Birds in Black Box woodlands in Hattah-Kulkyne NP, Nangiloc and Kings Billabong spring 2018 to autumn 2019, with an assessment of effects of recent environmental flows

Final report from surveys October 2018 to March 2019

Richard Loyn, Dan Eyles and Graham Hepworth

Eco Insights

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Unpublished report for the Mallee Catchment Management Authority

Mallee Catchment Management Authority
Cnr Eleventh St and Koorlong Ave
Mildura
Victoria 3500
03 5051 4322

By Richard Loyn and Dan Eyles

Eco Insights
0488-77 66 78
richard.loyn@bigpond.com

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Cover photo: recently flooded black box woodland (©Richard Loyn).

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Executive Summary

Surveys of birds were conducted on 84 sites in black box *Eucalyptus largiflorens* woodland and associated habitats in and near Hattah-Kulkyne National Park, during two sessions in spring 2018 and autumn 2019. The objective was to assess changes after environmental watering in 2014 and subsequent years, and to contribute to future monitoring, with special emphasis on the widespread but often-neglected black box woodlands. This follows initial work done before, during and immediately after the floods on nine occasions in 2014-18 (Loyn and Dutson 2015a, b; 2016a, b; 2017a, b, c; 2018). The sites included 61 sites in the Park (45 sites in black box woodland, five in river red gum, 11 in mallee or dune woodland) and 25 elsewhere (five sites in sparse black box woodland with an understorey of tangled lignum near Nangiloc, one site in river red gums beside the river in Nangiloc and 19 sites in black box woodlands at Kings Billabong near Mildura). Area-searches of 1 ha in 10 minutes were used to survey birds on these sites, with bush birds being the main subject of interest.

High bird numbers were recorded in spring 2018, mainly on sites that had been flooded in previous years. A large influx of nomadic woodswallows contributed part of this increase. Numbers of birds declined markedly between then and autumn 2019, presumably in response to an unusually dry summer. This decline was evident on most areas studied. Noisy Miners declined to a greater extent than many other species, and this provided opportunities for small birds to increase at some sites.

Analysis of data for the whole 6-year period showed that effects of environmental flows were generally strong and positive, with total numbers of birds being 60% higher on sites that had flooded for up to three years after flooding. Just one guild (seed-eaters that feed low to the ground) showed a negative response, and that was mainly due to a few species within the guild (notably Blue Bonnet). The analysis also highlighted the negative role of Noisy Miners, which responded positively to flooding and excluded most small birds from the new territories that they occupied. Fortunately miners then decreased quickly as floods receded, as mentioned above.

The study shows that environmental flows deliver benefits to the black box woodland ecosystem, that are evident in most bird guilds including insectivores that feed in the eucalypt canopy, shrubs and ground layers. This shows environmental flows at suitable frequencies may have wide-ranging benefits within the ecosystem.

Introduction

This is the seventh in a series of reports on birds in black box *Eucalyptus largiflorens* woodlands at and near Hattah-Kulkyne National Park, which aim to document effects of environmental watering events from 2014 to 2017, and to contribute to future monitoring. This report presents data and observations from field visits in October 2018 (spring) and March 2019 (autumn). It makes general comparisons with previous results, and compares bird abundance in black box sites at Hattah that were flooded or not flooded in spring 2017, over the two seasons of this assessment.

This report also includes a more comprehensive statistical analysis of the effects of flooding and other variables over the six years of monitoring from 2014 to 2019. This analysis focused primarily on effects of flooding (time since the last flood) and other contributing variables, including the roles of the despotic native Noisy Miner and its less common relative the Yellow-throated Miner.

The series of studies over six years from 2014 to 2019 represents a rare example of a sustained program examining effects of environmental flows on woodland birds, as opposed to aquatic fauna such as fish or waterbirds (which have also been studied at Hattah). There are several strong reasons for including woodland birds in programs of this sort. First, woodland birds are expected to respond not just to the influx of water itself, but to subsequent changes in health of the woodland trees and other vegetation after waters have receded (when fish and waterbirds have generally left the area). Second, birds represent a broad range of guilds for feeding and nesting, and so they can provide evidence for changes in productivity at various levels in complex woodland ecosystems (e.g. changes in abundance of insects in the canopy or shrub layers, or availability of nectar, fruit or seeds). Third, birds can be monitored at multiple sites much more easily than other fauna groups, and so it is possible to obtain more wide-ranging spatial than for groups such as invertebrates where sampling is more labour-intensive. These are among the reasons why forest or woodland birds have often been chosen for monitoring programs in forest management (Raison et al. 2001; Kavanagh et al. 2004; Loyn 2018) and in compiling state-of-the-environment reports.

As indicated in previous reports, the study was needed because black box woodlands form a large but poorly studied component of the flood-plain vegetation of the Murray-Darling Basin, which covers a large part of south-eastern Australia, including some of the most productive agricultural land and many areas of high environmental and cultural significance. The major rivers in the Basin distribute water over vast distances, sustaining human populations, agriculture and iconic ecosystems in a region with generally low and intermittent rainfall. The rivers have been regulated for many decades, and important decisions need to be made about allocating water for economic and environmental purposes (MDBA 2011, 2012): these decisions can often be controversial. The current set of studies helps provide new information about one of the extensive but poorly known natural features of the Basin (black box woodlands), to help government agencies make wise decisions about conserving their natural values and vitality.

The Hattah Lakes form a Ramsar-listed wetland and have been recognised as an ‘icon site’ in the Murray-Darling Basin. Funding was made available for various works to enable delivery of increased flows of water to the associated floodplain, under the Living Murray initiative, a joint initiative funded by the governments of New South Wales, Victoria, South Australia, Australian Capital Territory and the Commonwealth, coordinated by the Murray–Darling Basin Authority (e.g. MDBC 2006; MDBA 2009). These works included a pump station to pump water from the River Murray into

Chalka Creek (the main inlet to the lakes), new regulators and levees, and works to lower the bed of Chalka Creek, and were completed in 2010. Environmental flows were then made available as part of a coordinated system for delivering water from multiple holders of 'e-water' in the catchment, to help restore more natural flood regimes. Major flows were delivered in this way in 2014 and again in 2017, with the aim of watering substantial areas of black box woodland as well as the lakes and surrounding woodlands of river red gum *E. camaldulensis* (MDBA 2013). The 2017 event involved pumping 114 GL of water to the Hattah Lakes (but not to Lake Kramen in the south-east of the Park) from 3 July to 31 October 2017.

The short-term responses of birds to the 2014 flows were monitored from 2014 to 2017 (Loyn and Dutson 2015, 2016a, b, 2017a, c) and the short-term responses of birds to the 2017 flows were monitored in spring 2017 (during the 2017 watering event) and autumn 2018 (when most of the water had receded from the black box woodlands) (Loyn and Dutson 2018). The present report provides further information on subsequent changes as monitored in spring 2018 and autumn 2019, along with the more comprehensive analysis of recent environmental flows as mentioned above.

Methods

Study Areas

Hattah-Kulkyne National Park

Hattah-Kulkyne National Park is a large National Park (48,000 ha) 50 km south-east of Mildura in north-west Victoria. The Park contains important representations of the Murray Mallee, as well as woodlands of black box and River Red Gum. Most of the black box woodland has been classed as Riverine Chenopod Woodland, in terms of Ecological Vegetation Class (the vegetation classification adopted by the Victorian Government) (White et al. 2003). Further details are given in our earlier reports (Loyn and Dutson 2015; 2016a, b; 2017a, b, c; 2018).

Our initial sites had been selected in two parts of Hattah-Kulkyne National Park, each with extensive areas of black box woodland. One was in the north-west of the Park, mainly east of Mournpall Track near Lake Bitterang. The other was in the south-east of the Park, in the vicinity of Lake Kramen. These parts encompassed the largest accessible areas of black box woodland watered in 2014. Floodwaters reached their highest levels in the first area in August-September 2014, and in the second area in November-December 2014.

A natural flood occurred in spring 2016, supplemented with 30 GL pumped into the Hattah Lakes. A larger environmental flow was delivered in 2017-18, with 114 GL pumped into the Hattah Lakes from 3 July to 31 October 2017. The Lake Kramen system remained dry in both those years.

On each assessment we have selected and surveyed small numbers of supplementary sites in various habitats in the Park, and nearby near Nangiloc, and at Kings Billabong near Mildura, to strengthen the data, address new questions and provide contextual data (Table 1). In 2017-18 we selected and surveyed several new sites in mallee in dune woodland, as these seem to offer habitat for a range of species that proved to be unexpectedly scarce in black box woodland, along with species that move between these habitats.

For our 2018-19 surveys, we conducted 185 searches at 86 sites. These included 61 sites in the Hattah-Kulkyne National Park (45 in black box, five in river red gum, eight in mallee woodland and

three in other types of woodland on sand dunes). We also assessed five sites in sparse black box woodland near Nangiloc, one in riverside river red gum near Nangiloc and 19 sites in black box woodland at Kings Billabong.

Field methods

We conducted spring fieldwork from 20 to 24 November 2018, and autumn fieldwork from 18 to 29 March 2019.

Birds were surveyed on each site using timed area-searches (1 ha, 10 minutes) (after Loyn 1986, 1998). All surveys were undertaken in mild weather, with light wind and temperatures <35 °C. (This is higher than our usual limit of 32 °C, but this March was unusually hot and we needed to do a few counts in hotter weather than usual, and found that birds were surprisingly active despite the heat.)

On each search, an observer walked around the site, recording numbers of individual birds of each species seen or heard. Birds observed off the site were recorded separately and not considered further in the analysis. Birds flying over the site were considered as off-site unless they were species that typically search for prey in open air (swallows, martins, woodswallows and birds of prey). Birds flying below the canopy were considered as on-site, unless it was obvious that they were making long-distance movements with no intention of stopping in the site. Indirect signs of birds (scats, feathers or footprints) were scored as 0.1 in analysis. Observations or indirect signs of mammals and reptiles were treated in the same way as birds but are not considered further in this report.

As in previous assessments, the amount of eucalypt or mistletoe flowering was assessed on a scale 0 to 5, linked to tree species when more than one tree species was present at the site. Flooding onsite was scored for its extent (% cover) and depth.

Data presentation

Data were collated for each session (spring and autumn). Values were calculated for various guilds of species, by summing corresponding values for each species in the guild. As in previous reports, this was done for total native bush birds, water birds, introduced birds (of which there were none) and a range of groupings based on food, nest-site or migratory status. For the 2018-19 data, our main aim was to describe differences from the previous year, with special reference to any changes since the previous year or any apparent effects of previous flooding. Mean values were tabulated for woodland bird species and guilds by habitat and region.

Data analysis

A more comprehensive statistical analysis was then undertaken, using data from all 13 assessments (2014-19) to provide more definitive answers about effects of flooding on these sites. This analysis was restricted to black box woodland sites at Hattah, as that is the region that was specifically targeted by recent environmental flows. Altogether 69 sites of this sort had been surveyed since the study began in 2014, and 42 of those sites had each been surveyed ten times or more. Eight additional sites had been surveyed three to nine times and they were also included in a core sample of 50 sites for analysis. A further 19 sites had only been surveyed once or twice each and such sites were deemed non-core and omitted from this analysis.

Generalised linear mixed models (GLMMs) were run to assess relationships between numbers of birds in each guild (as dependent variables), and sets of potential explanatory variables. These variables included one of central interest, namely the time since the last flood, and a number of others that may have affected this relationship, e.g. cloud cover (0-5), wind (0-5), observer (four observers), geography (Mournpall in the west of the park or Kramen in the south-east), flowering index (0-5) and the abundance of miners (Noisy Miners and Yellow-throated Miners, the latter being much less common). Variables such as the % area of each site flooded at the time of survey, and whether the site flooded at all, were also considered.

Miners were considered as a numerical variable and the others were all considered as categorical variables (hence the need for mixed models). The variable for time since the last flood (TSF) had five levels for sites that flooded during the current period (2014-19): 0 = currently flooded (partly or wholly); 1 = last flooded 1-6 months ago; 2 = last flooded 6 months to <2 years ago; 3 = last flooded 2-3 years ago; and 4 = last flooded >3 years ago. Sites that did not flood during the current period were assigned to another level: 5 = not readily flood-prone, with the expectation that they may have experienced lower flooding frequencies historically (and longer intervals between floods) than the lower-lying sites that flooded during the current study. Those sites included a group that lay north of an artificial levy built to protect farmland from flooding many decades ago, so the low flooding frequency could be an artefact of that construction for those sites.

Sites, sessions and dates (nested within each of 13 monitoring session) were considered as random variables in the modelling process. Modelling was done using the GLMM program within the Genstat software package (Schall 1991), assuming Poisson distributions for count data and using logarithmic link functions. Dependent variables included major bird guilds and other groupings, and one ecologically influential bird species (Noisy Miner).

Models were built by including all variables that produced significant responses ($p<0.05$) when considered alone and then progressively discarding those that were no longer significant when analysed in combination. For the current purpose, the most useful models were seen as those involving time since last flood (TSF) as that variable can be controlled directly by land managers (primarily by delivering environmental flows). Miners were also seen as a useful variable because previous results have demonstrated their major influence on bird communities through their despotic exclusion of smaller bird species. Hence we built models for each guild with just those two variables, even if they did not appear in the best statistical models (and happily, they usually did appear in those models). For nectarivores, we built a model including flowering index (despite a lack of significant response when tested by itself), miners and TSF, as nectarivores were clearly attracted to flowering plants (mainly black box and mistletoe) but often excluded by miners. We also built models for all guilds with only time since last flood (TSF), as we recognised that flooding affected Noisy Miner abundance directly (and other variables, e.g. flowering index), and we needed to get a pure estimate of effects of flooding.

In interpreting the models, we recognised that guilds favouring short times after the last flood (categories 0 to 2 or 3) could be considered to benefit from recent environmental flows or frequent floods, whereas guilds favouring long times after the last flood (categories 4 or 5) could be considered to be disadvantaged. Any marked differences between categories 4 and 5 would indicate possible long-term effects of flooding or withholding water from particular sites.

Results

1. Main differences between 2018-19 and previous year (2017-18)

A major influx of aerial insectivores (White-browed and Masked Woodswallows) was evident at Hattah in spring 2018 (Table 1). Many were feeding in stands of mallee, taking insects and also feeding at the blossom. Flocks were often seen circling over black box, and taking flying insects in the air above. Flocks of several hundreds of these nomadic birds were sometimes seen drinking at the shores of nearby lakes, and perching in nearby eucalypts, sometimes also pouncing on insects from the ground nearby. An Australian Hobby attended one of those flocks, presumably taking some of the woodswallows as prey. Most of these woodswallows were observed at sites that had been flooded in 2017, and few were observed feeding over black box sites that had not been flooded in 2017 (Table 1).

In black box woodland at Hattah, five feeding guilds were more common in spring 2018 than they had been the previous autumn. These were aerial insectivores, bark-foraging insectivores, canopy-foraging insectivores, nectarivores and seed-eaters that mainly feed close to the ground. Conversely, two feeding guilds (miners and carnivores) were markedly less common in spring 2018 than they had been the previous autumn (Table 1). Miners had increased in Red Gum sites at Hattah (where they were feeding on nectar) but declined elsewhere.

Most species and guilds declined markedly between our assessments in spring 2018 and autumn 2019, with total bird abundance falling by 30-50% in groups of sites in black box at Hattah (Table 1), black box at Kings Billabong and Nangiloc (Table 2) and in river red gum, mallee and dune Woodland at Hattah (Table 3). One exception was in black box sites at Mournpall in Hattah that had not been flooded recently, where birds increased slightly to similar levels found in sites that had been flooded (Table 1). Miners declined markedly in all groups of sites (except mallee, a marginal habitat where few were found).

In spring 2018 five feeding guilds were found more commonly in black box sites at Hattah that had been flooded in 2017 than in those that remained dry (Table 1), namely miners; other nectarivores; bark-foraging insectivores (Brown Treecreeper); large insectivores that feed from open ground among trees or shrubs (White-winged Chough and Apostlebird) and seed-eaters that feed at all levels (e.g. Regent Parrot). Two of these guilds (bark-foraging insectivores and nectarivores other than miners) were found mainly at sites with few or no miners, showing that miners compete with these guilds for high-quality habitat. In contrast, seed-eaters that generally feed close to the ground (mainly certain parrots and pigeons) were found more commonly at sites that had not flooded in 2017 (Table 1). In spring 2018, total bird abundance and species richness was almost twice as high in sites that had been flooded in 2017 as in sites that had remained dry, even when the woodswallow flocks were excluded from the totals (Table 1).

By autumn 2019 this situation had changed, with total bird abundance falling in black box that had been flooded (and most other habitats) and rising to similar levels in nearby black box at Mournpall that had not been flooded (Table 1). Miners, aerial insectivores and seed-eaters that feed at all levels remained more common in sites that had been flooded than elsewhere (despite substantial

declines) and now a different two feeding guilds appeared to favour sites that had been flooded (canopy-foraging insectivores and small insectivores that feed from open ground among trees and seed-eaters that feed at all levels). Conversely, six feeding guilds were more common in sites that had remained dry (Table 1). These were bark-foraging insectivores, nectarivores other than miners, carnivores, large open-ground insectivores (feeding in open or among trees) and seed-eaters that feed mainly close to the ground.

Observed use of habitat resources

Extensive flowering was observed in river red gum in spring 2018 but not in autumn 2019, and this provided a major attraction for Noisy Miners. Moderate levels of flowering were observed in mallee in both seasons, attracting various honeyeaters and woodswallows.

Little flowering was observed in black box sites during the spring or autumn assessments, though a few individual black box trees were found to be in quite heavy flower at a few sites in autumn, especially at the eastern end of a dry floodplain west of Lake Bitterang (possibly fed by groundwater from that lake). Moderate levels of flowering were observed in some mallee sites, but not in river red gum. Small flocks of Yellow-plumed Honeyeaters were often seen moving west through our sites at Hattah and Kings Billabong in autumn 2019, suggesting a movement to a rich nectar source elsewhere (probably in mallee, as this is a mallee specialist). Small numbers were also seen feeding in black box, mainly taking lerps from foliage.

Two species of mistletoe provided useful sources of nectar for birds in particular sites across all habitats. One of them (harlequin mistletoe *Lysiana exocarpi*) grows mainly on narrow-leafed trees (not eucalypts), especially in dune woodland, and it attracted a wide range of honeyeaters, including a few White-fronted Honeyeaters, which had not previously been recorded on our surveys at Hattah. The more common mistletoe species (drooping mistletoe *Amyema pendulum*) grows mainly on eucalypts and was also used locally by honeyeaters: this species was generally more common close to rivers than elsewhere. Stands of willow wattle *Acacia salicina* were flowering profusely at some sites in autumn 2019, but wattles do not generally provide a useful nectar source for birds.

A small chenopod shrub (ruby saltbush *Enchylaena tomentosa*) had ripe red berries at many sites in autumn 2019, and a flock of Regent Parrots was seen feeding voraciously on them at one site in black box near Lake Kramen in autumn 2019. A range of honeyeaters and parrots were also seen feeding on the berries elsewhere, though not in abnormal concentrations.

2. Effects of environmental flows: statistical analysis of data 2014-19

For most guilds, the best statistical models included terms for TSF (time since last flood), miners and one or two other variables (e.g. flowering index, geographic group, cloud cover or observer). The latter variables made generally small contributions. Simple models with just TSF and miners, or TSF alone, proved highly informative (Table 4).

Total native land birds were ~60% more numerous in sites that were flooded (TSF = 0) or had been flooded in the last two years (TSF = 1 or 2) than in sites that had been flooded longer ago (TSF = 4) or remained dry (TSF = 5) ($p=0.002$). The positive effects of floods over a three-year period (TSF 0-3) were clearly evident for small birds (<60g) and miners (65g) (Figure 1), although these groups were

never numerous on the same sites as each other. Large birds (>70g) also showed significant positive responses to floods on a more erratic basis (being high at TSF = 1 or 3). Beyond three years after a flood (TSF =4), the composition of these three groups of birds was very similar to that in sites that had not flooded at all (TSF = 5) (Figure 1). Mid-sized land birds other than miners (60-70g) were more numerous in the first three years after floods (TSF = 0-3), and especially from six months to two years after floods (TSF = 2), than they were more than three years after a flood (TSF = 4), but they also proved common on dry sites that had remained unflooded (TSF = 5) (Table 4). This group contained only two common bird species (Red-rumped Parrot and Grey Shrike-thrush), with highly disparate habitat requirements, and does not warrant further attention.

Similar effects were found for most guilds (Table 4). For canopy-foraging insectivores and shrub-foraging insectivores, the effects of TSF were only significant when miners were included in the models, showing that miners were effectively excluding these birds from some of their favoured flooded habitats.

Four feeding guilds showed no significant effect of flooding (Table 4): these were carnivores (e.g. butcherbirds and crows), generalist insectivores (represented by one species, Grey Shrike-thrush), bark-foraging insectivores (Brown Treecreeper) and small insectivores that feed from open ground among trees (several species, e.g. Restless Flycatcher and Red-capped Robin). The three insectivorous guilds all showed strong negative responses to miners, and it is likely that the despotic aggression of miners prevented these birds from taking advantage of any increases in productivity due to flooding.

Two feeding guilds showed complex effects of flooding. Large insectivores that feed from open ground among trees (White-winged Chough and Apostlebird) were most numerous in black box two to three years after flooding (TSF = 3) and least numerous six months to two years after flooding (TSF = 2) or more than three years after flooding (TSF = 4) (Table 4). Flocks of these birds move widely through the landscape (including dry habitats such as mallee) and can be expected to respond in complex ways. Both species were sometimes found in sites that were actually flooded (despite their propensity for feeding from the ground), and White-winged Choughs in particular were seen feeding from wet mud as floods receded. Seed-eaters that feed close to the ground (parrots and pigeons) were collectively most common in sites that did not flood (TSF = 5), but they also became common in flooded sites at various times after floods (TSF = 1, 2 or 3) (Table 4). They were less common when such sites were actually flooded (understandably), and less common again on these sites more than three years after a flood (TSF = 4) (Table 4). That was the only feeding guild to be significantly more numerous in sites that did not flood (TSF =5) compared with sites that had flooded more than three years ago (TSF = 4). That preference varied between species within the guild: Blue Bonnets andRed-rumped Parrots showed a strong and continuing preference for dry sites (although some were found on flooded sites in the two years following floods), whereas Common Bronzewings were seen mainly in sites that had been flooded two or three years earlier.

All other feeding guilds showed strong positive effects of flooding, being more numerous in sites that had been recently flooded (TSF = 0-3) than in sites that remained dry (TSF = 5) or had not been flooded for more than three years (TSF = 4). With one of these guilds (seed-eaters that feed at all levels), numbers remained high on flooded sites more than three years after a flood (TSF = 4), showing that such sites continued to support plentiful supplies of some resources at least three

years after a flood, compared with sites that did not flood. These resources included berries of Ruby Saltbush, as described in the previous section. One of the species in this guild (Regent Parrot) appeared to become progressively more numerous with time since flood, while remaining rare on sites that had not flooded at all (Table 4).

Miners and their effects

Despotic miners had a strong negative effect on total abundance of birds other than miners, effectively replacing small birds so that total abundance of all birds (including miners) was slightly elevated where miners were numerous (Table 4). Large birds were found to respond positively to the abundance of miners ($p = 0.002$), and small birds responded negatively ($p<0.001$) (Table 4). Many small bird species were extremely rare where miners were common, whereas large birds were more evenly distributed.

No significant relationships with miners were found for large insectivores that feed from open ground among trees (White-winged Chough and Apostlebird), insectivores that feed from open ground which may be far from cover (e.g. Australian Magpie) or seed-eaters that feed low to the ground (parrots and pigeons) (Table 4). These guilds all include large birds that can co-exist with miners. A positive relationship with miners was also found for aerial insectivores, but that was due to the influx of woodswallows in spring 2018, and their association with recently flooded sites where Noisy Miners happened to be common. Nomadic woodswallows live in large flocks, which are not deterred by aggressive miners. Otherwise all feeding guilds showed strong negative relationships with miners (Table 4), that influenced their responses to flood regimes.

Noisy Miners were strongly influenced by flood regimes ($p<0.001$), being most common in the two years after a flood and least common more than three years after a flood (Table 4). More than three years after a flood (TSF = 4) their abundance was similar to that on sites that had not been flooded at all (TSF = 5) (Figure 1).

Flowering index

Flowering index made a significant contribution to models for Noisy Miner and the guild of seed-eaters that feed at all levels, but oddly not to nectarivores other than miners ($p = 0.113$) (Table 5), showing that miners were effectively dominating most of the flowering trees. The response of seed-eaters was evident at the highest levels of flowering recorded, when large parrots including Australian Ringnecks and Yellow Rosellas were seen feeding at the blossom. Red-rumped Parrots had also been seen feeding at black box blossom at Neds Corner in 2016 (pers. obs.). When flowering index was modelled against TSF, a significant relationship was found ($p<0.001$), with the index being highest 0-6 months after a flood (TSF = 1) and lowest in sites that had not flooded at all (TSF = 5) (Table 4).

Discussion

Changes in bird numbers between spring 2018 and autumn 2019

The widespread decline in bird numbers between spring 2018 and autumn 2019 is likely to be due to local climatic conditions over summer, which were unusually hot and dry. By autumn the only accessible water was in the Murray River, and in standing lakes at Hattah and Kings Billabong. Water levels in the Hattah Lakes had receded substantially since our spring surveys. Little flowering was observed in black box or river red gum woodlands in that season, and most of the flowering that was observed, was at sites where water from the 2017 floods had remained until recently, or that were close to standing water. Two features of the decline are of special interest.

First, the change was not uniform across sites, but involved a degree of redistribution from sites that had been flooded recently to nearby sites that had not been flooded. Presumably the dry conditions acted to reduce the ecological benefits of the recently flooded sites, encouraging a more uniform spread of birds through the black box woodlands. This was evident in the Mournpall region where recent floods had occurred, but not in the Kramen region or elsewhere where there had been no recent floods, and a general decline was observed in bird numbers from the high levels observed in spring 2018. This suggests that recent floods near Mournpall had helped deliver a degree of resilience to sites in that region, whereas the sites near Lake Kramen experienced a greater decline in productivity over the hot summer.

Second, proportionate declines were not uniform between species and guilds. Aerial insectivores declined massively, but this was expected as the guild contains two highly nomadic species of woodswallow, and the massive influx in spring 2018 was always expected to be temporary. Among other guilds, the greatest proportional decline was for miners (and specifically the more common of the two miner species, Noisy Miner). Noisy Miners remained mainly in areas where spasmodic flowering continued in the black box, and in nearby river red gum stands. This is of ecological significance as miners exclude smaller birds from their communal territories (Dow 1977; Loyn 1987; Grey et al. 1997, 1998), affecting community structure and earning them the title of despotic species (Mac Nally et al. 2012; Maron et al. 2013; Thomson et al. 2014). Noisy Miners have recently been recognised as having a strong influence in black box woodlands in New South Wales, just as they do here, contributing to the complex dynamics of floodplain woodlands (McGinness et al. 2018).

Some smaller birds were able to take advantage of the declining numbers of miners by moving in to vacated habitat. This was especially evident for canopy-foraging insectivores in the Mournpall region: these birds had increased by spring 2018 and they maintained that trend into autumn 2019. Hence the decline in miners in this region appears to have tempered the effects of dry conditions on the smaller birds that they exclude from their territories: the retreat of the miners provided new opportunities for small birds to occupy vacated habitats. In contrast, in the Kramen region canopy-foraging insectivores had increased greatly by spring 2018 (following declines in miners) but then low numbers were found in autumn 2019, presumably reflecting low productivity due to dry conditions on those sites where there had been no floods for over four years. This suggests that the black box woodland near Mournpall had maintained its productivity better than the black box

woodland near Lake Kramen, perhaps because of continued influence of groundwater from the nearby lakes in the Mournpall area and the effects of the 2017 floods.

Some seed-eaters had increased (e.g. Common Bronzewing), perhaps reflecting the longer time-frame of seed availability after flood events compared with more ephemeral food sources such as nectar and insects.

Declines were also observed in mallee and river red gum sites, with half as many land birds recorded as in 2017. Carnivores were an exception, with increases evident in both habitats (mainly due to increased numbers of butcherbirds). Miners had remained common in river red gum sites in spring 2018 (when there was extensive flowering of river red gum) but had declined markedly in both habitats by autumn 2019. As in black box, this would have tempered the declines in numbers of small birds including other nectarivores, by making new habitat available in vacated sites.

Effects of environmental flows: statistical analysis of data 2014-19

The analysis of data over six years 2014-19 has allowed us to distinguish key signals from the noise of random events that inevitably occur with complex ecosystems over time. Two signals have emerged strongly from the data. One is the influence of floods themselves, and this was strongly positive: most bird guilds (and total land birds) were more common in the 0-3 years after a flood than they were more than three years after a flood, or in sites that did not flood. Just one bird guild (seed-eaters that feed close to the ground) showed the reverse effect, being most numerous on sites that did not flood, and that applied mainly to a few species within the guild (notably Blue Bonnet and Crested Pigeon).

The second signal to emerge strongly was the role of despotic miners, as recognised in previous reports. The results show that miners and other birds respond strongly to floods, and where miners increase they exclude smaller birds and prevent them from gaining the full benefits of increased productivity caused by the floods. Fortunately for biodiversity as a whole, miners were as quick to decline after floods as they were to increase during them, and this allowed opportunities to open up for some of the smaller bird species, many of which are known to have positive effects on tree health. The declines in miners may have involved movement of birds as waters receded, and also mortality or reduced breeding success as the black box ecosystem dried out (especially in the recent hot summer).

The floods studied in this period were mainly delivered by environmental flows, though natural floods also contributed in spring 2016. Therefore the positive effects attributed to flooding in this analysis, can be attributed primarily to environmental flows.

Implications for ecosystem productivity and management

The positive effects of floods were evident for a wide range of guilds, including insectivores that feed in the canopy, shrubs and ground layers. This suggests that the floods had positive effects on all these components of the ecosystem, including the health of trees, shrubs and ground layers. Few negative effects were observed, and it seems that environmental flows at suitable intervals are a useful tool and can be expected to deliver benefits for woodland birds in the black box ecosystem, and other ecosystem components that contribute to the productivity of the system. The benefits were evident for most bird guilds over a span of three years post-flood, showing that the benefits

outlast the immediate effects of flooding, but nevertheless have a limited span of influence. In contrast, benefits of flooding for aquatic biota (including fish and waterbirds) may only be evident as long as water remains in the system. Longer-term benefits may accrue to all groups when floods facilitate increased health or breeding, allowing populations to increase and disperse over broad spatial scales.

Some cautionary notes should be added. One is that Noisy Miners will benefit from such flows, along with other birds, and this will reduce the level of benefits received by other birds. Some species may end up suffering negative consequences as a result. Another point is that some species already appear to favour areas that do not receive floods, either actively avoiding them (Blue Bonnet) or showing complex temporal responses to flood (e.g. White-winged Chough and Apostlebird). The latter two species are notably common in the black box woodlands and adjacent habitats at Hattah, and flocks move widely through different habitats (including flooded or recently flooded areas). It remains unclear why they are so much more common at Hattah than the other areas we have studied (Nangiloc, Kings Billabong, Mulcra Island and Lindsay Island). Apostlebirds have a very restricted Victorian range (Emison et al. 1987) and the needs of these species should be considered in plans for future management.

References

Emison, W.B., Beardsell, C.M., Norman, F.I., Loyn, R.H. and Bennett, S.C. (1987). Atlas of Victorian Birds. Department of Conservation, Forests & Lands with Royal Australasian Ornithologists Union, Melbourne, 271 pp.

Higgins, P.J., Peter, J.M. and Steele, W.K. (eds.) (2001). Handbook of Australian, New Zealand & Antarctic Birds. Volume 5: Tyrant-flycatchers to Chats. Oxford University Press, Melbourne.

Hunt, T., Paton, D.C. and Rogers, D. (2015). Birds in Black Box: avian community drivers in floodplain woodlands. Abstract, Australasian Ornithological Congress, Adelaide, November 2015.

Kavanagh, R.P., Loyn R.H., Smith, G.C., Taylor, R.J. and Catling, P.C. (2004). Which species should be monitored to indicate ecological sustainability in Australian forest management? Pp 959-987 *In* D. Lunney (Ed) Conservation of Australia's forest fauna (second edition). Royal Zoological Society of New South Wales, Mosman.

Landsberg, J.J. and Cork, S.J. (1997). Herbivory: interactions between eucalypts and the vertebrates and invertebrates that feed on them. Chapter 14 in Williams, J. and Woinarski, J. (eds.) Eucalypt Ecology: individuals to ecosystems. Cambridge University Press, Cambridge, UK.

Loyn, R.H. (1986). The 20 minute search - a simple method for counting forest birds. *Corella* 10: 58-60.

Loyn, R.H. (1987). Effects of patch area and habitat on bird abundances, species numbers and tree health in fragmented Victorian forests. Chapter 6 in Saunders, D.A., Arnold, G.W., Burbidge, A.A., and Hopkins, A.J.M. (eds), Nature Conservation: the role of remnants of native vegetation, pp. 65-77. Surrey Beatty & Sons, Sydney, 410 pp.

Loyn, R.H. 2018. Forest management and biodiversity conservation: assessing and managing impacts, with emphasis on birds and their habitats in Victoria, south-eastern Australia. D.Sc. Thesis, University of Melbourne (1003 pp.).

Loyn, R. and Dutson, G. (2015). Birds in Black Box woodlands in Hattah-Kulkyne NP: responses to environmental watering in 2014. Final report from 2014 surveys; and baseline for 2015 surveys. Unpublished report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. (2016a) Birds in Black Box woodlands in Hattah-Kulkyne NP 2015, one year after environmental watering in 2014, with comparative data from Nangiloc and Kings Billabong. Final report from 2015 surveys. Unpublished report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. 2016b. Birds in Black Box woodlands in Hattah-Kulkyne NP 2016, with comparative data from Nangiloc and Kings Billabong. Final report from 2016 surveys. Unpublished report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. 2017a. Birds in Black Box woodlands in Hattah-Kulkyne NP 2016, two years after environmental watering in 2014, with comparative data from Nangiloc and Kings Billabong. Unpublished report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. 2017b. Birds in floodplain woodland on Mulcra Island 2016. Unpublished report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. 2017c. Birds in Black Box woodlands in Hattah-Kulkyne NP, Nangiloc and Kings Billabong March to June 2017. Client report for the Mallee CMA by Eco Insights.

Loyn, R. and Dutson, G. 2018. Birds in Black Box woodlands in Hattah-Kulkyne NP, Nangiloc and Kings Billabong October 2017 to March 2018. Client report for the Mallee CMA by Eco Insights.

Loyn, R.H., Runnalls, R.G., Forward, G.Y. and Tyers, J. 1983. Territorial bell miners and other birds affecting populations of insect prey. *Science* 221: 1411-13.

Loyn, R.H., Lumsden, L.F., and Ward, K.A. (2002). Vertebrate fauna of Barmah Forest, a large forest of River Red Gum *Eucalyptus camaldulensis* on the floodplain of the Murray River. *Victorian Naturalist* 119: 114-132.

MacNally, R., Bowen, M., Howes, A., McAlpine, C.A. & Maron, M. (2012). Despotic, high-impact species and subcontinental scale control of avian assemblage structure. *Ecology* 93: 668–678.

Maron, M., Grey, M.J., Catterall, C.P., Major, R.E., Oliver, D.L., Clarke, M.J., Loyn, R.H., Mac Nally, R., Davidson, I. and Thomson, J.R. (2013). Avifaunal disarray due to a single despotic species. *Diversity & Distributions* 10: 1-12. DOI: 10.1111/ddi.12128.

McGinness HM, Arthur AD, Davies, M. (2018). Flood regimes driving vegetation and bird community transitions in semiarid floodplain woodlands. *Ecohydrology*. 2018;e1954. https://doi.org/10.1002/eco.1954.

MDBC (2006). The Hattah Lakes Icon Site Environmental Management Plan 2006-2007. Murray Darling Basin Commission, Canberra.

MDBA (2009). Environmental watering for tree species in The Living Murray icon sites: A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains. Murray-Darling Basin Authority, Canberra.

MDBA (2011). The Living Murray – one of Australia's largest river restoration projects. MurrayDarling Basin Authority, Canberra.

MBDA (2012). Hattah Lakes: Environmental water management plan 2012. Murray-Darling Basin Authority, Canberra.

MDBA (2013). The Living Murray annual environmental watering plan 2013-14. Murray-Darling Basin Authority, Canberra.

Moxham, C., Kenny, S. and Farmilo, M. (2014). The Living Murray Hattah Lakes Intervention Monitoring - Understorey Vegetation Monitoring Design. ARI report to MDBA.

Raison, R.J., Brown, A.G. and Flinn, D.W. 2001. *Criteria and indicators for sustainable forest management*. CAB International, Oxford.

Thomson, J.R., Maron, M., Grey, M.J., Catterall, C.P., Major, R.E., Oliver, D.L., Clarke, M.F., Loyn, R.H., Davidson, I., Ingwersen, D., Robinson, D., Kutt, A., MacDonald, M.A. and Mac Nally, R. (2014). Avifaunal disarray: quantifying models of the occurrence and ecological effects of a despotic bird species. *Diversity & Distributions* in press. doi:10.1111/ddi.12294

White, M, Oates, A, Barlow, T, Pelikan, M, Brown, J, Rosengren, N, Cheal, D, Sinclair, S and Sutter, G (2003). The vegetation of north-west Victoria: A report to the Wimmera, North Central and Mallee Catchment Management Authorities. Arthur Rylah Institute for Environmental Research, Melbourne.

Woinarski, J.C.Z., Recher, H.F. and Majer, J.D. (1997). Vertebrates of eucalypt formations. Chapter 13 in Williams, J. and Woinarski, J. (eds.) Eucalypt Ecology: individuals to ecosystems. Cambridge University Press, Cambridge, UK.

Table 1. Mean numbers of bird species and guilds counted in black box woodland at Hattah-Kulkyne National Park in spring 2018 and autumn 2019, on sites near the Mournpall Track which had flooded in 2016-17, sites in the same area that had not flooded, and sites near Lake Kramen (none of which flooded in 2016-17). Values are mean numbers observed on standard 10-minute area-searches each of 1 ha.

Year:	2018	2019	2018	2019	2018	2019
Season:	Spring	Autumn	Spring	Autumn	Spring	Autumn
Region:	MP	MP	MP	MP	K	K
Flooded in spring 2017?	Yes	Yes	No	No	No	No
Number of counts	22	20	8	9	18	21
Flowering index (0-5)	0	0.158	0	0	0	0
Species (land bird)						
Emu	0.15	0.06	0.56	0.04	0.07	0.07
Common Bronzewing	0.18	0.05	0.00	0.00	0.06	0.05
Crested Pigeon	0.36	0.35	0.38	1.44	0.06	0.33
Peaceful Dove	0.00	0.05	0.00	0.00	0.00	0.00
Australian Owlet-nightjar	0.00	0.00	0.00	0.00	0.00	0.00
Collared Sparrowhawk	0.00	0.00	0.00	0.00	0.00	0.00
Swamp Harrier	0.00	0.00	0.00	0.00	0.00	0.00
White-bellied Sea-Eagle	0.00	0.00	0.00	0.00	0.00	0.00
Whistling Kite	0.09	0.10	0.00	0.00	0.00	0.00
Australian Hobby	0.00	0.00	0.13	0.11	0.00	0.00
Galah	0.00	0.05	0.00	0.89	0.00	0.48
Little Corella	0.00	0.00	0.00	0.00	0.00	0.00
Sulphur-crested Cockatoo	0.00	0.00	0.13	0.00	0.00	0.00
Rainbow Lorikeet	0.00	0.00	0.00	0.00	0.00	0.00
Regent Parrot	0.68	0.10	0.00	0.00	1.00	1.43
Yellow Rosella	0.09	0.30	0.00	0.00	0.00	0.00
Australian Ringneck	1.36	2.25	0.00	1.22	0.06	0.57
Blue Bonnet	0.27	0.00	0.88	1.56	0.11	0.19
Red-rumped Parrot	1.41	0.10	1.75	0.00	0.00	0.14
Mulga Parrot	0.00	0.20	0.00	0.00	0.00	0.24
Laughing Kookaburra	0.00	0.00	0.00	0.00	0.00	0.00
Sacred Kingfisher	0.00	0.00	0.00	0.00	0.00	0.00
Rainbow Bee-eater	0.00	0.00	0.00	0.00	0.06	0.00
White-throated Treecreeper	0.00	0.00	0.00	0.00	0.00	0.00
Brown Treecreeper	0.59	0.05	0.13	0.56	0.06	0.00
Superb Fairy-wren	0.00	0.00	0.00	0.00	0.00	0.00
Splendid Fairy-wren	0.00	0.00	0.00	0.00	0.22	0.00
Variegated Fairy-wren	0.00	0.00	0.00	0.00	0.00	0.00
Weebill	2.00	2.00	1.13	1.67	3.56	1.19
Yellow-rumped Thornbill	0.00	0.00	0.00	0.00	0.00	0.00
Chestnut-rumped Thornbill	0.23	0.15	0.38	0.11	0.61	0.57
Inland Thornbill	0.00	0.00	0.00	0.00	0.00	0.00

Southern Whiteface	0.00	0.00	0.00	0.00	0.00	0.00
Spotted Pardalote	0.00	0.00	0.00	0.00	0.44	0.00
Striated Pardalote	0.64	1.05	0.38	0.44	0.61	0.62
Singing Honeyeater	0.00	0.00	0.00	0.00	0.00	0.05
White-eared Honeyeater	0.00	0.15	0.00	0.33	0.00	0.19
Yellow-plumed Honeyeater	0.05	0.00	0.00	0.56	0.00	0.00
White-plumed Honeyeater	0.36	0.10	0.13	0.11	0.00	0.00
White-fronted Honeyeater	0.00	0.05	0.00	0.00	0.00	0.00
Noisy Miner	5.91	3.05	3.25	2.33	2.41	0.52
Yellow-throated Miner	0.00	0.15	0.00	0.22	0.00	0.00
Spiny-cheeked Honeyeater	0.64	0.15	0.00	0.11	0.00	0.05
Red Wattlebird	0.00	0.00	0.00	0.00	0.00	0.00
Brown-headed Honeyeater	0.09	0.00	0.00	0.00	0.06	0.00
Blue-faced Honeyeater	0.00	0.00	0.00	0.00	0.00	0.00
Noisy Friarbird	0.00	0.00	0.00	0.00	0.00	0.00
Little Friarbird	0.27	0.00	0.13	0.00	0.00	0.00
Striped Honeyeater	0.41	0.35	0.25	0.11	0.00	0.10
White-browed Babbler	0.00	0.00	0.00	0.00	0.00	0.00
Chestnut-crowned Babbler	0.00	0.00	0.00	0.00	0.00	0.00
Varied Sittella	0.00	0.00	0.00	0.00	0.00	0.00
Black-faced Cuckoo-shrike	0.09	0.00	0.00	0.11	0.11	0.00
Rufous Whistler	0.00	0.00	0.00	0.00	0.44	0.14
Grey Shrike-thrush	0.09	0.10	0.13	0.00	0.17	0.24
Crested Bellbird	0.00	0.00	0.00	0.00	0.00	0.00
White-breasted Woodswallow	0.09	0.00	0.00	0.00	0.00	0.00
Masked Woodswallow	5.18	0.00	0.75	0.00	0.00	0.00
White-browed Woodswallow	21.27	0.00	1.75	0.00	0.00	0.00
Dusky Woodswallow	0.00	0.00	0.00	0.00	0.00	0.00
Grey Butcherbird	0.36	0.40	0.00	0.22	0.33	0.24
Pied Butcherbird	0.32	0.10	0.13	0.56	0.06	0.00
Australian Magpie	0.64	0.10	0.00	0.78	0.39	0.62
Grey Currawong	0.00	0.00	0.00	0.00	0.17	0.00
Grey Fantail	0.00	0.00	0.00	0.00	0.00	0.00
Willie Wagtail	0.14	0.20	0.00	0.22	0.00	0.00
Australian Raven	0.14	0.00	0.25	0.22	0.00	0.10
Little Raven	0.00	0.00	0.00	0.11	0.00	0.14
Little Crow	0.00	0.00	0.00	0.00	0.06	0.14
Restless Flycatcher	0.09	0.25	0.00	0.00	0.00	0.00
Magpie-lark	0.86	0.35	0.00	0.11	0.28	0.14
White-winged Chough	0.82	0.50	0.25	0.44	0.00	0.24
Apostlebird	0.18	0.70	0.00	1.33	1.33	0.00
Jacky Winter	0.00	0.00	0.00	0.00	0.00	0.00
Red-capped Robin	0.00	0.00	0.00	0.00	0.17	0.05
Hooded Robin	0.00	0.00	0.00	0.00	0.00	0.00
Silvereye	0.00	0.00	0.00	0.00	0.00	0.00

White-backed Swallow	0.00	0.00	0.00	0.00	0.00	0.00
Welcome Swallow	0.09	0.00	0.00	0.00	0.00	0.00
Tree Martin	0.00	0.20	0.00	0.00	0.00	0.00
Mistletoebird	0.00	0.00	0.00	0.00	0.00	0.00
Guild						
Aerial insectivores	26.64	0.20	2.50	0.00	0.06	0.00
Bark-foraging insectivores	0.59	0.05	0.13	0.56	0.06	0.00
Canopy-foraging insectivores	2.73	3.05	1.50	2.22	5.17	1.95
Damp-ground insectivores	0.00	0.00	0.00	0.00	0.00	0.00
Frugivores	0.00	0.00	0.00	0.00	0.00	0.00
Low-shrub-foraging insectivores	0.00	0.00	0.00	0.00	0.00	0.00
Miners	5.91	3.20	3.25	2.56	1.94	0.52
Nectarivores (other than miners)	1.82	0.80	0.50	1.22	0.06	0.38
Open-ground insectivores (may be far from cover)	1.64	0.65	0.00	1.11	0.67	0.76
Large open-ground insectivores (among trees or shrubs)	1.00	1.20	0.25	1.78	1.33	0.24
Small open-ground insectivores (among trees or shrubs)	0.09	0.25	0.00	0.00	0.39	0.05
Open-ground insectivores (among trees or shrubs)	1.09	1.45	0.25	1.78	1.72	0.29
Seed-eaters (feeding mainly close to ground)	2.20	0.86	3.69	3.93	0.29	1.50
Seed-eaters (feeding mainly in trees)	2.14	2.65	0.00	1.22	1.06	2.00
Tall-shrub-foraging insectivores	0.23	0.15	0.38	0.11	0.61	0.57
Shrub-foraging insectivores	0.23	0.15	0.38	0.11	0.61	0.57
Generalist insectivores	0.09	0.10	0.13	0.00	0.17	0.24
Carnivores (taking vertebrates & large invertebrates, etc)	0.91	0.60	0.50	1.22	0.61	0.62
Large land birds other than miners (>70g)	6.34	5.31	2.69	9.16	4.07	4.74
Small land birds other than miners (<60g)	31.86	4.90	4.88	4.22	6.22	3.19
Mid-sized land birds inc miners (60-70g)	1.77	0.20	2.00	0.00	0.17	0.38
Large hollow-nesters	2.41	2.70	1.00	3.67	1.17	2.67
Small hollow-nesters	2.86	1.75	2.63	1.11	1.28	1.57
Hollow-nesters	5.27	4.45	3.63	4.78	2.44	4.24
Summer migrant land birds	26.82	0.25	2.63	0.00	0.50	0.14
Introduced land birds	0.00	0.00	0.00	0.00	0.00	0.00
Native land birds	45.88	13.66	12.81	15.93	12.40	8.83
Total land birds	45.88	13.66	12.81	15.93	12.40	8.83
Total land birds excluding white-browed & masked woodswallows	19.43	13.66	10.31	15.93	12.40	8.83
Water birds	3.00	0.10	0.00	0.00	0.00	0.00
Land bird species per search	7.68	6.45	4.75	6.78	4.78	4.76
Water bird species per search	0.50	0.10	0.00	0.00	0.00	0.05
Total bird species per search	8.18	6.55	4.75	6.78	4.78	4.81
Native mammals	0.15	0.10	0.33	0.17	0.08	0.18
Introduced mammals	0.01	0.05	0.01	0.03	0.03	0.00

Table 2. Mean numbers of bird species and guilds counted in black box woodland at Kings Billabong (KB) and Nangiloc (N) in spring 2018 and autumn 2019. Some of these sites had received short natural floods in spring or summer 2016-17, but not environmental flows. Values are mean numbers observed on standard 10-minute area-searches each of 1 ha.

Year:	2018	2019	2018	2019
Season:	Spring	Autumn	Spring	Autumn
Region:	KB	KB	N	N
Number of counts:	26	21	10	5
Flowering index (0-5):	0	0	0	0
Species (land bird)				
Emu	0.00	0.00	0.01	0.00
Common Bronzewing	0.08	0.14	0.00	0.00
Crested Pigeon	0.31	0.05	0.20	0.20
Peaceful Dove	0.08	0.05	0.00	0.00
Australian Owlet-nightjar	0.00	0.00	0.00	0.00
Collared Sparrowhawk	0.00	0.05	0.00	0.00
Swamp Harrier	0.04	0.00	0.00	0.00
White-bellied Sea-Eagle	0.00	0.00	0.00	0.00
Whistling Kite	0.00	0.14	0.10	0.00
Australian Hobby	0.00	0.00	0.00	0.00
Galah	0.08	0.00	0.00	0.00
Little Corella	0.00	0.00	0.00	0.00
Sulphur-crested Cockatoo	0.00	0.00	0.00	0.00
Rainbow Lorikeet	0.00	0.00	0.00	0.00
Regent Parrot	0.00	0.00	0.00	0.00
Yellow Rosella	0.42	0.52	0.20	0.00
Australian Ringneck	0.00	0.38	0.00	0.00
Blue Bonnet	0.00	0.00	0.00	0.00
Red-rumped Parrot	0.12	0.29	0.20	0.00
Mulga Parrot	0.00	0.00	0.00	0.00
Laughing Kookaburra	0.00	0.05	0.00	0.00
Sacred Kingfisher	0.00	0.00	0.10	0.00
Rainbow Bee-eater	0.00	0.05	0.00	0.00
White-throated Treecreeper	0.00	0.05	0.00	0.00
Brown Treecreeper	0.42	0.14	0.00	0.00
Superb Fairy-wren	0.23	0.00	0.00	0.00
Splendid Fairy-wren	0.00	0.00	0.00	0.00
Variegated Fairy-wren	0.12	0.00	1.40	0.80
Weebill	6.31	1.95	3.10	1.00
Western Gerygone	0.04	0.00	0.00	0.00
Yellow-rumped Thornbill	0.00	0.10	0.00	0.00
Chestnut-rumped Thornbill	1.27	1.10	0.10	0.00
Inland Thornbill	0.23	0.00	0.10	0.00
Southern Whiteface	0.00	0.00	0.00	0.00

Spotted Pardalote	0.00	0.00	0.00	0.00
Striated Pardalote	0.46	2.43	0.40	0.40
Singing Honeyeater	0.00	0.00	0.00	0.00
White-eared Honeyeater	0.00	0.00	0.00	0.00
Yellow-plumed Honeyeater	0.15	0.76	0.00	0.00
White-plumed Honeyeater	2.65	1.33	0.20	0.20
White-fronted Honeyeater	0.00	0.05	0.00	0.00
Noisy Miner	1.65	0.48	0.00	0.00
Yellow-throated Miner	0.00	0.00	0.00	0.00
Spiny-cheeked Honeyeater	0.12	0.00	0.00	0.00
Red Wattlebird	0.04	0.24	0.00	0.00
Brown-headed Honeyeater	0.46	0.10	0.00	0.00
Blue-faced Honeyeater	0.00	0.00	0.00	0.00
Noisy Friarbird	0.00	0.00	0.00	0.00
Little Friarbird	0.35	0.00	0.00	0.00
Striped Honeyeater	0.27	0.10	0.00	0.00
White-browed Babbler	0.00	0.00	0.00	0.00
Chestnut-crowned Babbler	0.00	0.00	1.11	0.02
Varied Sittella	0.08	0.00	0.00	0.00
Black-faced Cuckoo-shrike	0.31	0.05	0.00	0.00
Rufous Whistler	0.81	0.10	0.00	0.00
Grey Shrike-thrush	0.62	0.43	0.00	0.00
Crested Bellbird	0.00	0.00	0.00	0.00
White-breasted Woodswallow	0.04	0.24	0.00	0.00
Masked Woodswallow	0.00	0.00	0.00	0.00
White-browed Woodswallow	0.08	0.00	0.00	0.00
Dusky Woodswallow	0.35	0.00	0.00	0.00
Grey Butcherbird	0.35	0.19	0.10	0.40
Pied Butcherbird	0.08	0.62	0.00	0.60
Australian Magpie	0.04	0.62	0.20	0.20
Grey Currawong	0.00	0.00	0.00	0.00
Grey Fantail	0.04	0.00	0.00	0.00
Willie Wagtail	0.50	0.19	0.00	0.00
Australian Raven	0.12	0.10	0.00	0.00
Little Raven	0.00	0.00	0.00	0.00
Little Crow	0.00	0.00	0.00	0.00
Restless Flycatcher	0.00	0.00	0.00	0.00
Magpie-lark	0.42	0.24	0.20	0.00
White-winged Chough	0.42	0.00	0.00	0.00
Apostlebird	0.00	0.00	0.00	0.00
Jacky Winter	0.00	0.00	0.00	0.00
Red-capped Robin	0.16	0.00	0.00	0.00
Hooded Robin	0.00	0.00	0.00	0.00
Silvereye	0.08	0.00	0.00	0.00
White-backed Swallow	0.00	0.05	0.00	0.00

Welcome Swallow	0.08	0.14	0.00	0.00
Tree Martin	0.42	0.24	0.00	0.00
Mistletoebird	0.00	0.10	0.00	0.00
Australian Reed-Warbler	0.04	0.05	0.00	0.00
Guild				
Aerial insectivores	0.96	0.71	0.00	0.00
Bark-foraging insectivores	0.50	0.19	0.00	0.00
Canopy-foraging insectivores	7.96	4.52	3.50	1.40
Damp-ground insectivores	0.00	0.00	0.00	0.00
Frugivores	0.08	0.10	0.00	0.00
Low-shrub-foraging insectivores	0.12	0.00	2.51	0.82
Miners	1.65	0.48	0.00	0.00
Nectarivores (other than miners)	4.04	2.57	0.20	0.20
Open-ground insectivores (may be far from cover)	0.96	1.14	0.40	0.20
Large open-ground insectivores (among trees or shrubs)	0.42	0.00	0.00	0.00
Small open-ground insectivores (among trees or shrubs)	0.38	0.00	0.00	0.00
Open-ground insectivores (among trees or shrubs)	0.81	0.00	0.00	0.00
Seed-eaters (feeding mainly close to ground)	0.65	0.52	0.41	0.20
Seed-eaters (feeding mainly in trees)	0.42	0.90	0.20	0.00
Tall-shrub-foraging insectivores	1.50	1.10	0.20	0.00
Shrub-foraging insectivores	1.62	1.10	2.71	0.82
Generalist insectivores	0.62	0.43	0.00	0.00
Carnivores (taking vertebrates & large invertebrates, etc)	0.58	1.14	0.30	1.00
Large land birds other than miners (>70g)	2.69	3.24	0.91	1.40
Small land birds other than miners (<60g)	15.42	9.19	6.51	2.42
Mid-sized land birds inc miners (60-70g)	1.08	0.71	0.20	0.00
Large hollow-nesters	0.50	0.95	0.20	0.00
Small hollow-nesters	2.69	4.24	0.80	0.40
Hollow-nesters	3.19	5.19	1.00	0.40
Summer migrant land birds	2.08	0.67	0.10	0.00
Introduced land birds	0.00	0.00	0.00	0.00
Native land birds	20.85	13.67	7.62	3.82
Total land birds	20.85	13.67	7.62	3.82
Total land birds excluding white-browed & masked woodswallows	20.77	13.67	7.62	3.82
Water birds	0.04	0.29	0.10	0.00
Land bird species per search	7.23	6.24	3.30	3.00
Water bird species per search	0.04	0.33	0.10	0.00
Total bird species per search	7.27	6.57	3.40	3.00
Native mammals	0.02	0.20	0.04	0.06
Introduced mammals	0.04	0.02	0.03	0.04

Table 3. Mean numbers of bird species and guilds counted in river red gum woodland (RG) and mallee or dune woodland (MX) at Hattah-Kulkyne National Park in spring 2018 and autumn 2019. All of the river red gum sites had experienced flooding in 2016 and 2017, augmented by environmental flows, and they remained close to standing water. The sites in mallee and dune woodland do not experience flooding. Values are mean numbers observed on standard 10-minute area-searches each of 1 ha.

Year:	2018	2019	2018	2019
Season:	Spring	Autumn	Spring	Autumn
Habitat:	RG	RG	MX	MX
Number of counts:	8	5	9	13
Flowering index (0-5):	0.857	0	0.222	0.308
% area flooded:	7.5	0	0	0
Species (land bird)				
Emu	0.00	0.04	0.06	0.05
Common Bronzewing	0.25	0.00	0.00	0.00
Crested Pigeon	0.00	0.00	0.00	0.08
Peaceful Dove	0.13	0.40	0.00	0.00
Australian Owlet-nightjar	0.00	0.00	0.00	0.08
Collared Sparrowhawk	0.00	0.00	0.00	0.00
Swamp Harrier	0.00	0.00	0.00	0.00
White-bellied Sea-Eagle	0.00	0.00	0.00	0.00
Whistling Kite	0.00	0.40	0.00	0.00
Australian Hobby	0.00	0.00	0.00	0.00
Galah	0.00	1.20	0.00	0.00
Little Corella	0.00	0.00	0.00	0.00
Sulphur-crested Cockatoo	0.13	0.20	0.00	0.00
Rainbow Lorikeet	0.00	0.00	0.00	0.00
Regent Parrot	0.00	0.00	0.00	0.00
Yellow Rosella	0.25	2.20	0.00	0.08
Australian Ringneck	0.25	1.20	0.22	0.92
Blue Bonnet	0.00	0.00	0.00	0.31
Red-rumped Parrot	0.75	0.80	0.00	0.00
Mulga Parrot	0.00	0.00	0.00	0.00
Laughing Kookaburra	0.13	0.40	0.00	0.00
Sacred Kingfisher	0.13	0.00	0.00	0.00
Rainbow Bee-eater	0.00	0.00	0.22	0.00
White-throated Treecreeper	0.00	0.00	0.00	0.00
Brown Treecreeper	1.13	0.40	0.11	0.00
Superb Fairy-wren	0.00	0.00	0.00	0.00
Splendid Fairy-wren	0.00	0.00	0.22	0.00
Variegated Fairy-wren	0.00	0.00	0.00	0.23
Weebill	0.75	0.20	2.56	1.85
Yellow-rumped Thornbill	0.00	0.00	0.00	0.46
Chestnut-rumped Thornbill	0.00	0.00	1.33	1.00

Inland Thornbill	0.00	0.00	0.11	0.00
Southern Whiteface	0.00	0.00	0.56	0.00
Spotted Pardalote	0.00	0.00	0.11	0.08
Striated Pardalote	2.00	1.00	0.78	0.69
Singing Honeyeater	0.00	0.00	0.00	0.08
White-eared Honeyeater	0.00	0.00	0.00	0.62
Yellow-plumed Honeyeater	0.00	0.00	1.22	0.77
White-plumed Honeyeater	2.13	1.40	0.00	0.00
White-fronted Honeyeater	0.00	0.00	0.00	0.38
Noisy Miner	9.38	2.40	0.00	0.23
Yellow-throated Miner	0.00	0.00	0.00	0.00
Spiny-cheeked Honeyeater	0.00	0.00	1.56	0.46
Red Wattlebird	0.00	0.00	0.00	0.00
Brown-headed Honeyeater	0.00	0.00	0.33	0.54
Blue-faced Honeyeater	0.25	0.00	0.00	0.00
Noisy Friarbird	0.00	0.00	0.00	0.00
Little Friarbird	0.13	0.00	0.00	0.00
Striped Honeyeater	0.00	0.20	0.00	0.31
White-browed Babbler	0.00	0.00	0.01	0.15
Chestnut-crowned Babbler	0.00	0.00	0.00	0.00
Varied Sittella	0.00	0.00	0.00	0.00
Black-faced Cuckoo-shrike	0.00	0.00	0.00	0.00
Rufous Whistler	0.00	0.00	0.67	0.00
Grey Shrike-thrush	0.00	0.00	0.00	0.00
Crested Bellbird	0.00	0.00	0.00	0.15
White-breasted Woodswallow	0.00	0.00	0.00	0.00
Masked Woodswallow	0.00	0.00	0.56	0.00
White-browed Woodswallow	0.00	0.00	14.78	0.00
Dusky Woodswallow	0.00	0.00	0.00	0.00
Grey Butcherbird	0.38	0.20	0.22	0.23
Pied Butcherbird	0.25	0.20	0.22	0.23
Australian Magpie	1.13	0.00	0.00	0.08
Grey Currawong	0.00	0.40	0.00	0.00
Grey Fantail	0.00	0.00	0.00	0.00
Willie Wagtail	0.00	0.00	0.00	0.15
Australian Raven	0.00	0.00	0.00	0.00
Little Raven	0.00	0.00	0.00	0.00
Little Crow	0.00	0.00	0.00	0.00
Restless Flycatcher	0.00	0.00	0.00	0.00
Magpie-lark	1.50	0.20	0.00	0.00
White-winged Chough	0.00	0.00	0.44	0.23
Apostlebird	0.00	0.00	0.00	0.00
Jacky Winter	0.00	0.00	0.00	0.08
Red-capped Robin	0.00	0.00	0.00	0.08
Hooded Robin	0.00	0.00	0.00	0.00

Silvereye	0.00	0.00	0.00	0.00
White-backed Swallow	0.00	0.00	0.00	0.00
Welcome Swallow	0.00	0.00	0.00	0.00
Tree Martin	0.25	0.40	0.00	0.00
Mistletoebird	0.00	0.00	0.00	0.00
Guild				
Aerial insectivores	0.25	0.40	15.56	0.00
Bark-foraging insectivores	1.13	0.40	0.11	0.00
Canopy-foraging insectivores	2.75	1.20	4.11	2.62
Damp-ground insectivores	0.00	0.00	0.00	0.00
Frugivores	0.00	0.00	0.00	0.00
Low-shrub-foraging insectivores	0.00	0.00	0.00	0.23
Miners	9.38	2.40	0.00	0.23
Nectarivores (other than miners)	2.50	1.60	3.11	3.15
Open-ground insectivores (may be far from cover)	2.63	0.20	0.56	0.69
Large open-ground insectivores (among trees or shrubs)	0.00	0.00	0.44	0.23
Small open-ground insectivores (among trees or shrubs)	0.00	0.00	0.22	0.38
Open-ground insectivores (among trees or shrubs)	0.00	0.00	0.67	0.62
Seed-eaters (feeding mainly close to ground)	1.25	2.64	0.06	0.44
Seed-eaters (feeding mainly in trees)	0.50	3.40	0.22	1.00
Tall-shrub-foraging insectivores	0.00	0.00	1.46	1.15
Shrub-foraging insectivores	0.00	0.00	1.46	1.38
Generalist insectivores	0.00	0.00	0.00	0.00
Carnivores (taking vertebrates & large invertebrates, etc)	0.88	1.60	0.44	0.46
Large land birds other than miners (>70g)	4.50	6.24	1.17	2.21
Small land birds other than miners (<60g)	6.50	4.00	25.12	7.62
Mid-sized land birds inc miners (60-70g)	0.88	0.80	0.00	0.15
Large hollow-nesters	0.75	5.20	0.22	1.31
Small hollow-nesters	4.25	2.60	2.22	1.77
Hollow-nesters	5.00	7.80	2.44	3.08
Summer migrant land birds	0.50	0.40	16.22	0.38
Introduced land birds	0.00	0.00	0.00	0.00
Native land birds	21.25	13.44	26.29	10.59
Total land birds	21.25	13.44	26.29	10.59
Total land birds excluding white-browed & masked woodswallows	21.25	13.44	10.96	10.59
Water birds	0.00	0.60	0.00	0.00
Land bird species per search	5.88	6.60	5.56	6.15
Water bird species per search	0.00	0.60	0.00	0.00
Total bird species per search	5.88	7.20	5.56	6.15
Native mammals	0.03	0.04	0.03	0.06
Introduced mammals	0.00	0.00	0.01	0.01

Table 4. Effects of miners and Time Since Flooding (TSF) on major bird guilds or species and flowering index in black box woodland at Hattah-Kulkyne National Park 2014-19, as revealed by Generalised Mixed Models. Miners (mainly Noisy Miners) were considered as a numerical variable and TSF as a categorical variable with six levels (0 = flooded or partly flooded at the time of the survey; 1 = flooded 0-6 months ago; 2 = flooded 6 months to two years ago; 3 = flooded two to three years ago; 4 = flooded more than three years ago; 5 = not flooded during the study or in recent years before the study).

Bird guild or species, and flowering index	**p**	**Effect**	**p**	**Effect**
Feeding guilds are marked FG	**Miners**		**TSF**	
Aerial insectivores FG	0.004	pos	0.001	0 > 2 > (3-5)
Bark-foraging insectivores FG	<0.001	neg	0.562	NS
Canopy-foraging insectivores FG	<0.001	neg	<0.001	(0-3) > (4, 5)
Noisy Miner	NA	NA	<0.001	(1, 2) > (0, 3) > (4, 5)
Nectarivores (other than miners) FG	0.001	neg	<0.001	3 > 5 > (0, 4, 2, 1)
Open-ground insectivores (may be far from cover) FG	0.316	NS	0.008	0 > 1 > 2 > 3 > (4, 5)
Large open-ground insectivores (among trees or shrubs) FG	0.968	NS	<0.001	3 > (1, 0, 5) > 4 > 2
Small open-ground insectivores (among trees or shrubs) FG	0.002	neg	0.258	NS
Seed-eaters (feeding mainly close to ground) FG	0.444	NS	<0.001	5 > (1, 3, 2) > 0 > 4
Seed-eaters (feeding mainly in trees) FG	<0.001	neg	<0.001	(4, 3, 2) > 1 > (0, 5)
Shrub-foraging insectivores FG	0.001	neg	0.019	(1, 3, 2) > 0 > (4, 5)
Generalist insectivores FG	<0.001	neg	0.201	NS
Carnivores (taking vertebrates & large invertebrates, etc) FG	0.228	NS	0.204	NS
Large land birds (>70g)	0.002	pos	0.037	(3, 1) > (5, 0, 4, 2)
Mid-sized land birds other than miners (60-70g)	<0.001	neg	0.002	2 > (5, 0, 3, 1) >4
Small land birds other than miners (<60g)	<0.001	neg	<0.001	(2, 0, 1) > 3 > (4, 5)
Hollow-nesters	0.06	NS	0.169	3 > (2, 1, 0) > (5, 4)
Total land birds	<0.001	pos	0.002	(0-3) > (4, 5)
Flowering index (0-5)	NA	NA	<0.001	1 > (2, 0) > (3, 4, 5)

Table 5. Effects of Flowering Index (FI) on selected bird species and guilds in black box woodland at Hattah-Kulkyne National Park 2014-19, as revealed by Generalised Mixed Models. The Flowering Index was assessed for each search of each site on a scale of 0 to 5, but the highest conceived level was not observed during this study. The Flowering Index was considered as a sole dependent variable, and (if it showed a significant effect) in combination with other variables such as Time Since Flood (TSF) and the abundance of miners (mainly Noisy Miners). Other feeding guilds did not show significant relationships with the Flowering Index.

Bird species or guild	**P**	**SE**	**Predicted mean for each level of Flowering Index**				
			0	1	2	3	4
Noisy Miner vs FI	0.002	0.320	2.43	2.88	4.00	3.53	4.78
Noisy Miner vs FI, cloud, TSF	0.028	0.134	2.48	2.89	3.70	3.30	4.52
Nectarivores other than miners vs FI	0.113	0.301	0.21	0.24	0.33	0.46	0.00
Seed-eaters mainly in trees vs FI	0.008	0.440	1.34	1.53	1.97	1.41	10.35
Seed-eaters mainly in trees vs FI, TSF, Miners	0.031	0.272	1.48	1.48	1.57	1.52	10.52
Total land birds vs FI	0.100	0.083	15.68	16.62	20.16	17.79	36.02

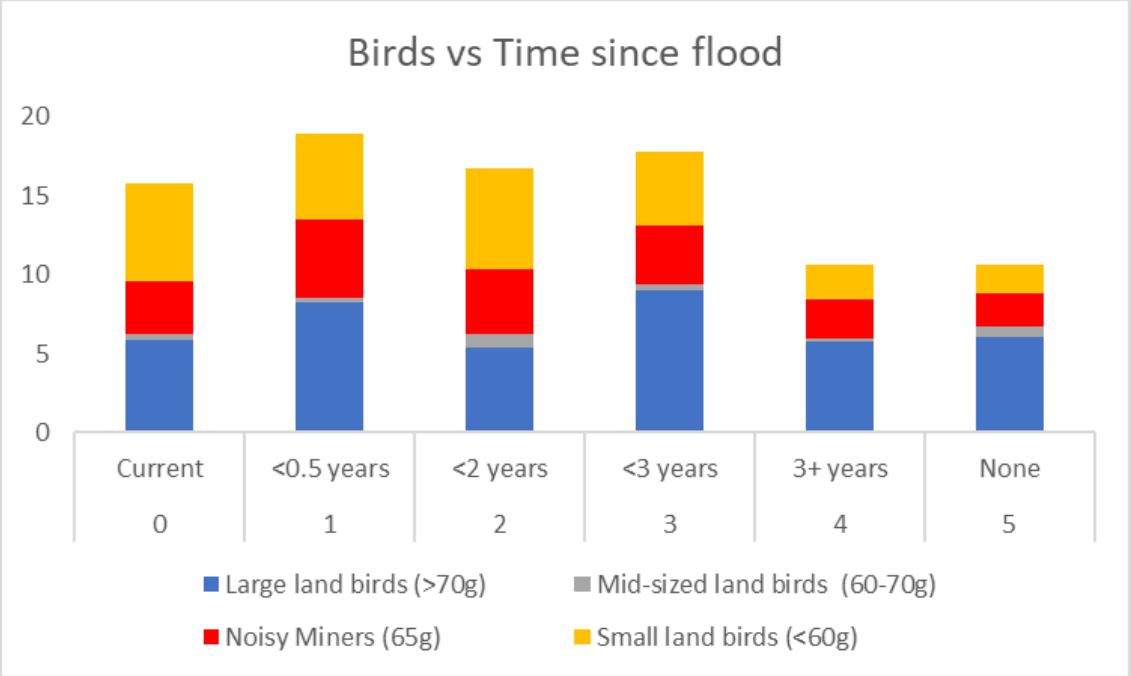

Figure 1. Mean abundances of land birds in black box woodland in the Hattah-Kulkyne National Park, north-west Victoria, in relation to time since flood (TSF), as predicted from Generalised Linear Mixed Models of data from 50 sites, 2014-19 (with average values for other relevant variables such as abundance of miners). The total values are considered as four groups: large land birds (>70g); mid-sized land birds other than miners (60-70g); miners (~65g) and small land birds (<60g).