The value of unlogged buffers for vulnerable bird species in the jarrah forest of south-west Western Australia

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ABSTRACT

Retaining strips of unlogged forest, called buffers, is a common strategy for maintaining populations of vulnerable species in production forests in Australia. I conducted a study to examine the effectiveness of buffers in maintaining populations of vulnerable bird species in jarrah forests of south-west Western Australia. I examined changes in the population densities of all bird species in buffers in the first 12 months after logging and compared these to changes in logged and unlogged forest. I also conducted detailed ecological studies on Golden Whistlers to determine whether buffers were important for this species and, if so, why they were important. Buffers were important in maintaining populations of vulnerable bird species after the first logging rotation. Of the six species that declined after logging, only one (the Golden Whistler) showed a significant decrease in buffers and the decrease was less than in logged forest. Buffers were important for Golden Whistlers in providing both foraging and nesting sites. Whistlers also moved the location of their territories to include buffers, indicating that they are critical for this species in production forests. Given their importance to vulnerable species, I recommend that buffers are not logged at the second logging rotation until research is conducted that demonstrates that the surrounding logged forest has matured sufficiently to support viable populations of vulnerable species.

Key words: buffers, unlogged strips, selective logging, jarrah forest, birds, Golden Whistler

Introduction

Most of south-west Western Australia's eucalypt forests, about 87 % of the 2.66 x 10^6 ha remaining, lie on public lands that are gazetted for multiple use. These multiple uses include apiculture, firewood collection, mining, tourism, water production, conservation and timber production (Anon 1998). The use of forests for both conservation and timber production has been controversial with many conservationists and scientists claiming that current timber harvesting practices threaten the biodiversity of forests (Smith 1991; Norton and Mitchell 1994; Calver and Dell 1998). In response to these claims, many land management agencies have implemented strategies that are designed to maintain sustainable populations of animals in production forests. One common method used is to retain strips of unlogged forest in logged areas (Loyn 1985a) and this method is currently used in most states of Australia where timber harvesting is conducted (Taylor 1991a; Wardell-Johnson and Nichols 1991; Wilson 1991). Retained strips of unlogged forest, often called buffers, can benefit wildlife in four main ways (Taylor 1991b): (1) they can provide habitat for little-known or still undescribed invertebrates, (2) they can provide old growth habitat among regrowth and act as a source of individuals to recolonise regenerating areas as they become suitable, (3) they can act as corridors to ensure populations in conservation reserves do not become isolated and (4) they can provide sheltering and nesting areas for species that can feed in regrowth but only if mature forest is nearby (Taylor 1991b). Despite all these benefits, most of the value of retained buffers is theoretical and little empirical data have been collected on their value (but see Recher *et al.* 1987; Claridge *et al.* 1991).

The jarrah forest occupies an area of approximately 2.14 x 10^6 ha between the 750 and 1400 mm isohyets in southwestern Australia (Dell and Havel 1989). Of this area, approximately 1.88 x 10^6 ha is located on public land and is managed for multiple use by the Department of Conservation and Land Management (CALM) (Anon 1998). In order to maintain multiple use principles in the jarrah forest, CALM has implemented several strategies to maintain faunal populations in production forests, including the retention of buffers. Buffers are retained within logged areas and around watercourses, diverse ecosystems and travel routes (CALM 1990, 1991, 1995). Despite their use, however, their value in maintaining faunal populations in production forests is not well understood.

This study examined the value of retained buffer strips for birds in the jarrah forest by determining changes in the density of all bird species in buffers, both before and after logging, and comparing these values to densities in logged and unlogged forests. In this paper I focus on the value of buffers for those species that declined significantly after logging (from Craig 1999) and hence are most vulnerable to logging impacts. I also undertook a synecological study of Golden Whistlers *Pachycephala pectoralis*, which have been shown to be adversely impacted by logging (Loyn 1980, 1985b; Smith 1985; Norwood *et al.* 1995; Craig 1999; Williams *et al.* 2001), to determine why buffers were important for this species. I examined their foraging and nesting ecology as well as their use of buffers before and after logging. The information gained was used to make recommendations on management practices to ensure the long-term viability of faunal populations in jarrah production forest.

Pp 774 - 782 in the *Conservation of Australia's Forest Fauna* (second edition) 2004, edited by Daniel Lunney. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

METHODS

Study area

The study was conducted in Kingston, Walcott, Warrup and Winnejup forest blocks (34°03'-10'S, 116°18'-25'E) approximately 25-30 km NE of Manjimup in the south-west of Western Australia. The study area was primarily unlogged low to medium rainfall (750-1000 mm yr^{-1}) jarrah forest. The average canopy height was 25-30 m, slightly taller in the gullies and the overstorey consisted almost entirely of two species, Jarrah *Eucalytpus marginata* and Marri *Corymbia calophylla*. Typical midstorey species were *Banksia littoralis* and *Hakea oleifolia* in the gullies and *B. grandis* and *Oxylobium lanceolatum* elsewhere. Common understorey species were *Agonis parviceps, H. varia* and *Melaleuca incana* in the gullies and *Bossiaea linophylla, H. lissocarpha, Leucopogon capitellatus, L. propinquus, Macrozamia riedleii* and *Xanthorrhoea preissii* elsewhere. Forest cover was continuous in the study area with isolated farmlots in the west, east and north and a pine plantation in the centre.

Silvicultural practices and retained forest strips

Forestry prescriptions in the jarrah forest are complicated. Only facts relevant to the interpretation of this paper are presented here. For full details see CALM (1990, 1991, 1995).

Logging at the first rotation: After logging at the first rotation three types of forest remain: gap, shelterwood and buffer (Fig. 1). Gaps are located where the forest has sufficient ground coppice and saplings to regenerate naturally. Gaps involve the removal of about 95% of basal area with 4 habitat trees and 8 potential habitat trees retained per ha. Gaps have a maximum size of 10 ha, are variable in shape and do not extend across ridges.

Shelterwoods are created in forest where there is insufficient ground coppice and saplings to regenerate gaps created by harvesting. In these circumstances, an overstorey is retained to provide seeds for regeneration. Shelterwoods involve the removal of about 40-60% of basal area with 4 habitat trees and 8 potential habitat trees retained per ha. There is no limit of the size of shelterwoods and they can extend across ridgelines.

Unlogged buffers are retained in several situations. During logging operations, buffers are retained between gaps. These buffers must be a minimum of 100 m wide. No buffers are retained in areas of shelterwood or between shelterwoods and gaps. Although not strictly buffers, unlogged forest is retained in coupes if the forest is poor quality (i.e. does not contain many merchantable trees) and cannot be harvested economically. Buffers are also retained around streams where they must extend for at least 20 m from the stream vegetation on both sides and be a minimum of 60 m wide. Buffers of variable width are retained around diverse ecosystems (granite outcrops, wetlands and heathlands) and buffers between 200 and 400 m wide are retained along travel routes (walking tracks and public access roads).

Logging at the second rotation: Areas of logged forest may be harvested again once they contain trees large enough to make subsequent harvest economically viable. Gaps are logged again when the advanced growth released by the first harvesting operation is large enough for an economically viable harvest. The time period for this will vary depending on site quality but would be at least 40 years.

Shelterwoods will be logged again when the retained overstorey has provided sufficient regeneration so that gaps can be created. Regeneration surveys are carried out 10 years after the first harvesting operation. In areas where there is sufficient ground coppice and saplings, gaps will be created. When these gaps are created at the second rotation, strips of shelterwood will be retained as buffer strips. If areas do not contain sufficient ground coppice and saplings 10 years after the first cutting cycle, then regeneration surveys will be conducted at 5 yearly

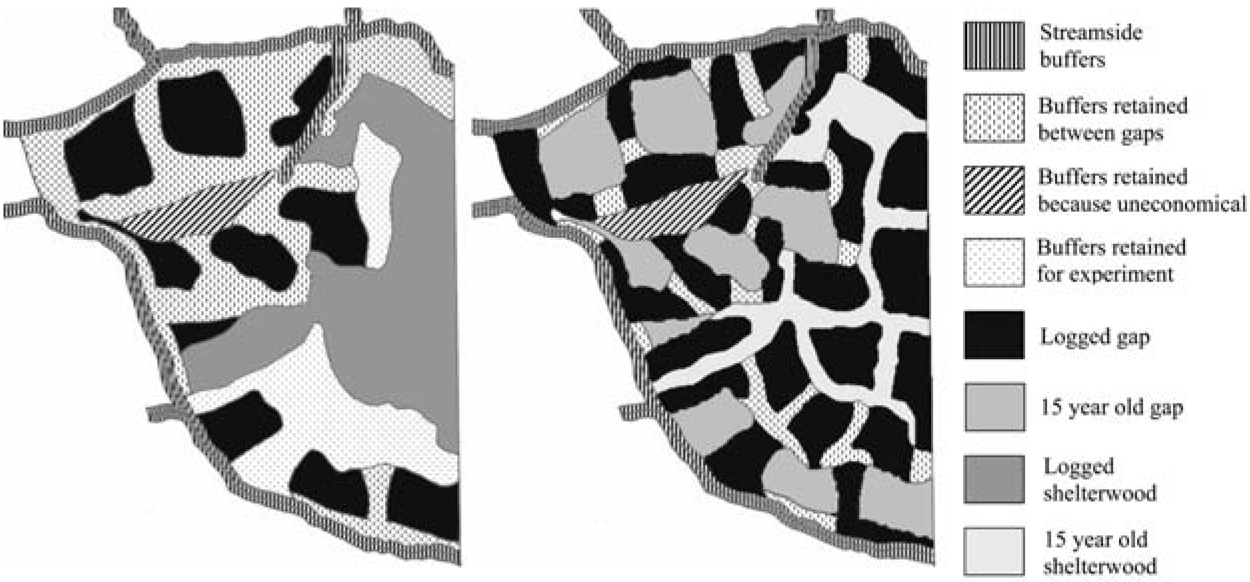

Figure 1. A map showing the spatial arrangement of gaps, shelterwoods and buffers in Kingston 5 coupe after logging at the first rotation (left). One possible arrangement of gaps, shelterwoods and buffers with their age since logging is shown to illustrate the potential effect of logging at the second rotation after 15 years (right).

intervals after this time until sufficient ground coppice and saplings are present to allow the creation of gaps.

Buffers around streams, diverse ecosystems and travel routes are never harvested. Poor quality forest may be harvested at any time if the price of timber increases and makes harvesting economically viable. There are no prescriptions for when buffers between gaps may be harvested but it will not be within 15 years of the first cutting cycle (N. Burrows, pers. comm.).

Methods

Bird densities were estimated on 39 square 1-ha plots located throughout the study area. The experiment, which assessed density changes at the first logging rotation, was a BACI (before, after, control, impact) design with plots assigned to one of four treatments: control (21 plots), buffer/gap edge (6), buffer/shelterwood edge (4) and buffer (8). Control plots were located outside logging coupes and were not logged or burnt for the duration of the study. In addition, they were interspersed between impact sites to avoid confounding effects of rainfall which decreased from the south-west to the north-east of the study area. Buffer plots were located in poor quality forest (3 plots), stream buffers (2) and buffers between gaps (3). Edge plots contained a mixture of buffers and logged forest and extended no further than 90 m from the buffer/logged edge, usually less. Bird densities were estimated using an area search method. Densities were estimated by searching the 1 ha plot for 30 min and recording all birds seen or heard on the plot. Counts were conducted throughout the day (cf. Craig and Roberts 2001) although 98% of counts were conducted within seven hours of sunrise. Counts were not conducted during rain, when the average wind speed was greater than 12.5 km/h or was gusting above 20 km/h. Over 95% of counts were conducted during light winds (cf. Craig and Roberts 2001).

Plots were assessed three times in each of three seasons (non-breeding (Jan-Apr), winter (May-August) and breeding (Sep-Dec)) for 12 months pre-logging and 12 months post-logging. Counts commenced in January 1994 and continued for 12 months to collect the pre-logging data. Logging took place between January and April 1995. Counts recommenced in May 1995 and continued for a further 12 months to collect post-logging data. Density estimates for each species were calculated by averaging counts from the three area searches on each plot in each season.

I mapped Golden Whistler territories on nine plots (three control, three gap and three shelterwood) of approximately 10 ha each between 20th August and 20th December in 1994 (prelogging) and 1995 (postlogging). Pairs of Golden Whistlers were nesting at this time and assumed to be defending territories from conspecifics. On each plot, Golden Whistlers were captured and colour banded. I followed marked birds until they were lost from view and mapped each location where they perched using reference trees and the program Locate II (Nams 1990). To help define territory boundaries I noted where disputes occurred and the location of conspecifics that occupied different territories. To locate nests I followed Golden Whistlers in an opportunistic manner during all activities.

Statistical analyses

To assess whether bird densities changed in buffers I analysed density estimates from control and buffer plots using a two-way univariate repeated measures analysis, with treatment (control and buffer) as the between factor and time (before and after) and season (non-breeding, winter and breeding) as the two factors within the repeated measure. Bird densities in buffers were considered to have changed due to logging if the treatment by time interaction was significant. Two community indices were analysed: total bird density (of all species combined) and number of species (the number recorded on each plot each season) as well as the six species that declined significantly after logging (from Craig 1999). I analysed whether populations changed along buffer edges using the same repeated measures analysis except that the treatments in the analysis were control, gap edge and shelterwood edge. Densities of species that declined after logging were expected to change in edge plots, as part of the plot was logged. To determine whether observed changes were caused by logging alone, or whether they were due to an edge effect (an increase or decrease in density along the edge), further analyses were conducted. Firstly, I calculated the expected population change from logging alone on each edge plot using the density declines of each species in gap and shelterwood (from Craig 1999) and the proportion of each plot that was gap or shelterwood and buffer. For example, if a plot was half gap and half buffer and the species' density remained the same in buffers but declined by 50% in gaps (data from Craig 1999), then I expected the density of the species on that plot to decline by 25%. Another species that declined by 60% in gaps and 30% in buffers would be expected to decline by 45% on the same plot. Observed and expected values, for each plot, were then compared using a paired *t*-test and, if significantly different, I concluded that there was a significant edge effect. All densities were transformed using $ln(x + 1)$ to remove heteroscedascity. Analyses were conducted using the programs Statview SE + Graphics 1.03 (Abacus Concepts 1988) and SuperANOVA 1.11 (Abacus Concepts 1993).

I analyzed the territory overlap of Golden Whistlers (the proportion of each territory occupied both before and after logging) in each treatment to determine whether birds moved the position of their territory in response to logging. The overlap was calculated as:

$$\frac{A_1}{A_1 + A_2 + A_3}$$

where A_1 is the area occupied both before and after logging, A_2 is the area occupied only before logging and A_3 is the area occupied only after logging. Differences in overlap between treatments were analyzed using a one-way ANOVA. I excluded from the analysis territories that were only held either before or after logging, and "territories" that contained 5 or fewer observations both before and after logging as I could not be certain they represented territorial birds. I used loglinear models to determine whether buffers were used more frequently after logging in gap and shelterwood plots compared to controls. Dummy "logged" areas were randomly assigned to portions of the control plots to enable comparison with logged plots. Analyses were conducted using the programs SuperANOVA 1.11 (Abacus Concepts 1993) and Systat 7.0 (SPSS 1997).

RESULTS

Value of buffers to the bird community

Relative to control plots, the total bird density in buffers declined significantly by 24.8% ($F_{1,27} = 10.50$, $p = 0.003$), and the decline was similar in all seasons ($F_{2,26} = 0.94$, $p = 0.404$) (Fig. 2). The number of species recorded per plot per season declined significantly, by 16.8% ($F_{1,27} = 7.81$, $p = 0.010$), and was the same in each season ($F_{2,26} = 0.07$, $p = 0.933$) (Fig. 2).

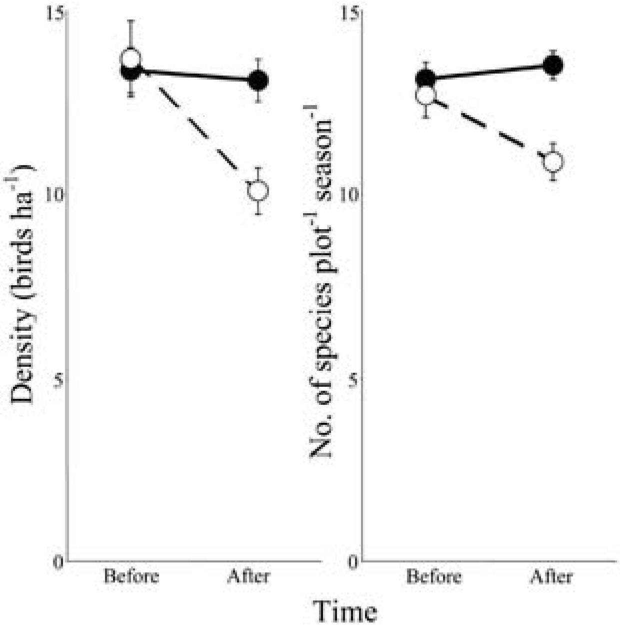

Figure 2. The change in bird density and species number in control and buffer plots. Control plots are shown with a solid circle and line while buffer plots are shown with an open circle and dashed line. Both variables declined significantly in buffer plots. Values are mean ± s.e.

Value of buffers for vulnerable species

Of the six species that declined significantly after logging (Craig 1999), only the Golden Whistler showed a significant change in abundance in buffers, relative to control plots ($F_{1,27} = 5.06$, $p = 0.033$), and the decline was similar in each season ($F_{2,26} = 0.25$, $p = 0.780$) (Fig. 3). The Spotted Pardalote *Pardalotus punctatus* ($F_{1,27} = 1.01$, $p = 0.325$), Striated Pardalote *Pardalotus striatus* ($F_{1,27} = 0.82$, $p = 0.374$), White-naped Honeyeater *Melithreptus lunatus* ($F_{1,27} = 1.54$, $p = 0.225$), Western Gerygone *Gerygone fusca* ($F_{1,27} = 0.07$, $p = 0.791$) and Grey Fantail *Rhipidura fuliginosa* ($F_{1,27} = 0.12$, $p = 0.729$) all showed non-significant changes in abundance (Fig. 3).

Edge effects created by retaining buffers in logging coupes

Overall bird density decreased along buffer edges ($F_{2,28} = 4.28$, $p = 0.024$) but densities were not significantly different from those expected from logging alone, for either gap ($t_5 = 0.96$, $p = 0.382$) or shelterwood edges ($t_3 = 0.89$, $p = 0.438$). The number of species changed significantly along edges ($F_{2,28} = 4.28$, $p = 0.024$) but the changes in gap ($t_5 = -0.17$, $p = 0.870$) and shelterwood edge plots ($t_3 = 1.09$, $p = 0.357$) were not significantly different from those expected from logging alone.

Of the six species that declined in abundance after logging, the Golden Whistler ($F_{2,28} = 5.06$, $p = 0.013$), Western Gerygone ($F_{2,28} = 5.92$, $p = 0.007$) and Striated Pardalote ($F_{2,28} = 5.54$, $p = 0.009$) all declined significantly in edge plots while the Grey Fantail ($F_{2,28} = 0.45$, $p = 0.645$), White-naped Honeyeater ($F_{2,28} = 2.05$, $p = 0.148$) and Spotted Pardalote ($F_{2,28} = 1.56$, $p = 0.228$) did not change significantly in abundance. However, none of the changes observed in edge plots differed significantly from those expected from logging alone (Table 1).

Use of buffers by Golden Whistlers

The overlap of individual Golden Whistler territories before and after logging was significantly greater in control areas than in gap and shelterwood areas ($F_{2,6} = 7.14$, $p = 0.026$) (Fig. 4). This indicates that Golden Whistlers moved the location of their territories after logging to include more buffer vegetation (Fig. 5). While 5 of 23 territories before logging did not contain any vegetation to be retained as buffers, all 20 territories after logging contained buffer vegetation. Golden Whistlers also spent significantly more time in buffers after logging than they did before ($\chi^2_2 = 16.49$, $p = 0.001$) (Fig. 6). They nested significantly more in buffers after logging than before ($\chi^2_1 = 3.89$, $p = 0.046$). Only 2 of 7 nests were located in buffers before logging but 7 of 9 nests were located there after logging.

Species	Gap Edge			Shelterwood Edge		
	Observed (birds ha^{-1})	Expected (birds ha^{-1})	t_5	Observed (birds ha^{-1})	Expected (birds ha^{-1})	t_3
Golden Whistler	0.33±0.05	0.32±0.08	0.26*	0.42±0.15	0.48±0.14	-1.93*
Grey Fantail	0.61±0.20	0.42±0.11	2.39*	0.94±0.28	0.51±0.19	2.21*
Western Gerygone	0.39±0.13	0.25±0.06	1.28*	0.25±0.15	0.42±0.11	-2.50*
White-naped Honeyeater	0.48±0.13	0.34±0.08	2.34*	0.50±0.19	0.50±0.13	-0.18*
Spotted Pardalote	0.22±0.10	0.21±0.11	0.08*	0.33±0.08	0.53±0.25	-0.60*
Striated Pardalote	0.33±0.08	0.35±0.06	-0.28*	0.31±0.09	0.45±0.18	-0.87*

Table 1. The observed densities of the six vulnerable species in gap and shelterwood edge plots compared to the densities expected from logging alone. The difference between the values was compared using a paired t-test (* = $p > 0.05$, ** = $p < 0.05$). Values are mean ± s.e.

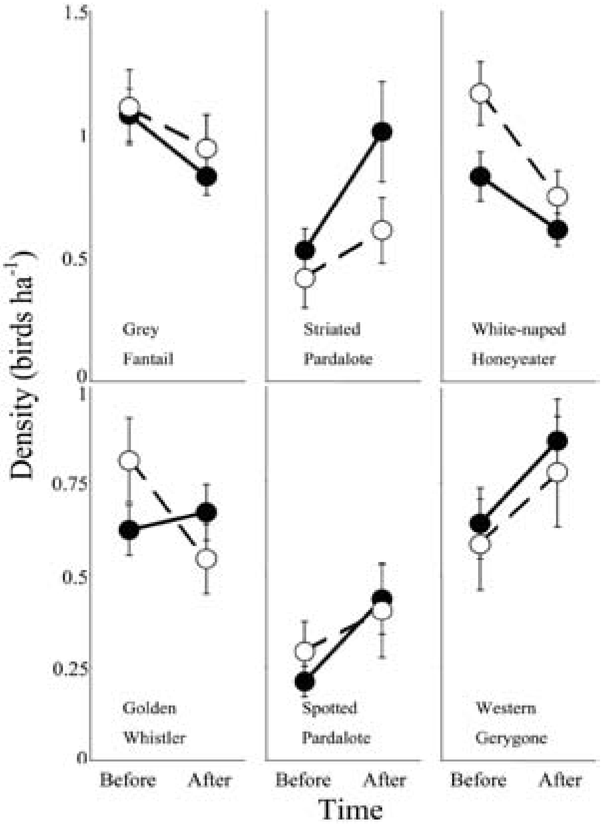

Figure 3. The changes in density in control and buffer plots for each of the six species that declined significantly after logging. Control plots are shown with a solid circle and line while buffer plots are shown with an open circle and dashed line. Values are mean ± s.e.

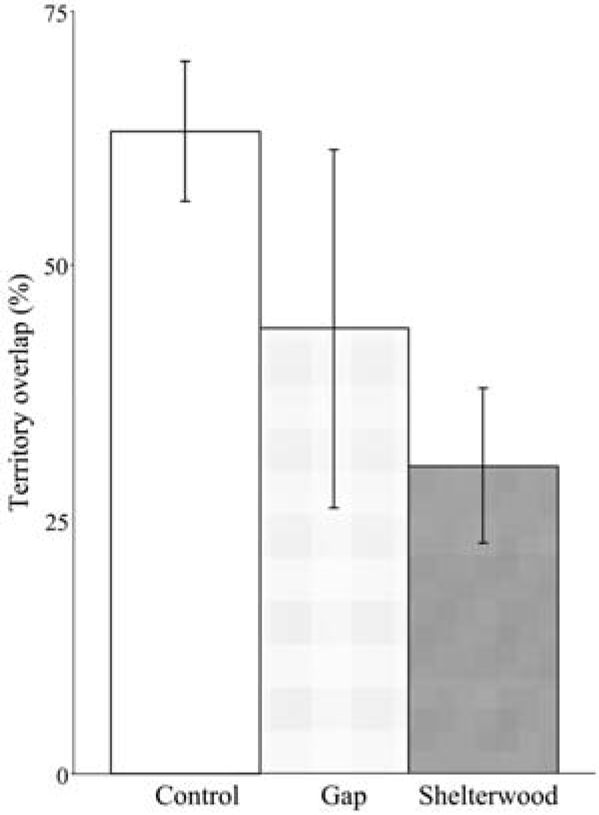

Figure 4. The territory overlap of individual Golden Whistlers in control, gap and shelterwood treatments. Values are mean ± s.e.

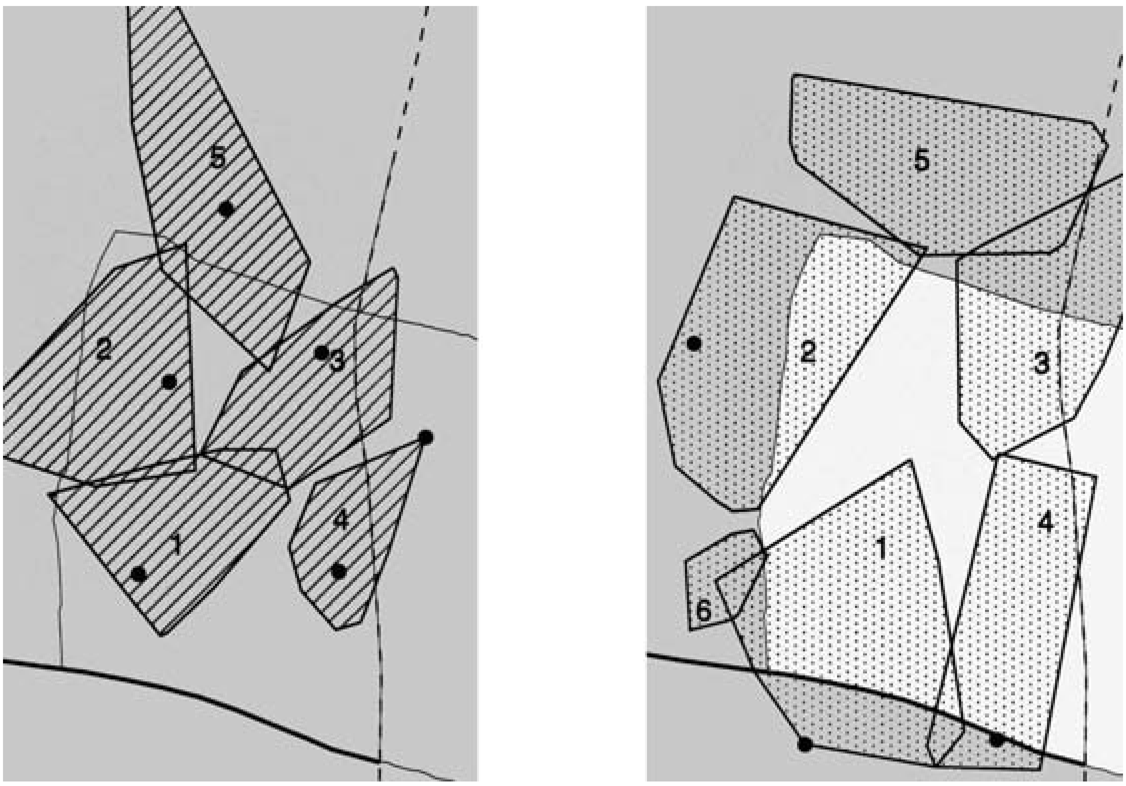

Figure 5. The location of Golden Whistler territories before (left) and after logging (right) on a plot that was cut to gap. Unlogged forest is shown as dark grey and logged forest as light grey with the location of nests shown by a circle. The areas adjacent to the northern, western and southern boundaries of the plot were buffers. The gap continued to the east of the logged area shown on the map as did the buffer. Note how most territories moved from the centre to the edge of the plot and how most nests are in the area to be logged before logging but all are in the buffers after logging.

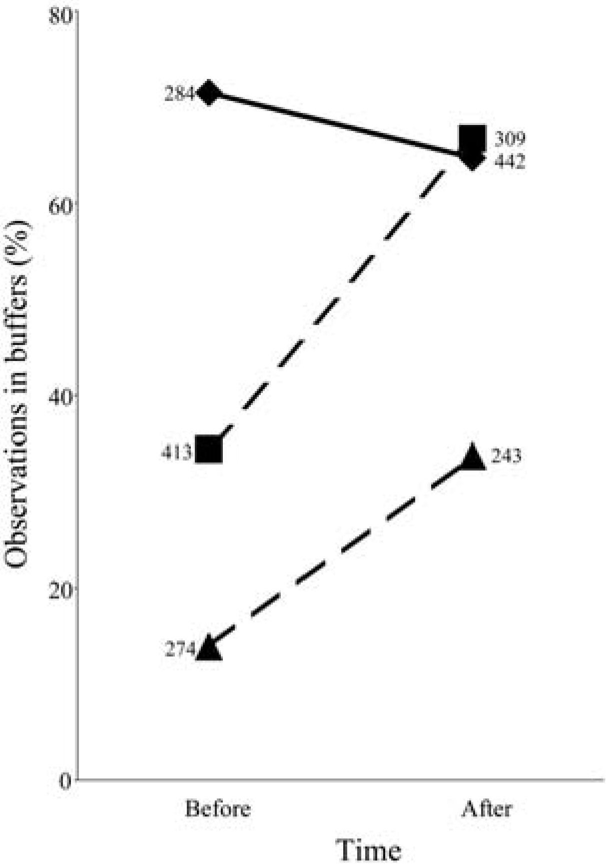

Figure 6. The percent of Golden Whistler observations in buffers on control, gap and shelterwood plots before and after logging. Controls are shown with a solid line and diamonds, gap with a dashed line and squares and shelterwood with a dotted line and triangles. The number of observations is shown next to the symbols. Golden Whistlers used buffers more often after logging on gap and shelterwood plots but not in control plots.

Discussion

Value of buffers at the first rotation

Bird communities in buffers differed significantly from those in unlogged forest, having lower densities and fewer species, and thus were affected by logging. However, the study provided unequivocal evidence of the benefit of buffers at the first logging rotation as it is clear that they play an important role in the persistence of vulnerable species in logged forest. Of the six species that declined after logging, only the Golden Whistler declined in buffers and, even in this species, the decline was less than in logged forest (Craig 1999).

We have a reasonable understanding of why buffers are important for Golden Whistlers after the first logging rotation. The species utilised them more after logging than before and this probably relates to its foraging ecology, as the species is primarily a canopy foliage insectivore in Western Australia (Wykes 1985; Recher and Davis 1998; Craig 2002). The unlogged forest in buffers provides a more continuous canopy and presumably, better foraging habitat. Golden Whistlers also nested more frequently in buffers after logging. The reasons for this are not clear but may relate to central foraging theory or to nest microclimate requirements (Craig 2002). In either case it seems that Golden Whistlers depend on buffers to provide suitable foraging and nesting habitat after logging. This is supported by the fact that Golden Whistlers moved the location of their territories after logging to include buffer vegetation, which suggest that buffers aid Golden Whistlers by providing an area of older vegetation in an area of regrowth.

The value of buffers to the remaining species that decline after logging, as interpreted here, is based purely on density estimates in buffers. None of these species declined significantly in buffers and, while density does not always provide a good estimate of habitat quality and productivity (van Horne 1983, Underwood and Roth 2002), it indicates that buffers are important for the persistence of these species in production forests. Given that the Western Gerygone, White-naped Honeyeater, Spotted Pardalote and Striated Pardalote are all canopy foliage insectivores (Recher and Holmes 1985; Recher and Davis 1998), it seems likely that these species are dependent on buffers to provide suitable foraging sites. Grey Fantails, while primarily taking aerial prey, also rely on canopy foliage for foraging (Recher *et al.* 1985, Recher and Holmes 1985; Holmes and Recher 1986; Recher and Davis 1998) and so probably also rely on buffers to provide suitable foraging sites. This suggests that buffers aid these species primarily by providing an area of older vegetation in an area of regrowth. Future research could concentrate on the reasons why these species persist reasonably well in buffers and whether this maintenance of density is matched by high levels of nesting success and other demographic parameters.

Value of buffers at the second rotation

Unfortunately the data reveal little about the long-term value of buffers for species that decline after logging. Recher *et al.* (1987) found that after both fire and drought in eastern Australia, the populations of birds in buffers less than 100 m wide declined significantly but bird populations on the widest buffer (247 m) did not. This suggests that only very wide buffers are adequately buffered against climatic fluctuations and implies that buffers less than 100 m wide in the jarrah forest may not be wide enough to sustain bird populations in the long-term.

Buffers are also considered to be important for birds in adjacent logged forest. Coulson and Coulson (1981) found that the abundance of birds in logged forest in Tasmania declined significantly when an adjacent unlogged buffer was logged. There are no data on the impact of logging at the second rotation to determine whether a similar decline could occur in jarrah forests. However, the average growth rate of jarrah coppice, 0.56 cm yr^{-1} in height (Abbott and Loneragan 1986), indicates that if buffers are logged after 15 years, then the surrounding logged forest would have a canopy height of approximately 8 m. As Golden Whistlers and White-naped Honeyeaters forage primarily above 8 m (Craig 2002), it is unlikely that the surrounding forest would provide suitable foraging habitat for these species. Thus, if logging of buffers took place after 15 years, there could be very large population declines in these two species, and possibly other vulnerable species as well. Future research should examine the impact of logging at the second rotation on all vulnerable species and a retrospective study is required to determine how long it takes for logged forest to become suitable habitat for vulnerable species.

Another management issue is the retention of shelterwood strips to function as buffers when large areas of shelterwood are cut to gap at the second logging rotation. Craig (1999) showed that the declines of vulnerable species are as great in areas of shelterwood as in areas of gap, which suggests that retained strips of shelterwood will not function effectively as buffers. However, it is not possible to determine how effective these strips might be as there are no data on the population levels of vulnerable species in shelterwood areas 10 years post-logging. Until this information is collected, it would be prudent to retain strips of unlogged forest in large shelterwood areas as we know that they can function effectively as buffers.

Edge effects created by retaining buffers in logging coupes

This study also found that the edges created by retaining buffers did not have a significant impact on the density or species richness of the bird community or the density of vulnerable species. This lack of a population response probably reflects the depauperate and generalist nature of the jarrah forest avifauna, which precludes specialisation for edges (Wykes 1985). However, many studies have shown that nest predation and nest parasitism can increase along edges (e.g. Burkey 1993; Donovan *et al.* 1997; Cooper and Francis 1998) and this could impact on bird populations in buffers (Flashpoler *et al.* 2001). Recent reviews have shown that levels of nest predation and parasitism are greatest within 50 m of an edge (Paton 1994; Murcia 1995) and may be high enough to limit the value of linear vegetation strips as breeding habitat (Major *et al.* 1999; Matthews *et al.* 2001). As buffers in the jarrah forest are normally 100 m wide, there is an urgent need to determine whether these negative features of edges occur in the jarrah forest, and if so, what their implications are for the long-term persistence of bird populations in unlogged buffers.

Recommendations for management and future research

This study has shown that unlogged buffers are an effective strategy to conserve populations of vulnerable bird species at the first logging rotation. Of the species that declined after logging, the Grey Fantail, Western Gerygone, White-naped Honeyeater, Spotted Pardalote and Striated Pardalote did not decline in buffers and the Golden Whistler showed a smaller decline than in logged forest. Current evidence also indicates that logging of buffers at the second rotation, after 15 years, would lead to population declines in Golden Whistlers and White-naped Honeyeaters, and possibly other vulnerable species. Therefore, buffers should not be logged after 15 years until research can demonstrate that this will not impact on the populations of vulnerable species. Evidence also suggests that strips of shelterwood will not function effectively as buffers 10 years after logging so strips of unlogged forest should be retained as buffers within large areas of shelterwood. Future research into (1) the impacts of logging buffers at the second rotation, (2) whether strips of shelterwood can function as buffers after the second logging rotation and (3) the potential impacts of nest predation and parasitism on bird populations in buffers, would greatly improve our ability to manage forests for both timber production and conservation and allow more thorough evaluation of the conservation value of buffers in production forests. Until such a time as this research is conducted, the data gathered in this study allow the suggestion to be made that forest management in the jarrah forest would be improved by (1) not logging buffers after 15 years at the second logging rotation and (2) retaining unlogged buffers within extensive areas of shelterwood.

Acknowledgements

J. Dale Roberts made a substantial contribution to all aspects of this paper. Don and Jean Craig, John Nicholls, Quinn McLachlan, Brycen Godfrey, Danae Haarman, Dylan Korczynskyj, Sam Blaxell, Fiona Scarff, Grant, Angela, Lee, and Douglas Wardell-Johnson, Wayne Zadow and Ray Garstone provided assistance in the field. Robyn Wilson, Stewart Hay, Rod Nowrojee, and Roy Fieldgate from Information Management Branch at the Department of Conservation and Land Management, Como conducted GIS analyses. Staff at the Department of Conservation and Land Management, Manjimup, provided logistical support. The University of Western Australia and the Department of Conservation and Land Management provided funding for this project. I was the recipient of a University Research Studentship from the University of Western Australia for the duration of this study. I am grateful to Isabelle Robichaud, Dan Lunney and Richard Loyn for comments on an earlier draft of this paper.

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APPENDIX I

Gap after logging.

A view of typical gap forest where about 95% of basal area is removed during logging operations. The large trees that remain are either habitat trees or unmerchantable trees. Note the fallen trees and debris that remain on the ground.

Shelterwood after logging.

A view of typical shelterwood forest. At this site about 60% of basal area was removed during logging operations. The large trees that remain will be used to provide seed for forest regeneration before they are also logged, which could be as soon as 10 years after the initial logging.

Shelterwood/Buffer edge. A view of shelterwood forest with an unlogged buffer in the background. This particular buffer was retained because the forest was considered unprofitable to log due to the poor yield of quality timber.