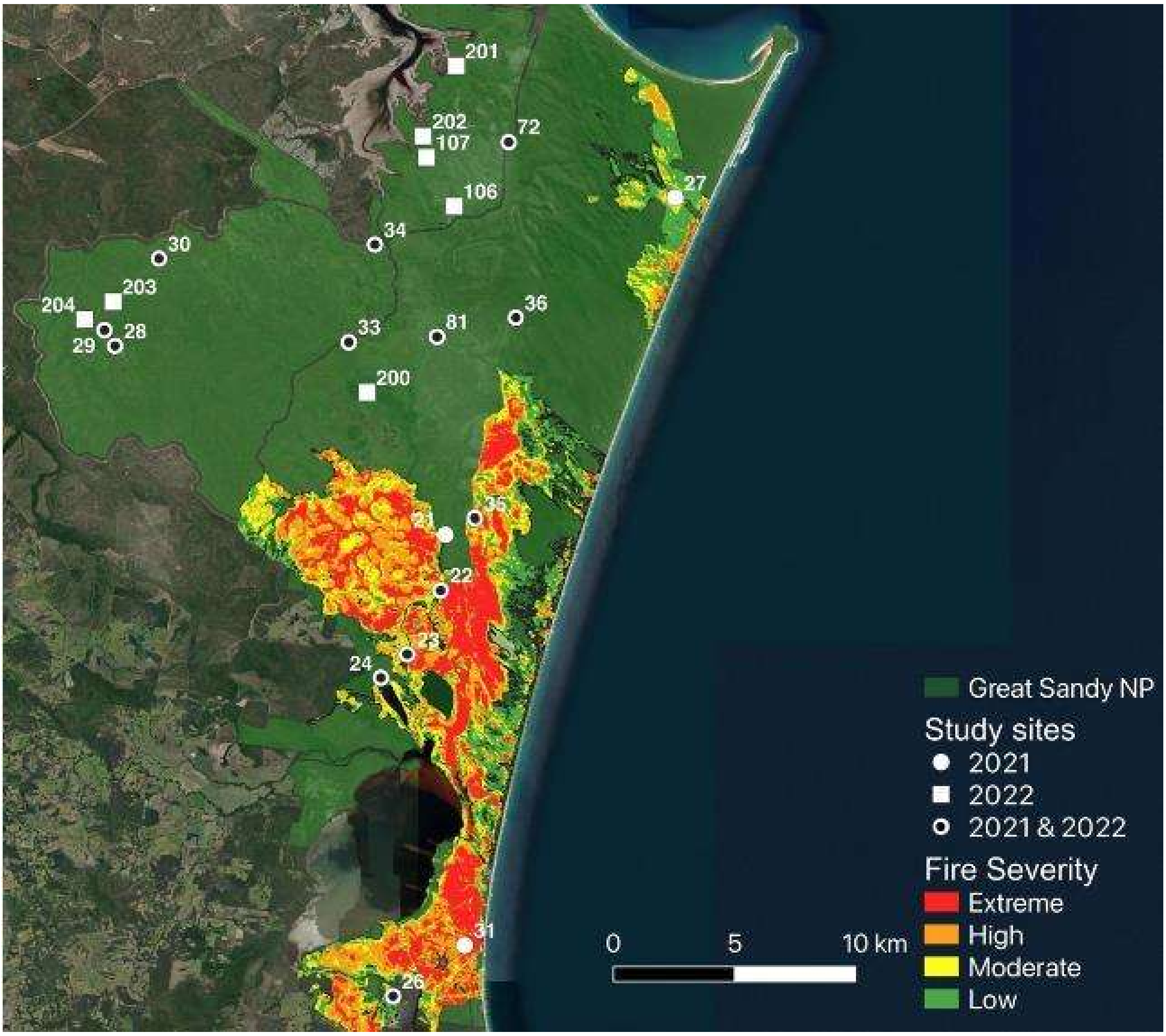


Figure 14: Location of monitoring sites for priority fish species, with respect to fire severity of the 2019–2020 fires.

Table 4: The number of sites and surveys across different wetland types and sites within or outside of the fire extent, for priority fish species from February 2021–May 2022. Refer to Appendix 2, Table A2.1 for more detail.

		Riverine		Palustrine		Lacustrine
	Total	Fire impacted	Not fire impacted	Fire impacted	Not fire impacted	Fire impacted
Number of sites	23	3	14	3	1	2
Number of surveys	39	6	24	5	1	3

Figure 15: Box traps deployed at Site 35 on the Noosa River (above) and electrofishing at Site 26 at the Lake Cooroibah Inlet (below).

4.3 Survey results

Eight of the 23 survey sites were affected by fire to varying degrees, with sub-catchment severity scores either 'low' (two sites) or high (six sites) (Figure 16). Fire severity categories to the riparian zone varied from 'none' to 'high' across the study sites (Figure 16). Within the aquatic zone, no sites were rated worse than 'moderate' severity, with 21 of the 23 sites scoring no fire impact due to ash, sediment and debris deposition.

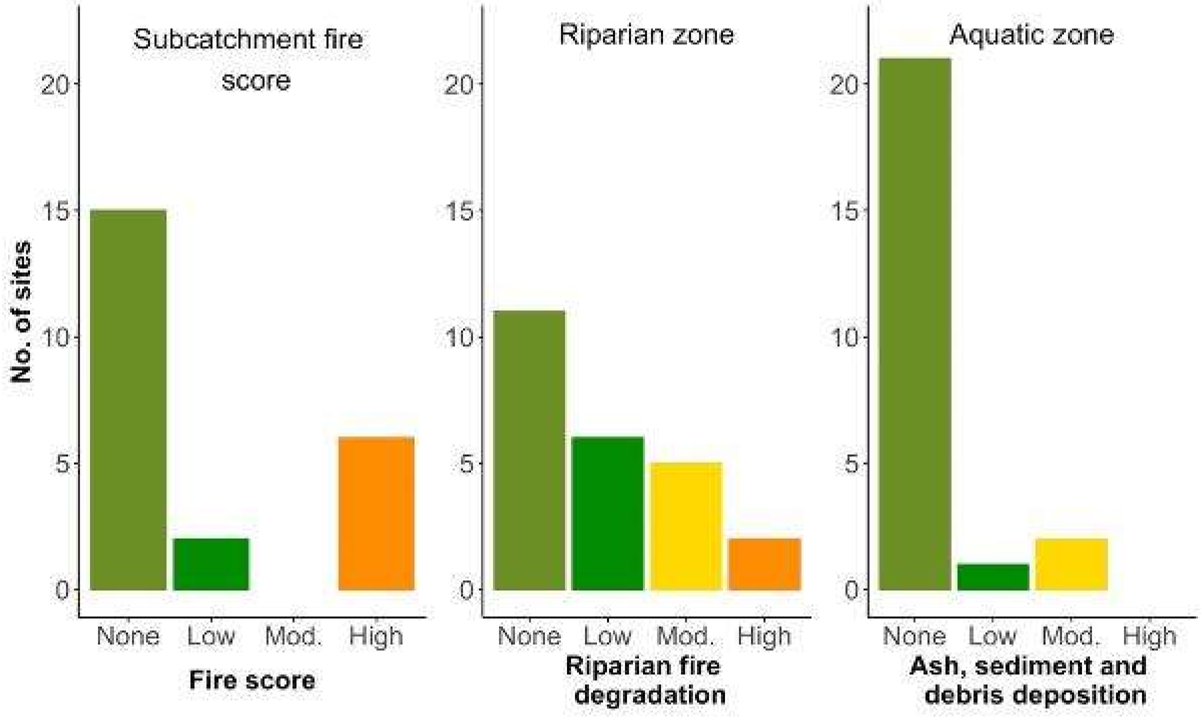


Figure 16: Number of sites within each category of sub-catchment average fire severity score, and fire impact for riparian and aquatic zones. Fire scores ranged from 'none' to 'high'. No 'extreme' scores were recorded.

Oxleyan pygmy perch and ornate rainbowfish were each found at 11 of the 23 study sites, and honey blue-eyes were found at three sites. Oxleyan pygmy perch, honey blue-eyes and ornate rainbowfish were found at three, four, and three previously unrecorded sites, respectively. Honey blue-eyes were only recorded in 2022.

Oxleyan pygmy perch were not recorded at three of the 11 sites where they had historically been recorded, none of which were fire impacted. Honey blue-eye were not recorded at the four sites where they had historically been recorded and none were fire impacted. Ornate rainbowfish were not recorded at three of the 10 sites where they had historically been recorded; one of which was fire impacted.

Oxleyan pygmy perch and ornate rainbowfish (Figure 17) were substantially more abundant in the non-fire-impacted sites, whereas the invasive mosquitofish and platy *Xiphophorus maculatus* were both more abundant at fire-impacted sites. Honey blue-eye were also more abundant at the single fire-impacted site compared with the two non-fire-impacted sites (Table 5).

In a similar pattern to abundance, all three native species were recorded at more unburnt sites. Platy were recorded at more fire-impacted sites, and mosquitofish were recorded at an even number of fire-impacted and non-fire-impacted sites (Table 5).

Water physiochemistry and nutrients varied considerably across survey sites; however, there were no notable differences between mean values for fire-impacted and non-fire-impacted sites (Tables 6 and 7). Records from 2022 exhibited substantially lower mean pH than those of 2021. The same trend was observed for conductivity, and the opposite was evident for turbidity.

Figure 17: Oxleyan pygmy perch caught at Site 34 on the Noosa River (above), ornate rainbowfish caught at Site 36 at Franki's Gulch (centre) and honey blue-eye at Site 30 on the Noosa River (below) at Cooloola.

Table 5: Results of the fish surveys, with the catch per unit of effort (CPUE) and frequency of occurrence of each species collected at fire-impacted and non-fire-impacted sites (*indicates invasive fish species). CPUE was calculated as the mean number of individuals per box trap and electrofishing shot (± standard deviation), with only sites where each species was present used in the calculations. Bold indicate the higher values for each species.

	CPUE (mean ± s.d.)				**Frequency of occurrence**	
	Electrofishing		Box traps			
Species	Fire impacted	Non-fire impacted	Fire impacted	Non-fire impacted	Fire impacted	Non-fire impacted
Oxleyan pygmy perch	0.72 ±0.25	**1.64 ±1.48**	0.11 ±0.07	**0.3 ±0.4**	4	**7**
Honey blue-eye	**1.5 ±0**	0.75 ±0.35	-	-	1	**2**
Ornate rainbowfish	1.38 ±1.24	**8.31 ±9.68**	0.05 ±0	**0.34 ±0.58**	3	**8**
Mosquitofish*	**8.94 ±16.85**	1.17 ±0.68	**3.79 ±5.21**	0.15 ±0.17	5	5
Platy*	**7.88 ±2.65**	0.75 ±0	**4.1 ±5.41**	0.1 ±0	**2**	1

Table 6: The mean values (± standard deviation) for water physiochemistry variables across fish survey sites in 2021 and 2022: temperature (°C), dissolved oxygen (%), pH, conductivity (μS/cm), turbidity (NTU).

	2021		2022	
	Non-fire impacted	Fire impacted	Non-fire impacted	Fire impacted
Dissolved O_2	54.3 ±27.5	67.74 ±48.62	62.65 ±19.43	41.41 ±13.85
pH	7.01 ±1.16	7.19 ±1.29	5.22 ±0.48	5.38 ±0.47
Conductivity	131.43 ±53.96	199.29 ±95.1	84.8 ±9.58	86.18 ±34.83
Temperature	22.51 ±2.67	26.03 ±2.62	21.27 ±0.85	23.28 ±1.45
Turbidity	1.96 ±1.44	3.26 ±2.5	4.35 ±4.5	4.64 ±4.31

Table 7: Summary of water nutrients results from four sites in 2021: dissolved organic carbon (mg/L), nitrogen (mg/L) and phosphorus (mg/L).

Site number	Site name	Organic carbon (dissolved)	Organic nitrogen (dissolved)	Total nitrogen (dissolved)	Total nitrogen (suspended)	Ammonium nitrogen as N	Total phosphorus (suspended)	Organic phosphorus (dissolved)
30	Noosa River 7	10.6	0.64	0.65	0.25	0.007	0.02	0.02
81	Pumphouse	7.2	0.57	0.62	0.02	0.015	0.02	0.02
33	Noosa River 4	4.7	0.6	0.6	0.06	0.006	0.02	0.02
34	Carland Creek	13.6	0.86	0.88	0.02	0.008	0.02	0.02

4.4 Discussion

The three native fish species of conservation concern were absent from sites where they had previously been recorded, and these absences appeared unrelated to fire incidence or severity. However, native fish abundance was much higher in non-fire-impacted sites, with the opposite being true for invasive fish species. This suggests that fire disturbance may negatively affect native fish species but not to the extent of causing localised extinctions, whereas invasive species are capable of persisting and proliferating in fire-impacted sites.

The relatively minor overall differences in fish species composition and abundances between fire-impacted and non-fire-impacted sites may be attributable to a number of factors, including: fire-impacted wetland habitats and their fish communities having partially recovered between the 2019–2020 fires and the time of surveys; and wallum wetlands and their fish communities being inherently resistant and resilient to fire disturbance, although this likely depends on factors such as wetland size, depth, riparian zone characteristics and contributing catchment size.

Flooding prior to the 2022 surveys may have resulted in greater connectivity between waterbodies and changes in the distribution and abundance of both native and invasive species. Honey blue-eye, which was not recorded in 2021, was found at two upstream riverine sites surveyed in 2021 and a Noosa River main channel site that was not previously surveyed. At a lacustrine site (#26 – Lake Cooroibah Inlet) which was close to, but disconnected from, the main channel and previously dominated by invasive fish species, a relatively lower abundance of invasive species was recorded in 2022. Presumably, these fish moved into the main channel with flooding of the site.

Coastal wallum and dune wetlands have a distinctive water chemistry characterised by high acidity (low pH) and very low nutrient status. This means they are highly vulnerable to deterioration in water quality associated with run-off and delivery of ash and sediment from fire-affected areas. This has the potential to significantly reduce water acidity (increase pH) due to the low buffering capacity of acid wetland systems, increase nutrient concentrations (potentially leading to algal blooms and reduced dissolved oxygen) and increase water turbidity (due to an increase in suspended sediments). These changes in water quality and habitat integrity can severely affect the acid-wetland specialist species of fish and other biota.

Except for dissolved oxygen at some sites, all water physiochemical values fell within the acceptable ranges for lowland rivers, and freshwater lakes and reservoirs, according to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality guidelines (2000). The differences observed between 2021 and 2021 may be attributed to the early 2022 floods that likely lowered conductivity and increased turbidity with the influx of fresh water. The lower pH values observed in 2022 more closely represent the physiochemistry of wallum wetlands, suggesting that the 2020 fires may have caused some alkalinisation of waterbodies and that they are gradually returning to a more acidic condition.

4.5 Recommendations

Reducing ongoing threats

- Protect native fish habitats from frequent or severe bushfire

  While wallum wetlands and their inhabitants may possibly be resilient to fire disturbance, increases in the frequency and intensity of fires may lead to permanent reductions in abundance and distributions, and even localised extinction, of these freshwater species. These risks can be minimised by strategic fire management designed and implemented to lessen the impact of future bushfires.
- Reduce impacts of invasive aquatic animals, especially mosquitofish.
- Reduce impacts of feral pigs that damage fish habitat.
- Reduce impact from weeds that invade wetlands and displace native plant species.

  The resilience of threatened fish species and their habitats to fire and other disturbances can be enhanced by minimising the impact of multiple stressors.

Ecological monitoring

- Establish a rapid response process.

  The current process for partners outside of DES to obtain approval, clarify protocols and organise site access to undertake surveys significantly delays an ability to quickly undertake post-fire assessments. A more streamlined process with pre-approvals is advised to enable better assessments of fire impacts and the rates of recovery of threatened fish species populations in the future. Continued collaboration between key government, park management and research groups will ensure that on-ground assessments and response actions are timely and efficient to protect threatened fish species.
- Ongoing monitoring to track changes in the distribution and abundance of priority species.

  It is important to track changes in fish populations and identify possible fire impacts. The inclusion of complementary sampling techniques, such as eDNA, would provide a more comprehensive set of baseline data on which to compare post-fire responses. It is recommended that a minimum monitoring frequency of four years, based on approximate El Niño-Southern Oscillation cycles, with additional sampling is adopted after a fire event. Monitoring sites should include a mixture of both ecologically stable and dynamic sites to improve understanding of different sensitivities to short- and long-term effects of disturbances such as fires.

Ecological research

- Improve understanding of the mechanisms by which fire affects freshwater fish species in wallum wetlands and how wetland characteristics may mediate the severity of these impacts.
- Improve understanding of the interactive effects of invasive fish species with fire, drought and flooding.

5 Priority frogs

5.1 Conservation context

The wallum sedgefrog *Litoria olongburensis*, wallum rocketfrog *Litoria freycineti* and wallum froglet *Crinia tinnula* are listed as Vulnerable, and the Cooloola sedgefrog *Litoria cooloolensis* as Near Threatened, under the NCA. These four species of acid frogs are restricted to the acidic waters and peat bogs of wet heath and wallum, and thus have specific needs in terms of water quality. The most specialised species appears to be the Cooloola sedgefrog, which prefers breeding sites with deeper pools and a good coverage of fringing sedges, particularly thickets of *Lepironia*.

The wallum froglet, wallum sedgefrog and wallum rocketfrog all had significant proportions (>15%) of their modelled state-wide habitat within the study area impacted by the 2019–2020 fires (Meiklejohn *et al*. 2020). There is concern that the 2019–2020 fires may have altered the preferred chemistry of the waters that these species inhabit, rendering them inhospitable. The wallum sedgefrog, wallum rocketfrog, wallum froglet and the Cooloola sedgefrog were priority species for Phase 1 surveys. Whilst the last of these species was the priority for Phase 2, results for all four acid frog species were included in this report, given the need to sustain monitoring efforts in the face of increasing threats of fire and droughts associated with a changing climate.

5.2 Survey sites and methods

Sites

Previously recorded localities of the four acid frog species across Cooloola were derived from WildNet to map the known occurrence of species relative to the 2019–2020 fires and to guide site selection (Figure 18). Historical records did not notably overlap the fire extent, although this was considered to be due to limited sampling effort across Cooloola, rather than reflecting the current distribution of the priority frog species.

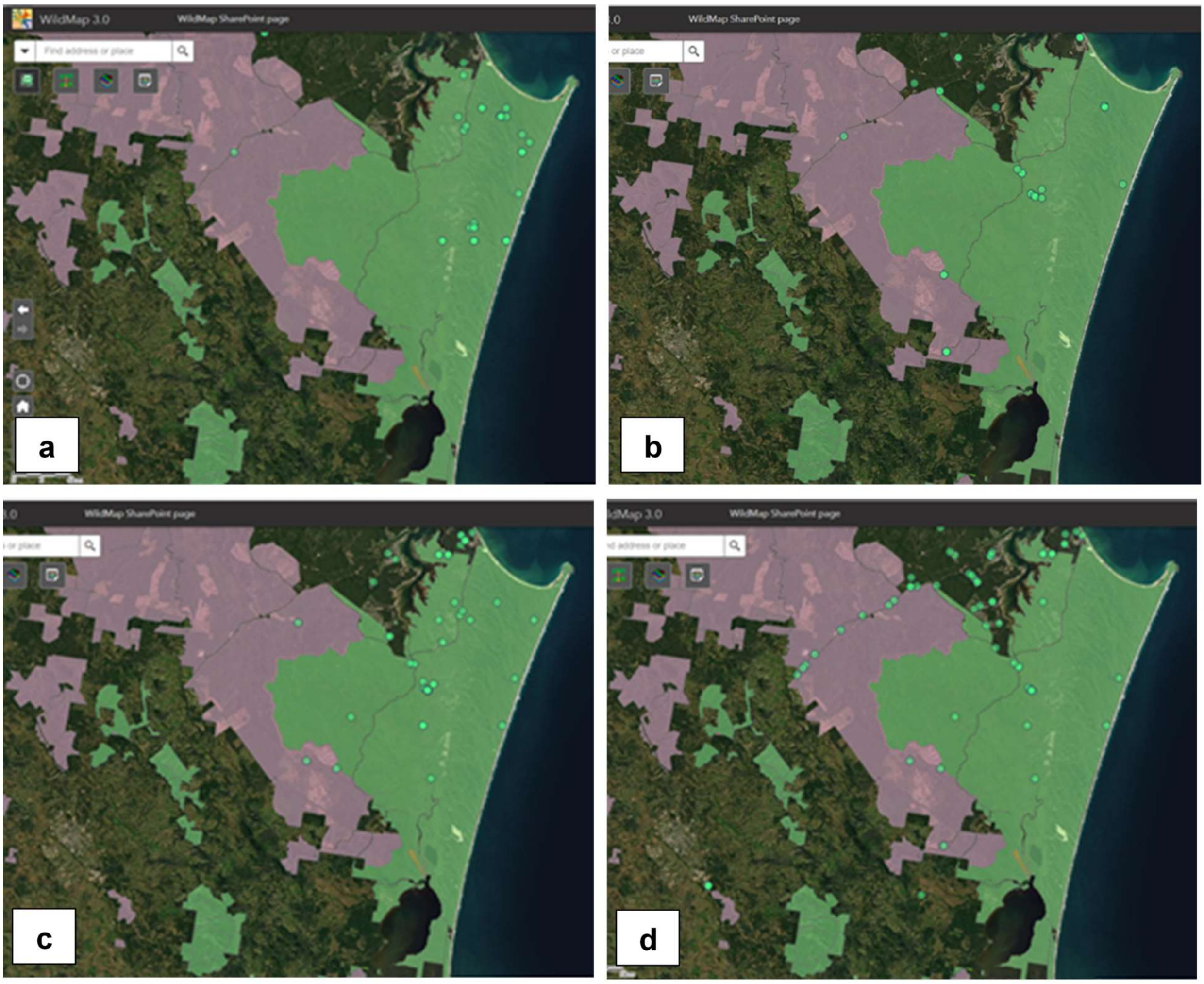


Figure 18: Locality records for the priority wallum acid frog species across Cooloola: a) Cooloola sedgefrog; b) wallum rocketfrog; c) wallum sedgefrog; and d) wallum froglet across national park (green) and state forest (pink).

Phase 1 surveys

A total of 59 (31 burnt and 28 unburnt) sites was selected on freshwater lakes, in wet heath and along the Noosa River at Cooloola and Noosa NP (Figure 19). Bioacoustic recording (BAR) sites (total 29) were only established across Cooloola, while 21 listening and nine active search sites were located in both Cooloola and Noosa NP. Of the 29 BAR sites, 12 were programmed specifically for frogs: to record each night for 14 minutes per hour, every hour; 5 minutes on the hour and half hour, 2 minutes on the quarter and three-quarter hour. Sites were located in areas surrounding water bodies, particularly permanent, deep lakes (Lake Coolamera, Lake Poona and Lake Freshwater, as well as unnamed lakes within wallum floodplain of the Noosa River), ephemeral lakes and seasonally wet wallum. Two sites at permanent lakes were in moist, unburnt forest, one was in burnt woodland and two in unburnt wallum sedgeland. Three sites at ephemeral lakes were in burnt landscapes, and one unburnt and three burnt sites were located across seasonally wet wallum swamps.

Phase 2 surveys

A total of 33 (9 burnt and 24 unburnt) sites were located on freshwater lakes, in wet heath and along the Noosa River floodplain in Cooloola (Figure 19). Nine bioacoustic recording sites and 24 listening sites were deployed. All the BAR sites were dedicated to frog surveys as opposed to incidental sampling of frogs while monitoring for ground parrots, which was the case for a proportion of the BAR sites in Phase 1. Although BARs were deployed for ground parrots during Phase 2, no frog records detected were used for this section of the report. The frog detection BARs were programmed to record each night for 8 minutes per hour, every hour; 2 minutes on the hour, quarter hour, half hour and three-quarter hour. Sites were in proximity to streams, water bodies and swamps, within the wallum floodplain of the Noosa River and Seary's Creek, at ephemeral lakes and in seasonally wet wallum.

Methods

Acoustic recordings were analysed by listening and analysing sonograms in Raven Pro software for the presence–absence of acid frogs. Due to the large number of nights surveyed (between 30 and 90+ depending on the site), up to four nights were initially analysed. These samples were based on the occurrence of reasonable precipitation in the previous 24 hours. Analysis was terminated once all four acid frogs were detected, even if all four nights were not analysed.

Frog survey methods were based on advice that Cooloola and wallum sedgefrogs can be monitored using both acoustic recorders and visual counts to derive estimates of frog numbers (Commonwealth Guidelines; H. Hines pers. comm.). Wallum froglets can be surveyed using listening (acoustic recorders and driving transects) for presence–absence (H. Hines pers. comm.). Calling times for most of these species can be predicted through weather events (e.g., passing low-pressure systems with rain) (H. Hines pers. comm.). Surveys should be undertaken in optimal climatic conditions, i.e. on windless nights at a time of peak activity for the species. Results are typically enhanced if the survey is within seven days of heavy rainfall between October and February. In contrast, wallum froglets call during the winter months. Despite this, estimating population numbers was not attempted, and the results reflect the presence–absence of any particular species at the time of survey.

Sites were surveyed for the four species of wallum acid frogs using bioacoustic recorders, physical listening or active searches (Figure 19).

5.3 Survey results

Phase 1

Frogs were present in both burnt and unburnt sites, but most sites contained no frogs (Figure 20). The wallum froglet and the cane toad *Rhinella marina* showed marginally higher presence at burnt sites, compared to unburnt sites (Figure 20). However, not all 52 sites surveyed were suitable for all four acid frogs. Many of the sites where BARs were deployed were not suitable for the Cooloola sedgefrog, whereas most sites were suitable for the wallum froglet and wallum sedgefrog. Suitability of sites for the wallum rocketfrog was mixed.

Of the 12 sites dedicated to frog monitoring, the wallum sedgefrog (Figure 21) was detected at 10. This species was only absent from the vicinity of the recording location at Lake Poona and in a woody site on the Noosa Plain. The wallum sedgefrog was recorded at an ephemeral waterbody site that had been burnt and was persistently dry throughout the survey period.

The wallum rocketfrog (Figure 21) was detected at 11 of the 12 sites, being absent only from a burnt and persistently dry ephemeral lake.

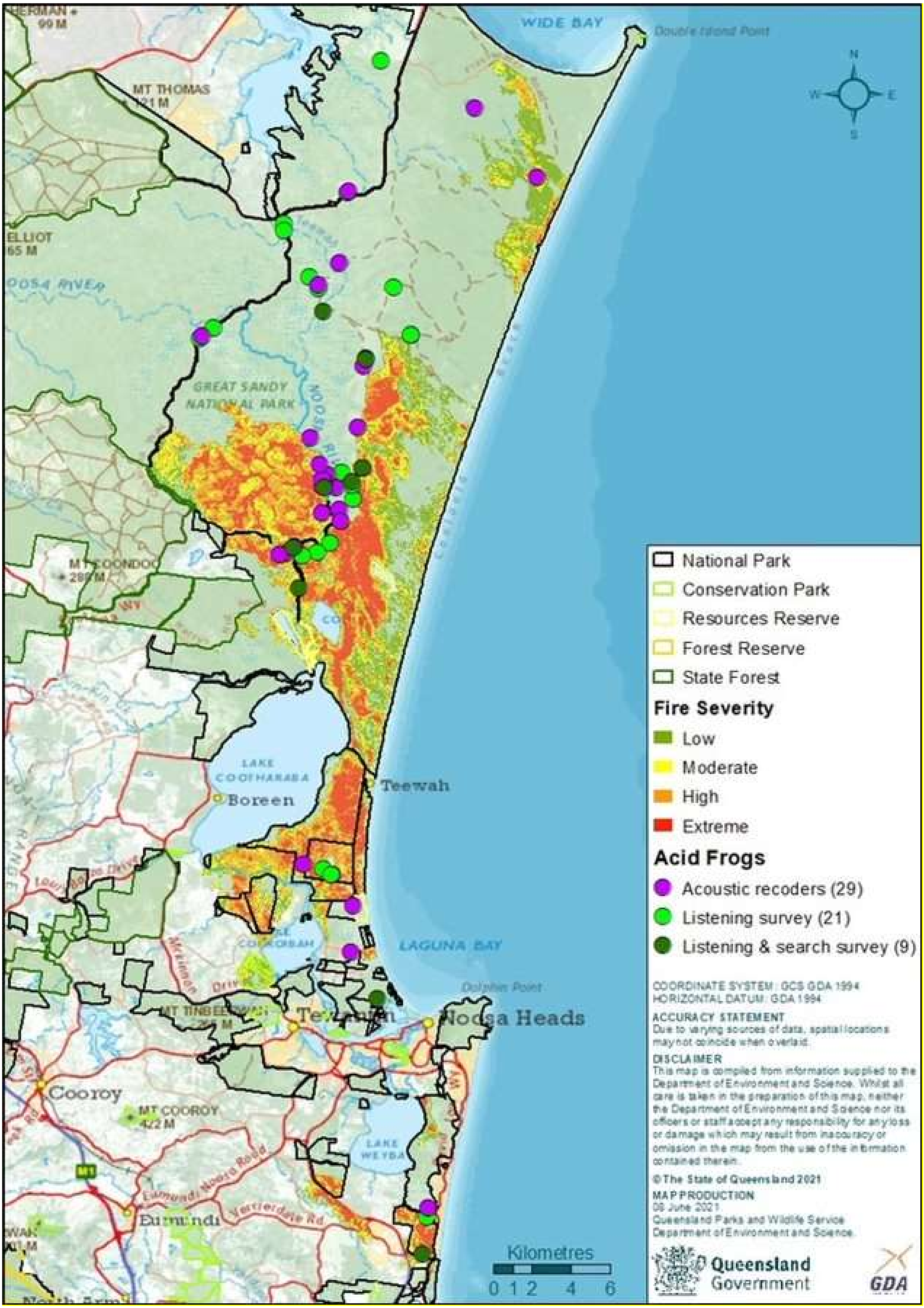


Figure 19: Location of dedicated monitoring sites for acid frogs at Cooloola, Noosa NP and Noosa North Shore.

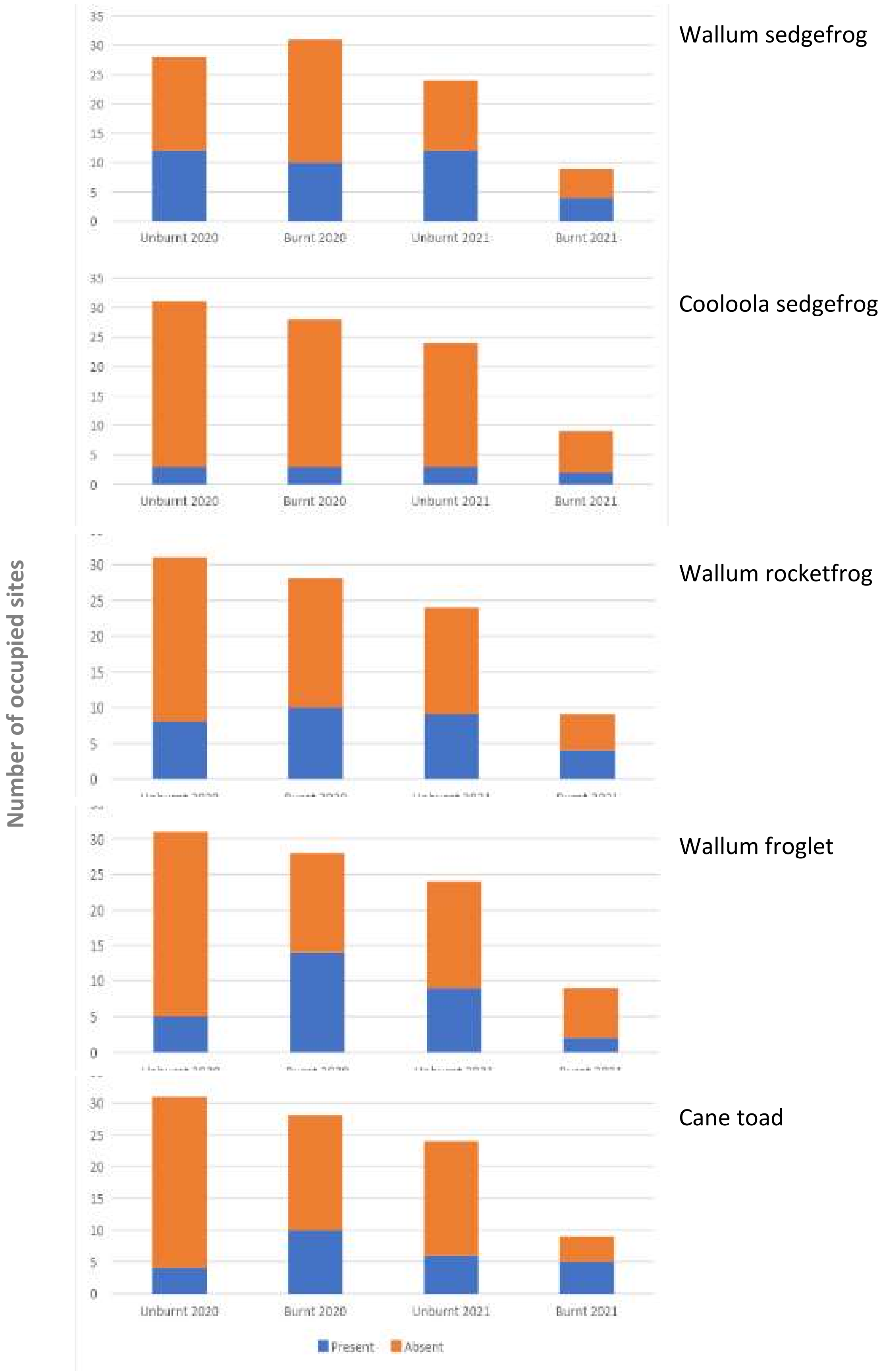


Figure 20: Occupancy of sites burnt and unburnt in the 2019–2020 fires for Phase 1 (2020: across 31 burnt sites and 28 unburnt sites) and Phase 2 (2021: across nine burnt and 24 unburnt sites) for each of the four priority species of wallum acid frogs and the cane toad, at Cooloola.

The Cooloola sedgefrog was recorded at previously known positive locations at Lakes Poona, Coolamera and Freshwater. This species was absent from the recording locations on permanent lakes on the Noosa floodplain but was detected in large numbers in an ephemeral lake with dense sedges and deep water at one end. The BAR at the Roy Weber Plain, a known site for the species, also detected this frog in numbers.

Despite not being a peak calling period, the wallum froglet was detected at seven of the 12 sites across burnt and unburnt lakes (both permanent and ephemeral) and wallum swamp wherever water was present.

Phase 2

As with Phase 1, acid frog species were present in both burnt and unburnt sites, but greater than 50% of sites contained no frogs (Figure 20). Not all sites surveyed were suitable for all four acid frogs in terms of habitat and microhabitat available. Many of the sites where BARs were deployed were not considered suitable for Cooloola sedgefrog, whereas many sites were considered suitable for the wallum froglet, wallum rocketfrog and wallum sedgefrog. The cane toad was present more on burnt than unburnt sites (Figure 20).

Of the 33 Phase 2 sites, wallum sedgefrog was detected at 16 sites; 12 of the 24 unburnt sites and four of the nine burnt sites. Wallum sedgefrog was the most frequently recorded of the acid frogs during Phase 2 surveys, being widely recorded at a variety of burnt and unburnt sites across the survey area.

The wallum rocketfrog was detected at 13 of the 33 Phase 2 sites: nine of the 24 unburnt sites and four of the nine burnt sites.

Cooloola sedgefrog was unsurprisingly recorded at previously known positive locations at Lakes Coolamera and Freshwater. This species was absent from the recording locations on permanent lakes on the Noosa floodplain but was detected in large numbers, along with many other species including the other three acid frogs, in an ephemeral lake with dense sedges and deep water at one end within woodland at the eastern edge of the floodplain (PBR0056). The BAR at the Roy Weber Plain, a known site for the species, also detected this frog in reasonable numbers, again with the other three acid frogs.

Despite not being surveyed across its peak calling period (winter), the wallum froglet was detected at nine of the 24 unburnt sites and two of the nine burnt sites.

Other species detected across the recording and listening sites, as well as a subjective assessment of abundance across the sites, are as follows: *Litoria caerulea* (common), *Litoria fallax* (rare), *Litoria gracilenta* (abundant), *Litoria nasuta* (common), *Litoria peronii* (uncommon), *Litoria rubella* (abundant), *Litoria tyleri* (common), *Limnodynastes peronii* (uncommon to rare), *Limnodynastes terraereginae* (uncommon), *Pseudophryne raveni* (rare) and *Uperoleia fusca* (common).

Figure 21: Wallum sedgefrog (left) and wallum rocketfrog (right) at Cooloola.

5.4 Discussion

In the context of the 2019–2020 fires at Cooloola, all four wallum acid frogs were detected at both unburnt and burnt sites, with most present across a spectrum of appropriate habitat types in the landscape, both burnt and unburnt. The wallum sedgefrog was the most frequently recorded acid frog species at the greatest number of sites, in both unburnt and burnt habitats.

Each of the acid frog species requires particular environmental conditions and habitats for breeding. Survey sites were mostly not stratified to favour any species. The exception to this was the Cooloola sedgefrog, which is the most specialised species in terms of breeding habitat requirements, preferring sites where deeper pools exist with a good coverage of fringing sedges, often within forest, woodland and wallum swamps. Despite some site selection to favour detection of this species, it was not present at all sites that intuitively it may seem to favour. For example, it was not detected across both Phase 1 and 2 surveys at the unburnt sites where it may have been expected to occur. These two ‘absent’ sites for Cooloola sedgefrog were medium-sized, moderately deep waterbodies surrounded by *Lepironia articulata* and other sedges, essentially within the wallum swamp of the Noosa River floodplain, with nearby riparian sclerophyll woodland. Both sustained reasonable populations of the wallum sedgefrog and the wallum froglet. In comparison, these sites were superficially similar to the BAR site on Roy Weber Plain where the Cooloola sedgefrog was consistently detected along with the other three acid frog species. Perhaps the position of each of these two waterbodies quite close to the Noosa River, which at times floods significantly, is not suitable for this species, despite its apparent ability to travel from waterbody to waterbody through habitat corridors.

5.5 Recommendations

Reducing ongoing threats

- Protect acid frog habitats from frequent or severe bushfire

  The planned burn program for Cooloola is appropriate for maintaining a diversity of post-fire habitat stages for acid frogs in the landscape. Longer fire intervals should be adopted until the ecosystems impacted by the 2019–2020 fires have recovered sufficiently, reverting to a pre-fire state, or near so.

- Reduce impacts of pigs to sites containing acid frogs

  The risk of significant damage to habitats, and of predation on frogs and their prey, makes pig control a priority.

- Reduce impacts of cane toads

  Predation by cane toads and competition for prey resources is of concern, especially after fires.

- Reduce impacts of weeds

  Weeds can alter the integrity and structure of acid frog habitats, especially after fires.

- Protect ephemeral or permanent lakes from water extraction during an emergency fire response

  Water extraction can remove or degrade microhabitats and introduce exotic water plants or aquatic fauna.

- Protect wetlands from changes to local hydrology and possible sedimentation.

  Roadworks and other manual interference with the soil around sites containing acid frogs may impact habitats.

Ecological monitoring

- Continue to monitor post-fire changes in populations/site occurrence of wallum acid frog species.

  Physical listening and bioacoustic recording surveys should be undertaken at sites at a minimum of 2–5-year intervals to confirm the continued presence of species over the long term. Liaise with programs underway by the Mary River Catchment Coordinating Committee.

- Monitor the regeneration of vegetation in burnt habitats.

Ecological research

- Undertake space for time studies of frog populations in relation to planned burn programs to ascertain how fire severity and fire frequency affect acid frog species in wallum wetlands, associated water bodies and waterways.
- Investigate whether negative interactions between cane toads/plant weed species and acid frogs can be detected and/or if cane toads/plant weed species dominate because of burning programs or bushfire.

6 Priority invertebrates

6.1 Conservation context

Fifteen invertebrate species were identified as regional endemics and therefore priority taxa for this project (Table 2). Of these 15 species, 10 have been suggested for future investigation: the earth-boring beetle *Australobolbus masneri*; three species of the Christmas beetle genus *Anoplognathus* (*A. debaari, A. hilleri, A. storeyi*); three species of the dung beetle genus *Onthophagus* (*O. cooloola, O. beelarong, O. yarrumba*); two dragonfly species (wallum vicetail *Hemigomphus cooloola* and wallum darner *Austroaeschna cooloola*); and the unusual cricket-like Cooloola monster (*Cooloola propator*). All 10 species have a substantial extent of their known distribution within the region and can be surveyed readily, while the almost exclusively subterranean Cooloola monster *C. propator* is an iconic species restricted to the coastal dunes of Cooloola and K'gari (Fraser Island). *Hemigomphus cooloola* and *Austroaeschna cooloola* are currently categorised as Vulnerable and Endangered, respectively, in the IUCN Red List of Threatened Species (Dow 2017a) but are not currently listed as threatened under Queensland or Commonwealth legislation.

Of the remaining five species, four (two crane flies *Molophilus (Superbomolophilus) cooloola* and *Paralimnophila (Paralimnophila) cooloola*, one lady beetle *Sticholotis cooloola*, one strepsipteran *Triozocera cooloolaensis*) are endemic to the Cooloola region yet only known from a few collections and are difficult to survey, whilst the katydid *Tinzeda fraserensis* does not occur in the region and is known only from Western Australia. Therefore, these species are not recommended as priority taxa for future monitoring (Table 8).

Two additional species were identified by experts as worthy of inclusion in this report: the coastal petaltail dragonfly *Petalura litorea* and the predatory ground beetle *Pamborus cooloolensis* (Table 8). *Petalura litorea* is considered Near Threatened under the IUCN Red List of Threatened Species (Dow 2017b) and is currently listed as Endangered under the New South Wales *Biodiversity Conservation Act 2016*. Habitat modelling prior to the surveys suggested that around 60% of the Queensland distribution of the coastal petaltail is within the Cooloola section of Great Sandy NP (likely to be an overestimate), and that 7% of the species' habitat in the park was impacted by the 2019–2020 fires.

Table 8: Summary of the 17 insect species prioritised for this project and whether they were recorded (✓) or not recorded (x) during Phase 1 surveys, alongside recommendations to include or exclude them in future monitoring.

Species	Infraorder	Family	Recorded	Recommendation
Australobolbus masneri	Coleoptera	Geotrupidae	x	Include
Anoplognathus debaari	Coleoptera	Scarabaeidae	x	Include
Anoplognathus hilleri	Coleoptera	Scarabaeidae	x	Include
Anoplognathus storeyi	Coleoptera	Scarabaeidae	x	Include
Onthophagus cooloola	Coleoptera	Scarabaeidae	x	Include
Onthophagus yarrumba	Coleoptera	Scarabaeidae	x	Include
Onthophagus beelarong	Coleoptera	Scarabaeidae	x	Include
Sticholotis cooloola	Coleoptera	Coccinellidae	x	Exclude: difficult to survey
Molophilus cooloola	Diptera	Limoniidae	x	Exclude: difficult to survey
Paralimnophila cooloola	Diptera	Limoniidae	x	Exclude: difficult to survey
Hemigomphus cooloola	Odonata	Gomphidae	✓	Include
Austroaeschna cooloola	Odonata	Telephlebiidae	✓	Include
Cooloola propator	Orthoptera	Cooloolidae	x	Possibly include in future
Tinzeda fraserensis	Orthoptera	Tettigoniidae	x	Exclude: only known from WA
Triozocera cooloolaensis	Strepsiptera	Corioxenidae	x	Exclude: difficult to survey
Pamborus cooloolensis	Coleoptera	Carabidae	✓	Include
Petalura litorea	Odonata	Petaluridae	✓	Include

6.2 Survey sites and methods

Survey sites were stratified across a range of fire severity classes (Figure 1) and the likely ecological impacts that would influence the post-fire condition (see Meiklejohn *et al*. 2020) relevant to invertebrate habitats (Table 9).

Six survey sites were selected in total, one within each of three fire severity classes across two habitat types: *Banksia aemula* and scribbly gum heathland on the Western Break; and *Eucalyptus pilularis* woodland on Kings Bore Road (Appendix 3, Table A3.1). Sites were surveyed from 11–16 February 2021. Standardised survey methods were used to target the priority taxa at each site: Malaise traps; unbaited pitfall traps; baited pitfall traps (using dung and mushroom baits); coloured pans; timed hand netting (during the day); and timed hand collecting of ants (during the day). Refer to Appendix 3 for further details on the methodology.

As there were no aquatic habitats in the original six survey sites, additional surveys to specifically target Odonata (dragonflies and damselflies) were conducted across an additional 12 sites (freshwater bodies) from 10–20 February 2021 (e.g., see Appendix 3, Figure A3.2). Individual odonates were either observed, photographed and/or hand netted and collected (Appendix 3, Figures A3.2 and A3.4). Additional post-fire records (both photographic and observational) of the priority species of dragonflies made by the Cooloola project team during this project are included in this report.

The locations of the various survey sites and the habitats sampled are shown in Figure 22.

Table 9: Attributes and description of 12 sites surveyed for Odonata across Cooloola, with the survey timing and if target taxa were collected, photographed, or observed (✓) or not (x).

Site number	Altitude	Type	Site and habitat description	Date	Taxa
1	156 m	Lentic	Poona Lake circumference, perched lake	12/02/2021	x
2	18 m	Lotic	Seary's Creek; Day Use Area, stream in heath	10–16/02/2021	✓
3	55 m	Lotic	Seary's Creek; Pettigrew's Rd, stream in gallery rainforest	16–17/02/2021	✓
4	16 m	Lotic	Wildflower Way, stream in low heath	14/02/2021	x
5	40 m	Lotic	Western Break; Franki's Gulch, stream in *Banksia aemula*/scribbly gum heath	10–16/02/2021	✓
6	13 m	Lotic	Pump Station Rd; Teewah Ck, stream in *B. aemula*/scribbly gum heath	16/01/2021	✓
7	12 m	Lotic	Kings Bore Rd; Teewah Ck, stream in *B. aemula*/scribbly gum heath	13/02/2021	✓
8	75 m	Lentic	Kings Bore Rd; Lake Cooloomera, Lake in *E. pilularis* woodland	11–16/02/2021	x
9	27 m	Lentic/ lotic	Floodplain Break; Joe's Gully, stream/boggy seepage in palustrine wetland	13–14/02/2021	✓
10	34 m	Lentic	Western Break; ephemeral lake/swamp in *E. pilularis* woodland	13–14/02/2021	x
11	8 m	Lotic	Small lake near Noosa River; 0.5 km NW Dutgee Camp River in palustrine wetland	20/1/2021	x
12	8 m	Lotic	Logs Landing Rd; Dutgee Camp, Noosa River in palustrine wetland	13/02/2021	x

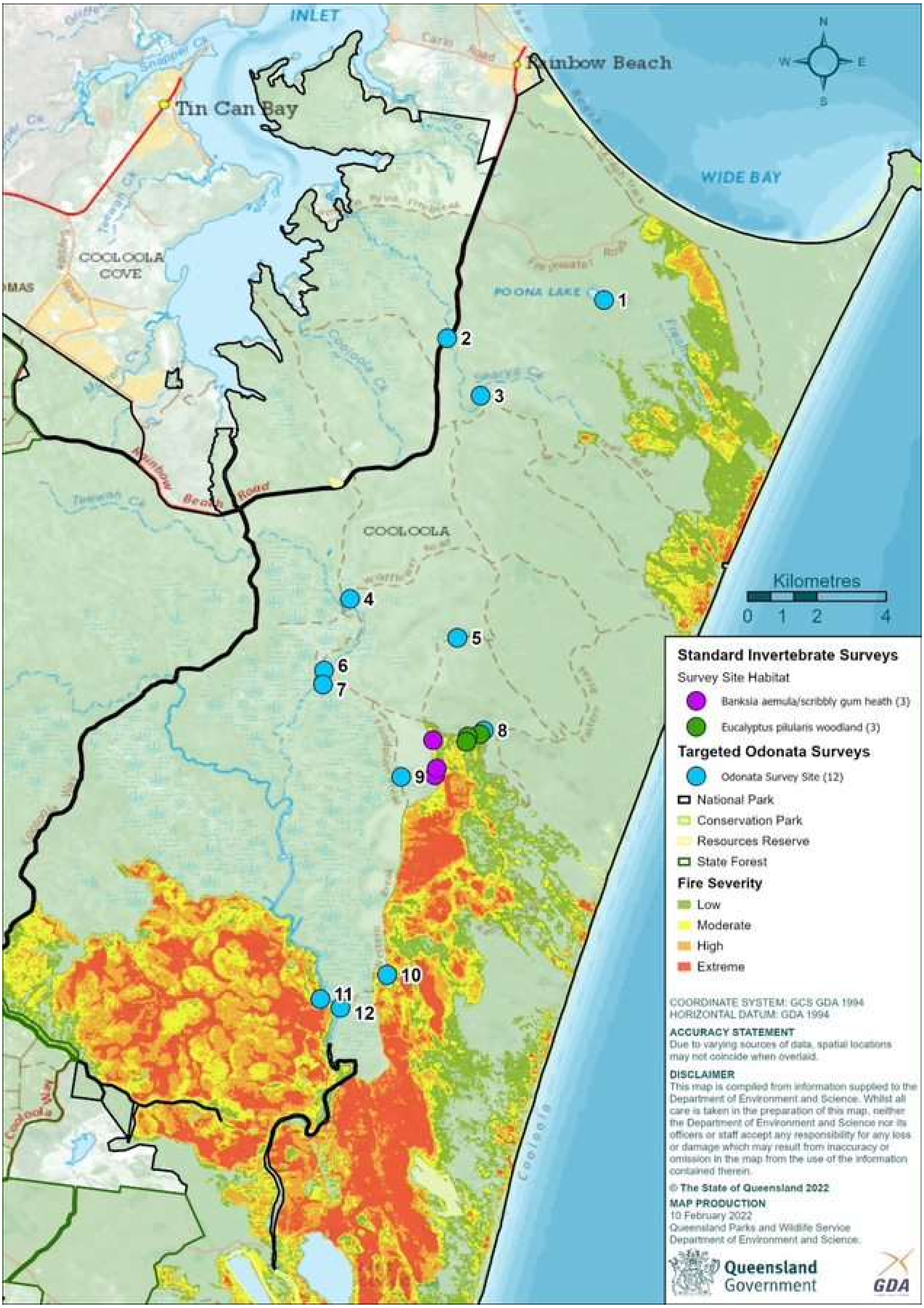


Figure 22: Location of invertebrate, and targeted Odonata survey sites across Cooloola.

6.3 Survey results

Of the 15 species initially flagged as priority taxa, only two (wallum vicetail *Hemigomphus cooloola* and wallum darner *Austroaeschna cooloola*) were recorded during the post-fire surveys. An additional two species were also recorded and considered worthy of future investigation (coastal petaltail dragonfly *Petalura litorea* and *Pamborus cooloolensis*) (Table 8). All four species are reported on below.

Wallum vicetail

The wallum vicetail was observed and photographed during targeted surveys for Odonata (e.g. Figure 23). One male and one female were recorded from the same location: Site 9 Joes Gully, along Floodplain Break (Site 9; Table 9). The female was observed ovipositing in a shallow rivulet running along the wheel tracks of the Floodplain Break. An additional male wallum vicetail was recorded at Joes Gully in late November 2020 (Michael Mathieson pers. comm.).

Figure 23: A male wallum vicetail observed at Floodplain Break, Joes Gully, in February 2021. (Photo: C. Burwell)

Wallum darner

The wallum darner (Figure 24) was observed and photographed at six locations during targeted surveys for Odonata: two locations at Site 5—in the stream running along Franki's Gulch (where it crosses the Western Break); two locations near Teewah Creek in the vicinity of Kings Bore Road (Site 7: Table 9); and sites along Seary's Creek (Sites 2 and 3; Table 9).

All observations of the wallum darner during these surveys, as well as previous locality records from Cooloola, were associated with small streams (lotic habitats) that ran through a variety of different habitats, ranging from heathland to littoral rainforest. All records for this project were from streams running through habitats that were unaffected by the 2019–2020 fires at Cooloola.

Figure 24: A male wallum darner observed at Teewah Creek in February 2021. (Photo: C. Burwell)

Coastal petaltail dragonfly

The coastal petaltail dragonfly (Figure 25) was observed and photographed during Odonata surveys. Two males were recorded at Site 6—Teewah Creek at the end of Pump Station Road; one male was recorded at Site 9 Joes Gully, Floodplain Break; and an individual of unknown sex was observed at a small lake on the western side of the Noosa River (Site 11: Table 9). Two of the localities at which the species was observed were in areas unaffected by the 2019–2020 fires, but Site 11 was impacted by the 2019–2020 fires, at low to moderate levels of fire severity (Figure 22).

Figure 25: A male coastal petaltail observed at Teewah Creek in January 2021. (Photo: C. Burwell)

Predatory ground beetle

Seven individual ground beetles *Pamborus cooloolensis* (Figure 26) were collected in baited and unbaited pitfall traps from the six survey sites where standardised surveys were undertaken. This species was recorded from sites in *Eucalyptus pilularis* woodland along Kings Bore Road that represented three fire severity classes (unburnt, moderate and high). A single beetle was also recorded from the long-unburnt site in *Banksia aemula*/scribbly gum heath on the Western Break. No beetles of this species were collected from the heath habitat on burnt sites.

Figure 26: Predatory ground beetle collected in an unbaited pitfall trap at an unburnt site in *Eucalyptus pilularis* woodland on Kings Bore Road, Cooloola. (Photo: © Queensland Museum, G. Thompson)

6.4 Discussion

Wallum vicetail, wallum darner and coastal petaltail dragonfly

The wallum vicetail, wallum darner and coastal petaltail dragonfly persisted at Cooloola following the 2019–2020 fires. The wallum vicetail and wallum darner were only recorded in unburnt habitats, while the coastal petaltail was recorded within unburnt and burnt habitats. The direct impacts of the fires on these species are difficult to assess due to the small number of observations and the fact that Odonata surveys were typically conducted in unburnt habitat associated with their aquatic lifestyles. According to Theischinger *et al*. (2021), wallum vicetail is known from both lotic (sandy and sluggish streams) and lentic (lake) habitats, but most adult records are associated with streams. Similarly, the wallum darner inhabits sandy, mostly densely vegetated streams (Theischinger *et al*. 2021), which is consistent with the localities it was recorded in during these surveys.

Direct impacts of fire on the adult wallum darner are likely to be small given that they are powerful fliers that could move away from fire fronts. The larval stages of wallum vicetail and wallum darner are aquatic (Theischinger 1998), and direct impacts on aquatic immature stages may also be negligible. Indirect impacts of fire on the aquatic nymphal stages of these species via, for example, changes in water chemistry and turbidity due to the deposition of ash into freshwater habitats, are unknown. Given that the aquatic habitats occupied by the nymphs of these species are largely within fire-adapted, heathland ecosystems, indirect impacts from fires may not be pronounced. However, potential impacts may be exacerbated in the future given the increasing threats posed by climate change through altered rainfall patterns and more severe and frequent droughts and fires.

In contrast, the nymphal stages of coastal petaltail have been described as semi-terrestrial, living within burrows in groundwater-dependent peat-swamps or mires. Extrapolating from the nymphal requirements of the closely related *Petalura gigantea*, the reproductive habitat for coastal petaltail is likely to be “a moist to saturated organic-rich or peaty substrate with a water table which is either generally near the surface or emergent as shallow seepage” (Baird 2017). The heathlands occupied by coastal petaltails in the study area are fire adapted and the peat-swamps and mires in the area are likely to be resilient to individual fires when they are saturated, as is the case for reproductive habitat of *P. gigantea* (Baird & Burgin 2016). As such, fire is likely to have minimal impacts on the reproductive habitat for coastal petaltail in the study area in the short term. However, ongoing climate change is likely to pose significant medium- to long-term threats to this species across its range. Increased frequency of more intense weather events, such as prolonged droughts, may have negative impacts on *P. litorea* by lowering groundwater levels and exacerbating fire impacts through the combustion of peatland soils (Baird & Burgin 2016; Baird 2017). In addition, lowering of the water table through excessive extraction of groundwater and the activities of invasive animals, such as pigs, pose threats to the nymphal habitat of *P. litorea*, as they do for the related *P. gigantea* (Baird & Burgin 2016; Baird 2017).

There have been no quantified surveys of the abundance of the wallum vicetail across any portion of its range that could be used to assess possible changes in its population size over time. The species was originally described from a series of approximately 40 adults collected at Seary's Creek between December 1984 and January 1986 (Watson 1991). This suggests the species was relatively common at that time, with relatively few observations of the species in the last decade, including at Seary's Creek. Whether the paucity of recent records represents a decline in the species' population, natural fluctuations in abundance or a decline in survey effort is impossible to determine.

Similarly, the distribution and ecology of wallum darner and coastal petaltail are very poorly documented. There have been no surveys to determine the abundance of either species across any part of their ranges, nor monitoring to assess changes over time and possible threatening processes.

Predatory ground beetle

The results of the standardised surveys revealed that the predatory ground beetle *Pamborus cooloolensis* persisted at Cooloola after the 2019–2020 fires and occupies a wider range of habitat types than expected. All previous, adequately geo-referenced locations for this species were in rainforest. Given that this survey collected them from *Eucalyptus pilularis* woodland and long-unburnt *Banksia aemula*/scribbly gum heath, the fire impacts on *P. cooloolensis* may be greater than initially anticipated based on an assumption of a rainforest-limited distribution. In eucalypt woodland, the species was recorded from survey sites representing a range of fire severity classes (unburnt, moderate and high). All woodland survey sites had some degree of canopy cover at the time of the survey. The species was also recorded from long-unburnt heath but not the two burnt heath sites. The ground layer of the unburnt heath was heavily shaded due to a very thick shrub layer, whilst the burnt heathland sites had a very open ground layer with little shrub or canopy cover. Despite the likely direct impacts of the 2019–2020 fires on *P. cooloolensis* populations across Cooloola, particularly in heath communities, the survey results suggest that the species has persisted, or at least recolonised burnt habitat, in some woodland communities. In addition, this species is considered secure at Cooloola, given that it also occupies rainforests, which were largely unaffected by the 2019–2020 fires (Meiklejohn *et al*. 2020).

6.5 Recommendations

Reducing ongoing threats

The breeding habitat of *Petalura litorea* at Cooloola is largely fire adapted, and in the absence of broader ecological knowledge, fire is not currently considered to be a threat.

- Reduce impacts of pigs

  There is some evidence that feral pigs pose a threat to the nymphs of other species of *Petalura*, whether through direct predation or the disturbance of breeding habitat (Baird 2017).

Ecological monitoring

- Monitor 11 invertebrate species including nine of the initial 15 prioritised species and the two additional species (Table 8) at a recommended minimum interval of five years.

  Inclusion of the iconic cricket *Cooloola propator* in future monitoring is debatable, given that this species is most effectively surveyed with long-term, gutter traps which can impact other invertebrate and plant species and collect non-target vertebrate species. Due to its subterranean lifestyle, the direct impacts of fire on this cricket species are likely to be minimal, although other impacts (e.g., lowering of water table, disturbance of habitat by pigs) on this poorly researched species are possible.

  Future monitoring of the wallum vicetail and the wallum darner is recommended in the short- and/or medium-term, given the potential threats posed by climate change and fire through altered hydrology and water quality. The methodology used in the Odonata surveys is appropriate, with more extensive geographical coverage of Cooloola recommended, particularly across wetlands (wallum vicetail) and streams (wallum darner) in fire-impacted areas. Incorporation of methods to quantify search effort and to provide estimates of the abundance of adults would also be valuable additions to the survey methodology. The methodology only surveyed adult wallum vicetail and wallum darner, but as the nymphal stages of these species have been described, and *A. cooloola* appears to be the only representative of the genus in the region, surveys of the aquatic immature stages could also be incorporated in future surveys.

Ongoing monitoring of *Petalura litorea* is recommended in the medium- to long-term, given the potential threats posed by climate change through altered hydrology and more intense and frequent fires that may cause the combustion of peatland soils. The Odonata survey methodology is appropriate, with more extensive geographical coverage of Cooloola recommended, particularly swamps and mires in fire-impacted areas. Incorporation of methods to quantify search effort and to provide estimates of the abundance of adults would also be valuable additions to the survey methodology. Adults of *P. litorea* have been collected or sighted from early October through to February, although Baird (2017) has suggested that the flying season may begin as early as mid-September. These surveys were conducted very late in the flying season of the species, providing some of the latest seasonal records. It is recommended that future surveys for adult *P. litorea* be conducted throughout the flying season, particularly between late November and mid-January to maximise the chances of recording the species, as suggested by Baird (2017). It is also recommended that surveys incorporate searches for the burrows of *P. litorea* nymphs, and for the exuviae left by adults that have emerged, to identify breeding habitats. This is best achieved post-fire, within two years of the habitat being burnt, as burrows are more easily detected following the removal of the surface layer of leaf litter (Baird 2017).

Pamborus cooloolensis appears to be currently secure at Cooloola, based on its likely persistence in rainforest and apparent fire tolerance within some woodland communities. Given that these woodlands are fire adapted, there are no specific on-ground management recommendations with regards to *P. cooloolensis*.

Ecological research

- Improve the limited understanding of the distribution and ecology of the 10 priority species that were not detected during these surveys (*Australobolbus masneri, Anoplognathus debaari, Anoplognathus hilleri, Anoplognathus storeyi, Onthophagus cooloola, Onthophagus beelarong, Onthophagus yarrumba* and *Cooloola propator*).
- Research into the fine-scale distribution, abundance, habitat requirements and general ecology of the wallum vicetail and wallum darner.

  The wallum vicetail is currently categorised as Vulnerable, and the wallum darner as Endangered, on the IUCN Red List of Threatened Species (Dow 2017a), but there are insufficient data available to identify population trends. Detailed monitoring and research into these species at Cooloola would redress this data deficiency and provide a better understanding of their conservation status and park management requirements. The wallum darner is a large, diurnal species and appears to be the only representative of the genus in the study area, making it readily amenable to observational and/or photographic survey techniques.

  The coastal petaltail is categorised as Near Threatened in the IUCN Red List of Threatened Species (Dow 2017b) and there is currently a lack of data to document population changes, particularly in Queensland. The species is listed as Endangered under the New South Wales *Biodiversity Conservation Act 2016* and designated as 'Data Deficient'. Baird (2017) summarised the available published and unpublished information on *P. litorea*, highlighting a paucity of data from Queensland. Detailed monitoring and research into this species at Cooloola would provide critical data to clarify its conservation status and guide management priorities. A better understanding of the species' reproductive habitat in the region, particularly in relation to fluctuating groundwater levels and the impacts of fire, are required.

- Undertake further surveys of the predatory ground beetle *P. cooloolensis* to clarify the distribution and ecology of this poorly known species, at Cooloola and K'gari (Fraser Island), particularly to understand the full range of occupied habitats.

7 Priority plants

7.1 Conservation context

Priority species

Four plant species were prioritised for this project: durringtonia *Durringtonia paludosa (*family Rubiaceae) listed as Near Threatened under the NCA; Fraser Island creeper *Tecomanthe hillii* (family Bignoniaceae*)* and *Gonocarpus effusus* (family Rubiaceae), both listed as Vulnerable under the NCA; and Mt. Emu she-oak *Allocasuarina emuina* (family Casuarinaceae), listed as Endangered under the NCA and the EPBC (Table 1). Whilst *Allocasuarina emuina* and *Gonocarpus effusus* occur in the Sunshine Coast region, neither species occurs at Cooloola, with *Gonocarpus effusus* only occurring on volcanic plugs and rhyolite/basalt cliffs, such as Mt Coolum.

Additional species of conservation concern

An additional 18 threatened plant species were identified as warranting post-fire survey effort and consideration of on-ground action to support recovery (Meiklejohn *et al*. 2020; M. Mathieson pers. comm.) (Table 10). Of these, five species had a significant proportion (>15%) of their modelled state-wide habitat within the study area impacted by the 2019–2020 fires (Meiklejohn *et al*. 2020) (Table 10).

Table 10: Additional threatened plant species surveyed, with their conservation status under State (NCA) and Commonwealth (EPBC) legislation (NT=Near Threatened; V=Vulnerable; E=Endangered; CE=Critically Endangered).

Common name	Species	NCA	EPBC	Common name	Species	NCA	EPBC
Whipstick wattle	*Acacia attenuata*	V	V	Silver glycine pea	*Glycine argyrea*	NT	-
Tiny wattle	*Acacia baueri* subsp. *baueri*	V	-		*Macarthuria complanata*	NT	-
Scented acronychia	*Acronychia littoralis*	E	E	Pineapple zamia	*Macrozamia pauli-guilielmi*	E	E
Christmas bells	*Blandfordia grandiflora*	E	-		*Melaleuca cheelii*	NT	-
Key's boronia	*Boronia keysi*	V	V	Swamp orchid	*Phaius australis*	E	E
Wide Bay boronia	*Boronia rivularis*	NT	-	Dark greenhood	*Pterostylis nigricans*	NT	-
Stinking cryptocarya	*Cryptocarya foetida*	V	V	Native guava	*Rhodomyrtus psidioides*	CE	CE
Coastal sprite orchid	*Diteilis simmondsii*	NT	-	Hairy hazelwood	*Symplocos harroldii*	NT	-
Swamp stringybark	*Eucalyptus conglomerata*	E	E	Southern penda	*Xanthostemon oppositifolius*	V	V

7.2 Survey sites and methods

Information from the Queensland Herbarium database (HerbRecs) for the prioritised species was checked and cross-referenced to the study areas and fire extent (Figure 1). Details of locations were recorded for priority species that were backed by specimens lodged at the Queensland Herbarium, and subsequently checked in the field to ascertain the impacts of the fires. Searches of additional areas where species were likely to occur were also conducted, and any sightings noted across Cooloola and Noosa NP survey areas (Figure 27). Information in the field was collected on approximate numbers of plants, evidence of fire impact (scorch, death, no effect), and response to fires (flowering, fruiting, sprouting, regeneration, lignotubers, epicormic growth).

7.3 Survey results

Priority species

Allocasuarina emuina is a fire-adapted species known to occur in Noosa NP and has been well studied over many years. Within Noosa NP the species was found in burnt and unburnt habitat, where plants were in flower (unburnt) or with coppicing from the base of burnt plants. As *A. emuina* depends on fire for germination, a fire frequency that allows for recruitment and growth to reproduction stage and beyond is important.

No *Durringtonia paludosa* plants were detected during searches. However, it is a known obligate seeder in wet heath and wetlands and is known to respond positively post-fire (G.P. Guymer pers. comm.)

Tecomanthe hillii is a rainforest species and would be moderately to severely affected if burnt. However, specimen-backed populations were largely unaffected and *T. hillii* is surviving well in Franki's Gulch (Figure 28).

Figure 27: Location of survey areas for priority plant species (yellow shaded) across Cooloola (top), Noosa North Shore (bottom left) and Peregian–Noosa NP (bottom right).

Additional species of conservation concern

A summary of results for the additional 18 plant species is as follows:

Known populations, represented by specimens at the Queensland Herbarium, of *Acronychia littoralis, Cryptocarya foetida, Diteilis simmondsii, Rhodomyrtus psidioides, Symplocos harroldii* and *Xanthostemon oppositifolius* were unaffected by the fires.

Acacia attenuata specimen-backed populations did not fall within the extent of the 2019–2020 bushfires and none were detected incidentally. As an obligate seeder, fire enhances germination if sufficient time between fires exists to replenish the seed bank.

Acacia baueri subsp. *baueri* was detected incidentally at two burnt sites, flowering and seeding. As an obligate seeder, fire enhances germination if sufficient time between fires exists to replenish the seed bank.

Blandfordia grandiflora or Christmas bells is a fire-tolerant species showing greatly enhanced flowering in the year or two following fires (Figure 29). Healthy populations were found throughout the survey area in suitable wallum-heath habitat, both burnt and unburnt. Resprouting and germination were noted.

Boronia keysii has several populations known to occur at Cooloola, with only one population north of Harry's Hut affected by the 2019–2020 fires. This species is an obligate seeder showing significant germination post-fire, although fire largely kills the mature plants. At the burnt site, many mature and senescing individuals were burnt and killed, and some that had been partly burnt were resprouting from unburnt stems. In addition, numerous individuals remained unburnt and were flowering well in late winter 2020. Across the burnt areas within the population, significant germination was observed, with 10–20 seedlings per square metre noted (Figure 30).

Boronia rivularis is a conspicuous and moderately common species at Cooloola (Figure 29). It responds similarly to its congener *B. keysii* where burnt. It was noted as flowering well, often in in large stands where unburnt, such as at Dutgee campground, and was germinating in good numbers at burnt sites along the Noosa River and north of Harry's Hut.

Eucalyptus conglomerata has known populations within the boundary of Cooloola that were not burnt during the 2019–2020 fires (M.T. Mathieson pers. obs.; J.J. Halford pers. comm.). However, trees of this species in Noosa NP (Peregian section) were lightly burnt and where affected, epicormic growth was abundant, with some seedlings present, presumably of this species. The species was also observed in Tewantin NP, where it was resprouting and germinating after a cool planned burn in 2020 conducted by QPWS.

Glycine argyrea was observed flowering after regeneration from seeds in woodland/heath communities in areas largely unaffected by fire but also in burnt areas. It is expected that this legume is fire tolerant given sufficiently long fire intervals. Presumed seedlings of this species were observed germinating in burnt areas north of Harry's Hut.

Macarthuria complanata was noted at a single location at the back of Marcus Beach in Noosa NP in the spring of 2020 (Figure 31). This perennial was growing in lightly burnt ground from thick rootstock and flowering well. Known locations in Cooloola were unaffected by fire.

Macrozamia pauli-guilielmi is a fire-tolerant species with subterranean trunks. It was noted at several locations across Cooloola in both burnt and unburnt areas. Masting events are often promoted by fire.

Melaleuca cheelii populations that occur in the study area were unaffected by the 2019–2020 fires (J.J. Halford pers. comm.).

Phaius australis, the swamp orchid, was found as a single population in unburnt country at Cooloola. This species is known to have some resilience to low–moderate intensity fire (L. Simmons pers. comm.), although hot fires and frequent, repeated burning will certainly eradicate the species from an area.

Pterostylis nigricans is a tuberous, terrestrial herb and would have been dormant during the 2019–2020 fires, lying mostly protected 5–10cm under the ground.

A new species recorded

A new species was recorded for Queensland during the surveys. The fire-adapted species *Trachymene composita* var. *composita* (Figure 31) was detected growing in a compact stand along the western firebreak in freshly burnt ground. Standing at 1–4m tall, it is reported to germinate only after a fire or other major disturbance and is often only detected after fire or clearing of ground. The previous most northerly record of this species was in the Tweed Shire, NSW, just south of the Coolangatta Airport. It also occurs further to the south in New South Wales, Victoria and Tasmania.

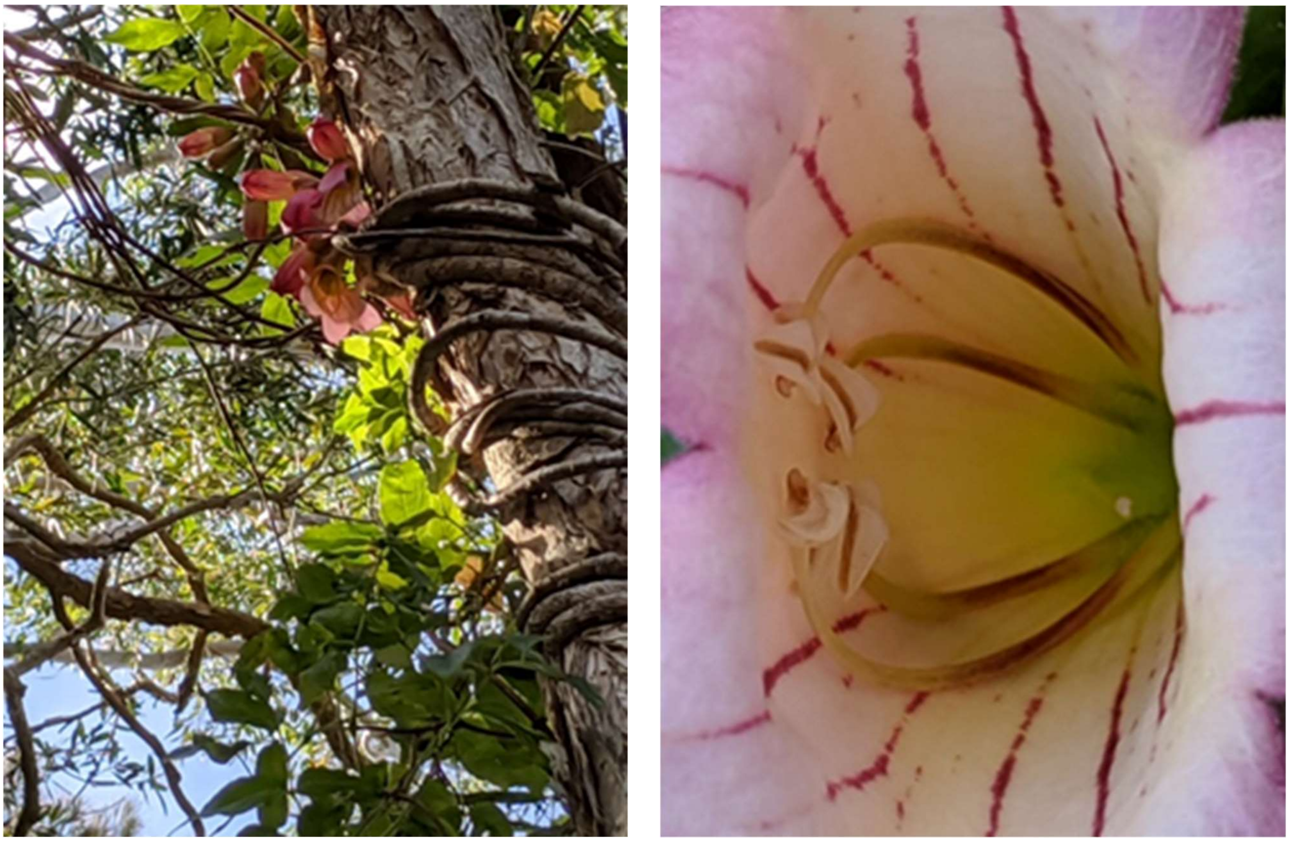


Figure 28: Fraser Island creeper *Tecomanthe hillii*, at Franki's Gully, at Cooloola.

Figure 29: *Blandfordia grandiflora* flowering in wallum heath north of Harry's Hut, (left) and *Boronia rivularis* on the Teewah Plain (right), Cooloola.

Figure 30: *Boronia keysii* (left) and *B. keysii* seedlings (right: yellow circles) germinating post-fire alongside *Ricinocarpus pinifolius*, another obligate seeder at Cooloola.

Figure 31: *Macarthuria complanata* growing in an area of low fire severity in Noosa NP (left), and *Trachymene composita* var. *composita* (right) at Cooloola.

7.4 Discussion

Twenty-three threatened species are distributed across the broader Cooloola, Noosa NP and Noosa North Shore landscape. Within the Cooloola study area, six species have no records, seven occur there but were unaffected by the 2019–2020 fires, and nine of the remaining 10 were observed with no unexpected results. Further work will be required to locate durringtonia. However, as a true wet heathland species, it is suspected to be quite fire tolerant (G. Guymer pers. comm.).

Two high-profile species, *Boronia keysii* and *Blandfordia grandiflora,* appear to have survived the 2019–2020 fires.

The 2019–2020 fires have not irreversibly damaged populations of any species assessed during this project. Extensive fires and fires that are too frequent are a threat to the conservation of many of these threatened species. The appropriate use of fire to reduce this risk and protect their habitats is critical. The threat of increasing droughts with a changing climate is also a significant concern for the persistence of viable threatened plant populations.

7.5 Recommendations

Reducing ongoing threats

- Protect threatened species and their habitats from future bushfires and high fire frequency.

  The appropriate use of planned burns is supported to reduce the risk to priority plant species and their habitats from the impacts of bushfire and too-frequent fire.

- Reduce the impact of ecosystem-transforming weeds on the recovery and ongoing health of heath and woodlands.

Ecological monitoring

- Ongoing monitoring of threatened plant species.

  The regular monitoring of *Blandfordia grandiflora* across the heath is suggested, as it has a tall flower spike with red flowers that can be readily recognised, simplifying the process of detection and identification. Christmas bells can usually be seen in both burnt and unburnt landscapes at flowering time, peaking in late spring and summer; however, the species can flower at any time of year. Whilst a fire-adapted species, it would still be sensitive to fires that are too frequent or severe, with populations at risk from insufficient, or a lack of, recruitment.

  The regular monitoring of *Boronia keysii* is suggested for woodland habitats.

Ecological research

- Further research is necessary to determine the fire intensity and frequency that threatened plant species require or can withstand.

8 Priority ecosystems

8.1 Fire-sensitive ecosystems

8.1.1 Conservation context

The area that includes the Cooloola section of Great Sandy NP, Great Sandy Resources Reserve, Cooroibah Conservation Park, Noosa NP and Cooloola (Noosa River) Resources Reserve protects 52 Regional Ecosystems (REs). Most of these (77%) were directly impacted by the 2019–2020 fires to differing degrees. Whilst many ecosystems and species are fire adapted, or reliant upon fire of an appropriate severity and interval for part of their life history, others may be damaged by fire of any severity. The latter fire-sensitive ecosystems, and their dependent flora and fauna species, may sustain significant long-term impacts from bushfires, including local extinction. To assess the likely impacts of bushfire on REs within the project area, analyses and results are described below according to their tolerance to fire.

Of the 40 REs impacted by the 2019–2020 fires, nine are fire-sensitive ecosystems, including rainforest and wetlands (Table 11). The deliberate use of fire is not recommended for the management of these REs (Queensland Herbarium 2021). One impacted RE is classed as 'Endangered' under the *Vegetation Management Act 1999* (VMA), meaning that less than 10% of its pre-clearing extent across the bioregion remains as remnant vegetation, or 10–30% of its pre-clearing extent remains and less than 10,000ha of remnant vegetation remains. Three REs are classed as 'Of concern' under the VMA, meaning that remnant vegetation is 10–30% of its pre-clearing extent across the bioregion, or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000ha.

Table 11: Fire-sensitive regional ecosystems impacted by the 2019–2020 fires, listed by identification number (RE#), with a description and classification under the *Vegetation Management Act 1999* (VMA Class).

RE#	Short description	VMA class
12.1.2	Saltpan vegetation including grassland, herbland and sedgeland on marine clay plains	Least concern
12.1.3	Mangrove shrubland to low closed forest on marine clay plains and estuaries	Least concern
12.2.1	Notophyll vine forest on parabolic high dunes	Of concern
12.2.3	Araucarian vine forest on parabolic high dunes	Of concern
12.2.5	*Corymbia intermedia* +/- *Lophostemon confertus* +/- *Banksia* spp. +/- *Callitris columellaris* open forest on beach ridges	Least concern
12.2.14	Foredune complex comprising *Spinifex sericeus* grassland and *Casuarina equisetifolia* subsp. *incana* low woodland/open forest	Least concern
12.3.7b	Naturally occurring instream waterholes and lagoons, both permanent and intermittent	Least concern
12.5.13a	Microphyll to notophyll vine forest +/- *Araucaria cunninghamii* on remnant Tertiary surfaces	Endangered
12.9-10.16	Araucarian microphyll to notophyll vine forest on Cainozoic and Mesozoic sediments	Of concern

8.1.2 Methods

To map and analyse likely ecological impacts, the distribution of the nine fire-impacted, fire-sensitive REs within the project area was intersected with Potential Ecological Impact (PEI) mapping (Laidlaw *et al*. 2022) (Figure 32). The area of each fire-impacted, fire-sensitive RE was calculated across Queensland, within the project area and within the burnt extent (Table 12).

Due to the significant ecological impacts observed in the foredune complex RE 12.2.14, three new BioCondition plots (after Eyre *et al*. 2015) were established at Cooloola to assess the post-fire condition for ongoing monitoring, with the three plots representing an unburnt area, and areas of high and catastrophic PEI (Figure 33).

8.1.3 Results

A total of 1,802ha of fire-sensitive REs was burnt during the 2019–2020 fires. The fire-sensitive REs with the greatest area impacted by fire within the project area were the open forest RE 12.2.5 and foredune complex 12.2.14. Approximately one-third of the Queensland distribution of the open forest RE 12.2.5 occurs within the project area, one-third of which was burnt. Whilst 77% of the Queensland distribution of foredune complex RE 12.2.14 occurs within the project area, only 3% was burnt (Table 12). Over 99% of the Queensland distribution of two rainforest REs (12.2.1 and 12.2.3) occur within the project area. In both cases, less than 1% of their distribution within the project area was burnt. The RE with the largest percentage of its distribution burnt within the project area (39%) was 12.5.13a; however, only 1% of its Queensland distribution is found within the project area.

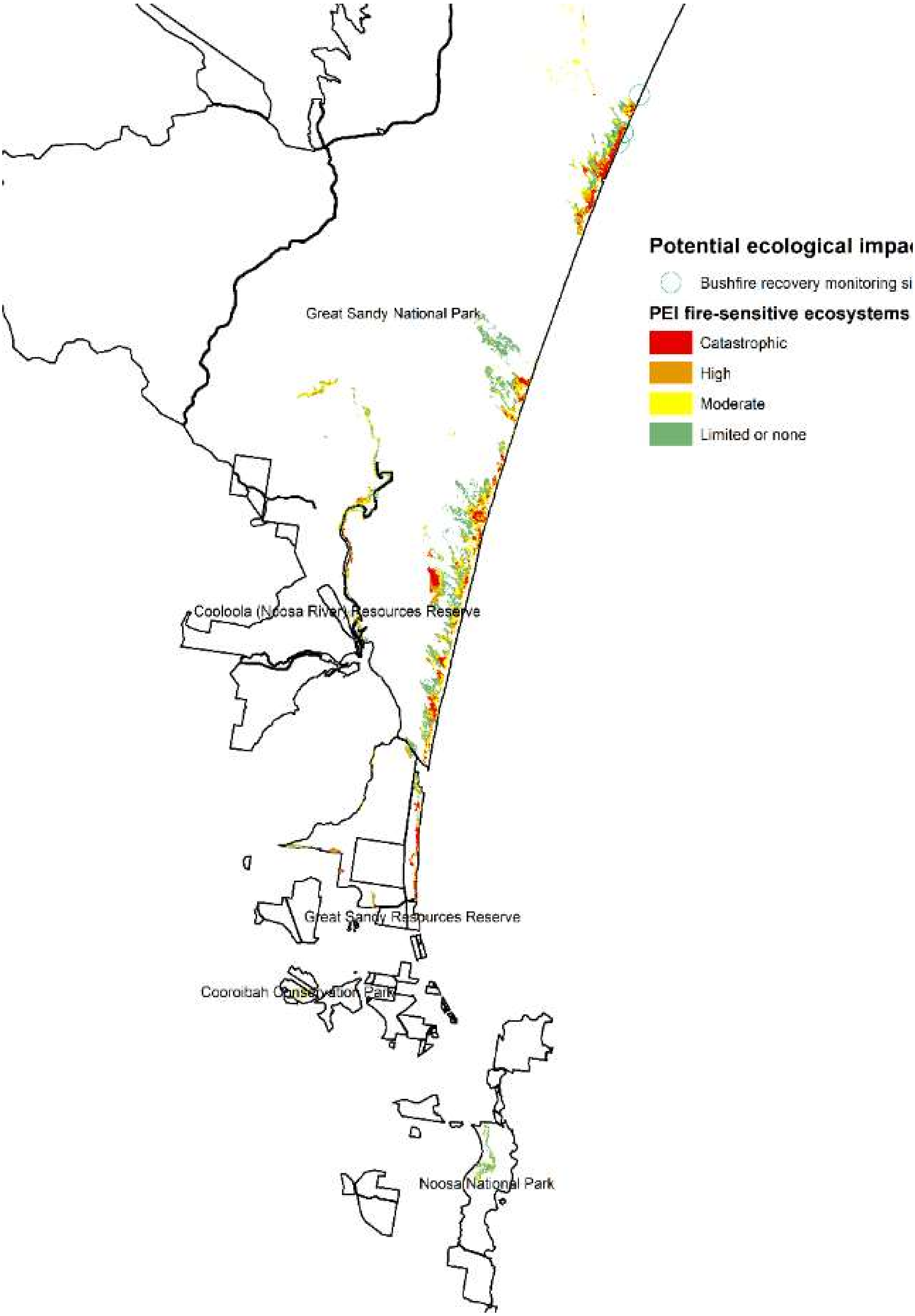


Figure 32: Distribution of the Potential Ecological Impact (PEI) across nine fire-impacted, fire-sensitive regional REs, with locations of three new BioCondition monitoring plots (○) in foredune complex RE 12.2.14.

Figure 33: BioCondition plots established in the foredune complex RE 12.2.14: unburnt (top), high PEI (middle) and catastrophic PEI (bottom) at Cooloola. (Photos: M. Laidlaw, 2021)

All burnt fire-sensitive REs within the project area experienced at least moderate ecological impacts (Figure 34). Eight (90%) of burnt fire-sensitive REs have 'areas of concern' where fire is likely to have resulted in high–catastrophic PEI (Figure 34). The RE with the largest relative 'area of greatest concern' (after Laidlaw *et al*. [2022] and defined as high to catastrophic PEI) was found to be the foredune complex RE 12.2.14, with 62% of the area burnt experiencing high to catastrophic PEI. Over half (52%) the area of fire-impacted rainforest RE 12.9-10.16 also experienced high to catastrophic PEI. Refer to Meiklejohn *et al*. (2020) for more detailed information of ecological impacts following the 2019–2020 fires in the project area.

Table 12: The level of fire impacts for each fire-impacted, fire-sensitive RE within the project area.

Regional Ecosystem	Area of remnant RE in Qld (ha)	Area of remnant RE within the project area (ha)	% Remnant RE within project area	Area of remnant RE burnt within the project area (ha)	% Remnant RE burnt within the project area
12.1.2	26,994	496	2	1	<1
12.1.3	51,692	2,804	5	7	<1
12.2.1	3,749	3,713	99	43	1
12.2.3	2,428	2,421	100	0.3	<1
12.2.5	10,759	3,305	31	1,179	36
12.2.14	21,733	16,627	77	553	3
12.3.7b	4,536	61	1	6	11
12.5.13a	4,949	28	1	11	39
12.9-10.16	8,569	81	1	1	1

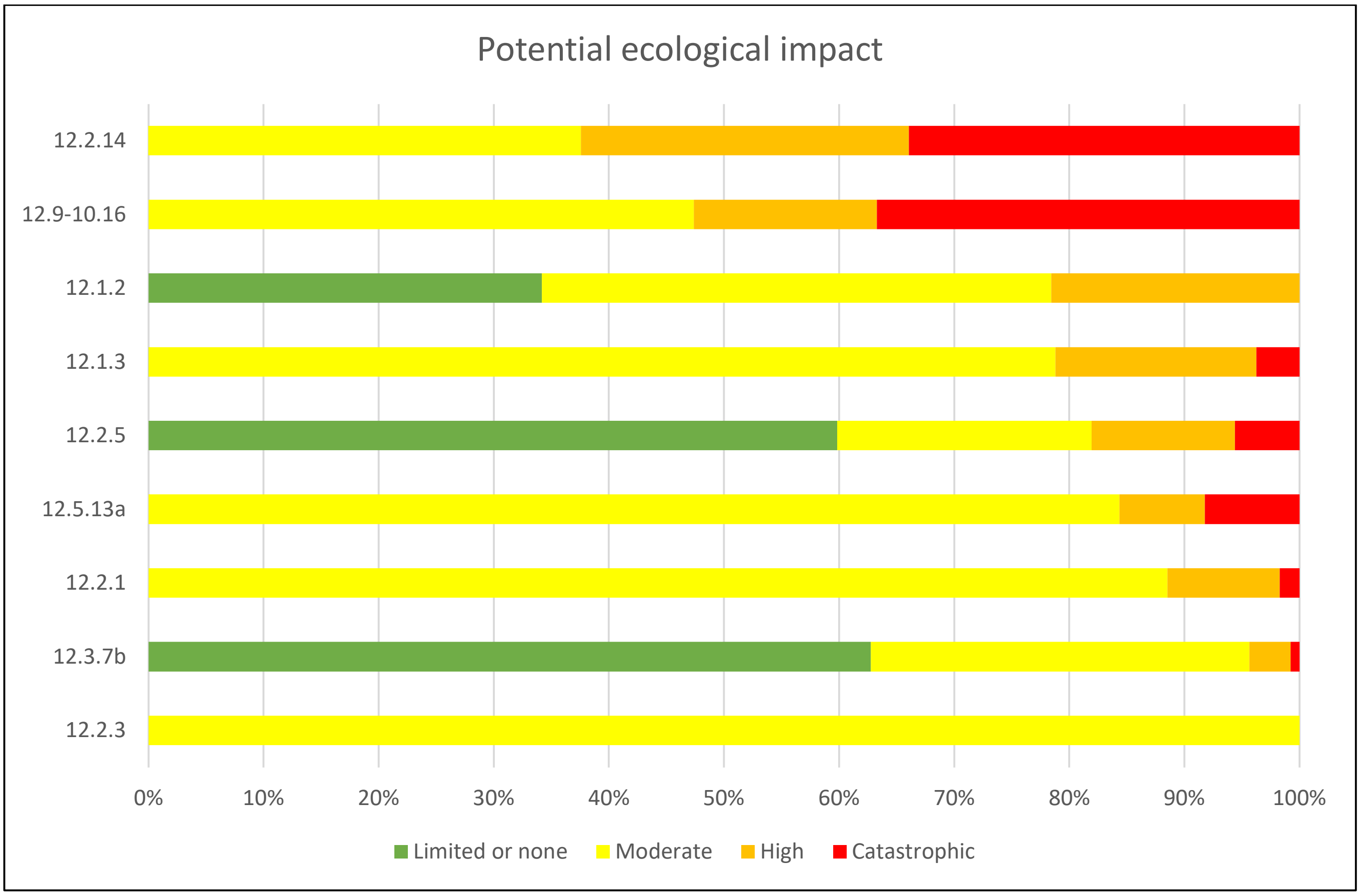


Figure 34: Fire-sensitive REs within the project area, with the relative PEI across the four categories (% area burnt).

8.1.4 Discussion

The foredune complex RE 12.2.14 was prioritised for the establishment of BioCondition monitoring plots given the impacts of the 2019–2020 fires based on the results of the PEI analysis, and given that it is fire-sensitive and the majority of its statewide distribution is represented at Cooloola. Field surveys of these BioCondition burnt and unburnt plots confirmed that the fire impacts were ecologically significant. At high PEI, understorey disturbance was significant, and some large mature trees were killed. At catastrophic PEI, however, all mature trees of *Banksia integrifolia* subsp. *integrifolia*, *Casuarina equisetifolia* and *Pandanus tectorius* within the plot were killed. Areas of RE 12.2.14 and the seven other REs with areas burnt resulting in catastrophic PEI (Figure 34) are at increased risk of invasion from ecosystem-transforming weeds and invasive fauna, limiting their capacity to recover. The burnt foredune complex RE 12.2.14 should continue to be monitored to assess the recovery trajectory. It is likely that these fire-impacted foredune areas will take decades to recover.

Fire-impacted, fire-sensitive REs are at risk from:

- loss of fire-sensitive biodiversity or in extreme cases, transition to another fire-tolerant RE
- invasion from fire-promoting weeds, including high-biomass grasses, vines and *Lantana camara*
- an increased threat from invasive fauna, including cats, pigs and cane toads.

Detailed recommendations for park management actions that can support the recovery of fire-impacted vegetation across the Cooloola area are provided by Meiklejohn *et al*. (2020).

8.2 Priority fire-tolerant ecosystems

8.2.1 Conservation context

Fire-tolerant REs are defined as those that can tolerate, or are reliant upon, fire of an appropriate severity and interval for part of their life history (Queensland Herbarium 2021). Of the 40 REs impacted by fire within the project area, 31 are considered fire-tolerant ecosystems (Table 13), including open forests, woodlands, heaths and sedgelands. Three of these REs are classed as 'Endangered' under the VMA, meaning that either less than 10% of their pre-clearing extent across the bioregion remains as remnant vegetation or 10–30% of their pre-clearing extent remains and less than 10,000ha of remnant vegetation remains. Fifteen REs are classed as 'Of concern' under the VMA, meaning that remnant vegetation is 10–30% of its pre-clearing extent across the bioregion or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000ha.

8.2.2 Methods

The distribution of 31 fire-impacted, fire-tolerant REs within the project area was intersected with PEI mapping (Laidlaw *et al*. 2022) to map and analyse likely ecological impacts (Figure 35). The areas of each impacted RE were calculated across Queensland, within the project area and within the fire extent (Table 14).

8.2.3 Results

A total of 13,504ha of fire-tolerant REs was burnt during the 2019–2020 bushfires, with RE 12.2.8 (Figure 36) and RE 12.9-10.4 (Table 14) having the largest area of impact (>2000ha). Fortunately, only limited areas of moderate to catastrophic PEI were incurred by most fire-tolerant REs within the project area (RE 12.2.6 – Figure 37; Figure 38).

A majority (99.6%) of the Queensland distribution of RE 12.2.4 is found within the project area; however, only 2% was burnt in 2019–2020 (Table 14). The entire mapped extent of both RE 12.5.3 and 12.9-10.7a within the project area was impacted by fire; however, this constitutes less than 5% and 1% of their Queensland distribution, respectively.

Approximately half (16) of the burnt fire-tolerant REs have 'areas of concern' where fire is likely to have resulted in high–catastrophic PEI (Figure 38). Whilst only having approximately one-quarter (23%) of its distribution within the project area burnt, RE 12.5.2a is likely to have experienced the most significant ecological impacts, with 62% of the area burnt being an 'area of concern'.

Further details on the impacts to ecosystems in each park can be found in the post-fire assessment (Meiklejohn *et al*. 2020).

Table 13: Fire-tolerant regional ecosystems impacted by the 2019–2020 fires, listed by identification number (RE#), with a description and classification under the *Vegetation Management Act 1999* (VMA Class).

RE#	Short description	VMA class
12.1.1	*Casuarina glauca* woodland on margins of marine clay plains	Of concern
12.2.4	*Syncarpia hillii*, *Lophostemon confertus* tall open to closed forest on parabolic high dunes	Of concern
12.2.6	*Eucalyptus racemosa* subsp. *racemosa* open forest on dunes and sand plains.	Least concern
12.2.7	*Melaleuca quinquenervia* or rarely *M. dealbata* open forest on sand plains	Least concern
12.2.8	*Eucalyptus pilularis* open forest on parabolic high dunes	Least concern
12.2.9	*Banksia aemula* low open woodland on dunes and sand plains.	Least concern
12.2.12	Closed heath on seasonally waterlogged sand plains	Least concern
12.2.13	Open or dry heath on dunes and beaches	Of concern
12.2.15	*Gahnia sieberiana*, *Empodisma minus*, *Gleichenia* spp. closed sedgeland in coastal swamps	Least concern
12.2.15a	*Gahnia sieberiana*, *Empodisma minus*, *Gleichenia* spp. closed sedgeland in coastal swamps	Least concern
12.2.15g	*Gahnia sieberiana*, *Empodisma minus*, *Gleichenia* spp. closed sedgeland in coastal swamps	Least concern
12.2.16	Sand blows largely devoid of vegetation	Of concern
12.3.2	*Eucalyptus grandis* tall open forest on alluvial plains	Of concern
12.3.4	*Melaleuca quinquenervia*, *Eucalyptus robusta* woodland on coastal alluvium	Of concern
12.3.5	*Melaleuca quinquenervia* open forest on coastal alluvium	Least concern
12.3.11	*Eucalyptus tereticornis* +/- *Eucalyptus siderophloia*, *Corymbia intermedia* open forest on alluvial plains usually near coast	Of concern
12.3.13	Closed heathland on seasonally waterlogged alluvial plains usually near coast	Least concern
12.3.14	*Banksia aemula* low woodland on alluvial plains usually near coast	Of concern
12.3.14a	*Eucalyptus racemosa* subsp. *racemosa* woodland to open forest	Of concern
12.5.2a	*Corymbia intermedia*, *Eucalyptus tereticornis* woodland	Endangered
12.5.3	*Eucalyptus racemosa* subsp. *racemosa* woodland on remnant Tertiary surfaces	Endangered
12.5.4	*Eucalyptus latisinensis* +/- *Corymbia intermedia*, *C. trachyphloia* subsp. *trachyphloia*, *Angophora leiocarpa*, *Eucalyptus exserta* woodland on complex of remnant Tertiary surfaces and Cainozoic and Mesozoic sediments	Least concern
12.5.6c	*Eucalyptus pilularis* open forest +/- *E. siderophloia*, *E. propinqua*, *Corymbia intermedia*, *E. microcorys*, *E. acmenoides*, *E. tereticornis, E. biturbinata*, Lophostemon confertus with *E. saligna*, *E. montivaga* at higher altitudes.	Endangered
12.5.9	Sedgeland to heathland in low lying areas on complex of remnant Tertiary surface and Tertiary sedimentary rocks	Of concern
12.5.10	*Eucalyptus latisinensis* and/or *Banksia aemula* low open woodland on complex of remnant Tertiary surface and Tertiary sedimentary rocks	Least concern
12.5.12	*Eucalyptus racemosa* subsp. *racemosa*, *E. latisinensis* +/- *Corymbia gummifera*, *C. intermedia*, *E. bancroftii* woodland with heathy understorey on remnant Tertiary surfaces	Of concern
12.8.20	Shrubby woodland with *Eucalyptus racemosa* subsp. *racemosa* or *E. dura* on Cainozoic igneous rocks	Of concern
12.9-10.1	Tall open forest often with *Eucalyptus resinifera*, *E. grandis*, *E. robusta* and *Corymbia intermedia* on sedimentary rocks, usually coastal	Of concern
12.9-10.4	*Eucalyptus racemosa* subsp. *racemosa* woodland on sedimentary rocks	Least concern
12.9-10.7a	*Eucalyptus siderophloia*, *Corymbia intermedia* +/- *E. tereticornis* and *Lophostemon confertus* open forest.	Of concern
12.9-10.22	Closed sedgeland and/or shrubland on sedimentary rocks. Generally coastal.	Of concern

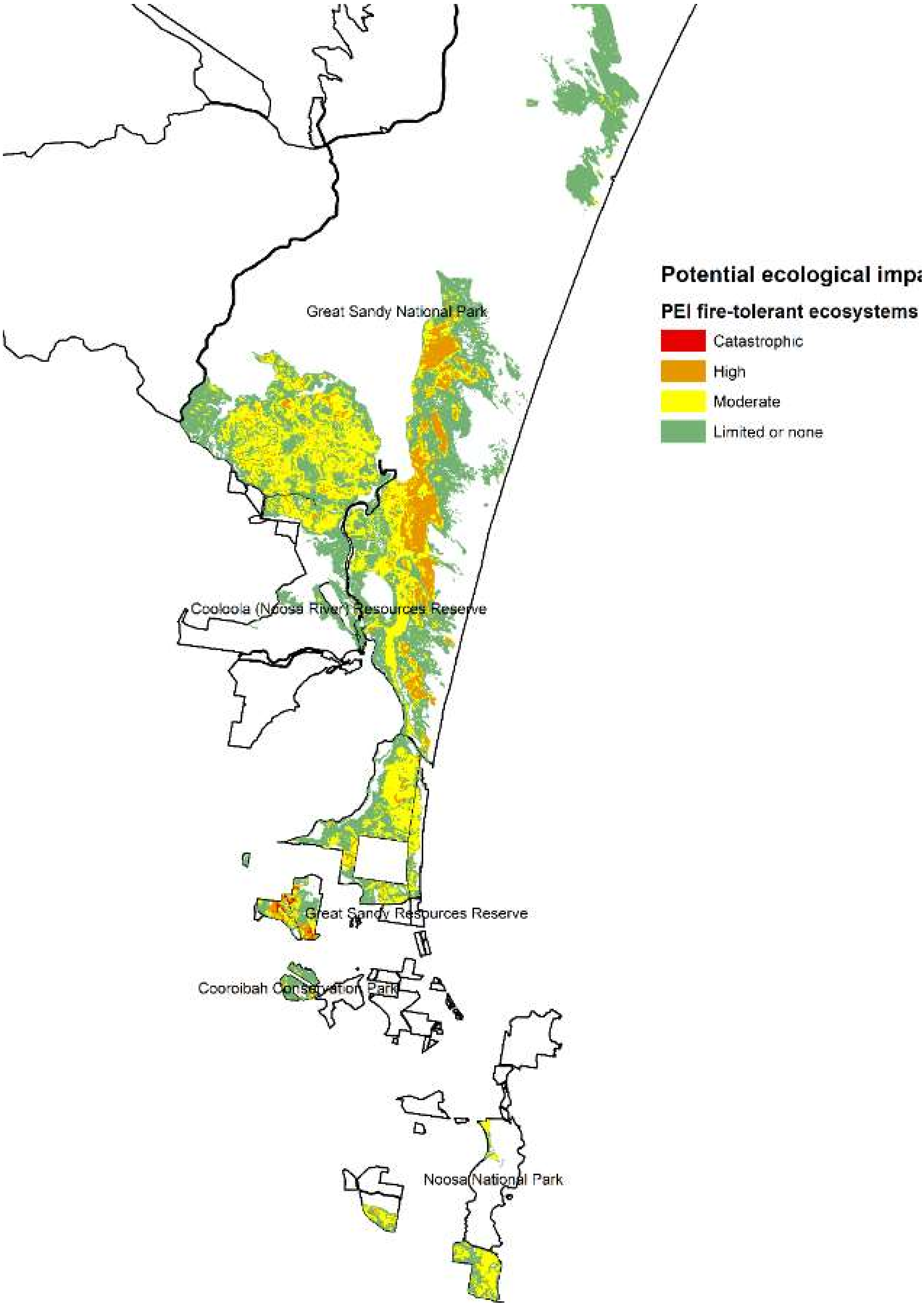


Figure 35: Distribution of fire-impacted, fire-tolerant REs at Cooloola across classes of Potential Ecological Impact.

Figure 36: RE 12.2.8 at Cooloola with limited Potential Ecological Impact, Feb. 2020. (Photo: M. Rix)

Figure 37: RE 12.2.6 with moderate Potential Ecological Impact, Feb. 2020. (Photo: M. Rix)

Table 14: The level of fire impacts for each fire-impacted, fire-tolerant RE within the project area.

Regional Ecosystem reference	Area of remnant RE in Qld (ha)	Area of remnant RE within the project area (ha)	% of remnant RE within project area	Area of remnant RE burnt within the project area (ha)	% of remnant RE burnt within the project area
12.1.1	3,433	81	2	9	11
12.2.4	9,770	9,728	100	177	2
12.2.6	69,359	55,839	81	1,885	3
12.2.7	18,522	7,451	40	1,459	20
12.2.8	21,565	20,035	93	2,374	12
12.2.9	56,716	45,448	80	955	2
12.2.12	10,830	6,293	58	1,420	23
12.2.13	233	69	30	2	3
12.2.15	21,803	17,273	79	114	1
12.2.15a	959	708	74	10	1
12.2.15g	1,057	967	91	67	7
12.2.16	5,390	4,172	77	<1	<1
12.3.2	7,241	162	2	18	11
12.3.4	7,884	1,339	17	371	28
12.3.5	19,845	3,315	17	851	26
12.3.11	40,350	66	0	14	22
12.3.13	12,269	4,131	34	971	24
12.3.14	5,395	219	4	34	15
12.3.14a	1,032	745	72	192	26
12.5.2a	2,538	275	11	62	23
12.5.3	5,318	267	5	267	100
12.5.4	94,478	1,957	2	7	0
12.5.6c	5,546	38	1	22	58
12.5.9	6,787	484	7	35	7
12.5.10	15,842	416	3	13	3
12.5.12	15,681	5,248	33	93	2
12.8.20	6,975	59	1	18	31
12.9-10.1	4,407	610	14	20	3
12.9-10.4	19,684	5,980	30	2,012	34
12.9-10.7a	2,149	8	0	8	100
12.9-10.22	1,372	106	8	22	21

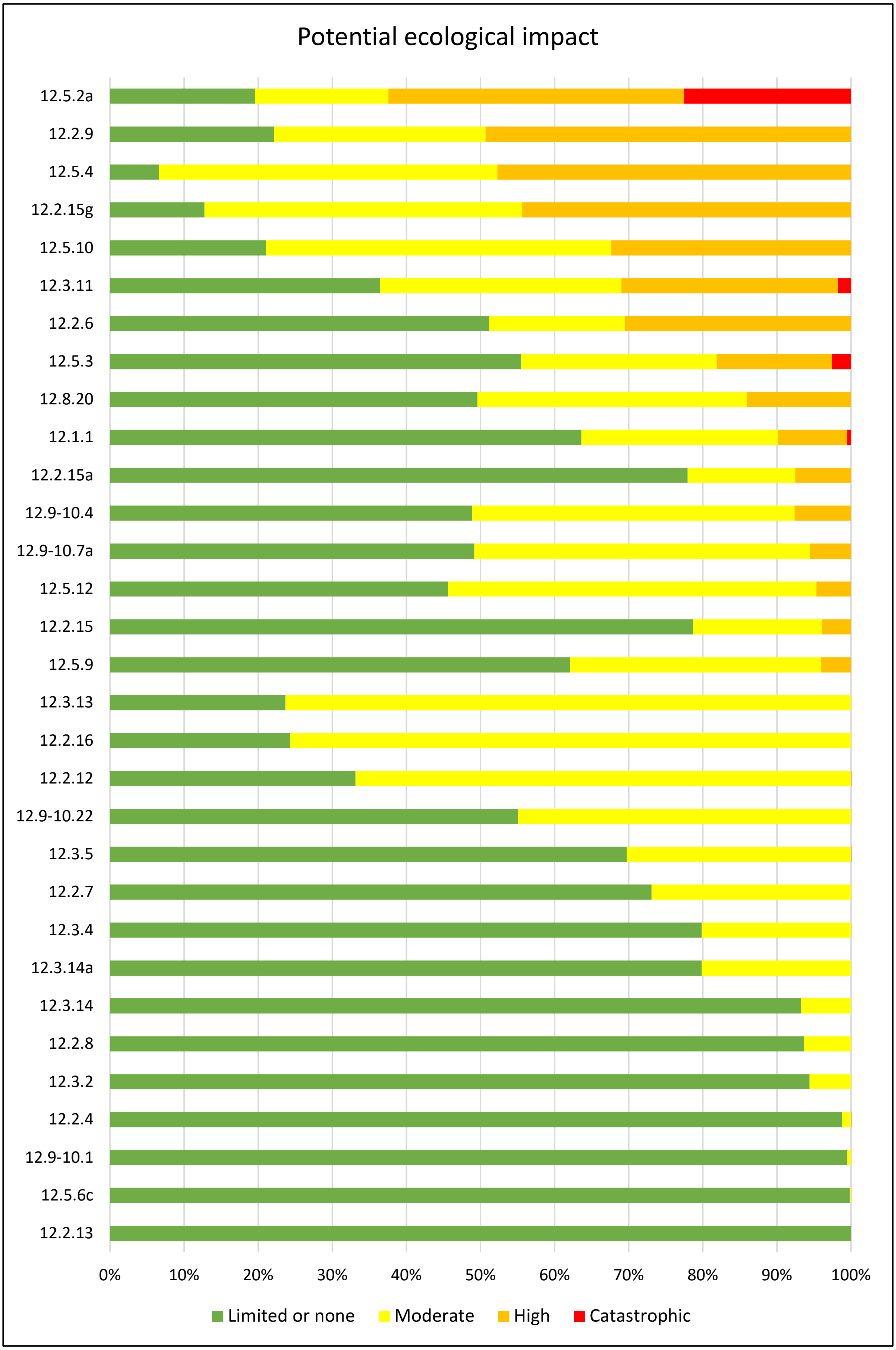


Figure 38: Fire-tolerant REs prioritised by 'area of greatest concern' as defined by high–catastrophic PEI.

8.2.4 Discussion

While many ecosystems and species are adapted to, or reliant upon, fire of an appropriate severity and interval for part of their life history, some REs are likely to have been subjected to catastrophic PEI over part of their burnt extent. Twenty-three percent of the burnt extent of RE 12.5.2a is likely to have experienced catastrophic PEI, while REs 12.5.3, 12.3.11 and 12.1.1 were also subjected to areas of catastrophic PEI in the vicinity of 6%, 2% and 0.5% of their burnt extent, respectively. These areas should be the focus of recovery actions to address their increased risk of invasion from ecosystem-transforming weeds, including high-biomass grasses and *Lantana camara*, and the increased threat from invasive fauna, such as cats, pigs and cane toads.

8.3 Recommendations

Reducing ongoing threats

- Protect fire-sensitive communities from fire

  Ensure that strategies for weed and fire management in adjacent fire-adapted communities aim to reduce the risk of fire encroachment into fire-sensitive REs.

- Prevent incursion of bitou bush *Chrysanthemoides monilifera* subsp. *rotundata* into any ecosystem

  Implement control as required in collaboration with programs led by Biosecurity Queensland.

- Reduce impacts of the leaf hopper *Jamella australia*e on *Pandanus tectorius* populations to support their recovery.
- Reduce impacts of pigs, which can damage regenerating plants and inhibit the recovery of ecosystems.
- Prevent the establishment of weeds in fire-sensitive REs.

  High-biomass grasses and *Lantana camara* are of particular concern, with early intervention and sustained control efforts required.

- Reduce impacts of weeds in fire-adapted REs.

  Weed species of concern include *Lantana camara* (Lantana), *Schinus terebinthifolius* (broadleaved pepper), high-biomass grasses such as *Andropogon virginicus* (whiskey grass) and vines such as *Dolichandra unguis-cati* (cat's claw creeper). Regular surveillance, early intervention and a rapid and sustained control effort is required.

- Reduce the impacts and potential spread of myrtle rust with appropriate checks and hygiene protocols.
- Prevent impacts on the foredune complex from inappropriate vehicle and recreational use and monitor for the risk of erosion and further vegetation loss.
- Avoid use of fire-fighting retardants in or near swamps, wetlands or heathlands.

Ecological monitoring

- Regularly monitor the three BioCondition plots established in RE 12.2.14.

  Monitoring frequency is recommended to be annual initially to closely track the post-fire recovery trajectory.

Ecological research

- Investigate ways to limit the extent of heath being burned during any one fire event (i.e. improving pyro-diversity or heterogeneity of age classes).
- Investigate the refinement of fire severity mapping of swamps to better detect areas where the peat layer burned.

9 Reducing threats to recovery

Reducing threats to the natural values of the Great Sandy NP is an ongoing priority for QPWS park management. Key values are identified through the Values Based Management Framework (DES 2020), which guides the development of the Great Sandy NP management plan and related park strategies, such as for fire and pest management, with the intent to implement an adaptive management approach.

As land managers, QPWS complies with the general biosecurity obligation under the State *Biosecurity Act 2014* to minimise the risks presented by invasive plants and animals. QPWS also works collaboratively with local government and adjoining landholders to achieve a more effective landscape-scale approach to control in line with the *Queensland invasive plants and animals strategy* (Department of Agriculture and Fisheries 2019).

Following the 2019–2020 fires, key threats to the recovery of priority threatened species in the post-fire landscape at Cooloola were identified by experts (Threatened Species Operations 2020). The location and focus of on-ground actions to reduce threats were determined using modelled habitat maps for priority species, local knowledge of park rangers and budget constraints. This was followed by implementation of actions across Phases 1 and 2 of the program.

9.1 Fire

The broad extent of the 2019–2020 bushfires across Cooloola was a result of the prolonged drought, above average temperatures, very low relative humidity and gusty winds that created dangerous fire conditions (Meiklejohn *et al*. 2020). It was recognised that any subsequent fire in the near future could be catastrophic for the recovery of threatened species. It was therefore critical to consider immediate actions that could mitigate that risk, as well as those that would proactively reduce the threat of unplanned fires in core habitats, over the medium and longer term.

Critical firelines

QPWS park management worked quickly after the 2019–2020 fires to remove hazards along the vehicle track network and restore safe access across Cooloola, which would support an emergency response to any subsequent fire. The condition of critical firelines was reviewed in terms of the location of core habitat for priority species, local knowledge from park rangers of the likely fire pathways and the flammability of associated vegetation types. An initial priority was to reinstate a 6.3km fireline on the western boundary of the park with Toolara State Forest (Figure 39). Subsequent work during Phase 2 delivered upgrades to five firelines over 17.6km to support landscape-scale fire management. These actions provided safer and more effective access for emergency response vehicles in a bushfire event and, therefore, a greater ability to limit the progression of fire into important habitats, such as that of the southern emu-wren and eastern ground parrot.

Figure 39: The firebreak reinstated along the boundary between Cooloola and Toolara State Forest (left) and an example of regenerating vegetation at Cooloola (right).

Planned burns

QPWS have an ongoing program of planned burns as part of the Great Sandy NP Fire Strategy to protect key park values. Implementation of strategic planned burns in fire-adapted vegetation communities, such as coastal heath, serves to reduce the fuel hazard and, hence, the potential severity of a bushfire. As a result, park managers have a greater capacity to control bushfire in the landscape and protect core refugia for threatened species populations. The use of planned burns to meet ecological guidelines (Queensland Herbarium 2021) can achieve important conservation outcomes by maintaining ecological health and a diversity of vegetation types across the park. Managing fire frequency can be critical to protecting some threatened species. Planned burns can help to maintain the diverse ecological conditions and resources required by wildlife, such as the range of seral stages of coastal heath that sustains essential seed stocks for ground parrots (section 3.1).

For fire management purposes, the park is fragmented into ‘blocks’ with an established rotation of planned burns every 7–10 years across blocks, so that adjacent blocks are not burned in the same year or consecutive years, if possible. An annual fire management program schedules planned burns in an optimal seasonal window, with the timing determined by suitable fire conditions. Following the 2019–2020 fires, the planned burn program was revised to exclude blocks that had burnt and to adapt plans for unburnt blocks where required to support the recovery of priority species. In Phase 2 of the program, planned burns were conducted across 2,236ha of fire-adapted vegetation to mitigate the risk of future fires and high severity fires.

Fire strategy

The fire strategy for the Great Sandy NP identifies the prioritised key values and the associated objectives of, and approach to, planned fire management across the park. Mapped zones highlight the areas for protecting life and infrastructure, as well as for fire exclusion, conservation and mitigation of the potential impacts of bushfire. The development of the strategy is guided by the state-wide QPWS Fire Management Strategy 2021–26 (DES 2021) and centred on the Values Based Management Framework (DES 2020). Following the 2019–2020 fires, the fire strategy for Cooloola was revised to support the recovery of priority threatened species in their core habitats.

9.2 Pest animals

Pigs and foxes, which have been part of the ongoing control program at Cooloola, were identified as significant threats to the initial recovery of priority threatened species (Threatened Species Operations 2020). Following consultation with park management, these species were strategically targeted for enhanced control efforts.

Pigs

Feral pigs broadly can cause extensive damage to crucial habitats, including wetlands that provide core habitat for acid frog and native fish species. Pigs can also consume these priority species and their food resources, which may include endemic invertebrates of concern, such as the aquatic larvae of priority dragonfly and damselfly species.

Broader impacts to the wet and dry heaths are also likely, presenting a threat of trampling and eating threatened plant species. Evidence of pig damage was observed in ground parrot habitat during surveys, and pigs were detected on bioacoustic recorders associated with ground parrot and southern emu-wren monitoring sites (Figure 40). In addition to modifying habitat and local hydrology, pigs can directly predate on nesting birds and chicks. Controlling pigs would also mitigate the risk of introducing or dispersing disease and weeds.

To detect pigs, four outdoor trail cameras were deployed at sites across Cooloola and adjoining the Noosa River, which park rangers identified as having a likely chance of pig activity at that time. Feral pig damage was observed, and pig images were captured on camera traps within these survey areas (Figure 40). Two pig traps were then established, with pre-feeding of corn to condition pigs to the traps, followed by the use of Hoggone® bait in specialised Hoggone® hoppers to specifically target lethal bait uptake by pigs. As a result, a total of 26 feral pigs were removed from the park during the program.

Foxes

Foxes were identified as a key threat to the eastern ground parrot and the southern emu-wren, noting that they could also predate on threatened frogs. At Cooloola, foxes typically establish dens in the foredunes where the substrate is suitable, and forage inland, including across habitats for priority species.

To assess the presence of foxes, outdoor trail cameras were deployed across suitable sites determined by park rangers, including the southern section of Cooloola near Teewah Village. Where foxes were detected (e.g. Figure 41), control methods were implemented, including baiting, trapping and den detection using conservation detection dogs. A total of one wild dog and 18 foxes was lethally controlled and two fox dens destroyed during the program.

Figure 40: Feral pig damage (left) and pig detection by a monitoring camera (right) at Cooloola.

Figure 41: Foxes captured on monitoring camera at Cooloola, with prey (left) and at den entrance (right).

9.3 Invasive plants

After a bushfire, weeds can quickly establish and expand their range, out-competing native species and hindering natural regeneration processes. Weeds that increase the fuel hazard can elevate the severity of future bushfires, which may alter vegetation structure, species composition and ecological processes. Identified as a threat to the recovery of the priority species, enhanced control of target weed species was undertaken over 77ha across Cooloola.

Invasive grasses

The rat's tail grasses *Sporobolus pyramidalis, S. natalensis, S. jacquemontii* and *S. fertilis* were of particular concern as they are listed as category 3 restricted invasive plants under the *Biosecurity Act 2014*, out-compete native grasses and cause significant degradation of natural areas. The small seeds can disperse readily, with the high level of recreational 4WD use at Cooloola presenting a significant risk of spreading these species further into the park, especially in a post-fire environment. Specific sites were therefore targeted for herbicide control (Figure 42).

Alongside rat's tail grass, other species of invasive grasses, such as thatch grass *Hyparrhenia rufa* and whiskey grass *Andropogon virginicus*, were controlled with herbicides over approximately 50ha across a range of sites (Table 15).

Singapore daisy

Singapore daisy *Sphagneticola trilobata* is listed as a category 3 restricted invasive plant under the *Biosecurity Act 2014*. It has invaded a range of environments, including sandy substrates, across coastal Queensland. As a rapidly growing ground cover, it forms dense mats that can smother native seedlings and shrubs and presents a significant risk to the recovery of fire-impacted foredune vegetation at Cooloola. This project extended the current control efforts with a focus on the Teewah Beach area (Table 15).

Table 15. Invasive weed management targets and locations.

Target weeds	Location
Invasive grasses	Harrys Hut Eurobi Road Teewah Village Teewah Pipeline Track Teewah Creek Firebreak Poverty Point Road Old Pump Station Road Wildflower Firebreak Investigator Firebreak Bilewilliam Road Carland Creek Firebreak
Singapore Daisy	Teewah Beach

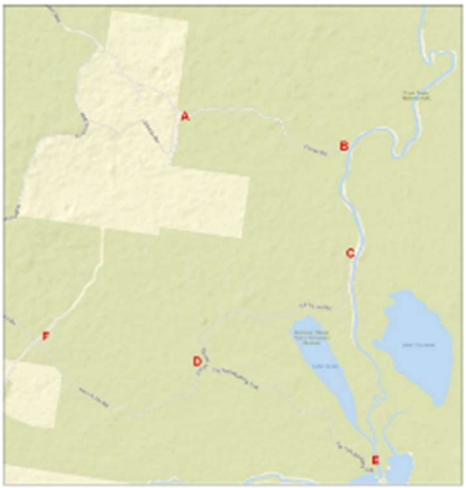


Figure 42. Sites sprayed for rat's tail grasses.

Pest strategy

The pest strategy for the Great Sandy NP prioritises the key values and outlines the objectives of, and approach to, the management of invasive animals and plants. Mapped zones can highlight the core areas for preventing incursions, eradication, reducing impact or containment of the pest species identified as a threat to key values. The development of the strategy is guided by the Values Based Management Framework (DES 2020) that aims to implement an adaptive management approach. The 2019–2020 fires were extensive at Cooloola, resulting in significant ecological impacts on key park values (Meiklejohn *et al*. 2020) and elevated levels of pest threats, especially to threatened species. As a result, the pest strategy for Cooloola was revised to ensure that the recovery of the priority threatened species was incorporated. This included reducing impacts from pigs, cats and foxes and preventing the spread of mosquitofish or establishment of invasive aquatic weeds and ecosystem-changing weeds.

10 Summary recommendations

Reducing ongoing threats to recovery

The recommendations for continuing to reduce the key threats to the ongoing post-fire recovery of priority species and ecosystem are summarised for future reference (Table 16). Refer to the relevant section for each priority species for further details and contact the scientific experts (Appendix 4) to provide guidance where required.

- It is essential to sustain investment in reducing the key threats to recovery.

This will optimise the returns from this significant Commonwealth funding and continue to provide ongoing conservation benefits and support for fire-impacted threatened species.

Table 16: Summary recommendations for reducing ongoing threats to the recovery of priority species.

Recommendation	Eastern ground parrot	Southern emu-wren	Fish	Acid-frogs	Insects	Plants	Fire-sensitive ecosystems
Fire							
Protect unburnt habitat from fire to enable recovery	✓	✓					
Protect from fire							✓
Protect habitat from fire intervals < recommended guidelines		✓	✓	✓		✓	
Maintain different post-fire age classes of heath and sedgelands through fire management that avoids breeding season	✓			✓		✓	
Protect wallum wetlands burnt in 2019–2020 from fire and apply the maximum fire interval in the recommended guidelines			✓	✓	✓		
Protect the lakes from water extraction during an emergency fire response			✓	✓	✓		
Pest animals							
Reduce impacts of pigs	✓	✓	✓	✓	✓		
Reduce impacts of cats and red foxes	✓	✓		✓			
Reduce impacts of mosquitofish			✓				
Reduce impacts of the leafhopper *Jamella australiae* on *Pandanus tectorius* populations.							✓
Invasive plants							
Reduce impacts of ecosystem-transforming weeds, including high-biomass grasses and Singapore daisy			✓	✓		✓	
Reduce impacts of high-biomass grasses, bitou bush and lantana							✓

Ecological monitoring and research

The recommendations for ongoing ecological monitoring and ecological research relevant to the priority species are summarised for future reference (Table 17). Please refer to the relevant section for each priority species for further details and contact the scientific experts (Appendix 4) to provide particular guidance where required.

Table 17: Summary recommendations for ecological monitoring and research for priority threatened species and priority ecosystems at Cooloola.

Recommendation	Eastern ground parrot	Southern emu-wren	Fish	Acid-frogs	Insects	Plants	Fire-sensitive ecosystems
Ecological monitoring							
Continue monitoring populations, particularly in fire-impacted sites	✓	✓	✓	✓	✓	✓	✓
Establish a rapid response process for post-disasters situations			✓				
Monitor the outcomes of planned burns on priority species	✓						
Ecological research							
Distribution, abundance and ecology					✓		
Interactive effects of multiple stressors			✓				
Impacts of fire and fire frequency on populations		✓	✓	✓		✓	
Population dynamics and threshold indicators of decline	✓						

11 Lessons learnt and forward guidance

This project was completed despite significant challenges to the planning, coordination and delivery of priority actions to support the recovery of threatened species after the 2019–2020 fires. It highlighted a lack of experience in addressing wildlife recovery across multiple protected areas following a natural disaster with broad-scale ecological impacts. Climate change predictions are for an increasing frequency and severity of bushfires (Canadell *et al*. 2022) and other natural disasters, hence wildlife will continue to be at risk. It is therefore important to capture the project learnings, advances made and opportunities to improve the capacity to protect Queensland's threatened species.

11.1 Risk management

Risks to wildlife

The 2019–2020 fires were extensive with broad ecological impacts, including direct mortality of wildlife, loss or degradation of habitats and increased chance of predation. The probability of such events occurring and impacting wildlife is likely to increase with a changing climate, with the most vulnerable being threatened species and fire-sensitive ecosystems and species. To protect threatened species and reduce the risk of other species being listed as threatened, it is vital to:

- update the assessment of risk from bushfire to threatened species, particularly those most at risk from extinction.

Decision making

A risk-based approach was used to prioritise threatened species for recovery actions under this program. This relied on information such as conservation status, species' traits, ecological requirements and their distribution relative to the fire extent (Threatened Species Operations 2020; Legge *et al.* 2021). The methodology used was best practice, yet the availability and reliability of core data were limited. This presents a significant risk that the species prioritised, and the decisions made to allocate funds or direct on-ground efforts may *not* be optimal for protecting species from decline or extinction. To improve the decision-making process and outcomes, it is important to:

- significantly enhance the capture and accessibility of reliable ecological information on threatened species.

Risk framework

This project addressed the post-fire *recovery* of impacted wildlife. Reducing the risk to wildlife from natural disasters needs to be more strategic and more proactive, rather than reactive. There is an opportunity to apply the National Disaster Risk Reduction Framework (AIDR 2009) for protecting life and property to the context of protecting wildlife (Legge *et al*. 2021), with consideration of prevention and mitigation, preparedness and response, as well as, of recovery. For wildlife this includes assessing the risk from climate change, developing adaptation plans for at-risk wildlife, strengthening networks, building better information systems and improving capacity for an emergency response. To support the Queensland Strategy for Disaster Resilience (QRA 2022), which says the State will 'require transformations in what governance systems value and how systemic risk is understood and addressed', it is recommended that:

- a more proactive and holistic framework is adopted to manage the increasing risks to wildlife from climate change.

11.2 Ecological data and expert services

To deliver this project, procedures and protocols had to be established to assess ecological impacts, identify priorities and implement surveys led by experts in a short timeframe. Significant improvements were made during this project and the broader program which need ongoing support and expansion to improve future wildlife recovery projects.

Threatened species data

The information required to identify the most fire-impacted threatened species, design species surveys and plan for threat reduction was often limited in its availability, currency and reliability. Where information was available, it was often derived from an expert or a range of data systems (e.g. WildNet; databases at the Queensland Herbarium and Queensland Museum). Improving the provision of data for threatened species is essential to support the recovery of populations, particularly after a natural disaster. Previous work has identified gaps in vertebrate fauna data (Smith 2013) which needs to be updated and expanded to assess other taxonomic groups to guide data collection priorities.

This project generated a significant volume of data that will improve the ecological understanding of the priority species, as well as other non-target species, at Cooloola. However, a centralised system to capture and secure this information with consistent protocols is lacking, resulting in external hard drives being used to store some data sets, presenting a significant business risk. Wherever feasible, data were uploaded to WildNet, pending the availability of skilled staff and time during the project. To improve knowledge and management of threatened species, to secure critical data and to support ongoing monitoring or a future emergency response, it is essential to:

- establish an information system that captures, secures and provides access to core data across QPWS business units and which seamlessly engages with relevant external systems to facilitate data sharing and collaboration
- update an assessment of the gaps in current threatened species data to prioritise data collection efforts.

Post-fire ecological assessment

To map fire severity and summarise the ecological impacts to key natural values, a new process needed to be established to provide guidance in the context of QPWS-managed protected areas (e.g., Meiklejohn *et al*. 2020). The methodology was then extended through an innovative approach to incorporate the fire sensitivity of ecosystems and map the potential ecological impacts (Laidlaw *et al*. 2022), which helped to better target recovery actions towards the most fire-impacted species and ecosystems. QPWS can now more efficiently undertake post-fire assessments of protected areas. To ensure ongoing capability for post-fire assessments, it is essential to:

- sustain the skills and capacity required for post-fire spatial and ecological analyses.
- sustain base-level investment to adopt and integrate technological improvements to the methodology.

Survey protocols

In this project, the innovative use of bioacoustics to survey the priority bird and frog species was successful and has established this as a suitable methodology for ongoing monitoring. However, recordings were analysed manually to identify calls, which was labour intensive and delayed provision of results to guide further recovery actions. Bioacoustic technology is rapidly evolving (see Sections 8.8 and 9.14 in Eyre *et al*. 2022), with the development of software programs to analyse and identify calls to species. Once this is available for priority species it will support a very cost-effective monitoring approach. It is therefore important to:

- invest in technological advances in survey methods that can optimise efforts and quickly provide resultant data.

Ecological expertise

Due to the extent of the 2019–2020 fires, this project was one of four to survey 56 threatened species, in addition to invertebrates, across six protected areas. At the same time, the late 2020 fires on K'gari (Fraser Island) also required post-fire ecological assessments and species' surveys. The expertise available to provide ecological guidance, lead field work, oversee projects and ensure consistency in survey methodology and data capture was limited. To improve capacity for wildlife recovery efforts, it is therefore vital to:

- recognise the unique skills that are required to plan, deliver and report on ecological surveys and assessments.
- expand capacity through a mentoring and recruitment process that targets specialist ecological skill sets.

Potential habitat mapping

To inform and guide recovery actions in the absence of adequate distributional data for threatened species, a potential habitat map was generated if a minimal set of locality data was available for the spatial modelling process (Laidlaw & Butler 2021; refer to Appendix 5 in Meiklejohn *et al*. 2020). Potential habitat maps were invaluable to help design surveys and guide on-ground efforts to reduce threats from pest animals, invasive plants or future fires. The maps for some species, such as the southern emu-wren, are not publicly available in order to protect them. Given the value of habitat mapping to improve conservation outcomes for many species, maps for 376 threatened species have been made available online through the '*Potential habitat models 2022–Queensland series*' on the Queensland Government QSpatial portal: Queensland Spatial Catalogue: Queensland Government (information.qld.gov.au)

The online provision of these maps supports greater consideration of threatened species in emergency planning and response for natural disasters, as recommended by Royal Commission Bushfire Royal Commission into National Natural Disaster Arrangements (recommendation 16.20: Binskin *et al*. 2020). It is therefore recommended that:

- online access to potential habitat maps for threatened species is maintained, with updates and inclusion of additional species when data are available.

11.3 Partnerships and networks

Scientific collaboration

This project was delivered in collaboration with the Queensland Herbarium, the Australian Rivers Institute at Griffith University and the Queensland Museum (Appendix 4), which facilitated field surveys of the priority taxa and ecosystems, data capture, analysis and interpretation, and provision of report content with forward recommendations.

The ability to secure this expertise was due to established relationships that shared common conservation concerns for the priority taxa. Amidst other work programs and an increasing chance of natural disasters, the availability of such expertise at short notice may become limited. It is therefore recommended that:

- formal agreements are established with existing partners to clarify a commitment to supporting wildlife recovery, the specific expertise that can be provided and the data-sharing arrangements.
- new partnerships are sought to expand the network of species experts for other taxa and geographical localities beyond that relevant to this project.

The lead time involved in this project to identify the required ecological experts, organise agreements and logistics, as well as initiate surveys, can be improved. As part of establishing formal arrangements with key partners for urgent wildlife recovery, it is advised that:

- pre-approval is provided with respect to permits, site access and ethics within a relevant wildlife recovery context and with appropriate conditions.

Contract land management services

Following the 2019–2020 fires, park managers had to deliver pest and fire management actions in a short timeframe, in addition to sustaining their normal work program. Existing relationships with adjoining land managers and local government helped to implement required works such as pig control and enhanced firelines. There was an additional need to quickly engage contractors to provide targeted weed and pest animal control activities to reduce impacts. After a natural disaster, demand for contract services can be high, limiting contractor availability, which is further constrained by the need to meet specific standards for protected areas to ensure that natural values are not at risk. To enhance future capacity to support threatened species' recovery, it is suggested that:

- networks are sustained with a range of suitably qualified local contractors to support and prioritise recovery efforts on park when needed. This should include First Nations teams whenever possible.

Strategic alignment

Learning from the lessons of this project and adopting the suggested improvements will support the State Government's Queensland Strategy for Disaster Resilience 2022 (Queensland Reconstruction Authority 2022), which includes enhanced cooperation across all levels of government, non-government organisations, the private sector and academics to strengthen resilience. This strategy encourages continuous improvement of processes and arrangements to ensure they remain effective and flexible, which is pertinent to wildlife recovery projects.

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Appendix 1: Detailed eastern ground parrot data

Table A1.1: Sites of eastern ground parrot surveys and results for 2020 and 2021, with: Site ID and location (N=north, S=south, E=east and W=west); Site type (AR=acoustic recorder, L=listen); burnt/unburnt status (and year); maximum (max) number of calls recorded at the site during any one survey period (dawn or dusk); duration of calling for the maximum period (minutes); number of surveys analysed (dawn and dusk); and number (#) of surveys in which calls were heard. Call index, bird number range and number of individuals were all calculated using method/formula of McFarland (in Spearritt & Krieger 2007).

Site ID and location	Site Type	Burnt/unburnt status	Max Calls	Duration of max (mins)	# Surveys analysed	# Surveys with calls	call index	bird # range	# Individuals
Surveyed 2020									
PBR0027, W side Noosa River Eurobi Rd S	AR	burnt 2019	16	5	44	5	32	4 - 10	6
PBR0007, W of airfield Noosa North Shore	AR	burnt 2019	12	14	66	3	9	1 - 3	3
PBR0008, E of airfield Noosa North Shore	AR	burnt 2019	532	52	126	120	116	> 12	15
PBR0009, S of airfield Noosa North Shore	AR	burnt 2019	62	36	126	44	17	2 - 6	4
PBR0028, W side Noosa River Eurobi Rd N	AR	burnt 2019	17	21	44	13	8	1 - 3	3
PBR0029, W side Noosa River opposite Dutgee	AR	burnt 2019	10	9	44	9	11	2 - 6	3
PBR0030, W side Noosa River opposite Camp 4	AR	burnt 2019	3	7	31	1	4	1 - 3	2
PBR0015, Woodland Drive Peregian S	L	burnt 2019	0	0	1	0	0	0	0
PBR0023, 2 km SW Campsite 3 Noosa River	L	burnt 2019	0	0	1	0	0	0	0
PBR0026, SE of Campsite 1, Noosa River	L	burnt 2019	0	0	1	0	0	0	0
PBR0001, 400m ENE Campsite 2 Noosa River	L	burnt 2019	63	25	2	2	25	4 - 10	5
PBR0006, S of helipad at Noosa River Campsite 3	L	burnt 2019	79	15	2	2	53	4-10	8
PBR0012, track S of airfield Noosa North Shore	L	burnt 2019	119	21	2	2	57	8 - 13	9
PBR0024, Old Pump Station Rd	L	burnt 2020	0		1	0	0	0	0
PBR0003, 460m N of Campsite 3 Noosa River	AR	unburnt 2019	17	4	14	7	43	4 - 10	7
PBR0004, 570m W of Flood Plain Break	AR	unburnt 2019	71	16	14	13	44	4 - 10	6
PBR0011, swamp N of Noosa North Shore village	AR	unburnt 2019	6	11	42	12	5	1 - 3	2
PBR0032, E of upper Noosa River, N of Dutgee	AR	unburnt 2019	2	1	18	2	20	4 - 10	4
PBR0016, Woodland Drive Peregian North	AR	unburnt 2019	1	1	1	1	10	4 - 10	4
PBR0031, E of Noosa River S of Dutgee	AR	unburnt 2019	1	1	1	1	10	2 - 6	3
PBR0017, 800m ESE of Dutgee	L	unburnt 2019	2	1	1	1	20	4 - 10	4
PBR0018, track to Dutgee E of Noosa River	L	unburnt 2019	32	18	1	1	18	2 - 6	4
PBR0041, 1km NNW of pump station Teewah Ck	L	unburnt 2019	125	25	1	1	50	4 - 10	8

Table A1.1 *continued*

Site ID and location	Site Type	Burnt/unburnt status	Max Calls	Duration of max (mins)	# Surveys analysed	# Surveys with calls	call index	bird # range	# Individuals
Surveyed 2020 *continued*									
PBR0020, Mt Bilewilam Firebreak	L	unburnt 2019	20	19	1	1	11	2 - 6	3
PBR0025, Roy Weber Plain	L	unburnt 2019	4	3	1	1	13	2 - 6	3
PBR0002, 1.1km NE Campsite 3 Noosa River	L	unburnt 2019	4	5	1	1	8	1 - 2	3
PBR0005, N of Joe's Gully	L	unburnt 2019	4	10	1	1	4	1 - 3	2
PBR0010, Runway intersection airfield Noosa N	L	unburnt 2019	211	60	1	1	35	4 - 10	6
PBR0013, Cooloola Way S of Pump Station Rd	L	unburnt 2019	163	42	1	1	39	4 - 10	7
PBR0014, Cooloola Way N of Pump Station Rd	L	unburnt 2019	12	16	1	1	8	1 - 3	3
PBR0021, Cooloola Way 7.2km SSW intersection	L	unburnt 2019	78	32	1	1	24	4 - 10	5
PBR0022, Cooloola Way 750m S of intersection	L	unburnt 2019	14	19	1	1	7	1 - 3	3
Surveyed 2021									
PBR0028, W side Noosa River, Eurobi Rd N	AR	burnt 2019	20	12	7	7	17	2 - 6	4
PBR0001, 400m ENE Campsite 2 Noosa River	AR	burnt 2019	14	7	7	5	20	4 - 10	4
PBR0040, E side Noosa River near Campsite 1	AR	burnt 2019	1	1	13	1	10	1 - 3	3
PBR0006, S of helipad at Noosa River Campsite 3	AR	burnt 2019	16	21	7	5	8	1 - 3	3
PBR0024, Old Pump Station Rd	AR	burnt 2020	70	13	7	7	54	4 - 10	8
PBR0033, 500m NW Dutgee E of Noosa River	AR	unburnt 2019	6	9	15	8	43	4 - 10	7
PBR0013, Cooloola Way S of Pump Station Rd	AR	unburnt 2019	275	27	7	7	102	> 12	15
PBR0041, 1km NNW of pump station Teewah Ck	AR	unburnt 2019	169	26	11	11	65	8 - 13	10
PBR0034, Poverty Point Firebreak	AR	unburnt 2019	123	56	7	7	20	4 - 10	4
PBR0042, S end Flood Plain Firebreak	AR	unburnt 2019	5	16	13	3	3	1 - 3	2
PBR0004, 570m W of Flood Plain Break	AR	unburnt 2019	42	19	7	7	22	4 - 10	4
PBR0035, Flood Plain FB 1.6km S pump station	AR	unburnt 2019	65	16	7	7	41	4 - 10	7
PBR0036, Wildflower Rd	AR	unburnt 2019	35	19	7	7	18	2 - 6	4
PBR0037, Roy Weber Firebreak	AR	unburnt 2019	0	0	13	0	0	0	0
PBR0014, Cooloola Way N of Pump Station Rd	AR	unburnt 2019	103	28	7	7	37	4 - 10	6
PBR0038, Near Campsite 13 Noosa River E	AR	unburnt 2019	246	40	7	7	62	8 - 13	9
PBR0021, Cooloola Way 7.2km SSW intersection	AR	unburnt 2019	166	24	7	7	69	8 - 13	10
PBR0031, E of Noosa River, S of Dutgee	AR	unburnt 2019	26	22	7	5	12	2 - 6	3
PBR0039, Poverty Point Rd	AR	unburnt 2019	20	15	7	7	13	2 - 6	3

Table A1.2: Comparison of call indices (Call index), bird number ranges (Bird # range) and abundances (# Individuals) between 2020 and 2021 and with historical records (Historical Years) of abundances (Historical num) derived from WildNet.

Burnt/unburnt status	Sites - 2020	Call index	Bird # range	# Individuals	Sites - 2021	Call index	Bird # range	# Individuals	Historical Years	Historical numbers
burnt 2019	PBR0027	32	4 - 10	6					1981, 1983	1, 1
burnt 2019	PBR0007	9	1 - 3	3					1987	>10
burnt 2019	PBR0008	116	> 12	15					1988, 1994	7 - 8, 1
burnt 2019	PBR0009	17	2 - 6	4					1987	3 - 4
burnt 2019	PBR0028	8	1 - 3	3	PBR0028	17	2 - 6	4	1981, 1983	1, 1
burnt 2019	PBR0029	11	2 - 6	3						
burnt 2019	PBR0030	4	1 - 3	2						
burnt 2019	PBR0015	0	0	0					1984, 1987, 1997, 2001	1, 1, 2 - 3, 5
burnt 2019	PBR0023	0	0	0					1991	1
burnt 2019	PBR0026	0	0	0					1981	1
burnt 2019	PBR0001	25	4 - 10	5	PBR0001	20	4 - 10	4	1991	1
burnt 2019	PBR0006	53	4-10	8	PBR0006	8	1 - 3	3	1983, 1984	1, 4 - 5
burnt 2019	PBR0012	57	8 - 13	9					1988, 1994	7 - 8, 1
burnt 2020	PBR0024	0	0	0	PBR0024	54	4 - 10	8	1987	1 - 2
burnt 2019					PBR0040	10	1 - 3	3	1981	1
unburnt 2019	PBR0003	43	4 - 10	7					1983	1
unburnt 2019	PBR0004	44	4 - 10	6	PBR0004	22	4 - 10	4		
unburnt 2019	PBR0011	5	1 - 3	2						
unburnt 2019	PBR0032	20	4 - 10	4						
unburnt 2019	PBR0016	10	1 - 3	3					1986, 1997	2, 2 - 3
unburnt 2019	PBR0031	10	2 - 6	3	PBR0031	12	2 - 6	3	1983, 1984	1, 4
unburnt 2019	PBR0017	20	4 - 10	4					1984, 1984	1, 4
unburnt 2019	PBR0018	18	2 - 6	4					1984	4
unburnt 2019	PBR0041	50	4 - 10	8	PBR0041	65	8 - 13	10	1987	1
unburnt 2019	PBR0020	11	2 - 6	3					1986	5
unburnt 2019	PBR0025	13	2 - 6	3					1984, 1986	1, 3 - 4
unburnt 2019	PBR0002	8	1 - 2	3					1983, 1984	1, 4
unburnt 2019	PBR0005	4	1 - 3	2	PBR0005	3	1 - 3	2		

Table A1.2 *continued*

Burnt/unburnt status	Sites - 2020	Call index	Bird # range	# Individuals	Sites - 2021	Call index	Bird # range	# Individuals	Historical Years	Historical numbers
unburnt 2019	PBR0010	35	4 - 10	6					1988	7 - 8
unburnt 2019	PBR0013	39	4 - 10	7	PBR0013I	102	> 12	15		
unburnt 2019	PBR0014	8	1 - 3	3	PBR0014	37	4 - 10	6	1983, 1986	10 - 15, 11 - 14
unburnt 2019	PBR0021	24	4 - 10	5	PBR0021	69	8 - 13	10	1987	3 - 4
unburnt 2019	PBR0022	7	1 - 3	3					1983, 1986	10 - 15, 11 - 14
unburnt 2019					PBR0033	43	4 - 10	7		
unburnt 2019					PBR0034	20	4 - 10	4		
unburnt 2019					PBR0035	41	4 - 10	7	1987	4
unburnt 2019					PBR0036	18	2 - 6	4	1983, 1986, 2003, 2004	1, 1, 1+, 4 - 5
unburnt 2019					PBR0037	0	0	0	1989	1
unburnt 2019					PBR0038	62	8 - 13	9	1973	1
unburnt 2019					PBR0039	13	2 - 6	3	1986, 1987	1, 6 - 8

Appendix 2: Priority fish survey information

Table A2.1: Details for the sites surveyed for priority fish species between February 2021 and May 2022.

Site type	Fire extent	Site number	Site name	Survey timing				Number of surveys
				Feb-21	Aug-21	Mar-22	May-22	
Riverine	N	21	Noosa River 8	11/2/2021				1
Palustrine	Y	22	Campsite 3	11/2/2021		23/3/2022		2
Riverine	Y	23	Harry's Hut	12/2/2021		30/3/2022		2
Riverine	N	24	Harry's Hut Rd	12/2/2021		30/3/2022		2
Lacustrine	Y	26	Lake Cooroibah Inlet	13/2/2021		1/4/2022		2
Lacustrine	Y	27	Freshwater Lake	14/2/2021				1
Riverine	Y	28	Noosa River 5	15/2/2021		31/3/2022		2
Riverine	Y	29	Noosa River 6	15/2/2021		25/3/2022		2
Riverine	N	30	Noosa River 7	15/2/2021	31/8/2021	25/3/2022		3
Palustrine	Y	31	Airfield Track	16/2/2021				1
Riverine	N	33	Noosa River 4	17/2/2021	1/9/2021	22/3/2022		3
Riverine	N	34	Carland Creek	17/2/2021	30/8/2021	21/3/2022		3
Palustrine	Y	35	Noosa River 9	18/2/2021		23/3/2022		2
Riverine	N	36	Franki's Gulch	18/2/2021		23/3/2022		2
Riverine	N	72	Seary's Creek		31/8/2021	21/3/2022		2
Riverine	N	81	Pumphouse		1/9/2021	22/3/2022		2
Palustrine	N	106	Cooloola Ck Lagoon				4/5/2022	1
Riverine	N	107	Poverty-Point Rd				4/5/2022	1
Riverine	N	200	Noosa River 10			24/3/2022		1
Riverine	N	201	Seary's Creek 2			24/3/2022		1
Riverine	N	202	Cooloola Creek			24/3/2022		1
Riverine	N	203	Noosa River 11			31/3/2022		1
Riverine	N	204	Noosa River 12			31/3/2022		1

Appendix 3: Invertebrate survey sites and methods

A3.1 Invertebrate survey sites

Figure A3.1: The invertebrate survey sites in *Eucalyptus pilularis* woodland and *Banksia aemula* heath, each with sites that were unburnt, moderately burnt and severely burnt. (Photos: M. Rix, Feb. 2020)

A3.2 Odonata survey sites

Figure A3.2: Odonata survey sites: 1. Site 1, Poona Lake circumference; 2. Site 3, Seary's Creek, Pettigrew's Rd; 3. Site 2, Seary's Creek Day Use Area; 4. Site 5, Western Break, Franki's Gulch; 5. Site 9, Floodplain Break, Joe's Gully; 6. Site 10, Western Break, ephemeral swamp. (Photos: C. Lambkin 1, 2, 3 & 6; M. Laidlaw 4; C. Burwell 5 , Feb. 2020)

A3.3. Invertebrate survey methods

Six standardised methods were used to sample invertebrates at each site, as outlined below.

Malaise trap: One trap was set at each site to target insects that fly upwards when hitting an obstruction (e.g., Diptera (flies) and Hymenoptera (bees, wasps)). The trap base was pegged to maximise the opening across an insect flight path and vegetation used to create a tunnelling effect to enhance the number of species caught over five days. The Townes style trap was 2m long and 2m high, with very fine mesh, a white roof, black walls and central barrier (Figure A3.3). A collecting jar was filled with ~300ml of 70% ethanol to kill and preserve captured insects.

Unbaited pitfall traps: 10 traps were arranged in a line 2.5–3m apart at each site and operated for five days to target ground active invertebrates. Traps were 120ml plastic vials with a 42mm internal diameter, three-quarters filled with 70% ethanol, with a square, black, plastic cover suspended 3–4cm above the trap (Figure A3.3).

Baited pitfall traps: eight traps were set in four pairs at each site, with each pair approximately 20m from the site centre, arranged in a cross formation. Traps in a pair were separated by at least 3m, with one baited with wallaby dung and the other with crushed mushrooms wrapped in Chux® kitchen cloth and suspended on wire pegs above a plastic cup (67mm internal diameter) three-quarters filled with 70% ethanol. Traps were operated for five days to target dung beetles, with wallaby dung baits replaced after two or three days (Figure A3.3).

Coloured pans: nine plastic bowls (three each of blue, white and yellow) were placed 2m apart in a line across each site and operated for two days to target flying pollinators. Each pan had an internal diameter of 14cm and held 250ml of water, with a drop of detergent to reduce surface water tension and optimise insect capture (Figure A3.4).

Hand netting: one netting sample was collected over a 30-minute period at each site, targeting insects flying or resting on vegetation within a 30–40m radius of the site centre. The hand net had a 1.2m-long handle and large 46cm diameter hoop, with a net bag of fine Polyganza to retain the smallest of specimens.

Ant collecting: one sample was collected between 09:05 and 16:50 hrs over a 60-minute period at each site, targeting foraging ant workers and ant nests within a 30–40m radius of the site centre. Not all observed ants were collected, as the aim was to maximise the number of species collected (Figure A3.4).

Targeted searching of Odonata was also conducted for at least one hour using hand nets and camera equipment to record species detected across sites that represented a range of freshwater bodies at Cooloola (e.g., Figure A3.2)

Figure A3.3: Malaise trap (left), unbaited pitfall trap (centre) and dung-baited pitfall trap (right). (Photos: C. Lambkin)

Figure A3.4: Ant collecting (left), a deployed coloured pan (centre) and hand netting Odonata (right) at Cooloola. (Photos: C. Lambkin)

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