Fire frequency in the Western Cape

First year progress report

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31 May 2007

This report is a summary of the work I have done in the first year of my masters. Each section is briefly discussed and the key results are summarised.

I began my MSc looking at fire models with the thought of creating a fire spread model for the Western Cape. This idea was set aside when I received the fire history records from the Western Cape Nature Conservation Board, WCNCB, for their reserves. I began an analysis of the determinants of fire size, but became frustrated with the lack of data for proposed determinants. The project focus then shifted to an analysis of large fires and the drivers behind the different definitions of large fires. This work produced interesting results, but was put on hold for the past three months while I was at the Australian National University, ANU. At the ANU I was introduced to the theory of fire frequency distributions and this work has defined the methodology of my project.

Even though my project seems to have jumped around a lot in a year, each section has added to my knowledge on the analysis of wild fires and has therefore been a valuable experience. Armed with this knowledge I now approach the second year of my MSc with a well defined project and more confidence. The objectives of this report are to consolidate this knowledge and present a clear path that will take me to the successful completion of my MSc.

This report includes:

- a diary of work undertaken last year and a few brief results,
- a description of fire frequency theory,
- research questions,
- a description of the analysis undertaken at ANU,
- an outline of possible thesis chapters, and
- a work plan for the following year.

Diary of my first year of this MSc

Table 1: Time spent on each section of work

Section of Work	Time spent on section
Fire Models	April ’06 – June ’06
Regression Analysis	July ’06 – September ‘06
Fuel Moisture	2 weeks in August ‘06
Large Fires	October ’06 – December ‘06
Fire Interval Distributions	February ’06 - present

Brief results from each section

Fire Models

My initial idea for an MSc was to build a fire model for the Western Cape. I explored some of the fire model literature and found myself focussing on fire spread models. I identified the different techniques used to simulate fire movement over a landscape and chose to build a cellular automata model. By exploring the cellular automata technique I built a simple fire spread model, see figure 1. This model propagated fire over a homogeneous landscape using probability of burning functions, but the functions were not parameterised to any data.

I enjoyed creating this model but it taught me that I needed a better understanding of the functions that describe fire and fire movement. A project of this kind needs to focus on fire behaviour and would need detailed data from individual fire events.

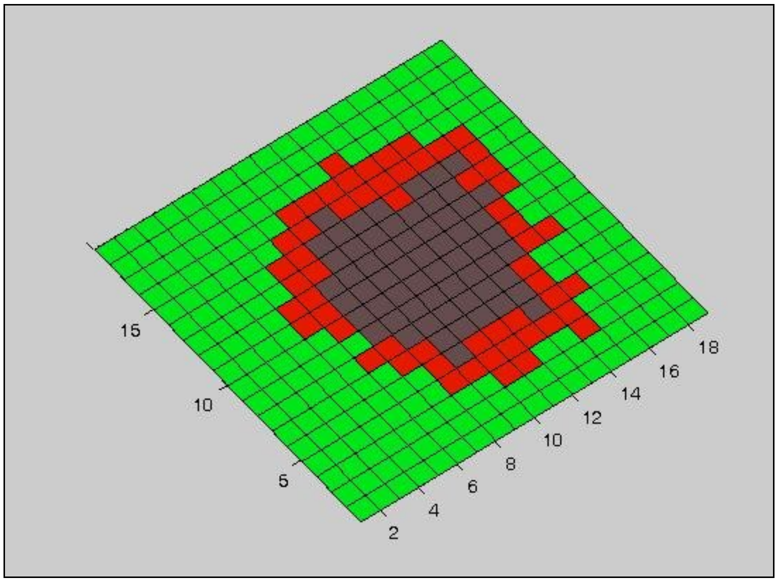

Figure 1: Screen capture of the cellular automata model

Regression Analysis

Upon receiving the WCNCB fire history data set I used regression analysis in an attempt to parameterise the factors affecting the size of individual fires. I attempted to explain fire size with the year and month of occurrence and age of the vegetation. Table 2 shows results of such a regression.

Table 2: Analysis of Variance

Response: log(Area Burnt)	Degrees of Freedom	Sum of Squares	Mean of Squares	F value	Pr(>F)
Months	11	42.46	3.86	1.8276	0.0468024
Years	28	131.34	4.69	2.2209	0.0003848
1/veld age	1	25.37	25.37	12.0130	0.0005718
Residuals	522	1102.57	2.11		

Variance explained 8.8%

There was a significant relationship between the size of fires and the age of the vegetation with larger fires occurring in older vegetation. This relationship is shown in figure 2.

These factors did not explain much of the variance of the data set and I found it very difficult to obtain other data for other variables.

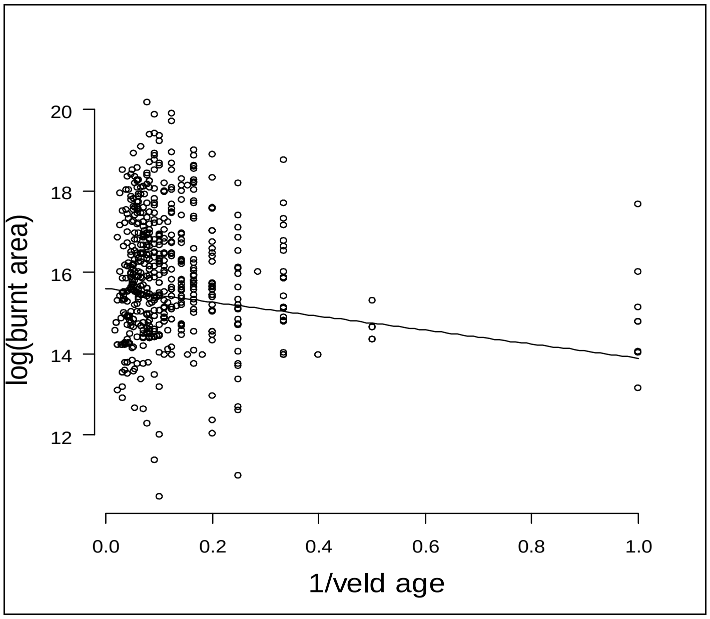

Figure 2: relationship between fire size and vegetation age

Fuel Moisture

One attempt to create another regression factor was to include precipitation data in an attempt to approximate fuel moisture. I obtained an interpolated daily precipitation data set of the Western Cape and used it to create a dryness index for each sampling point. This index represented each rainfall event as an immediate increase in moisture level which then slowly decayed to a dry state. Figure 3 shows an example of a dryness index ninety days prior to a fire.

The shortfall of this technique was the difficulty in relating the calculated moisture level to fuel moisture as I believe this research is still ongoing. The data sets themselves were limiting; the precipitation data ended in 2000, and very few fire records detailed the exact day of the fire. Despite it's limitations I used the dryness index in a regression analysis, but found it did not improve my results significantly.

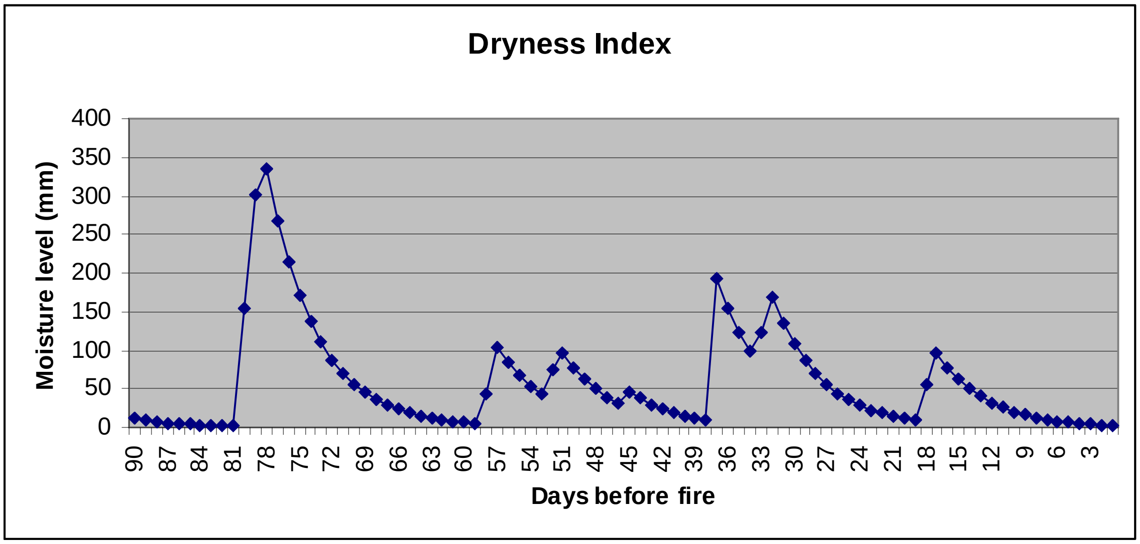

Figure 3: dryness index ninety days prior to a fire

Large Fires

I undertook an analysis of large fires in the Western Cape and defined large fires by two different methods. I differentiated between single fires that burnt a large area, large individual fires, and years in which multiple fires cumulatively burnt a large area, large fire years. A large individual fire burns an area greater than a thousand hectares, and a large fire year burns an area greater than five thousand hectares. This generally accounts for the top 25% of the records for each reserve. Large fires have a huge effect on the total area burnt in a year as can be seen in figure 4. Total area burnt also seems to be correlated to the number of fires in a year. (this is still to be tested)

The hypothesis of this analysis was that single large fire events are determined predominantly by weather patterns, and that large fire years are driven by fuel availability. I produced some preliminary results which seem to be able to support this hypothesis, but I was unable to confirm this before I left for Australia. Figure 5 displays the large individual fires for the Cederberg study site along with the annual variance in rainfall. It appears that large individual fires predominately occur in years of less than average rainfall.

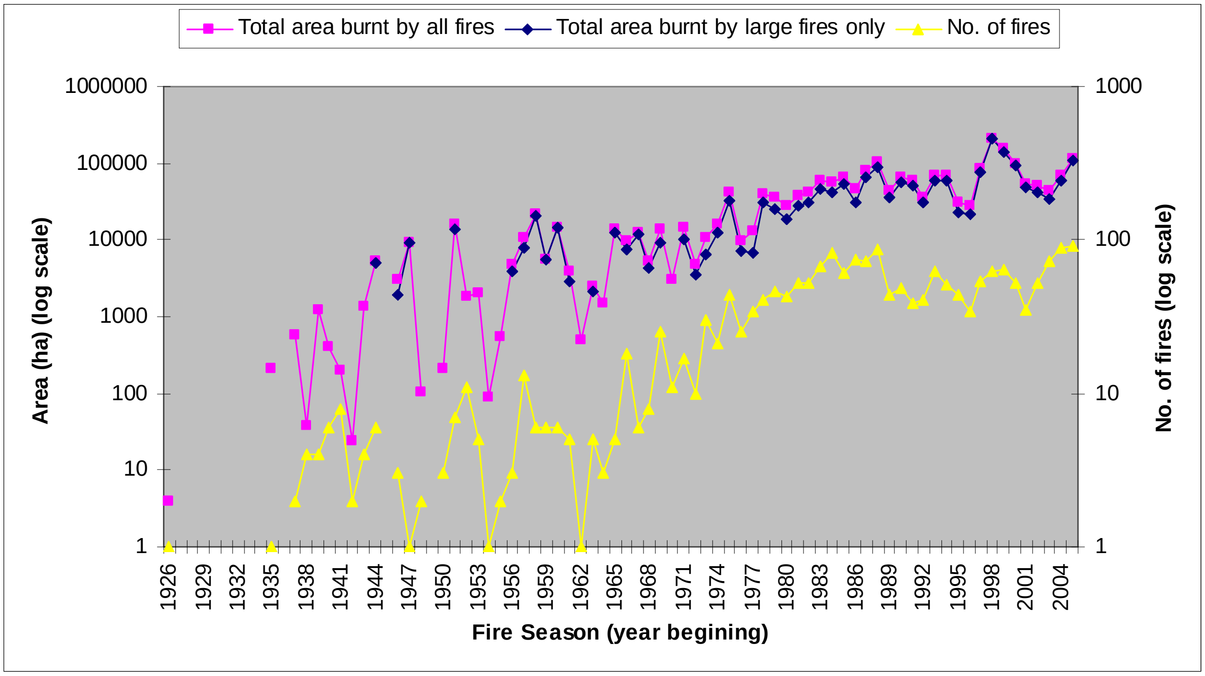

Figure 4: Area burnt by all fires compared to are burnt by large fires only for all the fire records in the Western Cape

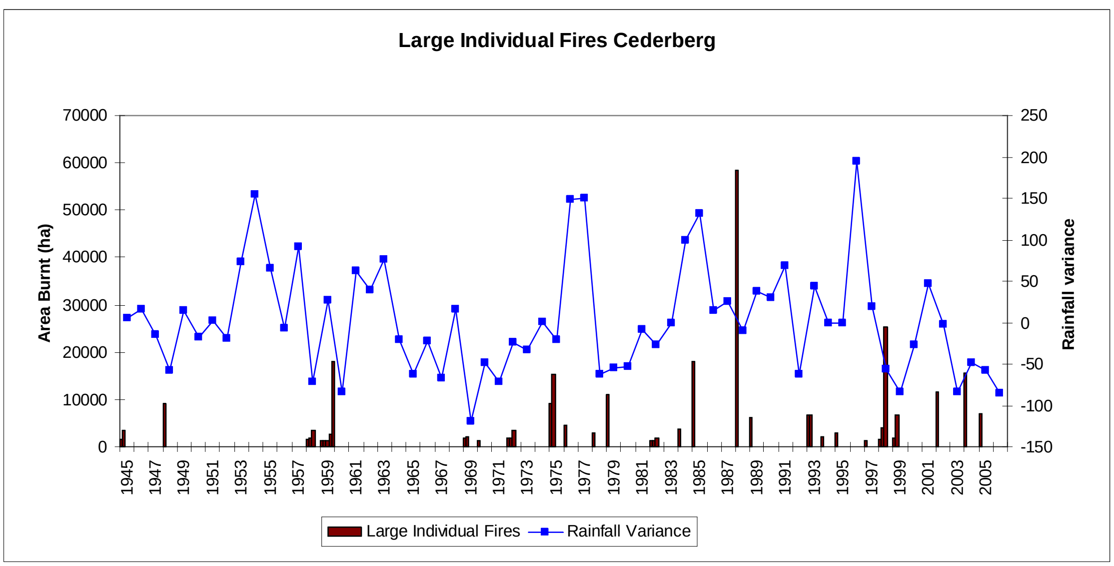

Figure 5: Large fires in the Cederberg and annual rainfall variance.

I found this analysis very interesting and would like to somehow return to it within the scope of my new project theme: fire frequency distributions.

Fire Frequency Distributions

Fire frequency is most commonly used for describing a fire regime (Li 2002), but before 1973 studies of fire frequency were just informal accounts of fire occurrence. A study in the Boundary Waters Canoe Area, Minnesota, by Heiselman (1973) was the first to estimate survivorship from fire as a description of fire frequency. From this beginning, work done by Van Wagner (1978) and Johnson (1979) has formalised fire frequency modelling into three probability distributions. These are defined as follows by;

1) The cumulative age distribution, $A(t)$, as the probability of surviving without fire longer than time t,

$$A(t) = \Pr(T > t)\,, \tag{1}$$

where $t \geq 0$ and T is the time at which fire occurs. $A(t)$ is also referred to as the time-since-fire distribution. This distribution is applicable to time-since-fire maps, i.e. snap shots of the vegetation age structure in a landscape. Fire frequency is inferred from the different proportions of vegetation ages in a single year.

2) The fire-interval distribution, $f(t)$, is the probability of fire occurring in the landscape in the interval t to $t + \Delta t$ per unit time and is related to $A(t)$ by

$$f(t) = -\frac{dA(t)}{dt}\,. \tag{2}$$

$f(t)$ describes the probability of mortality. This distribution uses inter-fire-intervals and thus requires long data sets.

3) The age-specific probability of burning at a point, $h(t)$, is the probability of fire occurring in an interval, assuming survival up to the beginning of the interval, and is related to both $A(t)$ and $f(t)$ by

$$h(t) = \frac{f(t)}{A(t)} \tag{3}$$

(Johnson and Gutsell 1994). $h(t)$ is the probability of burning at a point, PBP function. PBP can only be defined for a landscape on the assumption that fire frequency is unchanging.

Research Questions

1. Is there a change in the shape of the cumulative age distribution, $A(t)$ where t represents time-since-fire, through time, T? (there is a perception that the mean age of vegetation burned in fires getting younger)

    Null hypothesis (H_0) – No, there may be variation about a mean but the shape is stable.

    Alternative hypothesis (H_1) – Yes, there is a significant shift from one state to another

2. For H_0 true. Does PBP remain constant for mountain fynbos in the selected study areas?

    Null hypothesis (H_2) – PBP is constant through time.

    Alternative hypothesis (H_3) – PBP follows the pattern defined by the logistic model due to the slow initial accumulation of fuels leading to rapid fuel accumulation up to a maximum.

3. For H_1 true. What drives variability in $A(t)$?

    Null hypothesis (H_4) – Climatic patterns causing periods of severe-fire weather

    Alternative hypothesis (H_5) – Possible changes in the ignition frequency coupled with periods of severe-fire weather

    Alternative hypothesis (H_6) – Changes in fire management policy

    Alternative hypothesis (H_7) – No significant factors can be identified

4. What are the implications for biodiversity of small and large scale variability in $A(t)$?

    Use a model to predict possible vegetation age structures resulting from small and large scale shifts in fire frequency. The model structure will be based either on constant $A(t)$, H_0, or on a function of $A(t)$, H_1, that is changing though time.

Figure 6 shows how the research questions are related to each other based on their respective outcomes.

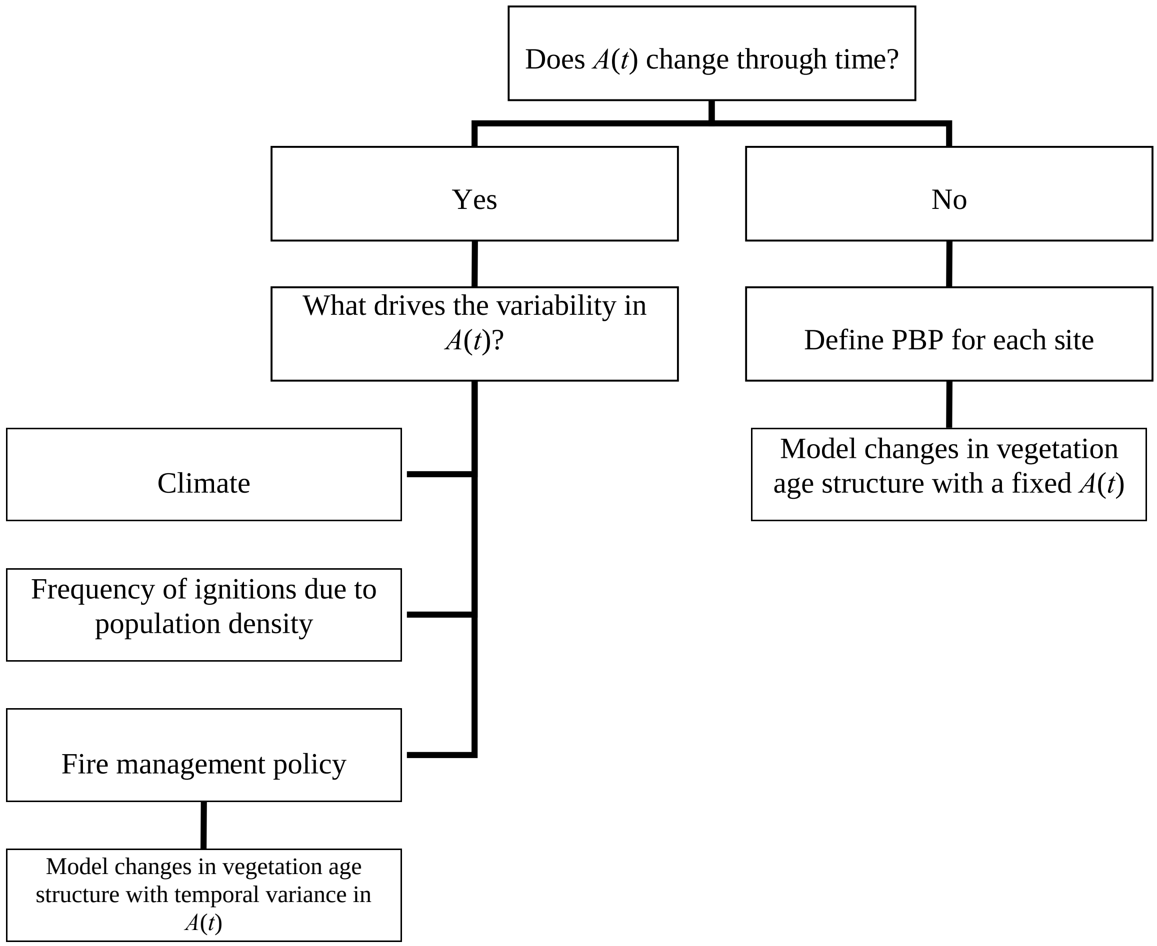

Figure 6: Flowchart of research questions

Fire Frequency Analysis Results

The following results are from the Cederberg. Point data was extracted from time-since-fire maps of successive years. This data was used to calculate the cumulative age distribution, $A(t)$, and plotted in order to visually detect a pattern. Figure 7 shows the resulting distributions from 1992 to 2003.

The choice of time periods represented in figure 7 highlight the difference in the shape of the cumulative age distribution between periods of low fire activity, graphs A&C, and high fire activity, graph B. Figure 8 shows the fire activity in the Cederberg between 1992 and 2003.

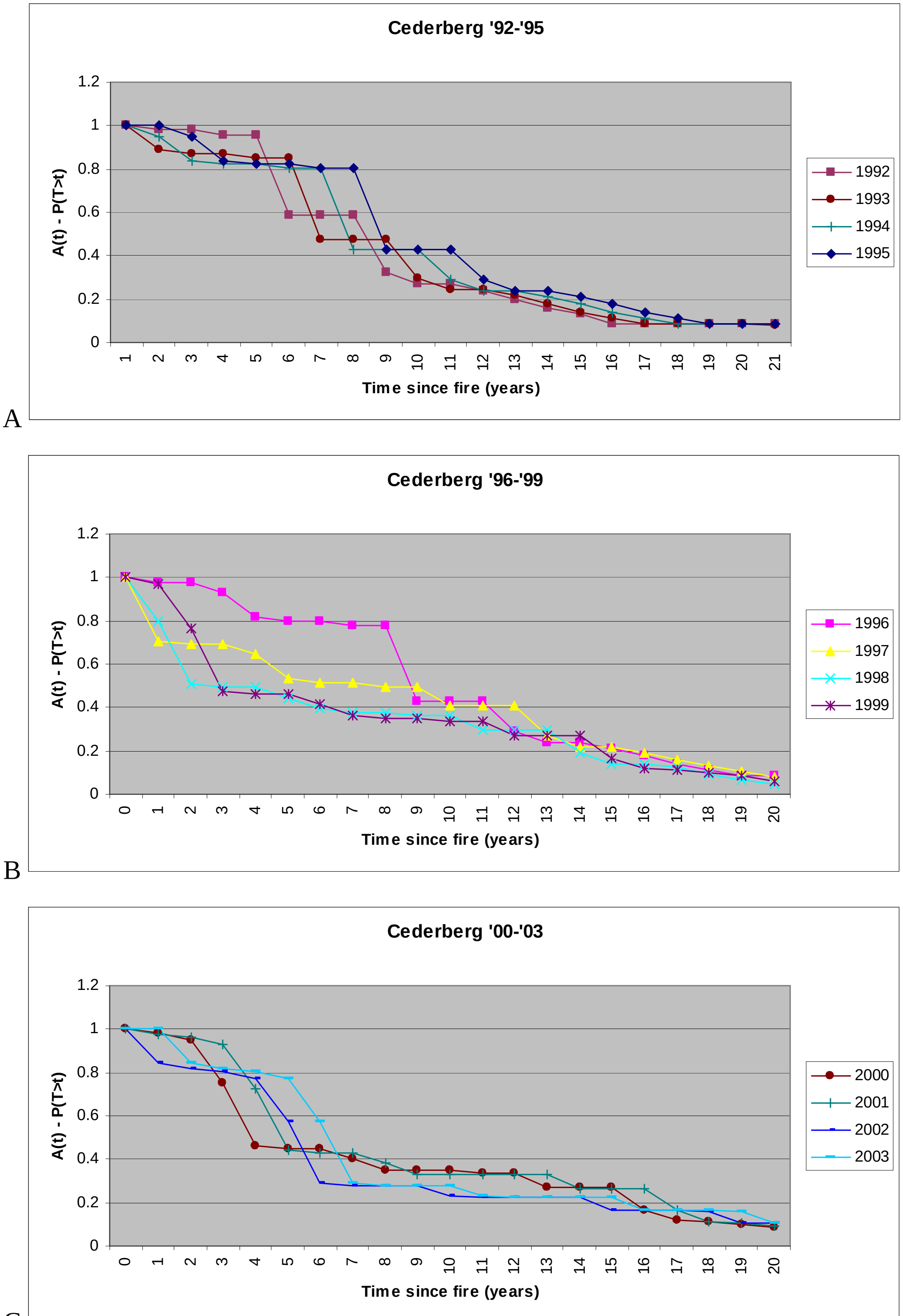

Figure 7: The cumulative age distribution, $A(t)$, of the Cederberg from A) 1992-1995, B) 1996-1999, C) 2000-2003

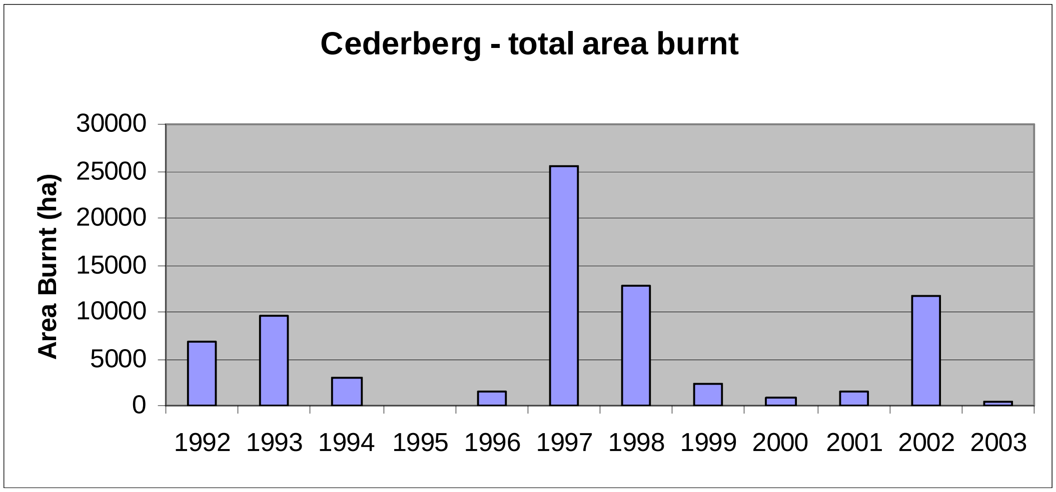

Figure 8: Total area burnt in the Cederberg 1992-2003

Fires affect the shape of the age distribution in two ways. When there is little to no fire activity in a year, A(t) shifts horizontally as each point in the landscape ages one year. For years when there is significant fire activity, 1997 and 1998, the shape of A(t) shifts vertically as the presence of burnt vegetation affects the relative cumulative proportions of the remaining landscape.

We can visually see that there is a pattern in the changes of the cumulative age distribution and a method to describe this pattern must be found. In conventional fire literature a model is selected for a region based on biological understanding of that system. I was thus encouraged to describe the above pattern by fitting a model to the data and creating a tree dimensional surface. My initial assumption was that fynbos will fit the Logistic model, but as can be seen in figure 9, it is very difficult (if not impossible) to fit a model to observed $A(t)$ data.

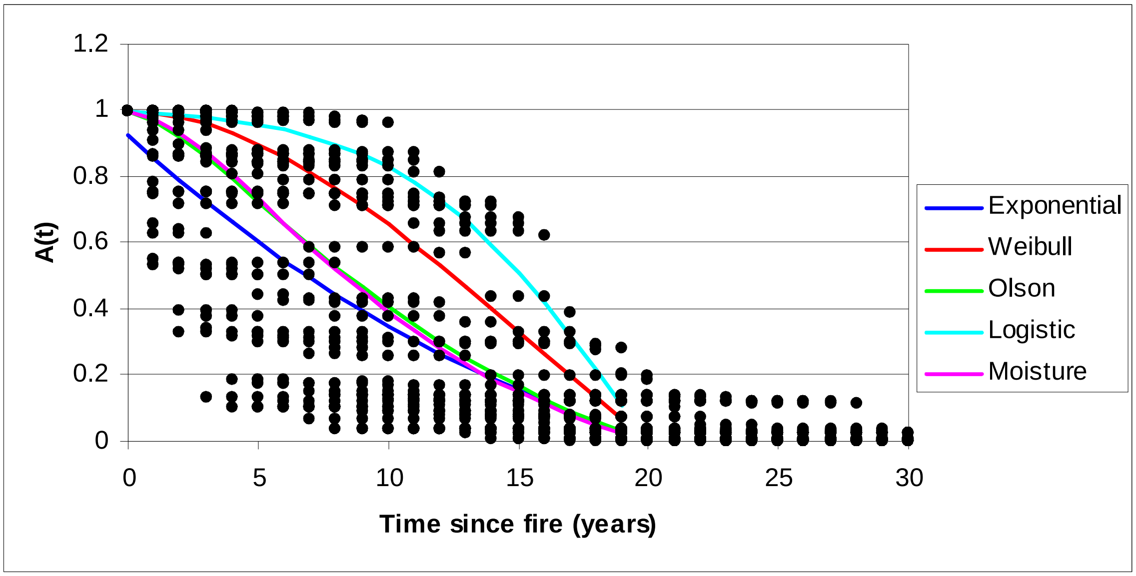

Figure 9: Observed $A(t)$ values with representations of five fire interval models.

In fact nowhere in the literature has anyone successfully modelled $A(t)$ from observed data. The preferred analysis technique is to fit a model to inter-fire. The most flexible of the fire interval models depicted above is the Weibull Model. It is also the model with the most comprehensive accompanying mathematical text. I thus attempted to analyse the data using fire intervals following the work done by Polakow and Dunne.

The 2-parameter Weibull model is given as:

$$f(t) = \begin{cases} \frac{c}{\gamma} t^{c-1} \exp\left(\frac{-t^c}{\gamma}\right) & t \geq 0 \\ 0 & t < 0 \end{cases}$$

I discovered that in order to fit the Weibull parameters more accurately I need to first censor my data. This I did and I fitted the model. An analysis of fire intervals is best performed by inspecting the fire intervals from the current year and looking back as far as the data will allow. Because I am attempting to detect temporal change I plotted the fire interval for periods ending in successive years, i.e. 1978-2005, 1978-2004, 1978-2003, etc. to create a variable three dimensional surface, as shown in figure 10. I chose 1978 as the first year of my dataset for all $f(t)$ calculations.

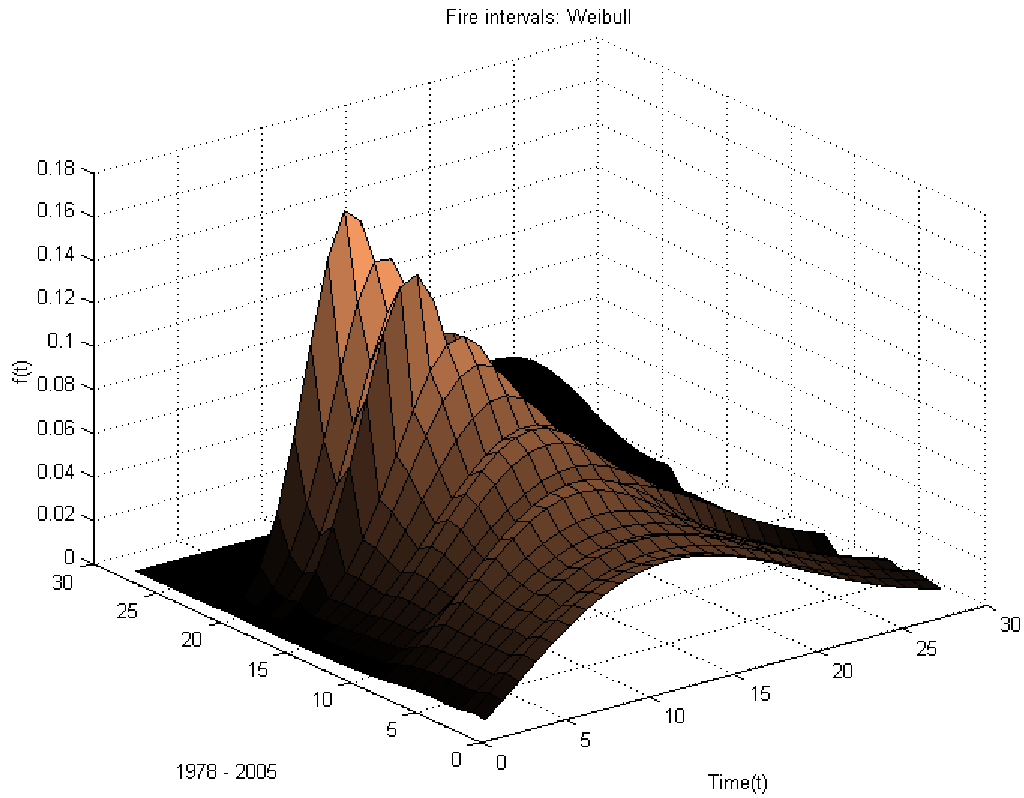

Figure 10: Modelled fire intervals for successive years using the Weibull model.

From the 25 years of data, accurate fire frequency information could only be obtained for the last 3 years. This is because this method changes the length of the dataset as $f(t)$ is calculated for earlier years and the data set is too short to accurately represent fire intervals. Thus the data set is inadequate to detect a change in fire frequency through inter-fire intervals.

The conventional fire frequency methodology of choosing a biological model to fit the data must be abandoned and instead I will use statistical techniques to explore $A(t)$ and let the data 'tell the story'.

References

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