CHAPTER 2

A Review of the Effects of Disturbance on Wildlife of the Karri Forest

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Abstract

This paper reviews current knowledge of ongoing research, and future research priorities, into the effects of disturbance on the flora and fauna of the karri forest and other communities in the Warren Botanical Subdistrict. Research on harvesting and regeneration, fire, naturalized species, and relevant biogeographic and evolutionary studies are considered in areas of retained native vegetation.

Biogeographic and evolutionary studies indicate that past climatic changes have led to changes in the distribution of species. Subsequent activities by humans, however, have been of greater significance in the decline of vulnerable species than have climatic changes. The development of an understanding of the overall pattern of the biota and the distribution of vulnerable species (including Gondwanan relicts) and their habitats remain a priority in biogeographic research.

Studies on harvesting and regeneration have maintained emphasis on silvicultural techniques to optimize timber production from regenerated stands. Wildlife research on the effects of timber harvesting has concentrated on birds, contributing to recommendations for a redistribution of road, river and stream zones to more effectively cater for fauna conservation in multiple use forests. The process of hollow formation in trees, the maintenance of vulnerable species, and the predictive modelling of community changes are research priorities in relation to harvesting and regeneration.

Studies on the effects of fire have been wide ranging including work on vascular plants, small mammals, birds and invertebrates, though gaps remain in studies that would allow predictive modelling and an understanding of fire responses of invertebrate communities and of vulnerable plant species. Continued research on the control of key naturalized species (e.g. *Phytophthora* and Red fox) and on the maintenance of community processes in the presence of these species are also priorities.

A multidisciplinary approach to process oriented research is recommended in disturbance ecology. Regional staff take an increasing role in ecological monitoring and experimental management.

INTRODUCTION

Community types containing karri (*Eucalyptus diversicolor*) occur in the Warren and Menzies Subdistricts of the Darling Botanical District (Beard 1980) in south-western Australia. The principal occurrence of karri is in the Warren Subdistrict (Fig. 1) with outliers in the Porongurup Range and near Manypeaks. Most land (169 000 ha) that now includes karri is administered by the Department of Conservation and Land Management (CALM) as State forests, nature reserves, national parks and conservation parks.

Karri occurs in many community types and the effects of disturbance may extend across community types. Hence we include the Warren Botanical Subdistrict as our area of coverage because it includes all karri State forest as well as neighbouring community types and enables placement of those components confined to the karri forest in a regional perspective. The boundaries of the Warren Subdistrict are defined by Beard (1980) and outlined in detail by Hopper *et al.* (this volume).

Disturbance can be natural, or owing to human interference. Humans have blurred the boundaries of natural disturbance, and virtually all forms of disturbance are now influenced by human activities. As Havel (1989) and Mills (1989) demonstrate, human impacts, particularly in the south-west forests, have increased greatly since European settlement, particularly when land use intensified in the 1960s. There have been major changes in the patterns of disturbance, few of which can be attributed to individual factors. Hobbs and Hopkins (1990) recognized four main categories of land use and resultant degrees of impact following European modification of Australian vegetation. These include:

(1) complete removal of the vegetation and disruption of ecological processes such as mining and urban development;

(2) replacement of vegetation by intensively managed systems such as agriculture and plantation forestry;

(3) utilization of existing vegetation with some consequent modification as occurs in forests managed for multiple uses; and

(4) management for nature conservation with minimal deliberate modification.

Concern has been expressed about the adequacy of knowledge of the long term effects of disturbance on the composition of the flora and fauna of the karri forest (Anon. 1986; Christensen 1986; Anon. 1988). Here we review the current state of knowledge and the existing research program on the effects of disturbance on the wildlife of the karri forest. We consider only the third and fourth of the categories of land use recognized by Hobbs and Hopkins (1990). Disturbances included within these categories include fire, logging and regeneration, and the effects of introduced species.

The long term effects of disturbance on the composition of the flora and fauna will be intimately tied to interactions with climatic change and with effects on soils and nutrients. These subjects are reviewed by Bartle (this volume), Shearer (this volume) and Abbott (this volume), and by Christensen and Abbott (1989) and we do not intend to address these issues here. Aquatic ecosystems are also reviewed elsewhere (Halse and Blyth, this volume). We therefore confine this review to the terrestrial biota, but take a wide view of long term effects. We also provide recommendations for future research.

CURRENT KNOWLEDGE

Evolutionary and biogeographical studies

FLORA

Research on the effects of disturbance on the flora of the Warren Subdistrict has been concentrated in karri forest in the Nornalup System. Inions *et al.* (1990) provided an overview of community types in which karri is a component. Site-based community studies provide benchmarks for monitoring change in the community types investigated. This study provided a floristic classification of community types in regrowth karri from 204 quadrats and 105 species. Thirteen community types were defined by cluster analysis, ordination and discriminant analysis of the 312-m^2 quadrats.

Inions *et al.* (1990) found that community types varied substantially in productivity, as measured by age-standardized top height and that this in turn was related to climatic and edaphic factors. Variables relating to rainfall distribution, radiation levels, soil acidity and phosphorus levels were found to be the most discriminatory between community types and each differed in stand productivity and in climatic and edaphic variables. The distribution of the community types defined, is broadly geographically based (Fig. 1), although overlap occurs within a single landform/soils unit (as defined by Churchward *et al.* 1988).

Climatic and edaphic influences on the distribution of karri have also been studied by Churchill (1968). He concluded that the distribution of karri was primarily determined by water availability expressed as rainfall during the wettest and driest months of the year. He suggested that this distribution has fluctuated markedly during the past 5000 years. Examination of charcoal accumulation in cones taken from peat swamps also enabled Churchill (1968) to present a 7000 year fire history of forest areas.

Griffin (1985) provided a floristic survey of Smiths Brook Nature Reserve; a small area near Manjimup dominated by karri forest. This survey defined and mapped five vegetation units including one artificially created by disturbance. The area was found to be relatively undisturbed by Europeans despite a number of tracks and the presence of many introduced species.

FAUNA

Vertebrate surveys of the Warren Subdistrict completed by the Forests Department of Western Australia are summarized by Christensen *et al.* (1985). These authors list 19 surveys completed in the southern forests between 1970 and 1982, 15 of which were in the Warren Botanical Subdistrict. Lists of vertebrates and vascular plants are presented by survey and by major vegetation type. The distribution and status of each vertebrate species is discussed and an analysis of faunal trends within the region, including relationships with adjacent fauna, is presented. Christensen *et al.* (1985) conclude that the vertebrate fauna of the forested south-west occurs in a faunal continuum with a strong north-south, and lesser east-west, influence that appears to be related to

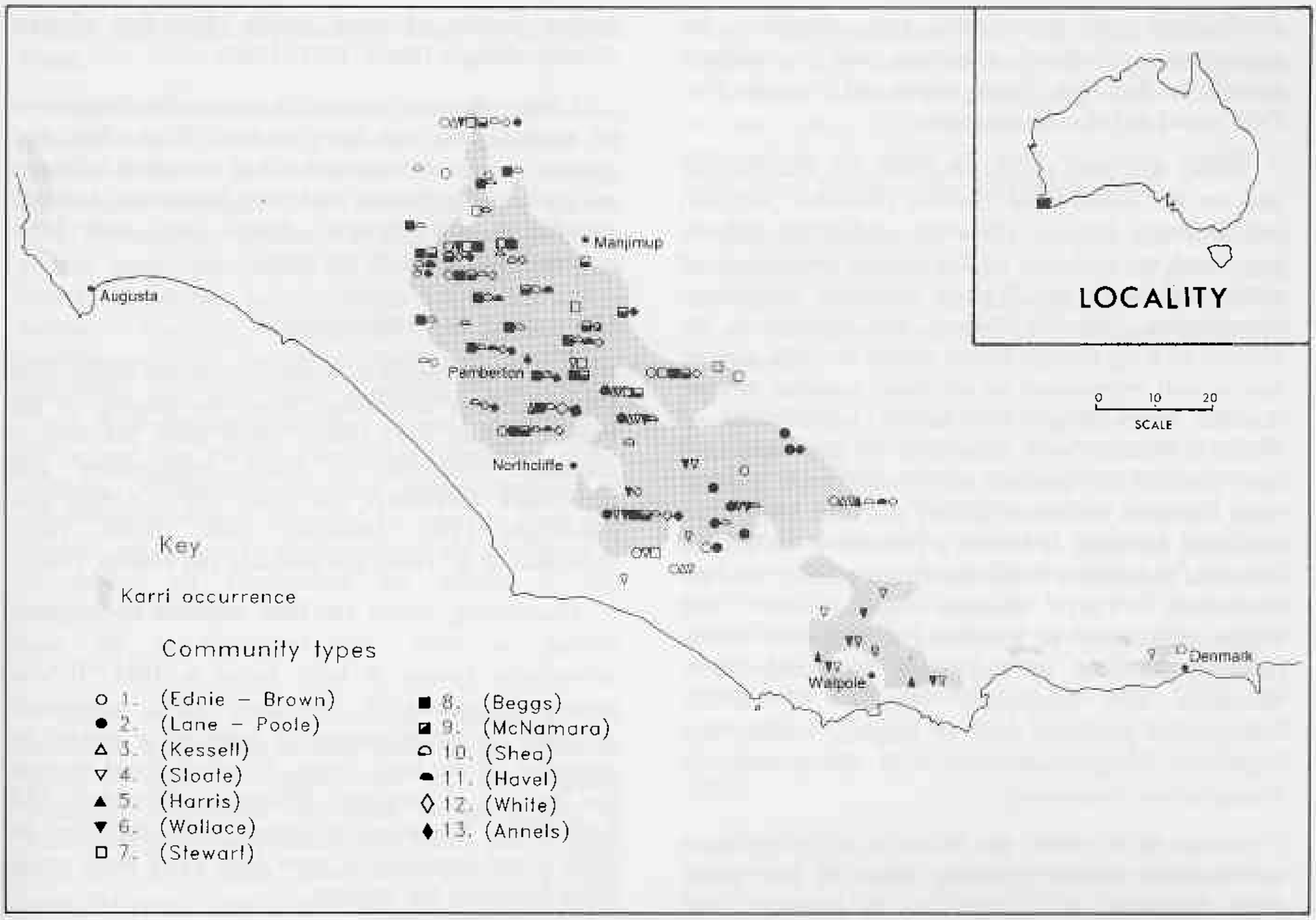

Figure 1
Distribution of community types defined by Inions *et al.* (1990) within the main distribution of karri forest. Major towns are also shown.

climatic factors. On a smaller scale, individual species distribution appeared to be influenced by vegetation and soil factors, although all species occurred across vegetation and soil gradients. Christensen *et al.* (1985) suggested that a possible reason for the lack of diversity of vertebrate fauna in the karri and tingle (*E. guilfoylei* and *E. jacksonii*) forests is that these forests occupy too small an area for dependent residents to have evolved in them.

How *et al.* (1987) present a survey of ground vertebrates and document a decline in numbers of many birds and mammals in the coastal heathlands and woodlands which adjoin the forest between Albany and Busselton, since European settlement. Several vulnerable ground birds and mammals, once present in this coastal area are not now found, or occur in very low numbers; for example, Numbat (*Myrmecobius fasciatus*), Woylie (*Bettongia penicillata*), Tammar (*Macropus eugenii*) and Chuditch (*Dasyurus geoffroyii*). Birds that have become locally extinct following European settlement include the Mallee Fowl (*Leipoo ocellata*), Western Whipbird (*Dasyornis longirostris*), Rufous Bristlebird (*D. broadbenti*), Noisy Scrub-bird (*Atrichornis clamosus*) and Bush Thick-knee (*Burhinus grallarius*).

Similarly, How *et al.* (1987) report a decline to low numbers of the Brush Wallaby (*Macropus irma*), Quokka (*Setonix brachyurus*), Common Brushtail (*Trichosurus vulpecula*) and Western Ringtail (*Pseudocheirus pereginus*) in these south-western areas. This study presents a good historical account of the reasons put forward for these disappearances. For instance, evidence presented by Carter (1923) is cited to explain the disappearance of the Mallee Fowl. According to Carter (1923), the Mallee Fowl was not uncommon in the coastal vegetation between Cape Naturalist and the mouth of the Warren River in 1902. Its populations had diminished by 1920 owing to the burning of the coastal vegetation to improve grazing for cattle. How *et al.* (1987) attributed the decline in ground dwelling vertebrates to a combination of the effects of changed fire regimes associated with the development of pastoralism and clearance for agriculture, introduced predators and competitors (chiefly the Red Fox, *Vulpes vulpes* and Domestic Cat, *Felis catus*) and disease epidemics.

Kabay and Start (1976) reviewed the distributional data on the Broad-faced Potoroo (*Potorous platypus*) and Gilbert's Potoroo (*Potorous tridactylus gilberti*) but found no evidence of the current occurrence of either species in the Warren Botanical Subdistrict. Nevertheless, Gilbert's Potoroo was collected in the vicinity of King George Sound during the 19th century and is well represented as sub-fossil material in cave deposits in Boranup. The habitat requirements of Gilbert's Potoroo were thought to be more restricted than those of the Quokka, itself considerably reduced since European settlement (Kabay and Start 1976). The continued existence of Gilbert's Potoroo in the Warren Botanical Subdistrict while considered unlikely was not discounted. They consider its decline and disappearance may be associated with several factors (disease, predation by foxes and cats, competition, alienation and subsequent clearing of habitat, management practices such as logging, burning and vegetation changes associated with the presence of *Phytophthora cinnamomi*).

Baynes *et al.* (1975) and Balme *et al.* (1978) report on mammal remains spanning about 30 000 years, from excavation in Devil's Lair in Boranup. Both studies suggest that throughout the period studied, a more varied mammal fauna persisted than is recorded in historic time. At some late Holocene period not represented in Devil's Lair, several species known not to inhabit forest disappeared from the district. This and the distribution of mammal species between 35 000 and 5000 years ago suggest that a drier climatic regime in the late Pleistocene gave way to a wetter regime in the Holocene (Balme *et al.* 1978).

Rich and Baird (1986) in presenting fossil evidence of birds from caves in the Boranup area suggest a fluctuating but currently wetter climate than during periods of glaciation. Smith (1977) discussed the effect of environmental change on six rare birds and proposed that all species were more widely distributed and abundant during the Tertiary Period and Pleistocene Epoch - Noisy Scrub-bird, Rufous Scrub-bird (*Atrichornis rufescens*), Rufous Bristlebird, Western Bristlebird, Eastern Bristlebird (*Dasyornis brachysterus*), and Western Whipbird (*Psophodes nigrogularis*) - four of which occurred in the Warren Botanical Subdistrict. Vegetational change from the late Tertiary onwards reduced these species to small remnant populations by the time Europeans arrived. However, the subsequent activities of Europeans (in particular burning and agricultural clearing) are suggested as being of even greater significance to the further decline of these species than that of past climatic changes (Smith 1977, 1985).

Likely effects of climatic change on the distribution of species have not been studied. It is clear that climatic change over aeons has had a marked influence on species distributions and that interaction between disturbance and climatic change may well have important influences in the future.

Harvesting and regeneration

Harvesting for timber in Western Australia began soon after European settlement. Since the passing of the Forests Act in 1919 (Nunn 1957) there has been a continued evolution in forest management and silviculture (Bradshaw and Lush 1981; Abbott and Loneragan 1986; Stoneman 1986; Havel 1989; Stoneman *et al.* 1989; and Breidahl and Hewett 1992).

Clearfelling, which had been replaced by selection cutting in 1938, was reinstated as the main silvicultural system in karri forest in 1967. It was reinstated because it was no longer considered necessary to retain groups of trees as a barrier to alienation of the karri forest, for silvicultural reasons and because of economic efficiencies (Bradshaw and Lush 1981). The woodchip industry was established in 1975 to use non-millable trees from karri forest areas being harvested for sawlogs.

Projected timber demands (Bradshaw and Lush 1981) and supply commitments have led to emphasis being placed on the ability to optimize sawlog production from regenerated stands. Rotheram's (1983) findings that retained trees suppress the growth rate of adjacent regeneration has lent support to this direction. The requirement for thinning of regrowth stands of karri is argued in Bradshaw and Lush (1981). Silvicultural research on karri has been comprehensively reviewed by Breidahl and Hewett (1992) and will not be discussed here other than in the context of disturbance ecology.

Occasional death of karri saplings and understorey species owing to *Armillaria luteobubalina* infection occurs in virgin karri forest and in regrowth karri where it has been related to the presence of nearby infected stumps. There is a decrease in mortality with increasing distance from these stumps (Pearce *et al.* 1986). More suppressed karri saplings were killed than dominant saplings but some degree of natural suppression of *A. luteobubalina* by other fungi has been observed (Pearce and Malajczuk 1990). The distribution and impact of *A. luteobubalina* in jarrah forest has been discussed by Shearer and Tippett (1988) who found that host mortality following infection was greater in the intermediate and low rainfall zones than high rainfall zones of the jarrah forest.

Uncontrolled use of machinery may damage either retained trees in thinning operations (Breidahl and Hewett 1992) or soils, site and tree roots through compaction (Wronski 1984). Breidahl and Hewett (1992) found some evidence of root deformity among planted stock, particularly on badly compacted sites where a hard pan had developed below the surface horizon. Therefore, compaction may affect the establishment and growth of karri and may affect hydrology and thus plant community composition. These problems can be avoided by good management, but in any case are not irreversible (Bradshaw 1978). Schuster (1979a) has examined various methods of rehabilitation of soils disturbed by logging. Deep soil ripping, application of fertilizers and the formation of an ashbed all ameliorated the effects of soil compaction (Schuster 1979b).

FLORISTICS

Inions *et al.* (1990) recorded annually at 144 permanent quadrats all vascular plant species visible in spring in order to compare pre and post logging treatment. Assessment was made before logging or burning on plots that included sites which had not been burnt for 7 to 15 years. Subsequently sites were either burnt (54 sites), clearfelled, burnt and regenerated (50 sites), clearfelled and regenerated (four sites) or left as controls (36 sites). Regeneration was by the seed tree method (18 sites) and by handplanting (36 sites). Assessment continued for five years after the operations and was used to determine whether community type, as defined from the presence or absence of 72 indicator species, remains the same following logging and burning. They concluded that all but one (a quadrat on a log landing) of the 144 quadrats remained as the same community type following these operations. Hence, although their classification was based in regrowth, they concluded that edaphic and climatic variables rather than disturbance were the major determinants of floristic pattern. However, they pointed out through reference to research on other disturbed forest types that many important stand characteristics, such as biomass, species abundance and cover, vary considerably with time since disturbance. Such variation of these characteristics could also be expected in karri forest.

Stoneman *et al.* (1988) measured forest canopy density in a range of different aged stands in karri and jarrah forest and found that total cover in karri forest reached the value of the unlogged stands within five years of regeneration, rose for another five years and then stabilized above the unlogged value. Overstorey canopy cover reached the unlogged value within ten years. They suggested that the rapid recovery in density in karri forest indicates that evapotranspiration is probably close to the pre-logging value within five to ten years of regeneration. Figures 2 to 7 demonstrate the rapid recovery of forest density in karri forest following fire and regeneration.

Breidahl and Hewett (1992) divided their review of silvicultural research into the floral cycle, germination and regeneration; and the management of the regrowth forest. Considerable research has been done on each of these topics.

Loneragan (1979) documents the floral cycle of karri and the influences on the development of the seed crop. Karri seeds periodically (approximately every four years). Production may be expected to be high and regular under high soil moisture conditions and low and irregular under conditions of low soil moisture. The variability of the karri seed cycle poses considerable practical problems in regenerating cutover stands by means of seed trees. Artificial means of regeneration were pioneered in the early 1970s (see Loneragan 1971) and are used for up to 50 per cent of the cutover area in some years (Breidahl and Hewett 1992).

The factors affecting the germination and early survival of karri have been studied in detail. Studies by Meachem (1960), Hatch (1960), Loneragan (1961, 1971), Loneragan and Loneragan (1964), White (1974), and Christensen and Schuster (1979) all concluded that ashbeds are the most favourable sites for the germination and early survival of karri following logging.

There has been relatively less silvicultural research on jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*) in the Warren Subdistrict, although much has been done in the Dale Subdistrict (see Loneragan 1961; Abbott and Loneragan 1986). Much of this work is applicable to the southern jarrah forest and has been used to formulate silvicultural guidelines for the southern jarrah forests (Bradshaw 1986).

The southern jarrah forest has a number of distinctive characteristics including greater variability of soil and landform types (see Churchward *et al.* 1988), more diverse range of understorey (see Strelein 1988) and a generally longer period of moist soil conditions, than the northern jarrah forest. The impacts of dieback disease may be severe in some community types (Grant and Blankendaal 1988; Strelein 1988), although Christensen (1975) reports resistance to the disease in highly productive sites of the southern jarrah forest. Outbreaks of defoliating insects have occurred in the southern jarrah forest. Leaf miner (*Perthida glyphopa*) has been studied by Mazanec (1980) and gum leaf skeletonizer (*Uraba*

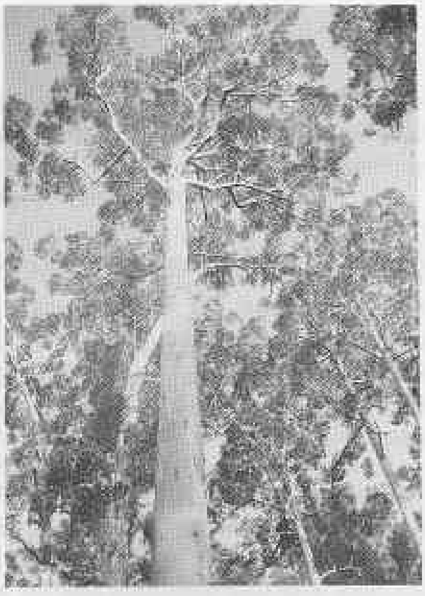

Figure 2
Mature forest near Pemberton
(Grant Wardell-Johnson)

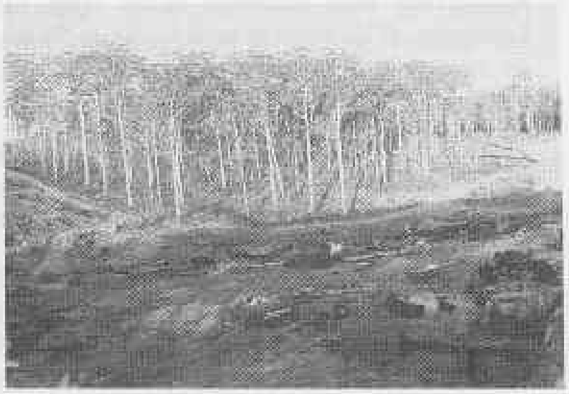

Figure 3
A logging coupe in karri forest following a regeneration burn near Pemberton
(Grant Wardell-Johnson)

Figure 4
The same area as in Fig. 3 four years after regeneration
(Grant Wardell-Johnson)

Figure 5
Fourteen-year old regeneration near Pemberton *(Grant Wardell-Johnson)*

Figure 6
Fifty-year old regeneration near Pemberton
(Grant Wardell-Johnson)

Figure 7
Crown in mature karri forest five years afer high intensity wildfire near Pemberton
(Grant Wardell-Johnson)

lugens) by Strelein (1989).The variability of lignotuber development in different sites is also a consideration when planning regeneration following logging operations (Strelein 1988).

Measurements of forest density in jarrah forest by Stoneman *et al.* (1988) show that overstorey canopy cover and total cover, in both high (>1100 mm) and low (<1100 mm) rainfall areas, exceeded 80 per cent of the unlogged value within five years of regeneration. They reached values similar to the unlogged value in about 20 years and thereafter remained at that value. However, forest density recovered more slowly on poorly drained sites than on better drained sites.

INVERTEBRATES

There are few studies on the effects of disturbance on invertebrates in the Warren Botanical Subdistrict. Two unpublished studies by Curry and Humphreys (1987, 1988) used malaise, light and pitfall trapping to sample insect communities in karri forest in spring and summer. Curry and Humphreys (1988) sampled for four years during which the forest was clearfelled, burnt and replanted with karri seedlings. Curry and Humphreys (1987) also sampled pine, jarrah and karri forest. Sampling in karri forest was carried out over six months in four stands of different management history: two-year-old regeneration; two-year-old, not regenerated; 44-year-old regeneration; and unlogged karri forest, seven years since prescription burning.

Curry and Humphreys (1988) discussed the limitations in their sampling design which included a lack of replication and likely site differences that confound treatment effects and the fact that in these studies, sampling was not continued to determine recovery of invertebrate populations with time since regeneration. Nevertheless, they concluded that logging and regeneration resulted in immediate and major changes to the insect community in karri forest. Dissimilarity between ridge and valley sites was found to be large in all sites but was always greater in regeneration than in mature forest. More families were reduced than increased by the disturbance but the response within orders varied widely. The Dipteran families were most affected by the treatment having both the highest proportion of families increased and decreased by the treatment. High sensitivity to disturbance was found for both the Diptera and Lepidoptera suggesting that these groups may be good indicator taxa. The Scolytinae, Leptopiinae, Sphaeroceridae and Nabidae were found only in treated sites and the Lasiocampidae, Arctiidae and Tachinidae in untreated sites, and represent potential indicator groups. At higher resolution some genera were present only on uncleared (*Digglesia, Pterolocera*) or on treatment (*Pollanisus, Calosoma*) sites. Further analysis may provide indicator species for the rapid evaluation of disturbance in karri forest.

Curry *et al.* (1985), in a study of two sites in karri forest over four years, found more aggregated captures and marked changes in the structure of arachnid communities (including changes in species dominance) immediately following clearfelling and regeneration. It has been suggested that relict groups of spiders and others with poor powers of dispersion may not readily re-establish in areas disturbed by logging or fire or by agricultural clearing even if the latter is rehabilitated (Main 1987, 1991).

BIRDS

Tingay and Tingay (1984) reviewed work on the effects of forest operations on bird communities in the karri forest and reported the results of a one-year census in karri forest with a range of management history. Sampling sites consisted of variable aged forest following regeneration after clearfelling and of mature forest which differed in the period since last burnt for fuel reduction purposes. Bird data were collected along fixed transects in each of four seasons, while vegetation was measured with a simple method of habitat description. They demonstrated that clearfelling of karri causes marked changes in vegetation structure, some of which are still evident 50 years afterwards (see Figs 2 to 6). These changes were found to significantly affect bird communities. However, bird species number and abundance increased with forest age. As expected, populations of species common in low, dense vegetation are larger in young regeneration than in mature forest. Many species in mature forest were absent or uncommon in young forest and a few species which are absent or uncommon in older forest occur in recently clearfelled and regenerated sites.

Most species which occur in mature forest were found to be present in sites of 50-year-old regeneration. However, the relative abundance of bird species in the 50-year-old regeneration fluctuated between seasons and was depressed in winter. Those in mature forest were more stable. It was suggested that 50-year-old forest may not have the continuity of niches present in mature forest (Tingay and Tingay 1984).

Tingay and Tingay (1984) recognized the limitations posed by their sampling technique. These limitations are chiefly concerned with likely site differences which may mask effects; and insufficient sampling effort to effectively record relative bird densities. Pike and Recher (1984) recommend that transects be censused over several days to account for differences caused by weather effects. Nevertheless, Tingay and Tingay's (1984) results demonstrated the influence of stand structure on bird community organization earlier demonstrated by Recher (1969, 1971) in a range of vegetation types on different continents. They also demonstrated that bird populations recover in regenerating forests, with time.

Wardell-Johnson (1987) and Christensen (1988) have reviewed the use of hollows by wildlife in the karri forest. Twenty species which use hollows occur in the karri forest and all occur in the Warren Botanical Subdistrict. Wardell-Johnson (1984) found that 14 of 44 species observed in karri forest in spring 1982 used hollows in trees as nest sites including 34 per cent of all bird detections (4327 total). Thus, hollows are important for the total numbers in bird communities in the karri forest as well as the numbers of species.

MAMMALS

Hollows are also important for mammals. Some 67 per cent (20 species) of the species of mammals occurring in the forest of the south-west use hollows. Nine species (30 per cent of the total forest mammal fauna) require hollows in trees in karri forest. However, not all available hollows are used and the study of the use of hollows in karri forest is, in practice, very difficult. Thus, Christensen (1988) found very little evidence of the use of tree hollows by wildlife in karri forest. Wardell-Johnson (1986) demonstrated the pattern of use of nest boxes by Mardos (*Antechinus flavipes leucogaster*) in 14-year-old regenerating karri forest and suggested that hollows may be limiting for this species in regrowth karri forest.

Mammals that use hollows in trees as nest sites have received little study in the Warren Botanical Subdistrict. The interactions between the Common Brushtail and Western Ringtail Possums, habitat trees and fire, however, have been studied in jarrah forest in the Perup Nature Reserve in the adjacent Menzies Subdistrict (Inions 1985; Inions *et al.* 1989).

Fire

Research on fire behaviour was started in the south-west jarrah forest by Peet (1965) and is now well understood in jarrah and karri forest (see Sneeuwjagt 1971; McCaw and Burrows 1989). Predictive models of fire behaviour in jarrah and karri forest have now been developed (Beck 1989).

McCaw and Burrows (1989) have reviewed the historical patterns of fire use in jarrah forest and report a change from frequent low intensity fires before European settlement, to intense fires following agricultural development and early uncontrolled exploitation of the forest for timber. A policy of fire exclusion was introduced with the Forests Act in 1919 and continued until 1954 when controlled burning for broadscale fuel reduction was developed. This latter policy has been modified to account for selected animal species (Christensen 1983), dieback disease (Shea *et al.* 1981; Burrows 1985), silvicultural requirements (Stoneman *et al.* 1989) and the recognition of fire exclusion areas (Christensen and Abbott 1989).

Several authors have discussed the issue of fire periodicity in the karri forest (Christensen 1972; Talbot 1973; White 1977; Underwood 1978; and Christensen and Annels 1985). Although a detailed examination has yet to be undertaken, fire in the karri forest appears to have been less frequent than in the jarrah forest and some areas may have escaped fires for 30 years or more (Christensen and Abbott 1989).

About 70 per cent of south-west forests are prescription burnt on rotation for fuel reduction. Sections of the northern and central parts of the Darling District have been burnt regularly for about 30 years and the southern areas for about 20 years. The length of time between burns where fuel is to be reduced is based on accumulation rates and averages five to six years for jarrah and seven to nine years for karri forests (Christensen and Abbott 1989). Other areas are burnt less frequently and Christensen and Abbott (1989) listed 42 areas from which fire is excluded as a deliberate policy. National parks and nature reserves include areas of no planned burn, intermediate frequency and fuel reduction (see for example, Smith *et al.* 1990). More than 50 per cent of the public land in the Darling District has not been burnt for more than six years (Muller[1] personal communication 1990).

The high fuel accumulation in karri regrowth (Sneeuwjagt and Peet 1979) prompted the development of techniques for conducting the first fuel reduction burns in young karri regrowth. McCaw (1986) found that such burns could be initiated after 14 to 20 years, depending on site quality, with minimal damage to regrowth.

VEGETATION AND FLORISTICS

Short-lived species that regenerate from soil-stored seed have been studied in detail, owing to their dominance in the understorey of the karri and adjacent forest. Christensen and Kimber (1975) found that certain species were prolific seeders with large seed reserves in the soil. They also found that heat stimulated germination of seed of some legumes and

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that very little germination of those species occurred without heat treatment. However, seed was killed where litter was deep, and seed at shallow depth. In addition, moisture in the fuel or soil has an insulating effect which reduces heat penetration and thus germination. In the field, germination was improved by burning under dry soil conditions but soil temperatures varied greatly within a few centimetres. This variability on a micro habitat scale was used to explain the persistent germination of fire-sensitive species (e.g. *Bossiaea laidlawiana* and *Crowea angustifolia* var. *dentata*) following repeated fires at frequent enough intervals to prevent seeding of the regenerated plants.

Several shorter-lived species of legumes reached maturity and commenced seed production within three years and then quickly senesced (Skinner 1984). The longer-lived legume species *Acacia pentadenia* and *Bossiaea linophylla* had similar seed production patterns. *Bossiaea laidlawiana* and the dominant Rhamnaceae species, *Trymalium floribundum*, did not reach full seed production by age eight. Few differences in seed production were noted with site.

Baird (1988) studied *Banksia seminuda* ssp. *seminuda*, a fire sensitive obligate seed regenerator with a long juvenile period. He found that the juvenile period of *B. seminuda* varies between five and thirteen years and recommended that the frequency of fires in the watercourse habitat of the species be reduced either by excluding fires from those sites or by ensuring the burn rotation interval was more than five years.

Peet and Van Didden (1973) studied the impact of prescribed burning on 'understorey shrubs' near Manjimup. They revealed marked changes in structure as the species recovered from the effects of fire. Persistent species, regenerating from lignotuberous root-stock, recovered rapidly, while 'fireweeds' regenerating from seed regained their former level in cover contribution only in the third year following fire. Sneeuwjagt (1971) described understorey fuels in karri forest using the Levy point technique (Levy and Madden 1933) and determined structural types based on the dominant species comprising the understorey.

Christensen and Kimber (1975) concluded that in karri forest, the mosaic effect of prescribed burning ensures the perpetuation of existing plant communities and that species numbers increased after fire in true and marginal wet sclerophyll forests.

The popularity of *Boronia megastigma* in the wildflower industry prompted a preliminary investigation into the ecology of this species. Christensen and Skinner (1978) suggested that a prescribed burning regime of periodic spring burns in the forest would be of greater benefit to this species in the long term than would more intense autumn burns on the same rotation. This is because, under a spring burning regime, the moist gully habitat of Boronia generally remains unburnt for one or more rotations. Christensen and Skinner (1978) concluded that Boronia sites should remain unburnt for 10 to 15 years and that picking was detrimental to the survival of Boronia plants.

INVERTEBRATES

Most studies on the effects of forest management practices on invertebrate communities in the Warren Subdistrict have concentrated on the effects of fire. These include work by Springett (1976, 1978, 1979), Koch and Majer (1980), Majer and Koch (1982) and Curry *et al.* (1985). These studies have all been in karri forest but have been relatively brief and lack detailed taxonomic treatment.

Majer and Abbott (1989) reviewed the influence of disturbance on the soil and litter invertebrates of the jarrah forest and considered that they were well understood, though conclusions reached have not always been in agreement. The impact of burning on these animals has important implications for the rate of nutrient cycling because many help regulate the decomposition of litter. There is a trend, eastwards from the areas of highest rainfall, of slower litter fauna recovery following disturbance (Majer 1985; Majer and Abbott 1989) which needs to be accounted for in studies of the impact of prescribed burning on decomposer systems.

In jarrah forest, Springett (1976, 1979) found that soil fauna levels had not recovered in the five to seven year interval between prescribed burning treatments, while Abbott (1984) found all but three taxa recovered in density within three years following fire. The importance of taxonomic resolution is critical in studies of the effects of disturbances on invertebrate communities. Conflicting conclusions may also be a consequence of the sampling methods used. Campbell and Tanton (1981) were critical of Springett's (1976) work on the grounds of poor sampling and extraction techniques.

The high rainfall zone of the Warren Subdistrict provides habitat for many species of relict invertebrate taxa. For example, Kendrick (1978) and Solem *et al.* (1982) described new species of extant and extinct snails from the Leuwin Naturaliste Ridge and suggested that those groups of species with poor colonization ability may be vulnerable to disturbance. It has been suggested that certain Gondwanan spider relicts evolved in a rainforest environment and are therefore endangered by the frequent occurrence of fire in their environment unless the time of burning coincides with their dormancy (Main 1987, 1991). Although fire may be a rare event in such sites, occasional high intensity fires are likely in areas of high fuel accumulations such as the karri/tingle forests where many of these Gondwanan relicts occur. Relict spider species such as *Chasmocephalon* sp., *Dardarnus* sp., *Baalebulb* sp. and *Moggridgea tingle* (Fig. 8) have persisted in the relatively non-seasonal climate and moist protected habitat of the red tingle (*Eucalyptus jacksoni*) forest, restricted to a small area (<6000 ha) near Walpole (Smith *et al.* 1990).

HERPETOFAUNA

The level of understanding of the herpetofauna in Western Australia has increased significantly in the past 20 years. There has been an increase in collections and surveys, a doubling of the species described or recognized (How *et al.* 1987) and a large increase in the number of publications (Daze 1984). Most early collectors avoided the subject and there is a poorly documented and recorded sub-fossil fauna. Hence it is difficult to evaluate historical changes in the herpetofauna. Apart from the *Geocrinia rosea* complex, there is little documented evidence on the effects of disturbance on reptiles and amphibians in the Warren Subdistrict.

The *Geocrinia rosea* complex includes four species of frogs exhibiting direct development of the eggs that are restricted to permanently damp sites in the lower south-west of Western Australia (Roberts *et al.* 1990; Wardell-Johnson and Roberts 1991). Two of these have been described only recently (Wardell-Johnson and Roberts 1989; Roberts *et al.* 1990). Wardell-Johnson and Roberts (1991) suggest that the rarity of their habitat requires conservative management practices in riparian habitat on private and public land alike and that protected riparian strips of native vegetation will be necessary to ensure their survival in the agricultural landscape (Fig. 9).

BIRDS

Christensen and Kimber (1975) studied the effects of a high intensity fire in summer, on birds (and mammals) occupying a 40 ha stand of karri regrowth which had not been burnt for 20 years and an adjacent control block. They reported that their results were difficult to interpret owing to large seasonal fluctuations of itinerants. Nevertheless, sightings declined in all strata immediately after the fire but recovered to above pre-fire levels in the lower three levels (four levels were studied) within five months. Christensen *et al.* (1985) concluded that the effect of fire on individual species was in general inversely proportional to their main foraging height in the foliage profile and is largely dependent on the intensity of the fire.

The two main layers forming the karri forest (understorey and overstorey, Fig. 10) support different components of the avifauna. High populations of a few species of residents occur in the homogenous and insulating structure of the understorey (Wooller and Brooker 1980; Wooller and Milewski 1981; Wardell-Johnson 1984, 1985). Four species (Golden

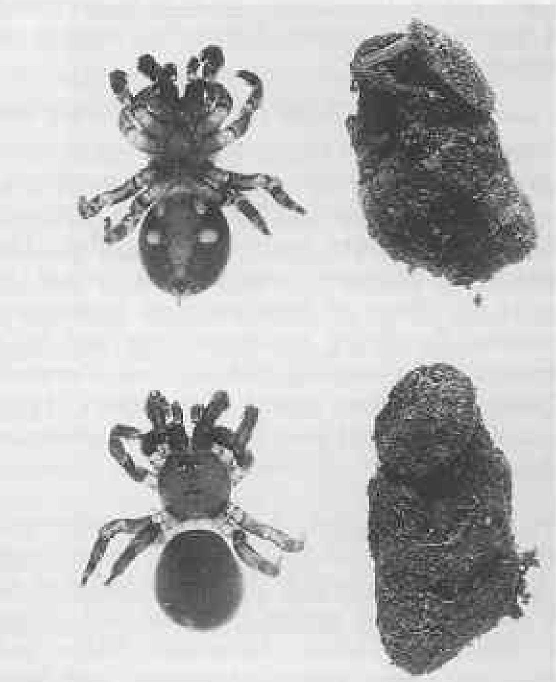

Figure 8
Moggridgea tingle , a relictual species of spider occurring only in the tingle forest near Walpole (Barbara York Main).

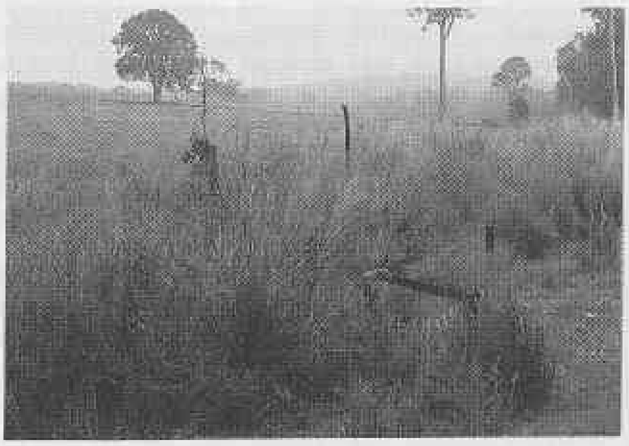

Figure 9
Remnant habitat of the endangered frog *Geocrinia alba* near Witchcliff. Over 70 per cent of the populations of this locally endemic species occur on private land

Whistler, *Pachycephala pectoralis*; White-browed Scrub-wren, *Sericornis frontalis*; White-breasted Robin, *Eopsaltria georgiana*; and Red-winged Fairy-wren, *Malurus elegans*) are common long-lived residents of the understorey with high annual survival rates of adult birds (Brown *et al.* 1990). Variability in the flowering of the canopy influenced the numbers of individuals (but not the number of species) present and seasonal differences in bird populations were greatest in the canopy (Wardell-Johnson 1984, 1985).

Wooller and Brooker (1980) report recovery of bird populations following a low intensity prescribed burn carried out in spring in Treen Brook Forest Block. They concluded that the composition of the bird community in the understorey was largely unaffected by prescribed burning and that many individuals remained in the area after such a fire.

Tingay and Tingay (1984) concluded that prescribed burning in spring in mature forest initially causes a short-term decrease in total abundance of birds followed by an invasion of small insectivorous species which prefer low, dense vegetation. Populations of these species were found to decline as the shrub stratum regenerates. Other species were found to increase in abundance until species number and abundance were largest in forest burnt six years previously. Thereafter, species number and abundance declined. However, some species were more common in long-unburnt forest.

Studies on the effects of disturbance on single species of birds in the Warren Botanical Subdistrict include Brown and Brown (1980), who examined co-operative breeding in robins of the genus *Eopsaltria*, and Rowley *et al.* (1988) who examined the ecology and breeding biology of the Red-winged Fairy-wren. Rowley *et al.* (1988) suggest that prescribed burning during spring may affect the Red-winged Fairy-wren because it is more abundant in areas not burnt for a long time and because of its poor colonizing ability.

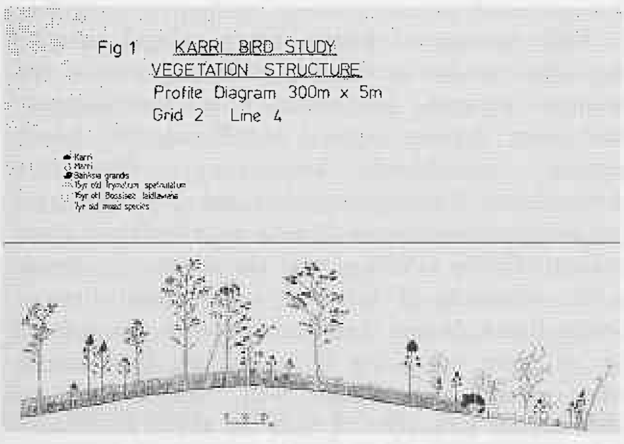

Figure 10
Profile diagram of mature karri forest in Grey Forest Block near Pemberton (Grant Wardell-Johnson).

MAMMALS

Research on the effects of fire on vertebrates in the Warren Botanical Subdistrict was initiated by Christensen and Kimber (1975). Their study reports on the effects of a prescribed fire, of wildfire intensity, on small mammals (and birds) in karri forest in Warren Forest Block near Pemberton. Three species of small mammals were regularly caught in 35 months of trapping, the House mouse (*Mus musculus*), Southern Bushrat (*Rattus fuscipes fuscipes*), and Mardo. House mice colonized the burnt plots within five months, reaching high levels in the year after the fire. No captures were reported 28 months after the fire. Recolonization by the bushrat started in the moist sites after 11.5 months and in more open understorey after 22.5 months. Mardos caught occasionally before the fire were not caught again during the 31 months following the fire. Christensen and Kimber (1975) present other trapping evidence to suggest that the Mardo may be more common in areas which have not been burnt for a decade or more and have high accumulations of litter and dead plant material. However, Mardos are also common in open woodland in Dryandra Forest and rare in karri/tingle forest regardless of biomass accumulation (Wardell-Johnson and Nichols 1991).

Wooller *et al.* (1981) and Wooller *et al.* (1984) have studied the Honey Possum (*Tarsipes rostratus*), in relation to season and nectar availability near Albany. The Honey Possum is considered vulnerable to habitat change brought about by dieback disease caused by the fungus *Phytopthora cinnamomi* or by fire regimes that disfavour key nectar producing taxa (for example, species of the families Proteaceae, Myrtaceae, Epacridaceae).

Christensen and Kimber (1975) report that the Quokka returns rapidly to swamp habitat after it has been burnt, but used it only as a feeding ground for at least a year. A large resident population was established within five years of fire. Christensen and Kimber (1975) suggest that there is some evidence for a population decline at 12-year-old sites and desertion of sites 15 years after fire. However, Quokkas are found in several places in the karri forest which have not been burnt for at least 20 years (Christensen unpublished data). Christensen (1980a) provided a detailed study of the ecology of the Woylie and Tammar in relation to fire in the neighbouring

Menzies Subdistrict. Neither species occur in the Warren Subdistrict.

The number of sightings of Western Grey Kangaroo (*Macropus fuliginosus*) and Brush Wallaby in relation to period since previous fire are presented by Christensen and Kimber (1975). Increased numbers of both species were evident in more recently burnt habitats. The Brush Wallaby was at the time considered common and almost half as many sightings of this species are reported as for the Western Grey Kangaroo.

Christensen and Kimber (1975) concluded that no one prescribed burning regime will encourage maximum population levels of all the mammal species in an ecosystem. They argued that prescribed burning should result in a mosaic effect if it is to simulate the uncontrolled fires and aboriginal burning of the period before colonization by Europeans. Infrequent high intensity fires and very frequent fires were considered factors unlikely to favour a burning mosaic.

Naturalized species

The present landscape in Australia is thought to have resulted from at least 40 000 years of human interaction (Singh *et al.* 1981). European settlement of Australia over the past 200 years has resulted in widespread and rapid modification of the environment, even in areas of retained native vegetation subject to minimal management. These changes are at least in part a result of the introduction, colonization and naturalization (Groves 1985) of a much greater range of species than before this period. The resultant mixture of native and introduced plant species that may exist in a metastable state has been termed synthetic vegetation (Bridgewater 1990). The term may be usefully applied to the biota in general and we may consider synthetic communities. Hence we include all introduced species that have become successfully established.

Though the Warren Subdistrict includes a more intact vertebrate fauna than possibly any other district or region in Western Australia, excepting the north-west Kimberley (Burbidge and McKenzie 1989), significant changes have occurred in species and community composition. Several animal introductions are now dominant components of the terrestrial fauna of the Subdistrict, for example, the Red fox, Domestic cat, European rabbit (*Oryctolagus cuniculus*), Black rat (*Rattus rattus*), House mouse, Laughing Kookaburra (*Daclo novaeguineae*) and European honey bee (*Apis mellifera*).

Other introductions are not yet well established but may become dominant components in the Subdistrict, for example, feral pig (*Sus scrofa*). The predicted expansion of the range of the Marine toad (*Bufo marinus*) (Sabath *et al.* 1981) and several species of birds (e.g. Common Starling, *Sturnus vulgaris*), and insects (e.g. European wasp) includes the south-west of Western Australia. None of these species is considered to be an ecological specialist and all except the Marine toad originate in climatic regimes similar to that in south-western Australia. Some species, such as the House mouse, are most common in communities subject to disturbance although this species is well established throughout south-western Australia.

The demise of many ground dwelling vertebrates in native vegetation has been largely attributed to the introduced Red fox which has also had considerable influence on the recovery of native fauna following disturbance (Christensen 1980b; Kinnear 1989; Kinnear *et al.* 1989; Friend 1990). The control or eradication of this species is considered the highest priority in fauna management in south-western Australia, along with the prevention of further introductions and expansions in the ranges of other introduced species, such as the Common Starling.

About 10 per cent of Australia's total of 15 000 to 20 000 species of vascular plants are introduced (Michael 1981). Although less taxa of weeds occur in the Warren Subdistrict than the Perth region (547 of 2057 (26 per cent) for Perth compared with 319 of 1947 (17 per cent) for Warren, Hopper *et al.* this volume), some of them pose major problems to conservation managers (Anon. 1987; Smith *et al.* 1990). For example, granite outcrop communities of the Porongurup Range, rich in endemic species, have been successfully invaded by *Plantago lanceolata*, *Cirsium vulgare*, *Briza* spp. and *Trifolium* spp. following disturbances such as grazing (Hopper *et al.* this volume). Similarly, *Rubus discolor*, *Rubus selmeri* and *Solanum nigrum* are dominant species along some creeklines in the karri forest (Fig. 11).

Major sources of weeds include rubbish tip sites (e.g. *Zantedeschia aethiopica*, *Ricinus communis* and *Solanum nigrum*), settlements (e.g. *Leptospermum laevigatum*, *Boralea pinnata* and *Eucalyptus sieberi*) adjacent agricultural land (e.g. *Pennisetum clandestinum*, *Ehrharta calycina* and *Trifolium* spp.) and revegetation schemes (e.g. *Acacia dealbata*, *Pinus radiata*). Griffin (1985) related the presence of weeds to the proximity of farmland and frequent fires in Smiths Brook Nature Reserve. However, the role of fire in either enhancing or minimizing invasions in native plant communities will depend on the physiological properties of both the native community and the invading organisms, and the fire regime (Christensen and Burrows 1986). Generally, frequent fire favours resprouting perennials over non-resprouting species, disadvantages species which

Figure 11
Blackberry (*Rubus* sp.) infestation along the Warren River near Pemberton. Blackberry is capable of becoming a dominant structural component of the flora in some riparian zones in the karri forest (Grant Wardell-Johnson).

rely solely on on-plant storage of seed, promotes herbaceous over woody plants, promotes grasses and forbs over dicotyledons, creates pure stands and reduces subsequent fire intensity (Vogl 1977). Frequent fire or other disturbance also favours aggressive introduced species and allows wind-dispersed species to establish. In this context, the word 'frequent' means less than a five-year interval. Many introduced species are able to resprout from rootstocks, and thereby survive a wide range of fire regimes (Christensen and Burrows 1986). Many introduced species, particularly grasses, are also aided in their spread and establishment by fertilizer drift from agricultural land.

Plant disease caused by introduced (and native) pathogens are perhaps the most serious disturbances to remnant native vegetation in the south-west. Dieback disease caused by the soil-borne pathogen *Phytophthora cinnamomi* has been present in the jarrah forest since the 1920s (see Shearer and Tippett 1989 for a review). Most of the information relating environment to disease development has come from research in the high rainfall zone of the Dale Botanical Subdistrict. However, the impact of plant disease in heath communities may be more serious than previously envisaged and major structural changes can occur (Wills 1992; Fig. 12).

Regeneration, dieback and site productivity were discussed by Strelein (1988) in the management of 17 site types in southern jarrah forest. All but one site type (type Q - high quality forest on fertile well drained loams) have some susceptibility to dieback disease, suggesting that logging operations could be more problematic than in the northern jarrah forest owing to the presence of high water tables and a longer period of moist soil conditions. However, climatic differences between northern and southern areas result in shorter periods of suitable soil temperatures and soil moisture levels which are necessary for activity of the fungus (Christensen 1975).

Although much is known about *Phytophthora cinnamomi* in jarrah forest, relatively little is known about most of the other *Phytophthora* species, or about *P. cinnamomi* in any other communities. *Phytophthora citricola* probably has the greatest potential to compound the problem of dieback disease caused by *P. cinnamomi* in the jarrah forest (Shearer and Tippett 1989). Other species may be serious pathogens in other environments. Air dispersed canker-causing fungi, such as *Botryosphaeria ribis* (Old *et al.* 1990), have severe impact in sandplain communities (Fig. 13) well outside the karri forest.

Figure 12
Impact of dieback disease caused by *Phytophthora cinnamomi* in a sandplain community near Walpole (Grant Wardell-Johnson).

CURRENT RESEARCH

Research relevant to disturbance ecology in the Warren Subdistrict is currently being undertaken within CALM's Biogeography, Native Forest Silviculture, Economic Entomology, Fire, Fauna and Flora research programs.

Figure 13
Impact of air-borne canker disease on a sand plain community at Black Point (Ray Wills).

Current disturbance research continues to concentrate on karri and jarrah. The effects of thinning and fertilizing on stem diameter, height, crown and branch development in karri regrowth forest in community types Stoate, Shea and Annels (Inions *et al.* 1990) is currently being examined by Hewett[2] (personal communication 1990). She is recording the cover-abundance of all vascular plant species in thinning experiments. Experiments to examine aspects of establishment, scrub control, site factors and fertilizing, spacing and establishment in disturbed jarrah sites are also currently in progress (Strelein[3], personal communication 1990).

Growth rate, crown recovery, bark thickness changes, and stem damage in response to fire in karri regrowth is currently being studied by McCaw[4] (personal communication 1990). Hewett (personal communication 1990) is examining similar responses in community type Stoate.

The incidence of borer (*Tryphocaria acanthocera*) infestation in karri forest is also being examined. The external symptoms of infestation of karri by borer and the incidence of infestation of borer in even-aged karri are currently being examined by Abbott[5] (personal communication 1990). The impact of wood-rotting fungi on karri regrowth in a variety of community types is currently being investigated by Davison[6] (personal communication 1990).

Current studies on economic entomology in the jarrah forest of the Warren Subdistrict include research on the impacts of jarrah leafminer and gum leaf skeletonizer on the growth of jarrah (Abbott, personal communication 1990). Abbott is also comparing effects between the northern and southern jarrah forest and examining the effects of fire on these insects. Farr[7] (personal communication) is examining fecundity and spatial distribution of gum leaf skeletonizer in relation to jarrah in the Warren Subdistrict.

Wardell-Johnson is examining floristics within an age series in a single community type to determine whether plant species composition and cover in the karri forest is related to age since disturbance. A complete list of vascular plant species has been gathered from 95 permanently located 400-m^2 quadrats, within a single community type (Shea) (Inions *et al.* 1990).

Current research on birds in the Warren Botanical Subdistrict includes an eight-year study in permanent sites in karri forest in Gray Forest Block. Following a two-year period of calibration (see Wardell-Johnson 1985), sites were either burnt, small gap (3 ha) felled, clearfelled or left as controls. Mistnetting, censusing and foraging observations were used to study the birds for five years after the operations. The structure and floristics of the vegetation are also assessed annually. Bird community composition is similar in small (3 ha) and large areas of retained mature forest and these areas have an important influence on the species composition of adjacent regrowth (Wardell-Johnson, unpublished data). Understorey bird species rapidly colonize regrowth as its structure develops.

The same methods of censusing birds employed in Gray Forest Block were used in a survey of the Walpole-Nornalup National Park. Survey sites were chosen according to different burn ages in all major vegetation structural types in the area. Since starting the work in December 1985, a wildfire burnt 34 of the 67 survey points in the Hilltop section of the Park, allowing the response of the bird community and terrestrial vertebrate fauna following wildfire to be assessed in comparison with sites that were not burnt. This work also addresses edge effects and structural changes to the vegetation. Measures of the vegetation

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3 G.J. Strelein, Department of Conservation and Land Management, Bunbury.

4 W.L. McCaw, Department of Conservation and Land Management, Manjimup.

5 I. Abbott, Department of Conservation and Land Management, Como.

6 E. Davison, Department of Conservation and Land Management, Como.

7 J. Farr, Department of Conservation and Land Management, Manjimup.

structure and floristics were made each year for two years.

Serventy[8] (personal communication 1983) censused a 10.4-ha study site in a 105-ha coup of jarrah-marri forest near Pemberton between 1976 and 1982. The stand was heavily selection cut in 1978. Total numbers of individuals and species declined following logging but regained pre-cutting levels four years later (1982). Species using the outer foliage, mid-storey and understorey remained lower by 1982, while birds inhabiting the shrub layer increased. The lack of an untreated control limited the applicability of the results obtained, although they may be used as comparative data for other studies.

Research is in progress to determine whether hollows are limiting in the recolonization of regenerating karri coupes by Mardos and to investigate the effects of karri forest management techniques on hollow-nesting animals. Nest boxes are used in both studies though in the latter study only six species have so far used the boxes. Nest box studies are of limited use in tall forest as many species nest above the height where nest boxes can feasibly be located. Similarly, very large nest sites are required by some species.

A detailed study of the distribution and commercial utilization of Boronia species will enable the development of a wildlife management program for species subject to commercial exploitation (Hopper,[9] personal communication 1989).

Monitoring of long-term responses of plants to fire regimes commenced with work by Christensen in 1971 who aimed to remove *Bossiaea laidlawiana* and *Crowea angustifolia* var. *dentata* from an area of mixed jarrah and karri forest near Manjimup using fire of varying frequency. A total of six burns were completed in the treatments burnt at three-year intervals by 1986, but both *C. angustifolia* and *B. laidlawiana* were still found to be dominant (Christensen and Abbott 1989). The frequently burnt (three-year intervals) treatments were also found to have the highest number of species of plants.

Recent studies by Burrows include spring and summer burning of three, six and 12-year rotations in four study locations. These studies aim to provide biomass accumulation rates, complete species lists and structural data over a range of associations and fire regimes. Four main study locations were chosen: an area of karri forest at Strickland Road; low scrub and sedgeland sites of the Pingerup landform unit (Churchward *et al.* 1988); open jarrah forest at Perup; and an area of jarrah forest in the Blackwood Plateau. The latter two sites are in the Menzies Botanical Subdistrict.

The response to fire of all vascular plant species recorded in 145 permanent plots is being examined in the Walpole-Nornalup National Park. A total of 770 species have so far been collected. Monthly revisits to the quadrats has enabled the provision of a more complete species list for the quadrats, the recording of flowering status of all vascular plant species encountered and an understanding of the response of each species to disturbance. This study will provide similar information on fire in community type Wallace (Inions *et al.* 1990) in the Walpole area as research on community type Shea (Inions *et al.* 1990) in the Manjimup area.

Research to examine the ecological effects of an intense fire in karri forest was established by Christensen in 1971. Trapping continued until 1983, providing 12 years of trapping data on the effects of fire on populations of small mammals. Population fluctuations of the Southern Bushrat were found to override the long-term effects of a single fire on this species.

Research on plant disease in the southern forest and coastal areas of Western Australia is now in progress (Wills[10] personal communication 1990). Long term monitoring plots are being established and dieback vulnerability is being assessed on a species by species basis·

Current research on introduced predators emphasizes the severe impact of the fox on native fauna. Algar[11] (personal communication 1989) is researching its ecology and biology to find an efficient method of control. His work includes sites in the Darling District (e.g. Perup Nature Reserve where it is associated with the long-term monitoring of the Woylie population: Burrows[12], personal communication 1990) but not the Warren. Studies designed to enable the eradication or long-term effective control of the fox will be necessary for the future management of ground dwelling vertebrates generally in Australia. Christensen conducted a preliminary study of the Quokka in karri forest.

8. J. Serventy, Department of Conservation and Land Management, Manjimup.

9. S.D. Hopper, Department of Conservation and Land Management, Woodvale.

10. R.T. Wills, Department of Conservation and Land Management, Manjimup.

11. D. Algar, Department of Conservation and Land Management, Woodvale.

12. N.D. Burrows, Department of Conservation and Land Management, Woodvale.

Predation by foxes and the scarcity of study animals led to the termination of this work. The possible influence of disturbance (e.g. roadworks and felling operations) on predation of vulnerable species like the Quokka requires investigation.

Collections of the Warren Subdistrict flora are ongoing and continue to contribute to the knowledge of the naturalized flora of the area.

HIGH PRIORITY ADDITIONAL RESEARCH REQUIREMENTS

Most ecological research on the effects of disturbance on wildlife of the Warren Botanical Subdistrict has been in karri forest in the Nornalup system. Exceptions include studies in the Walpole-Nornalup and Mt. Frankland National Parks by Wardell-Johnson and along the south-coast between Albany and Busselton by Gibson[13] (personal communication 1990). We believe an expansion of such research into surrounding community types is needed, both in terms of single species studies and site-based ecological surveys. It is essential to understand the karri forest in the context of the Warren Botanical Subdistrict as a whole. Hence an understanding of the overall pattern of the biota for the Subdistrict is required.

Site-based ecological research should be expanded independently to the siting of specific coupes to provide a baseline understanding of the pattern of karri forest biota. A 'pre-logging survey' approach to ecological research is not considered to be a profitable use of limited resources. Rather, an investigation should be made which emphasizes particular groups or taxa.

The poor taxonomic base of invertebrate work urges that high priority be given to such work in the Warren Botanical Subdistrict in general and the karri forest in particular. Experimental work to examine the effects of disturbance on invertebrates will establish those vulnerable taxa and sites in need of special consideration in management operations and allow operations to be designed accordingly. Curry and Humphreys (1988) provide some insight into this problem for taxa caught in malaise and light traps but they did not study recovery after regeneration. Considerable additional work is required, including studies on ground dwelling invertebrates. Further experimental work should be accompanied by considerable taxonomic work. Groups that include relictual taxa of poor colonization ability are in particular need of study. Sites in high rainfall zones in karri-tingle forest may be expected to harbour such species.

Research on the growth of karri should now be directed to regeneration in areas where it grows in association with marri and jarrah (e.g. community-type Stewart, Inions *et al.* 1990). Some of the sites currently logged for jarrah are difficult to regenerate (Strelein 1988; Bradshaw[14], personal communication 1989). The most urgent silvicultural research on jarrah in the Warren Subdistrict is concerned with regeneration and establishment techniques on these sites. The identification and mapping of these sites may require further community study.

The opening of the canopy in thinning operations may extend the burning season in karri regrowth stands (McCaw, personal communication 1990). However, accumulations of logging debris may pose a considerable fire hazard. Fire behaviour is well understood in young unthinned stands and should now be directed to thinned stands.

While it is well established that stand structure is critical to the organization of species and communities at any one place or time (Recher 1969, 1971), temporal and spatial scales must be considered in examining the effects of broadscale management operations on wildlife (Recher *et al.* 1987). Rotation length and conservation strategies with respect to retention of mature forest are important in this context (see Fig. 14). For example, two forms of conservation strategy exist in the karri forest; discrete areas of forest reserved from logging such as national parks and nature reserves; and unlogged areas in any forest block (blocks average about 5000 ha). A series of corridors of forest are left unlogged on a block by block basis forming a network of corridors of road, river and stream zones which connect with National Parks and Nature Reserves. Continuing research into the optimal distribution of these and their long term management (Wardell-Johnson *et al.* 1991) is desirable.

Research is also required on the influence of individual mature trees (e.g. habitat trees) on particular species or communites in the context of clearfelling and other logging methods. Detailed studies to determine an age series of vertebrate and invertebrate (particularly those species of poor colonization ability) fauna in areas of intensive harvesting remain a high priority. The study of bird

13. N. Gibson, Department of Conservation and Land Management, Woodvale.

14. J. Bradshaw, Department of Conservation and Land Management, Manjimup.

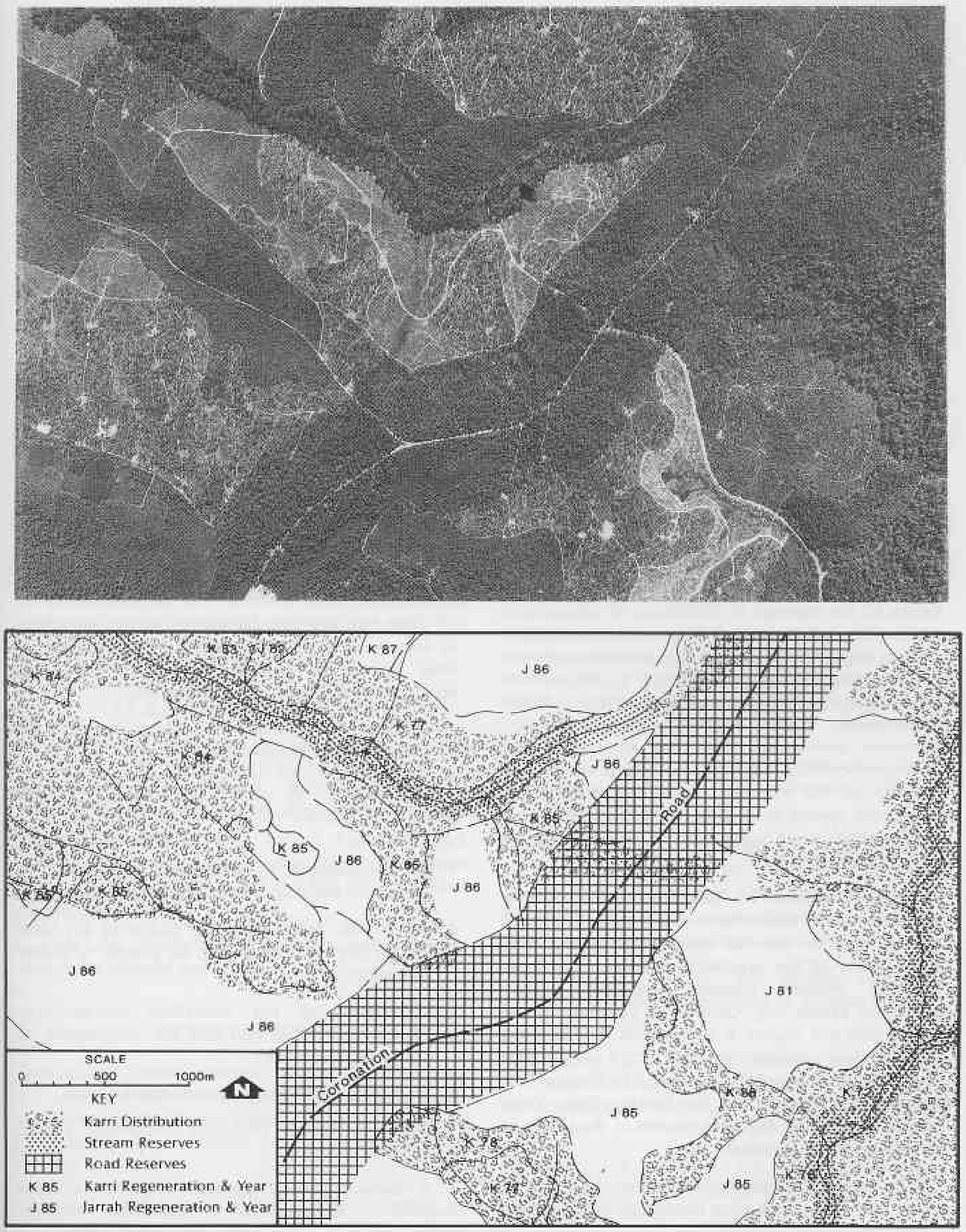

Figure 14
The spatial pattern of harvesting and regeneration in an area near Pemberton. Note the pattern of the distribution of road, river and stream zones.

communities in areas of different management history in the karri forest is a logical extension of the studies in permanent plots described earlier, as the composition of the community occurring in the overstorey is affected by structural change for a considerable time (Tingay and Tingay 1984).

The program approach adopted by the Department of Conservation and Land Management should be used in further research in the Warren Subdistrict to allow the establishment of integrated studies on the most pressing areas remaining. For example, data on the distribution of most forest vertebrates are inadequate to define changes in status or be useful for predictive modelling of the effects of disturbance. Models of the impact of disturbance will follow from integrated studies such as those on fire in the Eyre District (Friend,[15] personal communication 1989).

Considerable research is now available or in progress on plant species known to regenerate effectively from soil-stored seed or that resprout from lignotubers following disturbance. However, not all species regenerating by other means (e.g. canopy stored seed) have been studied. For example, little is known of the response to disturbance or management needs of most fire-sensitive obligate seed regenerators with a long juvenile period (e.g. *Banksia seminuda* ssp. *remanans*, *Banksia verticillata* (Fig. 15), *Banksia occidentalis*, *Grevillea brevicuspis*, *Hakea lasianthoides*, *Hakea oleifolia*, *Dryandra sessilis*, *Persoonia microcarpa*, *Petrophile diversifolia* and *Isopogon formosus*). Similarly, no work is currently in progress on the response of bulbous, cormous or herbaceous species to disturbance, particularly spring burning, that occurs when many of these species are actively growing.

Research emphasis on fauna is required on species considered to be vulnerable to disturbance. Species of animals of poor dispersal ability (e.g. snails, some Arachnidae), of low population densities (e.g. Brush Wallaby, Western Ringtail), requiring patchily distributed habitat (e.g. Quokka) or requiring habitat components that require a considerable time to form (e.g. hollow nesting species such as Baudins Cockatoo, *Calyptorhynchus baudinii*, McKenzies Bat, *Falsistrellis mckenziei* and the Barking Owl, *Ninox connivens*) must be studied in relation to the effects of forest use and management.

The timing and cause of formation of hollows in karri, marri and jarrah trees requires further research. Research by Mackowski (1984) and Faunt[16] (personal communication 1990) would serve as a useful basis for the detailed study of these eucalypts. In view of the long term required for hollow formation in karri (Wardell-Johnson, unpublished data), marri (Wardell-Johnson, unpublished data), and jarrah (Inions 1985) trees, the guild of birds and mammals requiring hollows as nesting sites should be examined in detail and preferably as single species studies.

Dieback disease has the potential to lead to major long term structural and floristic changes in a wide range of vegetation communities in the south-west leading to changes in animal communities. The monitoring of fauna in association with the establishment of quadrats for floristic study will allow predictions of the future of dieback-infected communities.

Changes in biomass and cover that may result following disturbance may also lead to changes in microbial communities (Shearer, this volume). The importance of microflora and fauna in the functioning of ecosystems has not been studied in the Warren Subdistrict and will require urgent attention.

There has been considerable research on the effects of disturbance on wildlife of the karri forest. Priority areas for further research relevant to disturbance ecology in the Warren Subdistrict include:

- development of an improved understanding of the overall pattern of the biota;
- the impact of disturbance on invertebrate communities and the identification of indicator taxa;
- the development of predictive models of the impacts of disturbance on vertebrate communities;
- the growth, development and decline of key plant species (e.g. karri) including the process of hollow formation;
- the control of key naturalized species (e.g. *Phytophthora*, Red fox) and the maintenance of community processes;
- the role of microflora/fauna communities; and
- vulnerable species (including Gondwanan relicts) and their habitats.

A multidisciplinary approach to process oriented research is recommended in disturbance ecology.

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Figure 15
A stand of *Banksia verticulata* four years after fire in the Walpole-Nornalup National Park. This species has on-plant seed storage and is sensitive to fire (Grant Wardell-Johnson).

Regional staff are now involved in the establishment and monitoring of ecological reference sites applicable to operations involving disturbance.

ACKNOWLEDGEMENTS

We thank Ian Abbott, Janet Farr, Penni Hewett, Angas Hopkins, Lachlan McCaw, Roger Underwood and Ray Wills, for comments on an earlier draft of this manuscript. Joanne Healey typed a draft of this manuscript, Michelle Pree drafted Figure 1, Paul Davies and Annette Turpin drafted Figure 8, Barbara York Main provided Figure 9 and Ray Wills provided Figure 14.

We also thank Malcolm Howes and Marianne Lewis for editorial comments.

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