

## **FIRE INTERVAL SEQUENCES TO AID IN SITE SELECTION FOR BIODIVERSITY STUDIES: MAPPING THE FIRE REGIME**

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### **Abstract**

Determining the impact of fire regimes on biota is often limited by the lack of good knowledge about fire history: where have fires occurred, how big were they, and at what time of the year and with what intensity did they burn? On the other hand, where fire history has been well documented, the complexity of this information can be daunting. In this paper, we show how a simplification of the fire history data into fire interval sequences can provide a basis for studying the impact of contemporary fire history on biodiversity. Our study centred on an area of 50 000 ha northeast of Walpole, Western Australia, that was all burnt in the fire season of 2002/03. We considered fire interval to be the most important factor in determining species composition. We categorized fire intervals as short ( $\leq 5$  y), moderate (6–9 y) or long ( $\geq 10$  y), based on information on primary juvenile periods and likely fire return times. For each polygon in the FHD, short intervals were assigned a '1', moderate a '2' and long a '3'. This resulted in a sequence of numbers (made up of 1s, 2s and 3s) that indicated the pattern of fire intervals in reverse time series for every given area. For biological studies, successive short fire intervals (sequences of numbers that contained '11') and consecutive long fire intervals (sequences containing '33') were considered likely to be the most influential on species composition (e.g. localized extinction of serotinous obligate seeders). This paper details the methods used to derive the fire interval sequences, and how these were used to aid site selection for investigations of fire regime on biota.

**Key words:** Geographic Information Systems, fire history, fire management

### **Introduction**

Research on the influence of fire on biodiversity often suffers from a lack of underlying knowledge of the fire history in the study area. Particularly for contemporary periods (say, the last 50 years), the underlying fire history may differ significantly between study sites, and may, in fact, be the determining cause of differences between sites, rather than the experimental treatments that are applied. In most cases, fire history is not known or is poorly recorded with inaccurate spatial resolution (Kitchin and Reid 1999). In rare cases, fire history information is accurate in space and time, and provides an excellent background to fire regime studies. However, with accurate information comes complexity in both space and time, and researchers are unlikely to identify replicate study areas that have had exactly the same fire history for the period of information available. In this paper, we describe a process that simplifies patterns of fire intervals through time, classifying individual intervals into long, short or moderate fire intervals, and joining these together to show the sequence of fire intervals through time. This process takes place in a Geographic Information System (GIS), and the sequences of fire intervals can be mapped to show the historical fire interval patterns across the landscape to aid in site selection for fire ecology (or other ecological) studies.

This project draws on existing work conducted by the Western Australian Department of Conservation and Land Management (CALM) to develop a fire history database (FHD) for the Warren Region in the southwest of Western Australia (McCaw *et al.* 2005). Since 1937, fires in southwestern Australian forests were recorded on maps with detail on the type (wildfire or prescribed burn) and season (summer, autumn, spring or winter) of the fire. This information has recently been incorporated into a GIS that allows the user to identify the fire history for any given polygon (or 'parcel of land' in real world terms) (McCaw *et al.* 2005). Our overall research aim is to investigate the effects that the contemporary fire history has had on the diversity and abundance of vascular flora, vertebrate fauna, invertebrate fauna, fungi, mosses and lichens using the FHD as a source of information to determine where the study plots should be located. Of particular interest are those organisms that are 'fire-regime sensitive'; that is, they may become locally extinct as a result of repeated fire that is of an inappropriate frequency, season, intensity or combination of such (Gill and Bradstock 1995; Burrows and Friend 1998). This includes organisms that are sensitive to fire that is too frequent, or those that are sensitive to prolonged exclusion of fire (Keith 1996; Menges *et al.* 2006). In the latter case, wildfires can burn with unusual severity leading to long-term changes in vegetation structure and damage to soil properties, water cycles and nutrient cycling (DeBano *et al.* 1998). Because this is a retrospective study, the communities to be studied are very much determined by what pattern the fire history shows across the landscape, and this paper provides a description of how we have characterised fire intervals in our chosen study area.

One of the aims of our overall study is to develop a methodology for characterising and representing historical fire interval data in relation to biological research. This paper describes the methodology we used to determine fire interval sequences across the landscape, which is the second outcome of the proposed research. The first is the construction of the FHD, which has been described in a general sense by McCaw *et al.* (2005), and in detail by Hamilton and Wittkuhn (*in prep.*). We believe that the outcomes of the research will have far-reaching benefits to fire ecology research around the world, and will have applications to other historical (non fire-related) data as well.

## Materials and Methods

### *The fire history database (FHD)*

Since 1937, forest fires in southwestern Australia have been recorded on paper maps by relevant districts of the Forests Department (before 1985) and CALM. These were photographed to microfiche to economise on space, and recently have been scanned and digitised to GIS for the Warren Region. More recent fire data (1995–present) was contained in raster or vector format and was incorporated into the FHD. For the purposes of our study, fire history information prior to 1972 was not included for determination of fire intervals as the accuracy of some fire boundaries was questionable due to the lack of cadastral information or other resources (such as aerial photography) to aid accurate mapping (Hamilton and Wittkuhn *in prep.*). Fire data for each year was digitised in ArcView™ 3.1 as polygon shapefiles, and attributed information that was contained on the maps or in the database, such as whether the fire was a prescribed burn or wildfire and in which season it burnt. The data was validated by investigating complementary fire records (including aerial photographs), speaking with fire officers in the districts and re-evaluation of the original images. To complete the FHD, layers from all years were merged so that it was possible to determine all fires that occurred in a given area. A complete description of the methods used to create the FHD are given in Hamilton and Wittkuhn (*in prep.*).

### *Study area*

In order to investigate the effect of past fire regimes on biodiversity, it was necessary to remove or minimise the effect of other variables that may also affect biodiversity across the landscape. The most obvious of these is time-since-fire. In jarrah forest communities, species richness and diversity increases with time-since-fire until 3-5 years, after which a gradual decline occurs (Bell and Koch 1980). The initial increase results from species that are ‘fire weeds’ (germinate from soil-stored seed after fire and complete their life cycle within 5-7 years). We considered it important to have all study sites at the same time-since-fire to account for this, and preferred sites that were between 3 and 5 years old so that the number of extant plant species was maximised. We identified a contiguous 50 000 ha study area 30 km north east of Walpole, all of which was burnt in either wildfires or prescribed burns in the fire season of 2002-03. This area also contained a range of contemporary fire regimes within common vegetation complexes, and was relatively free of disturbances such as logging. The vegetation in the study area was a mosaic of predominantly jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) forest interspersed by winter wetlands that varied in species composition, and ranged from low woodlands to shrublands and sedgeland.

### *Classifying fire intervals*

For this study, we were interested in the pattern of fire intervals (temporal pattern) across the landscape (spatial pattern), so that we could identify sites with a similar vegetation type that had contrasting fire histories. The interval between fires was inferred by interrogating the overlapping polygons (fire events) for any location with a unique fire history. The process followed to create fire interval information is detailed in the following section. Since the aim of our study was to investigate the influence of fire history on biota, we reasoned that the fire intervals could be classed as ‘short’, ‘moderate’ or ‘long’ based on attributes of the flora and local knowledge on the minimum interval that could carry a fire. To do this, we investigated the ‘Fire Response Database’ developed by Neil Burrows and Bruce Ward for flora of southwestern Australia. This database contains information on primary juvenile period, and can be used to base management decisions on minimum fire intervals (Burrows and Friend 1998; Gill and Nicholls 1989). The database was cross-referenced with species lists from a research project in similar vegetation types to the ones we are investigating to find those species that have long primary juvenile periods. The species that are most at risk of depletion from a frequently burnt landscape are those that have a long juvenile primary period, are serotinous (retain seeds in the canopy) and are killed when subject to 100 % scorch (Whelan 1995). Less information is available on how long species live for, and thus how to classify a long fire interval. In our case, we doubled the short fire interval, and made a classification based on what fuel age a potentially large, intense fire may occur.

### *Calculation of the fire interval code*

A unioned FHD layer was created (Using ArcMap™ 9.1) so that only one polygon existed for each location with a unique fire history. A unique identifier (id1) was created for each location. Using the presence and absence of attributes for each year, a 'Fire Frequency' (number of fires for a given location since 1972) was also created. The merged FHD was then unioned with this dataset, with the effect of adding back multiple layers for each location and associated attributes. A second unique identifier (id2) was created for every overlapping polygon. This associated table from the shapefile was used as the basis for calculating the related fire interval sequences. This table was converted to a Microsoft Excel format.

Using Excel, all records were sorted firstly by the unique identifier (id1), and then by year of fire in a descending order. This had the effect of grouping the data into spatial groups with the records for each group being arranged from most recent to least recent. Fields were calculated for each fire interval (number of years between fires). For the study area the maximum number of intervals was four (resulting from five fires over 33 years), but the methodology would be applicable to any number of fire intervals. For each record, fire intervals were calculated as the difference between the year of the fire for that record and the following record, with reference to the position in the spatial group. The first interval is associated with the first record of the group and the last interval (if less than or equal to four intervals) is associated with the second last record. There is no interval for the last record because the time to the previous fire (prior to our cut-off point of 1972) is unknown.

In the Excel spreadsheet, the field 'interval type' was created with reference to the fire interval (in years) for each record, and assigned either a number '1' (if fire interval  $\leq 5$  years), '2' (if interval 6–9 years) or '3' (if interval  $\geq 10$  years). Another field, 'interval pattern' was created for the first record in each spatial group, by multiplying the first interval by 1000, the second interval by 100, the third by 10 and the fourth by 1, and adding the result of each. This has the effect of arranging the 4 intervals in a sequence from most recent to least recent. For example, if the actual fire intervals going back in time are 12 y, 3 y, 6y, 10 y, then the fire interval sequence is '3123', and is a single number that can be displayed in the GIS interface (Fig. 1a).

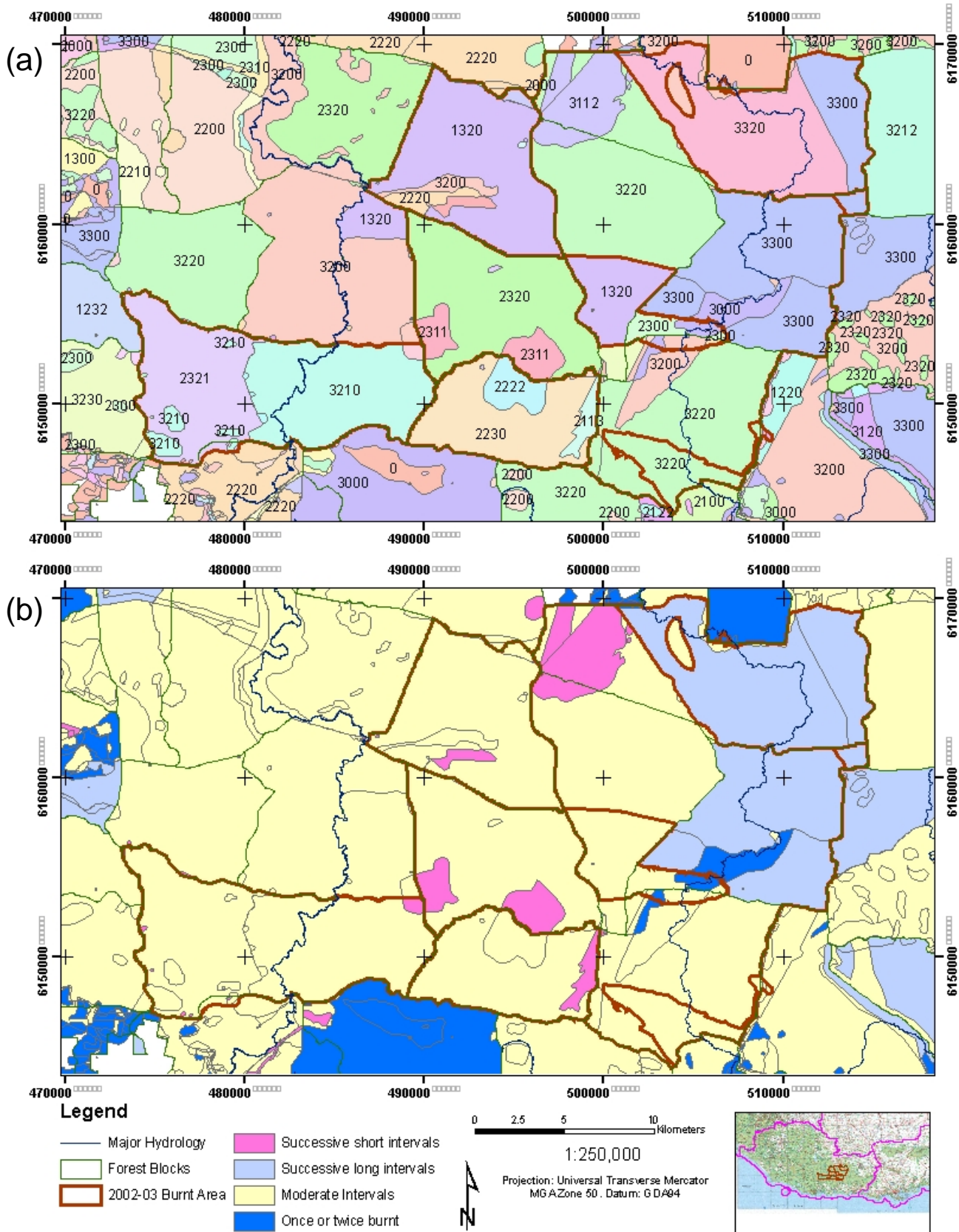
Using the unique identifier (id2) for each record, the calculated fire interval data (consisting of actual fire intervals in years, and the fire interval sequence) was re-joined to the fire history shapefile (containing information on fires for all years). This allowed for a spatial representation of the interval sequence, and allows the user to quickly map the fire interval sequences and then obtain more accurate information on all the fires from the attribute table.

### *Application of the fire interval sequence – studying the influence of fire intervals on biodiversity*

Areas that have experienced successive short fire intervals (two intervals  $\leq 5$  y; designated by a code of '11') or successive long fire intervals (two intervals  $\geq 10$  y; designated by a code of '33') at some stage in the last 33 years were considered biologically important and were highlighted as potential study areas (Fig. 1b). Areas that have been only 'once or twice burnt' in the last 33 years (having either one fire interval or none at all) were categorised separately, although generally may also contain two successive long intervals. 'Moderate' fire intervals were defined as all other areas without successive short or long fire intervals that have been burnt more than twice, i.e. contain at least two intervals. This class may contain significant variation within interval sequences. Successive short and long fire intervals and moderate intervals were mapped for all locations (Fig. 1b). The rationale behind this is that successive short fire intervals or successive long fire intervals may result in localized extinction of 'fire regime-specific' taxa, but those with a moderate disturbance frequency (the 'Intermediate Disturbance Hypothesis') will maintain a higher diversity of species (Whelan 1995; Huston 2003). We decided that for this study, the *actual* pattern of fire intervals was likely to determine the occurrence of fire regime-specific taxa in our plots, rather than the *average* fire interval (Gill 1977).

## **Results and Discussion**

Converting complex fire interval data into a single number sequence that represents the pattern of fire interval through time allows the user of the FHD to rapidly assess the spatial patterning of historical fire intervals across the landscape. The output that is generated simplifies the complex temporal and spatial components, but retains detailed information on individual fire events, including type (prescribed or unplanned), year and season of the fire. This is demonstrated in Fig. 1a that shows all fire interval sequences in our study area.



**Fig. 1:** depiction of fire interval sequences in reverse time series for our study area 30 km northeast of Walpole. (a) Fire interval sequences for the study area, where '1' = fire interval  $\leq 5$  years; '2' = fire interval 6-9 y; 3 = fire interval  $\geq 10$  y, as described in the text. (b) Fire interval sequences containing '11' (successive short intervals) or '33' (successive long intervals) mapped against moderate intervals and those areas burnt only once or twice.

For the purposes of our overall study design, which was to investigate the influence of past fire intervals on abundance and diversity of biota, we concentrated on those intervals with '11' or '33' in the sequence of numbers. For our study area, this resulted in five independent areas of successive short intervals, and two adjacent although unique areas of successive long intervals. Additionally, there was one area that had experienced only 2 fires in the past 33 years (in 1972 and 2002), and thus had a fire interval code of '3000' (Fig. 1b).

The fire interval sequences provide an effective initial analysis of potential study areas in a spatial sense. Using Arcview™, it is possible to interrogate the data to highlight particular fire interval sequences (for example those that are considered important for an ecological study). Using other available data layers (such as vegetation types, topographic information, rainfall isohyets, etc...), an integrated approach can be taken to search for study areas that have similar characteristics. Retrospective studies have inherent difficulties, such as assumptions that the study areas are similar in all ways other than the historical 'treatment'. By using GIS data layers, it is possible to denote areas that are similar in all physical, meteorological and geographical respects. However, ground truthing of these sites is essential.

To our knowledge, this is the first representation of fire interval data in such a way, and represents a significant step in the way we are able to investigate complex historical datasets. To do this work, we were fortunate to have an accurate spatial history of fire occurrence for an area of approximately 1 million hectares, which we reduced to 50 000 ha for the specific purpose of studying fire history influences on biota. Constructing similar fire interval sequences would not be possible without accurate spatial and temporal information.

We considered this approach more useful to investigations of contemporary fire history (30 years or so) than fitting statistical distributions such as that of Weibull, which provides a description of fire intervals at much larger spatial scales (Baker 1989). Because we were concerned with investigations of fire intervals for plot-based surveys, we required much finer scale investigations of fire intervals (at the scale of knowing where past fires overlapped). In addition, we wanted to maintain the actual fire history data so that the exact fire history of each plot was known, rather than a broad-brush approach that statistical output provides.

Statistical analysis of fire intervals also provides mean fire intervals and variation in fire interval (Gill and McCarthy 1998), which fails to identify the successive short or long fire intervals that we considered important in our studies on fire history and biodiversity. An area that has a low mean fire interval (suggesting frequent fire) may not have a species composition any different to an area with a higher mean fire interval (suggesting infrequent fire), if the *actual* intervals do not have any significant biological effects. We argue that it is important to recognise where fire intervals are below or above certain thresholds as well as the order in which fire intervals occur. The fire interval sequences that we have developed aid in identifying these thresholds and temporal patterns.

## **Conclusions**

Fire history information has complexity in both temporal and spatial dimensions. Here, we have presented a method to classify fire intervals as 'short', 'moderate' or 'long' based on vital attributes of the flora and realistic fire return intervals as related to fuel accumulation and flammability. Our method permits rapid investigation of the sequences of fire intervals across the landscape that can be used to investigate spatial complexity of contemporary fire intervals, and can aid in research of the impacts of fire regimes on biodiversity. When this information is linked to the original fire history database, the dataset is powerful in terms of its potential to investigate real fire regimes in the contemporary era. This method of classification and mapping has potential to be applied to a range of other complex data (not necessarily fire related).

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