Short-term impacts of prescribed burning on Orange-bellied Parrot (*Neophema chrysogaster*) food plant abundance.

Summary

Fire has important implications for the availability of suitable types of habitat for animals. Different species vary in their responses to fire, and quantifying the responses of key habitat attributes may facilitate manipulation of fire regimes to improve conditions for species of conservation concern. The Orange-bellied Parrot *Neophema chrysogaster* prefers recently burned habitat for foraging when breeding but knowledge of how fire affects this species and its habitat is limited. We implemented a two-year before-after-control-impact (BACI) study to quantify short-term impacts of fire on food plants and habitat features. Relative to control sites, the four food plants we monitored in the treatment area responded differently to fire: one did not recover, two reached pre-burn abundance after 20 months and another recovered by one year after fire, and by 20 months was more common in treatment sites. Relative to controls, the proportion of bare earth at treatment sites increased after fire then gradually declined, while mean vegetation height at treatment plots declined after fire then gradually increased. Twenty months after fire, parrots foraged on abundant regeneration of the Dwarf Everlasting (*Helichrysum pumilum*) and fed the seeds of this species to their nestlings. Fire alters the availability of key resources needed by breeding Orange-bellied Parrots, and ongoing manipulation of fire regimes may relieve limitation of natural foods for this species.

Key Words

Fire, *Actinotus bellidioides, Boronia citriodora, Eurychorda complanata, Helichrysum pumilum*,

Introduction

Fire is a major driver of vegetation community composition and structure. In fire-prone landscapes, variation in plant responses to fire can have important implications for the availability of different types of habitat for animals. Vegetation communities can rapidly transition to different states if burning regimes are inappropriate (Holz*, et al.* 2015). Many animals are specialized for particular habitat attributes that vary with fire histories (Baker*, et al.* 2010;Kelly*, et al.* 2017;Legge*, et al.* 2015). Manipulation of fire regimes to improve conditions for species of conservation concern is a crucial management action in flammable ecosystems (Legge*, et al.* 2011). However, successful management of fire for conservation purposes depends on good knowledge of how available habitats change under different burning regimes. If fire is manipulated to maximize the availability of crucial resources, populations limited by fire-sensitive resources can recover (Legge*, et al.* 2015). Quantifying how ecosystems change with fire management, and identifying the impacts of these changes on species of conservation concern, is crucial to improving biodiversity conservation with fire management (Bowman*, et al.* 2016;Bradstock*, et al.* 2005).

Orange-bellied Parrot (*Neophema chrysogaster*) may be the world's rarest parrot and breed in fire-prone Button Grass (*Gymnoschoenus sphaerocephalus*) moorlands in south western Tasmania (Brown and Wilson 1980). Moorland vegetation communities are shaped by fire (Marsden-Smedley and Kirkpatrick 2000), but fire regimes changed drastically following European occupation of the area (Marsden-Smedley 1998). The Orange-bellied Parrot has dietary preferences for early successional plants that are believed to be most abundant within eight years of fire in moorlands (Brown and Wilson 1980). Consequently, fire management plans aim to create mosaics of different fire ages (Marsden-Smedley 1993), but implementation of these plans has been limited (Stojanovic*, et al.* 2017). Furthermore, information about how the preferred food plants of the Orange-bellied Parrot respond to fire, or whether burning directly improves parrot demographic rates is mostly anecdotal. Addressing these knowledge gaps is an urgent conservation priority given the potential impact of breeding season food availability on population decline of this species (Department of Environment 2016) and the shortage of natural foods at the last wild breeding location (Stojanovic*, et al.* 2017).

In April 2018 the Tasmanian National Parks and Wildlife Service (NPWS) and the Tasmanian Department of Primary Industries, Parks, Water and Environment implemented two planned burns in potential foraging habitat of the Orange-bellied Parrot. We used this opportunity to implement a before-after-control-impact study that aimed to quantify short-term temporal changes in abundance of four key Orange-bellied Parrot food plants in response to the fire.

Methods

Study species and area

The last known breeding population of Orange-bellied Parrots is at Melaleuca, southwestern Tasmania, Australia (Lat: 43°25'16.54", Long: 146° 9'44.14"). Orange-bellied Parrots have been managed there since 1979, with a focus on providing nest boxes, supplementary food and monitoring of survival by volunteers (Department of Environment 2016). Ad libitum delivery of supplementary food throughout the breeding season provides the main diet of nestlings at the study site in contemporary times (Department of Environment 2016).

Our study area focused on two discrete burn units: 1) Melaleuca Airstrip South, a 19 ha area south of the Melaleuca airstrip (hereafter: Melaleuca), and 2) Cox Bluff, a 548 ha area from Cox Bight beach, encompassing Cox Bluff, to the New Harbor Track intersection (hereafter: Cox Bight). Within burn units, sites were 3 m diameter search areas spaced > 50 m apart, scattered randomly in accessible habitat. The Cox Bight sites followed the South Coast Track (which formed the eastern edge of the burn footprint) and were placed in moorland habitat on flats or gentle hill slopes with a north-easterly aspect. Sites were spaced ~ 4 m from the track on both the eastern side (unburned) and the western side (burned). At Melaleuca the topography was flat and sites were spaced throughout the burn area and in unburned habitat within 300m of the burn edge. The nearest sites between the Melaleuca airstrip and Cox Bight were 5 km apart. All known extant Orange-bellied Parrots nest within 2 km of Melaleuca, so it is unlikely that any parrots nested close enough to Cox Bight to exploit it as potential foraging habitat. Based on site assessments in the aftermath of the fire, we switched sites that inadvertently burned to the treatment group and vice versa. The final sample size at Melaleuca was 20 treatment and 19 control sites, and at Cox Bight there were 20 treatment and 18 control sites (77 total, comprising 40 treatment and 37 control). At Melaleuca the sites were spread over areas of approximately 3 km^2 and approximately 4 km^2 at Cox Bight.

Plant data

We recorded the abundance of four Orange-bellied Parrot food plants (Brown and Wilson 1980;Stojanovic*, et al.* 2017): Tiny Flannel-flower (*Actinotus bellidioides*)*,* Lemon-scented Borinia (*Boronia citriodora*)*,* Flat Cord-rush *(Eurychorda complanata*) and Dwarf Everlasting (*Helichrysum pumilum*). We scored their site level abundance categorically: 0 – absent, 1 – one to five plants, 2 – five to 20 plants, 3 – > 20 plants. We estimated the proportion of bare earth (i.e. no vegetation) cover and mean vegetation height (cm) at each site. We also recorded whether woody shrubs were present at sites, as these may suppress food plant regeneration (Stojanovic*, et al.* 2017). We surveyed sites five times: the day before they were burned (hereafter 'before'), and after fire at intervals of one week, eight, 12 and 20 months.

In 2019, we opportunistically investigated the crop contents of four nestling Orange-bellied Parrots from three broods to identify whether provisioning adults ate natural foods. We did not use invasive crop sampling to minimise the impacts of our study. Instead, we inspected crops via the dorsal side of the neck where the very thin transparent crop walls make the crop contents clearly visible (Figure 1). We used electronic callipers to measure the length and width of the subset of seeds clearly visible through the crop walls of two nestlings, focussing specifically on seeds that looked different to those offered as supplementary food (the grain sizes of supplementary food are much larger than natural foods). We also collected Dwarf Everlasting seed at the study area (after observations of adult parrots feeding on them – Supplementary Materials, video) and compared the length and breadth of these seeds to those measured through the crop walls of nestlings.

Analytical approach

All analyses were conducted in R (R Development Core Team 2020), and we compared competing models using differences in Akaike Information Criterion (ΔAIC <2) (Burnham and Anderson 2002).

We used ordinal logistic regression to model the categorical abundance scores of each plant species. We used the abundance categories as the response variables, and fitted models with the following fixed effects: treatment, time, treatment × time, location (i.e. Melaleuca or Cox Bight) and whether the site supported woody shrubs in the before period (yes/no). We implemented ordinal logistic regression using the *polr* function in the package MASS (Venables and Ripley 2002). We used generalised linear models to evaluate the impacts of the same fixed effects on the proportion of bare earth in each site (using a binomial error distribution). We used linear models to fit the same fixed effects to the estimated mean height of vegetation in sites (which we log transformed to fit a normal distribution).

Results

Based on ΔAIC we found strong support for an effect of the interaction between treatment × time on all four plant species, as well as bare earth and vegetation height at sites (Table 1). All plant species were comparably abundant at both treatment and control sites before fire. Immediately after fire, there was no above-ground living vegetation at burned sites, but vegetation was unchanged at controls. Plant species differed in their recovery after the fire. Abundance of the Tiny Flannel-flower gradually increased over time, peaking at 12 months after fire, and declining to abundances comparable to control sites by 24 months (Figure 2a). We only observed flowering of Tiny Flannel-flowers in the second year of the study and only at burned sites. Abundance of the Lemon-scented Boronia was generally low but increased over the course of the study slightly more in treatment than control sites (Figure 2b). Flowering of Lemon-scented Boronias was recorded throughout the study in control sites, but only at 20 months in treatment sites. Boronia flowers are distinctive, making flowering plants easier to observe. It is possible that we underestimated Lemon-scented Boronia abundance in shrubby control sites when they were not flowering. Although common in control sites, the Flat Cord-rush did not recover in the treatment area during the study (Figure 2c), but flowering and seeding was observed over the whole study period in control sites. At treatment sites Dwarf Everlasting abundance reached levels comparable to controls after only eight months, but by 24 months the chance of recording more than twenty plants per site was substantially higher than at controls (Figure 2d). Flowering of Dwarf Everlastings occurred sporadically throughout the study at control sites, but at treatment sites flowering did not occur until 20 months, when flowering was very abundant in the burned area.

The proportion of bare earth at sites was similar in treatment and controls before fire. This remained constant in controls, but after fire the proportion of bare earth peaked in treatment sites at one week and then declined over time (Figure 3a). Likewise, vegetation height was similar between treatment and control sites, but declined steeply after the fire in treatment sites, and then partially recovered over time (Figure 3b).

Seeds collected from Dwarf Everlastings growing at Melaleuca were mean 1.73mm long and 0.76 mm wide (n = 15 seeds). We measured eight intact seeds in the crops of two nestling that were visible enough to confirm they were not fragments of other food particles in crops, and these were mean 1.54mm long and 0.85 mm wide. Compared to known seeds of Dwarf Everlastings, we found no difference in the length (Welch two sample t-test: $p = 0.07$) or width (Welch two sample t-test: $p = 0.20$) of seeds between the crops of nestlings and those we collected from Dwarf Everlastings, and the colours of both seeds were the same. Furthermore, the seeds of Dwarf Everlastings have a characteristic plume of hairs on one end (an adaptation for wind dispersal) and these were visible on some seeds in the crops of nestlings we handled. We also observed adult Orange-bellied Parrots foraging on this abundant food source in the Melaleuca burn area throughout the breeding season (Supplementary Materials: video).

Discussion

Managing fire for conservation is an important aspect of population recovery for species limited by fire-sensitive habitat attributes. Fire had important consequences for food availability for Orange-bellied Parrots. Fire altered plant composition, abundance and habitat structural attributes of burned sites. The four plants we studied had very different responses to fire. There were comparable abundances of all four food plants in both control and treatment sites in the 'before' period. Of the four species, the Flat Cord-rush was most sensitive to fire and disappeared from treatment sites for the remainder of the study period. Both Tiny Flannel-flowers and Lemon-scented Boronias temporarily disappeared from treatmement sites but recovered within 24 months. Dwarf Everlastings recovered the most rapidly from fire, and by 20 months were more abundant in treatment than control sites. Observations of adult Orange-bellied Parrots foraging on seeds of Dwarf Everlastings and of those seeds in the crops of nestlings indicates that at least to some extent, this abundant new food source was recognised and exploited by adult parrots provisioning their young. The last fire at the study area was in 2011 (https://maps.thelist.tas.gov.au/listmap/app/list/map), and due to their short life span, most living Orange-bellied Parrots are unlikely to have experienced foraging in recently burned habitat when breeding. Our results demonstrate that the species still retains enough behavioural plasticity to identify natural food resources in the wild and incorporate these into their diets.

In addition to altering the abundance of food plants, fire changed the structure of habitat in the treatment area. The proportion of bare earth increased and the height of vegetation decreased in treatment sites relative to controls, but these attributes began to recover over time. Structural attributes of habitat may be of importance for foraging efficiency of

Orange-bellied Parrots, which are mostly ground feeders both in the breeding range (Brown and Wilson 1980) and elsewhere (Loyn*, et al.* 1986). By reducing clutter and increasing accessibility of small regenerating plants, fire may facilitate efficient natural foraging behaviours. Furthermore, the impacts of fire on plant growth forms may also improve resource availability. For example, Lemon-scented Boronia forms a small shrub > 1 m height in long unburned habitats (Brown and Wilson 1980) but within 20 months of fire, this species regenerated at treatment sites as small ~ 12 cm tall plants that flowered and seeded even at this reduced size. If foraging on the ground is more efficient for Orange-bellied Parrots than clambering through shrubs, small, regenerating shrubs in burned areas may be more accessible than larger plants in dense shrubby habitats (Brown and Wilson 1980). Investigating how these structural attributes of burned habitat affect foraging behaviour of Orange-bellied Parrots may be challenging in contemporary times given their reliance on supplementary feeding and small population size. Although supplementary feeding is a central component of the contemporary recovery program for Orange-bellied Parrots (Department of Environment 2016), supplementary food can heighten risk of disease transmission (Galbraith*, et al.* 2014;Tollington*, et al.* 2015) and predation (Hanmer*, et al.* 2017). Long-term recovery of Orange-bellied Parrots will depend on whether they learn to exploit natural food sources in areas where supplementary food is not available (Department of Environment 2016). Our results are encouraging because Orange-bellied Parrots recognised the burned area as a foraging resource 20 months after fire, and this behavioural plasticity might facilitate further investigation of habitat selection and preference in moorlands with differing fire histories.

Our study only considers the short term impact of fire at two sites on a limited range of Orange-bellied Parrot food plants. Even within our limited sample we demonstrate that different plants had divergent responses to the same stimulus, and further evaluation of the recovery of other food plants at more locations will improve information about how food availability might be enhanced for Orange-bellied Parrots. Altered fire regimes have dramatically affected the vegetation of south western Tasmania (Marsden-Smedley and Kirkpatrick 2000) and fire is recognised as an important conservation priority for land management in the Tasmanian Wilderness World Heritage Area (DPIPWE 2015). Our results provide the first quantitative evidence for an increase in Orange-bellied Parrot food plants following planned burns, providing a starting point for evidence-based evaluation of this management action. Land managers should continue to implement planned burns in the immediate Orange-bellied Parrot breeding area (i.e. the Melaleuca valley) to provide foraging habitat and reduce the risk of large-scale wildfire. Continued long-term monitoring at existing sites, as well as the creation of new sites in future burn units can be used to provide information to determine the optimal fire regime and spatial configuration of burning to provide foraging habitat for the Orange-bellied Parrot. Given the importance of cool, patchy fire mosaics in maintaining biodiversity in buttongrass moorlands (Marsden-Smedley and Kirkpatrick 2000) it is unsurprising that altered fire regimes are a threat to the Orange-bellied Parrot (Department of Environment 2016). Furthermore, our results suggest that in the immediate aftermath of fire, food may be very scarce for Orange-bellied Parrots. Preventing large-scale wildfire is thus an important conservation priority for these birds, and in such an event, supplementary feeding may be essential to overcome food shortages. By improving understanding of how different components of vegetation communities respond, manipulation of fire regimes can be optimised to relieve habitat limitation for focal species of conservation concern (Legge*, et al.* 2011). Our study demonstrates that this approach can yield important information over short time-frames that can inform management planning and conservation management.

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Figure Captions

Figure 1. Image showing the dorsal view of the crop of an orange-bellied nestling. The head is positioned at the top of the image, and the neck is positioned along the left side of the crop wall (approximately below the white arrows). The thin crop walls in this position show the crop contents clearly through the transparent skin. Large millet seeds from the supplementary feeders are visible (two examples highlighted with white arrows). The red arrows show two seeds of *Helichrysum pumilum*, which regenerated abundantly after fire and their seeds were exploited by adult Orange-bellied Parrots as food for their nestlings.

Figure 2. Modelled estimates of temporal change in plant abundance in response to prescribed burning. Fire affected treatment sites (left panels) at one week, whereas control sites (right panels) did not burn. We recorded abundance of plants at sites categorically: 0) species absent, 1) 1 – 5 plants, 2) 5 – 20 plants, and 3) > 20 plants.

Figure 3. Modelled estimates and confidence intervals of (a) percent bare earth cover and (b) vegetation height at treatment and control sites over time.

Table 1. List of models fitted to each response variable ranked by AIC. * indicates the preferred model. Treatment refers to whether sites were burned or not in a prescribed fire, time refers to the five time periods when surveys were undertaken, shrubs refers to whether these were present/absent at sites.

Response Variable	**Model**	**d.f.**	**AIC**	**ΔAIC**
Dwarf Everlasting	treatment × time*	12	844.44	0.00
	time	7	886.30	41.86
	shrubs	4	942.03	97.59
	treatment	4	952.84	108.40
	null	3	953.13	108.69
Tiny Flannel-flower	treatment × time*	12	810.28	0.00
	treatment	4	861.36	51.08
	time	7	862.09	51.81
	null	3	886.43	76.15
	shrubs	4	888.02	77.74
Lemon-scented Boronia	treatment × time*	12	274.95	0.00
	time	7	282.12	7.17
	shrubs	4	363.17	88.22
	null	3	363.19	88.24
	treatment	4	364.44	89.49
Flat Cord-rush	treatment × time*	12	629.93	0.00
	treatment	4	779.01	149.08
	time	7	849.63	219.70
	shrubs	4	882.48	252.55

	null	3	899.01	269.08
% bare earth	treatment × time*	10	4,757.29	0.00
	treatment	2	6,731.67	1,974.38
	time	5	8,629.50	3,872.21
	shrubs	2	10,488.80	5,731.51
	null	1	10,542.22	5,784.93
vegetation height	treatment × time*	11	390.40	0.00
	treatment	3	709.04	318.64
	time	6	827.00	436.60
	null	2	918.41	528.01
	shrubs	3	918.48	528.08