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Impacts of bushfire on the Glossy Black-Cockatoo *Calyptorhynchus lathami* and its single food source in eastern Victoria

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Abstract. The Glossy Black-Cockatoo *Calyptorhynchus lathami* eats only unripened seeds extracted from green cones of *Allocasuarina* and *Casuarina* trees. This specialised feeding habit results in Glossy Black-Cockatoos leaving unique evidence of having fed in a tree (i.e. feeding sign). The frequency of feeding sign beneath Black Sheoak *Allocasuarina littoralis* trees in East Gippsland, Victoria, was used as an index of the presence of Glossy Black-Cockatoos before and after intense and widespread bushfires during the summer of 2019–2020. Species distribution models for the cockatoo and its major food tree in the region were used to define 175 survey points in forested parts of East Gippsland. Survey points were visited in mid 2019, to score the presence or absence of Black Sheoak and Glossy Black-Cockatoo feeding sign. Following the 2019–2020 bushfires, all sites where Black Sheoak was present pre-fire were revisited twice within the following 28 months to search for feeding sign and score the extent of regeneration of Black Sheoak. Across all sites, the frequency of sites with feeding sign effectively halved between the pre-fire survey and first post-fire survey, then halved again between the first and second post-fire surveys, an overall decline of 76%. After 25–28 months, regeneration of Black Sheoak, in the form of either basal sprouting of established trees or seed germination, was observed at 80.6% of burnt sites, with a tendency for highest rates of regeneration at lower-fire-severity sites and for suckering to be more common than seedlings at higher-fire-severity sites. These results highlight the vulnerability of the Glossy Black-Cockatoo to reductions in the availability of its specialised food. The greatest threat to food security stems from increased frequency and intensity of fire, as predicted for the region by climate change models.

Introduction

The Glossy Black-Cockatoo *Calyptorhynchus lathami* has an extremely restricted diet — unripened seeds extracted from the closed, 'green' cones of small trees belonging to the genus *Allocasuarina* (Family Casuarinaceae), with only very occasional reports of feeding on the closely related genus *Casuarina* (Chapman 2007; North *et al*. 2020). The species of *Allocasuarina* utilised by the Glossy Black-Cockatoo vary geographically but usually one or two species are preferred in any given area (Chapman 2007). In Victoria, records of the Glossy Black-Cockatoo are concentrated in East Gippsland, along the coast and in the foothills and valleys, mostly east of Lake Tyers (Emison *et al*. 1987). There, and in adjacent parts of New South Wales, this species overwhelmingly prefers the seeds of the Black Sheoak *A. littoralis* (Clout 1989; Forshaw & Cooper 2016; PM, MS & KS pers obs.). Generally, Black Sheoak grows on sites with low soil-nutrient status, including on near-coastal sands or heavy clay soils, or among rocks (Walsh & Entwisle 1996). It occurs in scattered small stands as a subcanopy tree up to 10 m tall, among mixed eucalypt forest. In East Gippsland, the only other widespread *Allocasuarina* species is Scrub Sheoak *A. paludosa*, a shrub that grows in heathlands (Walsh & Entwisle 1996). There are no records of Glossy Black-Cockatoos feeding on seeds of Scrub Sheoak. However, three individuals were observed feeding on the closely related Green Sheoak *A. paradoxa* in the south-eastern suburbs of Melbourne from mid May 2020 until late July 2020, and two birds were still being reported at the time of writing in June 2023. These are the first Victorian records of the Glossy Black-Cockatoo outside East Gippsland or north-eastern Victoria for about a century. These individuals are likely to have been displaced by the 2019–2020 bushfires.

Glossy Black-Cockatoos extract seeds from *Allocasuarina* cones using the massive bill, which is highly adapted for this task (Forshaw & Cooper 2002) (Figure 1). The cone is snipped from the tree using the bill and transferred to one foot (almost always the left: Magrath 1994). Seed extraction involves rotating the cone in an anti-clockwise direction against the broad, curved blade formed by the distal end of the lower mandible, slicing through the woody cone allowing the seeds to be progressively extracted using the finely pointed upper mandible in concert with the fleshy tongue (Figure 1). This process results in the woody remnants of the cone being discarded, so that trees in which Glossy Black-Cockatoos have been feeding can be identified by the presence of cone fragments (hereafter called feeding sign) on the ground beneath (Figure 2). No other animal species is known to leave this feeding sign in south-eastern Australia (Clout 1989; Lenz 2004a; North *et al*. 2020; PM, MS & KS pers. obs.).

Given the highly specialised diet, which is also patchily distributed in time and space, population density of the Glossy Black-Cockatoo is typically very low, making them difficult to monitor by traditional methods involving sighting or hearing birds. Therefore, scoring presence or absence of the unique feeding sign is considered a more efficient means of monitoring presence of the species (Clout 1989; this paper).

Reliance on the tiny seeds (Figure 3) of a single, patchily distributed, small tree species represents an unparalleled level of dietary specialisation among Australian birds (Chapman 2007; North *et al*. 2020). Glossy Black-

Figure 1. Glossy Black-Cockatoo extracting seeds from an unripened cone of Green Sheoak, Frankston North, Victoria, 23 June 2020. Photo: Peter Menkhorst

Cockatoos are also selective in their choice of individual feed trees, with tree selection being driven by nutritional profitability and tree size (Chapman & Paton 2006; North *et al*. 2020). Further, because the Black Sheoak is dioecious (having separate male and female trees: Walsh & Entwisle 1996), roughly half the population of Black Sheoak trees produce no food for the cockatoo.

The woody cones of *Allocasuarina* species mature over a period of 6–9 months and remain palatable for Glossy Black-Cockatoos for about a year (Cameron & Cunningham 2006). Thus, food is available for the cockatoos year-round, although large home ranges are needed to provide enough individual trees with green cones to guarantee supply. For example, Lenz (2004b) estimated that a single Glossy Black-Cockatoo requires 83–122 cones per day, equating to 60,000–89,000 cones of the necessary age and dietary quality per year for a pair of birds.

Drying and opening of the cones of Black Sheoaks, and hence shedding of the seeds, is induced by hot, dry conditions and by fire. This process renders the seeds inaccessible to the cockatoo, which has never been reported to feed from the ground (Higgins 1999; Forshaw & Cooper 2016). Some seeds are shed in late summer, but many cones remain closed throughout the summer, unless there is a fire (Clout 1989). Fire removes the food of the Glossy Black-Cockatoo by two processes: hot fires burn the cones and seeds, and cooler fires cause mature cones to open and shed their seeds.

Figure 2. Litter beneath a Black Sheoak tree in which a Glossy Black-Cockatoo had recently fed. Naturally fallen old cones (grey) that had shed their seed are intermixed with the chewed remains (honey-coloured) of previously unopened cones discarded by the cockatoo. Photo: Peter Menkhorst

Figure 3. Seeds of Black Sheoak. The kernel (the nutritious part) is contained within the black section; the pale section is a membrane to promote wind dispersal. Photo: Peter Menkhorst

In mid 2019, we commenced a study of the distribution and feeding preferences of the Glossy Black-Cockatoo in East Gippsland. The primary aim of this initial study was to investigate the occupancy rate of feeding Glossy Black-Cockatoos in Black Sheoak stands in the survey area, as indicated by the presence of chewed cone ends. In December 2019 and January 2020, intense bushfires burned 64% of the Glossy Black-Cockatoo's modelled habitat in Victoria, with 26% of that modelled habitat being affected by high-severity fire (Anon. 2020). This created an opportunity to investigate the impacts of the fires on the cockatoo. Two extra aims were added for the post-fire component: (1) to assess survivorship of the Black Sheoak stands, and the availability of cones, following the 2019–2020 bushfires; and (2) compare site occupancy rates before and after the fires in both burnt and unburnt forest.

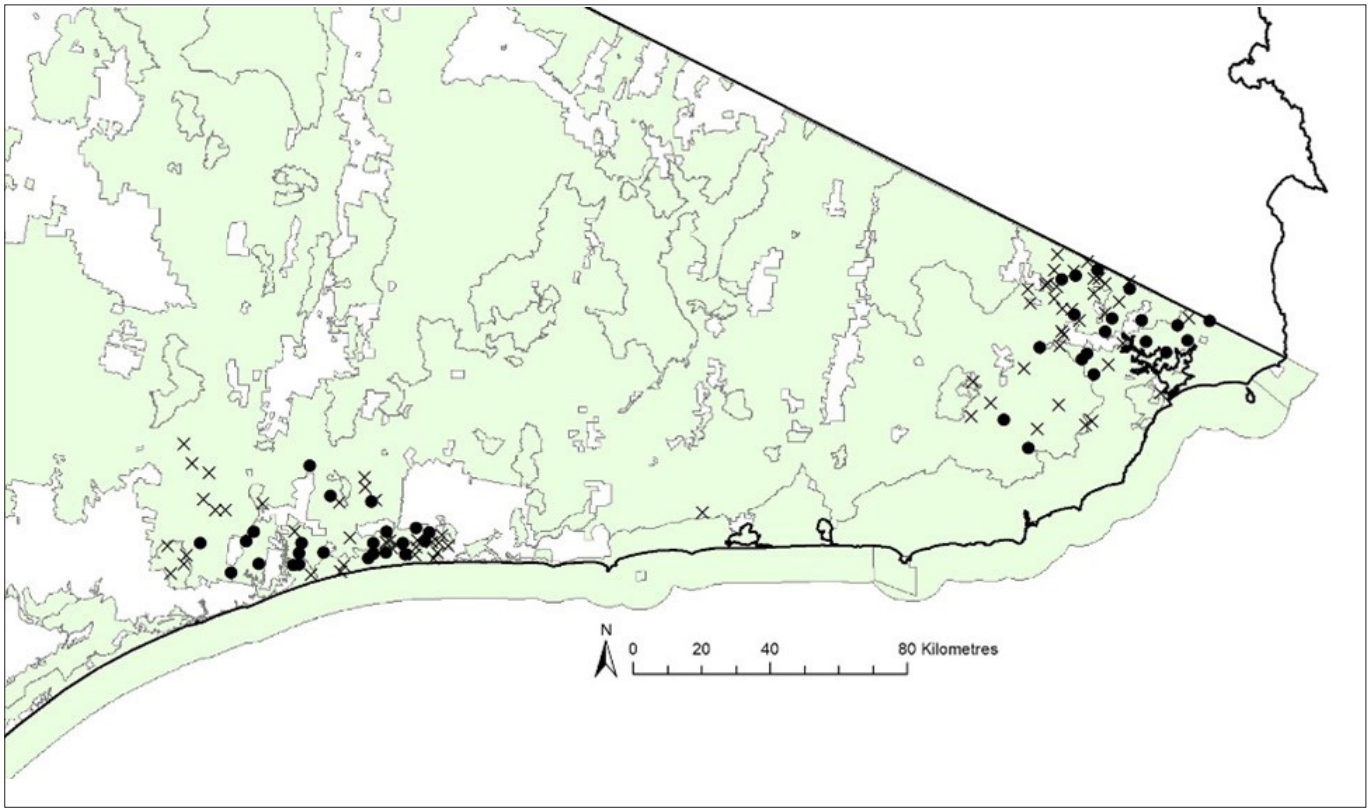

Figure 4. Location of survey sites in East Gippsland, Victoria, pre-fires (visited in May and November 2019). Black dots = chewed cones present beneath at least one Black Sheoak tree; black crosses = Black Sheoak present but no feeding sign found; green = crown land.

Methods

Selection of sample sites

Habitat distribution models for the Glossy Black-Cockatoo and for Black Sheoak were prepared by colleagues at the Arthur Rylah Institute for Environmental Research (part of the Victorian Government's Department of Energy, Environment and Climate Action; see Lui *et al*. 2011 for details of the modelling procedure). Within the modelled area, 175 survey sites were allocated using a stratified random sampling procedure based on (1) probability of occurrence of both species and (2) selection of sites within practical walking distance (~500 m) of a vehicle track, with at least 300 m between sites.

Collection of data at sample sites

During May and November 2019, a hand-held GPS unit was used to navigate to as many of the survey sites as possible. Altogether, 174 stratified random sites were sampled, and 112 of those had Black Sheoak present (defined as at least one Black Sheoak stem within 50 m of the GPS point). At those 112 sites where Black Sheoak was present, a 30 x 30-m quadrat was centred on the Black Sheoak tree nearest to the GPS point. Within each quadrat the following data were collected:

1. The size class of each Black Sheoak stem, based on diameter at breast height (dbh). Size classes were 2–5, 6–15, 16–50 and >50 cm.
2. The number of fresh honey-coloured cones (as distinct from weathered grey cones) on each tree that carried fully formed cones, scored using three categories: 0, 1–200, and >200.
3. The number of honey-coloured, chewed cone ends (Figure 2) on the ground beneath each tree that had fully formed cones, scored using four categories: 0, 1–20, 21–100, >100.
4. The number, sex and age class (adult, juvenile) of any Glossy Black-Cockatoos present, along with any other observations on the natural history of the cockatoos.

After the extensive 2019–2020 bushfires in East Gippsland, the 112 sites that had Black Sheoak present pre-fire were revisited to collect comparable data to assess the impacts of the bushfires on the frequency of Glossy Black-Cockatoo feeding sign and on Black Sheoak survival and cone availability. The locations of the 112 survey sites relative to fire intensity are shown in Figures 4–6 (for details of the fire intensity mapping and links to the data layers see Anon. 2020, p. 5). Sample sites in unburnt forest to the west of Orbost were resampled in March 2020, and sites in burnt forest were resampled in June 2020. Many tracks were closed or impassable to vehicles because of fallen trees or burnt bridges, necessitating extensive hiking on tracks and cross-country. Data collected during the first revisit, 2–7 months post-fire, are hereafter called 'short post-fire' samples. The sites were again visited in March, May or June 2022, 25–28 months post-fire, and the same data were recorded – hereafter called 'long post-fire' samples.

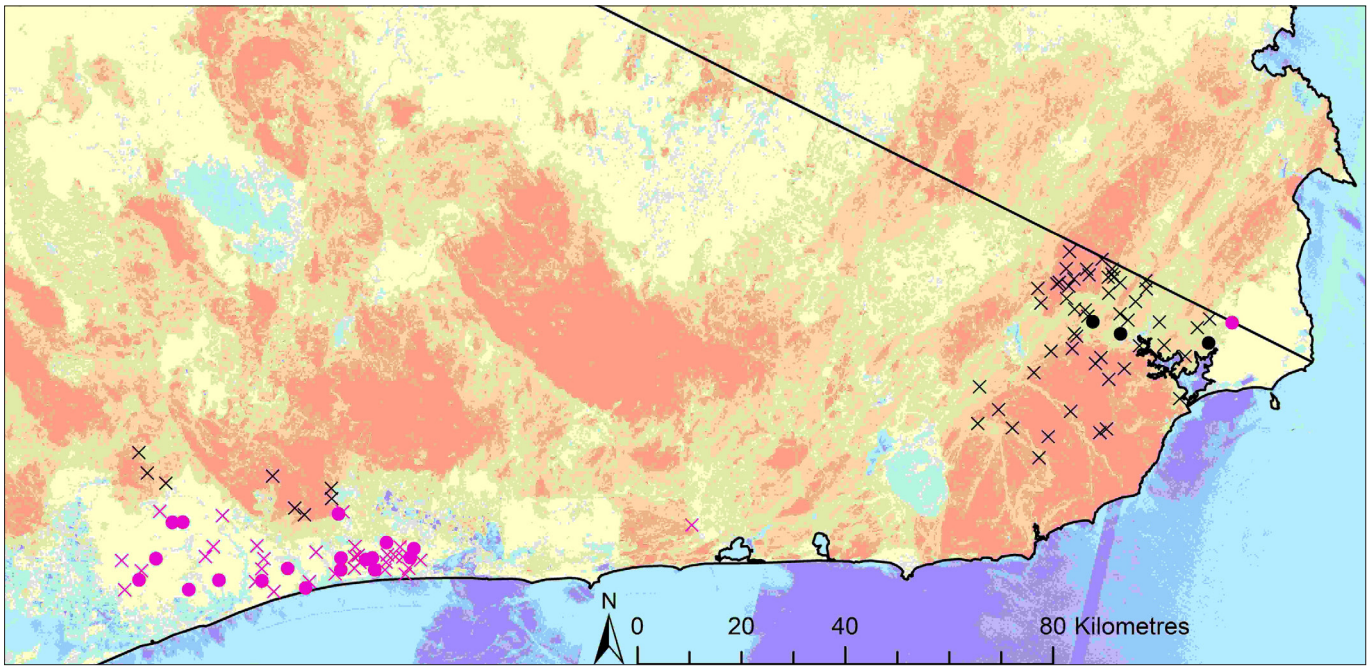

Figure 5. Location of survey sites in East Gippsland visited short post-fire (March and June 2020) overlain with modelled fire severity based on Sentinel 2 satellite imagery (Anon. 2020, p. 5; pale yellow = unburnt; pale blue = no data because of cloud cover or smoke haze; pale green = <80% canopy scorch; pale red = >80% canopy scorch; dark red = >80% canopy removal). Pink dots and crosses represent unburnt sites; black dots and crosses represent burnt sites. Dots = chewed cones present beneath at least one Black Sheoak tree, crosses = Black Sheoak present but no feeding sign found.

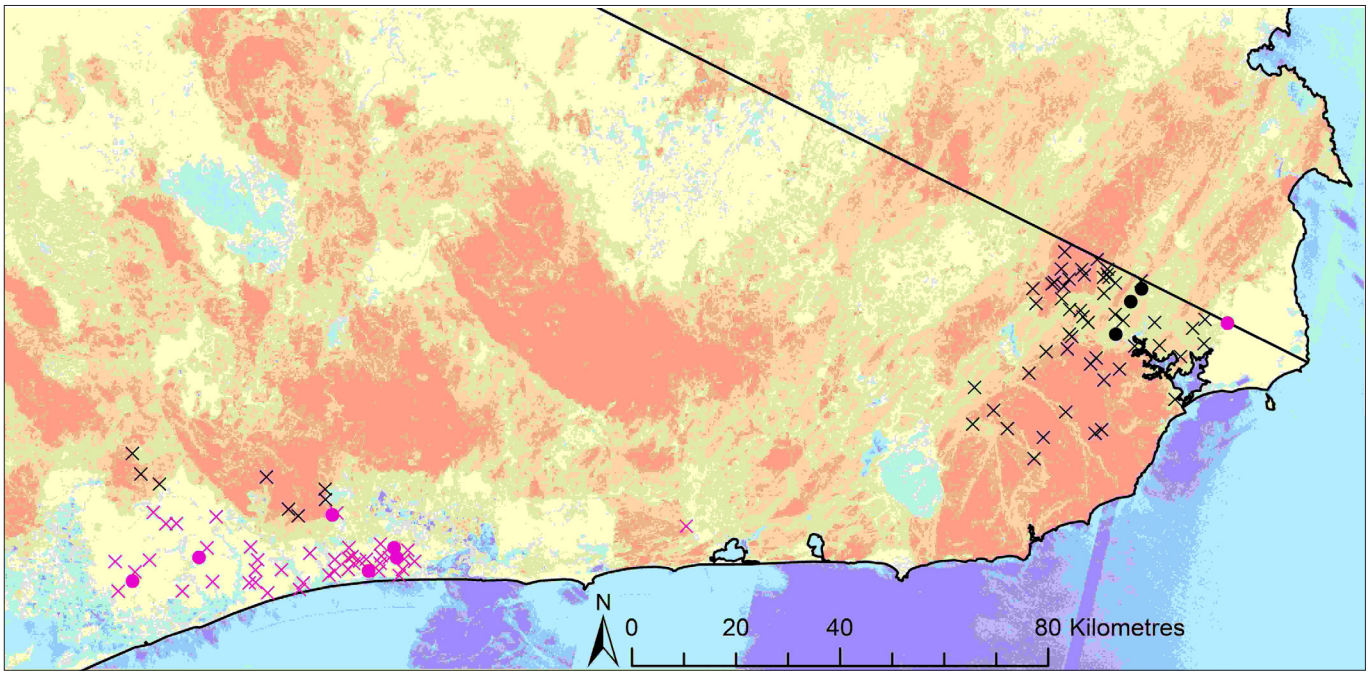

Figure 6. Location of survey sites in East Gippsland visited long post-fire (March, May or June 2022) overlain with modelled fire severity based on Sentinel 2 satellite imagery (Anon. 2020, p. 5; pale yellow = unburnt; pale blue = no data because of cloud cover or smoke haze; pale green = <80% canopy scorch; pale red = >80% canopy scorch; dark red = >80% canopy removal). Pink dots and crosses represent unburnt sites; black dots and crosses represent burnt sites. Dots = chewed cones present beneath at least one Black Sheoak tree, crosses = Black Sheoak present but no feeding sign found.

During the short post-fire visit, each site was given a fire severity score based on the degree of burning of the above-ground parts of Black Sheoak trees in the quadrat (Figures 7–8):

1. Unburnt – no evidence of recent fire
2. Fire severity score 1 – lightly burnt, <70% of Black Sheoak foliage scorched or burnt
3. Fire severity score 2 – moderately burnt, >70% of Black Sheoak foliage scorched or burnt
4. Fire severity score 3 – severely burnt, above-ground parts of most Black Sheoak trees burnt.

This paper considers only data relating to presence of feeding sign pre- and post-fire and presence of Black Sheoak regeneration post-fire, relative to fire severity.

Figure 7. A stand of Black Sheoak burnt by an intense fire in January 2020 and photographed in June 2020. The green epicormic growth is on *Eucalyptus* trees intermixed with the Black Sheoaks. Photo: Martin Schulz

Figure 8. Black Sheoak in a less intensively burnt site with scorched foliage *c.* 4 months post-fire. The impact of foliage scorch on the future production of cones and seed is unknown. Photo: Martin Schulz

Results

Presence of feeding sign before and after bushfire

Table 1 presents the frequency of the presence of chewed cone ends at the 112 sites that had Black Sheoak present in the pre-fire assessment, and had been assessed three times: pre-fire, short post-fire and long post-fire.

Pre-fire, chewed cone ends were found at 42 of the 112 sites (37.5%). Short post-fire and within the fire footprint, the frequency of chewed cone ends was 3 out of 62 sites (4.8%). Short post-fire and outside the fire footprint (mostly south of the Princes Highway between Lake Tyers and Orbost), the presence of chewed cone ends was six times higher than at burnt sites but also slightly lower than the pre-fire condition (38% vs 44%). By long post-fire, the frequency of chewed cone ends at burnt sites remained very low (4.8%) but in the unburnt area it had declined to roughly one quarter of the pre-fire rate and one third of the short post-fire rate (Table 1).

Across burnt sites, the frequency of positive sites (chewed cone ends present) declined by 85% between the pre-fire and short post-fire samples, with no change between short and long post-fire. In the unburnt sites, the decline was 13.6% by short post-fire with a further 63.2% decline to long post-fire and a 68.2% overall decline. Across all sites, the frequency of positive sites effectively halved between the pre-fire survey and the short post-fire survey, then halved again between the short and long post-fire surveys, an overall decline of 76.2% (Table 1). Note that between the short post-fire and long post-fire visits, 10 of the 50 unburnt sites had been burnt during planned fuel-reduction fires. In the long post-fire visits, none of the 10 fuel-reduced sites showed feeding sign whereas 7 of the 40 (17.5%) unburnt sites that were not subsequently treated to a fuel-reduction burn had feeding sign.

Presence of regenerating Black Sheoak post-fire

During the short post-fire survey, no regeneration of Black Sheoak was observed, although we were not specifically looking for it at that time. However, by the long post-fire survey, 80.6% of burnt sites showed some regeneration (Figures 9–10) – either suckering from the base of burnt stems (72.6%), or seedling germination (48.4%), or both. At unburnt sites, suckering was found at 8% of sites and seedlings at 24% of sites (n = 50). Figure 11 shows the relationship between the presence of suckering and

Table 1. Number and proportion of 112 quadrats that had evidence of feeding (chewed cone ends) by Glossy Black-Cockatoos in 2019–2020 bushfires in East Gippsland, relative to time since fire and burn status. * Becomes 17.5% if the 10 sites that were subjected to a fuel-reduction burn between the short and long post-fire visits are excluded.

Burn status in 2019–2020 bushfires	*Time relative to the bushfires*			*% decline, pre-fire to long post-fire*
	Pre-fire (May or November 2019) and subsequently burnt/unburnt	*Short post-fire (March or June 2020)*	*Long post-fire (March, May or June 2022)*	
Burnt, n = 62	20 (32.3%)	3 (4.8%)	3 (4.8%)	85.0
Unburnt, n = 50	22 (44.0%)	19 (38.0%)	7 (14.0%)*	68.2
All sites, n = 112	42 (37.5%)	22 (19.6%)	10 (8.9%)	76.2

Figure 9. Black Sheoak resprouting from the base *c*. 28 months post-fire. Photo: Martin Schulz

Figure 10. Black Sheoak seedlings *c*. 28 months post-fire. Photo: Martin Schulz

seedlings, and fire severity. At unburnt sites, suckering was rare, seedlings less so. During the long post-fire visits (25–28 months post-fire), both forms of regeneration were commonly found at burnt sites, with a tendency for highest rates at lower-fire-intensity sites and for suckering to be more commonly present than seedlings at higher-fire-intensity sites.

Efficacy of feeding sign as a monitoring tool

The relative efficacy of searching for feeding sign, rather than relying on sighting or hearing birds, is indicated by the rate at which Glossy Black-Cockatoos were seen or heard at the survey sites during our data collection visits – they were seen at 2 out of 112 sites (0.18%) during each of the three data collection phases (pre-fire, short post-fire, long post-fire). This represents a 200-fold improvement in detection rate based on a comparison of pre-fire data (0.18:37.5).

Incidental sightings away from the survey sites were also rare – during 54 days in the field (dawn to dusk), Glossy Black-Cockatoos were encountered away from the survey sites on 13 occasions. Most sightings were of two or three birds, either a pair or a pair with a juvenile. There were six instances of aggregations of up to 11 birds at dusk at water points, either puddles on a track or at a fire dam in the forest. The three incidental sightings during the long post-fire surveys were all of single birds, something not observed pre-fire.

Discussion

This study highlights the extreme dietary specialisation of the Glossy Black-Cockatoo, leading to heightened vulnerability to fire, including from relatively low intensity fire. It is essential that areas with high densities of Black Sheoak are identified, mapped and accorded extra protection during planned fires and, if possible, during

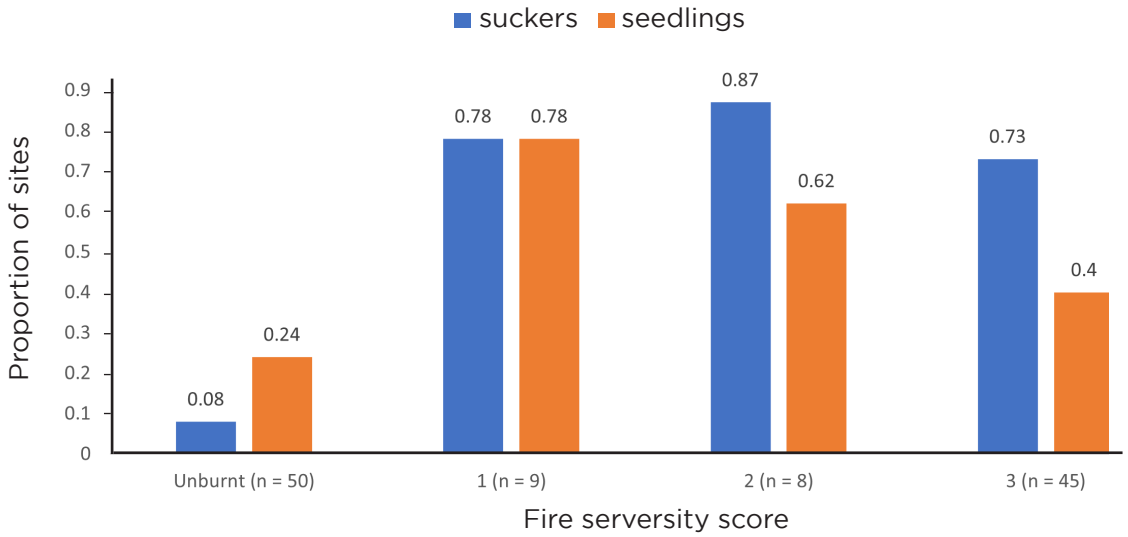

Figure 11. Proportion of sites at which regeneration of Black Sheoak was observed during long post-fire (25–28 months) visits by fire severity score as assigned in the field. Unburnt = no evidence of recent fire; 1 = lightly burnt, <70% of Black Sheoak foliage scorched or burnt; 2 = moderately burnt, >70% of Black Sheoak foliage scorched or burnt; 3 = severely burnt, above-ground parts of most Black Sheoak trees burnt.

bushfires. Burning of unburnt stands of Black Sheoak in the decade following extensive fires, when food availability for the Glossy Black-Cockatoo will be at its lowest, is highly undesirable.

Population monitoring, potentially using the successful strategy adopted in this study, will be needed to determine post-fire population recovery rates. The continuing population decline detected in the 48,000-ha area of unburnt forest is particularly alarming and monitoring is required to track future population trends. Reasons for this continuing decline in the unburnt habitat may relate to that area being insufficient to support the remaining Glossy Black-Cockatoos, including immigrants from burnt country, in the longer term.

Based on the frequency of chewed cone ends at the 112 sample sites monitored pre- and post-fire, we estimate that the Victorian population of the Glossy Black-Cockatoo declined by ~75% following the 2019–2020 bushfires. Given the species' low breeding capacity — only a single egg is laid per breeding attempt (Forshaw & Cooper 2016) — it is likely to take many decades for the population to recover. Future widespread bushfires during this population recovery period will likely result in further population decline. Climate-change models predict higher mean temperatures and lower cool-season rainfall in East Gippsland (Clarke *et al*. 2019), conditions likely to promote increased bushfire frequency and intensity (Di Virgilio *et al*. 2019; Dowdy *et al*. 2019). Thus, fire regimes are likely to be a key driver of the abundance of Black Sheoak in the future, and therefore will also be central to the capacity of the Glossy Black-Cockatoo to survive. Hot fire is thought to frequently kill Black Sheoak (Clout 1989; Morrison & Renwick 2000) although the results presented here suggest a higher survivorship. The age at which a resprouting Black Sheoak tree, or a seedling, will begin producing viable seeds has been estimated at 5–20 years (Morrison & Renwick 2000). Independently of the research reported here, PM observed seedlings in an area burnt at medium intensity near Genoa Peak, in East Gippsland, to be flowering in October 2022, 32 months post-fire (Figure 12), suggesting that limited cone production is possible within 4–5 years under ideal conditions [in this case, three successive years (2020, 2021, 2022) of high rainfall]. However, the level of seed production in sapling *Allocasuarina* is unknown, as is the capacity and willingness of Glossy Black-Cockatoos to feed in saplings.

A further on-going threat to the Glossy Black-Cockatoo is a likely continuing reduction in the availability of suitable nest hollows in mature *Eucalyptus* trees (Cameron 2006). Major causes of loss of hollow-bearing trees in the forests of East Gippsland include fire (planned and unplanned), management aimed at enhancing capacity for fire suppression, including construction of roads and fuel breaks and removal of trees considered to be hazardous, and timber harvesting (Garnett *et al*. 2003; Bluff 2016), but note that commercial timber harvesting has now ceased in native forests on public land in Victoria.

The South-eastern Glossy Black-Cockatoo (subspecies *lathami*, the subspecies occurring from south-eastern Queensland to East Gippsland) was recently classified as Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (DCCEEW 2023), following the assessment of Cameron *et al*. (2021). Our results and their management implications, if more widely applicable within the distribution of the taxon, suggest that a classification of vulnerable may underestimate the risk of extinction of the taxon following the 2019–2020 bushfires. Our results also suggest a far worse prognosis than estimated by an expert elicitation process (which included PM) that was conducted after the 2019–2020 bushfires (Figure 6b in Legge *et al*. 2022).

Figure 12. Seedling Black Sheoak in a burnt area near Genoa Peak flowering in October 2022, 32 months post-fire. Photo: Peter Menkhorst

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