

# **The relationship between Hot Spots from NOAA AVHRR Imagery and Fires in southwestern Australian Forests**

**A. Malcolm Gill<sup>1</sup>, Gerard van Didden<sup>2</sup> and Peter H.R. Moore<sup>3</sup>**

<sup>1</sup>Honorary Research Fellow, Centre for Plant Biodiversity Research, CSIRO Plant Industry

<sup>2</sup>Consultant, Sawyers Valley, Western Australia, formerly with Western Australian Department of Conservation and Land Management, Fire Section.

<sup>3</sup>Senior Technical Officer, Centre for Plant Biodiversity Research, CSIRO Plant Industry

## *Abstract*

The task of relating 'fire hot spots' (FHS) detected daily by satellite to actual fires on the ground is a complex one. There are difficulties of satellite detection including obfuscation by cloud and by sunglint due to low-angle views. On the ground, fire statistics may be collated by a number of agencies in different ways and with different degrees of precision. In this study we have used daily maps of FHS from NOAA AVHRR imagery for the period September through May, 1998-99, and for the same period in 1999-2000 and compared them with locations of prescribed and unplanned fires on the same days. FHS were detected on a daily basis and grouped into 'events' (clusters). By comparing events from day to day for temporal and geographic overlap, multiple counting was avoided. Being explicit and quantitative about the possible errors due to poor imagery or cloud obfuscation in detecting FHS was important to the evaluation of the results. Close co-operation with the agency determining the presence of real fires whether unplanned or prescribed (Western Australian Department of Conservation and Land Management) was found to be essential. We determined the numbers of fires not matched by 'events', numbers of fires that were matched with 'events', and numbers of 'events' evident apparently without fire occurrence. In the forested southwest many fires were undetected by satellite and there were many 'events' unmatched by real fires. Inadequate imagery (especially due to cloud obfuscation) was a major reason for the non detection of fires. Low intensity fires under tree canopies may be a reason for poor detection even when appropriate imagery was available. A further problem with poor detection, and the occurrences of many unmatched 'events', could be due to large errors in matching locations (up to 3km error for automatic processing of images for FHS).

## **Introduction**

The 'environment' may be seen as a number of components linked by a number of processes. The processes operate at widely different rates - like those of evolution and flooding. To formally assess the 'State of the Environment' either one can examine the components for any change from the previous assessment or measure departure of processes from a standard range. Changes in components are easier to evaluate and impose standards on, than are changes in processes but changes in components will need to be evaluated against the processes that caused the change if any conclusion is to be drawn about any necessary restorative action.

One major natural process is the passage of fire and its contribution to the fire regimes of a site. It is believed that there are many thousands of fires each year dispersed unevenly across Australia (e.g. Luke 1961) and affecting plant communities from tropical rainforest to desert grassland, from pine plantation to wheat crop. From perhaps 4% (Craig *et al.* 2002) to 15% (Luke and McArthur 1978, p.341) of the land is affected annually (roughly half to one million km<sup>2</sup>) but it is unequally distributed, the predominance of fire-affected area being in the savanna of northern Australia (Craig *et al.* 2002). Fire occurrences are relevant to greenhouse-gas accounting, changed solar radiation levels on the earth, threats and enhancements of biodiversity and the pursuits of pastoralism and agriculture.

Despite the importance of fires to land managers, policy makers (especially on Greenhouse matters and biodiversity) and emergency services, there is no centralized data base from which to examine occurrences of fires across Australia.

Individual agencies keep records of various quality and continual budget constraints are likely to decrease standards in this area. Ideally, national records would be collated by a national agency which would also examine satellite imagery each day for the whole continent to augment and cross correlate regional data. Before this would be practical, however, the efficacy of remote detection of fires and its correspondence with real fires in different environments would need to be shown. This report deals with the detection of fires in a relatively difficult area - because it is forested - using the crudest of satellite data (pixels of 1.1 km a side).

The task of relating the numbers of fire hot spots (FHS) detected by satellite with fires actually occurring on the ground is a complex task. Often there are several agencies attending and reporting fires (see Gill and Moore, in press, for an overview). Involved in reporting fires may be an emergency service agency, one or more land management agencies, one or more local volunteer fire brigades (usually supported by the emergency service agency) and even urban brigades (sometimes under the same emergency service agency as the volunteers) and individual farmers. To achieve uniform and effective reportage of fires, we chose the forest lands of the Western Australian Department of Conservation and Land Management (CALM) as our study area. CALM has a long history of fire reporting and fire management in these forests (Gill and Moore 1997). We expected that satellite detection of fires would be difficult because of forest cover but we were confident that there would be many target fires occurring in the study area because of the practice of regularly burning the forest to a prescription (i.e. prescribed burning) and the generally fire-prone nature of the landscape.

The aims of this study were:

- (i) to use evening overpasses of NOAA AVHRR satellites to detect FHS in imagery of the CALM estate;
- (ii) to plot FHS in the target area and determine by FHS-clustering the numbers and locations of apparent fire events (ie. 'FHS-events' or 'events');
- (iii) to obtain data for real fires from CALM and plot their origin ('prescribed' or 'unplanned') and locations;
- (iv) to allocate FHS-events (to prescribed fires, unplanned fires or the apparent absence of fire);
- (v) to record real fires undetected by FHS-events;
- (vi) to evaluate the outputs of the study in the light of a potential national system of fire monitoring.

## **Study Area and Methods**

Most of the *Eucalyptus* forests of southwestern Australia are managed by CALM as National Parks, Nature Reserves or State Forests. The CALM Estate is contained within three Forest Regions which, in turn forms part of the standardized satellite scene of this study - bounded by Latitude 31 and 35.25<sup>0</sup> S. and Longitude 114.25 and 118<sup>0</sup> E. The total satellite scene used each day was about 150,000 km<sup>2</sup> in area; the Forests Regions comprised about 78,000 km<sup>2</sup> and the CALM estate about 23,000 km<sup>2</sup>. Only the CALM Estate is considered in this report. For more information on the fire

regimes and biodiversity of the southwest forests see the companion report of State of the Environment (Gill 2002) and Gill and Moore (1997).

The satellite data was drawn from the most appropriate NOAA satellite by the Western Australian Department of Land Administration (DOLA), the choice depending on the timing of the orbit (see Craig *et al.* 2002). Evening passes were appropriate for maximum opportunity for the detection of the radiant signal (including strength of signal from the fire). If the overpass was too late then a fire may have been extinguished or have died down to the point of non detection. If too early then sunglint may obscure the signal. Details of the methods of receiving imagery and automatically detecting FHS are to be found in Craig *et al.*(2002) and on <http://www.rss.dola.wa.gov.au>.

Each satellite image was examined for the effects of cloud or low sun angle (sun glint) as these obfuscate FHS and cause 'missing data' to be noted. Locations of FHS, automatically recorded on DOLA images, were recorded in degrees and minutes but CALM fire locations were recorded in decimal degrees and prescribed burns were listed as alpha-numeric locations in a Forestry-grid system (echoing the administrative origin of part of CALM from the Department of Forestry); conversions to a common system were made. Clusters of FHS, events, in the 1.1 km ground field of view were marked as 'events' for comparison with real fires.

A 1:500,000 map was used to show the locations of all real fires in the CALM Estate. Only fires greater than 1 hectare in area were considered. While such fires are the most numerous (Gill and Moore 1997) this size is less than 1% of the standard size of a pixel on the satellite image. If, after a match of a real fire with a satellite FHS-event, further FHS were detected in the same area on subsequent days they were referred to as 're-ignitions'. As 're-ignitions' were repetitions of fires recorded on previous days they were noted but not included in most analyses (exceptions are noted).

The study periods for data acquisition, September 1998 to May 1999 and September 1999 to May 2000, include times when most of the area is burnt in southwest forests. Indeed, CALM figures for each of the two years of study reveal that close to 96% of the total area burnt by prescribed fires (deliberately lit management fires) and almost all that burnt by unplanned fires ('wildfires') was during the September to May period (see also below).

One of us (G.v.D.), permanently located in Western Australia, is experienced in the data-keeping procedures of CALM having been involved for many years. He was able to work with CALM officers at Head Office and in the Districts to obtain the best possible results for fire occurrences and locations. He was also able to work with DOLA in the Leeuwin Centre at Floreat Park (Perth) to process satellite images. He was also able to rationalize the different mapping projections used for different applications - satellite imagery, prescribed fires, unplanned fires. Credit for all data collation and primary processing is his.

## Results

### *Satellite imagery*

On days when cloud covered the area at the time of the evening satellite overpass no data was available. Cloudy scenes occurred from 1 to 13 days per month, September and May being strongly affected in both years, while scenes with part cloudiness varied from zero to 8 days per month. Taken together, scenes adversely affected for half or more days of the month occurred in four of the 18 months of the study period (Fig. 1). Imagery taken when there was low sun angle that gave inadequate data quality and days in which the satellite was out of range (satellite too far east) - added to the few days in which no satellite data at all was available (a maximum of 6 in February 2000) - rose to a peak in November 1998 of 24 days and in January 2000 of 15 days (Fig. 2). Numbers of days on which none of these problems existed ('imagery-suitable days') rose from a minimum of 3 in November 1998 to a maximum of 17 in February 1999 and in April 2000 (Fig. 3). There were only 7 months out of 18 in which 15 or more days had suitable imagery (Fig. 3).

### *Fire Hot Spots and 'events'*

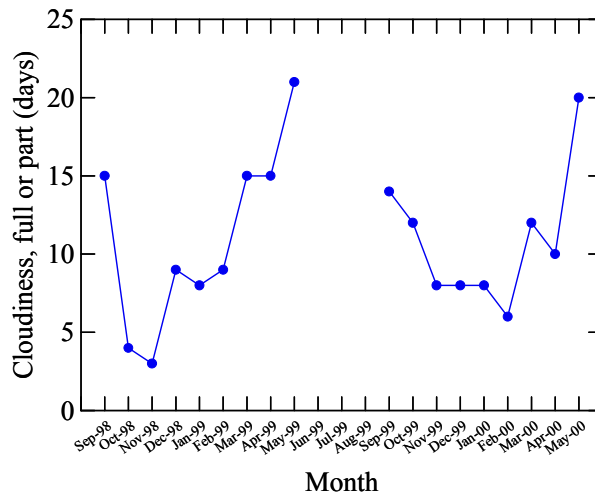
Fire Hot Spots (FHS) varied from 6 to 488 per month. For days on which detection was possible, the numbers varied from 2 to 83. The numbers of FHS per event varied from 2 to 10.

In the second year of the study, data were more comprehensive than the first year. Total numbers of events showed a bimodal distribution with time in which peaks were reached in November 1999 - 80 events - and April 2000 - 73 events. In that period from September 1999 to May 2000 there were 311 events (Fig. 4).

### *Actual fires*

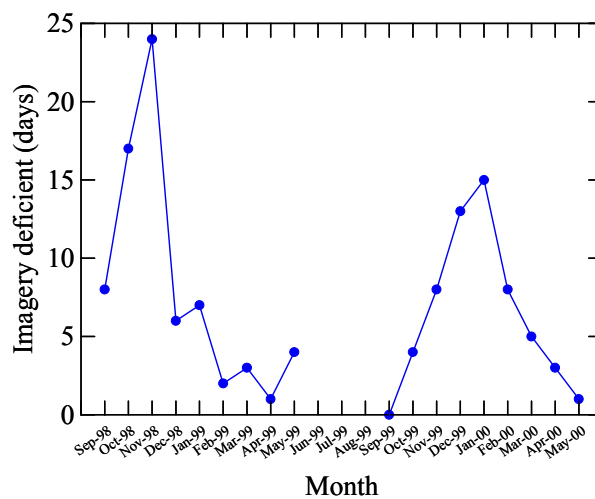
Fires were classified as 'prescribed' or 'unplanned' (also called 'wild'). The former were ignited for management purposes; the latter were ignited by lightning or, more

Figure 1.



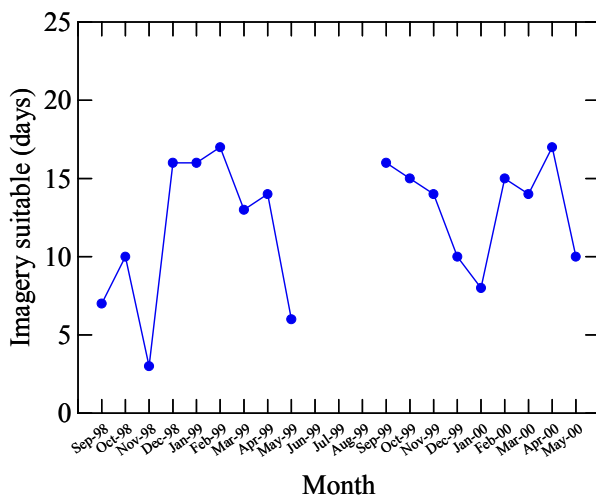
Number of days per month on which full or part cloud obfuscation of the ground occurred during the periods September 1998-May 1999 and September 1999 to May 2000

Figure 2.



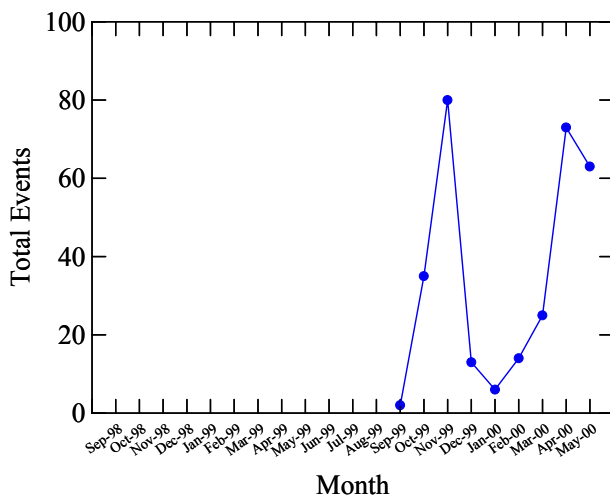
Number of days per month during the periods September 1998-May 1999 and September 1999 to May 2000 in which imagery was deficient in ways other than cloud obfuscation (out of range, low sun angle etc.)

Figure 3.



Number of days per month on which imagery was suitable during the periods September 1998-May 1999 and September 1999 to May 2000

Figure 4.



Number of 'events' per month matched with real fires, or otherwise, during the periods September 1998-May 1999 and September 1999 to May 2000

commonly, by the public. In the first study period there were 546 fires (423 prescribed and 123 unplanned) while in the second there were 991 fires (766 prescribed fires and 225 unplanned fires) equal to or greater than 1 ha in area (Fig. 5). Most prescribed fires were in spring, the peak during the second study period being in November when there were 200 fires; this was followed by a secondary peak in autumn as there were 126 fires in May (Fig. 5). The numbers of unplanned fires in the second study period peaked in December 1999 with 50 occurrences (Fig. 5). In November 1999 there were 235 fires altogether (Fig. 5).

### *Event accounting*

We can take events and account for them in relation to actual fires or we can take actual fires and account for them in relation to events. The former is addressed here, the latter in the next section. Events can be matched with actual fires or they can be seen to be 'unmatched'. Matched events fell into two classes: the first were those that could be identified with a CALM prescribed fire or with an unplanned fire. There were 120 matched events in the second study period (102 prescribed fires and 18 unplanned fires). Unmatched events totalled 191 in the second period. Numbers of events matched to actual fires by month are shown in Fig. 6.

### *Actual-fire accounting*

Taking actual fires as a starting point, actual records of prescribed and unplanned fires may be accounted for as: 'numbers of matches' (equal to numbers of matched events, see above section and Fig. 6); 'not seen due to lack of suitable imagery'; and 'undetected although there was suitable imagery'. In the second study period there were 120 fires matched with events (as above), 463 undetected fires due to the absence of suitable imagery (360 prescribed fires and 103 unplanned fires) and 408 fires that remained undetected even though imagery appeared suitable (304 prescribed fires and 104 unplanned fires). Numbers of fires in the categories of 'matched', 'no suitable imagery', 'remained undetected' and 'total fires' are shown in Fig 7.

### *Two-way accounting of fires and Events*

From the previous two sections we are in a position to account for all fires and all events for the second study period:

Total FIRES = 991 (120 matched to events + 871 which were not).

Total EVENTS = 311 (120 matched to fires + 191 which were not).

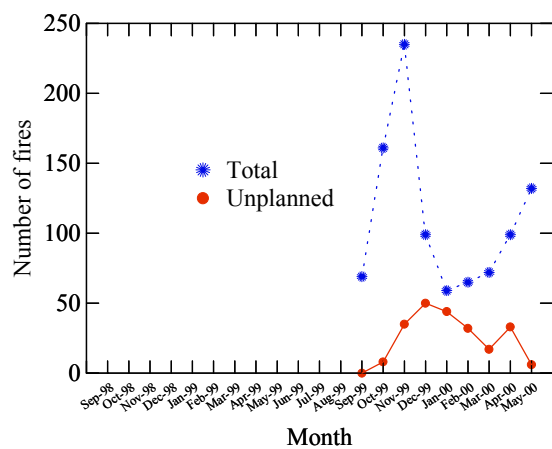
[Note that the 120 matched 'fires' and the 120 'matched events' are exactly the same fires and events.]

The Grand Total of EVENTS and FIRES = 1182 [(991+191) or (311 + 87)]

### *Estimating areas burned from FHS*

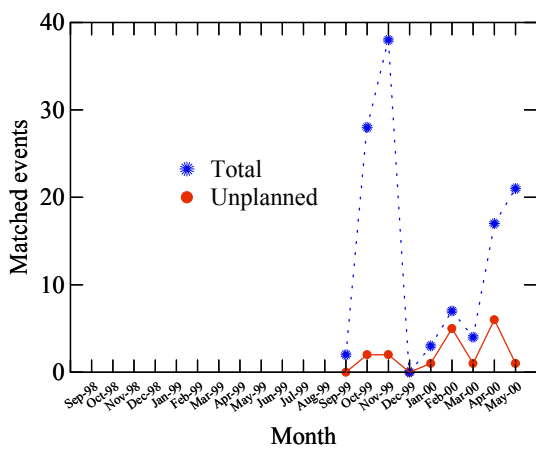
Given that there were many days when satellite data were unavailable or unsuitable, the use of NOAA AVHRR FHS for locating the positions of all the fires that occurred was inadequate. However, there was the possibility that there could be a correlation between average daily numbers of FHS detected on days when imagery was available

Figure 5.



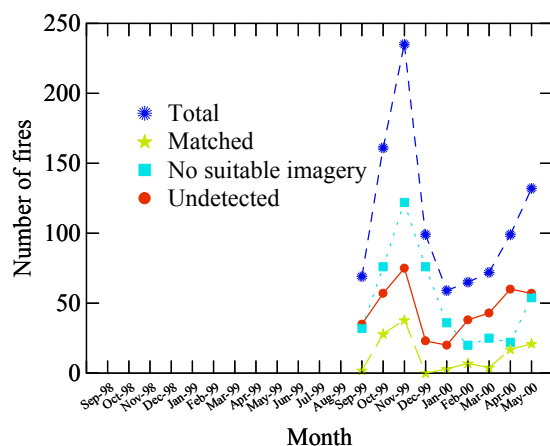
Number of fires per month, unplanned and total (unplanned plus prescribed), during the period September 1999 to May 2000

Figure 6.



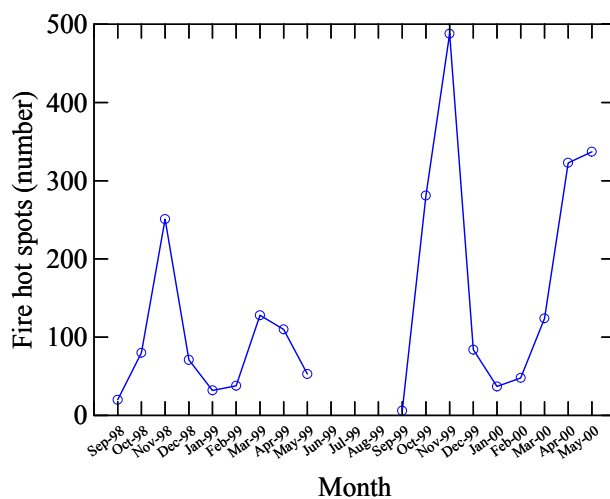
Number of 'events' matched with real fires, prescribed or unplanned, per month during the period September 1999 to May 2000

Figure 7.



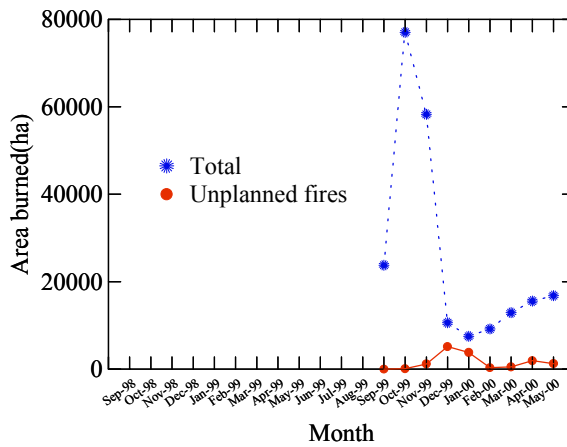
Number of fires per month which either matched satellite 'events', remained undetected although imagery was suitable, or occurred when imagery was unsuitable, during the period September 1999 to May 2000

Figure 8.



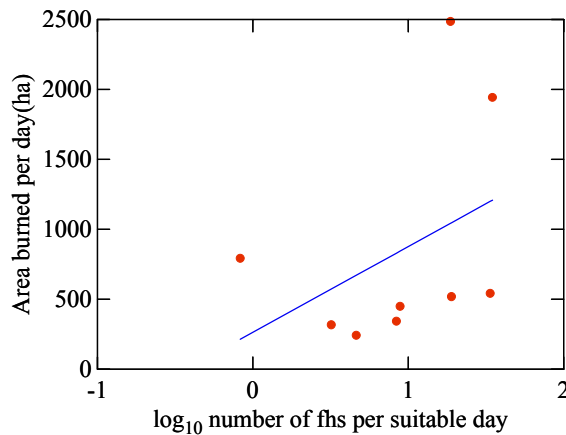
Number of Fire Hot Spots as a function of month of detection during the periods September 1998-May 1999 and September 1999 to May 2000

Figure 9.



Area burnt per month (prescribed and total) during the second study period. The total includes unplanned fires as well as prescribed fires

Figure 10.



Average area burned per day for each month of the second study period as a function of the logarithm of the average number of detected Fire Hot Spots (fhs) per day

and average area burnt daily irrespective of location and the numbers of days of suitable satellite data. This, if successful, would provide estimates of areas which could be used in studies of fire effects provided practices of CALM did not change. Fig. 8 shows the raw numbers of FHS detected per day on a monthly basis. Fig. 9 shows the monthly areas burned by prescribed and unplanned fires for the second study period (seasonal data, only, were available for the first period). Fig. 10 shows the average area burnt per day (for each month of the second study period) as a function of the logarithm of the average number of FHS per appropriate day (satellite

data available) for any one month. The correlation co-efficient was 0.4 ( $R^2$  value was 0.16). The relationship was not significant statistically ( $P>0.05$ ).

## Discussion

There is a need for a fire accounting of Australia as a whole but the way this should be done has not yet been formulated. This remains an urgent task if we are to have accurate estimates of greenhouse-gas emissions and smoke particulates for any one year let alone the fundamental data on fire occurrences for the documentation of fire regimes. All of these are essential for State-of-the-environment reporting. Suppression agencies and land managers need the data for their own accounting and planning purposes together with that for numbers of occurrences. In this study we examined the value of events detected by NOAA satellite for estimating the numbers of occurrences of fires on the ground. The study area was one in which the data for actual fires was believed to be accurate and complete yet in an area where satellite imagery would be 'put to the test'. Many difficulties were encountered.

Our comparisons have been made between what the satellite detected and what ground observers have detected and reported. It is possible that the satellite 'saw' fires that did exist, 'saw' fires that did not exist, and did not 'see' some fires that actually occurred. To assess these possibilities, comparisons with actual fires are appropriate. However, it is possible that, while actual fires are detected and reported, there may be some fires that are either not detected or not reported. As we had no way of knowing the latter, the record of fires attended on the ground was taken to be a true and complete record.

In this study there were relatively few fires detected whether they were unplanned or of the usual large prescribed type. For example, in the second year of study only 8% unplanned fires were matched with clusters of Fire Hot Spots (events) (18 out of 225). Only unplanned fires greater than 1 ha in area were considered in this study. These fires are small relative to the size of the satellite pixel (less than 1%) but it is still possible that these fires could have been detected if they were spreading at the time of the satellite overpass. However, small fires are likely to be of low intensity, partly obscured by tree canopies and be put out quickly.

For prescribed fires, 13% were matched with 'events' in the second study period. These fires were deliberately lit on days when they will be of low intensity and largely go out at night. However there will be a great deal of heat generated in the area affected by the fire and there can be numerous logs burning for some time after the litter has been burnt. The cover provided by tree canopies can be expected to reduce the chances of detection.

One major source of failure to match fires with events was the large number of days on which imagery was unsuitable for event detection. For example, in the second study period 360 prescribed fires (47%) occurred on days when imagery was unavailable or inadequate because of cloud or other problems. For unplanned fires the equivalent figures were 103 and 46%. Some, but not all, of this problem may be overcome with the analysis of data from numbers of satellites and an increase in the number of receiving stations but it is considered that the problem will persist. Another possibility, however, is to use imagery of finer resolution to detect burned areas when

scenes are cloud free rather than try to detect FHS daily. The main impediment to the use of such imagery is cost.

Despite the argument of the above paragraph, there were still many fires that remained undetected on days when imagery was available. For example if we look at the percentage of prescribed and unplanned fires that occurred on days with suitable imagery in the second study period, the respective figures are 40% (304/766) and 46% (104/225). It is possible that the reason for this is that most of the fires were of low intensity and that many of the unplanned fires were still relatively small. Among the unplanned fires, grouped in order-of-magnitude classes, we can expect that the 2-10 ha size (still only about 10% the size of a pixel) would be numerically dominant over other classes as the number of fires in each successive class usually declines. The upper limit of the next larger size class (11-100 ha) is still only about the size of the satellite pixel. While Cahoon *et al.* (1999) considered that NOAA-AVHRR (as used in this study) could theoretically detect a fire with 435m<sup>2</sup> of “flame-front area” (4.35% of one ha or *ca.* 0.04% of the pixel size), such an area is not necessarily present in the evening when fires have died down and the satellite is passing overhead. Prescribed fires ignited from many incendiaries during the day may be expected to have greater maximum flame areas per pixel at their peak than a fire of similar fire-front intensity ignited from a spot location. Most unplanned fires start from a single location but if they are spreading on extreme fire-weather days in heavy fuels, they can be expected to have large deep flames.

A potentially major source of error could be associated with the problems of accurately matching the real location of a FHS with that declared on the processed image. It has been estimated by DOLA that the mismatch in location could be as much as 3km and often about 1km (1 pixel). The mismatching of locations of real fires and FHS was not formally addressed during this study.

Our attempt to match average areas burnt per day with the average number of fires per day for each month of the second study period showed a promising trend but it appears that the loss of FHS data due to the various problems outlined in this discussion were too great for any predictive relationship to be apparent.

Where will NOAA satellite data be best for the detection of fires and the measurement of their areas? While the latter part of the question is important it is largely outside the scope of this report. The first part of the question goes some way towards answering the second part however. We can investigate this question by a process of elimination of the problems detected in this study. Problems of cloud obfuscation are greatest in southwestern Tasmania and in northern Australia (Craig *et al.* 2002). However, the seasonality of cloud obfuscation is less of an influence in the north than is believed to occur in the south in relation to the seasonal presence of fires. Low sun angles will be a problem but may occur across southern Australia (this study; Craig *et al.* 2002). Areas in which forest cover is high will be at a disadvantage (this study) as will areas where topography is rough. The matching of images from different receivers also poses problems (Craig *et al.* 2002). Therefore, the best areas are likely to be in semi-arid, arid and savanna zones of Australia, a large area in total. In the less suitable areas for NOAA AVHRR, Landsat or MODIS should be evaluated and agency maps, aerial photography and other data should be assessed and collated routinely. There is a need for a detailed study aimed at the determination of the best and most cost-effective mix of techniques for the long-term collection, collation, storage and retrieval of a spatially-explicit national fire-data set. This is not a trivial matter

especially where several agencies are operating in the same region. Data bases of emergency service agencies are not necessarily confined to landscape fires as they may include house fires, road accidents etc. all under the heading 'incidents'. The areas of jurisdiction of land management agencies are changing continually so data on these changes needs to be examined also. A feasibility study is recommended beginning with an evaluation of: data sources, procedures used in collection, collation and display; possible sources of error; and, their accessibility.

## **Conclusion**

The validation of FHS-events with actual fires is new to Australia and unusual elsewhere apparently. Reliable satellite data are unlikely to be a substitute for real data in forested areas of southern Australia. An effective national system of fire reporting will involve a range of techniques. The best mix of those techniques, including a variety of remote sensing methods, needs to be determined in detail for the Australian land mass if State-of-the-environment reporting is going to be comprehensive. A feasibility study for a spatially-explicit yearly accounting of landscape fires in Australia is recommended.

## **Acknowledgments**

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