RETAINING REMNANT MATURE FOREST FOR NATURE CONSERVATION: A REVIEW OF THE SYSTEM OF ROAD, RIVER AND STREAM ZONES IN THE KARRI FOREST

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Introduction

Karri (*Eucalyptus diversicolor*) occurs predominantly in the Nornalup and Denmark Systems of the Warren Botanical Subdistrict of Beard (1980). Of the 167 500 ha of karri in this area, approximately 48 700 ha occurs in nature reserves, national parks and proposed conservation parks. The other 118 800 ha is gazetted as State forest and managed for multiple uses (Anon 1987a).

Harvesting for timber in Western Australia began soon after European settlement. Since the passing of the Forests Act in 1918 (Nunn 1957) there has been a continued evolution in forest management and silviculture (Stoneman 1986, Stoneman *et al.* 1989, Bradshaw and Lush 1981, Abbott and Loneragan 1986 and Havel 1989). In the karri forest, for example, clearfelling was replaced by selection cutting in 1938. It was reinstated as the main silvicultural system in 1967. The woodchip industry was established to utilise non-millable trees in the karri forest in 1975.

Within State forest, we divide the structure of the karri forest into four categories based on how timber is removed and the forest regenerated (Fig. 1).

The first category consists of approximately 65 800 ha of mature forest (including 25 200 ha of pure karri and 40 600 ha of mixed karri/marri). This includes unlogged stands where the forest canopy is recognisable as a single layer of mature and senescent trees, and approximately 25 300 ha of forest which has had some timber removed but where the mature forest character has been little altered.

The second category includes approximately 5 900 ha of largely even-aged stands resulted from clearfelling and slash burning, clearing for agriculture, or wildfires prior to 1940. Areas of this regrowth may include up to ten mature trees per hectare retained at the time of logging, burning or clearing. These highly productive stands (heights of 45-50m are reached by 50 years of age) are mostly in the Big Brook and Treen Brook forest blocks to the west of Pemberton. Thinning commenced in these stands in 1980, removing suppressed and subdominant trees, and is progressing through this older regrowth at a rate of approximately 400 ha per year. The resulting stands consist of dominant and co-dominant trees at a stocking of not less than 90 stems per hectare. Second and subsequent thinnings are planned for the future.

A third category includes two-tiered forest resulting from group selection cutting from 1940 to 1966. These stands consist of a mosaic of patches of mature and regenerated forest which vary in size from less than a quarter of a hectare up to two hectares. Any patches of regrowth greater than two hectares is treated as even-aged forest. Two-tiered forest covers an area of 8 900 ha. The silvicultural prescription for these forests varies with the quality of the regrowth and the size of the gap in which it grows. Some areas will be thinned several times before clearfelling, while others will be pre-logged to remove smaller trees that would otherwise be damaged in the subsequent clearfelling. There is a further 3 300 ha of two-tiered forests not created by selection cutting, but resulting from moderate fires in mature forest.

Category four includes approximately 33 000 ha of even-aged forest logged and regenerated after the silvicultural practice of clearfelling was reinstated in 1967. The average coupe size has varied considerably over time. In the early 1970s coupes were up to 200 ha. By 1981/82 coupe size had fallen to 85 ha. In 1990 the average coupe size in karri was 47 ha. An average of 30 such areas are cut each year giving a total clearfelled area of less then 1 500 ha per annum (Anon 1987b). Stands are regenerated using a high intensity slash burn in summer or autumn, using seed trees as the source of regeneration if seed is available. Direct seeding, planting nursery raised seedlings, or a combination of both, is used in 50 percent of the area regenerated. These even aged patches will be first thinned when they acquire a top height of 30m. Thinning intensity will vary with site quality, but will generally leave 350 - 400 stems per hectare. Second and subsequent thinnings will also be carried out. Thinning of these younger stands commenced in 1990. The planned rate for the first few years is 300 ha per year subsequently increasing to around 800 ha per year.

The first cutting cycle should be completed by 2040 if cutting continues at the present rate (based on area not volume). If this regime continues State forest will be a mosaic of largely even-aged patches of regeneration, the bulk of which will be less than 100 years old. This will be interspersed with mature forest in conservation areas which will, together with the road, river and stream zones, provide a vital area for fauna dependent on mature habitat (Fig. 2).

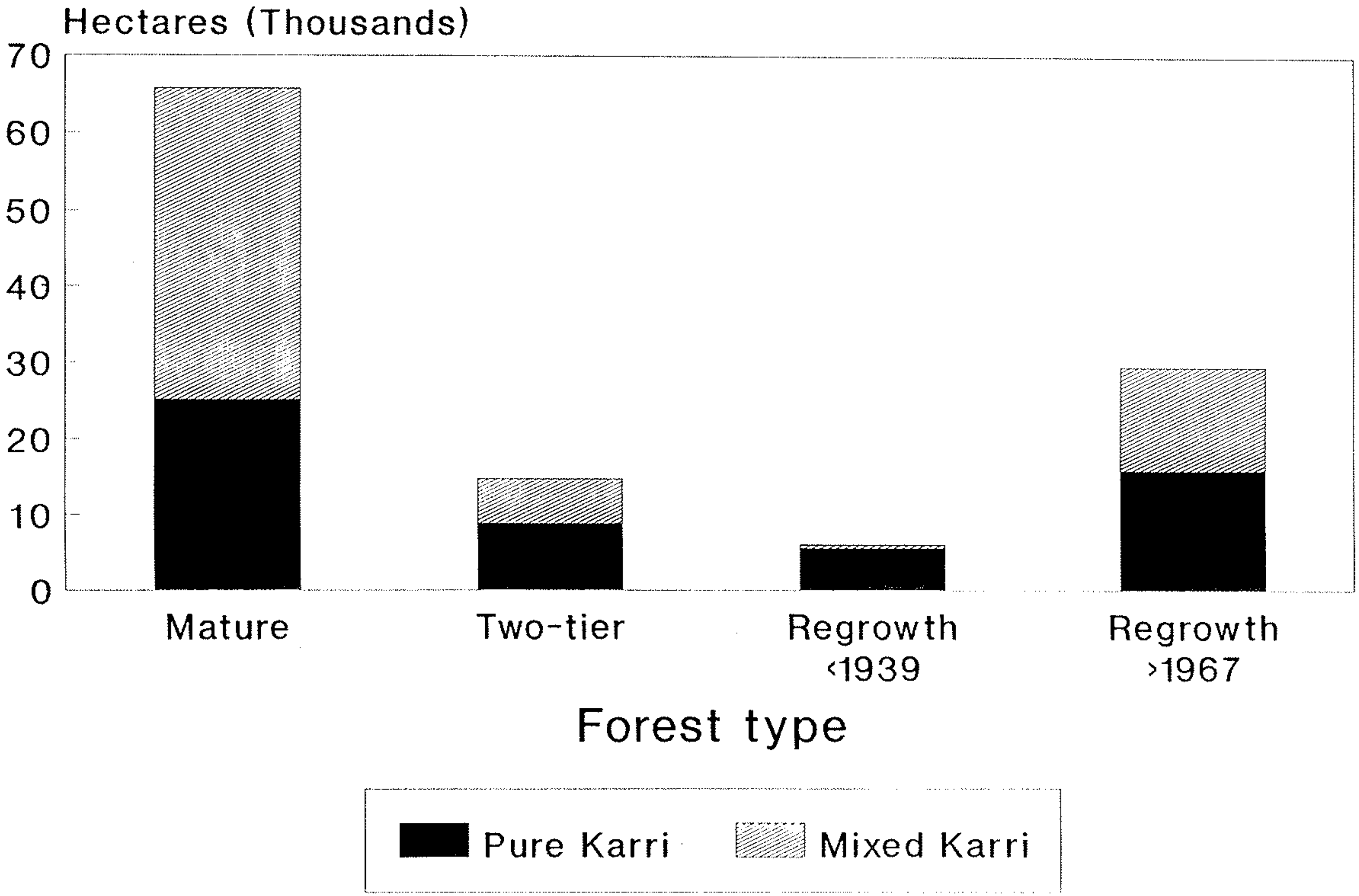
Two forms of conservation strategy were designated with the Environmental Impact Statement (EIS) for the introduction of woodchipping in 1975 (Anon 1972). The first involved discrete areas of forest reserved from exploitation such as National parks, nature reserves and management priority areas for flora, fauna and landscape. The second involved a network of remnant mature vegetation to be left unlogged along road, river and stream systems and comprising some 20 percent of the forest within each forest block. Thus a series of strips or corridors of forest were left unlogged on a block by block basis forming a network of mature forest on road, river and stream zones to connect with the reserve system. After the reserve system was designated, road zones of 800 m total width, river zones of 400 m total width and stream zones of 200 m total width were allocated such that approximately 20 percent of the forest block remained unlogged. This system aimed to ensure the regional conservation of species and communities. 73 700 ha of road, river and stream zones (including 24 300 ha of karri forest) were designated and mapped throughout the Nornalup and Denmark Systems of the Warren Botanical Subdistrict (Anon 1987a).

A review of the existing road, river and stream zone system (Wardell-Johnson 1987) recommended a redistribution of the network to more effectively cater for wildlife in the karri forest. This review assumed no reduction in timber yield and continuation of the 73 700 ha of unlogged road, river and stream zones. A subsequent report (Anon 1988) also recommended a reallocation, and the selective logging of some road and river zones. A total 500 000 m^3 of karri sawlogs was to be removed from the road, river and stream zone system, to compensate for timber made unavailable by the reservation of the Shannon National Park (Anon 1988).

This paper considers only the biological issues concerned with the most appropriate distribution and management of the current area of road, river and stream zones. We review the existing conservation system within karri forest in State forest. We begin by reviewing the theory and practice of wildlife conservation in areas subject to harvesting. We refer to research carried out in the Warren Sub-district since 1971 which allows a preliminary assessment of the conservation value of the current of road, river and stream zone system. We conclude by recommending a reallocation of this system. Our main emphasis will be on the karri forest of the Nornalup and Denmark Systems, though timber production also occurs in jarrah (*Eucalyptus marginata*) forest. Silvicultural systems are different in jarrah forest where, for example, habitat trees and crop trees are retained throughout the harvested area. We conclude by recommending that a system of road, river and stream zones should be put in place in all areas of State forest.

Figure 1

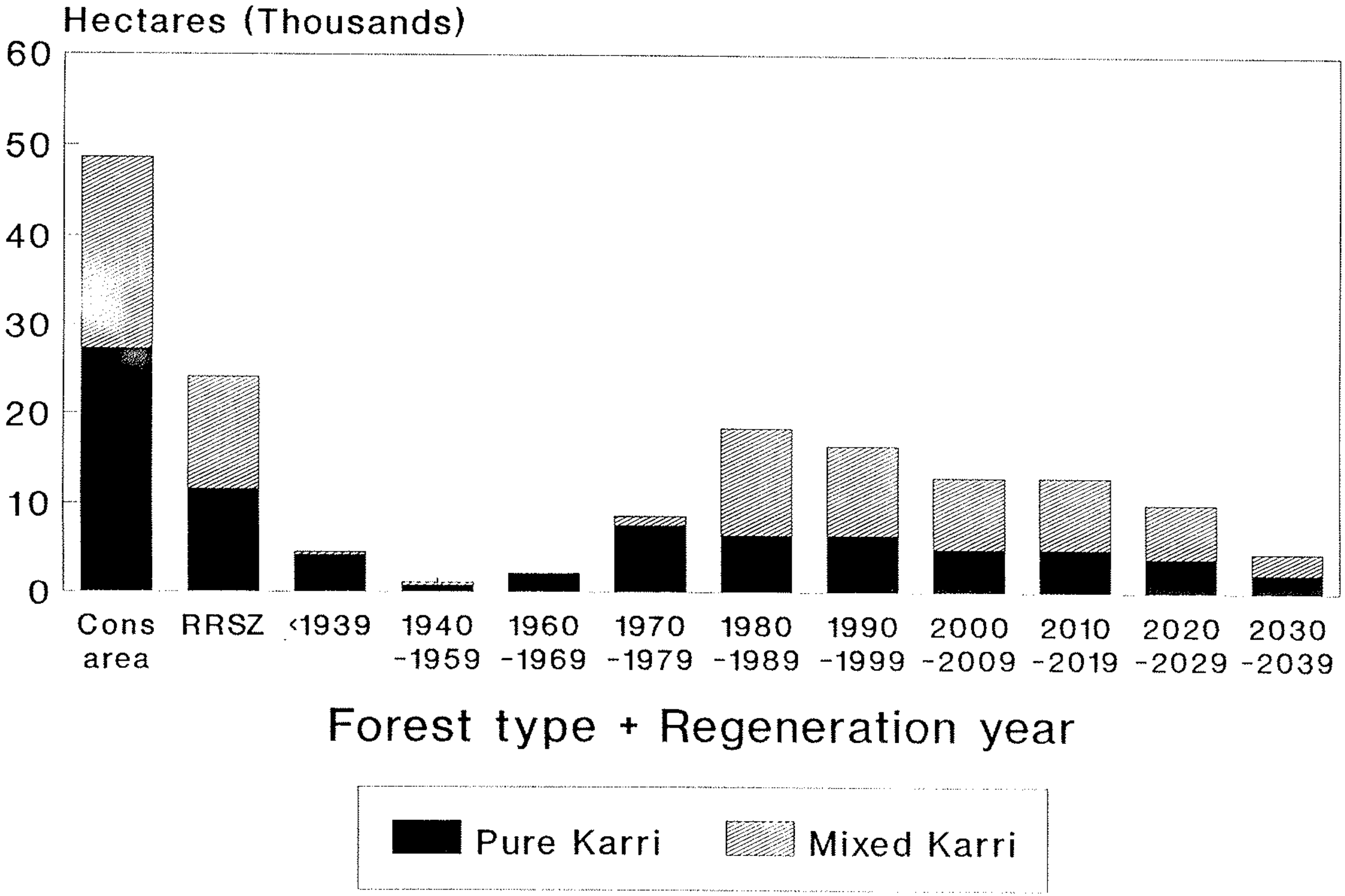
Area of Karri Forest
Tenure : State Forest - 1990



Areas incl road, river and stream zones

Figure 2

Area of Karri Forest
All CALM Lands - 2040



Cons area = Nat Pk, Nat Res, Cons Pk

Approaches to Wildlife Conservation

There is an abundant world literature on the interaction between timber harvest, regeneration and wildlife, particularly birds. For instance, it is well established that the organisation of bird species and communities at any one place or time is determined primarily by the structure of their habitat within a given forest type (Recher 1969, 1971, Tingay and Tingay 1984 for the karri forest). Temporal and spatial scales must be considered, however, in examining the effects of broadscale management operations on wildlife.

Five approaches to wildlife conservation in areas subject to harvesting operations can be defined.

(1) *Reserve more and/or larger areas specifically for wildlife (eg, national parks or nature reserves) and not make particular effort to conserve wildlife in areas used for other purposes (eg, mineral extraction or timber production).*

This approach is unlikely to sample the full range of species, communities and genetic diversity of forest wildlife in a region and would isolate populations and hinder recolonisation. While recognising the need for large reserves for wildlife, we reject this approach as a viable option. We stress the need for multiple use forest to contribute to fauna conservation and be managed in a manner sympathetic to that objective.

(2) *Manage for selected components of the habitat that are known or assumed to be limiting. Trees bearing hollows is an obvious example due to their long time in formation (Inions 1985, Inions et al. 1989, MacKowski 1984).*

There are several disadvantages in using only this approach. Firstly trees provide more than hollows (eg, the provision of nest boxes does not fill the role of mature forest). Secondly, certain management constraints such as fire control and suppression of surrounding regrowth (Rotheram 1983) must be addressed, and thirdly we may be directing conservation efforts at the wrong scale (eg, localised invertebrate fauna of poor colonisation ability are not considered). Habitat trees are of considerable importance however, particularly in areas where large gaps occur or in areas managed under short rotations, and should be a part of the total strategy.

(3) *Extend felling rotations so that there is time for suitable habitat to develop and be recolonised by breeding populations from surrounding undisturbed areas before it is logged again.*

This option involves the sustained yield of suitable habitat. We have yet to obtain detailed knowledge of the growth and development of trees (eg, see Jacobs 1955) and stands as habitat in the karri forest. In any case, present timber commitments in the karri forest largely limit this option until the second rotation. Changes may enable the extension of the current nominal rotation (Bradshaw and Lush 1981) beyond 100 years. This option may, however, already be available for particularly valuable areas as envisaged by Recher *et al.* (1987). Management can also be used to enhance the development of desirable characteristics eg, fire for the formation of hollows.

(4) *Reduce gap sizes or change silvicultural regimes.*

Within any given cutting level, this option leads to the completion of cutting within a forest block, and the overall area, in the same time scale and may not offer an improvement except where gap-sizes are very large. In addition there may be some disadvantages such as a requirement for additional roads. Small gaps lead to problems with damage to regrowth during removal of larger trees of the second crop. Regeneration burning without damage to regrowth is also very difficult. However, the influence of adjacent mature forest on the recolonisation of regeneration benefits from this approach.

(5) *Retain strips or patches of mature forest within harvested areas.*

This option has been found to be useful in the initial logging phase in Australia, North America and New Zealand. It is particularly attractive where important areas of sensitive wildlife occur in patches. Riparian zones, rock outcrops, areas of poor regeneration potential and areas of high nutrient status are examples. It is also useful where previous logging has encouraged patch formation (eg, some areas of jarrah forest).

At the scale of the entire south-west, option one is vital to wildlife conservation. Each of the other options, however, contribute to wildlife conservation at the scale of a forest block. The first and fifth options were those originally chosen when the EIS was drawn up in preparation for the introduction of woodchipping in the karri forest in Western Australia in 1975 (Anon 1972). Options two and four have also been used in the jarrah forest. Option three is being considered in a review of forest management in Western Australia that is currently underway (Jones personal communication 1991). We believe that option five remains the most valuable for wildlife conservation and should continue to be the first priority in multiple use forest containing karri.

Models of size, shape and placement of zones for wildlife habitat

Four principles derived from the theory of island biogeography (MacArthur and Wilson 1967) are widely accepted among biologists for most wildlife (Recher *et al.* 1987 page 178):

"1. large reserves retain more species than small ones;

2. reserves with a small boundary in relation to area retain more species of the original habitat than those with long or irregular boundaries

3. linking reserves with corridors is an effective way to enhance the size of reserves; and

4. multiple reserves provide a hedge against catastrophic loss."

We need to consider the relevance of these theories to reserves amongst multiple use forest which includes wildlife conservation components. Some species may be corridor specific within regrowth, but this will not be the case for all species and the value of regrowth as habitat will vary with time. Remnants of retained mature forest are vital to the regional conservation of a broad spectrum of species (Loyn 1980, Loyn 1985, Recher *et al.* 1980, 1987, Recher 1985, Shields *et al.* 1986). Harris and Scheck (1991) argue that a managed, interconnected system of protected areas that utilises movement corridors is better than a system of dispersed protected areas with no connected corridors. As logging proceeds, these patches and strips of unlogged forest will represent a major resource for wildlife requiring mature forest (dependent fauna *sensu* Tyndale-Biscoe and Calaby 1975). These patches have already figured in the development of management plans for nature conservation in the karri forest (Anon 1987a). The distribution of these retained patches will become critical as mature forest within multiple use forests becomes more highly fragmented. The large area of regrowth forest will provide some, but not all the needs of wildlife dependent on mature forest. Given the large area of regrowth forest, some effort should also be made into maintaining the later developing characteristics of these stands.

Dependent fauna include species that require hollows. In karri forest 20 species of birds are known to use hollows (Christensen and Kimber 1977). Wardell-Johnson (1984) found that 14 of 44 species, or 32 percent, of birds observed in karri forest in spring 1982 were species that used tree hollows as nest sites. Thirty four percent of all bird detections (4 327 total) were using hollows during this period. Hence hollows are not only important for the large numbers of species, but also for the total numbers of birds in communities in the south-west forests. This trend has also been recorded for mammals. Nine species (30 percent of the total forest mammal fauna) require hollows in trees in the karri forest. The sensitivity of these species to fragmentation is not known.

Hollows take a long time to form. Of forty trees examined in four small areas of karri forest, the youngest to contain hollows suitable as nesting sites for small passerines, was 168 years (Wardell-Johnson and Christensen 1991). However none of the coupes examined had experienced high intensity fire during the time of the records examined. High intensity fire decreased the average age of trees containing hollows occupied by possums by about 100 years in a study carried out in jarrah forest in the Perup Nature Reserve (Inions 1985, Inions *et al.* 1989). Fire may be a useful tool in promoting hollow development in karri regrowth.

Mature forest is required by animals for many purposes besides nest sites. Mature trees are also perching and shelter sites, as well as foraging substrates. All of these purposes can be fulfilled by regrowth of sufficient age and development, and some may be fulfilled initially by isolated dead trees (Wardell-Johnson own data). Isolated trees may be inadequate for some animal species for which stand characteristics are important (Swallow *et al.* 1986). The other values of mature forest and the changing characteristics of the stand with time must be considered.

The most valuable areas for wildlife conservation tend to be those lowest in the landscape profile (Dobbyns and Ryan 1983, Loyn 1980, Smith 1985, Recher *et al.* 1980, 1987, Shields 1984) and those with the highest nutrient status (Braithwaite *et al.* 1984). Sites lowest in the profile are most valuable for the spectrum of bird species found in any particular forest type and include greater numbers of individuals than upland sites (Loyn 1980, Recher *et al.* 1980, Recher *et al.* 1987, Watkins personal communication 1987, Wardell-Johnson own data). The structure of the habitat (Recher 1971) and the position in the profile are critical factors (Howe *et al.* 1981). Sites lowest in the profile are also valuable for other vertebrate groups (Recher *et al.* 1987), and for invertebrate conservation (see Halse and Blyth 1991). This is not to say that upland habitat is unimportant for conservation, but known vulnerable species have only been found in lowland habitat and these sites should be priority areas in wildlife conservation.

The mammal fauna of the karri forest is not rich but includes several vulnerable species such as *Setonix brachyuris* (Quokka) and *Falsistrellis mckenzei* (McKenzies Bat). In the karri forest, small mammals reach their highest numbers (species and individuals) in sites low in the profile (Christensen and Kimber 1975). The *Hydromys chrysogaster* (Water Rat) and the Quokka are most common in these sites. Stream terrace areas are critical habitat for the Quokka (Christensen and Kimber 1975).

The reptile and frog fauna of the karri forest is also not rich but includes several endemic species such as *Geocrinia lutea* and *G. rosea*. Other terrestrial breeding species restricted to the south-west such as *Pseudophryne nichollsi* are most abundant there. Sites lowest in the profile are most valuable for the full spectrum of amphibians found in the karri forest including species restricted to these sites (eg, *Geocrinia lutea* Wardell-Johnson and Roberts 1991). All reptiles known in the karri forest also occur in stream zones including two that are most common there (*Chelodina oblonga* and *Egernia luctuosa*). Recher *et al.* (1987) found that species abundances of frogs and reptiles were more affected by aspect than by disturbance by logging at Eden, New South Wales. They found no evidence of any of these species being disadvantaged by logging, regeneration and maintenance of creek reserves. We would expect position in the profile also to be important, but concur with Recher *et al.* (1987) for those species studied in the karri forest (Wardell-Johnson and Roberts 1991).

Although the relatively small area and isolated nature of the south-west forests, together with previous climate changes, may have worked against evolutionary diversity in the larger vertebrates, there is a larger, though imperfectly known, profusion of smaller vertebrates and invertebrates. Hence, in wildlife conservation, we need to be considering not only those species and communities that are dependent on habitat components readily perceived (eg, hollows and hollow nesting species), but also those of different scales. These include species of poor colonisation ability (eg, some snails and spiders) and species and habitats that are of limited distribution.

Aquatic fauna of the karri forest has been reviewed by Halse and Blyth (1991). They report the occurrence of nine species of native fish and five species of decapod crustacean in streams in karri forest. The aquatic invertebrate fauna of the karri forest is imperfectly known, but research in the jarrah forest in the south-west of Western Australia (Bunn 1986, Bunn *et al.* 1986) suggest that 200-300 species of macro-invertebrate and a large number of smaller animals occur, undoubtably including many that have yet to be named. Many of the species are endemic to Western Australia and probably a considerable number including Gondwanan relicts (see Main 1987, 1991) are restricted to the karri forest. Some species with restricted distributions are intolerant of environmental changes. This suggests that measures should be taken to minimise the undesirable impact of harvesting operations on the stream environment. Undisturbed zones along streams can protect those sites from sedimentation, changes in water temperature, erosion and log-jams and thus conserve sensitive and vulnerable invertebrate species and communities (Campbell and Doeg 1989).

Riparian zones are a small but critical source of diversity within the forest system. A high proportion of the landform units defined by Churchward *et al.* (1988) are based on riparian zones (17 of 52) but these occupy a minor proportion of the total landscape of their study area. Riparian zones are also sensitive to disturbance. Although the communities in these zones may recover rapidly, they can also be altered by soil compaction, erosion and sedimentation during harvesting and regeneration operations (Halse and Blyth 1991). Sedimentation in particular could cause long-term impact on aquatic invertebrate communities. These changes can be largely prevented by retaining strips of undisturbed riparian vegetation of approximately 30 m width (Clinnick 1985).

Optimal width and length attributes of corridors for mature forest dependent species, are impossible to specify because they are species, time, habitat and landscape specific (Friend 1991). The size of the corridor should always be assessed in comparison with the organism being conserved. For example invertebrates require a different scale of corridor to medium-sized mammals but a corridor suitable for the latter will usually also be suitable for the former. Fine-scale variation in habitat must however be considered for some invertebrates (eg, Gondwanan relicts see Main 1987, 1991) Thus information on the requirements of species high in the food chain or most vulnerable to habitat change (including invertebrates) should be gathered and used as a minimum estimate of necessary widths.

Hopper *et al.* (1991) have provided a list of vascular flora from the Warren Botanical Sub-district which includes 1778 native and 299 introduced taxa. They suggest that coastal heath, granite outcrops, swamps and woodlands include the majority of the endemics and threatened taxa. The main karri forest has few of the endemics and none of the Declared Rare Flora nor any species requiring monitoring. Nevertheless several vulnerable species occur on the margins of the karri forest. For example *Banksia seminuda* ssp. *seminuda*, a species common in stream zones on the margins of the karri forest and in other forest in high rainfall areas of the south-west, is vulnerable to frequent fires (Baird 1988). Wardell-Johnson *et al.* (1989) derived a floristic classification of the Walpole-Nornalup National Park based on 219 quadrats and 233 species. Only three of the 12 community types include forest, highlighting the diversity of vegetation bordering the forest of the area. The recognition of the need for a thorough survey to address the possibility of poorly known and vulnerable plant taxa should be recognised in a redistribution of the road, river and stream zone network. Hence, any scheme must allow for local scale planning particularly for rare or vulnerable species.

Discussion

Many biological surveys have been carried out in the Warren Botanical Subdistrict (see Christensen *et al.* 1985 and How *et al.* 1987), but a thorough biogeographic survey is yet to be undertaken. The pattern of the biota in the area can currently be assessed from the patterns of landforms and soils (see Churchward *et al.* 1988) and vegetation structure (see Smith 1972, Wardell-Johnson and Nichols 1991). Such assessments are limited by assumptions concerning pervasive homogeneity of units and determinism (McKenzie *et al.* 1989, 1991). Similarly, although many studies have examined the impact of disturbance in the Warren Botanical Subdistrict (see Christensen and Kimber 1975 and Wardell-Johnson and Christensen 1991 for reviews), no studies have been designed to look specifically at the effectiveness of the current or proposed road, river and stream zone network for wildlife. A preliminary assessment of the present system of road, river and stream zones can be made however, based on wildlife research carried out in the Nornalup System of the Warren Botanical Subdistrict since 1971 (see Christensen and Kimber 1975, Wardell-Johnson and Christensen 1991). This system could be improved by rearrangement.

We believe that a shift in emphasis from road to stream zones is desirable in the context of wildlife conservation in south-west forests. This is necessary because, although effective where allocated, there is no formal protection of some stream zones and other important habitat areas under the current system. Following completion of harvest within a forest block, large areas of regeneration will occur between remnant mature vegetation. Species that are dependent on mature forest will not be catered for by differences in the age of adjacent areas of regeneration logged during the same cutting cycle. This is because some habitat components (eg, hollows) take much longer to form than the envisaged age differences of the regrowth within a forest block. These components should be retained but the more important principle concerns the distribution of retained mature forest and other habitat.

The effectiveness of this shift in emphasis will depend on the sustainability of narrow zones low in the profile and also on the zones being of adequate width for fauna conservation. Recher *et al.* (1987) found that retained mature forest of less than 40 m total width was inadequate for fauna conservation in pine plantations in eastern Australia. Not only were such reserves too narrow to provide the resources necessary for wildlife but also trees retained within such sites were found to be subject to loss of vigour and windthrow. Exceptions have been observed including very narrow zones (less than 20 m total width) along streams in areas of steep slopes such as Gray 5 which have not deteriorated in the 10 years since regeneration. There are also considerable areas of relatively narrow road reserve adjacent to cleared private property. Observations of these areas and the variation in age classes within such stands suggest that much narrower zones than the 800 m zones along roads will be sustainable. Similarly, zones on streams are likely to be better protected from windthrow than upland sites, although these may be more subject to changes in hydrological balances in areas of limited relief.

Recher *et al.* (1987) recommends large widths on remnants based on the theory of central place. Many species at Eden (eg, various species of glider) require patchy resources over a large area of undisturbed habitat. Thus many species require large, approximately circular territories which are inadequately catered for by narrow zones. Gliders are not present in south-western Australia, although this theory may hold for other mammals and birds. Similarly this theory could be tested for Quokkas in Dombakup Forest Block where trapping data have been gathered prior to logging (Christensen *et al.* 1985). The current rotation is now complete in this forest block allowing assessment of the effectiveness of the 200 m wide corridor for Quokka movement and habitat.

Highest order streams (such as rivers) supply greater variation in habitat and harbour more species than lower order streams. They usually have a greater width of terracing (where terracing is present) and more areas of steep slope than lower order streams. Thus the larger buffers should be allocated to the largest streams (based on the size of the stream).

Remnant vegetation 50 m either side of gullies is likely to be adequate to maintain a high proportion of the conservation values within coupes in the karri forest based on the species known to occur there. It will however be necessary to ensure that all streams include such zones and that the zones are linked across saddles. This will ensure that the conservation values are enhanced in a greater proportion of any forest block than under the current scenario. This scheme would maximise the distribution of remnant mature forest and other habitat in the karri forest. Retained patches of connected forest will most effectively serve as wildlife corridors, as areas for dispersal and colonisation and will provide the best opportunity for the conservation of patchily distributed species. The same recommendations apply to jarrah forest, where habitat groups and crop trees are retained.

One major reason for the richness of riparian zones is that they represent ecotones between major landscape features. Ecotones represent sites of exceptional species richness. Other sites that include ecotonal features include granite monadnocks and sites in swampy terrain. These sites are of exceptional importance in adding to the habitat diversity present in the south-west (see Hopper *et al.* 1991, Wardell-Johnson and Christensen 1991). Although these sites are not disturbed by timber harvest, their recognition as valuable sites for wildlife conservation should be acknowledged in any proposed change to the existing system. Dieback caused by *Phytopthora spp.* can have a severe impact in some of these communities. These sites should have protection from traffic and timber harvesting operations.

Recommendations to optimise wildlife values

1. All drainage lines (as marked on CALM 1:50 000 maps and interpreted through aerial photography) should be protected by retained vegetation.

2. A width of approximately 50 m on each side of first-order, second-order and third-order drainage lines should be retained. This would be considered as a 100 m total width, with a minimum of 20 m on any side to enable zone boundaries to follow ecological boundaries.

3. A width of approximately 100 m on each side of fourth-order drainage lines should be retained. This would be considered as a 200 m total width, with a minimum of 50 m on any side to enable zone boundaries to follow ecological boundaries.

4. A width of approximately 200 m each side of fifth-order and greater drainage lines (rivers) should be retained. This would be considered as a 400 m total width with a minimum of 100 m on any side to enable zone boundaries to follow ecological boundaries.

5. Ecological boundaries should be used to define stream zone boundaries and may include terraces on larger streams (eg, Dombakup Brook, Big Brook) in which case the zone edge will be above the terrace to include a narrow band of mature trees and to ensure that roads are above steep slopes and seasonally moist sites.

6. All seepage sites and valley head-waters should be protected. These sites may contain merchantable trees albeit at wide spacing. These areas are readily identified using aerial photographs and on the ground by the presence of *Lepidosperma tetraquestrum* or *Oxylobium lanceolatum*. These areas should not be harvested.

7. Movement corridors should cross saddles and join stream head-waters.

    a. In the northern part of the Nornalup System, karri occurs low in the profile (Bradshaw and Lush 1981) and allowance should be made in silvicultural prescriptions for the jarrah forest for the continuation of movement corridors between catchments.

b. In the central part of the Nornalup System, karri occurs throughout the landscape (Bradshaw and Lush 1981). The retention of corridors of karri forest linking catchments will be necessary.

c. In the southern part of the Nornalup System and in the Denmark System, karri occurs only in the highest parts of the landscape or adjacent steep gullies. In these areas special emphasis should be paid to granite outcrop sites which are surrounded by karri forest.

8. Additional protection of stream zones would be created by reallocation of existing zones from road to stream zones. Road zones would then be reduced to an aesthetically acceptable landscape criterion and the balance made available for stream zones. Similarly, 200 m wide zones along third-order or smaller streams would be reduced to 100 m.

9. The scope for reallocation includes the Warren Sub-district but the principles should be applied more generally in the Darling Botanical District.

10. As with the present system of road, river and stream zones, proposed zones should be allocated and demarcated prior to the commencement of harvesting operations in a forest block. For those forest blocks where the first harvesting rotation is nearing completion (eg, Dombakup, Warren, Iffley), the introduction of these guidelines would be delayed until the second rotation.

11. No timber harvesting should occur within designated stream and river zones. Vehicle movement should be minimised across stream zones and should be restricted to well designed road crossings.

12. Coupes in which harvesting operations are being conducted may include forest retained in stream zones. These zones may need to be burnt at the time of regeneration, in which case prescribed fire should be of low intensity. Adjacent stream zones should not be burnt at the same time unless it is essential to achieve security in the regeneration burn or reduce the risk of fire damage to the zone itself. Prescribed fire should be excluded from at least some zones.

13. In addition to the existing zones, there are other areas which would not be logged but which are important wildlife habitat. These areas include

a. Granite outcrops which are usually surrounded by shallow, sensitive and moist soils. These areas should be subject to a zone of undisturbed vegetation including transitional vegetation to at least 50 m from the surface rock. Outcrops shown on API plans (0.2 ha or greater) would be formally recognised, although all areas of shallow soils would receive protection in implementation.

b. Areas of jarrah forest and woodland in the Warren Subdistrict which are difficult to regenerate or highly susceptible to dieback (site-types R, B, F and A of Strelein 1988). Timber harvest in these areas should be deferred.

c. Areas of shrubland which include valuable wildlife habitat and considerable variety in floristic pattern (eg, Wardell-Johnson *et al.* 1989, Hopper *et al.* 1991). These areas are not subject to harvesting but may be subject to other operations. They should be designated for protection in forest plans accordingly.

14. The impact of disturbance on the wildlife of road, river and stream zones will require research. No research has been carried out on the effects of disturbance on predation in these zones. Predation may be an important factor for some species of medium-sized mammal that are already in decline (eg, Quokka). Soule and Gilpin (1991) provide a theoretical basis for suggesting that the mortality rate of a species will be the major factor that determines the limits of corridor capability for those species that depend on corridors as movement zones between habitat. In the meantime it is recommended that harvesting, regeneration and thinning operations not be carried out in river and stream zones.

15. Groups of trees and logs should be retained to maintain habitat components within a forest coupe.

Conclusion and reallocation in practice

Wildlife conservation values would be retained in a greater proportion of any forest block by this scheme. Retained patches of connected forest will most effectively serve as wildlife corridors, areas of dispersal and colonisation, and as transitional ecotones. They will also provide a better opportunity for the conservation of patchily distributed species.

Wardell-Johnson (1987) examined case studies of a reallocation of the existing road, river and stream zone system in six forest blocks. He assumed no reduction in timber yield or increase in area of zones. There was considerable variation between loss and gain in area following redistribution, although equal numbers of forest blocks showed an increase, as showed a decrease, in the total area contained within road, river and stream zones. In addition, no area had less than 10 percent retained remnant vegetation. The aim of the existing system for about 20 percent of the forest in each forest block to be retained unlogged, was seen as a good idea, but has little scientific basis and variations to this would allow the best use of the area available.

The knowledge and data base from which these recommendations have been derived, like the forest environment for which they are intended, is not constant. Questions of corridor capability, the linear nature of road, river and stream zones, and the patchy distribution of wildlife make it difficult to predict the long-term effectiveness of managing wildlife in these ways and it is recommended that the program of research advocated during a previous review (Wardell-Johnson and Halse 1988) be implemented to determine the viability of the scheme advocated.

Acknowledgements

We thank the Lands and Forests Commission for hosting the workshop, Sharon Jones for the FMIS interrogation and Allan Burbidge, John Blyth, Jack Bradshaw, Gavin Butcher, Roger Underwood, Alan Walker and Ray Wills for comments on an earlier draft of the manuscript. Sharon Eccleston typed a draft of the manuscript.

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CAPTIONS FOR FIGURES

Figure 1 Area of karri in State forest in 1990. Categories are based on logging and regeneration history. The area of road, river and stream zones is included in the total.

Figure 2 Estimated area of karri on all CALM land in 2040. Categories are based on logging and regeneration history. Areas assume a gradual reduction in cutting levels in mature forest, and the maintenance of current areas of road, river and stream zones.

PROCEEDINGS OF A SEMINAR

A REVIEW OF ROAD, RIVER AND STREAM ZONES IN SOUTH WEST FORESTS

Held at Manjimup

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