How Fires Affect Biodiversity

By Dr A. Malcolm Gill (1996)

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Abstract

The ways in which fires affect biodiversity are considered using examples from the semi-arid mallee, the cold Tablelands of Tasmania, the woodlands of the Australian Capital Territory (ACT) and coastal heathlands of mainland southeastern Australia. In the mallee, many plant species lie hidden in the soil as propagules - rather than being apparent as mature plants. Fire may allow these species to germinate and appear above ground. In Tasmania, the endemic pencil pines, *Athrotaxis* spp., are very fire sensitive, grow very slowly, have seed for regeneration only infrequently, and have low rates of spread. Their relationships with fire regimes have not been fully determined but fires, even in mature communities, may cause local extinctions. In the ACT, understanding the local persistence of the common mistletoe, *Amyema miquellii*, in relation to fire requires consideration of the heights this hemiparasite lodges in trees because different fire intensities generated in grassy understoreys can kill plants at varying heights. If a population is killed by fire, a source of seed outside the burned area is needed to replenish it *via* the mistletoe bird. In southeastern heathlands, the vulnerable ground parrot may be found. For the maintenance of a reliable source of seed to feed on, fires may be necessary to suppress shrubs and enhance graminoids. Birds may recolonise sites a year or more after fire if there are suitable breeding populations within dispersal distance. The relationships between fires, fuels, plants and animals have various levels of dependency, some illustrated in this paper, but our knowledge of the interactions of fires and most organisms - even vascular plants and vertebrates - is limited.

Key words

fire regimes, biodiversity, mallee, mistletoe, endemic conifers, ground parrots.

Introduction

With about 20,000 species of vascular plants, a similar number of species of non-vascular plants, 5800 species of vertebrate animals, over 200,000 species of invertebrates and 250,000 species of fungi, the biodiversity of Australia (Nielsen and West 1994) is immense. Considering that fires may affect most of the land surface of Australia, there are many opportunities for fires to promote or adversely affect biodiversity. A number of principles relating fires to biodiversity are known but how fires affect all Australian species is far from well known. Even among vascular plants we have recorded only the crudest type of response to fires for a little over ten per cent of the flora. The Author is compiling a Register from the literature and from lists made by collaborators. By understanding relationships between organisms of different trophic levels and how fires affect them, rather than studying how fires affect different species at different trophic levels separately, a more comprehensive appreciation of the effects of fires on biodiversity can be obtained.

If one considers the inter-relationships between plants and between plants and animals, it appears that there are some relationships more critical than others in relation to their responses to fires. If a species is absolutely dependent on another, and the latter is a fire sensitive one and thus more likely to become extinct (Gill and Bradstock 1995), then the combination is sensitive. On the other hand, if an animal species is a generalist herbivore, it may be expected to be less sensitive to fires from the point of view of species' dependencies.

In this paper, ways in which fires affect biodiversity are considered by example. The first example arises from what were perhaps the most disastrous fires in Australian social history, in 1939. The example concerns plants which respond to fires after direct exposure and those which respond to fires although no plant is actually exposed to them. The second example comes from what may have been the most disastrous fire in Australian ecological history, in 1960-61. In that example, a woody plant and its dependent non-vascular plant are examined in terms of their long-term persistence. The third example concerns the way fires affect a dependent plant-plant-animal relationship. The final example is of a bird dependent on one group of plants but adversely affected by another; in this case fires suppress the latter group, albeit temporarily.

Fires are a consumer of plant material and, as such, have dependencies on those plants which produce the fuel. While all plants may be said to produce fuel, only a small proportion contribute significantly to the fuel which carries the fire. Removal of the fuel contribution of most species will make no difference to fire spread. The extent of dependency varies from place to place. In the examples that follow, the relationship between fires and fuel sources as well as that between sections of the biota will be described and illustrated.

Influence Diagrams

For each example, below, a diagram of presumed relationships has been constructed (Figs. 1-4). These diagrams illustrate some of the variety found among interactions between fires, plants and animals. Organisms, parts of organisms, and fire, are linked in the diagrams by sets of arrows. If there is only one arrow this suggests that the arrowed item is absolutely dependent on the indicated source. A fruit or seed is absolutely dependent on the mother species so the single arrow indicates this. Of course, if there is more than one arrow, then the relationship is less dependent. If a fire adversely affects an organism, or part of an organism, then this is indicated by an arrow with bars across the shaft.

Victorian Mallee burnt in the '39 Fires

In terms of lives lost and area covered, the 1939 fires were the most serious in Australian history. Seventy one lives were lost (Pyne 1991) while a large proportion of the Victorian forest estate was burnt (Luke and McArthur 1978). Parts of Tasmania, South Australia, New South Wales (NSW) and the ACT were also affected (Pyne 1991) during a fire season focussed on January 13, 'Black Friday'. Three days before the calamitous events of 'Black Friday', a fire burnt in the Victorian mallee north of Hattah. Although small - only '25 acres' - this fire was one of great interest because its effects on the flora were examined by an astute observer and reported in *The Victorian Naturalist* (Zimmer 1940).

The vegetation at the site consisted of 'mixed Mallee scrub and porcupine grass' and was 'identical' with the surrounding country. About six weeks after the fire a 'splendid downpour' of 373 points of rain (95mm) occurred. Soon the burnt area was a 'mass of flowering annuals, perennials and seedlings' while the unburned area apparently showed no effect of the fire or the rain. Nearly a year after the fire, 63 species were recorded in the burnt area, of which 53 were 'new' to the site. The new plants consisted of 26 species of annuals, 14 species of perennials and 13 species of shrubs.

There are two possible sources for the 'new' plant species - from an on-site soil-seed bank or from an external source. Given the rate of response of these species and their numbers, the soil-seed bank is the most likely source (Fig.1). As time since fire increased, the number of species would decline until only the small number originally present would again be visible. The new species would be expected to rejoin the soil-seed pool and represent hidden biodiversity - to be revealed only by another fire. Species of the hidden biodiversity may be called ephemerals (Fig.1, below).

The variety among the species of the site was remarkable. Among the old species there were several mallee species (*Eucalyptus* spp.), the prickly hummock grass *Triodia irritans* and the rhizomatous *Dianella revoluta*. Overall there were 23 families represented. The fire was carried in the old species (litter, dead standing matter and live plants). The fire was unlikely to be dependent on the miserable and scanty specimens of *Stipa*, *Tricoryne*, *Gahnia* etc. that Zimmer listed, but likely to have spread in the eucalypt litter (26 per cent cover) and plants of *Triodia* (five per cent). There was much bare ground (69 per cent) at the time of the fire so the fuel was discontinuous. Under these conditions, fire spread would be dependent on wind-blown flames from the *Triodia* being long enough to cross gaps or on burning brands from the mallee eucalypts being lofted from one patch to another (Bradstock and Gill, 1993).

Fires affect the plant biodiversity of the mallee community according to the responses of the individual species and the competitive relationships between them. From the general circumstances (Fig. 4.1), I have singled out two examples to illustrate some plant species' responses to fires: (i) mallee eucalypts ('old' species in Zimmer's terms); and, (ii) the herbaceous *Haloragis odontocarpa* (one of the 'new' species), both studied by Noble (1982, 1989).

Figure 1:

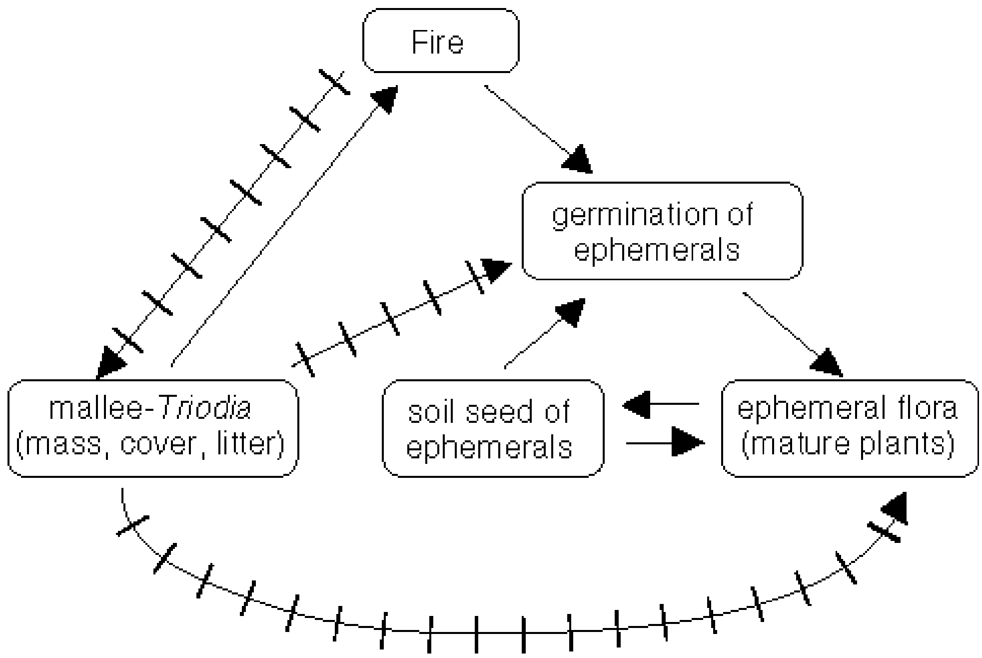

Figure 1: Some of the inter-relationships between fire, fuel, ephemerals and long-lived plant species in the Victorian mallee. The relationships illustrated should be considered to be indicative rather than definitive. The plain arrows represent positive influences, the barred arrows negative influences.

The mallee eucalypts studied by Noble (1982) are classified as resprouters. When burned, adult plants of these species react by resprouting with only a small percentage dying under usual circumstances. However, Noble (1982) showed that with repeated burning in autumn it is possible to markedly reduce populations. Spring burning, however, had remarkably little effect.

H. odontocarpa is an herbaceous species of the hidden diversity of mature mallee. At Pooncarie, in Noble's (1989) experiments, it appeared in abundance in the first post-fire growing season if plots were burned in spring or autumn but not winter. The extent of the response was apparently a feature of the size of the soil-seed pool of the species because two paddocks with quite different intervals since the last fire responded differently (Noble 1989). Differences in soils between the paddocks were not considered, implicitly, to affect the abundances of this species.

Tasmanian Fires (1960-'61) and their impact on pencil pines

On the Central Plateau of Tasmania in 1960-61, a large fire (Mitchell 1962) became what was arguably the most ecologically significant fire to be recorded throughout Australian history. This fire burned an area of over 30,000 ha including 'extensive areas of deciduous beech and coniferous vegetation' (Jonathan Marsden-Smedley, Draft Management Plan for Central Plateau, in preparation); it burned peats (Mitchell 1962) thought to be over 3000 years old (after Thomas and Hope 1994; McPhail 1994 pers comm); and, caused local extinctions of certain endemic conifers, viz. *Athrotaxis cupressoides*, *Diselma archeri* and *Podocarpus lawrencii* (Kirkpatrick and Dickinson 1984). This fire was one of several which burned from October until February, eventually covering an area of highland of about '500 square miles' (1300 km2, (Mitchell 1962). 'The damage caused by these fires can be regarded as no less than catastrophic _ in increasing the erosion hazard [and damage to] the hydrology of the catchment.... This is probably the first time this area has been burnt, certainly since settlement, as it is normally too wet.' (Mitchell 1962). Ten years after the fires, Shepherd (unpub) estimated that 307 km2 of the 1280 km2 that had been severely burned had attained only ten per cent cover (Shepherd et al. 1975). These areas 'are unlikely to regain their prefire state within the next several thousand years' (Marsden-Smedley, unpub.).

Athrotaxis has three species, two of which - *A. selaginoides* and *A. cupressoides* - are considered here. These species have similar life histories and overlapping distributions. They occur in parts of the Central Plateau and western Tasmania (Cullen and Kirkpatrick 1988). Of particular significance to biodiversity conservation is the presence of an epiphyllous lichen *Roccellinastrum flavescens* exclusively on the leaves of *A. cupressoides* in Central Tasmania (Kantvilas 1990 and Fig. 4.2a), in a wet and cold environment. Some of the remarkable features of the phenologies and life histories of *Athrotaxis* spp. are that:

- they are very long lived - over 1000 years (Ogden 1978) but fire sensitive (Kirkpatrick and Dickinson 1984);

- seed production may not begin until plants have a stature of about 2 metres (Cullen 1987);

- growth rates in height are very slow, plants 1 m tall having an average age of 42 years in one example from *A. selaginoides* and 55 years in *A. cupressoides* (Ogden 1978);

- seed production is episodic, heavy seeding occurring at five to six year intervals (Calais and Kirkpatrick 1983), and synchronous (Cullen and Kirkpatrick 1988a);

- seeds are dispersed soon after maturity as cones and are not serotinous (Ogden, 1978; P. Cullen, 1994 pers comm); and,

- root suckering may take place in *A. cupressoides*, particularly in bogs (Cullen and Kirkpatrick 1988a).

The 1960s fires probably burned over terrain that was largely organic although some *Athrotaxis* appear to have been at least partly rooted in mineral soil (from photographs). Presumably peat fires were ignited by fires burning fuels above the ground surface. It is possible to have a surface fire over peat without having a peat fire if the substrate is too wet to ignite. The distinction between these fire types is important because although surface fires may kill above-ground parts of plants, buried buds and seeds often survive them; in peat fires, however, all below ground tissues may be killed thereby confining sources of regeneration to unburned areas. *Athrotaxis* may grow on substrates varying from block streams (non-organic terrain) to well drained soils to bogs (Cullen and Kirkpatrick 1988a).

What caused the apparent local extinctions of *Athrotaxis* in the Central Plateau areas burned by fires more than 30 years ago? Many conifers hold seeds in cones and release them when killed by fire or other agencies, but this avenue for regeneration of the species is unlikely in *Athrotaxis* because of the episodic nature of seed production and lack of serotiny among cones (see above). Some areas of *Athrotaxis* undoubtedly remained unburned, thereby providing a potential source of seeds for regeneration in adjacent burned areas. However, if first seeding takes place when plants reach heights of 2m, if dispersal distance is equal to two times plant height (Forestry Commission of Tasmania Internal Report, quoted by Cullen, 1987), and plants attain heights of 2 m in 100 years, a spread rate of about 4cm yr-1 may be estimated. Even if the plant height reached at first seeding was ten times that used in the calculation, the rate is still incredibly slow. Another potential source of regeneration may occur when root suckers develop in mineral soils after shoot systems have been killed by surface fires. However, suckering appears to be less likely in mineral soils, being largely confined to bogs, and only in *A. cupressoides* (Cullen and Kirkpatrick 1988a). Root suckering would have been infrequent where peat, which commonly burned in the fires of the sixties (Mitchell 1962), burned to completion.

The above considerations seem to suggest that any fire is anathema to the survival of *Athrotaxis*. However, 'Fire appears to have initiated some new stands [of *A. cupressoides*] on the Central Plateau ..... a long time ago' (Cullen and Kirkpatrick 1988a) and there are also instances of *A. selaginoides* regenerating after fire (Ogden 1978; Cullen 1987). The details of the mechanisms whereby the genus has regenerated after fires remain a topic for further study but four suggestions arise. They are: that root suckering in *A. cupressoides*, at least, has been sufficient for regeneration among plants subject to surface fires; that fires in the past have had a high perimeter to area ratio enabling substantial proportions of burned areas to be recolonised in a relatively short time from unburned plants near fire edges; that fires in the past may have immediately preceded the start of autumn seed shed thereby allowing regeneration from seed; and, that regeneration has been more successful in the past than at present because fewer herbivores were present before European colonisation. The last of these has particular appeal in the light of the comment by Cullen and Kirkpatrick, (1988a) that: 'the onset of regeneration failure of *A. cupressoides* broadly coincides with the introduction of sheep and cattle'.

Seedlings and suckers of *Athrotaxis* are palatable to vertebrate herbivores (Cullen and Kirkpatrick 1988a). Wallabies have been present throughout the temporal context considered here; however, from the early 1800s, sheep and cattle were grazed on the high plains - attaining high densities particularly in the latter part of the century (Shepherd 1973). In the 1900s herbivory by domestic animals was added to by the arrival of the feral rabbit which attained plague proportions between 1920 and 1953 (Shepherd 1973). Today, the sheep and cattle are excluded while the rabbits and native herbivores remain.

The loss of *Athrotaxis* from parts of the Central Plateau of Tasmania in the 1960s - perhaps in contrast to *Athrotaxis* persistence after fires in pre-European times - may be attributed to the scale of the fires and the presence of enhanced populations of vertebrate herbivores (Fig. 4.2b). Because *Athrotaxis* is often confined to fire-protected, or fire shadow areas, fires appear to have been an important factor in shaping the distribution of the genus (Cullen and Kirkpatrick 1988b). Loss of biodiversity in the form of *Athrotaxis* spp. is amplified when species, such as the epiphytic lichen mentioned at the outset, is absolutely dependent on this genus as a host (Kantvilas 1990).

Figure 2:

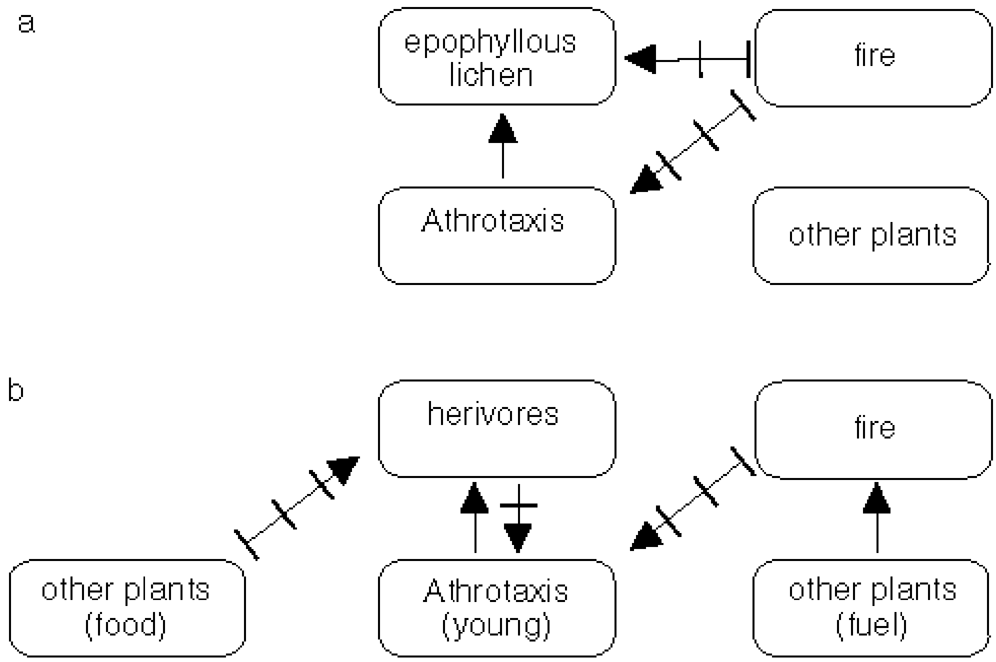

Figure 2: Some of the inter-relationships between fire, fuels. pencil pines (*Athrotaxis*) and an *Athrotaxis*-dependent lichen. Fire may kill mature *Athrotaxis* to ground level (a). Herbivores can comsume small plants (b). The relationship illustrated should be considered to be indicative rather than definitive.

Mistletoe in an ACT woodland

Mistletoes are woody hemiparasites belonging to a number of families of flowering plants. Australia has 15 genera of mistletoes with 84 species (Barlow 1984). These species occur throughout mainland Australia but not in Tasmania. Mistletoes show a variety of forms and sizes and could show a variety of responses to fires although they are often regarded as fire sensitive (e.g. Gill 1981a). Mistletoes appear to have increased in abundance in disturbed areas since the turn of the century (Coleman 1949). Heavily infested host trees may die - together with the mistletoes that killed them. Mistletoes draw on the resources of the host and, therefore, depress its diameter increment (Nicholson 1955). Although native, Coleman, (1949) referred to the mistletoe as a 'menace' while Hartigan (1960) noted the 'aggressive character of the pest'.

In the ACT, mistletoes are abundant in places. Indeed concern has been expressed about their effects on host trees and a research project on their control was instituted recently by the ACT Parks and Conservation Service (Gill and Moore 1993). Mistletoes in the ACT belong to two genera of the family Loranthaceae - *Amyema* and *Muellerina* (Burbidge and Gray 1970). Two of the three *Amyema* species there occur on eucalypts, the other on *Casuarina*. *A. miquellii* is very common on woodland trees of *E. polyanthemos*, *E. melliodora* and *E. blakelyi*.

A. miquellii, like most mistletoes, is spread by the mistletoe bird, *Dicaeum hirundinaceum*, in the ACT. Other birds including honeyeaters (*Acanthagenys rufogularis, Meliphaga lewinii*) and silver eyes (*Zosterops lateralis*) are potential dispersers (Frith 1979; Liddy 1983), but the mistletoe bird is the 'basic disseminator of mistletoes in Australia' (Liddy 1983). The mistletoe bird will take food other than mistletoe fruits but the latter seem to be the main food item (Frith 1979). We can simplify the situation by suggesting that we have a mistletoe dependent on a host genus and a bird dependent on a plant type. If the mistletoe is eliminated, the mistletoe bird is also lost from the area according to this scenario. Perhaps insects or other small organisms are dependent on the bird or the plant as well so these could be lost in the absence of the mistletoe. Biodiversity is reduced with the loss of the mistletoe, increased if the mistletoe invades.

The mistletoe bird carries the mistletoe seed to a host branch where the seed germinates. It penetrates the host and causes a knobby haustorium to form - the connection zone of the host and the mistletoe. The mistletoes may occur near the ground or at heights up to 20 m in the canopies of the trees in this example. These pendulous mistletoes can attain lengths of nearly 4 m.

If the haustorium is killed so too is the mistletoe. Killing the bark tissue around the haustorium will kill the plant. The principles are the same as those for the death of other woody dicotyledons. As the mistletoe increases in size, so does the bark thickness on the haustorium, so more heat is necessary to kill the plant (Gill and Moore 1993).

Fires in this woodland example are dependent on grasses rather than the litter from the eucalypts (Fig. 3a, below). The eucalypts are fire tolerant when mature but we can regard the mistletoes as sensitive for our illustration. If the fire is of low intensity, the leaf death caused by the fire will be confined to the zone near the ground and mistletoes high up in tree canopies will be unaffected (Fig. 3a, below). If the fire intensity is high then even the mistletoes high in the canopy may be killed (Fig.3b, below). With no seeds in the soil-seed pool and no viable seeds in the plant canopies, the species is eliminated but not necessarily permanently. Mistletoe birds may carry seed back into the burnt area so that the plants re-establish. The rate and timing of reinvasion after fire is not known. Figure 3 illustrates some of the dependencies, or likely dependencies, in this system.

Figure 3a:

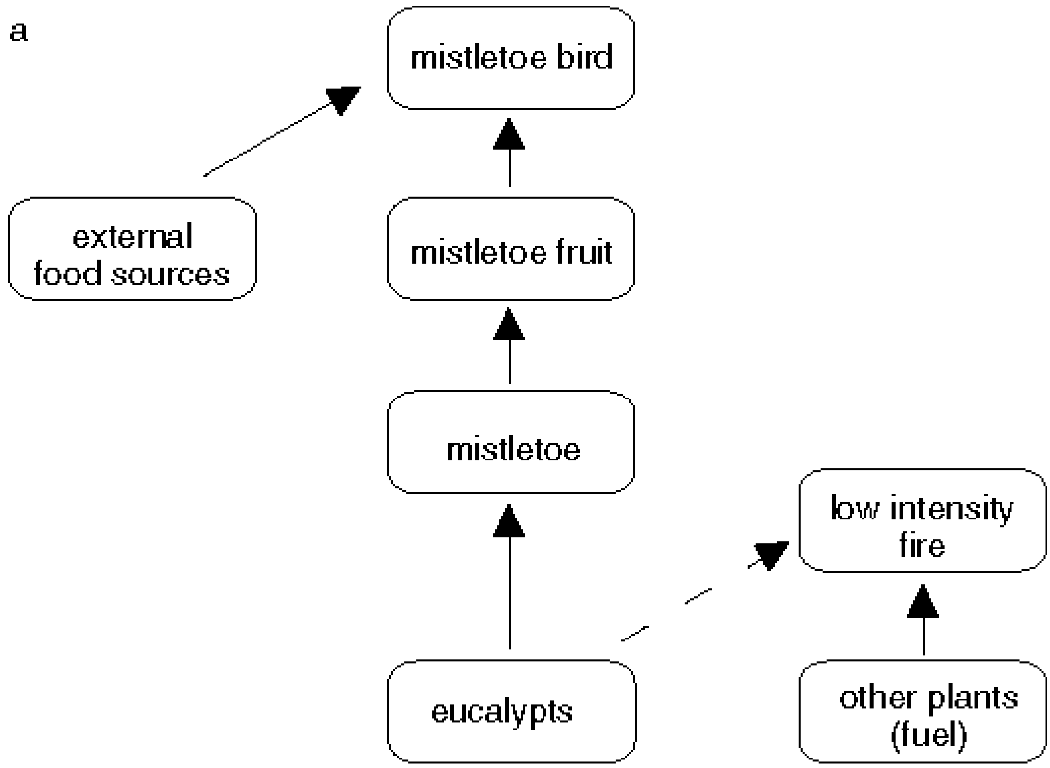

Figure 3a: Some of the inter-relationships between fire, fuels, mistletoes and mistletoe birds. With a low intensity fire the mistletoes and their hosts are not affected.

Figure 3b:

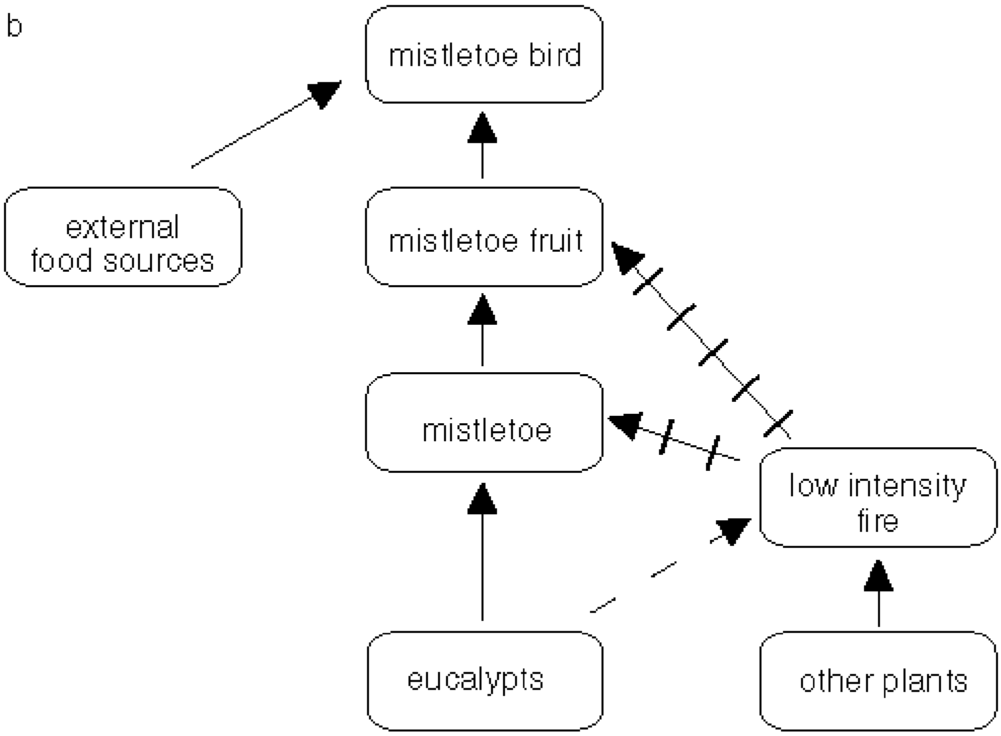

Figure 3b: Some of the inter-relationships between fire, fuels, mistletoes and mistletoe birds continued. With a high intensity fire the hemi-parasite and any fruit may be killed whil the host may be only canopy-damaged.

Both relationships illustrated in 3a and 3b should be considered to be indicative rather than definitive.

Ground parrots in swamps and heaths in southeastern Australia

There are only three ground parrot species in the world, one in New Zealand and two Australian species, one rare, one possibly extinct (Frith 1979). *Pezoporus wallicus* of southeastern Australia is the object of our attention here. This species is confined to heaths and swamps with substantial components of graminoid sedges (Meredith et al. 1984; McFarland 1992). The latter author described the species as 'an elusive ground-dwelling granivore'. Its main food items seem to be seeds - of both monocotyledons, such as graminoid sedges, and various dicotyledons (Meredith et al. 1984; McFarland 1992).

Fires at intervals of greater than 20 years were too rare for ground parrots to survive in suitable Victorian heathlands (Meredith et al. 1984) while in southeastern Queensland, a comparable figure was 13 years (McFarland 1992). No ground parrots were found in heathlands with three or more fires four to six years apart in Victoria (Meredith et al. 1984) but parrots apparently survived these frequencies in southeastern Queensland (McFarland 1992). In Victorian sedgelands - where 'fires are uncommon' - habitats remain suitable 'independent of fire age' (Meredith et al. 1984, and Fig. 4a).

The explanation for the differences in fire intervals for the success of the ground parrots seems to lie with the behaviour of shrubs in relation to that of the graminoid sedges. If shrubs cause the decline of graminoid sedges by overtopping them, then the quality of habitat deteriorates - probably due to a lack of graminoid seed - and a fire is needed to restore the balance of sedges over shrubs (Fig. 4b, Meredith et al. 1984). We can assume that the processes of dominance are faster in the warmer north, hence the recommended shorter fire intervals there (McFarland 1992). In the sedgelands, shrubs are not present in sufficient numbers to overtop the sedges so fires are unnecessary to enhance the ground parrot habitat (Fig. 4a).

Figure 4:

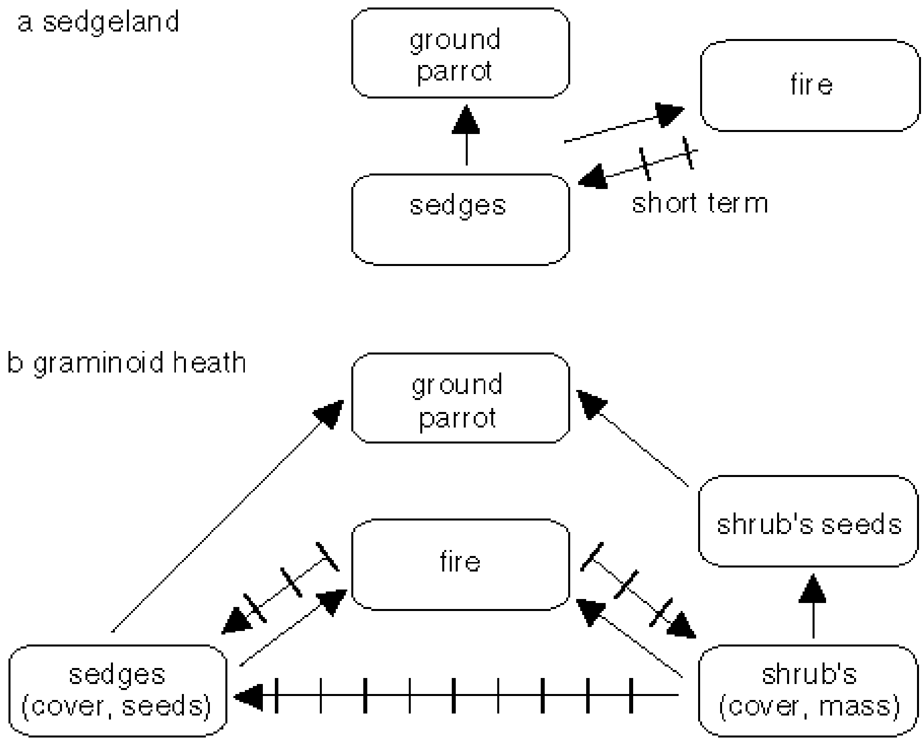

Figure 4: Some of the inter-relationships between fire, fuels and ground parrots. In sedgelands (a), the relationships are relatively simple with the occurances of fires having only short term effects. In graminoid heaths (b), the relationships are more complex, the destruction of shrub cover contributing to the long term persistence of ground parrots at the site. The relationships illustrated should be be considered to be indicative rather than definitive.

Parrots do not survive in recently burnt habitat but may colonise after one year in the north (McFarland 1992) and probably after about three years in the south (Meredith et al. 1984). Thus if all the habitat in a region is burned at the same time, then the species may become locally extinct. Recolonisation seems to depend on young birds so the presence of breeding birds within dispersal range is essential for the maintenance of a biodiversity which includes ground parrots.

Discussion and conclusions

Plant diversity can be categorised as either apparent or hidden. Apparent diversity is that which can be observed directly. Hidden diversity is that which can only be observed by manipulation of the propagule pool in the soil. Fires may strongly affect the ratio of hidden to apparent plant diversity. The mallee example showed that hidden plant diversity may be greater than that which is apparent in a mature plant community. The ratio of hidden to apparent plant diversity changes from place to place and community to community as well as with time since fire. Hidden diversity is not necessarily revealed by any one stimulus at any one time; otherwise experiments in the mallee in western NSW would not have revealed that season of burning and rainfall affected the number of plant species appearing from the hidden pool after fire (Noble 1989).

Fires can eliminate plant species from local areas as the *Athrotaxis* example showed. A wider review (Gill and Bradstock 1995) showed that species made locally extinct by fires were predominantly seeder species. Seeder species are those which have fire sensitive adults. Fire-related variables which have a direct influence on species survival are the elements of the fire regime, *viz*. types of fires (peat or surface fire), intensities of fires, seasonality of fires and frequencies of fires (Gill 1975). It is to be expected that the way these variables are treated will change as we learn more about the ways plants respond to fires. For example, temperature-time profiles, either predicted or measured, may partially or fully replace the need for distinguishing fire types and fire intensities; seasonality may resolve itself into biological and physical effects. Our views on the effects of fire frequencies, or fire-interval distributions, are already changing - at least for heathlands (Keith and Bradstock 1994; Cary 1994 pers comm).

The *Athrotaxis* and mistletoe examples touched on a the importance of spatial effects in the recolonisation of species where all potential sources of regeneration within a burned area have been killed. Distance from sources of propagules, in unburned areas, was a prime consideration in recolonisation. Thus, attention becomes focussed on distances from unburned edges rather that the actual area of a fire. Area is an inappropriate element of the fire regime if intensity is important because intensities vary within any one fire area (e.g. Gill 1981b). Spatial considerations may be important when considering the effects of herbivores on regenerating plants (Gill and Bradstock 1995).

It is a matter of observation that if a herbivore, frugivore, epiphyte or plant parasite is dependent on a plant that can be eliminated by a particular fire regime, then it too will be eliminated. Connections between plants and animals can be less direct than this, however, as the case of the ground parrot showed. Dicotyledonous shrubs growing up after fire could gradually overtop the main, faster maturing, monocotyledonous food plants of the parrot until the habitat became unsuitable. The situation could be reversed by a fire which at least top-killed the shrubs. Where these shrubs were absent, however, fires appeared unnecessary to maintain habitat. In the latter case, Meredith et al. (1984) declared the habitat optimum while in the former case, the habitat may be called suboptimum. Because the latter habitat is dependent on a particular fire regime for its persistence and is broken in time it could be called facultative habitat (see Gill and Bradstock 1995). Concepts such as optimum and suboptimum, core and facultative, and refuge habitats need further consideration elsewhere.

Vascular plants and vertebrate animals have been the main groups for discussion in this paper. However, these organisms are only a small part of the biodiversity of terrestrial Australia. They are the largest and best known organisms, both taxonomically and ecologically in Australia. Despite this, only a fraction of plant species have been noted as to their most rudimentary fire responses in a Register (Gill and Bradstock 1992). Within the group for which some response has been noted, variations in behaviour of ecotypes of some species is being revealed, but any genetic study of fire-related ecotypes remains to be done.

Fires affect biodiversity - animal and plant, hidden and apparent. There are interactions between plants and fires because plants supply the fuels for fires that, in turn, affect the plants. Animals, too, depend on plants as food, protective cover and nesting or roosting sites. Knowledge of the degree of dependence of fires and animals on plants is important to the understanding of ecosystem function and conservation; it provides a little explored avenue for future research.

Acknowledgments

Dr P. Cullen kindly vetted the section on *Athrotaxis*.

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