GUIDELINES FOR ECOLOGICALLY SUSTAINABLE FIRE MANAGEMENT

NSW BIODIVERSITY STRATEGY

JULY 2004

GUIDELINES FOR ECOLOGICALLY SUSTAINABLE FIRE MANAGEMENT

A project undertaken for the
NSW Biodiversity Strategy

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PROJECT SUMMARY

1. BIODIVERSITY PROJECT DESCRIPTION

Project objective/s

The project aimed to develop a broad and comprehensive set of guidelines to support ecologically sustainable fire management. These predictive guidelines identify an appropriate range of fire intervals compatible with the conservation of vascular plants and threatened fauna within broad vegetation types found in NSW. The guidelines are presented in a form that is readily applied to landscape-level fire management planning.

Methods

Methods entailed review and evaluation of current published information and the development and application of systems of functional classification of species responses to fire regimes. Comparative analysis of species responses of vascular plants within defined vegetation formations was carried out. Fire interval guidelines defining an acceptable range between upper and lower "thresholds" were then derived. These temporal guidelines are presented in conjunction with a spatial guideline, that can be used to define an appropriate level of variation in fire intervals at a landscape scale. Information on responses of threatened fauna were compiled and classified and evaluated in relation to the vegetation guidelines.

Key results

Floristic data were of adequate quantity and quality for definition of guidelines through formal analyses in eleven out of fourteen vegetation formations. Data on threatened species of fauna were generally inadequate. For a minority of threatened fauna species, the available data indicated that they were unlikely to be disadvantaged by fire regimes within the domain of guidelines specified for relevant vegetation formations. Summaries of guidelines and a breakdown of relevant information used in their derivation are presented for each vegetation formation.

Implications for biodiversity conservation management

The guidelines provide a broad ranging and systematic basis for the prediction and evaluation of responses of vegetation and threatened fauna to different fire frequencies. The uses and limitations of the fire integrated interval/spatial guidelines as a predictive tool for sustainable fire management are discussed. In particular it is emphasized that monitoring is required to verify and inform predictions made on the basis of these guidelines in a local context and to improve the knowledge base generally.

PROJECT SUMMARY

1: INTRODUCTION

1.1: BACKGROUND

1.1.1: Introduction

Choices between different management options for protection of life and property from bushfires need to be made on an informed basis if fire management is to be ecologically sustainable. Knowledge of the responses of biodiversity to a wide range of fire regimes is required to inform decision-making across landscapes.

This project aimed to provide a distillation of relevant ecological knowledge on the effects of fire frequency based on a consistent and well established scientific methodology. It also aimed to capture and summarise this knowledge in a form that can be readily applied to fire management planning and environmental assessment in conservation reserves and elsewhere, within the framework provided by contemporary legislation.

1.1.2: Fire Management Legislation and Policy

The NSW Biodiversity Strategy recognises inappropriate fire regimes as a threatening process. This project was implemented under Priority Action 43 ‘Manage fire in accordance with ecologically sustainable development principles’ of the Strategy. In addition, high frequency fire has been listed as a key threatening process under the *Threatened Species Conservation Act 1995.*

The scope of legislation related to both fire management and biodiversity conservation is very broad. The obligations to protect life, property and assets from adverse fire impacts and those to maintain and protect natural and cultural heritage are not mutually exclusive. Resolution of the demands imposed by these diverse objectives requires a flexible and adaptive approach to fire management.

RELEVANT LEGISLATION

Various acts and regulations govern actions related to the control and suppression of fire as well as responsibilities to conserve the natural and cultural environment. These include:

- *Environmental Planning and Assessment Act 1979*
- *Environmental Planning and Assessment Regulation 2000*
- *Environmental Protection and Biodiversity Conservation Act 1999 (Commonwealth)*
- *Fire Brigades Act 1989*
- *National Parks and Wildlife Act 1974*
- *National Parks and Wildlife (Land Management) Regulation 1987*
- *Native Vegetation Conservation Act 1997*

- *Protection of the Environment Operations Act 1997*
- *Rural Fires Act 1997*

  Bushfires and Environmental Assessment Amendment Act 2002
- *Rural Fires Regulation 2002*
- *Threatened Species Conservation Act 1995*
- *Wilderness Act 1987*

HIGH FREQUENCY FIRE: A KEY TREATENING PROCESS

"High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition" has been listed by the NSW Scientific Committee as a key threatening process under the Threatened Species Conservation Act 1995.

FIRE MANAGEMENT OBJECTIVES OF THE NPWS

The primary objectives of fire management by the NPWS are to:

- protect life, property and community assets from the adverse impacts of fire;
- develop and implement cooperative and coordinated fire management arrangements with other fire authorities, reserve neighbours and the community;
- manage fire regimes within reserves to maintain and enhance biodiversity;
- protect Aboriginal sites, historic places and culturally significant features known to exist within NSW from damage by fire; and
- assist other fire agencies, land management authorities and landholders in developing fire-management practices to conserve biodiversity and cultural heritage across the landscape.

The maintenance of biodiversity to avoid the extinction of natural species, populations and communities within the landscape underpins fire management activities within the NPWS.

* From *Fire Management Manual*, NSW NPWS 2001

1.1.3: Principles of Fire Ecology

Fires are recurrent disturbances in landscapes. Ecological effects are therefore shaped by fire regimes, namely the collective effects of fire frequency, intensity, season and type (Gill *et al.* 2002, Gill and Bradstock 2003). At a landscape-scale each of these components will exhibit variation, and the nature of this variation will have important ecological consequences (Gill *et al.* 2002, Gill and Bradstock 2003). Spatial variation in fire regime components is best regarded as a landscape measure or metric that can be expressed in statistical terms (e.g. mean and variance of proportion affected by differing levels each component - Gill and Bradstock 2003).

There is interplay between the capacity of species to survive and regenerate from fire and the interval between fires (a measure of fire frequency). Many species require a characteristic amount of time to acquire a capacity to survive and replenish their regeneration capacity. Fire intensity may determine the proportion of individuals that survive a particular fire. It may also affect regeneration processes such as seed germination in plants, often positively. Fire season may affect various biological responses to a fire event. Fire type differentiates principally between above-ground and subterranean fires. The latter type of fire typically occurs in organic soils (e.g. peat) found in some cool climate ecosystems (e.g. high latitudes and/or altitudes). Fire regimes therefore have both temporal (i.e. length of between-fire interval) and non-temporal (intensity, season and type) components. There are general interactions between these components and their consequent biological effects. Effects of particular fire regimes may vary strongly among species as a function of contrasting life history characteristics.

The fire regime at any point on the ground reflects the sum of individual fires that have occurred there, including the characteristics and timing of each fire. A spectrum of different fire regimes is possible in most ecosystems, reflecting differences in the number, size and circumstances (e.g. weather) surrounding individual fires. Management can affect fire regimes through alterations to rates of ignition and spread of fires. The effects of different management activities and strategies on fire regimes are complex and poorly known. Outcomes will be strongly dependent on context.

Exploration of the effects of different management scenarios on fire regime characteristics is beyond the scope of this project and report. This report does however deal with a distillation of ecological knowledge on effects of fire regimes, for future use in a flexible management framework. While elements of such a framework and the interpretation and use of guidelines within it are discussed here, the detail of derivation is also beyond the scope of this project and report. Nonetheless, a flexible management approach may be employed to develop an understanding of the outcomes of particular management strategies, through adaptive inference using predictions from existing ecological knowledge and targeted monitoring of resultant fire regimes and their ecological effects.

The objective of this project was to produce a review of existing knowledge on the functional responses of species to fire and a resultant set of predictive fire interval guidelines for use in a flexible, adaptive management framework.

Individual species that occur at a given point in the landscape will be able to cope with some portion of the possible spectrum of fire regimes. A species may decline and be eventually lost from that point, if the fire regimes that occur there are adverse. Different species exhibit different tolerances to fire regimes according to their biology. Knowledge of the limits of these tolerances and their variability among the biota characteristic of any particular ecological community is important.

The characteristic fire regime limits of plant species in a community are of fundamental importance. Changes in abundance and cover of dominant species may strongly influence the structure and composition of plant communities. Interactions between species, such as competition and inhibition, influence floristic composition and particular fire regimes may strongly affect these processes. Plant communities also function as key elements of habitat for animals. Changes in floristics and structure can therefore profoundly alter the habitat value of vegetation for particular animal species.

Fire regimes and their effects need to be evaluated at landscape scales. As noted, at any point in time fire regimes will be spatially variable in most landscapes. As a consequence, different ecological effects may occur at different points across a landscape, even within the same ecological community. Fire regimes may be adverse (beyond the limits of tolerance) for individual species at certain points in a community but not at others.

The significance of adverse fire regimes must therefore be viewed in a landscape context. Management to avoid the decline and loss of species at large spatial scales is identified as a key conservation issue in the State Biodiversity Strategy. The NSW

National Parks and Wildlife Service, for example, has adopted “avoidance of extinction” from adverse fire regimes, as an explicit fire management objective for its Reserves.

CONSERVATION PRINCIPLES

The principal goal of NPWS fire management for biodiversity conservation is to avoid the extinction of species that occur naturally within its reserves. This implies avoiding disruption to ecosystem processes that may be associated with the decline and loss of native species. Individual plant and animal species require particular fire regimes for their long-term survival. Such requirements may vary within the ecological and geographic range of species.

The dynamic nature of natural ecosystems necessitates an adaptive approach to fire management. All fire-management planning adopted by the NPWS will be based around this premise.

* From *Fire Management Manual*, NSW NPWS 2001

The varying nature of fire regimes across most landscapes constitutes an “invisible mosaic” (Gill and Bradstock 2003, Gill *et al.* 2003) that can only be understood through compilation of adequate spatial records of fires over time. Mapping of the “invisible mosaic” in this manner facilitates interpretation of the ecological responses of plants and animals at landscape scales. The key factor for biodiversity conservation is the degree or spatial extent of any adverse fire regimes (Gill *et al.* 2002, Bradstock and Kenny 2003). When fire regimes become adverse across the majority of the habitat for any given species in a landscape, a high chance of loss of that species from the entire landscape may result. Adverse fire regimes that are confined to a minor proportion of the habitat of any particular species may result in localized losses but may have little effect on the persistence of that species across the entire landscape.

To summarize, this project is based on the application of the following general principles.

1) The ecological effects of fire are determined by fire regimes.
2) Species of plants and animals have limits of tolerance to fire regimes, which can be exceeded under particular circumstances.
3) Knowledge of the limits of tolerance to fire regimes (‘thresholds’), characteristic of particular plant communities can be used to predict the ecological effects of particular management strategies. The ecological outcomes of decisions made on this basis should be subsequently verified through appropriate monitoring.
4) The floristic composition and physical structure of plant communities determine the quality of habitat for many animal species. Fire regime effects on plant communities therefore affect animals.
5) Management guidelines developed for plant communities are generally applicable to animals because of the importance of vegetation as habitat.
6) Fire regimes are partly invisible because they are shaped by recurrent events. A spatial fire history record is needed to describe the set of fire regimes that prevail in landscape at any particular time.
7) The effects of fire regimes in general, and adverse fire regimes in particular, need to be understood at broad spatial scales. In particular, management needs to address potential losses of species that may result from adverse fire regimes, at a landscape scale or above.
8) The loss of a species from a landscape may occur when adverse fire regimes predominate across the bulk of its habitat in that landscape. In this sense, adverse fire regimes may act as a dynamic fragmentation process.

1.1.4: Derivation and Use of Ecological Guidelines in Fire Management for Biodiversity Conservation

Simple predictive models are routinely used in fire management to fulfil a number of tasks. For example fire behaviour models are routinely used in planning and operations, for the prediction of rate of spread and intensity of both prescribed and unplanned fires (Gill 2001). The use of fire behaviour models is often supported by other models used to predict key input variables such as weather and fuel load. Such tools have a relatively long history of use by managers and supporting research. Additional tools dealing with ecological effects are required to augment those that predict the nature and behaviour of individual fires.

A variety of management approaches, which rely on simple guidelines to predict ecological responses to fire regimes, have been developed and implemented within Australia and elsewhere. Such approaches attempt to deal with the recurrent nature of fire by defining either ideal distributions or domains of between-fire intervals and time since last fire classes (e.g. Richardson *et al.* 1994, Baird *et al.* 1994, Bradstock *et al.* 1995, Richards *et al.* 1999, van Wilgen and Scott 2001, Bradstock and Kenny 2003). Such approaches have been focussed largely on individual ecosystems, reserves or landscapes, through analysis of functional responses of species to temporal aspects of individual fires (e.g. time since fire) and fire regimes (between fire intervals). The vital attributes scheme (Noble and Slatyer 1980, Noble and Gitay 1996) has been used in a number of ecosystems (e.g. van Wilgen *et al.* 1992, van Wilgen and Forsyth 1992, Tolhurst and Friend 2001, Bradstock and Kenny in press) to distinguish key groups of plant species that may be sensitive to changes in fire regimes.

Sensitivity to fire regimes is a function of life history traits (e.g. for plants – “vital attributes” Noble and Slatyer 1980). Particular combinations of traits may represent species or functional types (Noble and Slatyer 1980, Noble and Gitay 1996). Species may be classified accordingly if knowledge is available to characterize vital attributes.

A key outcome of the vital attributes system is that differing functional types of plants will have differential sensitivity to recurrent disturbances such as fire (Noble and Slatyer 1980, Noble and Gitay 1996). Functional types that are most sensitive to disturbance are those in which established individuals (adults and juveniles) are prone to death by disturbance (i.e. no capacity for vegetative recovery) and where seedbanks may be exhausted by disturbance. In terms of fire, sensitive functional types of this kind will be characterized by species that exhibit a high probability of mortality of juveniles and adults irrespective of fire intensity, plus seedbank types where germination is strongly cued to fire. Evidence suggests that such ‘fire interval sensitive’ species may be found in a wide range of Australian plant communities (e.g. Bradstock *et al.* 2002).

Among functional types that are relatively sensitive to recurrent disturbance, the length of the interval between individual disturbance events may be critical in determining population responses. Sensitivity to length of the interval between disturbances reflects the importance of timing of key processes such as maturation, the initiation of vegetative recovery and senescence. Quantification of key vital attributes of species classified as potentially sensitive to recurrent fire, may be used to examine comparative responses of species within any particular sensitive functional type. The outcome of such a comparison may be used to indicate the extent of changes in species composition that may occur under particular fire regimes.

Such a comparative analysis can also be used to define a desirable fire interval domain, with limits that demarcate changes in composition for a particular set of species. Richardson *et al.* (1994), van Wilgen and Scott (2001) and Bradstock and

Kenny (2003) present examples of this approach where a domain of appropriate between-fire intervals has been derived through vital attribute analyses within individual plant communities. In these cases the domain consisted of specified maximum and minimum intervals between fire. Thus recurrent fires at intervals within the domain were predicted to maintain the species complement, whereas intervals of lengths either shorter or longer were predicted to lead to the decline and loss of plant species belonging to sensitive functional types. van Wilgen and Scott (2001) have characterized the boundaries of such a domain as “Thresholds of Potential Concern” (TPC). Richardson *et al.* 1994, van Wilgen and Scott 2001 and Bradstock and Kenny (2003) have illustrated how TPC’s based on fire intervals may be applied in interactive management systems to examine the consequences of recurrent fire within temperate landscapes containing species-rich plant communities. Bond and Archibald (2003) have illustrated the history of development and wider significance of TPC approaches to management in relation to fire and other management factors.

In this report we describe the development of TPC-style fire interval domains for broad vegetation groupings within NSW based on vital attribute analyses. We derive fire interval guidelines or “thresholds” based on broad ranging analyses of vital attribute information for vascular plant species known to occur in these vegetation groupings. Such “temporal” guidelines are presented in conjunction with a guideline defining critical levels of spatial variation in fire intervals. We also attempt to resolve the fire interval guidelines with available information indicative of responses of species of fauna scheduled under the *Threatened Species Conservation Act*. Details of the methods are given below.

1.2: LIMITATIONS

The guidelines presented in this document and the accompanying fire response databases are based on current, available data. There are significant gaps in this data, especially in particular regions (e.g. far western NSW), and for cryptic or particularly poorly known threatened fauna, such as the Microchiroptera (insectivorous bats). These guidelines will need to be reassessed in the future as new data becomes available. Interpretation of the guidelines for management should be done in association with local expert knowledge and monitoring programs.

The information contained in this report, particularly the fire interval guidelines presented in sections 3 & 4 below, is intended for predictive use. Such use can support decision-making through the prediction of particular ecological effects that may result from particular actions at a given time and place. The predictive guidelines presented here therefore function in a similar way to other tools that are commonly employed in fire management such as fire behaviour, fuel moisture, weather and fuel accumulation models. Models of this kind capture the salient relationships between key variables and indicate possible responses. In doing this, they simplify or do not attempt to deal with much of the variation in key factors that may occur in reality (Gill 2001). This does not mean that such predictive tools are invalid or useless. It does mean that they have to be used with caution and with due regard for the domains of key variables on which they are based (Gill 2001).

The guidelines presented here are intended for application at relatively large spatial scales. Accordingly they seek to define an appropriate level of spatial and temporal variation in between fire intervals (see below). Such an approach is compatible with a management objective that seeks to minimize risk of sustained decline or loss of species at a landscape scale. The adoption of such an objective (or any alternative) is the sole prerogative and responsibility of the user. The guidelines presented here may not be suitable for use in instances where differing conservation objectives are employed.

Ultimately the worth of the guidelines presented here is as a complement to real world observation. Ongoing feedback and interplay between prediction and monitoring can serve many functions ranging from evaluation of performance through to upgrading of the knowledge base on which predictions are based. The value of monitoring cannot be over emphasised. In particular, monitoring is needed to investigate the condition of biota before and after instigating management actions, and to fill the many gaps in basic knowledge of fire responses of biota. The threatened fauna database in particular is a new database, and it is therefore anticipated that significant additional data will be included in the future as knowledge grows.

2: METHODOLOGY

2.1: OVERVIEW OF APPROACH

The general approach is summarized in Fig. 2a. Broad vegetation groupings, or formations, which reflect structural, floristic and ecological similarities were used to produce a state-wide summary of general fire interval guidelines. Floristic lists were compiled from several sources for each vegetation formation. A domain of “desirable” fire intervals was then derived through vital attribute analysis of the component plant species (see above). The domain was that which is consistent with maintenance of plant species populations within the relevant vegetation grouping.

Species lists of threatened fauna likely to be present within these broad vegetation communities were compiled based on published information on habitat and distribution. Published fire response information was collected for fauna. This was extremely limited and was generally insufficient to assess what constitute acceptable domains of fire intervals for faunal communities. Instead, those functional responses to fire likely to be important were summarized. These may be used in the future to develop a comprehensive fire response scheme for fauna. These attributes can also aid managers in predicting the likely effects of a proposed fire management regime on a set of threatened fauna present in an area.

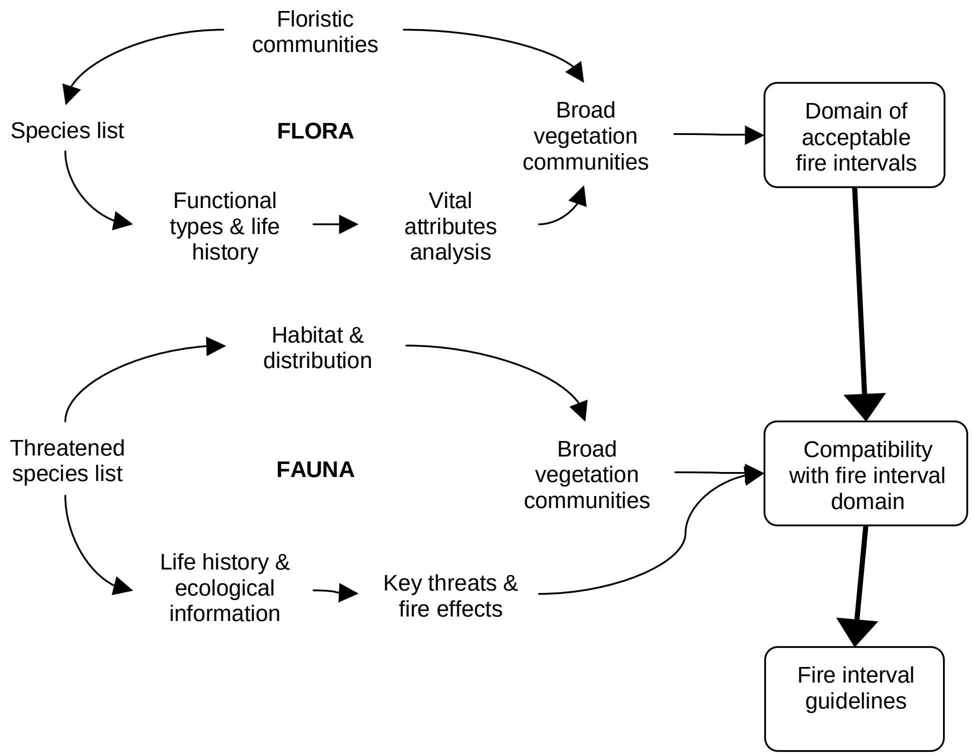

Figure 2a An overview of the approach used to develop fire interval guidelines

2.2: FIRE RESPONSE DATABASES

2.2.1: Flora Data Collation

Information on the fire response, life history, habitat and distribution of flora species occurring within NSW was collated from a wide range of sources, including published books and papers, threatened species recovery plans, vegetation survey reports, and expert opinion. Previous data collations (e.g. Gill & Bradstock 1992, Benson & McDougall 1993) were a primary source of information. The data categories collected are listed in Table 2a.

2.2.2: Threatened Fauna Data Collation

Information on the fire response, life history, habitat and distribution of fauna species and populations listed as threatened within NSW was collated from a wide range of sources, including books, published papers, threatened species recovery plans, unpublished reports, theses and expert opinion. This is a new database, and feedback on the structure is invited. The data categories collected are listed in bold in Table 2b. Those proposed for use in an extended form of the database currently under development are marked with an asterisk.

NSW Flora and Threatened Fauna Fire Response Databases

The databases are available in MS Excel format from NSW NPWS. Please contact:

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TABLE 2A: DATA CATEGORIES IN THE FLORA FIRE RESPONSE DATABASE

Category	Data	Details
Species	Species name	Follows current RBG nomenclature
	Synonym	
	Family	
	Group	Dicotyledon, monocotyledon, etc
	Life form	Herb, shrub, etc
	Life cycle	Perennial, annual, etc
Regeneration	Fire response	Seeder, resprouter or variable
	Comments on fire response	Notes on conflicting fire response
	Resprout location	Lignotuber, epicormic, etc
	Vegetative spread	Ability to spread vegetatively
	Post-fire abundance	Short-term post-fire abundance changes
Reproduction	Seed storage	Persistent soil, transient or canopy
	Seed dispersal mechanism	Known or implied dispersal vector
	Seed dispersal distance	Local or wide seed dispersal
	Seed weight/size	Mass or size of diaspore; diaspore type
	Seed viability	Recorded percent or rating of viability
	Seed dormancy	Recorded percent or method of dormancy
	Germination cue	Known germination cues
	Fecundity	Recorded rating of fecundity
	Seed predation	Recorded level of seed predation
	Post-fire recruitment	Presence/absence or no. seedlings/area
	Establishment	Need for disturbance to allow seedling establishment: intolerant, tolerant or requiring
	Pyrogenic flowering	Ability for rapid post-fire flowering
Life History	Primary juvenile period	Time to first flowering
	Seed set	Time to first seed set
	Seed bank developed	Time to develop adequate seedbank for population replacement
	Secondary juvenile period	Time to flowering after resprouting
	Fire tolerance	Time to reach fire tolerance, e.g. lignotuber development
	Life span	Known or estimated life span
	Seedbank longevity	Known or estimated life span of stored seed
	Maturity	Where a general time to maturity figure has been given without specifying details
	Extinction	Where a general time to extinction figure has been given without specifying details
	Recommended fire intervals	Minimum or maximum appropriate fire interval recommended by expert or recovery plan
Habitat	Conservation status	Listings on TSC act, ESP act and Rotap
	Distribution, botanical divisions	Known distribution within NSW botanical division, from RBG
	Distribution, extra NSW	Known distribution outside NSW
	Vegetation	Structural vegetation types in which species occurs
	Habitat	Preferred soil type, drainage, etc
	Abundance	Widespread or restricted
	Flowering time	Peak flowering times
Data	National fire response register	Fire response data from the National Fire Response Register
	Additional fire response references	Fire response data not included in the National Fire Response Register
	Other info: reference	Referencing of life history data
Vital Attributes	Vital attributes group	Functional type as determined by available data
	Sensitivity to frequent fire, etc	Ranking of likelihood of extinction or decline with frequent or infrequent fire
	Minimum maturity, etc	Summary of available life history data
	VA data, etc	Ranking of data quality

TABLE 2B: DATA CATEGORIES IN THE THREATENED FAUNA FIRE RESPONSE DATABASE

Category	Data	Details
Species	**Class/group**	Mammals, birds, reptiles, amphibians, invertebrates
	Scientific name	From TSC Act schedules
	*Synonyms	
	Common name	From TSC Act schedules
	Family	
	Status in NSW	Endangered or vulnerable status from TSC Act schedules
Habitat	**Distribution by botanical divisions**	Allocated to NSW botanical divisions from Wildlife Atlas records and other reliable locality data
	Habitat description	Summary from the published literature
	Habitat by vegetation formations	Allocated to formations of Keith (2002)
	*Extent of current distribution	Area (km^2) in NSW in which species occurs
	*Geographic concentration	Degree to which population concentrates or aggregates seasonally
Microhabitat	**Activity substrate**	The substrate in which majority of time is spent
	*Microhabitat description	Description of important components of habitat used, e.g. logs, sphagnum moss
	*Level of groundcover required	Ranked low, medium, high or N/A
	*Level of mid-storey required	Ranked low, medium, high or N/A
	Location of shelter/roost	Ground, mid-storey, canopy, below-ground
	Flammability of shelter/roost	Vegetation, hollow, log, burrow, rock/soil
	Shelter constructed	Complex constructed shelter required
	*Leaf litter required	Yes, if significantly utilised
	*Specific breeding nest requirements	Location of nest specifically constructed for breeding
Diet	*Description of diet	Description of major food items consumed
	Feeding category	Omnivore, herbivore, insectivore, granivore, mycophage, frugivore, nectarivore, carnivore, exudivore.
Mobility	*Mean home range	Mean home range in hectares
	*Max. daily distance moved	Max. distance moved daily (in kilometres)
	*Max. distance moved	Max. recorded distance moved (in kilometres)
	Level of mobility	Allocated to qualitative categories: low, medium, high, or nomadic
	*Grouping behaviour	Clumped or dispersed
Life History	*Mean body weight	Average body weight in grams
	*Mean body length	Average head-body length in millimetres
	*Description of reproductive patterns	Description of season, mating system, degree of synchrony, flexibility, and any other features of note
	*Minimum age of reproduction	Minimum age of reproduction in years
	*Usual lifespan	Usual lifespan in years
	*Breeding season	Spring/summer/autumn/winter
	*Fixed or flexible time of breeding	Fixed, or can respond to food or rainfall events
	*Semelparous/iteroparous	Individuals breed only once, or repeatedly breed during a lifetime
	*Number of litters per year	Typical number of litters/year
	*Av. Number of offspring/litter	Average number of young/litter
	*Flexible breeding strategies	Ability to replace a lost clutch, post-partum oestrus, irruptive breeding
	*Fecundity score	Average number of offspring produced per female per year, grouped into classes
	*Viviparous/oviparous/ ovoviviparous	Live bearing or egg-laying
	*Duration of parental care	Number of days, from birth to weaning for mammals, egg-laying to independence for birds, frogs, (oviparous) reptiles and invertebrates
	*Survival of offspring	Proportion of juveniles surviving to independence
	*Dispersal season of offspring	Spring/summer/autumn/winter

Fire response	**Data quality**	Categorised as none, inadequate, limited or good
	Direct (acute) fire effects	Effects of the combustion and subsequent shock phase until vegetation regrowth begins
	Short-term post-fire response	Early succession (approx. /first 3 years)
	Medium to long-term post-fire response	Mid to late-succession (3+ years post-fire)
	General fire (regime) response	The response of the species to a particular regime of fires, e.g. frequent
	*Inferred/predicted fire response	Based on published ecological and life history information
Data	**Comments**	As necessary to clarify/expand relevant points
	References	Referencing of the fire response & other information

2.3: ATTRIBUTES IN THE FIRE RESPONSE DATABASES

2.3.1: Vital Attributes for Flora

Noble and Slatyer (1980) defined a range of plant traits (vital attributes) which summarize modes of persistence and establishment in relation to recurrent fire (Appendix Table 6a). Particular combinations of attributes constitute functional types to which species may be allocated (Noble and Gitay 1996). These types represent differing syndromes of behaviour in relation to disturbance frequency (Noble and Slatyer 1980, Noble and Gitay 1996), including the likelihood of local extinction (Appendix Table 6b).

The vital attributes pertaining to persistence divide species by fire response and seedbank type. The obligate seeder categories are: D (widely dispersed seeds), S (persistent soil seedbank, with residual seedbank remaining after a fire), G (persistent soil seedbank, with seedbank exhausted by fire), and C (short-lived seedbank, including canopy-stored and transient seedbanks). Resprouters are divided into: V (revert to immature phase, e.g. lignotuber shoots), U (rapidly reproductively mature), and W (adults resprout but juveniles killed). Resprouters can be further described by the seedbank characteristics described for seeders. Other combinations of persistence attributes are summarised by the attribute that determines its behaviour (see Appendix Table 6a for details of trait combinations).

Establishment attributes describe the conditions under which seedlings are able to establish and grow: I (intolerant of competition, establish only after disturbance), T (tolerant of a wide range of conditions, establish both after and in between disturbances), and R (require conditions of a mature community, establish only in undisturbed communities).

Data within the Flora Fire Response Database were used to assign species into functional types. While the available data sources provided a comprehensive overview, there were significant gaps in knowledge and instances of conflicting information. Rules were derived to resolve these issues for mode of regeneration, mode of seed storage and establishment requirements (Table 2c). For example, if a species was characterized as being both a seeder and a resprouter in differing data sources, the response indicated by the majority of sources was adopted. Where no clear majority of sources was present to indicate a preferred fire response, the more sensitive vital attribute category was assumed to apply (e.g. seeder rather than resprouter in this case).

TABLE 2C: RULES FOR MISSING OR CONFLICTING VITAL ATTRIBUTES DATA

Missing data	Assume vital attribute

seeder with no seedbank category information	category of other species in genus or:
species with hard seed coat	S
species without hard seed coat	G
species with no seed dormancy	C
no establishment category given:	
species with a fire-related germination cue	I
species with a hard seed coat	I
Conflicting data	**Assume vital attribute**
seeder species that may sometimes resprout	appropriate seeder category
equal seeder and resprouter observations	appropriate seeder category
given both S and C categories for seedbank	C
given both I and T establishment categories	T
given both R and T establishment categories	T

Sensitivity to Fire Regimes

As noted, Noble and Slatyer (1980), Noble and Gitay (1996) determined which functional types were susceptible to extinction under either frequent or infrequent disturbance regimes. Sensitivity to fire frequency was ranked according to these predictions (Appendix, Table 6b). Species with high sensitivity to frequent fire are those in which established plants have no vegetative capacity for recovery from fire and seed reserves are exhausted by disturbance (obligate seeders dependent on regeneration from seedbanks stored in plant canopies or in the soil; CI and GI functional types). Typically such species are vulnerable to recurrent fire of most intensities during the juvenile stage. Time to maturation (the primary juvenile period) is a key attribute of such species. Species sensitive to low frequency fire are those in which establishment of seedlings is cued to fire (i.e. establishment is inhibited in unburnt conditions). Extinction may occur when the interval between fires exceeds the life-span of established plants and/or seedbanks. This may include a species with a range of other attributes pertaining to persistence and seedbank type (Noble and Slatyer 1980).

Noble and Slatyer's system recognises only a dichotomous response to disturbance frequency, whereas the ranking system applied here allows for an intermediate outcome. For example, Noble and Slatyer (1980) classified species with persistent soil-stored seedbanks which are not exhausted after a single fire (S vital attribute) as being insensitive to frequent fire. Similarly, resprouters which require time to recover maturity after fire (V vital attribute), and species reliant on dispersal of seeds for recovery from fire (D vital attribute) were considered insensitive to frequent fire. Local research (Auld 1987, Bradstock 1990, Keith 1996, Bradstock *et al.* 1997) has indicated that while S, V and D species may not be rendered locally extinct or suffer a severe decline after a single short fire interval, a persistent regime of high frequency fire may have such effects. Research involving broad-scale comparisons (e.g. landscape and biogeographic levels) on the outcomes of fire regimes on the composition of plant communities provides further general validation of these predicted trends (e.g. Lamont and Markey 1994, Morrison *et al.* 1995, Kitchin 2001, Clarke and Knox 2002, Clarke 2002).

2.3.2: Functional Responses of Fauna to Fire Regimes

To date, no systematic functional classification of the responses of fauna to fire has been developed, although Friend (1993), Keith *et al*. (2002) and Whelan *et al*. (2002) have identified some of the ecological and life-history attributes that are important in determining the response of vertebrates to fire. Shelter type, foraging patterns (activity substrate), mobility and breadth of diet are key characteristics, and these are included as primary variables in the Threatened Fauna Fire Response Database.

In contrast to many plants, the functional equivalents of dormant seeds or ability to resprout are lacking in higher vertebrates: if a species is eliminated from a patch or area by any particular fire, recovery will be dependent on dispersal from elsewhere. In this sense many animal species may be characterised as D species under the vital attributes system. D type species persist in landscapes by avoiding fire in refugia and by avoiding unsuitable post-fire conditions. Additionally, however, a high degree of mobility in animals (e.g. the ability to move daily or seasonally) may allow many species to use burnt areas provided these are adjacent to refuges (such as rock outcrops) that provide critical resource/s. Characterisation of the ability (or dependence) of an individual to regularly use different habitat elements remains a central issue in the development of a functional classification of animal responses to fire.

We anticipate that contributions to the new fauna database may provide a comprehensive basis for development of such a scheme in the future. Preliminary models and much of the content of the full database have been implemented, and further work to complete this component is suggested.

Sensitivity to Fire Regimes

Fire response information was found for 29% of threatened fauna species, with ‘good’ fire response information available for only 3%. Even for species with well described fire responses, such as the eastern bristlebird *Dasyornis brachypterus* and Hastings River mouse *Pseudomys oralis*, the interpretation of such information for fire management remains controversial and unclear (e.g. Baker 1997, NPWS 2000, Smith *et al.* 1996, Tasker 2002, Meek 2002). Given the paucity of data for threatened species, no sensitivity analysis was carried out.

2.4: ALLOCATION TO BROAD VEGETATION COMMUNITIES

The broad vegetation groupings produced by Keith (2002) for the NSW Statewide Vegetation Map (Biodiversity Strategy Project 13.11) have been utilised. This is a classification of physiognomic formations adapted from Beadle & Costin’s (1952) system that is widely applied in Australia. Ecological characteristics of the formations are described in Table 2d.

2.4.1: Flora Species Lists per Vegetation Type

Species lists were compiled for each of the broad vegetation formations of Table 2d from several sources: Ashton 1981, Love 1981, Webb & Tracey 1981, Keith 2002. Species lists were also produced from the NSW Flora Fire Response Database V1.0, based on information in the vegetation type, habitat (this information was originally mostly sourced from Harden 1990-1993 and Benson & McDougall 1993) and distribution (originally sourced from the RBG) categories.

2.4.2: Threatened Fauna Species Lists per Vegetation Type

Lists of threatened fauna species were compiled for each of the vegetation formations in Table 2d from the Threatened Fauna Fire Response Database, based on information in the habitat description category. This information was largely sourced from Strahan (1995), Menkhorst (1995), The Handbook of Australian, New Zealand, and Antarctic Birds (Vols. 1-6, 1990-2002), Cogger (1996) and Ayers (1995), supplemented with scientific papers and recovery plans wherever available. Distribution information from the Wildlife Atlas was also used to assist in this process.

TABLE 2D: VEGETATION FORMATIONS OF NEW SOUTH WALES (KEITH 2002)

Formation	Description
A. Rainforests	Forests of broad-leaved mesomorphic trees, with vines, ferns and palms. Includes Cunoniaceae, Sapindaceae, Monimiaceae, Apocynaceae, Rubiaceae. Coast and tablelands in mesic sites on fertile soils.
B1. Wet sclerophyll forests	Tall forests of scleromorphic trees (typically eucalypts) with dense understoreys of mesomorphic shrubs, ferns and forbs. Includes Myrtaceae, Rubiaceae, Cunoniaceae, Dryopteridaceae, Blechnaceae, Asteraceae. Relatively fertile soils in high rainfall parts of coast and tablelands.
B2. Semi-mesic grassy forests	Tall forests of scleromorphic trees (typically eucalypts), with grassy understoreys and sparse strata of mesomorphic shrubs. Includes Myrtaceae, Poaceae, Euphorbiaceae, Fabaceae, Casuarinaceae and Asteraceae. Coast and tablelands in high rainfall regions and along major inland watercourses on relatively fertile soils.
C. Swamp sclerophyll forests	Forests of scleromorphic trees (eucalypts, paperbarks, casurinas) with sparse shrub strata and continuous groundcover of hydrophilous graminoids and forbs. Includes Myrtaceae, Cyperaceae, Ranunculaceae, Blechnaceae, Poaceae. Flood-prone plains and riparian zones principally along the coast and inland rivers.
D. Sclerophyll grassy woodlands	Woodlands of scleromorphic trees (typically eucalypts), with understories of grasses and forbs and sparse shrubs. Includes Myrtaceae, Poaceae, Asteraceae, Epacridaceae and Pittosporaceae. Rolling terrain with fertile soils and moderate rainfall on the coast, tablelands and western slopes.
E1. Dry sclerophyll shrub/grass forests	Forests of scleromorphic trees (typically eucalypts), with mixed semi-scleromorphic shrub and grass understoreys. Includes Myrtaceae, Poaceae, Asteraceae, Epacridaeceae, Dilleniaceae and Fabaceae. Moderately fertile soils in moderate rainfall areas of the coast, tablelands and western slopes.
E2. Dry sclerophyll shrub forests	Low forests of scleromorphic trees (typically eucalypts), with understoreys of scleromorphic shrubs and sparse groundcover. Includes Myrtaceae, Proteaceae, Epacridaceae, Fabaceae and Cyperaceae. Regions receiving high to moderate rainfall on the coast, tablelands and western slopes.
F. Semi-arid woodlands	Open woodlands of scleromorphic trees (eucalypts, acacias, casuarinas), with open understoreys of xeromorphic shrubs, grasses and forbs, including many ephemeral species. Includes Myrtaceae, Fabaceae, Myoporaceae, Asteraceae, Poaceae and Acanthaceae. Low-moderate rainfall regions of the near western plains, including infrequently flood-prone sites.
G. Heathlands	Dense to open shrublands of small-leaved scleromorphic shrubs and sedges. Includes Proteaceae, Fabaceae, Epacridaceae, Myrtaceae, Casuarinaceae and Cyperaceae. High rainfall regions of the coast and tablelands on infertile soils, often in exposed topographic positions.
H. Alpine complex	Mosaics of herbfields, grasslands and shrublands. Includes Epacridaceae, Asteraceae, Gentianaceae, Ranunculaceae, Poaceae and Cyperaceae. High, snow-prone parts of the southern ranges.
I. Grasslands	Closed tussock grasslands with a variable compliment of forbs. Includes Poaceae, Asteraceae, Fabaceae, Geraniaceae and Chenopodiaceae. Fertile soils of the tablelands and western floodplains.
J. Freshwater wetlands	Swamp forests, wet shrublands or sedgelands, usually with a dense groundcover of graminoids. Includes Cyperaceae, Restionaceae, Juncaceae, Haloragaceae, Ranunculaceae and Myrtaceae. Throughout NSW on peaty soils with impeded drainage.
K. Estuarine and saline wetlands	Low forests, shrublands and herbfields of mangroves, succulent shrubs or marine herbs. Includes Verbenaceae, Chenopodiaceae, Juncaceae and Poaceae. Coastal estuaries and saline sites of the western plains.
M. Arid and semi-arid shrublands	Open shrublands of xeromorphic shrubs, hummock or tussock grasses and ephemeral herbs. Includes Fabaceae, Proteaeceae, Myoporaceae, Asteraceae, Chenopodiaceae, Casuarinaceae and Poaceae. Low rainfall regions of the far western plains.

2.5: THE FIRE INTERVAL GUIDELINES

2.5.1: Flora Vital Attributes Analysis

A domain of acceptable fire intervals was calculated for each broad vegetation formation. This domain specifies upper and lower limits of fire intervals, beyond which significant decline of species populations and the possibility of local extinction is predicted (Richardson *et al*. 1994, Bradstock *et al.* 1995). These upper and lower limits can be calculated based on the available life history data of species deemed most sensitive to decline/extinction with frequent and infrequent fire (see above). The lower limit is set on the basis of the maximum time to maturity among species sensitive to frequent disturbance, and the upper limit on the minimum time to extinction evident among species sensitive to infrequent disturbance.

Data Analysis

For each broad vegetation formation, species from the compiled list were assigned to vital attribute groups ranked by their sensitivity to both frequent and infrequent fire. Available life history data was summarized and critical life history graphs produced (minimum maturity, maximum maturity, and life-span plus seedbank longevity; see below) grouped by sensitivity rankings.

From the minimum maturity graph for each community, the highest figure for species in the most sensitive category was assigned as the minimum fire interval for that community (i.e. the lower ” threshold” or limit to the acceptable domain). If a shorter inter-fire interval than this is experienced, this graph indicates the number of species that are predicted to be adversely affected (local decline or extinction).

Decline of populations may still occur if fires recur at the minimum interval due to a variety of demographic restrictions. For example, maturation time within a population may be variable, soon after maturation seedbank reserves will be minimal, and new cohorts of resprouters may not have reached fire tolerance. Thus, any maturity values higher than those used to determine the minimum fire interval were considered through comparison of both the minimum and maximum maturity graphs. All values on the minimum maturity graph, and all but the insensitive species on the maximum maturity graph were noted. The guidelines indicate the highest such value and it is suggested that some inter-fire intervals of this length may be needed to ensure maintenance of populations of all species.

The maximum fire interval was derived from the decline/extinction (lifespan plus seedbank longevity) graph for each community. The lowest figure in the most sensitive category in each community was assigned as the maximum fire interval (i.e. upper “threshold” or limit to the acceptable domain).

These pivotal species (those on which the fire interval domain has been based) were critically assessed for data quality, and any data considered dubious (see below) was excluded from the guideline calculations.

Variability in life history data

While for some species there was only a single value for maturity or lifespan, many species have a range of values (data from different sources, data in different categories, etc). From the Flora Fire Response Database, life history data for each species was summarised down to four figures:

- minimum maturity: the lowest figure in the range of values recorded in the various maturity categories (Table 2a: primary juvenile period, seed set, seedbank development, secondary juvenile period, fire tolerance, unspecified maturity, recommended minimum fire interval)
- maximum maturity: the highest figure in the range of values recorded in the various maturity categories(Table 2a: primary juvenile period, seed set, seedbank development, secondary juvenile period, fire tolerance, unspecified maturity, recommended minimum fire interval). If only one figure was recorded this was included only in minimum maturity (except values for seedbank development or recommended minimum fire interval which were classed as maximum maturity)
- maximum lifespan: the highest figure recorded for life span
- lifespan plus seedbank longevity: the highest figure recorded for life span plus the figure recorded for seedbank longevity or an estimate of seedbank longevity based on seed morphology.

Data quality

Various rules were created for the treatment of imprecise or absent life history data, and for estimating seedbank longevity (Table 2d). There were also some instances of life history data in the Database coming from values estimated by the source reference (e.g. “juvenile period approximately 5 years”, “life span possibly 20-30 years”). Such values were included in the overall summaries (data summary tables and life history graphs), but were excluded from guideline calculations if belonging to pivotal species.

Data quantity issues are dealt with in section 3.1.4.

TABLE 2E: RULES FOR LIFE HISTORY DATA

Imprecise data:		
Category	**Value given**	**Use value**
juvenile period	< x	X
juvenile period	> x	x + 2
juvenile period	x.y	x + 1
secondary juvenile period	Absent	2 (U vital attribute only)
life span	< x	X
life span	> x	X
Seedbank	< x	X
Seedbank	> x	X
Seedbank	half-life	2 * half-life
Absent seedbank longevity data:		
Seedbank type	**Hard seed coat**	**Seedbank longevity estimate**
Unknown	No	0
Transient	No	0
Persistent	No	10
Persistent	Yes	30

2.5.2: Threatened Fauna Fire Response Information

The data available on the fire responses of threatened fauna were of a fundamentally different nature to the fire-response data for flora, being mostly unsystematic and qualitative. For the majority of threatened fauna considered there was no information on their response to fire, and for those where there was it was mostly the response to a single fire event rather than to a particular fire regime. For some species little ecological information of any sort is available. Consequently, there was insufficient empirical data to calculate fire intervals or sensitivity rankings for fauna.

For 71% of threatened fauna species apparently nothing is known about their response to fire, and for only six threatened species (two mammals and four birds) is there good information on fire response, although even then it is far from well understood. Considerable research has been carried out on the response of these six species, *Isoodon obesulus* southern brown bandicoot, *Pseudomys gracilicaudatus* eastern chestnut mouse, *Atrichornis rufescens* rufous scrubbird, *Dasyornis brachypterus* eastern bristlebird, *Leipoa ocellata* mallee fowl, and *Pezoporus wallicus* ground parrot, to individual fire events as well as to particular fire frequencies or regimes.

For a further 14% (27 species) of threatened fauna limited information on fire response is available:

Mammals:

Aepyprymnus rufescens	Rufous Bettong
Cercartetus nanus	Eastern Pygmy Possum
Phascolarctos cinereus	Koala
Potorous tridactylus	Long-nosed Potoroo
Pseudomys apodemoides	Silky Mouse
Pseudomys hermannsburgensis	Sandy Inland Mouse
Pseudomys oralis	Hastings River Mouse
Sminthopsis leucopus	White-footed Dunnart

Birds:

Amytornis textilis	Thick-billed Grasswren
Calyptorhynchus lathami	Glossy Black-cockatoo
Cinclosoma castanotus	Chestnut Quail-thrush
Climacteris picumnus victoriae	Brown Treecreeper (Eastern sub-species)
Drymodes brunneopygia	Southern Scrub-robin
Erythrotriorchis radiatus	Red Goshawk
Hylacola cauta	Shy Heathwren
Lichenostomus cratitius	Purple-gaped Honeyeater
Neophema chrysogaster	Orange-bellied Parrot
Neophema pulchella	Turquoise Parrot
Neophema splendida	Scarlet-chested Parrot
Pachycephala rufogularis	Red-lored Whistler
Polytelis anthopeplus	Regent Parrot

Reptiles:

Diplodactylus conspicillatus	Fat-tailed Diplodactylus
Eulamprus leuraensis	Blue Mountains Water Skink

Frogs:

Assa darlingtoni	Pouched Frog
Crinia tinnula	Wallum Froglet
Pseudophryne corroboree	Southern Corroboree Frog

Arthropods:

Paralucia spinifera	Bathurst Copper Butterfly

In the absence of direct information on fire responses of fauna, information about the structural and floristic requirements of a species could be used to gauge whether the intervals proposed for a vegetation formation, on the basis of the floristic data, were appropriate for the fauna. However, the use of habitat structure as a surrogate indicator of suitable fire regimes is problematic because the habitats associated with fauna reflect many other factors. These include competition with other species (Higgs & Fox 1993, Thompson & Fox 1993, Maitz & Dickman 2002), and predation. Such interspecific interactions may force some species to use more complex habitats than they would otherwise choose, or to use only refuge habitats when a range may be used in the absence of predators (Brown 1988, Dickman 1992, Lima and Dill 1990).

The determination of appropriate fire intervals from the plant fire response data is made on the basis on maintaining floristic composition. Habitat suitability for most fauna, however, is determined to a large degree by the structural composition of the vegetation (Fox 1982, Catling and Coops 1999, Catling et al 2001). The suitability of habitat within a formation for a particular animal species changes over time as vegetation structure changes. The domain of fire intervals given for a vegetation formation represents a potentially wide range of vegetation structures in most cases. For many species of fauna the appropriate fire interval to maintain suitable habitat is therefore likely to lie within some part of the domain of acceptable fire intervals determined on the basis of plant species composition.

The work of Fox (1982, 1983) in Myall Lakes and Newsome and Catling (1983) in Nadgee Nature Reserve documented the seral response of small mammals to individual fire events, and Fox (1982) developed this into a ‘habitat accommodation model’. In this successional model species colonise an area when it meets their habitat requirements, and then decline in abundance as the conditions become sub-optimal and they are out-competed by species for which the conditions have become optimal. The habitat requirements of different species within a formation may often be for quite contrasting post-fire stages. Subsequent studies have confirmed that many species are responding to the changes in the habitat (vegetation) rather than to fire *per se* (e.g. Monamy & Fox 2000).

In the absence of a fire response scheme for fauna, managing for variable fire intervals, within the domain required for maintenance of flora, is therefore a plausible management approach for maintenance of faunal diversity. Such an approach is predicted to produce a suitable range of habitat structure in most instances. This should be re-assessed as more information becomes available. In addition, because the majority of threatened fauna are very restricted in their distribution, it would be inappropriate to use the requirements of particular threatened fauna to modify the fire interval guidelines for an entire vegetation formation.

For this reason, as well as the paucity of fire response information available for threatened fauna, we have not attempted to modify the fire frequency thresholds developed on the basis of the plant floristic database. However, for each vegetation formation we have indicated the number of species that have available fire response information and assessed the suggested fire intervals on the basis of this information. Application of the fire interval guidelines in any specific locality should take into account local occurrences of threatened fauna and any special requirements of such fauna, if known.

In conclusion, it is anticipated that the main value of the Threatened Fauna Fire Response database will be:

1) as a public repository of fire response (and other) information on threatened fauna,
2) as a source of information that managers can use in a particular location to assess whether a given fire, or a proposed fire regime is appropriate for those threatened animals known to occur in an area.

In time, it is planned that the information in the database will be used to develop a vital attributes-style scheme to describe and predict the response of fauna to fire regimes.

3: GUIDELINES SUMMARY

3.1: INTERPRETATION

3.1.1: Spatial variation

These guidelines are not meant to be used as prescriptions, but rather as TPC-style guidelines to be used in a flexible and iterative management framework with a conservation objective that deals with minimization of landscape-level risks to biodiversity (see above). They define a domain of “acceptable” fire intervals that are predicted to be consistent with the maintenance of existing plant species. Inter-fire interval guidelines predict the condition of a vegetation community at a particular point in the landscape (see above). Throughout a landscape there will be a variety of fire interval combinations at any time (Gill *et al.* 2002, Gill and Bradstock 2003). Such variation arises because fires differ widely in size and homogeneity of area burned within perimeters (i.e. patchiness - Gill *et al.* 2003). The cumulative consequence of this spatial variation is an “invisible mosaic” of fire intervals, as discussed above. The nature of this interval distribution across the landscape will fluctuate in both time and space.

In terms of biodiversity conservation, the chief concern is the amount of the landscape that is subject to adverse fire regimes (i.e. outside the acceptable fire interval domain). Such insights stem from recent advances in landscape ecology in general and their application to fire in particular (e.g. McCarthy *et al.* 1999, Bradstock and Kenny 2003). The effects of adverse between-fire intervals (too short or long) on a community will be some function of the area affected. For example, within a particular management context such effects could be considered to be unimportant if the area affected is relatively small. Decline or extinction of species due to adverse intervals in patches within vegetation may be offset, through recolonization from other neighbouring patches, subject to more favourable fire intervals. Provided that the relative abundance of patches experiencing both favourable and unfavourable fire intervals remains at a level where recolonization outweighs losses, no global decline of affected species will result. Should the opposite occur (i.e. losses from patches outweigh recolonization) global decline and loss of affected species in the landscape may be highly likely. Hence the proportions of favourable and unfavourable intervals that are experienced in any landscape will be critical to the persistence of resident species that ‘fire interval’ sensitive

Landscape ecological research that accounts for dispersal characteristics of common plants species can be used to define the critical balance between adverse and favourable between-fire intervals (e.g. Bradstock and Kenny 2003). Hence if more than 50 % of any particular vegetation formation is subject to intervals beyond the appropriate domain, then the decline or possible losses of species from the entire landscape may be expected. A spatial guideline of this kind can therefore be integrated with the temporal guidelines (i.e. “acceptable” fire interval range) described in this report, to provide a system for predicting the effects of fire regimes on floristic composition in landscapes.

A number of important consequences follow.

1) Use of the fire interval guidelines to predict effects on biodiversity is dependent on an explicit consideration of the proportion of the landscape potentially affected by either adverse or favourable fire intervals.
2) The consequences of any particular fire, irrespective of size, shape and “patchiness” cannot be understood without knowledge of the boundaries of fires that have immediately preceded it. Such knowledge is needed to understand how the “invisible mosaic” of fire intervals across the landscape is affected by that particular fire.
3) “Patchy” fires are not automatically beneficial to biodiversity. Differing configurations of patch size, shape and recurrence will affect the “invisible” mosaic of fire intervals in a plethora of ways (e.g. Gill *et al.* 2003). Some may be favourable to biodiversity, others may not (e.g. Bradstock *et al.* in press). The integrated temporal (fire interval) and spatial guidelines presented here provide an appropriate methodology for judging how any particular fire may contribute toward a landscape-level biodiversity response.
4) The integrated temporal/spatial guidelines may also be used to assess the level of habitat of sufficient quality (e.g. structural complexity) necessary to maintain viable populations of particular animal species in a landscape (e.g. Andersen *et al.* 2003, Bradstock *et al.* in press).
5) The integrated temporal/spatial guidelines provide a platform to guide adaptive intervention. Differing fire management activities may be required at different times to maintain landscape-level fire interval variation at an appropriate level. Management emphases may also vary according to local context.
6) In particular, the integrated temporal/spatial guidelines, provide in many landscapes, considerable scope for strategic use of prescribed fire without possible adverse ecological consequences. In this sense, the guidelines offer a way of overcoming conflicts in landscapes where management must concurrently minimize risks to people and their property on the one hand and biodiversity on the other.
7) The guidelines when used within an appropriate adaptive management framework provide a means for evaluating options and uncertainty. Unplanned fires may occur at any time in most landscapes, hence the guidelines provide some basis for predicting the consequences of unplanned events at any particular time, based on the state of prevailing landscape-scale fire regimes. In turn, the effects of mitigation through management intervention (i.e. the sum of planned and unplanned events and their effects on fire regimes and therefore biodiversity) may also be predicted.

Ultimately the use and accuracy of any predictions derived from the guidelines will depend on the quality of information available concerning fire regimes in any specific instance. Poor mapping of fires will lead to errors in the estimation of a fire interval distribution for a particular landscape. Both under or over-estimation of area burned in any particular fire can cause errors in predicted biodiversity responses. Similarly, the quality of predictions derived from the guidelines will be affected by the duration of the fire history available for any landscape. A short record of fires will be more likely to yield inaccurate predictions. Users of the guidelines are urged to critically appraise fire history information in each specific instance and to take into account the sort of biases in predictions that may result when using the guidelines. A long-term investment in comprehensive fire mapping and systems for storage and analysis of such data will minimize these problems in the future.

3.1.2: Fire Intervals

The minimum interval (based on the minimum maturity requirements of plant species sensitive to extinction under frequent fire regimes) is the shortest inter-fire interval needed to avoid any localized declines or losses of species as a result of too frequent fire. It should be noted that this is an extreme minimum value, as it is based on primary juvenile periods and does not include time to replenish seedbank reserves (see below). Fires at shorter intervals than the minimum specified interval (especially when sustained without respite) are therefore predicted to result in the depletion of populations and local losses of species over the affected area, particularly when sustained without interruption (e.g. more than two successive intervals less than specified minimum). In contrast, for a majority of species within each formation, the “optimum” interval is likely to fall somewhere within the domain between the minimum and maximum intervals.

For example, a period of 3 reproductive years beyond the minimum fire interval (Keith et al. 2002) may be required for seed production and building of seedbank reserves. Short inter-fire intervals (at or below the minimum threshold for the community) may followed by a longer interval of at least the minimum interval plus three years may be required to allow for recovery of affected species.

A suggestion has been included for most formations, for consideration of occasional specific intervals within the domain bounded by the upper and lower thresholds. This is based on the minimum maturity values of all plant species (including species deemed less sensitive to decline/extinction from frequent fire and sensitive species that were filtered out of the primary data) as well as the maximum maturity figures of all but the least sensitive species.

The maximum interval indicates the predicted time since fire beyond which a plant species may be lost from the community due to senescence of both adult plants and any stored seedbank. It is emphasised that the data underpinning these estimates (life-span and seed bank longevity) is sparse and generally based on assumptions and generalisations rather than quantitative life history studies (e.g. Bradstock and Kenny 2003). Considerable uncertainty therefore surrounds these estimates in most cases.

Long-unburnt vegetation also provides important or essential habitat elements for fauna, such as tree hollows or dense cover, and many threatened species require a mosaic of vegetation of different post-fire ages. For example, a number of threatened bird species require patches of old mallee woodland because of the presence of abundant hollows (Woinarski 1999). In some communities long-unburnt areas are very rare and afford an excellent opportunity for monitoring and research into the processes of plant senescence, recruitment and habitat utilisation. Such opportunities are needed in order to improve our ability to predict appropriate maximum fire intervals.

Prescribed fire can potentially be used to achieve conservation objectives in long unburnt vegetation that may have exceeded the maximum interval. Use of “ecological burning” in this way would be predicated on some assessment of the extent and significance of the area affected (i.e. intervals greater than relevant maximum) within a particular landscape context (see above). Such intervention may be considered, for example, when a large proportion of any formation within a landscape has exceeded the recommended maximum interval (see above). Given uncertainties in estimation of these thresholds, areas that have remained unburnt for a duration in excess of the maximum recommended interval, should be thoroughly examined for plant species diversity and abundance, plus structural attributes, prior to active use of fire for ecological burning purposes.

Planned burning of long unburnt vegetation can potentially yield more detailed insights into senescence processes if pre and post- fire monitoring is done within a more general comparative framework (i.e. comparison of results from burning of long unburnt sites with results from burnt sites with alternative, prior fire histories). A progressive series of burns spread over time may be required to yield insights from monitoring into the significance of senescence of soil-stored seedbanks in particular. Operations of this kind may be possible where large areas of long unburnt vegetation are available.

3.1.3: Other Fire Regime Issues

Within the domain of appropriate intervals suggested here, it is important that the actual inter-fire intervals experienced at a site or patch are variable. While recurrent burning at the minimum threshold (i.e. several successive short intervals) will lead to a critical decline in species sensitive to frequent disturbance, repetition of long intervals may have the same effect on those sensitive to infrequent fire. Sustained intervals in the mid-range of the domain could lead to dominance of particular species at the expense of others (Keith et al. 2002). Greatest species diversity may be maintained in some plant communities by ensuring variation in the length of inter-fire intervals (e.g. Morrison et al. 1995, Bradstock et al. 1995, Tozer and Bradstock 2002).

Intensity & Season

Elements of the fire regime other than frequency (e.g. intensity and season) were not explicitly considered for a number of reasons. The influence of fire intensity on plants is dual, affecting mortality of established individuals plus seeds and post-fire germination opportunities for the seedbank. As noted above, much of the vital attribute analysis was based on species with vulnerable life-history stages where individuals may be susceptible to death by fire, irrespective of intensity. Aspects of plant survival in relation to intensity are not well understood in many species capable of resprouting or other forms of vegetative post-fire recovery. Many species (notably in the Fabaceae) require a heat-cue for germination, and exhibit low levels of establishment after low-intensity fires. Sustained repetition of low-intensity fires can render such species vulnerable to decline and local extinction (Auld & O'Connell 1991). Possession of, or adaptation for, a heat-cue has been recorded in the Flora Fire Response Database. Relationships between intensity and establishment are not well documented for other functional groups of flora.

The vital attributes system can be adapted to more comprehensively deal with variable effects of fire intensity on seedling establishment and plant survival (Noble and Gitay 1996). We anticipate that as more information on effects of intensity accumulate it will be possible to derive systematic guidelines dealing with intensity. One example of such an attempt is given by Bradstock et al. (1995). A second major limitation is the lack of past or current information on fire intensity across landscapes. Current mapping of fires generally deals with fire perimeters at varying levels of spatial resolution. Given technological developments in remote sensing and GIS (e.g. Kitchin 2001), acquisition of a comprehensive capability to record indices of fire intensity across landscapes is anticipated in the near future. Further refinement of ecological decision-support systems in order to use such information will be a priority.

Fire intensity is commonly assumed to be a major determinant of the degree of mortality and injury to fauna but there are few studies that have quantified intensity/survival relationships. Seasonal impacts are related to pre- and post-fire climatic conditions (importantly rainfall and temperature), the coincidence of fire with breeding cycles and the effect of season on fire intensity. A fire in spring may have quite a different impact to a fire in autumn, even if the interval is the same.

In the absence of a comprehensive predictive approach, it is important that some variation in the intensity and seasonal occurrence of fires should occur, where possible, in landscapes.

3.1.4: Local Management

These guidelines are indicative only and are based on broad, generalised communities. For the purposes of local management, the process used to produce these guidelines can be applied to local species lists utilising the fire response databases. Local expert knowledge should be used to guide interpretation of appropriate management procedures. Where threatened species have conflicting fire regime requirements, a combination of ecological information and management priorities should be used to determine the appropriate fire management approach in any given area.

3.1.5: Data Availability

These guidelines are based on species for which life history information was available, not on all species present within a community. It is possible that there are species present that have longer maturity or shorter life spans than is currently known. It is acknowledged that these guidelines should be adjusted as more information is gained. In instances where appropriate life history information was available for less than 1/3 of plant species present within a formation, a definite range of fire intervals has not been given within the summary table, though an approximate range is suggested. This is the maximum known maturity and minimum known life span, but because current information is inadequate it is considered probable that species with longer maturity or shorter life span may be present.

3.2: FIRE INTERVAL GUIDELINES

The fire interval guidelines are summarised in Table 3a for each state-wide vegetation formation. Chapter 4 gives details on the development of these guidelines for each vegetation formation.

TABLE 3A: FIRE INTERVAL GUIDELINES

Vegetation formation	Minimum interval	Maximum interval	Notes
Rainforest	N/a	n/a	Fire should be avoided
Alpine complex	N/a	n/a	Fire should be avoided
Estuarine and saline wetland	N/a	n/a	Fire should be avoided
Wet sclerophyll forest	25	60	Crown fires should be avoided in the lower end of the interval range
Semi-mesic grassy forest	10	50	Occasional intervals greater than 15 years may be desirable. Crown fires should be avoided in the lower end of the interval range
Swamp sclerophyll forest	7	35	Some intervals greater than 20 years may be desirable.
Sclerophyll grassy woodland	5	40	Minimum interval of 10 years should apply in the Southern Tablelands area. Occasional intervals greater than 15 years may be desirable
Dry sclerophyll shrub/grass forest	5	50	Occasional intervals greater than 25 years may be desirable
Dry sclerophyll shrub forest	7	30	Occasional intervals greater than 25 years may be desirable
Semi-arid woodland	6*	40*	There was insufficient data to give definite intervals. Available data indicates minimum intervals should be at least 5-10 years, and maximum intervals approximately 40 years
Arid and semi-arid shrubland	6*	40*	There was insufficient data to give definite intervals. Available data indicates minimum intervals should be at least 5-6 years, and maximum intervals approximately 40 years. A minimum of 10-15 years should apply to communities containing *Callitris.* Fire should be avoided in Chenopod shrublands
Heathland	7	30	Occasional intervals greater than 20 years may be desirable
Grassland	2	10*	Occasional intervals greater than 7 years should be included in coastal areas. There was insufficient data to give a definite maximum interval; available evidence indicates maximum intervals should be approximately 10 years.
Freshwater wetland	6	35	Occasional intervals greater than 30 years may be desirable.

FOR USE IN MANAGEMENT AT A LANDSCAPE SCALE, IT IS RECOMMENDED THAT THE RANGE OF INTERVALS INDICATED SHOULD PREVAIL OVER AT LEAST 50% OF THE AREA WITHIN EACH EXTANT VEGETATION FORMATION.

NB Section 3.1.1 must be read in order to correctly interpret this table.

* intervals given are tentative due to insufficient data.

4: Guideline details

4.1: SUMMARY

The fire interval recommendations are detailed below for each broad vegetation formation. Rainforest, alpine complex, and saline wetland were considered to rarely experience fire, and plant species within these vegetation formations were poorly represented in the Flora Fire Response Database. Thus, species data is not summarised for these three vegetation formations. For the remaining fire-prone vegetation formations the following data are presented:

- a summary table of the proportion of seeders and resprouters, the proportion of plant species for which life history data was available, the number of threatened fauna occurring in the formation, and the proportion of these for which good fire response information is available (and in brackets the number for which any fire data is available),
- histograms of plant life history data:
  - minimum time to maturity;
  - maximum time to maturity;
  - 'time to extinction', i.e. lifespan plus seedbank longevity,

  Data in these graphs is grouped by sensitivity to the pertinent fire regime:
  - solid = most sensitive, regime likely to cause extinction or decline;
  - hatched = partly sensitive, persistent regime likely to cause decline or extinction;
  - dotted = insensitive, regime unlikely to cause extinction or decline;
  - open = insufficient vital attribute data to rank sensitivity.

  Please note that for ease of presentation, these graphs may not have a continuous linear scale on the x axis,
- A pie chart showing the proportion of plant species in each vital attribute category; divided into seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.2: RAINFORESTS

Rainforest is generally considered to be a “fire-sensitive” community, with fire viewed as a destructive force. This is a simplistic view, with the critical factor (as with all communities) being fire frequency. Rainforest communities can make a slow but adequate recovery after a single fire event (McMahon 1987, Chesterfield et al. 1990, Williams 2000), but most rainforest species are unable to survive recurrent fire, thus making fire frequency an important factor in the distribution of rainforest (Bowman 2000).

Fire should be discouraged in rainforest communities, and actively excluded from any areas previously affected by fire, logging, storm damage or other disturbance. Fifty-five threatened fauna were recorded from rainforests. Available information on fire response indicate that the impacts of fire on threatened fauna, such as the pouched frog and rufous scrubbird, may be severe (Lemckert 2000, Ferrier 1984).

4.3: ALPINE COMPLEX

'Alpine Complex' as defined by Keith (2002) consists only of alpine heath, herbfield, bog, fen and fjaeldmark on the Kosciusko Plateau. Sub-alpine and montane forests, woodlands, heathlands and wetlands fall under other broad vegetation types. This strictly alpine formation is not fire-prone (fire occurs only rarely under exceptional weather conditions; Wahren et al. 2001) and does not rely on disturbance for recruitment as fire-prone communities do (alpine communities have an extremely high proportion of species with tolerant establishment: Kirkpatrick et al. 2002, NSW Flora Fire Response Database). Recovery after disturbance (fire, grazing and mechanical disturbance) in these alpine communities is very slow (McCarthy & Tolhurst 2000, Kirkpatrick et al. 2002), with some dominant species being extremely fire-sensitive (Kirkpatrick & Dickinson 1984, Costin et al. 2000). Fire has a significant negative impact on soils in these areas, with considerable loss of organic material and nutrients, and substantial erosion (Kirkpatrick & Dickinson 1984). There is almost no information on fire impacts on threatened alpine fauna. Prescribed burning may negatively affect populations of the northern and southern corroboree frogs (*Pseudophryne corroboree* and *P. pengilleyi*) by exposing them to predation and the elements (Recovery Plans, NPWS 2000).

Fire exclusion is considered appropriate for the Alpine Complex.

4.4: ESTUARINE AND SALINE WETLANDS

The saline wetland group consist of mangroves, saltmarshes, seagrass meadows and inland saline lakes. These are not fire-prone communities and fire exclusion is considered appropriate.

4.5: WET SCLEROPHYLL FORESTS

Wet Sclerophyll forests are tall eucalypt forests with dense understoreys of mesomorphic shrubs, ferns and forbs. Wet sclerophyll forests are considered to be a successional stage between open forest and rainforest, leading to differences of opinion regarding management. Frequent fires (c. 15-20 years) will favour the sclerophyllous species over the rainforest elements, with the forest tending towards dry sclerophyll forest or even scrub. Conversely, long fire intervals (c. 100 years) allow encroachment of more rainforest species while suppressing establishment of sclerophyll species, resulting in ‘expansion’ of rainforest into wet sclerophyll forests (Ashton 1981).

Fire frequency effects on wet sclerophyll forest have been better studied in the tropics of northern Australia where rainforest expansion is the greater issue (Harrington 1995, Russell-Smith & Stanton 2002), and Victoria where the converse is of more concern (Ashton 1981), than they have in NSW.

The dominant eucalypts in wet sclerophyll forest are sometimes fire-sensitive (e.g Ashton 1981) and eucalypt species do not accumulate soil seedbanks (Ashton 1979), putting these canopy species in the most sensitive category with respect to frequent fire. Thus the minimum inter-fire interval is critical to both the floristic composition and structure of these forests. As maturity information was not available for all of these dominant eucalypts, care must be taken with the minimum interval described here.

After the data filtering process, the domain of acceptable fire intervals for wet sclerophyll forest was calculated as 25 to 60 years. Crown fires should be avoided in the lower end of this range. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

TABLE 4A: SPECIES DATA FOR WET SCLEROPHYLL FORESTS

	no. species	% of total species
Flora		
Total plant species list	275	
Regeneration strategy:		
Seeders	94	34.2
Resprouters	150	54.5
Availability of Life History Data:		
Minimum maturity data available	84	30.5
Maximum maturity data available	39	14.2
Lifespan data available	115	41.8
Fauna		
Total threatened fauna list	55	
Good (any) fire response information available	2 (12)	3.6

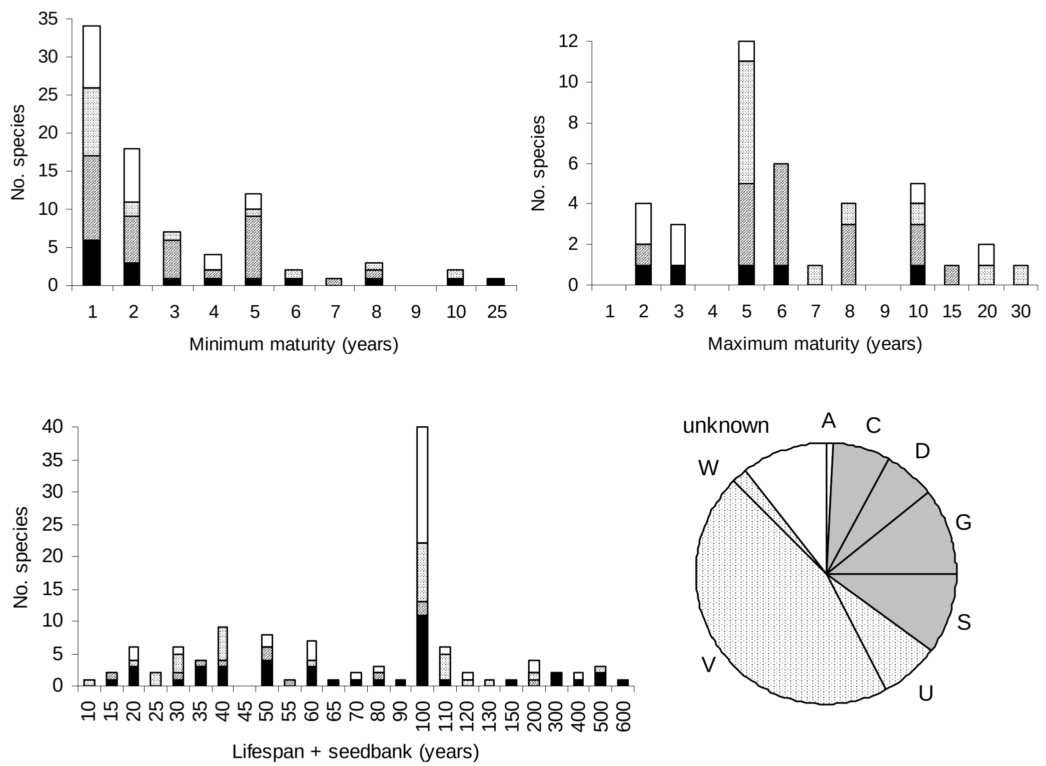


Figure 4a Life history data and regeneration strategy (persistence vital attributes) for wet sclerophyll forest. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.6: SEMI-MESIC GRASSY FORESTS

Semi-mesic Grassy Forest is similar to Wet Sclerophyll Forest, but with a more open canopy layer, sparser shrub layer, and a prominent grassy or herbaceous groundcover. As for wet sclerophyll forest, maturity information was not available for all of the dominant eucalypts (some may be obligate seeders), so care must be taken with the minimum interval described here.

After the data filtering process, the domain of acceptable fire intervals for semi-mesic grassy forest was calculated as 10 to 50 years. Some intervals greater than 15 years are desirable. Crown fires should not occur in the lower end of this range. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

TABLE 4B: SPECIES DATA FOR SEMI-MESIC GRASSY FORESTS

	no. species	% of total species
Flora		
Total plant species list	191	
Regeneration strategy:		
Seeders	55	31.3
Resprouters	121	68.8
Availability of Life History Data:		
minimum maturity data available	80	41.9
maximum maturity data available	37	19.4
lifespan data available	103	53.9
Fauna		
Total threatened fauna list	28	
Good (any) fire response information available	1 (10)	3.6

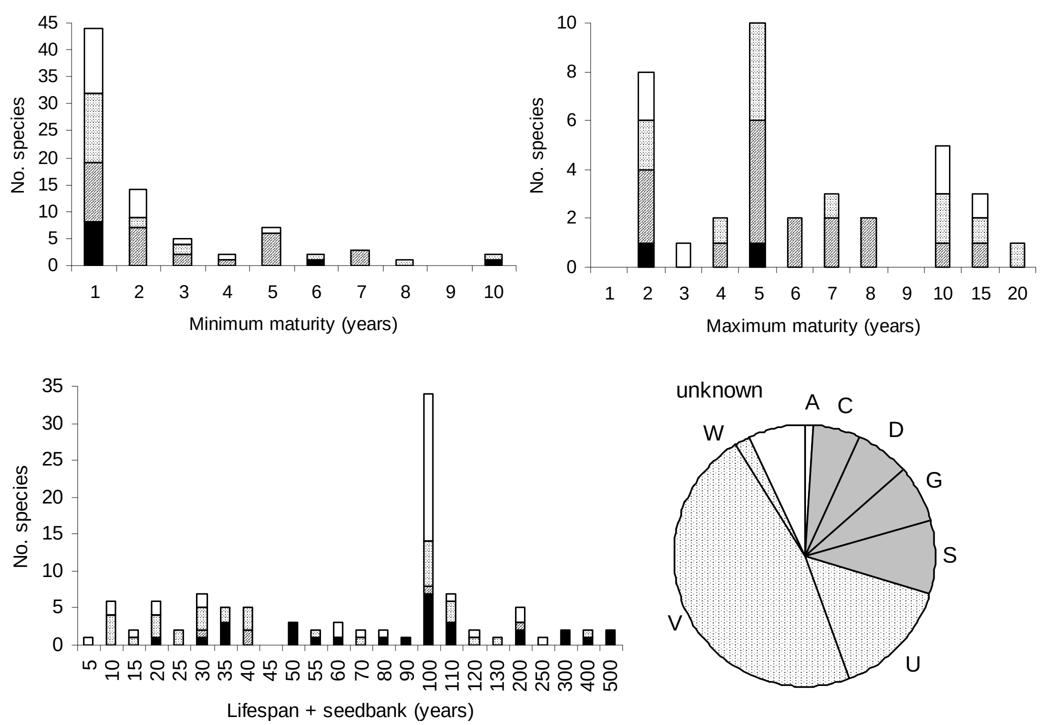


Figure 4b Life history data and regeneration strategy (persistence vital attributes) for semi-mesic grassy forest. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence

attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

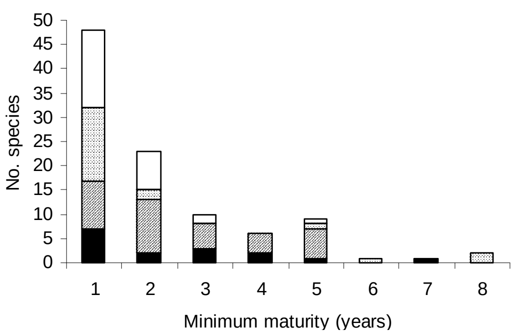
4.7: SWAMP SCLEROPHYLL FORESTS

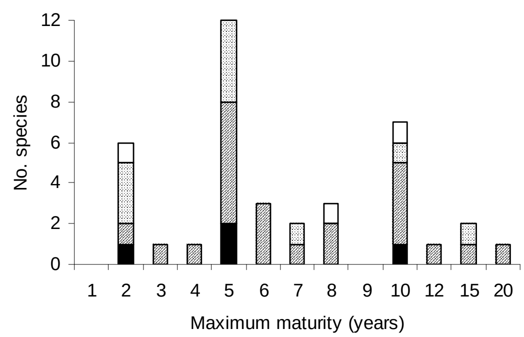
The Swamp Sclerophyll Forest formation consists of mixed *Eucalyptus-Casuarina* forests with a groundcover of hydrophilous graminoids and forbs. These occur on coastal dune swales, flood-plains and riparian zones principally along the coast and inland rivers. Little research has been done on fire impacts in these vegetation types.

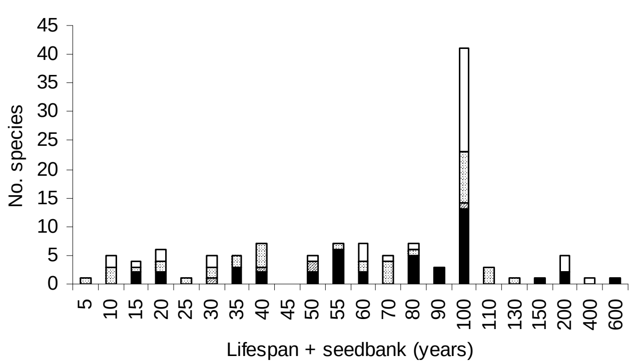
After the data filtering process, the domain of acceptable fire intervals for swamp sclerophyll forest was calculated as 7 to 35 years. Some intervals greater than 20 years are desirable. There was insufficient data to assess the suitability of the proposed intervals for threatened fauna.

TABLE 4C: SPECIES DATA FOR SWAMP SCLEROPHYLL FORESTS

	no. species	% of total species
Flora		
Total plant species list	263	
Regeneration strategy:		
Seeders	82	31.2
Resprouters	152	57.8
Availability of Life History Data:		
minimum maturity data available	100	38.0
maximum maturity data available	39	14.8
lifespan data available	121	46.0
Fauna		
Total threatened fauna list	45	
Good fire response information available	0 (8)	0







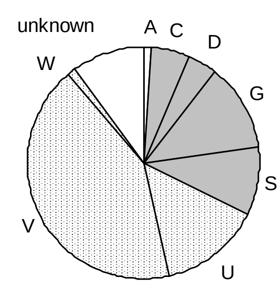


Figure 4c Life history data and regeneration strategy (persistence vital attributes) for swamp sclerophyll forest. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.8: SCLEROPHYLL GRASSY WOODLANDS

Sclerophyll Grassy Woodlands are open eucalypt woodlands with a sparse shrub stratum and continuous grassy groundcover. Most of these woodlands have been extensively cleared for pastoral use, and remnants may be substantially altered by grazing. Local management must consider the condition and fragmentation of communities, as well as interactions between fire and grazing.

Sclerophyll grassy woodlands are another case where differences of opinion on management strategy occur. Some arguments look at grassland dynamics, and thus advocate short inter-fire intervals as appropriate for maximum diversity of the grass and forb layer (as dominant grass species, most notably *Themeda*, tend to out-compete other grasses and forbs). However, the presence of a tree canopy reduces the competitive advantage of the dominant grasses, allowing greater species diversity to occur (Prober et al. 2002). Regeneration of the canopy species (and sparse shrub layer) must also be considered. Recurrent short intervals do not allow new cohorts of these to gain either fire tolerance or maturity. While intermediate fire intervals may allow a shrub layer to ‘invade’, longer fire intervals can see senescence of these shrubs returning the system to a predominately grassy one.

After the data filtering process, the domain of acceptable fire intervals for sclerophyll grassy woodland was calculated as 5 to 40 years. In the Southern Tablelands region a minimum interval of 10 years applies. Some intervals greater than 15 years are desirable. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

TABLE 4D: SPECIES DATA FOR SCLEROPHYLL GRASSY WOODLANDS

	no. species	% of total species
Flora		
Total plant species list	346	
Regeneration strategy:		
Seeders	77	22.3
Resprouters	205	59.2
Availability of Life History Data:		
minimum maturity data available	130	37.6
maximum maturity data available	32	9.2
lifespan data available	127	36.7
Fauna		
Total threatened fauna list	56	
Good fire response information available	2 (18)	3.6

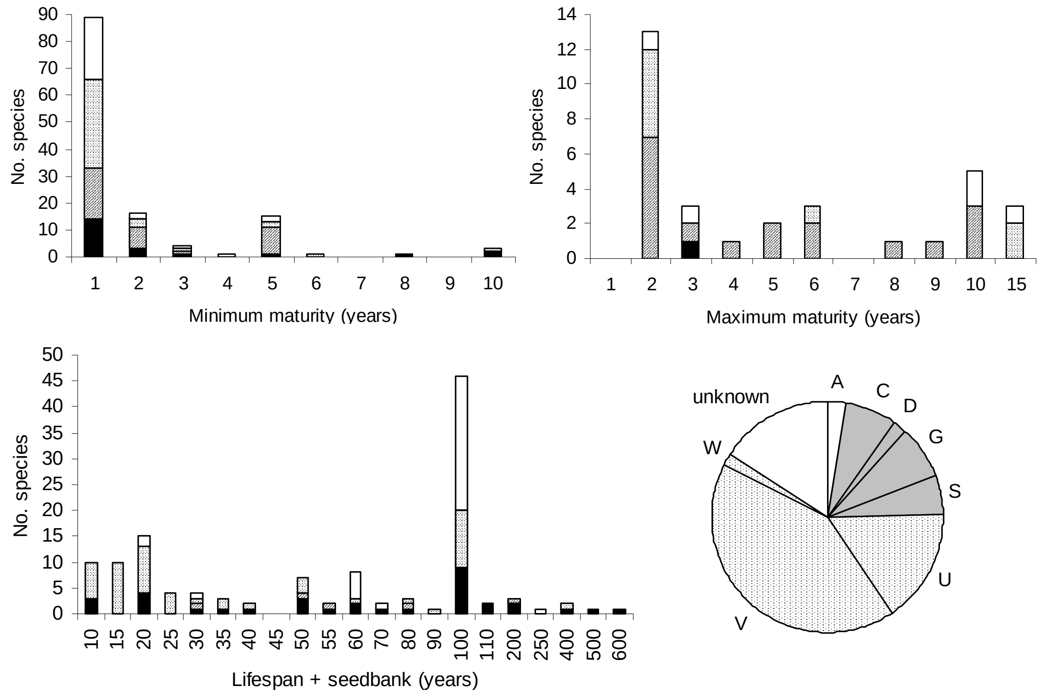


Figure 4d Life history data and regeneration strategy (persistence vital attributes) for sclerophyll grassy woodland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.9: DRY SCLEROPHYLL SHRUB/GRASS FORESTS

The Dry Sclerophyll Shrub/Grass Forest formation consists of open eucalypt forests with sparse shrub stratum and continuous grassy groundcover. Many of these forests have been fragmented by agricultural use, and the structure of some communities has been extensively simplified by grazing and frequent burning. Management issues are similar to those for Sclerophyll Grassy Woodland.

After the data filtering process, the domain of acceptable fire intervals for grassy dry sclerophyll forest was calculated as 5 to 50 years. Some intervals greater than 25 years are desirable. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

TABLE 4E: SPECIES DATA FOR DRY SCLEROPHYLL SHRUB/GRASS FORESTS

	no. species	% of total species
Flora		
Total plant species list	290	
Regeneration strategy:		
Seeders	49	16.9
Resprouters	205	70.7
Availability of Life History Data:		
minimum maturity data available	110	37.9
maximum maturity data available	38	13.1
lifespan data available	115	39.7
Fauna		
Total threatened fauna list	46	
Good fire response information available	2 (18)	4.3

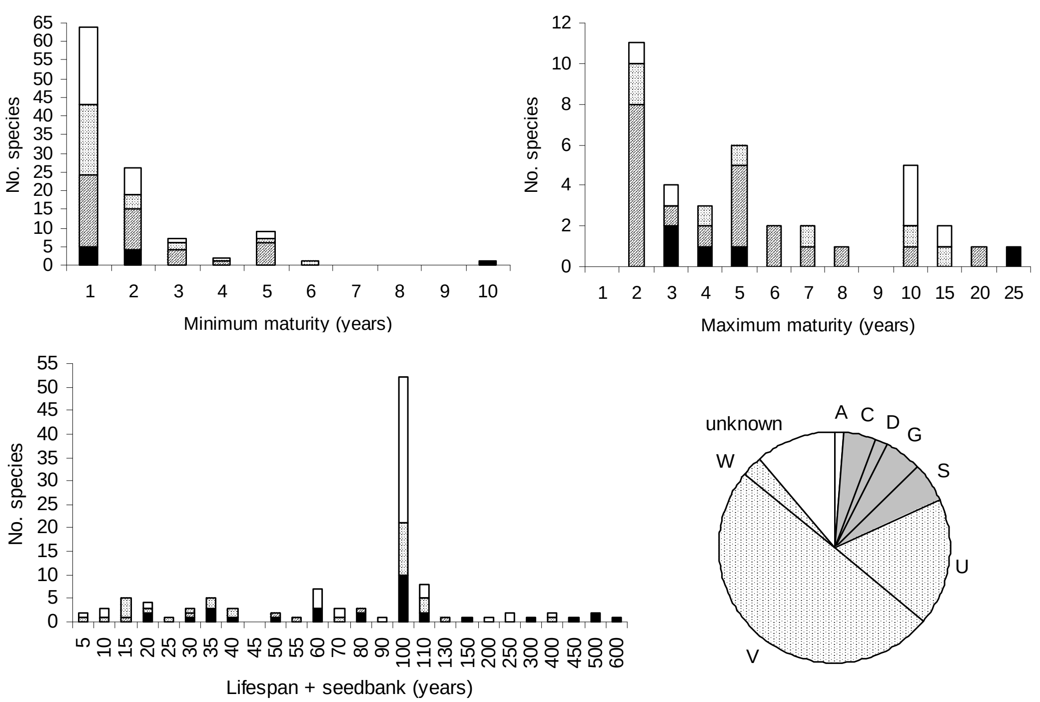


Figure 4e Life history data and regeneration strategy (persistence vital attributes) for dry sclerophyll shrub/grass forest. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G =

persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.10: DRY SCLEROPHYLL SHRUB FORESTS

This vegetation type (including open forests and woodlands with a shrubby understorey) is the most thoroughly studied in NSW with respect to floristic effects of fire frequency. Demographic models (e.g. Bradstock & O'Connell 1998, Burgman & Lamont 1990) predict that the shrubby understorey component of dry sclerophyll forest (consisting of many serotinous obligate seeders with relatively long primary juvenile periods) is the most at risk from short inter-fire intervals. Numerous studies have supported this prediction, finding reduced abundance or absence of many of these and other species in frequently burnt areas (i.e. inter-fire intervals <7 years) (Fox & Fox 1986, Niuewenhuis 1987, Cary & Morrison 1995, Morrison et al. 1996).

After the data filtering process, the domain of acceptable fire intervals for shrubby dry sclerophyll forest was calculated as 7 to 30 years. Some intervals in the higher end of the range (c. 25 years) are desirable. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

Fuel accumulation is rapid in dry sclerophyll forest, with fuel loads of c. 10 t/ha reached within 2-5 years of low intensity fire (Birk 1979, Raison et al. 1983, Morrison et al. 1996). Potential conflicts between management strategies for fuel reduction and biodiversity conservation in these forests can be resolved through careful landscape-level planning. This issue is discussed in detail elsewhere (Conroy 1996, Morrison et al. 1996, Bradstock et al. 1998, Bradstock & Gill 2001).

TABLE 4F: SPECIES DATA FOR DRY SCLEROPHYLL SHRUB FORESTS

	no. species	% of total species
Flora		
Total plant species list	1155	
Regeneration strategy:		
Seeders	495	42.9
Resprouters	601	52.0
Availability of Life History Data:		
Minimum maturity data available	433	37.5
Maximum maturity data available	181	15.7
Lifespan data available	423	36.7
Fauna		
Total threatened fauna list	51	
Good fire response information available	2 (15)	3.9

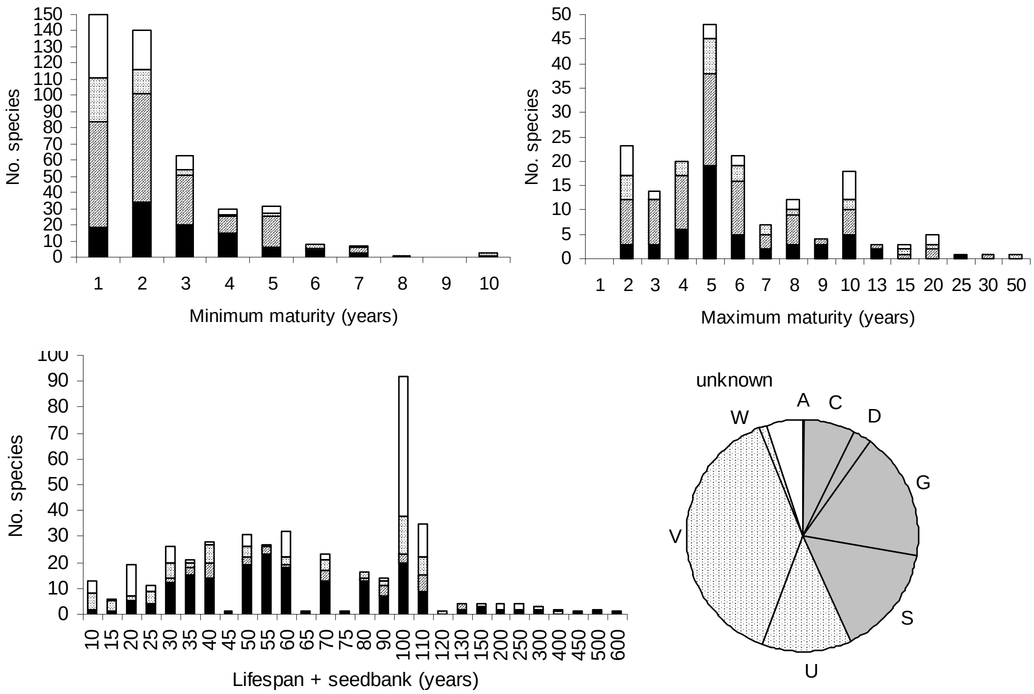


Figure 4f Life history data and regeneration strategy (persistence vital attributes) for dry sclerophyll shrub forest. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.11: SEMI-ARID WOODLANDS

The Semi-arid Woodland formation consists of open woodlands dominated by *Eucalyptus, Callitris, Casuarina or Acacia*. Understoreys contain xeromorphic shrubs, grasses and forbs, many of which are ephemeral. Many communities have been depleted by agricultural clearing and degraded by overgrazing.

Data quantity was insufficient for definite guidelines to be given for semi-arid woodland. The minimum interval should be at least 5-10 years, and the maximum approximately 40 years. A number of birds require some areas of old mallee, i.e. more than 30-50 years post-fire age, such as Major Mitchell's cockatoo (*Cacatua leadbeateri*), whilst others prefer, or require, mallee less than 10 years old, such as the chestnut quail thrush (*Cinclosoma castanotus*), shy heathwren (*Hylacola cauta*) and scarlet-chested parrot (*Neophema splendida*) (see Woinarski 1999 for references). Yet other species utilise adjacent old (>30 years, and preferably > 60 years) and young mallee (<10 years, which may contain greater food resources), such as the mallee fowl *Leipoa ocellata* (Benshemesh 1990, 1992). The data for threatened fauna also therefore indicate that the suggested intervals for this formation should be treated cautiously, and that some intervals longer than 40 years would be appropriate.

TABLE 4G: SPECIES DATA FOR SEMI-ARID WOODLANDS

	no. species	% of total species
Flora		
total species list	470	

Regeneration strategy:		
Seeders	148	31.5
Resprouters	215	45.7
Availability of Life History Data:		
Minimum maturity data available	131	27.9
Maximum maturity data available	34	7.2
Lifespan data available	90	19.1
Fauna		
Total threatened fauna list	59	
Good fire response information available	1 (23)	1.7

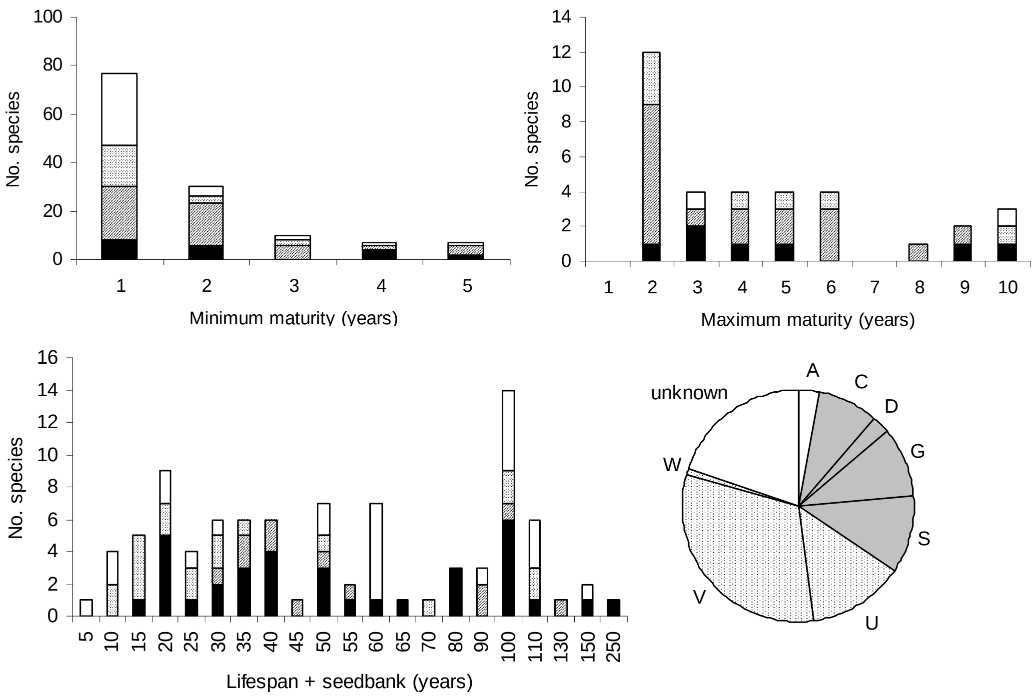


Figure 4g Life history data and regeneration strategy (persistence vital attributes) for semi-arid woodland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.12: ARID AND SEMI-ARID SHRUBLANDS

The Arid and Semi-arid Shrublands formation includes mallee, mulga, and chenopod shrublands. Some communities have been fragmented and degraded by clearing and grazing. Grazing of seedlings and resprouts by feral animals can severely reduce post-fire regeneration.

Bradstock & Cohn (2002) describe potential fire-mediated pathways in mallee communities. Fire frequency of 10-15 years may eliminate the mallee cypress pine (*Callitris verrucosa*). Coexistence of all species should occur at fire intervals of 20-25 years, though high densities of *Callitris* may negatively affect survival of *Acacia* spp. and spinifex (*Triodia scariosa*). In long unburnt mallee, *Callitris* may come to dominate over the eucalypts.

Occurrence of unplanned fires in mulga is infrequent (c. 30-50 year intervals). Hodgkinson (2002) considers that this 'natural' fire frequency is sufficient for fire-related biological processes, and thus neither prescribed burning nor suppression of wildfires is necessary to meet biodiversity objectives.

Chenopod shrublands have low flammability, and are considered extremely fire-sensitive (Leigh 1981). Chenopod species are mostly obligate seeders with only local seed dispersal and no effective post-fire seedbank (Bradstock & Cohn 2002).

Data quantity was insufficient for definite guidelines to be given for arid and semi-arid shrubland. The minimum interval for mallee and mulga communities should be at least 5-6 years, and the maximum approximately 40 years. A minimum of 10-15 years should apply to communities containing *Callitris*. Fire should be avoided in chenopod shrublands.

The limited data for fauna suggest that for a number of threatened species such as the silky mouse (*Pseudomys apodemoides*), Shy heathwren (*Hylacola cauta*), Scarlet-chested Parrot (*Neophema splendida*) and Chestnut Quail-thrush (*Cinclosoma castanotus*) the minimum fire interval should not be more than 5 years (Cockburn 1981, Woinarski 1999).

TABLE 4H: SPECIES DATA FOR ARID AND SEMI-ARID SHRUBLANDS

	no. species	% of total species
Flora		
Total plant species list	373	
Regeneration strategy:		
Seeders	118	31.6
Resprouters	141	37.8
Availability of Life History Data:		
Minimum maturity data available	45	12.1
Maximum maturity data available	5	1.3
Lifespan data available	26	7.0
Fauna		
Total threatened fauna list	54	
Good fire response information available	1 (19)	1.9

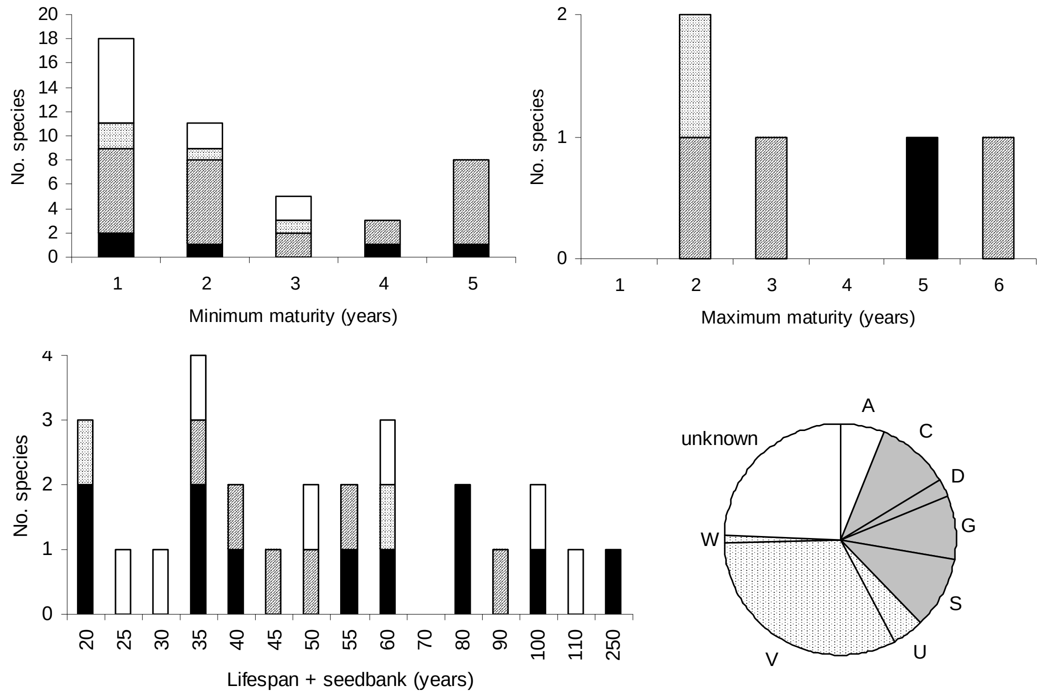


Figure 4h Life history data and regeneration strategy (persistence vital attributes) for arid and semi-arid shrubland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.13: HEATHLANDS

The composition of Heathlands is very similar to the shrubby understorey component of dry sclerophyll forest, with the same high number of serotinous obligate seeders. Management concerns are thus very similar to those discussed for Dry Sclerophyll Shrub Forest.

After the data filtering process, the domain of acceptable fire intervals for heathland was calculated as 7 to 30 years. Some intervals greater than 20 years are desirable. The proposed fire intervals, derived from floristic analysis, are compatible with the requirements of threatened fauna with known fire response information.

TABLE 4I: SPECIES DATA FOR HEATHLANDS

	no. species	% of total species
Flora		
Total plant species list	706	
Regeneration strategy:		
Seeders	318	45.0
Resprouters	373	52.8
Availability of Life History Data:		
minimum maturity data available	355	50.3
maximum maturity data available	155	22.0
lifespan data available	330	46.7

Fauna

Total threatened fauna list	33	
Good fire response information available	4 (16)	12.1

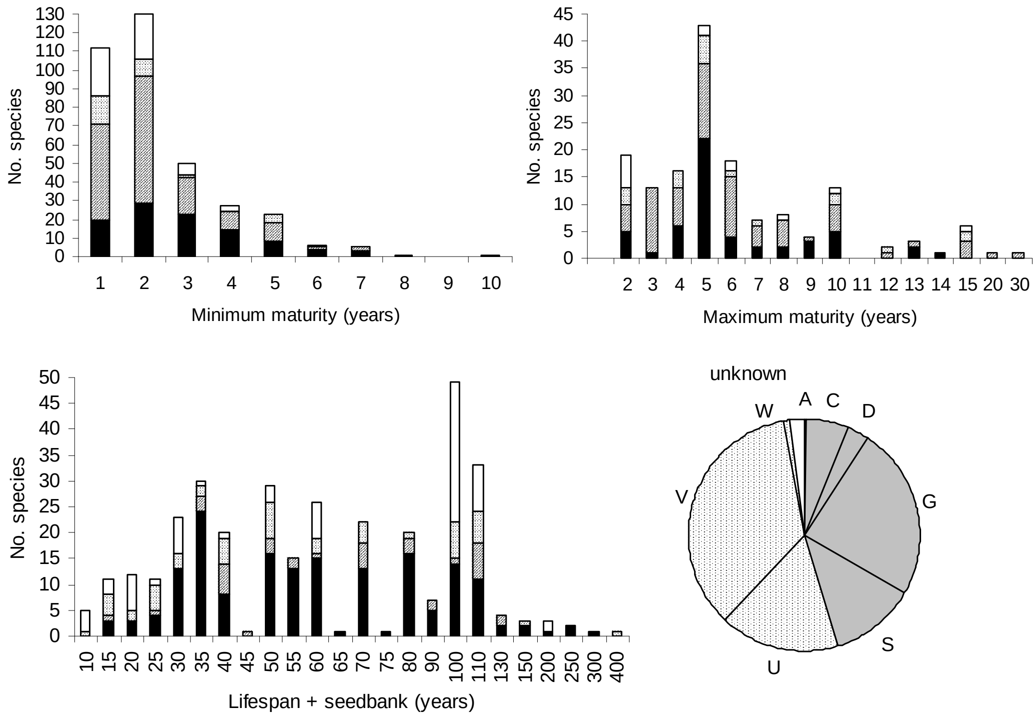


Figure 4i Life history data and regeneration strategy (persistence vital attributes) for heathland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.14: GRASSLANDS

Most knowledge of grassland dynamics comes from the *Themeda* grasslands of Victoria. These communities are dominated by a few large, perennial tussock grasses (*Themeda* and *Poa* species) which rapidly out-compete other grasses and forbs. The inter-tussock species are predominately post-fire flowering resprouters with transient seedbanks. Recruitment is not linked to fire, but relies on canopy gaps and climatic conditions. Thus the rapid biomass increase of the dominant tussock species results in decreased species diversity (Morgan 1998, Lunt & Morgan 2002). In productive *Themeda* grasslands, fire intervals of 1-3 years are recommended to allow opportunities for recruitment of inter-tussock species (Morgan 1998). This competitive exclusion is likely to occur much more slowly in low productivity grasslands (*Austrodanthonia* and *Austrostipa* dominants), such that frequent burning for biomass removal may not be required (Lunt & Morgan 2002).

In the absence of fire for longer periods, decline in the dominant tussock species occurs (*Themeda* productivity declines at 7 years since fire, and substantial degeneration occurs at 11 years; Morgan & Lunt 1999) and invasion by exotic species is a significant risk (Lunt & Morgan 1999, Costello et al. 2000, Lunt & Morgan 2002).

After the data filtering process, the minimum interval for grassland was calculated as 2 years. Some intervals greater than 7 years are desirable in coastal communities containing *Leucopogon*. Data quantity and quality was insufficient to give a maximum interval. From the available data (after filtering) it should be less than 40 years. However, research (as discussed above) indicates 10 years may be more appropriate. The large proportion of species with longevity in the 10-20 year range implies that with a sufficient quantity of data, more sensitive species would fall in this range. There was inadequate data to assess the suitability of the proposed domain of intervals for threatened fauna.

TABLE 4J: SPECIES DATA FOR GRASSLANDS

	no. species	% of total species
Flora		
Total plant species list	212	
Regeneration strategy:		
Seeders	46	21.7
Resprouters	107	50.5
Availability of Life History Data:		
minimum maturity data available	93	43.9
maximum maturity data available	8	3.8
lifespan data available	58	27.4
Fauna		
Total threatened fauna list	51	
Good fire response information available	1 (12)	2.0

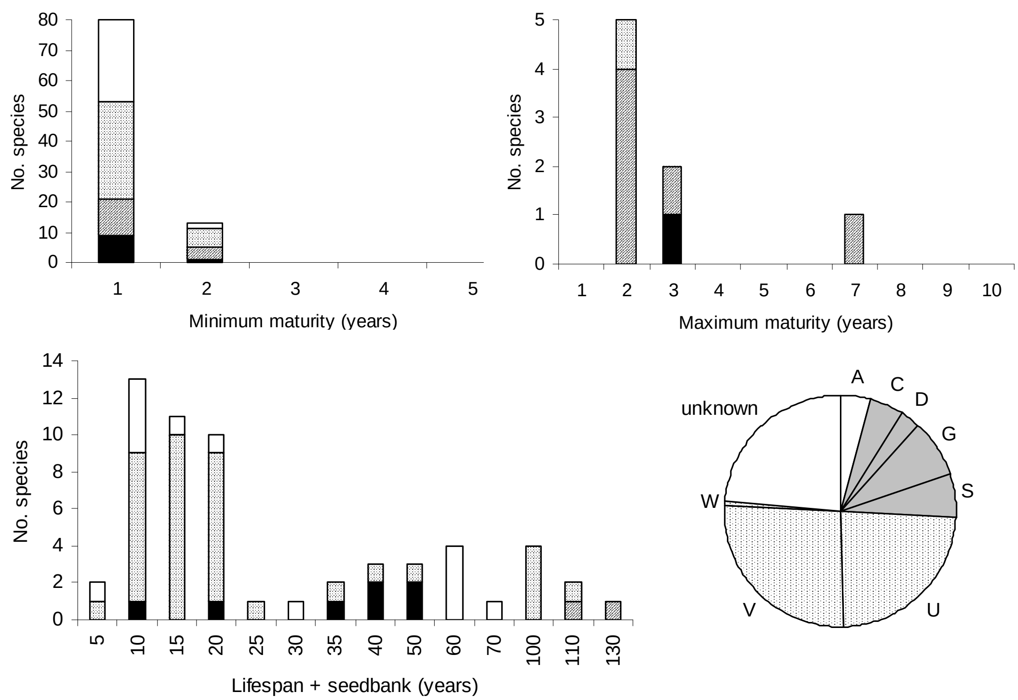


Figure 4j Life history data and regeneration strategy (persistence vital attributes) for grassland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

4.15: FRESHWATER WETLANDS

The Freshwater Wetland formation consists of swamp heaths, bogs, and floodplain shrublands. These may be either periodically or permanently inundated with fresh water. These communities may be vulnerable to peat fires when the substrate is dry.

After the data filtering process, the domain of acceptable fire intervals for freshwater wetland was calculated as 6 to 35 years. Some intervals greater than 30 years are desirable. There were insufficient data to assess the suitability of the suggested domain of fire intervals for threatened fauna.

TABLE 4K: SPECIES DATA FOR FRESHWATER WETLANDS

	no. species	% of total species
Flora		
Total plant species list	294	
Regeneration strategy:		
Seeders	64	21.8
Resprouters	164	55.8
Availability of Life History Data:		
minimum maturity data available	135	45.9
maximum maturity data available	37	12.6
lifespan data available	133	45.2
Fauna		
Total threatened fauna list	35	
Good fire response information available	3 (9)	8.6

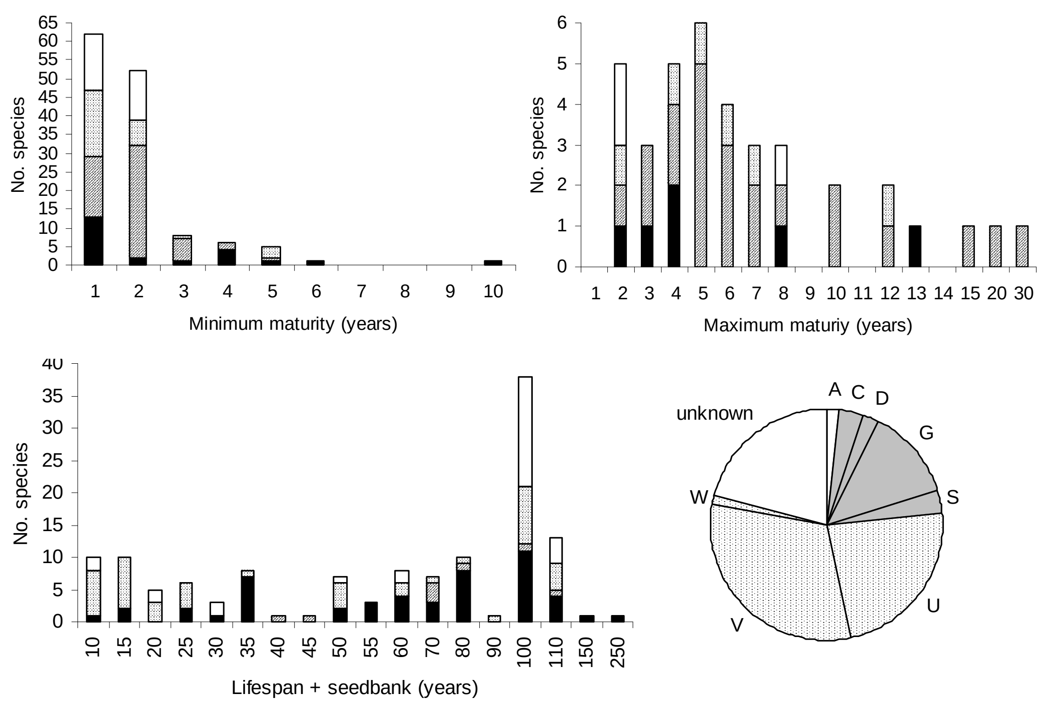


Figure 4k Life history data and regeneration strategy (persistence vital attributes) for freshwater wetland. Solid bars = most sensitive species; hatched bars = partly sensitive; dotted bars = insensitive; open bars – sensitivity unknown. Persistence attributes: seeders (C = serotinous or transient seedbank; D = wide seed dispersal; G = persistent but exhausted seedbank; S = persistent seedbank), resprouters (U = rapid post-fire flowering; V = resprout but revert to juvenile phase; W = adults resprout but juveniles killed) and others (A = annual; unknown = no data available on fire response).

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6: APPENDIX

TABLE 6A: VITAL ATTRIBUTES SYSTEM OF NOBLE & SLATYER (1980)

Persistence: Vital attribute		Persistence attributes	Lifestage
D		Propagules widely dispersed (hence always available)	JMPE
S		Propagules long lived, some remain after disturbance	JMP
G		Propagules long lived, exhausted after disturbance	MP
C		Propagules short lived	M
V		Resprout but lose reproductively mature tissue	JM
U		Survive unharmed or resprout and rapidly reproductively mature	J**M**
W		Adults resprout (and reproductively mature) but juveniles die	**M**
Combinations	Act like		
UD WD	Δ	Resprout, reproductively mature, propagules dispersed	J**M**PE
US WS UG	Σ	Resprout, reproductively mature, propagules stored	J**M**P
WG	Γ	Resprout, reproductively mature, propagules exhausted	**M**P
SD GD CD VD	D		
VS VG	S		
VC	V		
UC VW	U		
WC	W		

Establishment: Vital attribute	Tolerance	Establishment
I	Intolerant of competition	Establish and grow only after disturbance
T	Tolerant of a wide range of site conditions	Establish and grow both after disturbance and in mature community
R	Require conditions of mature community	Establish only in mature community

Describes attributes of persistence and establishment. Lifestage refers to the lifestage in which the method of persistence is available: J = juvenile, M = mature, **M** = mature tissue persists, P = propagule, E = locally extinct

TABLE 6B: SENSITIVITY TO DISTURBANCE

Group	Functional type	Disturbance regime resulting in local extinction	Sensitivity to disturbance: Frequent	Infrequent
1	DT ST VT	none	3	3
2	GT CT	frequent (interval < m)	1	3
3	DI	none	2	2
4	SI	infrequent (interval > l+e)	2	1
5	GI	either (m > interval > l+e)	1	1
6	CI	either (m > interval > l)	1	1
7	VI	infrequent (interval > l)	2	1
8	DR SR	none	2	3
9	GR CR VR	first disturbance	1	3
10a	ΔT ΣT ΓT UT WT	none	3	3
10b	ΔR ΣR ΓR UR WR	none	2	3
11	ΔI	none	2	3
12	ΣI	infrequent (interval > l+e)	2	1
13	ΓI	either (m > interval > l+e)	1	1
14	UI WI	infrequent (interval > l)	2	1

Functional types and disturbance regimes resulting in extinction of Noble and Slatyer (1980) ranked by sensitivity to frequent or infrequent disturbance regimes. 1 = most sensitive (disturbance regime will result in local decline or extinction), 2 = partly sensitive (persistent disturbance regime likely to lead to local decline or extinction) 3 = least sensitive (disturbance regime unlikely to lead to local decline or extinction). Extinction may occur when intervals between disturbance events are less than the time to reproductive maturity (m) or greater than the life span (l) or life span and seedbank longevity (l+e).