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Evaluation of three fire detection systems

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Important Notice

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1 Executive summary

The events of Black Saturday, February 7, 2009, illustrated the immense potential destructive power that bushfires can have under extreme fire weather conditions. A number of systems have been proposed to aid the detection of the outbreak of a bushfire and thus increase the probability that it can be controlled before it develops into a catastrophic event. This study grew out of the Australian Government Attorney General's Department need for a quantitative assessment of the performance of a number of these systems being proposed for fire detection use in Australia.

The study assessed three systems: EYEfi, FireWatch, and Forest Watch, all based on image analysis from sensors mounted on fixed towers. We considered the ability of the systems to detect and locate fires, to provide information about fires for developing situational awareness, and potential for integration with agency operations. During the trial the FireWatch and Forest Watch companies provided supervised automatic fire detection: their computer systems analysed images to detect smoke, detections were validated by human operators and reported to fire agencies. EYEfi did not conduct automatic smoke detection but did manually target and report some fires. All systems were available to agency staff to provide images and other information for fire monitoring and situational awareness.

The ability of the systems to detect and locate fires was compared with a trained human observer using a series of planned fires near Tumut, NSW. The potential for the systems to provide operational information to fire managers was tested using a network of cameras in the Otway Ranges region of Victoria. The field trials were conducted from March 3rd to May 15th , 2010. Fire weather was mild during this period, following good February and March rain, and no instances of greater than high fire danger were experienced during the assessment period at either location. During the trial:

- Six intentional active research fires were conducted in forest fuels (only at Tumut) for which all fire behaviour information (including ignition time, rate of forward spread, rate of area and perimeter growth) were collected. Five fires spread actively and one self-extinguished. The tower observer saw all six fires, FireWatch reported one and Forest Watch zero. Six other stationary research fires were conducted, including two at night. The tower observer saw three fires, FireWatch reported three and Forest Watch three. EYEfi targeted one daylight windrow fire and was not staffed for the night fires. Some night time images of already going prescribed burns were recorded by all systems, demonstrating night vision capability.
- 37 prescribed fires and burn-off fires were conducted as part of normal land management tasks during the post-fire season burning period by Forests NSW, NSW National Parks and Wildlife Service and Victorian Department of Sustainability and Environment. These included burning of piles of logging residue and prescribed burning in native forests. The burns were much larger than the research burns and the cameras performed better during this part of the trial. One unplanned bushfire was reported in Victoria and none in NSW.
- Over 250 private fires (mostly agricultural burning off) occurred across the study areas during the assessment period. Where possible, information about fire occurrence was inferred from formal fire permits or multiple sources of identification to assess detection performance. The camera systems reported many fires but comparison with tower observations in NSW and cross-referencing between camera reports in Victoria showed that a high proportion of private burns were not reported.

- Reporting of false alarms was not a problem for any of the systems tested.

All the camera systems tested were able to observe and locate fires during both day and night. However, detection by the camera systems was slower and less reliable than by a trained human observer. At present it is not possible to rely on cameras as a sole primary detection method and they are not a suitable replacement for staffed fire towers. Cameras could be used in combination with other detection methods particularly at night, or in remote locations. The cameras could also be used to aid the development of situational awareness and to add value to other data by integration with agency systems.

The human camera operator is an integral part of all the camera systems. Skilled operators are required to decide whether computer generated alerts are fires or false alarms, and to validate fire locations provided by the systems.

Very limited use was made of the camera systems by operational staff during the trial, mainly to cross check alerts from other systems. This was because there was only one wildfire during the trial rather than because of any problems with the camera systems. Discussions with agency staff suggest that any of the systems could provide useful information for monitoring fires, and that how the information is integrated into agency systems and practice is likely to be more important than the type of field hardware used.

Integration with agency infrastructure (primarily towers and IT systems) was successful given the constraints of the trial requiring that no system could be fully integrated in to agency systems. Agency working practices and training would need to be adapted to ensure that best use was made of information available from a camera system. Each system uses different methods to operate and monitor cameras and to distribute alerts and images to fire managers. The different approaches to managing and distributing information are likely to be important in determining which system best suits a given agency and fire management problem and would need to be considered in any deployment.

Future work could focus on assessment of detection performance in summer conditions using research fires and could test the operational capability of the systems by closer integration with agency systems during a fire season. Both areas of research would benefit from using updates to camera technologies described in the camera company submissions appended to this report.

2 Introduction

Wildfires, or bushfires, are a major concern around the world, resulting in significant economic, ecological and social costs each year to infrastructure, ecosystems, lives and property. The wildfires in Victoria in February 2009 are estimated to have caused approximately A$1.1B in damage through over 10,000 claims (Insurance Council of Australia 2010). Efforts to mitigate the effects of wildfires include prohibiting actions that may start fires under weather conditions conducive to the outbreak of fires, reducing the amount and structure of fuels in which fires may ignite and through which they may burn, and undertaking suppression of fires when they do breakout. However, under severe fire weather conditions, the chances of restricting the spread of a fire is very much reduced and in many cases is impossible unless the fire is held up by regions that have been heavily fuel-reduced or there is rapid initial attack while the fire is still small.

Plucinski et al. (2007, 2008) analysed the success of initial attack of wildfires conducted by a range of firefighting resources in a wide range of Australian fuels over a number of fire seasons. Four main determinants of the success of early fire containment efforts were found:

- time delay between detection and initial attack,
- prevailing weather,
- level of fuel hazard, and
- the size of the fire at arrival of initial attack response.

While these particular studies did not include analysis of time taken to detect fires, the size of the fire at arrival of the initial attack response is a function of the size of the fire at detection, fuel type, and weather conditions. The earlier the outbreak of a fire is detected, the smaller it will be when the initial attack response arrives and therefore the greater the potential for the initial attack to be successful and, therefore, for fire outbreaks to be kept from becoming large conflagrations. That is, the early detection of wildfires is critical to the success of subsequent actions to suppress them.

2.1 Fire detection

Detection is defined in the Australasian Fire and Emergency Service Authorities Wildfire glossary[1] as:

> The discovery of a fire. Individuals, fire towers, reconnaissance aircraft and automatic devices may be used, either alone or in combination.

Early detection is a key element for the successful delivery of any fire management program. (Luke and McArthur 1978) state that early initial attack is essential to success in fire suppression. However, organising to save time between the moment of ignition and the start of effective work on a fire does not always receive the attention it deserves from those responsible for fire response planning. Time may be lost in various ways during this critical period. There may be delays in detection, reporting, dispatching of suppression resources, resource travel time to the fire, deciding suppression tactics and inadequate or insufficient suppression resources. The acceleration phase of a fire from ignition to a quasi-steady rate of spread (as well as perimeter and/or area growth) is perhaps the most important phase of fire development because often it

[1] http://knowledgeweb.afac.com.au/national_data__and__glossary/wildfire_glossary, accessed on 23 June 2010.

represents the only time when suppression can be effective.

Bushfire detection methods can be generally grouped into two distinct categories:

1. Volunteer reporting- public reporting of fires (Triple 0), public aircraft, ground based field staff (agency and industry field staff)
2. Operational detection systems: fire towers, aerial patrols, electronic lightning detectors, automatic detection systems

The majority of the urban and rural fire services rely on volunteer reporting of fires. This process relies on public fire prevention information programs that provide information to the general public on effective communications in the event of a fire emergency such as the Triple 0 emergency phone number which is well publicised (i.e. road side signs, media advertisements, etc). Observations of fire outbreaks by members of the public and telephoned directly to fire agencies or through emergency phone number systems have always been a common source of fire occurrence information. As mobile phone networks have become more widespread across the country-side, observations of fire outbreaks by the general public are becoming more prevalent, particularly in well-settled areas. For example, less than 1% of fires reported to the NSW Rural Fire Service between July 2004 and June 2009 were reported by agency fire lookouts, while over 95% were reported by the general public or agency staff (B. Tan[2], pers. comm. 2010). On the other hand, in areas with few people or poor communications there is greater reliance on more formal detection and reporting systems. For example 34% of bushfires fires reported to the Victorian Country Fire Authority between July 1974 and June 1984 were reported by fire towers (Rees 1984).

In the case of the land management agencies (i.e. public forest land, conservation and national parks, plantations) the issue of fire detection is far more complex and costly. The remoteness and vastness of public land, high value forest assets, low population settlement, and inadequate communication networks mean that the agencies have to provide their own detection systems. These systems include fire towers, detection aircraft, electronic lightning detectors, and more recently the potential application of automated detection systems.

The land management agencies in co-operative arrangement with rural fire agencies operate an extensive network of fire towers. Towers are located strategically around the region to ensure maximum coverage of the protected area. Tower based bushfire ignition detection methods rely upon direct observation of a fire or its smoke by trained fire observers and direct reporting of observations to a local fire control office via radio or mobile phone. Often fire towers are also used to gather hourly weather information and other assessments of conditions.

Other detection methods include the use of dedicated spotter aircraft flown at regular intervals on set patterns over the landscape from which a human observer scans for fires, dedicated aircraft utilising infra-red line scan or forward-looking infra-red (FLIR) instead of human observation, and satellite platforms using similar observational technology (visual and infra-red bands). There is also increasing potential for the use of unmanned aerial vehicles (UAVs) that incorporate these observation technologies. Currently there are no operational systems of this type but there is significant development of such systems for military purposes that will eventually make its way to the firefighting sector.

[2]Dr Billy Tan, Research Scientist, NSW Rural Fire Service unpublished data.

Certain types fire detection (i.e. fire towers, spotter planes, etc) are only operated during specific periods when it is deemed of critical need. For example, fire towers are not manned outside of the fire season, spotter planes are only operated when the forecast fire weather conditions reach a critical value. In some cases, dedicated fire detection systems are employed when the benefits associated with reductions in risk outweigh the costs. This is mostly evidenced in places like plantations and other high value assets where there is a readily discernible benefit for a given level of risk.

2.2 Situational awareness

Situation awareness is defined by Endsley (1995) as "The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." In essence this means, being aware of what is happening around you to understand how information, events, and your own actions will impact your goals and objectives, both now and in the near future. Situation awareness is one component of a larger framework of factors necessary for decision-making and assessment of performance of actions once decisions have been made (Fig. 2.1). Three levels of situation awareness are defined in this framework: perception of elements in current situation, comprehension of current situation and project of future state of the situation.

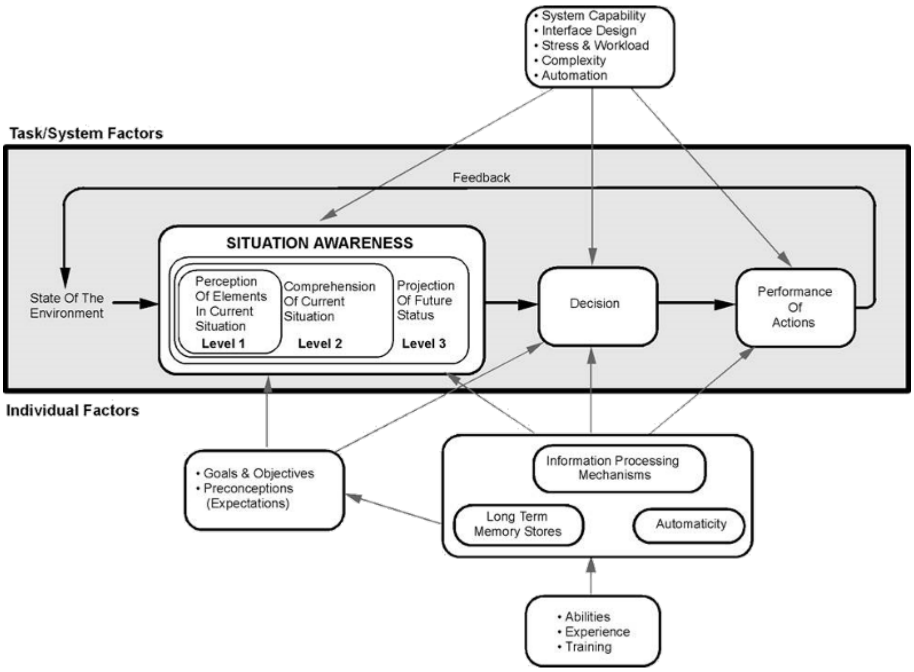


Figure 2.1: Model of decision making factors of Endsley (1995) in which situation awareness is comprised of three levels of perception, comprehension and projection of current situations.

In the context of planning, preparation and suppression of wildfires these levels of situation awareness correspond to knowledge of fire locations, understanding of current growth and behaviour of these fires, and where these fires will go in the near future. Situation awareness is necessary at every level of a fire suppression action: from that of the individual firefighter needing to know what is safe and what is not (tactical situation awareness), the sector/division boss needing to know where to send firefighters on a particular part of a fire, the incident controller tasked with controlling a single fire, through to the state-level incident controller with responsibility for multiple fires with multiple agency interdependence and multiple critical obligations (strategic situation awareness).

At its most basic, fire detection provides information for only part of the first level of situation awareness. Knowledge of the outbreak of a fire is critical to the immediate decision making process involved in initiating suppression (choice of suppression resource type, source of suppression resource, directions and commands to suppression resource). Once the decision has been made to initiate suppression, fire detection becomes less important and emphasis is then placed on fire monitoring: we know the fire is there but what is it doing? This then becomes critical for ongoing suppression actions, suppression planning, public warnings, etc.

Current fire detection systems are used for both the fire detection phase and fire monitoring phase. Suppression crews, once sent to a fire, become another source of information for determining strategic situation awareness. Fire towers and spotter planes, aircraft with IR capability also provide critical information about fire progress necessary for projecting fire behaviour for the purpose of planning and issuing warnings. The extent to which these are employed depends upon the scale of the incident, the fire agencies involved and the potential for deterioration of the situation.

However, gathering data is only half the task. Providing that data in the form of useable information to the incident controller in a manner that minimises data overload and maximises decision-making potential is also essential.

2.3 Bushfire behaviour and outbreak detection

In southern Australia, the bushfire season generally extends from October to March, with occasional years that begin a month earlier or finish a month later (Luke and McArthur 1978). The weather conditions associated with the bushfire season are such that bushfires are more likely to breakout, to be more difficult to control and be more likely to cause damage when they do occur. Fires may occur outside the fire season, but the conditions are generally such that the behaviour of these bushfires do not represent any significant threat. The shoulders of the bushfire season are generally when fire is employed to achieve particular land management objectives (i.e. prescribed burning when fires will still burn but not burn out of control).

The behaviour of a fire is determined by the type, structure and amount of fuel that is being consumed by the fire, the weather and the topography. In any particular fire season there will be a range of fire behaviours, from fires that are low intensity and slow moving to fires that are high intensity and fasting moving, mainly dictated by seasonal weather conditions. In years that are marked by good winter and spring rainfall, grassfires may be common when the summer is dry. In years that have significant extended drought during winter and spring, forest fires may be more common.

In Australia, the McArthur forest and grassland fire danger rating systems (McArthur 1966, 1967) are employed to determine when the weather and fuel conditions are conducive to the outbreak and rapid growth of bushfires. When the fire danger index is low, the chance of fire outbreak is low and the potential for fire growth minimal. When the index is greater than 50, the chance of fire outbreak is high and the potential for fire growth is great; total fire bans are imposed to reduce ignition sources and fire agencies step up preparation for firefighting.

Any bushfire detection system must thus be able to detect the outbreak of a bushfire under the broad range of conditions under which a bushfire may occur, but most critically when fire danger conditions are high to extreme.

A number of environmental factors (fuel, weather and topography) influence the fire ignition, in conjunction with the resultant fire behaviour, may play a role in determining the ability of any fire outbreak detection system to detect a fire. These might include:

- Fuel and forest structure
  - fuel type in which the ignition occurs
  - fuel type in which the fire spreads
  - fuel type for observation (e.g. open forest vs. dense crown)
  - moisture content of live and dead fuel
- Environmental conditions
  - general weather (air temperature, humidity, wind speed and direction)
  - site specific weather (i.e. under canopy, within topography, etc.)
  - time of day
  - atmospheric stability
  - atmospheric visibility
  - cloud cover
- Topography
  - slope/aspect
  - location of ignition
  - location of observation tower
  - distance between ignition and observer
  - blind spots
- Fire conditions
  - ignition source (smouldering/flaming/lightning)
  - ignition source size
  - behaviour and rate of growth of perimeter
  - behaviour and rate of spread of headfire
  - smouldering/rate of smoke production
  - flaming/rate of smoke production
  - optical density of smoke
  - convective activity

3 The current study

3.1 Study objective

The current study follows on directly from a literature survey carried out for the Australian Government Attorney General's Department (AGD) of three tower-based systems being proposed for the detection and monitoring of bushfires in Australia (Matthews et al. 2009). The three systems assessed in this study were:

- EYEfi SPARC, [Click for web site]
- FireWatch, [Click for web site]
- Forest Watch. [Click for web site]

These products were used because the companies are active in Australia and were able to provide and operate their systems on the short lead times available for this project. Other commercial systems include:

- Forest Vu [Click for web site]
- Adelie [Click for web site]
- Forest Fire Finder [Click for web site]
- Fire Sage [Click for web site]
- AlarmEYE [Click for web site]

Smoke and fire detection are the subject of active scientific research and many papers detailing the science and technology of these study areas have been published which are not yet associated with commercial products.

The aim of the current study was to assess the ability of these commerical systems to detect the outbreak of fires, to not detect events that are not fires, to provide information for situational awareness, and potential to integrate into fire service systems and processes. The performance of each system is benchmarked against a trained human observer.

The systems tested used "supervised detection" to report fires. That is, a human operator is required to assess images and alerts[3] from the camera system to determine whether a fire has been observed and needs to be reported. Thus the potential for human error is inherent in the systems and performance will depend to some extent on operator skill as well as the technical performance of cameras and analysis algorithms. We tested the performance of the complete systems, including their human operators.

We do not provide any assessment or recommendation of whether the camera detection systems should be implemented in Australia. Any decision would require a cost-benefit analysis taking into account at least: cost-benefit relative to other detection methods or other fire management options (e.g. suppression resources, prescribed burning), scale of installation (e.g. complete coverage vs supplementing existing detection methods), tenure, assets to be protected, existing detection infrastructure, efficacy of the systems, inter-agency operations and budget considerations. These parameters are agency and location specific and cannot be addressed in a general sense in any meaningful way. We do not provide any information on system purchase or running costs in this report.

[3]EYEfi did not provide computer generated smoke alerts during this trial.

3.2 Detection assessment methodology

In developing the assessment methodology for this study, it was impractical to consider all combinations of factors listed in section 2.3 for all possible conditions that may be experienced for all types of fire seasons. Owing to the time and setup constraints of the study, the assessment was to be completed in the 2009/10 financial year. However, due to the late initiation of the detection systems, the assessment was restricted to the post-2009/10 fire season burning period (15^{th} March–9^{th} May 2010).

Two locations were selected by the local agencies for the assessment: the Otway ranges in Victoria and near Tumut, New South Wales. The Otway ranges (see Fig. 5.2) is a mix of native forest managed by Victorian Department of Sustainability and Environment (DSE) and private agricultural land in moderately complex topography located on the south-western coast of Victoria. Five fire towers oversee this region. Cameras from each system vendor were deployed on four of these towers. The fire towers were not staffed on some days during the trial.

The location near Tumut (see Fig. 7.1) is primarily softwood plantation owned and managed by Forests NSW (FNSW) with some native forest also managed by Forests NSW surrounded by private agricultural lands in undulating topography on the western slopes of the Great Dividing Ranges. One fire tower oversees this region (Mt Tumorrama). One camera from each system vendor was deployed on this tower[4]. The Tumorrama tower was staffed during normal work hours by a trained FNSW fire observer during the assessment period.

The study considered three fire types:

1. intentionally lit fires for research purposes (Research burns) in which all aspects of ignition and fire behaviour were recorded;
2. wildfires and intentionally lit fires for land management purposes (Agency burns) in which only outbreak or ignition information was formally recorded; and
3. other fires (Private burns) in which no formal ignition information was recorded and other sources of information were used to establish fire occurrence.

Agency burning (assessment type 2) and private burning assessments (assessment type 3) were conducted at both study locations. Research burning (assessment type 1) was conducted only at Tumut. The quality of the ignition and fire behaviour data reduces from the highest quality in assessment type 1 to lowest quality in assessment type 3.

The primary performance measures used in each assessment type were:

- ability to detect and locate fire outbreaks (1,2, 3)
- size of fire when detected (1),
- rate of growth of fire when detected (1)
- time taken to report a fire to the fire control centre (1,2,3),
- accuracy of location in the landscape of fire report (1,2)
- number of false alarms generated.

[4]One system vendor had to employ a second camera on another tower for triangulation purposes. Detection reports from this camera were not considered in this report.

All research burns were conducted blind. That is the observers did not know where or when these burns would be lit. FNSW burns in NSW were also conducted blind. Information about the location and planned date of ignition were available on public websites for DSE burns in Victoria. We did not prevent camera companies from accessing this publicly available information.

After completion of initial data analysis by CSIRO at the end of the trial period, maps, ignition times, and analysis of whether burns were or were not reported were provided to each company for the research and agency burns. This was done to allow the companies to correct any errors of omission in associating detection reports with burns, and to identify any burns that were obscured by other cameras, poles, etc on the fire towers. No retrospective fire reporting was permitted.

3.2.1 Research burning

Research burning assessed the detection capability of each system against a set of known ignitions and fire behaviour with the aim of quantifying the time of detection against rate of growth of fires in different fuels and fire weather conditions. A subset of factors were determined that would provide sufficient statistical redundancy for analysis. Broadly, these were:

- three fuel types:
  - grasslands/agricultural land
  - native forest (*Eucalyptus sp.*)
  - mature pine plantation (*Pinus radiata*)
- three distance ranges from tower
  - 5-10 km
  - 10-20 km
  - 20-30 km
- three ignition periods
  - late morning
  - mid-afternoon
  - late afternoon/early evening
- four slope/topographic combinations
- three fire danger rating classes
  - moderate (Forest Fire Danger Index 5–12)
  - high (FFDI 12–24)
  - very high (FFDI 24–50)

However, the late commencement of the project and the mild late summer and autumn weather conditions, in addition to operational considerations of the Tumut region of Forests NSW, meant that a much more restricted research agenda had to be developed. Four forest locations (three native forest and one pine plantation) and one grassland location were identified with a range of 11–22 km from the fire tower. At each location 4–6 plots 0.5–1.0 ha in size were prepared to contain research fires. However, inclement weather associated with the mild burning season further restricted the number of research burns that were carried out.

3.2.2 Agency burns and wildfires

Agency burns are those fires conducted under particular weather and fuel prescriptions to achieve particular land management objectives. Following the bushfire season, agencies undertake prescribed burns when the weather has moderated and there generally has been some amount of rain to reduce fire behaviour. Wildfires are those unplanned fires that breakout and which agencies attempt to undertake suppression or some form of control. For this assessment, two methodologies were employed:

- For prescribed burns, information on fire size and location, fuels, weather, and fire behaviour was obtained from burn plans and the use of a fire behaviour data sheet completed by the crew conducting the burn.
- For wildfires, information on fuels and weather was obtained from a simple fire behaviour data sheet completed by the first suppression resources that responded to the fire.

3.2.3 Private burns

Private burns are those fires ignited by private citizens generally for agricultural purposes (e.g. stubble burning following harvest) but may also include rubbish removal. For the purpose of this study, these burns took two forms: those conducted during the burning season with an approved burn permit, in which case some information about location and date of ignition might be available, and those conducted after the burning season for which no permit was required and about which no information beyond camera or tower reports was available.

3.3 Agency integration capability

In order to provide some assessment of the ability of each detection system to integrate with each land management agency's fire management infrastructure, post-assessment discussions with agency staff were undertaken. These took the form of feedback on each systems operation, alerting system and overall detection efficiency in terms of high necessity alerts (e.g. wildfires), low necessity alerts (e.g. prescribed burns, permit fires or out-of-season burning), false positives and false negatives.

4 Description of detection systems

The three tower-based fire detection systems all use instruments deployed on field towers, and communicate images and alerts to operators in offices which may be remote from the towers. However, the three systems differ considerably in the technologies used, as described in the following sections. Description of each systems examines the following areas:

- **Field installation.** The equipment installed in the field and infrastructure requirements.
- **Communications.** Requirements for communications between the field installation and the base station(s).
- **Office installation.** The equipment used to monitor and control the system.
- **Fire detection and monitoring.** The methods used to detect smoke and/or fires and to communicate detections to the fire manager. Due to the proprietary nature of the systems only an overview of the methods used is given.

- **Integration**. The methods used to integrate the smoke detection system with fire agencies GIS and command systems. Also, the system's capabilities for making use of existing agency data.
- **Operational use and testing**. Current operational and testing installations around the world and results of field testing.

The descriptions below cover each system as deployed during the trial. The companies were invited to supply additional material on future capability or capabilities not tested during this trial. This material is included in the Appendices. We have not assessed the validity of the additional material.

4.1 EYEfi

EYEfi SPARC provides images and data to help fire agency staff detect, monitor, and respond to bushfires. When an observer sees smoke, the EYEfi camera is used to map its location on the ground. EYEfi also includes a weather station and an automatic lightning detector. EYEfi is able to display information from many other data sources. Access and control of cameras is distributed across the fire management agency.

4.1.1 Field installation

An EYEfi SPARC installation consists of a camera (operating in colour during the day, ultra low-light grey-scale at night), weather station, lightning detection sensor, communications unit, and hardware to power the system. Other types of camera may be used if required, e.g. thermal cameras. An EYEfi unit may be installed on existing or dedicated towers. EYEfi units may also be installed on emergency services vehicles or trailers. EYEfi have an agreement with Telstra to use their towers throughout Australia. The camera used in this trial was a standard definition (720×576 pixels) colour video camera on a pan-tilt-zoom (PTZ) mount. Other cameras may be substituted. Images were recorded as 24-bit colour (red-green-blue, 8 bits per channel) during the day. At night the camera operated in grey-scale low-light mode, including near-infrared light. The weather station is a scientific grade unit which measures air temperature, humidity, wind speed and direction, solar radiation, and rainfall. The lightning detection sensor is a third party unit which detects the location of lightning strikes by triangulation from three antennae on the sensor. The communications unit collects data from the camera and sensors for transmission to the data centre. It also controls the camera in response to commands from users or the system. The system is powered by solar panels or main power. The camera uses visual and near-infrared light. Anything which impedes normal vision (smoke, fog, cloud, etc) will also impair the vision of the cameras. Geolocation is performed by SPARC using orientation data from the camera PTZ mount and is not affected by visibility.

4.1.2 Communications

EYEfi SPARC requires a low bandwidth (less than 0.25 Mbps) connection to the data centre. Communications is normally over Telstra's 3G network. If required, the emergency services State Mobile Radio (SMR) network, Ethernet, wireless, or other connections may be used. Because Telstra's national network network is used for communication, it is not necessary to build a dedicated network for EYEfi.

4.1.3 Office installation

All field units communicate wirelessly with a central server at Telstra's data centre in Melbourne. This server handles communication with the field units, image analysis, interaction with third party computer systems (e.g. Victorian Mapping and Address Service, or PSMA servers), and communication with users. The server is transparently scalable, with capacity for serveral 1000s of cameras. Data centre facilities are used to store images and event logs. Users interact with the system using an interface based on Microsoft Internet Explorer. Any Windows computer can be used to access the system via the internet or over agency networks. Currently, EYEfi is connected to Victorian Government networks to allow direct connection from desktop PCs. Similar arrangements are possible in other states. Users log in with a profile that determines which cameras they can access and control. Access to cameras can be shared across agencies because EYEfi uses is a cloud-based application.

4.1.4 Fire detection and monitoring

EYEfi SPARC provides images and data to help fire agency staff detect, monitor, and respond to bushfires. The system can be used is several ways:

- When smoke is detected by a tower observer or any users viewing camera images, the camera is manually directed to the base of the plume. EYEfi software calculates then maps the location and orientation of the camera to a location on the ground using the SPARC algorithms with data from the camera mount and a spatial database. Triangulation from a second tower is not required. An event is generated, which includes a location (street address, lat-lon, and grid reference), an image from the camera plus vegetation and slope data, and alerts are sent out. Any user of the system can then view the event in the EYEfi web software.
- Reverse lookup can be used to confirm smoke sightings (e.g. from 000 calls). In this mode an address or coordinate is entered by the user, or the user clicks a location on the map, and the system directs a camera to look at that location.
- When lightning is detected, an event is created for the location of each strike and a camera is automatically directed to view the site. Users can then view images from the EYEfi cameras to examine the location of the strike.
- Users can manually control EYEfi cameras to obtain information about fire behaviour and can access weather data.
- 'Virtual triangulation' can be used to automatically determine and direct the camera with the best line-of-sight to a map location selected by the user.
- Cameras can be used to map areas on the ground, 'geofencing' (e.g. areas downwind of a fire). These areas can be sent to Telstra's national Emergency Alert system to identify and alert residents.

EYEfi SPARC does not currently offer automatic smoke detection. Smoke detection is planned for introduction in 2010 and was tested using data collected during the present project.

4.1.5 Integration

Currently EYEfi uses spatial data from the Victorian Mapping and Addressing Service (VMAS), PSMA and Microsoft Bing Maps. VMAS is compatible with national Public Sector Mapping Agencies (PSMA) standards. The systems communicate via an application programming interface (API, meaning they communicate by transmitting questions and answers, rather than directly accessing each other's data). An API is also in place to communicate with Telstra's national Emergency Alert system. Information from other systems within the fire agency or from other agencies can also be integrated. For example the current VicRoads EYEfi system can show the location of emergency response vehicles in the EYEfi application.

Event notifications can be sent to users via email and SMS. Users can access archived camera and event data via the EYEfi web interface over agency networks or via the internet. Because EYEfi uses a web browser based interface and all data processing is done at its data centre, no dedicated/proprietary hardware or software are installed within the customer agency's IT infrastructure.

4.1.6 Operational use and testing

A pilot test of the EYEfi SPARC system was conducted in the fire season of 2008/09 in co-operation with Victorian Department of Sustainability and Environment's Spatial Information Infrastructure (SII) directorate. The cameras, without weather station or lightning sensors, were installed at four locations in Victoria (Mt Toorongo, Mt Riddell, Mt St Leonard, Poley fire tower) and made accessible to DSE staff. During the test the system used geographic data from DSE's VMAS system to demonstrate integration of the two systems. SII regarded the trial as a success and were particularly impressed at the ease with which EYEfi was able to work with existing systems. Plans to test the use of EYEfi as part of fire operations were aborted due to the occurrence of the Black Saturday fires a few days after the cameras were installed. Images and data from cameras were used in preparing a submission on fire behaviour to the Royal Commission by the DSE (Tolhurst 2009), and have been requested by the Royal Commission, Country Fire Authority Fire investigators, and Victoria Police Phoenix Taskforce to help them map fire progress and timing on Black Saturday and as a knowledge/learning tool to understand fire behaviour and phenomena. The accuracy of georeferencing by EYEfi was tested by the CRC for Spatial Information. The system was found to be accurate to 150 m with 95% confidence at a range of 15 km (Collier 2009).

The EYEfi technology, network, application and infrastructure have been used by the Victorian Government for four years. EYEfi cameras are in operational use at fixed locations and on mobile vehicles in Melbourne by VicRoads and Victoria Police. The Melbourne Grand Prix, VicRoads, Yarra Trams and Victoria Dept of Infrastructure use EYEfi trailers for various projects.

4.2 FireWatch

FireWatch is an automated fire detection system. An image sensor mounted on a tower scans the landscape to detect smoke during the day and night. When smoke is detected, the location of the origin of the smoke on the ground is automatically calculated and an operator using a dedicated workstation is notified to alert the fire manager once the operator has determined that the automatic detection alert is indeed a bushfire and not smoke from a known emission source.

4.2.1 Field installation

A FireWatch installation consists of an imaging sensor, data processing unit, communications hardware, and hardware to power the system. The unit may be installed on existing or dedicated towers. The sensor is a high definition (1360 $\times$ 1024 pixels) sensor manufactured by FireWatch. Images are recorded as a single grey-scale channel at 14-bit (16384 levels) resolution. The sensor is sensitive to radiation in the visible and near-infrared. Different automatically switched filters are used during the day and night to improve smoke detection accuracy. (Red light during the day, near-infrared light at night. Custom filters may be used for particular environments). The sensor is installed on a pan-tilt mount. The data processing unit is a small-scale low-power industrial computer. This controls the sensor mount, performs image analysis, and sends alerts and images back to the control centre. The system can be powered by mains, wind, or solar power, as available. A colour camera may optionally be added to allow viewing of live images (although this is not a standard part of the FireWatch system). The system detects visual and near-infrared light sources. Anything which impedes normal vision (smoke, fog, cloud, etc.) will also impair the operation of the sensor but near-infrared offers some improvement over visual light during hazy conditions.

4.2.2 Communications

FireWatch requires a low bandwidth connection of 0.064 Mbps (0.25 Mbps with a live camera) connection back to the base station. Communications may be over ISDN telephone line, 3G networks or microwave links, depending on the location of the installation. FireWatch do not recommend use of 3G networks.

4.2.3 Office installation

Field installations are connected to servers via wireless links and ISDN, as described above. Each server can connect to many sensors. The servers are used to link the sensors to monitoring workstations and to remote users. Servers may be centrally located, e.g in a data centre, or distributed, e.g. in regional offices, as required. Operators use thin-client software on Windows PCs. The workstations are used to display images from the field installations, control the sensors when required, and issue alerts. Each operator can monitor 5 - 8 sensors, based on experience with existing installations in Europe. The servers also allow remote users to view images and alerts from the system over agency networks using FireWatch software. Remote users cannot control the sensors unless the system is configured to allow this.

4.2.4 Fire detection and monitoring

FireWatch is an automated smoke detection system. In normal operation the sensor rotates 360° every 4–6 minutes during the day and every 8 - 12 minutes at night, depending upon the on-site field of view and chosen operation mode. Images from the sensor are analysed to detect smoke during the day, or smoke illuminated by near-infrared radiation emitted by fires at night. When smoke is detected, the software identifies the origin of the smoke and maps its position on the screen to a location on the ground using terrain information stored in the field computer. An alert is then issued for confirmation by the operator. Triangulation is not necessary but may be used to improve accuracy if the operator recognises that a second tower can also detect the smoke. The operator may use a contrast control to highlight smoke, or may direct the system to return to the alert location every 20–30 seconds to build up a sequence of images. Automatic smoke detection continues while the sensor is under manual control. Where meteorological information is available (e.g. from the Bureau of Meteorology) this is also used.

The sensitivity of the Firewatch software can be optimised to return a specified maximum number of false alarms per day, with the level of sensitivity determined by the customer. The user can also manually exclude problem areas (e.g. industrial smoke stacks) or smokes that are known to be safe (e.g. prescribed burns).

4.2.5 Integration

FireWatch uses dedicated servers and workstations running FireWatch software. These are housed within fire control centres, either centrally or regionally. Map information is displayed within the FireWatch software using data stored on the FireWatch server or workstation or drawn from the host agency's data. When a smoke alert is confirmed by the operator an alert can be sent electronically by the workstation operator, or the system can automatically send out the alarm without operator intervention to the responsible Emergency Services authority. Automatic notification is not recommended due to the high likelihood of false alarms.

4.2.6 Operational use and testing

Tests of FireWatch are planned, underway, or completed in Germany, South Africa, Portugal, Italy, Greece, Estonia, Croatia, Montenegro, Serbia, Kazakhstan. Tests were recently complete in Lithuania and 84 sensor units and 25 Control systems will be deployed. Forest Watch was also included in the South African and Lithuanian tests. Operational FireWatch systems are in use in Germany (178 towers, 22 control rooms), Estonia (5 towers, 1 control room), Cyprus (2 towers, 1 control room) and Mexico (1 tower, 1 control room). Pilot scale systems (1 or 2 towers) are in use in the Czech Republic, Portugal, Spain, Italy, Greece, and the USA.

4.3 Forest Watch

Forest Watch is a semi-automatic fire detection system. An off-the-shelf camera mounted on a tower scans the landscape to detect smoke during the day and fire glow at night to an optimal distance of 16–20 km. When smoke is detected, an operator using a dedicated workstation is directed to identify the origin of the smoke, which is then mapped to a location on the ground and used to alert the fire manager.

4.3.1 Field installation

A Forest Watch installation consists of one or two cameras, data processing unit, communications hardware, and hardware to power the system. The cameras are a standard definition colour video camera on a PTZ mount. Images are recorded as 24-bit colour (RGB, 8 bits per channel) during the day. At night the camera operates in grey-scale low-light mode, including sampling of near-infrared light. Field hardware may be installed on existing or dedicated towers. The data processing unit is a proprietary computer. This controls the camera mount, performs image analysis, and sends alerts and images back to the base station. The system can be powered by mains or solar power, as available. The system uses visual and near-infrared light. Anything which impedes normal vision (smoke, fog, cloud, etc) will also impair the operation of the cameras, although attenuation differs between the visible and near-infra red bands.

4.3.2 Communications

Forest Watch requires a low bandwidth (0.25 Mbps) connection back to the base station. Communications may be over 3G networks or microwave links, depending on the location of the installation.

4.3.3 Office installation

Field installations are connected to a server via wireless links, as described above. The server stores images and alerts collected from the field installation. Operators interact with the system from dedicated workstations. The workstations are standard Windows PCs, but with high end graphics cards and associated motherboards, running Forest Watch software, each of which can monitor to up to 8 cameras. The workstations are used to display images from the field installations, control the cameras when required, and issue alerts. A second server may be added to the system to allow viewing of images from the cameras over the internet by the general public connected via web browser.

4.3.4 Fire detection and monitoring

Forest Watch is a semi-automatic fire detection system. In normal operation the camera rotates 360° every 6 minutes. Images from the camera are analysed to detect smoke during the day, or fire glow at night. When smoke is detected, the workstation operator is alerted. The operator then identifies the origin of the smoke in the camera image, or dismisses a false alarm. Forest Watch software then determines the location of the smoke by associating the position on a camera's field of view with a location on the ground using digital terrain model information stored in the field computer. Triangulation from a second tower is not required but may be used where a fire is located in dead ground which does not have direct line-of-sight from a single camera. The operator may control the camera to zoom in on a fire if required. A second camera may be used to allow scanning to continue while using the other camera to investigate or monitor a fire. A panoramic composite image is also available to view the entire area scanned by the camera for better situational awareness. The operator may select a location on a map and the system will direct a camera to view that location.

The detection software attempts to automatically detect and self-tunes to exclude non-smoke sources of movement and light (e.g. clouds during the day, town lights at night). The user can also manually exclude smoke that is known to be safe (e.g. factory smoke stacks, prescribed burns).

4.3.5 Integration

Forest Watch uses dedicated servers and workstations running Forest Watch software. These are housed within fire control centres, either centrally or regionally. Map information is displayed using standard GIS software using terrain data stored on the Forest Watch server but can also access data stored on other servers as required. When smoke is detected an alert can be sent electronically by the workstation operator.

4.3.6 Operational use and testing

Tests of Forest Watch have been completed in South Africa, Canada (MacAuley et al. 2004; Schroeder 2004), Lithuania and Douglas County, USA. FireWatch was also included in the South African, and Lithuanian tests. In the South African test Forest Watch was selected on the basis of cost, flexibility, and user preference for a colour camera (B. Bothma[5], pers. comm. 2009). Only the Canadian test is documented (MacAuley et al. 2004; Schroeder 2004). Forest Watch performed adequately in this test: test fires were reliably detected up to 20 km range but false alarms were also generated. Forest Watch note that system development has continued since 2004. Operational Forest Watch systems are in use in South Africa (83 towers), Swaziland (5 towers), USA (22 towers), Canada (4 towers), Chile (20 towers), and Slovakia (4 towers). A pilot scale operation (two towers) is installed in Greece. The related Harbour Watch system has been deployed in South Africa and Namibia.

[5]Mr Ben Bothma, KomatiLand Forest, SA.

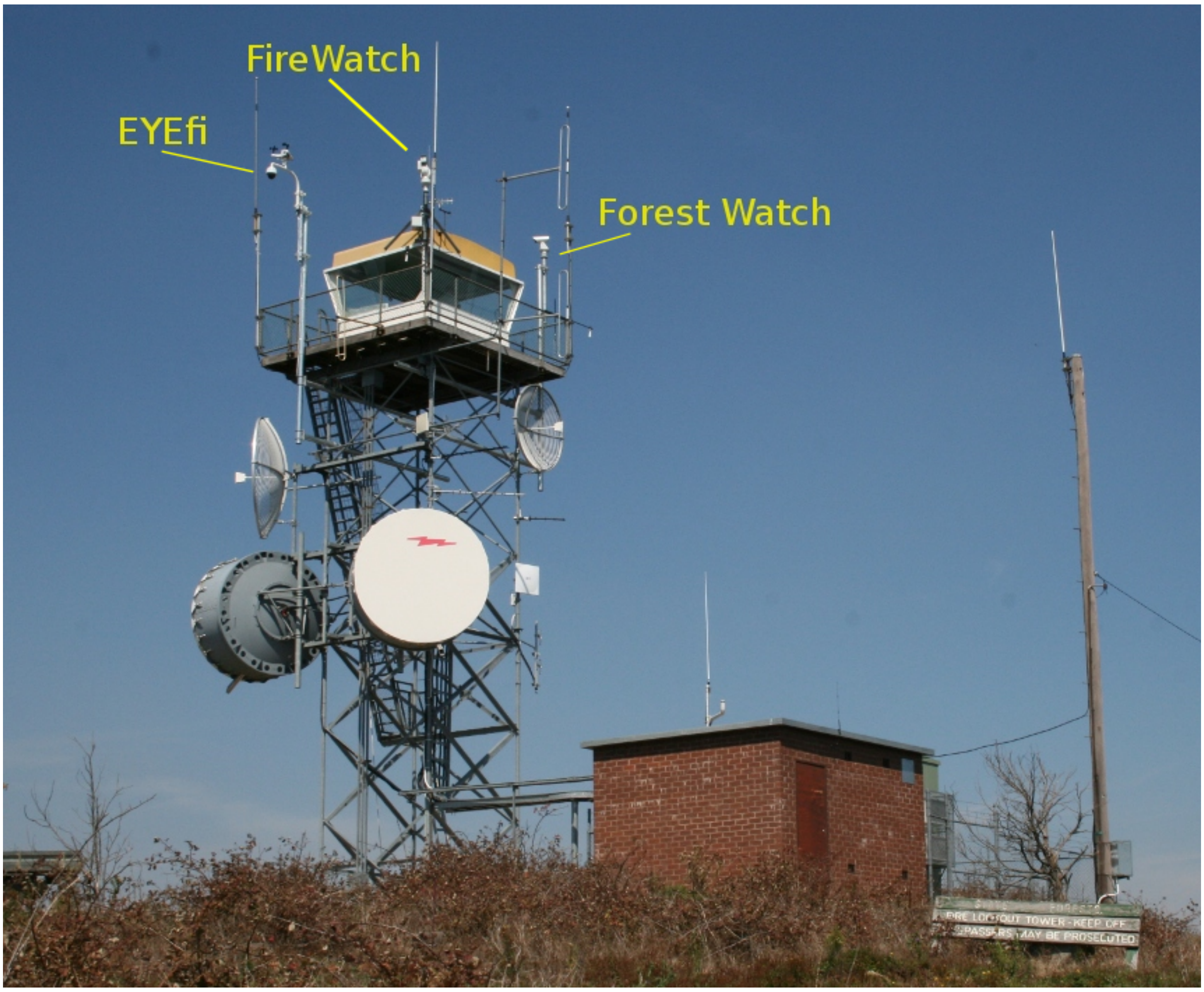


Figure 5.1: Mt Tumorrama fire tower, looking southwest.

5 Operation of detection systems

In NSW one sensor from each of the companies was installed on the corners of the Mt Tumorrama fire tower (Figure 5.1). An additional FireWatch sensor was installed on Compass Hill to provide detection locations by triangulation. Detections made only by the Compass Hill sensor were not used in this report. Where a fire was detected by both sensors, the detection time from the Mt Tumorrama sensor was used.

In Victoria, one sensor from each company was installed on the fire towers at Mt Porndon, Crowes Lookout, Mt Cowley, and Peters Hill (Figure 5.2). Second FireWatch and Forest Watch sensors were installed on Mt Cowley because it was not possible to locate a single sensor without excessive obstruction due to other sensors and poles on the tower.

The sensor systems were tested at their current state of development. All systems are under active development, as described in the company submissions (Appendices **??**, **??** and **??**). The detection assessment methods required that the systems did not change significantly during the trial, so no provision was made for updates or changes to system software or hardware[6].

[6]Some minor changes were made to EYEfi's hosted application (e.g. inclusion of weather data in alerts) but these had no impact on the trial.

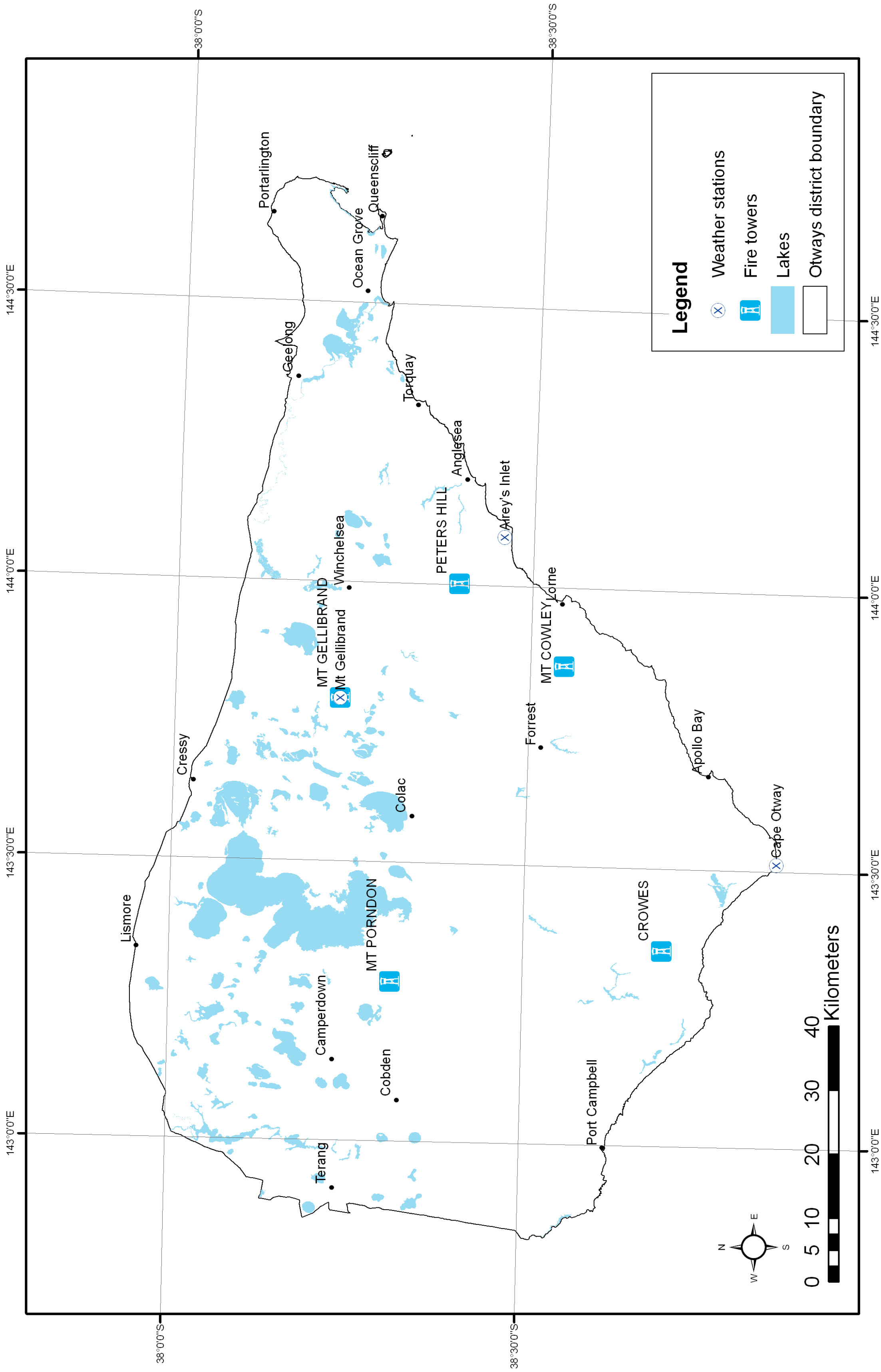


Figure 5.2: Location of fire observations towers and weather stations in Victoria.

5.1 Tower operations

The Mt Tumorrama tower was staffed by an experienced tower operator during the period March 16th to 26th from 9:00 to approximately 17:00 each day. The tower operator kept detailed notes on all smoke sightings including:

- Bearing and distance to smoke. For some sightings an estimated distance range (e.g. 60 - 70 km) was recorded.
- Fire type: windrow, forest burn, or private stubble/grass burn.
- For some sightings a geographic area (e.g. Bungongo State Forest), FNSW compartment number, or nearby road was also recorded.
- A photograph of the smoke was taken for many but not all smoke sightings.

The tower operator communicated sightings to the Forests NSW fire control room in Tumut via telephone. This differed from the usual practice of using radio, to avoid alerting computer operators in the fire control room to smoke sightings. To avoid alerting the tower operator to research burns, fire crews did not make a radio call prior to ignition.

On March 18th, 22nd and 26th, a CSIRO researcher was stationed in the tower to observe and validate the tower operator's observations. The researcher observed the tower operator, kept notes on radio traffic, and documented smoke sightings using a high-definition video recorder. The researcher did not provide any information or feedback to the tower operator on research burning plans or operations.

5.2 EYEfi operations

Data processing for the EYEfi system was done using EYEfi's application hosted in Telstra's Melbourne data centre. EYEfi software was installed on a PC in the Tumut fire control room and on a PC in the Colac control centre. Agency staff in Tumut and Colac had full control of the system, allowing them to monitor and control the cameras, perform targeting and lookup operations, and review system history. Active monitoring of the cameras by EYEfi was not performed in Victoria. In New South Wales, the cameras were monitored on March 16th and 17th and some other dates to test targeting of research burns. The cameras were not monitored routinely by EYEfi because EYEfi does not presently provide automatic smoke detection. Automatic lightning detection was used during the trial. The detection results in subsequent sections need to be read with this in mind. Video from the Tumut camera was later used in offline testing of smoke detection algorithms. EYEfi were not given any information to aid location of burns for this testing (i.e. burn information described above was provided after offline testing was complete).

5.3 FireWatch operations

FireWatch established a control room at Deakin University in Burwood, Victoria. This centre hosted two workstations—one each for NSW and Victoria sensors—and a manager's overview display wall. The control centre was staffed 24 h a day during the trial period. A secondary system was installed in the Colac fire control centre to allow DSE staff to view alerts. This secondary system did not allow control of the sensor or detection operations. A workstation was installed in the Tumut fire control room. This system allowed full control of the Mt Tumorrama sensor. It was operated by FireWatch staff during the research burning period (March 15th-26th, 2010), and was also available to FNSW staff to view detections during the full trial period.

5.4 Forest Watch operations

Forest Watch established a control room at the offices of Fire Fighting Technologies International in Sydney, NSW. This centre hosted two workstations, one each for NSW and Victoria cameras. The cameras were monitored during the research burning trial (March 15th-26th), and from April 6th until the end of the trial. Workstations were also installed in the Tumut fire control room and Colac fire control centre. These system could be configured to allow full control of the cameras or to be used to view alerts only.

5.5 Agency operations

Because this was a trial, none of the detection systems were integrated into normal fire management operations. In NSW, fire detection alerts were sent by email and SMS message to the district fire manager, and an SMS was also copied to CSIRO. In Victoria, detections were notified by telephone call to the fire control centre, followed up with an email report. An SMS message was also sent to CSIRO. Fire managers in NSW and Victoria had access to all three systems to view alerts and images as required.

5.6 Assessment data

At the end of the trial all relevant fire detection information was collected from all participants:

- The Mt Tumorrama tower operator provided us with a typed record of smoke sightings and photographs taken. Electronic copies of photographs were also provided.
- EYEfi created a login to their system to allow a CSIRO scientist to review targeting information. Target data (location, time) and images were downloaded from the EYEfi web interface.
- FireWatch provided a spreadsheet summarising detections, and for each detection an electronic document with detection data, a map, and one or more sensor images.
- Forest Watch provided a spreadsheet summarising detections, and for each detection two still images and a map. For selected detections a longer sequence of still images was also provided.
- At the end of the trial a debriefing session was held at the DSE office in Colac. Operational staff provided feedback about the operation of detection systems during the trial and their thoughts on potential use of the systems.

When assessing detection times we used the time that the detection was recorded by each system. We had planned to use alerts received by SMS to assess time between detection and reporting fires. Unfortunately varying delays in delivery of SMSs meant that this data was unreliable and could not be used.

6 Weather conditions during the trial

6.1 Methods

Daily weather records were obtained from the Bureau of Meteorology for these stations:

- Gundagai, NSW
- Airey's Inlet, Vic
- Cape Otway, Vic
- Mt Gellibrand, Vic

Records included daily rainfall to 9 am, minimum and maximum temperature, 3pm relative humidity, and 3 pm wind speed covering the period 1st May, 2009 to 9th May, 2010. Keetch-Byram drought index (KBDI, a measure of seasonal rainfall deficit (Keetch and Byram 1968)) and drought factor (DF, a measure of fuel dryness, (McArthur 1967)) were calculated using a computer algorithm adapted from Bureau of Meteorology methods (K. Finkele[7], pers. comm.).

6.2 Results

Rainfall in the 12 months to the start of the trial was average or slightly above average for both the NSW and Victorian study areas. Rain over southeastern Australia during late summer and in the first week of March was sufficient to drop the KBDI close to zero at the beginning of the trial (which normally does not happen until winter), and the KBDI remained below 50 for the duration of the trial, except at Mt Gelligrand where KBDI was between 50 and 100. So, from a seasonal perspective, the entire trial was conducted in very mild, autumn conditions, with no periods of dry, summer-like conditions as is sometimes experienced during autumn.

The NSW component of the trial was also conducted during typical autumn weather. 92.2 mm of rain fell at Gundagai in February, followed by 93.6 mm just after the start of the trial at the beginning of March. Temperatures and humidity in March were moderate, with maximum temperatures ranging 21.5–32.1°C, and humidity only as low as 24 %. Wind speeds were very low due to the presence of large high pressure systems over south-eastern Australia for much of the trial; 3 pm wind speeds were less than 10 km h^{-1} for most of the trial period.

The combination of early rain and low wind speeds hampered the research trial. Grass sites identified when planning the project were too green to be used. Rain delayed the start of the research burning, and the moderate humidity and low wind speeds meant that fires lit from point ignitions spread only slowly. However, conditions were good for prescribed fire and many other burns were lit by state land managers and private landowners.

Conditions were similar in Victoria, with regular rain throughout the trial period (March 1st–May 9th), moderate temperature and humidity, but a range of wind speeds up to 60 km h^{-1}. These conditions offered many opportunities for prescribed burning, with many burns lit by DSE and private landowners.

Conditions were not conducive to wildfires. Only 1 unplanned fire was reported in Victoria, and none in New South Wales.

7 Detection evaluation I: Research burning

The objective of the research burning component of the study was to document the behaviour of controlled experiments of point source ignition fires to characterise the initial phase of fire growth and acceleration from a typical wildfire ignition. The development or acceleration phase

[7]Dr. Klara Finkele, Research Scientist, Bureau of Meteorology.

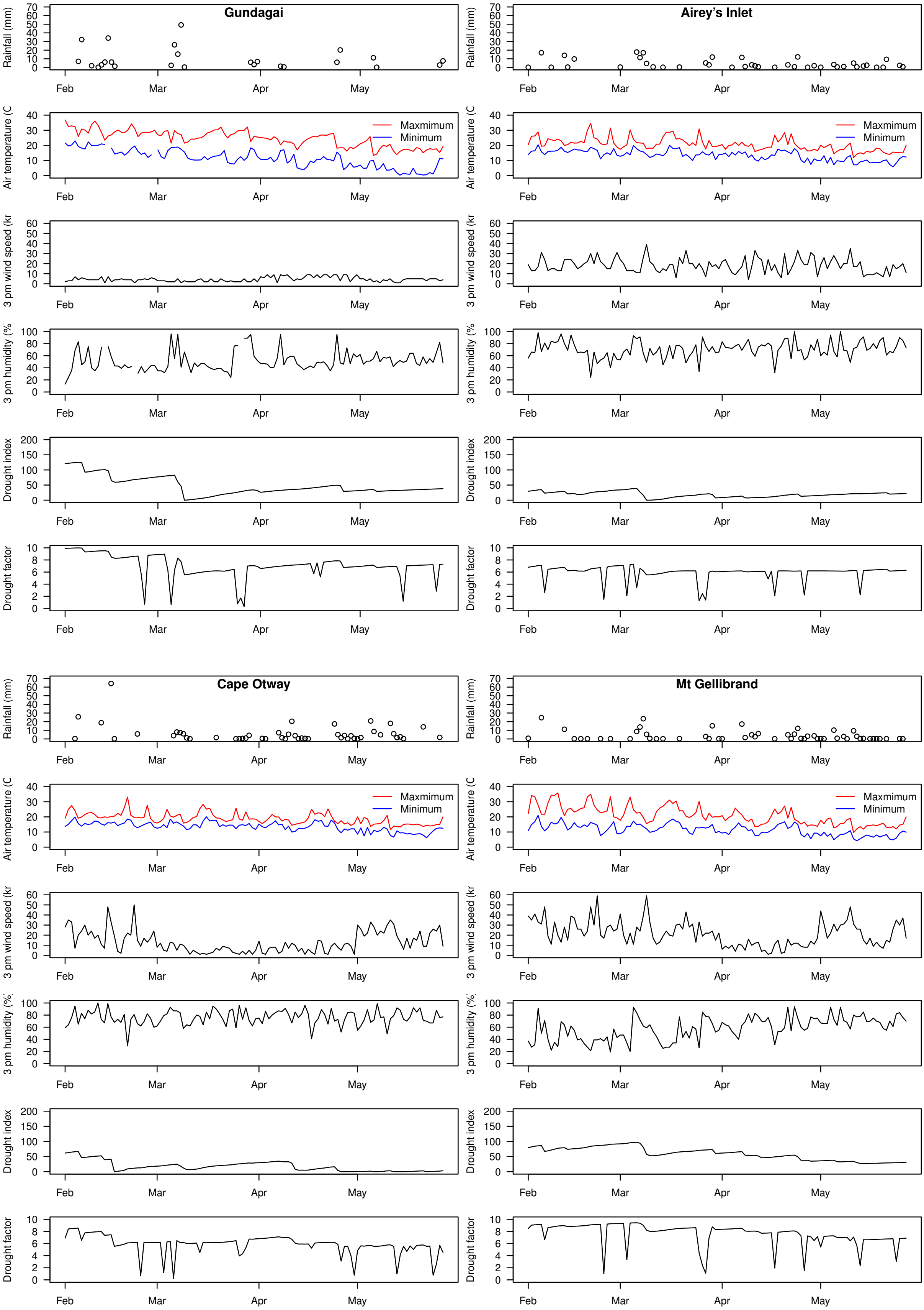


Figure 6.1: Daily weather measurements from Bureau of Meteorology stations in the trial areas.

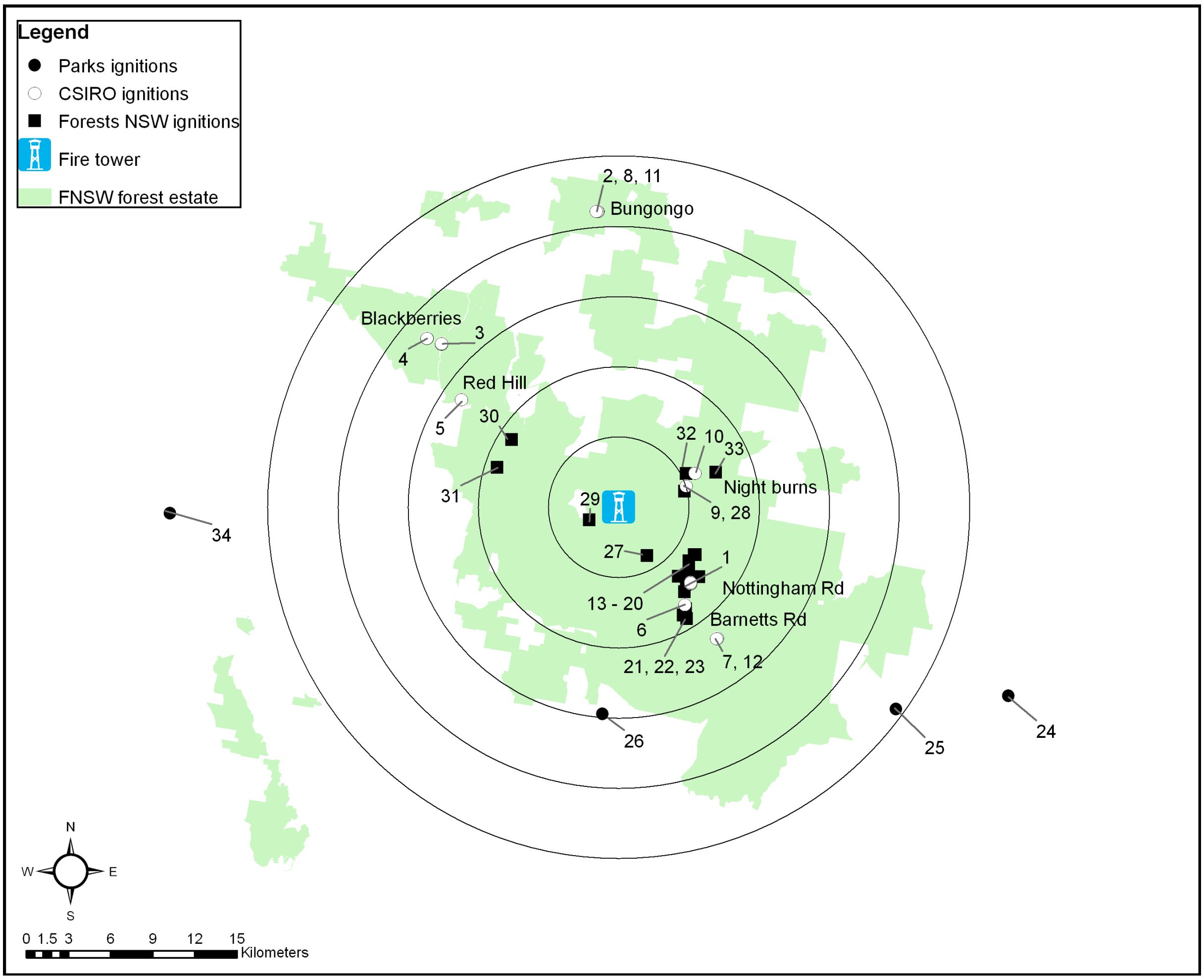


Figure 7.1: Burns lit by CSIRO and fire agencies in NSW. Ranging circles are at 5 km intervals. Numbers correspond to rows in Tables 7.4 and 8.1.

of a bushfire, from ignition to quasi-steady rate of spread, is perhaps the most important phase of fire behaviour because often it represents the only time period in which suppression efforts may be effective. A series of experimental fires were conducted to collect fuel, weather, fire and smoke behaviour data to evaluate the camera detection systems associated with the acceleration phase of fire in different fuel types and burning conditions. The aim was to evaluate the visibility of smoke from fires in a range of burning conditions at different distances from the detection tower and correlate this with the behaviour and growth rate of the fire.

7.1 Methods

7.1.1 Burns conducted

We conducted research burns in forest fuels and also burnt some pine plantation windrows and blackberries. Sites were selected to minimise the chance of cameras being unable to detect burns because of obstruction by other cameras and poles on the Mt Tumorrama tower. The camera companies were given an opportunity to provide feedback on any burns which they thought were obstructed by obstacles or sun glare. EYEfi reported no problems. The Red Hill sites were partially obscured for Forest Watch by poles on the tower. The two night burns were

Figure 7.2: Understorey eucalypt fuel characteristics at the Barnetts site (top left) showing the grassy surface fuel with patches of near-surface fuel. The Bungongo site (top right) is a mixture of live and dead bracken and litter near-surface layer underneath the live bracken elevated fuel layer. Bottom) General view of the pine plantation fuel complex at the Red Hill site.

conducted in a location such that the EYEfi camera was in the field of view of the FireWatch camera but this did not affect detection. The night burning sites were later burnt during the day by FNSW as operational burns. For these burns some problems with glare were reported (See the section on operational agency burning, Section 8).

7.1.1.1 Forest sites

Three experimental forest sites were established (Figure 7.1):

- **Barnetts site.** The Barnetts site is in mixed high-elevation forests consisting of narrow leaf peppermint (Eucalyptus radiata), mountain gum (E. dalrympleana), and snow gum (E. pauciflora). The surface fuel is a mixture of leaf, twig, bark and grassy fuel of snow grass (Poa sp.) (Figure 7.2, top left).
- **Bungongo site.** The Bungongo site is located in the Bungongo State Forest. This site is a dry eucalypt forest consisting of red stringbark (E. macrorhyncha), candle bark (E. rubida), apple box (E. bridgesiana) and narrow leaf peppermint (E. radiata). The understorey fuel is a mixture of leaf, twig, bark and grassy (Poa sp.) and bracken fuels (Figure 7.2, top right)
- **Red Hill site.** Mature pine plantation (Pinus radiata) located along Yass road on a north facing slope. The plantation is a well stocked stand with good canopy cover. The surface fuels are continuous litter layer with duff formation and scattered patches of moderately dense low shrub understorey (Figure 7.2, bottom).

Four experimental plots were established at the Bungongo and Barnetts sites using a bulldozer and existing roads. Plots were approximately 1 ha in size (100 $\times$ 100 m), aligned with positive slope to burn under westerly to north-westerly winds. The Red Hill site was bounded by a road and bulldozer line but individual plots were not established.

Plans to conduct fires in grass fuels were abandoned because rain in late February and early March meant that no sufficiently cured grass sites existed within the study area for research burning (i.e. average degree of curing within these sites was less than 50%). Crop stubble fires on lower elevation private land at distances $>$ 20 km were observed during the trial (See Section 9).

7.1.1.2 Other burns

In addition to the forest burns, several other burns were conducted:

- **Nottingham Rd windrow**: On March 15th a pair of windrows were lit near Nottingham Rd, south-east of the tower. The windrows were ignited at 14:47 and 15:05 and allowed to burn freely.
- **Barnetts Rd window**: At 9:03 on March 19th a windrow was ignited in an unburned area south of the tower during a period in which there was low lying haze in the area.
- **Night burns**: Windrows were ignited at 20:16 and 21:35 on the evening of March 24th to the east of the tower. These burns were used to test the ability of the camera systems to detect fire at night. The first burn was located so that flames would be visible from the tower, the second so that only smoke would be visible.
- **Blackberries**: On the morning of March 18th two patches of dead blackberries were burned.

These burns were documented using video and still images, and some fire behaviour observations were made for up to one hour from ignition. Complete fuel and fire behaviour measurements were not made as most of these are not meaningful for stationary fires in non-standard fuels. The size of the fires was characterised as length burned at the end of observations for windrows, and total area for blackberries, both measured using differential GPS.

7.1.2 Fuel assessment

The fuels that provide the energy flux that enables a fire to spread forward have generally been assumed to be those fuels that are consumed in the continuous flaming zone of a fire front (Luke and McArthur 1978). Fuel measurements taken before a fire only provide an estimate of the available fuel load because fuel consumption depends on environmental conditions and the intensity of the fire itself. Thus, detailed fuel surveys were conducted to describe the fuel structure, composition and continuity of each of the experimental plots at each experimental site.

Fuel sampling was done to determine the fuel quantity, structure, composition and continuity for all the fire plots. A scoring system based on the Project Vesta fuel assessment methodology (Gould et al. 2007b) was used to quantify the fuel structure, continuity and cover of the different fuel layers in the two eucalypt forest sites.

Fuel samples were taken from all experimental plots in two different sampling designs:

- **Hazard scoring in eucalypt fuels**: Recent developments using hazard rating systems to assess the fuel factors affecting fire behaviour and suppression difficulty represents a new approach in fuel assessment. This technique emphasises the whole fuel complex by combining a hazard rating for each of the different fuel layers i.e. bark, elevated, near-surface and surface fuels layers in eucalypt forests. The field guide for dry eucalypt forest (Gould et al. 2007a) was used to assess the fuel complex at the Barnetts and Bungongo sites. Fuel sampling points were located along two transect lines parallel to the proposed direction of the head fire spread. Five points per line space approximately 20 m apart were used. At each sampling point percent cover score and fuel hazard score of the four fuel layers were scored according to the tables in the field guide. The fuel depth and/or height of the four layers were recorded and some plots were photographed.
- **Fuel assessments in pine plantations.** The fuel complex in pine plantations can be characterised has having a dynamic structure with significant changes in fuel quantity, and vertical and horizontal continuity depending on the plantation management practices and age. Cruz and Plucinski (2009) describe pine plantation fuel complexes using six classifications based on rotation of the plantation and the thinning and pruning regimes. The Red Hill plantation was assessed as a PRADO5 fuel (See Table 7.1 and Table 2 in Cruz and Plucinski (2009)). Ten samples plots were randomly selected throughout the plantation and at each sample point photograph taken and the following measurements were taken:
  - litter fuel depth (mm),
  - pine litter L-H depth (mm),
  - overstorey canopy height (m),
  - canopy based height (m)
  - percent canopy cover score, and

Table 7.1: Characteristics of PRAD05 pine fuel type (Cruz and Plucinski 2009)

Fuel strata	Fuel Description
Surface fuel	Continuous litter layer with duff formation; development of moderately dense low shrub understorey.
Ladder fuels	Absent.
Crown fuel	Well stocked stand with good canopy cover, canopy base height higher than 10 m.

  - bark hazard score (see Gould et al. (2007a))

7.1.3 Weather measurements

7.1.3.1 In-forest weather station

On designated burning days a plot was selected for the experiment and in the adjacent plot a portable in-forest weather station was set up approximately 60 minutes or more prior to proposed ignition time. A 2-m tower was installed under the forest canopy located in a representative area of canopy and vegetation cover of the proposed burn plot. Instruments on the tower measured the weather elements, which were recorded on a data logger at 1-minute intervals, with the following sensors:

- cup anemometer and wind vane at 2 m,
- temperature, relative humidity and solar radiation sensors at 2 m.

7.1.3.2 In-forest wind measurements

The cup anemometer at the 2-m weather station has a high start-up speed of 1 m s^{-1} and under light and variable wind conditions the sensor will record zero wind speed. Two additional 5-m towers were installed with more sensitive instruments to measure light and variable wind speed and direction under the forest canopy. Two sonic anemometers with data loggers recorded 1-minute average wind speed and direction at 5 metres under the forest canopy from 10 Hz measurements. These instruments were located within 50 m from the experimental fires either in an adjacent plot or a safe distance from the proposed ignition point.

7.1.4 Fire behaviour measurements

7.1.4.1 Fuel moisture

Prior to ignition five grab samples of approximately 30 grams were taken of the fine dead fuels from the surface fuel (upper litter layer on the forest floor), profile surface fuel (full depth of the litter layer above the mineral soil including the surface litter), and the near-surface fuel layer (dead grass, bracken, and suspended leaves). Additional fuel moisture samples were taken after the completion of the experiments of the surface and near-surface fine dead fuel. All the fuel samples were placed in tins and sealed for transport to the work centre where they were weighed and oven-dried at 102°C for 24 hours and then re-weighed. Fuel moisture content was expressed as a percentage of oven-dried weight.

7.1.4.2 Fire spread

Field experiments were designed to measure fire growth and smoke characteristics under the prevailing weather and slope conditions. Each fire was lit with a drip torch producing a small point ignition approximately 0.5 m diameter. Rates of spread were measured by marking the position of the fire front, flanks and backing fire perimeters at two minute intervals with pre-numbered metal tags. If the fire progression was slow the tagging intervals were extended to 5 or 10 minute intervals depending on the rate of fire growth. At two minute intervals experienced fire behaviour observers recorded ocular estimates of: fuel continuity, fuel type, flame height, flame depth, flame angle. Additional notes were made on up-draughts, down draughts, smoke colour and behaviour of the smoke plume under the forest canopy. Photographs and video of the fire progression and smoke behaviour were also recorded.

After the fire, the position of the fire perimeter markers and ignition point were surveyed using differential GPS unit and the latitude and longitude locations recorded onto an ARC Pad GIS layer. The survey measurements were imported in ARC Map to plot the location of the fire perimeter makers. The fire perimeter-isochrones were interpolated by eye between plotted fire perimeters markers for each time interval (Figure 7.5). The rate of spread was taken as the maximum distance that the fire front advanced between each successive fire-perimeter isochrone. The fire area and fire perimeter for each fire perimeter isochrone were calculated in ARC Map. Maximum rate of spread for each time period, cumulative distance travelled, fire area and fire perimeter were plotted against time for the duration of the fire to determine the acceleration and growth rate of the fire.

The weather variables were averaged for the duration of the experimental burn and the fuel data was averaged for each experimental plot.

7.1.4.3 Smoke characterisation

A research observer was located at a vantage point outside the experimental area to observe the smoke characteristics above the forest canopy. The location was either a vantage point near the burn plot or the Mt Tumorrama lookout tower. The time was recorded when the smoke was first seen above the forest canopy as well as smoke colour, density and angle of plume rise. Video footage of the above canopy plume was recorded.

7.2 Results

7.2.1 Burns and fires

7.2.1.1 Forest sites

Six experimental fires were conducted in March 2010 to evaluate the detection of fires by the cameras and a lookout tower operator. There were three burns at the Bungongo site, two burns at the Barnetts site and one burn at the Red Hill site. The experimental burn in the pine plantation (Red Hill site) had unsustained forward spread at a rate of less than 0.2 m min^{-1}. Twenty minutes after ignition, with only 20% flaming perimeter, the experiment ceased with no measurable data on fire progression and fire growth and thus is not included in the fire behaviour analysis.

All the research fires were carried out between 1200 and 1500 hours on suitable days. Summary of the fuel, weather, fire behaviour and smoke characteristics from the research burns are given in Table 7.2. While the conditions during the actual research fires were marginal for prescribed burning there was considerable smoke for detection. The mild burning conditions and slow fire development was reflected by the high fuel moisture and mild weather conditions at the time of the experiments. The experiments were conducted under very light and variable wind conditions under the forest canopy. Figure 7.3 shows 2 hours of typical under canopy winds during an experiment.

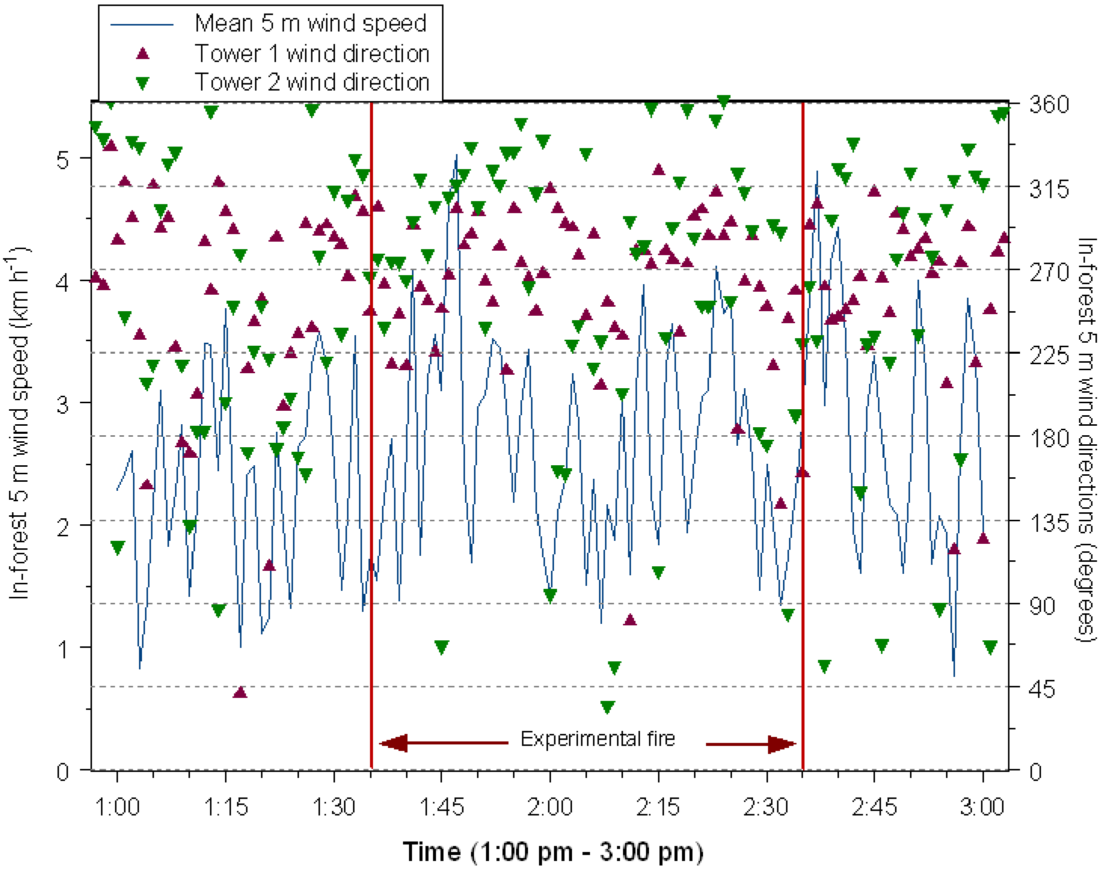


Figure 7.3: In-forest mean wind speed and wind direction from two sonic anemometers at 5 m at Bungongo Plot D1 experimental fire.

Figure 7.4: Experimental fire Bungongo Plot D2 (left) ignition point and (right) fire and smoke characteristics 37 minutes after ignition.

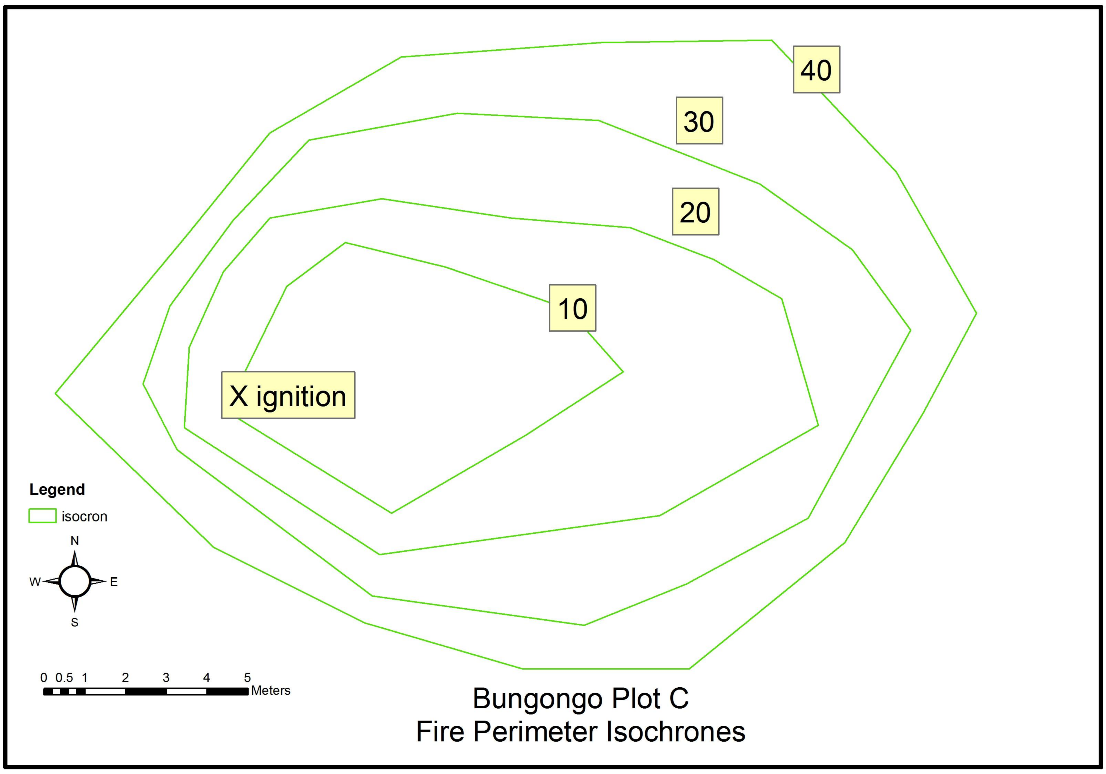


Figure 7.5: Example of the 10-minute fire perimeter isochrones of experimental fire Bungongo Plot C.

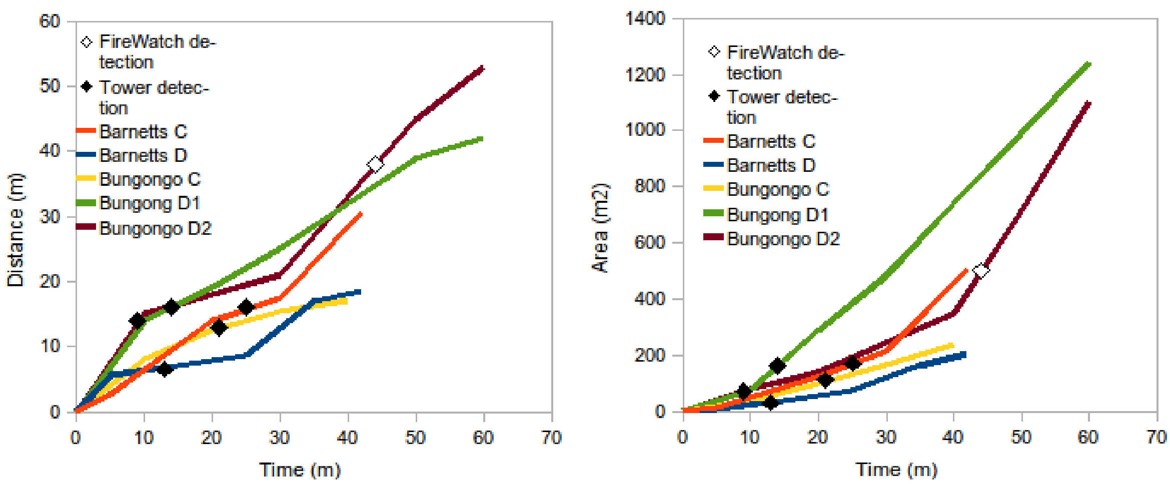


Figure 7.6: Left) Cumulative distance of fire spread from ignition of individual experimental fires. The slope of the line indicates the rate of spread. Right) Cumulative area burnt from ignition by the individual experimental fires. Points show detection times for each fire by different detection systems. Barnetts D burn (blue lines) was allowed to continue burning after observations were completed, reaching a size of 1 ha (10,000 m^2) after approximately 24 h.

All fires started with a point ignition source and slowly spread under the prevailing fire behaviour conditions. Figure 7.4 shows a typical ignition point and the fire and smoke characteristics some time after ignition. Rates of spread were calculated from fire perimeter isochrones, such as those shown in Figure 7.5, and varied from 0.2 to 1.5 m min^{-1}. Fire intensity ranged from $<$10 to 625 kW m^{-1} and flame height varied from 0.1 to 1.5 m. The cumulative distance travelled by the head fire from the point of origin is shown in Figure 7.6. This illustrates the variation in spread (rate of forward spread for any time period is given by the slope of the line) common in prescribed burning operations and caused by local variation in fuel structure, dead fuel moisture content and wind. The initial spread rates from the point ignition were slow.

The initial rates of spread of the Bungongo fires Plot D1 and D2 were higher that the other fires even though these fires were spreading under lighter winds conditions than the Barnetts burns. The Bungongo fires were burning in more continuous litter surface fuel layer with bracken in near-surface layer compared to the Barnetts fires which had scattered patches of green *Poa sp.* grass in the surface fuel layer (See Figure 7.2).

The rate of fire growth (i.e. area burnt) ranged from 1.8 to 39.3 m^2 min^{-1}, and in Figure 7.6 the cumulative fire area is shown for the individual fires. The variation in the different growth rates depended on many factors: dead fuel moisture content, surface fuel distribution, combustion rate, burn-out time of fuels, local winds in the flame zone and atmospheric stability.

Variation in smoke colour tones, atmospheric and burning conditions make smoke characterisation and detection a complex task. Smoke may vary in colour from white to blue or black depending on the burning fuel and combustion. The time of observation of the smoke first appearing above the forest canopy varied from 2 to 20 minutes after ignition and was white or grey in colour with a plume angle of 90 degrees (i.e. vertical plume rise). Most of the smoke came from the smouldering combustion of the courser woody material behind the flame front, see Figure 7.4.

Table 7.2: Fuel, weather, fire behaviour mean and standard deviation values (in brackets) of the research fires.

	Bungongo Site			**Barnetts Rd Site**		**Red Hill**
Fire plot	**C**	**D1**	**D2**	**C**	**D**	**A**
Burn date (dd/mm/yy)	25/03/10	17/03/10	23/03/10	26/03/10	22/03/10	18/03/10
Ignition time (hh:mm)	14:02	14:00	13:35	12:34	14:01	14:!0
Duration (minutes)	40	60	60	42	42[c]	20
Fuel descriptions						
Surface fuel depth (mm)	14 (2.1)	27 (10.6)	27 (10.6)	25 (10.9)	18 (2.8)	17 (4.2)
Pine litter L-H depth (mm)	-	-	-	-	-	14 (3.2)
Surface fuel hazard score	2.2 (0.3)	2.6 (0.6)	2.6 (0.6)	3.1 (0.2)	2.8 (0.6)	-
Surface fuel cover score	3.7 (0.5)	3.5 (0.7)	3.5 (0.7)	2.8 (1.0)	2.9 (0.6)	-
Near-surface fuel height (cm)	14 (3.9)	27 (8.2)	27 (8.2)	18.0 (3.5)	17.2 (3.8)	-
Near-surface fuel hazard score	3 (0)	2.8 (0.6)	2.8 (0.6)	2.6 (0.6)	3.2 (0.3)	-
Near-surface fuel cover score	1.5 (0.7)	2.6 (1.2)	2.6 (1.2)	2.2 (0.8)	2.4 (0.5)	-
Elevated fuel height (m)	1.2 (0.7)	0.85 (0.2)	0.85 (0.2)	1.2 (0.5)	2.0 (0.4)	-
Elevated fuel hazard score	1.1 (0.3)	2.7 (0.5)	2.7 (0.5)	2.4 (0.5)	2.0 (0)	-
Elevated fuel cover score	2.5 (0.7)	2.9 (1.0)	2.9 (1.0)	2.0 (0.7)	1.6 (0.5)	-
Overstorey canopy height (m)	26 (2.1)	26 (3.9)	26 (3.9)	24.8 (7.6)	38 (1.3)	29 (3.6)
Bark hazard score	2.5 (0.4)	3.5 (0.5)	3.5 (0.5)	2.8 (0.4)	2.1 (0.3)	1 (0)
Overstorey cover score	2.5 (0.8)	4.2 (1.1)	4.2 (1.1)	2.2 (1.1)	2.3 (0.5)	3 (0)
Pine canopy base height (m)	-	-	-	-	-	18 (3.6)
Fire weather variables						
Temperature (°C)	23 (0.3)	25 (0.4)	23 (0.2)	22 (0.5)	20 (0.2)	26 (0.1)
Relative humidity (%)	44 (2.5)	40 (1.5)	27 (1.5)	35 (19)	45 (1.5)	37 (1.7)
In-forest wind direction at 5 m	NNW	NW	NW	W	WNW	S
Wind speed at 5 m (km h^{-1})	2.4 (0.8)	2.7 (1.4)	2.6 (0.9)	3.1 (0.7)	4.2 (0.9)	1.7 (0.7)
Fire behaviour variables						
Pre fire fine dead fuel moisture						
Surface fuel (%)	11.8 (0.9)	11.7 (2.5)	12.3 (2.6)	14.0 (2.4)	13.1 (2.5)	12.2 (1.2)
Near Surface fuel (%)	14.3 (.18)	14.1 (1.0)	11.1 (0.6)	14.2 (1.3)	13.6 (0.8)	31.1 (11.5)
Profile (%)	20.3 (1.5)	19.0 (2.9)	17.3 (5.5)	15.9 (3.9)	26.0 (13.5)	NA
Post fire fuel moisture						
Surface fuel (%)	13.1 (2.9)	11.0 (1.1)	9.3 (1.7)	9.1 (1.1)	13.5 (2.4)	NA
Near Surface fuel (%)	12.8 (0.6)	12.5 (0.5)	10.7 (0.7)	12.3 (0.5)	13.9 (1.6)	NA
Rate of spread (m min^{-1})	0.4 (9.2)	0.7 (0.4)	0.8 (0.5)	0.7 (0.3)	0.5 (0.4)	< 0.2[a]
Flame height (m)	0.2 (0.05)	0.5 (0.3)	0.5 (0.2)	0.4 (0.4)	0.3 (0.2)	0.1 (0.05)
Flame angle (°)	114 (12)	104 (14)	110 (14)	86 (15)	85 (20)	78 (26)
Flame depth (m)	0.2 (0.04)	0.2 (0.06)	0.3 (0.2)	0.3 (0.05)	0.2 (0.05)	0.1 (0.05)
Fireline intensity (kW m^{-1})[b]	7 (4)	89 (80)	102 (90)	96 (175)	32 (43)	8 (9)
Total fire area (m^2)	239	1245	1106	509	205[c]	NA
Total fire perimeter (m)	58	144	124	83	57	NA
Smoke characteristics						
Time smoke seen above canopy	14:20	14:03	13:37	NA	NA	14:14
Smoke rise angle (degrees)	90	60	90	NA	NA	90
Smoke colour	White	Grey	Grey	NA	NA	White

[a] Unsustained forward fire spread with less than 20% flaming perimeter 20 minutes after ignition.

[b] Byram's fireline intensity calculated from flame length (Wilson 1980).

[c] This fire was allowed to continue burning, eventually burning the entire 1 ha plot after approx. 24 h.

Table 7.3: Other burns.

Site	Nottingham Rd	Blackberries 1	Blackberries 2	Barnetts Rd	Night 1	Night 2
Fuel type	Windrow	Blackberries	Blackberries	Windrow	Windrow	Windrow
Ignition time	15/03 15:05	18/03 10:17	18/03 10:57	19/03 9:03	24/03 20:16	24/03 21:35
Duration (min)	50	15	22	40	45	45
Length (m)	57	-	-	20	17	18
Area (m^2)	-	80	760	-	-	-
Smoke colour	White	Grey	Grey	Brown	NA	NA
Angle	45	30	30	45	NA	NA

7.2.1.2 Other burns

Observations for the six non-forest burns are summarised in Table 7.3.

7.2.2 Detections

During the research trial, burns were reported by the tower and cameras only. No 000 calls were received and no other detection methods were used. Detection locations for research burns from the tower and camera systems are shown in Figure 7.7, detection times and location accuracy are listed in Table 7.4.

Tower observer: All burns in forest fuels were seen by the tower observer within 30 minutes at a size of less than 200 m^{-2} (Figure 7.6). Neither of the blackberry fires were seen, despite reaching sizes of 80 and 760 m^{-2}. The Barnetts Rd windrow was noted at 11:10 as "building steadily over the past 2 hours", so was seen a short but unspecified time after ignition. No distance was given . The two night burns were not seen initially because the tower was unoccupied but were seen the following morning. The tower observed outperformed the camera systems when the tower was occupied with the highest proportion of detections and shortest reporting time. Locations were accurate but in some cases imprecise. For nearby burns locations were given to within a few 100 m. The location of the Bungongo burns was given as bearing, distance of 20–25 km, and location "Bungongo State Forest near Bungongo Road", which was accurate but covers an area approximately 8 $\times$ 4 km in size.

EYEfi: EYEfi did not provide automatic detection during the trial. One research burn was targeted by EYEfi. The single target was located to within 100 m of the true location.

FireWatch: One windrow, one forest burn, and both night burns were reported by FireWatch. FireWatch was the only camera system to report any of the forest burns, although detection was later than the tower operator by 35 minutes and the fire was five times larger at detection (Figure 7.6). Time to detection relative to the other camera systems was mixed. Accurate locations were given for most detections, the largest error was 11% distance for the Nottingham Rd windrow. One night burn was reported before ignition. As the time stamps on all other detections were accurate, it appears that the system alerted on vehicle headlights.

Forest Watch: One windrow and both night burns were reported by Forest Watch. It is likely that the blackberry fires were obscured by poles on the tower. Time to detection relative to the other camera systems was mixed. Accurate locations were given for the three detections, the largest error was 5% for the second night burn. One night burn was reported before ignition. As the time stamps on all other detections were accurate, it appears that the system alerted on vehicle headlights.

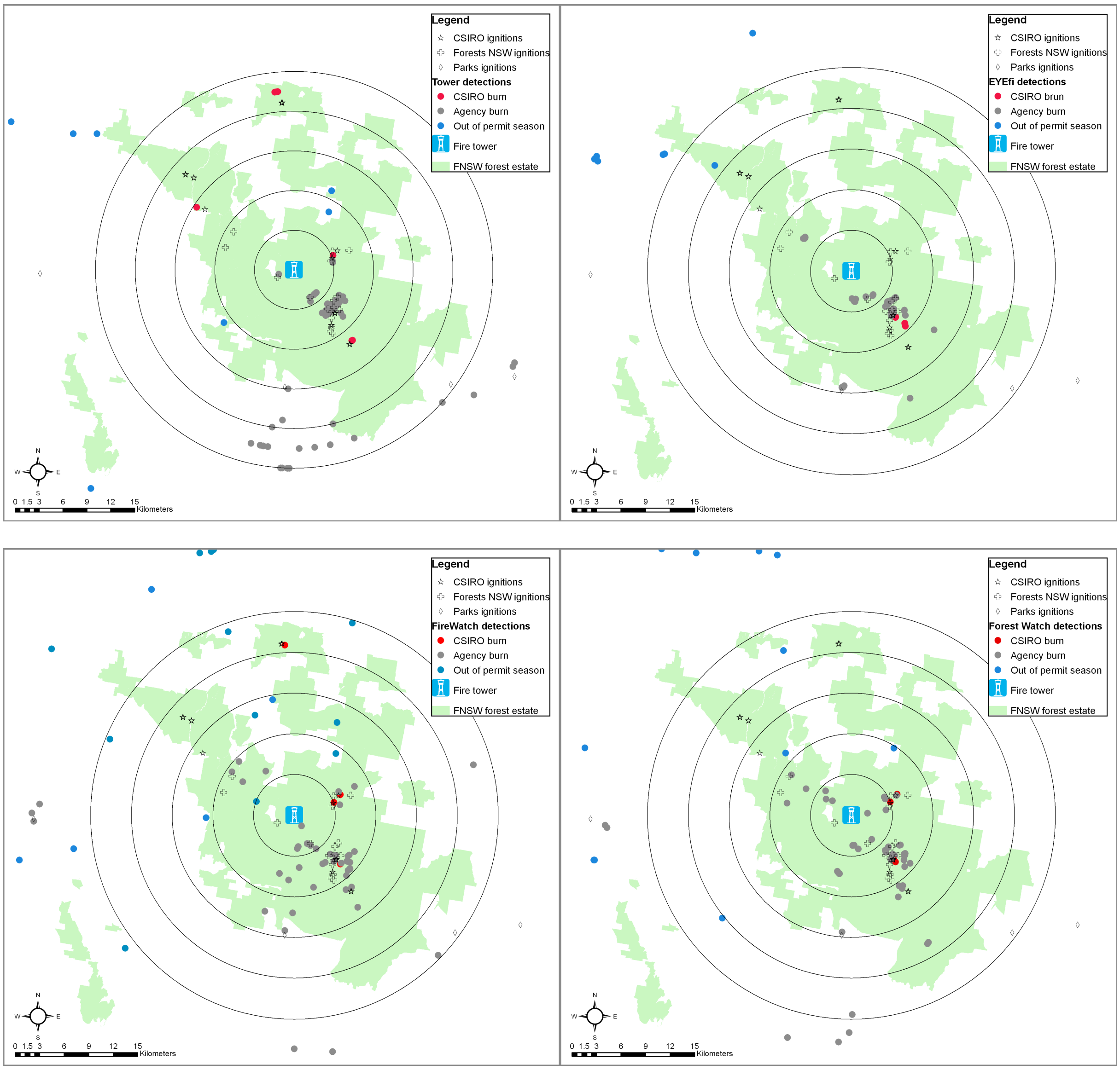


Figure 7.7: Location of fire detections by tower operator and camera systems. See Tables 7.4 and 8.1 for details of detection times and accuracy. Private burns beyond the extent of these maps are shown in Figure 9.1.

Table 7.4: Fire reporting summary for research burns.

	Ignition details			Site details		Tower			EYEfi			FireWatch			Forest Watch		
	Date	Range (km)	Bearing	Location	Fuel type	Seen	Time (min)	Error (km)	Target[f]	Time (min)	Error (km)	Seen	Time (min)	Error (km)	Seen	Time (min)	Error (km)
1	15/03 15:05	7.5	136	Nottingham Rd	Windrow	NA[a]	-	-	Yes	67	0.1	Yes	40	0.8	Yes	20	0.1
2	17/03 14:00	21.1	355	Bungongo Rd	Eucalyptus	Yes	14	1.4	NA	-	-	No	-	-	No	-	-
3	18/03 10:17	17.1	312	Blackberries 1	Blackberries	No	-	-	NA	-	-	No	-	-	NA[g]	-	-
4	18/03 10:57	18.1	310	Blackberries 2	Blackberries	No	-	-	NA	-	-	No	-	-	NA[g]	-	-
5	18/03 14:10	14.6	303	Red Hill	Pine	Yes	15	0.3	NA	-	-	No	-	-	NA[g]	-	-
6	19/03 09:03	8.3	146	Barnetts Rd	Windrow	Yes	e	e	NA	-	-	No	-	-	No	-	-
7	22/03 14:01	11.6	142	Barnetts Rd	Eucalyptus	Yes	25	0.1	NA	-	-	No	-	-	No	-	-
8	23/03 13:34	21.1	355	Bungongo Rd	Eucalyptus	Yes	9	1.4	NA	-	-	Yes	44	0.4	No	-	-
9	24/03 20:16	5.0	72	Night 1	Windrow	Yes	764[b]	0.2	NA	-	-	Yes	17	0.1	Yes	-10[c]	0.1
10	24/03 21:35	5.9	65	Night 2	Windrow	Yes	764[b]	0.2	NA	-	-	Yes	-15[d]	0.2	Yes	42	0.3
11	25/03 14:02	21.1	355	Bungongo Rd	Eucalyptus	Yes	21	1.4	NA	-	-	No	-	-	No	-	-
12	26/03 12:34	11.6	142	Barnetts Rd	Eucalyptus	Yes	13	0.1	NA	-	-	No	-	-	No	-	-

[a] Tower unoccupied.

[b] Tower unoccupied at night. Burns seen next morning.

[c] Detection before ignition. System appears to have detected vehicle headlights. Forest Watch provided us with a sequence of images of this burn, change from headlights to fire is not apparent at 20:18 but is at 20:27.

[d] Detection before ignition. System appears to have detected vehicle headlights. Burn is clearly visible as a burn in later image at 22:10.

[e] See text for details.

[f] EYEfi did not provide active fire detection during the trial. Rows with ”Yes” are burns that were targeted by EYEfi staff. Time is the time the target was made, location error is on the same basis as other systems.

[g] The bases of these burns were near or obscured by poles mounted on the tower.

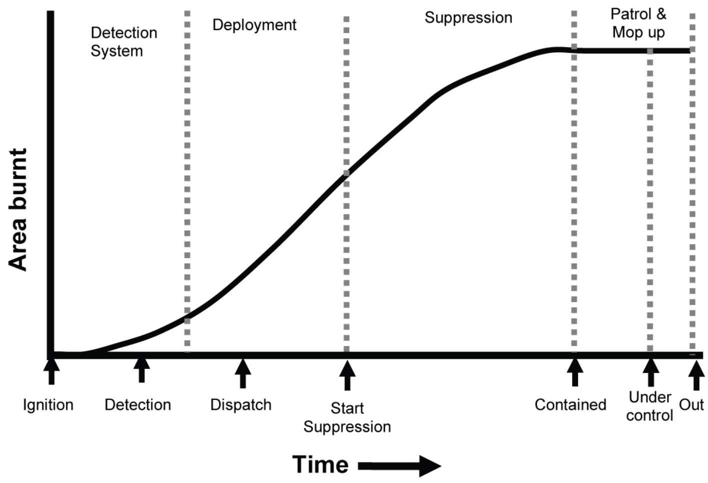


Figure 7.8: Schematic diagram illustrating the life cycle of a bushfire fires and the different stages of response in suppressing the fire.

Night observations In addition to the two nighttime research burns, all companies provided reports of fires at night. These were updates of already going fires lit during the day, namely windrow and prescribed burns. Fire glow from flame and light from illumination of the smoke were visible in images from both the broadband sensor used by FireWatch and the night mode of the colour cameras used by Forest Watch and EYEfi. There was not enough data collected to comment on the relative performance of the two types of camera at night.

7.3 Discussion

The research burns were conducted in autumn. The following sections discuss important differences between summer and autumn conditions for fire growth, smoke characteristics, and atmospheric haze. The possible impacts of these differences on smoke detection are explored.

7.3.1 Fire growth

The burning conditions during the actual experimental fires were either below optimal or marginal conditions for experimental fires. These burns were not representative of the rate of fire growth (area burnt or perimeter length) under dry summer conditions. The development phases of area burnt of a bushfire from ignition to extinguishment (the life cycle of a bushfire) is shown in Figure 7.8. The initial growth phase is perhaps the most important phase of fire behaviour because after it represent the only time period in which suppression efforts may be effective under extreme fire weather conditions.

Suppression tactics generally begin with constructing a line around the flaming edge to contain the fire. Containment is critical to limiting fire spread, area burnt and subsequent losses. Resources are dispatched to a bushfire based on estimates of fire behaviour, resource productivity, the current and expect fire size (i.e. rate area burnt or rate of perimeter growth) and other going fires (i.e. the current fire load of a fire agency). Ineffectual detection and dispatching can result in a fire that escapes initial attack efforts with consequent increase in the order of magnitude of suppression costs, area burnt and potential losses. The experimental fires presented in this study were very slow spreading and only marginally self-sustaining due to light variable wind conditions, high dead fuel moisture contents, and discontinuous surface litter cover. These resulted in highly convoluted fire shapes and growth rates.

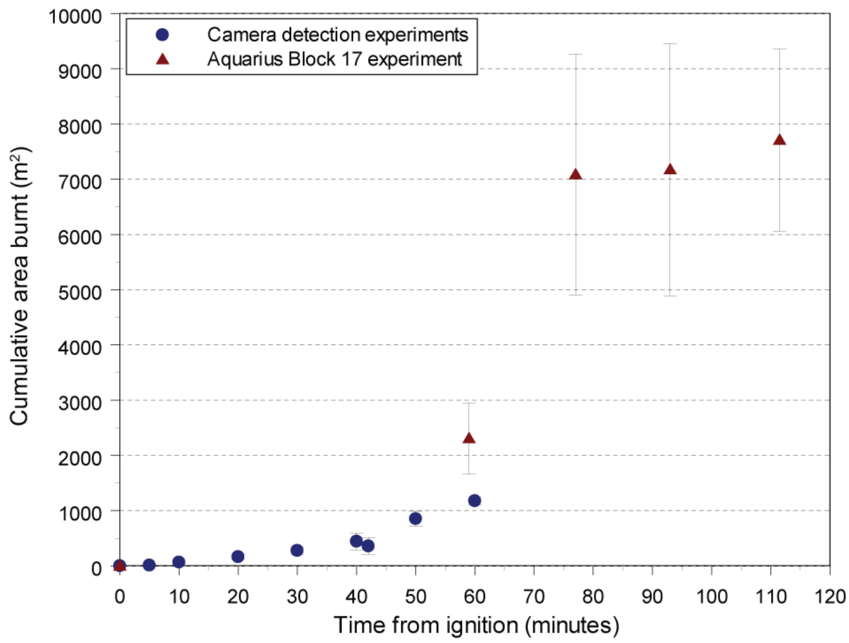


Figure 7.9: Comparison of the mean cumulative area burnt of two sets of burning experiments; camera detection experiments (circles) and Project Aquarius multi-ignition experiment (triangles) (Gould et al. 1996). Error bars indicate 1 standard error.

A fire ignited as a point source takes a long time to accelerate to its equilibrium rate of spread for the prevailing conditions (Cheney and Gould 1995; McAlpine and Wakimoto 1991), and there is a lack of detailed research on fire growth from a point-source ignition in eucalypt fuels. Gould et al. (1996) described point-source ignition fires from one set of multi-point-source ignition experiments conducted during the Project Aquarius study in the 1980s. The Aquarius experiment was burnt under a forest fire danger rating of 6, similar to that of the current camera detection experiments, except the dead fuel moisture content was much lower ($\simeq$7 percent). In the Aquarius multi-point ignition fires (14 ignitions), the individual fire sizes 60 minutes after ignition ranged from 473 to 8948 m^2, with a mean area of 2300 m^2 (Figure 7.9). The maximum area after 60 minutes of the camera detection research fires (two fires) was less than half the average area of the Aquarius fires.

For fires burning under low to moderate forest fire danger ratings and drier fuel moisture content ($<$ 8 percent) there is the potential of a 7-fold increase in area burnt within the first hour of ignition compared to the area actually burnt in the camera detection research fires. The average increase in area of the Aquarius experiments within two hours of ignition was 300 percent (see Figure 7.9). Therefore, even under low to moderate forest fire danger ratings under dry summer conditions, the time delay in detection of a fire can result in a rate of area growth of up to 1500 m^2 (or 0.15 ha) every ten minutes.

7.3.2 Smoke characteristics

Bushfire smoke is a complex mixture of carbon dioxide, water vapour, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, and trace minerals. Smoke characteristics (colour, density, etc.) and composition depends on multiple factors, in-

Figure 7.10: left) Smoke plume from four experimental fires 16 minutes after ignition from 120 m long ignition lines. (Source: Gould et al. (2007a)). right) Smoke from Barnetts Rd fire 30 minutes after ignition from a point source, fire is approximately 17 × 15 m in size, 11.6 km from the tower.

cluding fuel type and moisture content, weather conditions, stage of fire development, and terrain, which all influence fire behaviour and the development of the smoke plume. In general, windy conditions contribute to lower smoke concentration because the smoke mixes into a larger volume of air. However, stronger winds will lead to faster spreading fires, resulting in larger fires and plume columns.

Combustion residue comprising carbon particles and complex hydrocarbons caused by the incomplete combustion of fuels, along with water vapour, a by-product of cellulosic combustion, contributes to what we see as smoke. The colour, brightness, density and texture difference have a role in an observer's decision whether a distant object is smoke, cloud, or dust. However, the critical aspect is the pattern of movement.

Biswell (1989) describes smoke plume colour characteristics, and particle size for different burning or combustion conditions for wildland fires. The different smoke plume categories are:

1. Invisible smoke plume: produced by very intense fires burning in extremely dry fuels on days of low humidity and windy conditions. In this case, the vapour rising above the fire disappears so quickly that the small particles (<0.1 microns) do not aggregate and become large enough to be seen.

2. Blue smoke plume: comes from a fire that is less intense than the one described above. The blue colour signifies somewhat dry fuels, as well as good meteorological conditions for burning. The particles are mostly 0.15 to 0.3 microns in diameter. This smoke is marginally visible.

3. White smoke plume: from burning of heavy understorey fuels or wet fuels. Much of the colour comes from water vapour. This smoke is easily seen because of larger particle sizes (0.6 microns) producing light-scattering in the visible spectrum.

4. Yellow-grey-black smoke plume: generally produced by intense wildfires that consume nearly everything in their path. The yellow and grey colours comes from the burning of green material and the black comes from burning large volumes of fuels with insufficient ventilation and oxygen supply, as well as from burning fuels high resin and oil content. This is the most visible type of smoke plume.

The smoke plumes produced from the camera detection research fires were shallow and white with very little vertical plume development. In contrast, the smoke plume from the Project Vesta experimental fires under dry summer conditions (Gould et al. 2007a) produced a mixture of white and grey colour smoke (Figure 7.10) with much more pronounced vertical development. Under normal summer burning conditions higher intensity fires will produce smoke plumes with more horizontal and vertical movement leading to more rapid plume development. On clear days detection of these type of plumes might be easier and quicker compared to the detection of smoke plume from the research fires. However, on high fire danger days atmospheric stability and haze will impede detection and strong winds may prevent vertical plume development until a fire reaches a large size.

7.3.3 Atmospheric clarity

A key aspect of all fire detection methods based on visual observation of smoke is atmospheric clarity, or rather atmospheric haziness. Very high to extreme fire danger days are generally associated with a deep mixed (boundary) layer associated with unstable atmospheric conditions and high surface heating rates. Convection acts to mix high speed winds from the geostrophic layer down to the surface, bringing gusty conditions, but also acts to raise dust to the top of the mixed layer. The result of this raised dust is to create hazy atmospheric conditions that deteriorates visibility.

Figure 7.11 shows two photographs taken at the same location on two different days of fire danger and atmospheric clarity. It illustrates the effect of raised dust on the clarity and distance that can be viewed under days of elevated fire danger. It is on these types of days that timely detection of fire outbreaks is critical to initiating timely suppression responses.

Figure 7.11: (left) A view of the Brindabella ranges from north Canberra on the afternoon of November 19, 2009. Forest fire danger index at 3pm was 50 (fire danger rating: Extreme). Maximum visibility is in the order of 15-20 km due to raised dust. **right)** The same view on the afternoon of November 30, 2009. Forest fire danger index was 3 (FDR: Low). Visibility is in the order of 40+ km.

The atmospheric conditions that occurred during this study did not replicate the hazy, raised-dust conditions associated with these critical days and thus did not provide the challenging atmospheric conditions that would be encountered on bad fire days during the fire season. While the smoky conditions created by the agency lighting of windrows did create complicated observation conditions they were not comparable to days of elevated fire danger and raised dust.

8 Detection evaluation II: Agency burning

This section covers burns conducted by fire agencies in NSW and Victoria during the trial, including windrow burning by FNSW, and prescribed burning in Eucalyptus forest by parks agencies in NSW and the ACT, and by DSE in Victoria. These burns differ from the research burns in that a large area of fuel was ignited, producing large amounts of smoke compared to the point ignitions used in the research burns. Thus detection performance was not representative of what might be expected from a point ignition (e.g. lightning or arson) because the ignition method makes these burns easier to see. Also, information about the location and planned date of ignition were available on public websites for DSE burns in Victoria. We did not prevent camera companies from accessing this publicly available information.

8.1 Methods

Short fire behaviour record sheets were provided to FNSW and DSE to record information about prescribed burns and bushfires during the trial period (See Appendix B). For windrow burning FNSW supplied us with maps showing time and location of compartments that were burned. Locations and ignition times for parks prescribed burns were obtained from parks staff by telephone conversations. In addition to fire behaviour forms, DSE also supplied GIS layers containing the location, perimeter, and area of burns and fires.

8.2 Results

8.2.1 Burns and fires

8.2.1.1 NSW

The locations of FNSW and parks burns are shown in Figure 7.1 and summarised in Table 8.1. During the trial period Forests NSW conducted a program of windrow burning to prepare harvested pine plantation for a new crop ("Windrow" fuel type in Table 8.1). Many windrows were burnt for each listed ignition, generating multiple small smoke plumes over the area of the burn and generating a large amount of smoke (Figure 8.2). Exceptions were the ignitions on March 25th and 26th , which were single windrows. The windrows burnt for several days, creating widespread haze during days of calm conditions. Further burning inside the FNSW area to the south and south-east of the tower (bearing range 121° to 180°) initially burnt on March 16th and 17th was conducted in late April but ignition times were not recorded.

Four prescribed fires were lit within view of the tower by NSW and ACT National Parks ("Eucalyptus" fuel type in Table 8.1). These were broad area burns ignited by aerial incendiary method or roadside ignition with drip torches. They generated a large plume of smoke within a short time (Figure 8.2) and burnt for several days.

8.2.1.2 Victoria

In Victoria, DSE lit 15 prescribed burns in Eucalyptus forest fuel within the study area, ranging in size from 5 to 1075 ha (Table 8.2 and Figure 8.1). These were broad area burns ignited from the roadside with drip torches. They generated a large plume of smoke within a short time and most burnt for several days. Some fires were partially extinguished by rain and subsequently reignited.

One wildfire managed by DSE was reported during the trial, an 84 ha fire at Yeodene. This fire was first reported to DSE by a 000 call.

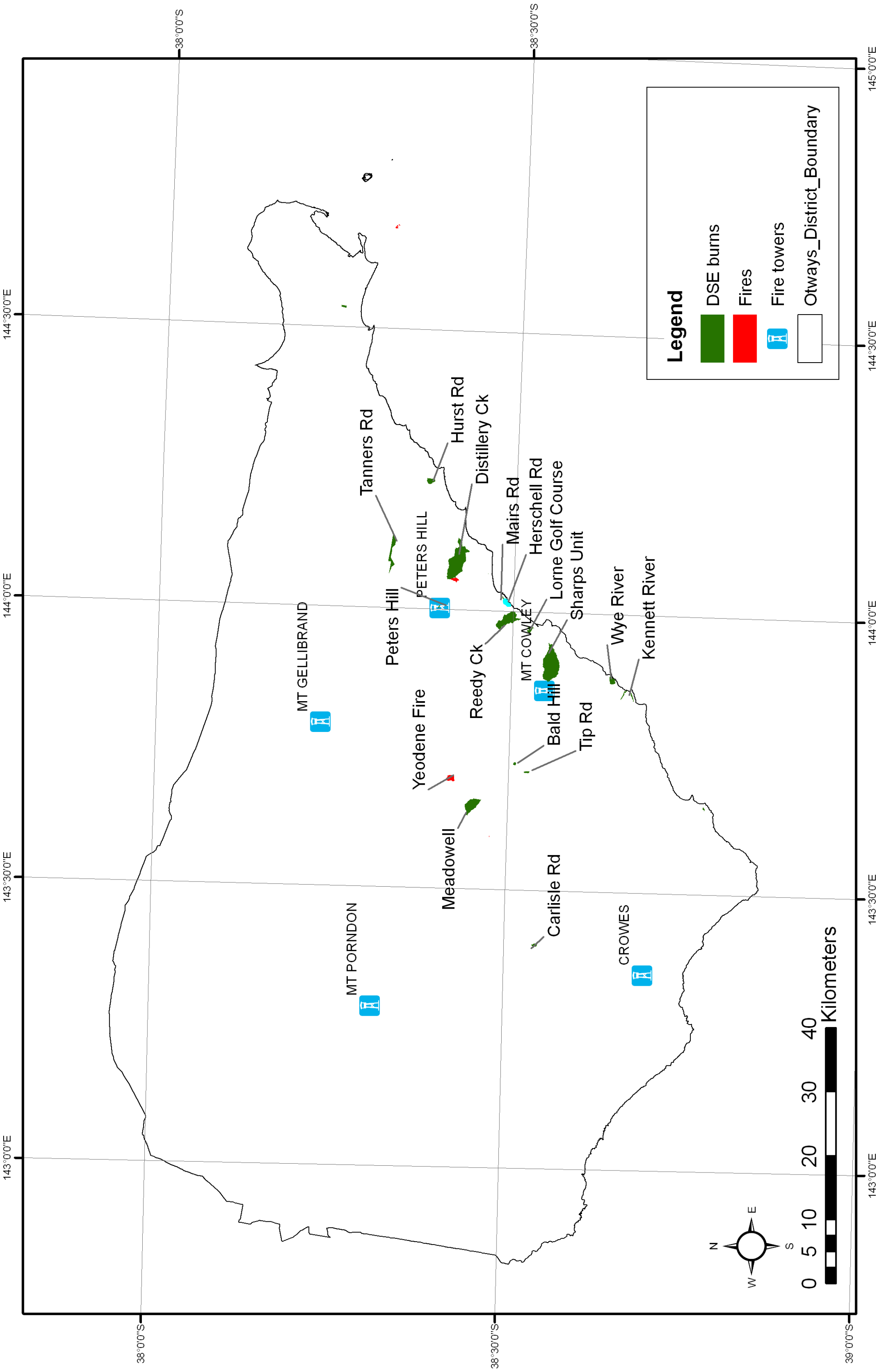


Figure 8.1: Location of fire and DSE burns Victoria.

Table 8.1: Fire reporting summary for agency burns in NSW. See text for discussion of detection and reporting of windrow burning on 16-17 March.

	Ignition details			Site details		Tower			EYEfi			FireWatch			Forest Watch		
	Date	Range (km)	Bearing	Location	Fuel type	Seen	Time (min)	Error (km)	Target[g]	Time (min)	Error (km)	Seen	Time (min)	Error (km)	Seen	Time (min)	Error (km)
13	16/03 9:20[1]	7.6	130	Cpt 921	Windrow	Yes	165	1	Yes	20	0.2	Yes	17	1.8	Yes	45	0.2
14	16/03 9:30[1]	6.9	133	Cpt 920	Windrow	Yes	155	1	Yes	10	0.2	Yes	37	2.8	Yes	35	0.3
15	16/03 13:20[2]	7.1	137	Cpt 925	Windrow	No	-	-	NA	-	-	Yes	38	4.1	No	-	-
16	16/03 13:55[2]	6.3	127	Cpt 913	Windrow	Yes	47	0.6	NA	-	-	No	-	-	No	-	-
17	16/03 14:37[2]	6.4	121	Cpt 913	Windrow	Yes	5	0.6	NA	-	-	No	-	-	No	-	-
18	16/03 14:43[3]	6.5	138	Cpt 919	Windrow	No	-	-	NA	-	-	No	-	-	No	-	-
19	17/03 9:12[3]	7.7	141	Cpt 925	Windrow	Yes	45	1.3	Yes	78	4.4	No	-	-	No	-	-
20	17/03 9:25[4]	6.4	121	Cpt 913	Windrow	Yes	43	1	Yes	35	0.1	Yes	347	2.3	Yes	46	0.7
21	17/03 11:05[5]	8.7	146	Cpt 766	Windrow	Yes	10	1.6	NA	-	-	No	-	-	No	-	-
22	17/03 11:20[5]	9.0	148	Cpt 771	Windrow	Yes	7	1.6	NA	-	-	No	-	-	No	-	-
23	17/03 11:30[5]	9.3	148	Cpt 772	Windrow	Yes	13	1.8	NA	-	-	No	-	-	No	-	-
24	18/03	27.5	114	Namadji NP	Eucalyptus	Yes	-[e]	1	NA	-	-	No	-	-	No	-	-
25	19/03 12:30	24.4	125	Prescribed burn	Eucalyptus	Yes	61	0[d]	NA	-	-	Yes	55	0[d]	Yes	123	8
26	19/03 14:20	14.8	184	Prescribed burn	Eucalyptus	Yes	8	0[d]	Yes	177	0[d]	Yes	10	0[d]	Yes	46	0[d]
27	23/03 13:16	4.4	154	Yankee Ned Hill	Windrow	Yes	0	0[d]	Yes	244	0[d]	Yes	11	0[d]	Yes[i]	-	-
28	25/03 17:30	4.8	75	Cpt 707	Windrow	Yes	0	0.2	NA	-	-	Yes	129[j]	18.1	No	-	-
29	26/03 9:30	2.3	245	Eucalyptus slash	Windrow	Yes	30	0.5	NA	-	-	NA[h]	-	-	No	-	-
30	21/04[b]	9.0	301	Wyangle Rd	Windrow	NA[a]	-	-	Yes	-[e]	0[d]	Yes	-[e]	0[d]	Yes	-[e]	0[d]
31	29/04 9:30	9.1	287	Billo Rd	Windrow	NA[a]	-	-	NA	-	-	No	-	-	Yes	224	0.9
32	29/04 14:25[c]	5.4	63	Patterson's Rd	Windrow	NA[a]	-	-	NA	-	-	Yes	f	1.0	Yes	70	0.5
33	5/05 14:30	7.3	70	Byes Rd	Windrow	NA[a]	-	-	NA	-	-	Yes	234[j]	1.5	Yes	159	3.0
34	14-16/04	31	271	Minjary Forest	Eucalyptus	NA[a]	-	-	NA	-	-	Yes	-[e]	0[d]	Yes	-[e]	2.2

[1-5] All ignitions with the same number considered detected if at least one was detected.
[a] Tower unoccupied.
[b] Further ignitions on 22/04 and 29/04.
[c] Further ignitions on 3/05 and 5/05.
[d] Inside burn perimeter.
[e] Exact ignition time unavailable.
[f] Reported on 3/05.
[g] EYEfi did not provide active fire detection during the trial. Rows with "Yes" are burns that were targeted by EYEfi staff. Time is the time the target was made, location error is on the same basis as other systems.
[h] Smoke from the burn was below the bottom of the field of view of the FireWatch camera.
[i] The Forest Watch operator was in Tumut at this time. Fire was detected but not recorded in the fire log.
[j] The EYEfi camera was within the field of view for this burn. FireWatch state that sun glare from the EYEfi hardware delayed detection.

Table 8.2: Fire reporting summary for agency burns in Victoria. EYEfi did not provide automatic detection. Tower detections are not included because, as per normal practice, they were notified before ignitions.

Ignition details			Site details			FireWatch			Forest Watch		
Date	Long.	Lat.	Location	Fuel type	Size (ha)	Seen	Time (min)	Error (km)	Seen	Time (min)	Error (km)
2/03 14:50[a]	143.697	-38.419	Yeodene Fire	Eucalyptus	84	Yes	43	0[b]	NA[c]	-	-
3/03 11:55	143.882	-38.643	Kennett River	Eucalyptus	16	No	-	-	NA	-	-
3/03 12:44[e]	143.853	-38.672	Wye River	Eucalyptus	83	Yes	1437	4.8	NA	-	-
4/03 13:10	143.908	-38.556	Sharps Unit	Eucalyptus	1065	Yes	23	0[c]	NA	-	-
14/03 14:01	143.402	-38.554	Carlisle-Colac Rd	Eucalyptus	30	Yes	21	0.8	NA	-	-
15/03 17:00	144.087	-38.419	Distillery Creek	Eucalyptus	1075	Yes	152	0[b]	NA	-	-
17/03 14:38	144.015	-38.490	Herschell Rd[f]	Eucalyptus	19	No	-	-	NA	-	-
17/03 14:38	144.023	-38.486	Mairs Rd[f]	Eucalyptus	9	No	-	-	NA	-	-
18/03 14:48	143.968	-38.525	Lorne Golf Course	Eucalyptus	54	Yes	1459	0.1	NA	-	-
23/03 15:29	143.650	-38.449	Meadowell	Eucalyptus	340	Yes	100	5.7	NA	-	-
24/03 13:00	143.986	-38.492	Lorne Reedy Creek	Eucalyptus	460	Yes	36	0[b]	NA	-	-
24/03 15:10	143.727	-38.509	Forrest Bald Hill	Eucalyptus	16	Yes	17	6.4	NA	-	-
25/03 14:46	143.712	-38.526	Forrest Tip Rd	Eucalyptus	20	Yes	26	3.7	NA	-	-
19/04 12:20[d]	144.229	-38.378	Anglesea Hurst Rd	Eucalyptus	84	Yes	1416	0[b]	Yes	1419	1.9
19/04 11:43	144.101	-38.325	Anglesea Tanners Rd	Eucalyptus	59	Yes	226	10.0	Yes	38	4.3
20/04 12:22	144.004	-38.396	Peters Hill	Eucalyptus	5	Yes	11	0.2	Yes	12	0[b]

[a] Time of 000 call.
[b] Inside burn perimeter.
[c] Forest Watch cameras were not monitored before 6th April, 2010.
[d] Burn extinguished by light rain on 19th subsequently reignited on 20th April at an unspecified time. Cameras have detected 2nd attempt at ignition.
[e] Second ignition 4/03 13:09.
[f] These two burns were on opposite sides of a road and would likely have been indistinguishable.

Figure 8.2: left) Smoke plumes from burning windrows (Source: Mal Baker). right) smoke from prescribed burn in Eucalyptus forest (Source: Mal Baker).

8.2.2 Detections

8.2.2.1 NSW

Tower and camera detections of operational burns are shown as grey dots in Figure 7.7.

Windrow burning: On March 16th and 17th, Forests NSW lit a large number of pine windrows to the south-east of the tower. Superscripts next to ignition times in Table 8.1 indicate ignitions that from the perspective of the tower were likely to be indistinguishable to camera operators. The tower operator, who had excellent local knowledge, was able to distinguish most of the ignitions as separate events in separate compartments. The ignitions caused some difficulties for the camera operators as they were unsure how to report the large number of smoke plumes appearing in rapid succession in a small area. All systems reported the initial ignitions on March 16th and 17th. The lack of subsequent reports for specific ignitions we regard as a decision about how to report the fires rather than failure to detect them.

Tower: On March 16th and 17th, locations were given as bearing, range, and compartment number. Some of the compartment numbers given by the tower operator did not match those in the records from FNSW, so we have used the bearing and ranges to assess location accuracy, which ranges from 0.6 to 1.8 km. The first ignitions of each day were noted when the tower opened at 12:00 on the 16th and 9:00 on the 17th subsequent ignitions were reported 7 to 47 min after ignition. All remaining burns were seen by the tower when it was occupied. Detection times ranged from immediate detection to 61 minutes. Some detections were located within burns areas, the largest error was approximately 1.8 km for one windrow burn.

EYEfi: The first windrow ignitions were targeted on March 16th and 17th. All except one of the windrow burns later in the trial were not targeted, but two of the four prescribed fires were targeted. Most locations were accurate to $<$ 0.2 km, with one error of 4.4 km.

FireWatch: The first windrow ignitions were reported at 9:37 on the 16th and 15:12 on the 17th. Four of the 7 windrow burns later in the trial were reported, as were three of the four prescribed fires. Detection times ranged from 10 to 129 minutes for fires with known ignition times. Some locations were given inside burn perimeters (i.e. zero error) but errors of up to 18.1 km were recorded.

Forest Watch: The first windrow ignitions were reported at 10:05 on the 16th and 10:11 on the 17th. Four of the 7 windrow burns later in the trial were reported, as were three of the four prescribed fires. Detection times ranged from 35 to 224 minutes for fires with known ignition times. Some locations were given inside burn perimeters (i.e. zero error), and the largest error recorded was 3.0 km.

8.2.2.2 Victoria

EYEfi: EYEfi did not provide smoke detection for their cameras in Victoria. The cameras were not used by DSE staff to target any of their prescribed burns.

FireWatch: 12 of the 15 DSE burns were reported by FireWatch, the Yeodene wildfire was also reported. The fire was detected 43 minutes after it was reported to the fire control centre by a 000 call (DSE crews attended the fire before the FireWatch alert was received). Detection times for prescribed burns varied widely from 11 minutes for the Peters Hill burn to over 24 hours for the Lorne Golf Course burn. Accuracy of locations also varied widely, three fires were located within their perimeters (i.e. zero error) while others were reported up to 10 km from the correct location. Some of the larger errors were due to topographic shadowing, while others appear to be due to errors in identifying the base of the smoke (See Box 10.1 for explanation of error types). The largest errors were for burns seen from only one tower, all fires for which triangulation was possible were accurately located.

Forest Watch: All three of the DSE burns lit when the Forest Watch system was monitored were reported. Detection times ranged from 12 minutes to almost 24 h. Location errors varied from 0 to 4.3 km. As with FireWatch, larger errors appear to be due to shadowing or incorrect identification of the base of the smoke column.

9 Detection evaluation III: Private burning

This section covers all other burns not included in the previous sections. The majority of these were farmers burning stubble, although there were a number of smaller burns (e.g. bonfires, rubbish burns). Stubble burns have similar characteristics to the operational prescribed burns, in that a large area is ignited, producing lots of smoke very rapidly, and so present an easier detection challenge than point ignitions.

9.1 Methods

9.1.1 Tower records

Tower observations of private burns around Mt Tumorrama were compiled in the same manner as observations of research and agency burns for the period when the tower was operating.

Tower observer radio logs were obtained from the three DSE towers: Peters Hill, Mt Cowley, and Crowes Lookout. These towers were operating as normal, in contrast to the Mt Tumorrama tower. This meant that less detailed records of observations of fires were kept: in some cases the operator noted the location and nature of a burn, for others only a bearing was recorded, particularly during times of very active private burning. Also, as per normal practice, tower operators were notified before agency prescribed burns were lit. Tower records were used to validate camera detections. Because the tower records were informal, it was not feasible to plot the sightings in ARC Map.

9.1.2 Burning permits

Copies of burning permits were obtained from the CFA and from Colac-Otway and Corangamite shire councils. These were used to validate fire detections. Permits were not used to determine missed fires because the issuing of a permit did not guarantee a fire.

Records were provided as permit forms (CFA, Corangamite shire) or spreadsheets (Colac-Otway shire) describing permit period, fuel type and location. Permit forms were converted to plain text documents and period, location, and fuel type records were extracted and compiled using a Python script. Locations were given as street addresses and/or VICMAP page-grid references. Street addresses were manually converted to longitude-latitude (WGS84 datum) pairs using Google Maps software. VICMAP locations were converted to easting-northing (AGD94 datum) pairs. The processed data was then imported into ARC Map.

9.1.3 Detection analysis

For the Victoria trial, all detection reports from the camera systems were assigned to four categories:

1. Detections or updates of DSE burns and fires (See Section 8),
2. Private burns validated by tower observations and/or burn permits,
3. Detections outside of permit season,
4. Detections inside permit season which could not be associated with a permit or tower report.

Classification was performed manually by comparing the location of detections with known events (DSE burns, permits) in ARC Map, and by comparing detection bearings and distances with tower records.

For the NSW trial, detections when the tower was operating were cross referenced with tower observations. Detections of private burns when the tower was not operating were cross-referenced between camera systems but were not classified since all fell within category 3. Relative detection times were calculated where a burn was reported by more than one system. No information on locational errors was available as the true location of the burns was not known.

9.2 Results

9.2.1 NSW

During the period of the research burning (March 15th to 26th), the tower and cameras reported a large number of private burns, mostly stubble burns on farms to the north-west of the trial area (Figure 9.1). The cameras continued to report private burning activity during the remainder of the trial period. Because these fires were conducted outside of the permit period no documentation exists apart from the detection reports. Table 9.1 lists all fires reported by the tower operator and cameras not included in the research or agency burning program.

Tower: 47 burns were recorded across all systems during the period when the tower was operating at distances of up to 100 km from the tower. 45 of the 47 were reported by the tower operator and none were reported by a camera before the tower operator. The remaining two were reported by cameras when the tower was focused on the out-of-control Yankee Ned burn to the south-east of the tower.

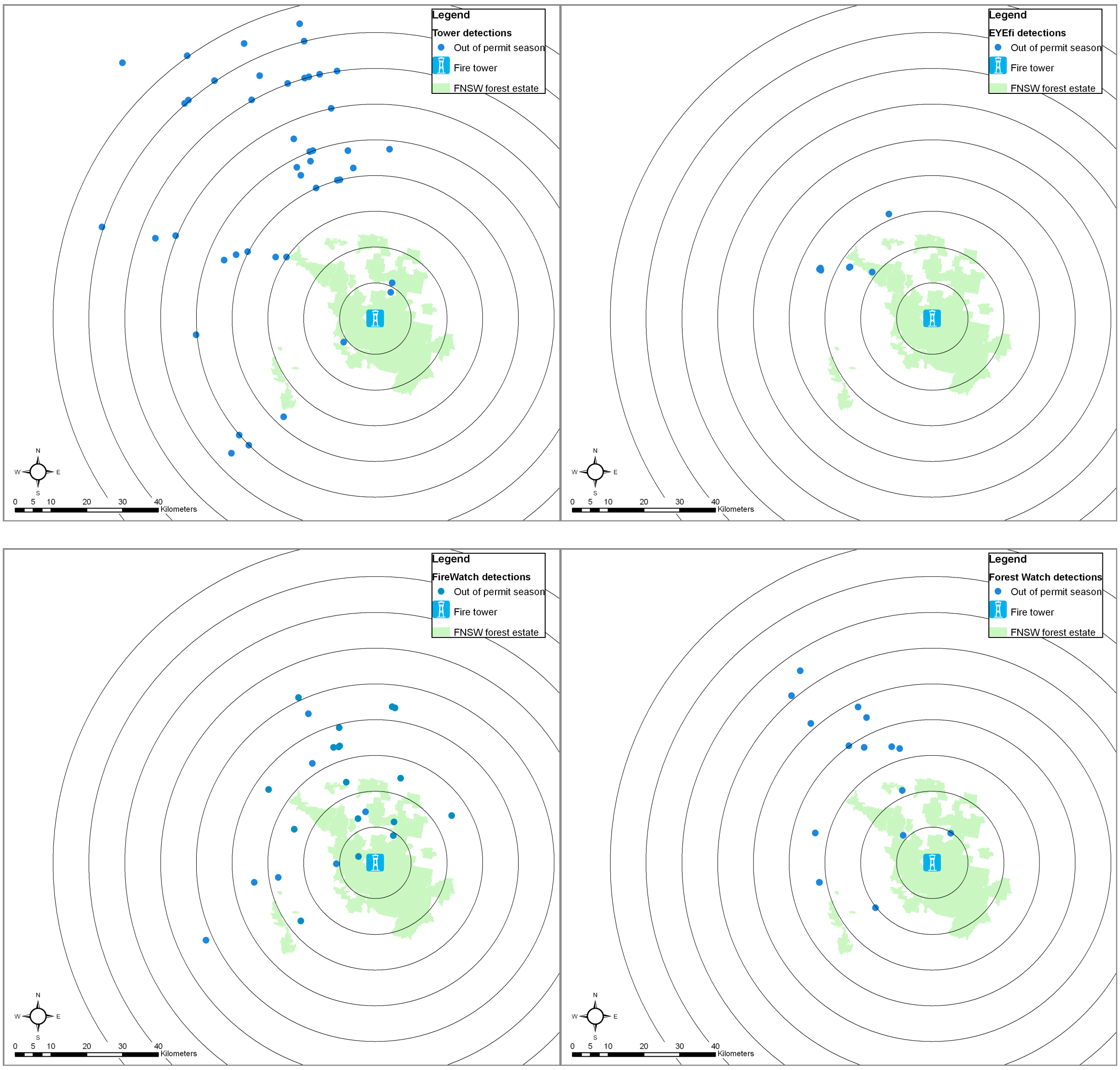


Figure 9.1: Fire detection reports for private burns in NSW. (top left) Tower detections. (top right) EYEfi detections. (bottom left) FireWatch detections. (bottom right) Forest Watch detections. Ranging circles at 10 km intervals. Burns detected by more than one system are listed in Table 9.1.

EYEfi: Four burns were targeted, at distances of up to 35 km from the tower. One of these was also reported 8 minutes later by FireWatch. None of the reports for which alerts were sent by EYEfi were false alarms.

FireWatch: 28 burns were reported by FireWatch over 67 days at distances of up to 52 km, including five of the 47 when the tower was operating, four that were also seen by other cameras, and 19 that were only reported by FireWatch. FireWatch was first to report two, second to report six, and third to report one of the nine burns also seen by another method. One report (T0012, 19/03 13:10) was reported on FNSW tenure but could not be validated against FNSW records. It may have been a false alarm or mislocated small private burn.

Forest Watch: 15 burns were reported by Forest Watch over 45 days at distances of up to 66 km, including two of the 47 when the tower was operating, three that were also seen by other cameras, and ten that were only reported by Forest Watch. Forest Watch was first to report two, second to report two, and third to report one of the five burns also seen by another method. None of the reports were false alarms.

These results show that all the cameras missed most of the stubble burns reported when the tower was operating. When the tower was not operating, only four of 31 burns were reported by more than one camera, meaning that many burns reported by one camera system were missed by the others.

Table 9.1: Fire reporting summary for other burns in NSW. Date column is time of first report. Time columns are delay after first report.

Ignition details			Description	Tower		EYEfi		FireWatch		Forest Watch	
Date	range (km)	bearing		Seen	Time (min)	Target[3]	Time (min)	Seen	Time (min)	Seen	Time (min)
Period when tower was occupied - 47 detections.											
16/03 12:36	100	336	Stubble	Yes	-	NA	-	No	-	No	-
16/03 12:56	85	346	Stubble	Yes	-	NA	-	No	-	No	-
16/03 12:58	85	336	Stubble	Yes	-	NA	-	No	-	No	-
16/03 13:04	45	334	Stubble	Yes	-	NA	-	No	-	No	-
16/03 14:03	40	345	Stubble	Yes	-	NA	-	No	-	No	-
16/03 14:35	90	321	Stubble	Yes	-	NA	-	No	-	No	-
16/03 14:55	40	346	Stubble	Yes	-	NA	-	No	-	No	-
16/03 15:14	50	263	Stubble	Yes	-	NA	-	No	-	No	-
16/03 16:26	65	291	Stubble	Yes	-	NA	-	No	-	No	-
17/03 15:24	40	299	Stubble	Yes	-	NA	-	No	-	No	-
17/03 16:40	30	307	Stubble	Yes	-	NA	-	No	-	No	-
18/03 14:08	40	337	Stubble	Yes	-	NA	-	No	-	No	-
18/03 15:25	14.5	22	Stubble	Yes	-	NA	-	No	-	No	-
19/03 14:18	55	337	Stubble	Yes	-	NA	-	No	-	No	-
19/03 14:23	47.5	351	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:01	60	294	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:16	70	348	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:25	37.5	219	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:45	47.5	4	Stubble	Yes	-	NA	-	Yes	3	No	-
19/03 15:46	70	345	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:47	90	327	Stubble	Yes	-	NA	-	No	-	No	-
19/03 15:55	55	223	Stubble	Yes	-	NA	-	No	-	No	-

Table 9.1: Fire reporting summary for other burns in NSW. Date column is time of first report. Time columns are delay after first report.

Ignition details			Description	Tower		EYEfi		FireWatch		Forest Watch	
Date	range (km)	bearing		Seen	Time (min)	Target[3]	Time (min)	Seen	Time (min)	Seen	Time (min)
19/03 16:03	42.5	296	Stubble	Yes	-	NA	-	No	-	No	-
19/03 16:05	80	328	Stubble	Yes	-	NA	-	No	-	No	-
22/03 9:46	11	24.5	Grass	Yes	-	NA	-	No	-	No	-
22/03 13:45	100	315	Stubble	Yes	-	NA	-	No	-	No	-
22/03 14:08	70	347	Stubble	Yes	-	NA	-	No	-	No	-
22/03 14:10	8.5	30	Grass	Yes	-	NA	-	Yes	36	Yes	12
22/03 14:13	70	351	Stubble	Yes	-	NA	-	No	-	No	-
22/03 14:20	70	330	Stubble	Yes	-	NA	-	No	-	No	-
22/03 14:34	100	339	Stubble	Yes	-	NA	-	No	-	No	-
22/03 14:55	42.5	351	Stubble	Yes	-	NA	-	No	-	No	-
22/03 15:10	50	338	Stubble	Yes	-	NA	-	Yes	14	Yes	18
22/03 15:20	70	344	Stubble	Yes	-	NA	-	No	-	No	-
22/03 15:36	60	347	Stubble	Yes	-	NA	-	No	-	No	-
22/03 16:56	11	232	Eucalyptus	Yes	-	NA	-	No	-	No	-
23/03 9:52	50	229	Stubble	Yes	-	NA	-	No	-	No	-
23/03 12:45	80	345	Stubble	Yes	-	NA	-	No	-	No	-
23/03 13:11	50	339	Stubble	Yes	-	NA	-	No	-	No	-
23/03 14:18	32.5	301	Stubble	Yes	-	NA	-	Yes	17	No	-
23/03 15:27	80	288	Stubble	Yes	-	NA	-	No	-	No	-
23/03 16:07	38.7	346	Stubble	No[2]	-	NA	-	Yes	-	No	-
23/03 17:26	27.1	301	Stubble	No[2]	-	Yes	-	No	-	No	-
26/03 12:00	47.5	337	Stubble	Yes	-	NA	-	No	-	No	-
26/03 13:55	75	334	Stubble	Yes	-	NA	-	No	-	No	-
26/03 13:55	70	339	Stubble	Yes	-	NA	-	No	-	No	-
26/03 13:55	47.5	332	Stubble	Yes	-	NA	-	No	-	No	-
Burns reported by more than one camera while tower unoccupied - 4 detections.											
15/03 15:41	38.0	261	Stubble	NA[1]	-	Yes	-	Yes	8	No	-
15/03 16:41	48.1	334	Private burn	NA[1]	-	NA	-	Yes	2	Yes	-
13/04 6:08	30.0	259.9	Private burn	NA[1]	-	NA	-	Yes	-	Yes	181
28/04 14:54	45.5	335	Private burn	NA[1]	-	NA	-	Yes	27	Yes	-
Burns reported by EYEfi only - 2 detections.											
13/03 14:37	31.6	337	Private burn	NA[1]	-	Yes	-	No	-	No	-
16/03 9:44	21.1	307	Private burn	NA[1]	-	Yes	-	No	-	No	-
Burns reported by FireWatch only - 19 detections.											
3/03 13:55	18.3	344	Private burn	NA[1]	-	NA	-	Yes	-	No	-
11/03 15:23	46.9	318	Private burn	NA[1]	-	NA	-	Yes	-	No	-
11/03 15:24	34.4	338	Private burn	NA[1]	-	NA	-	Yes	-	No	-
12/03 14:48	24.4	314	Private burn	NA[1]	-	NA	-	Yes	-	No	-
4/04 13:46	43.8	5	Private burn	NA[1]	-	NA	-	Yes	-	No	-
5/04 15:18	34.0	342	Private burn	NA[1]	-	NA	-	Yes	-	No	-
6/04 13:39	4.9	289	Private burn	NA[1]	-	NA	-	Yes	-	No	-
8/04 14:32	32.6	327	Private burn	NA[1]	-	NA	-	Yes	-	No	-
13/04 12:16	34.2	340	Private burn	NA[1]	-	NA	-	Yes	-	No	-
13/04 14:39	24.6	16	Private burn	NA[1]	-	NA	-	Yes	-	No	-

Table 9.1: Fire reporting summary for other burns in NSW. Date column is time of first report. Time columns are delay after first report.

Ignition details			Description	Tower		EYEfi		FireWatch		Forest Watch	
Date	range (km)	bearing		Seen	Time (min)	Target[3]	Time (min)	Seen	Time (min)	Seen	Time (min)
15/04 9:25	7.4	193	Private burn	NA[1]	-	NA	-	Yes	-	No	-
15/04 16:26	26.3	231	Private burn	NA[1]	-	NA	-	Yes	-	No	-
16/04 15:18	10.7	267	Private burn	NA[1]	-	NA	-	Yes	-	No	-
19/04 17:04	23.9	340	Private burn	NA[1]	-	NA	-	Yes	-	No	-
21/04 14:25	25.0	57	Private burn	NA[1]	-	NA	-	Yes	-	No	-
22/04 15:49	13.2	338	Private burn	NA[1]	-	NA	-	Yes	-	No	-
23/04 14:07	51.8	245	Private burn	NA[1]	-	NA	-	Yes	-	No	-
28/04 18:26	14.4	349	Private burn	NA[1]	-	NA	-	Yes	-	No	-
8/05 18:41	27.2	261	Private burn	NA[1]	-	NA	-	Yes	-	No	-
Burns reported by ForestWatch only - 10 detections.											
15/03 14:18	33.6	283	Private burn	NA[1]	-	NA	-	No	-	Yes	-
16/04 14:27	20.1	231	Private burn	NA[1]	-	NA	-	No	-	Yes	-
21/04 9:48	21.9	337	Private burn	NA[1]	-	NA	-	No	-	Yes	-
22/04 15:01	51.1	318	Private burn	NA[1]	-	NA	-	No	-	Yes	-
23/04 12:54	37.3	329	Private burn	NA[1]	-	NA	-	No	-	Yes	-
23/04 14:50	11.0	313	Private burn	NA[1]	-	NA	-	No	-	Yes	-
23/04 15:34	57.1	319	Private burn	NA[1]	-	NA	-	No	-	Yes	-
23/04 15:38	65.5	325	Private burn	NA[1]	-	NA	-	No	-	Yes	-
27/04 9:39	31.8	259	Private burn	NA[1]	-	NA	-	No	-	Yes	-
30/04 16:34	33.3	344	Private burn	NA[1]	-	NA	-	No	-	Yes	-

9.2.2 Victoria

Fire permit season ended on 22nd March in the Surf Coast shire and on April 30th in Corangamite and Colac-Otway shires (Figure 9.2). During the trial, permits were issued for 321 burns, mostly for stubble burning, which were likely to have been large enough to be detected by the cameras if lit (Figure 9.2).

EYEfi: The EYEfi system was used to target two fires in Victoria (Figure 9.3), one to the north-east of Peters Hill, the other to the north-west of Crowes lookout. Both were private burns.

FireWatch: 217 fire detection reports over 70 days were received from FireWatch in Victoria (Figure 9.4). Of these:

1. 36 (17%) were detections or updates of DSE burns and fires (See Section 8),
2. 44 (20%) were private burns validated by tower observations and/or burn permits,
3. 96 (44%) were outside of permit season,
4. 22 (10%) were inside permit season but could not be associated with a permit or tower

[1]No tower observer.

[2]Tower observer decided to ignore stubble burns to focus on Yankee Ned fire.

[3]EYEfi did not provide active fire detection during the trial. Rows with ”Yes” are burns that were targeted by EYEfi staff. Time is the time the target was made, location error is on the same basis as other systems.

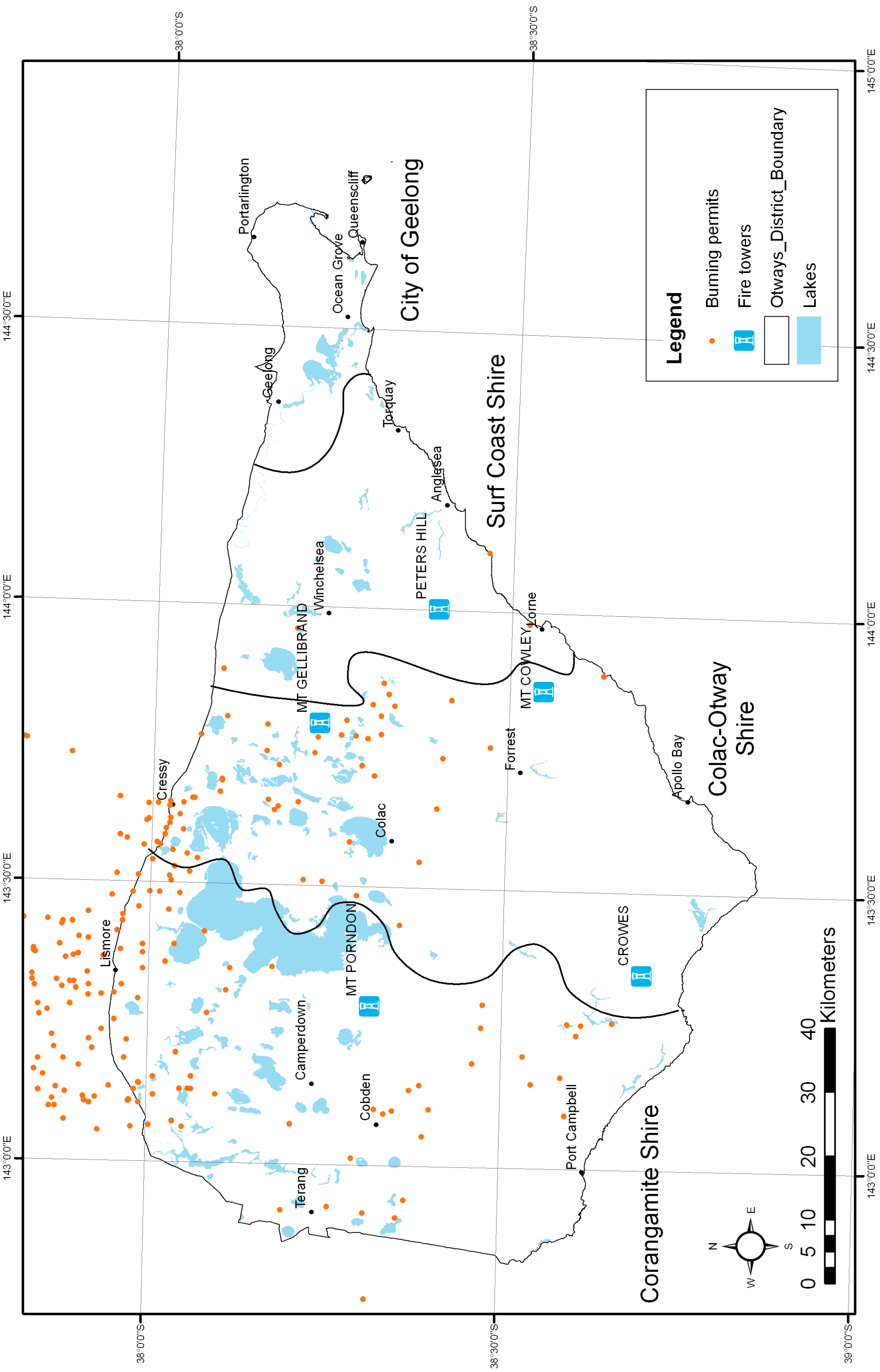


Figure 9.2: Burning permits issued by CFA, Colac-Otway shire, and Corangamite shire during the trial period. Permits were not obtained for Surf Coast shire (east of Peters Hill tower), as all detections during the permit period (until March 22nd) were validated using tower or DSE observations.

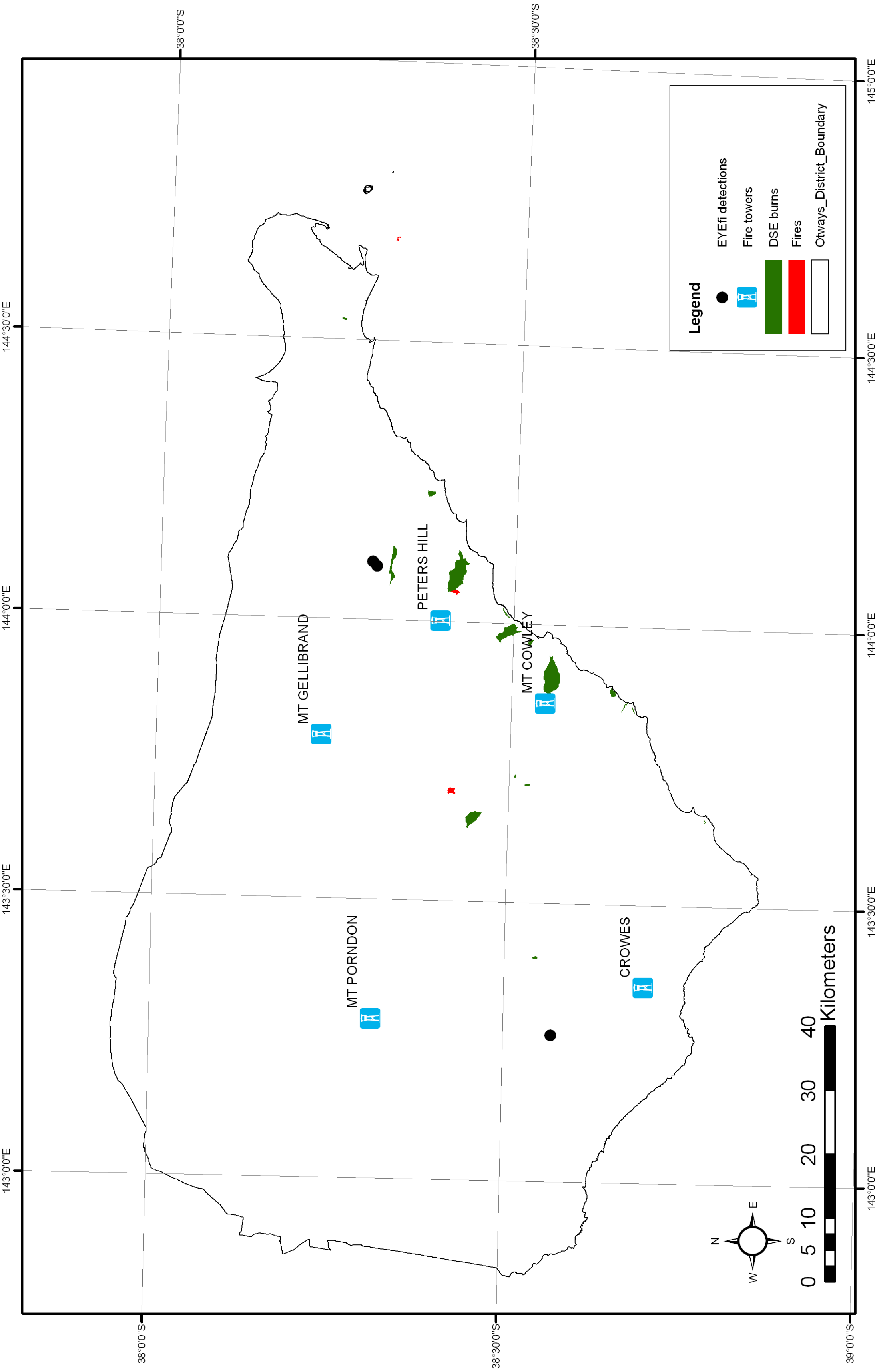


Figure 9.3: Targets recorded using EYEfi system in Victoria.

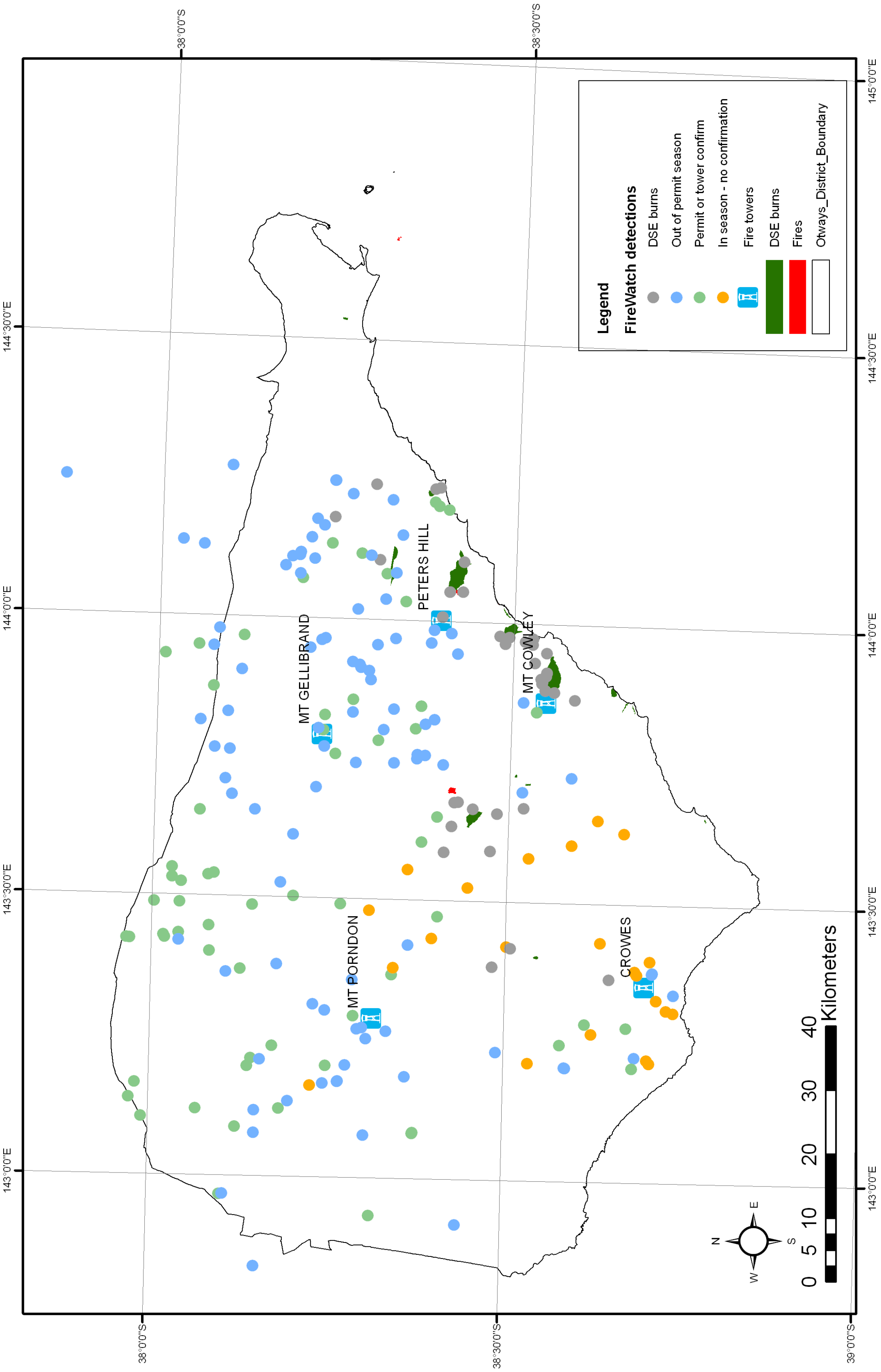


Figure 9.4: Fire detection reports from FireWatch system in Victoria.

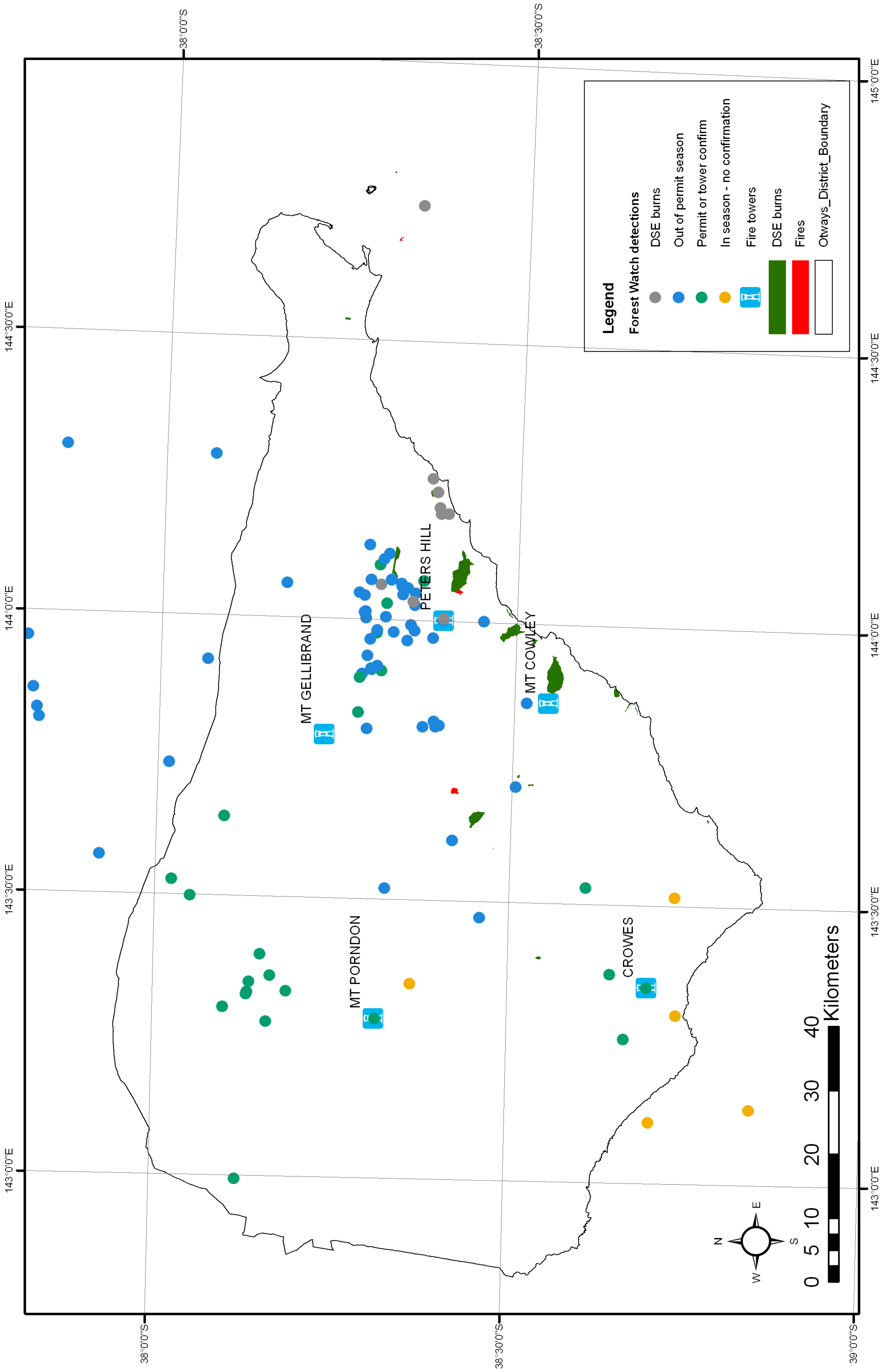


Figure 9.5: Fire detection reports from Forest Watch system in Victoria.

Table 9.2: Consistency of fire reporting in Victoria. Columns are burns reported per day for FireWatch and Forest Watch, and the number of reports which were common to both systems. Updates of already reported burns have been excluded.

Date	FireWatch	Forest Watch	Matches
April 6	2	13	0
7	1	1	1
8	-	-	-
9	2	3	0
10	-	-	-
11	-	-	-
12	2	1	1
13	6	5	2
14	2	7	2
15	2	8	1
16	3	2	1
17	-	-	-
18	3	-	-
19	9	15	3
20	12	19	4
21	1	-	-
22	12	7	3
cont.			
23	-	-	-
24	-	-	-
25	1	-	-
26	2	-	-
27	2	-	-
28	-	-	-
29	-	-	-
30	3	3	0
May 1	12	-	-
2	2	-	-
3	9	-	-
4	11	1	0
5	4	-	-
6	1	-	-
7	2	-	-
8	3	-	-
9	5	-	-
Total	**114**	**85**	**18**

report.

Forest Watch: 101 fire detection reports over 33 days were received from Forest Watch in Victoria (Figure 9.4). Of these:

1. 9 (9%) were detections or updates of DSE burns and fires (See Section 8),
2. 24 (24%) were private burns validated by tower observations and/or burn permits,
3. 53 (52%) were outside of permit season,
4. 5 (5%) were inside permit season but could not be associated with a permit or tower report,
5. 10 (10%) were unusable due to temporary equipment problems.

For FireWatch and Forest Watch the reports in category 4 could be:

- Burns for which a permit was issued but either the detection or permit were mis-located and could not be matched on our maps,
- Burns for which a permit was issued but the permit was omitted from the data sets provided to us,
- False alarms,

It is not possible to comment further on these events except to note that we could not positively identify any as obvious false alarms (e.g. dust or mist), although there were some which were unclear, particularly night images.

Although we do not have information on how many fires were lit during the trial, cross-referencing the FireWatch and Forest Watch detection records indicates that both systems did not report all burns. Table 9.2 lists the number of detections by day for each systems. Using detection locations and bearings, and camera images we cross-referenced reports between systems. The third column in Table 9.2 lists the number of burns on each day which were reported by both systems. Since neither system consistently reported more burns than the other, and because the number of matching burns was less than the total reported, it is clear that both systems missed some burns. It is not possible to determine whether these burns were missed because computer algorithms did not detect smoke or because human operators incorrectly dismissed alerts.

10 Operational feasibility

Assessment of the operational feasibility of the cameras is based on the results presented in preceding sections, discussion with fire agency staff involved in the trial (both office and field staff), discussion with EYEfi, FireWatch, and Forest Watch representatives (including visits to control rooms and product demonstrations), and our own observations during the trial. Except where specific systems are mentioned these comments are general and apply to all the systems tested.

10.1 Fire detection

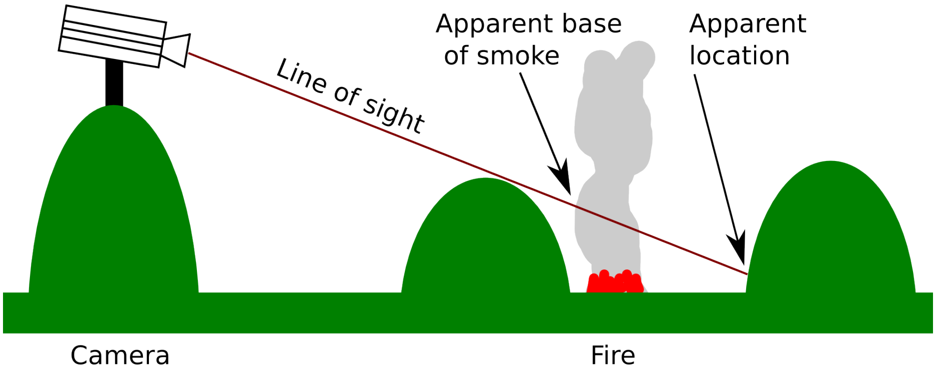
In the comparative tests performed at Tumut, the two automatic fire detection systems (FireWatch and Forest Watch) performed less well at detecting fires than the human observer. The cameras reported a lower proportion of fires and took longer to detect those fires which were reported. The low rate of detection for small research burns was of particular concern, given the need to detect fires quickly if they are to be suppressed by initial attack. It is likely that if the research burns had been allowed to burn freely through the landscape they would eventually have been detected, however such detection would not represent success as early detection is paramount. Note also that one of the burns was allowed to burn an entire 1 ha plot but was not detected by either camera system.

Detection performance was better for prescribed burns in NSW and Victoria, but these were large fires which, had they been wildfires of the same size burning under summer conditions would in most cases certainly have been beyond capacity for successful initial attack.

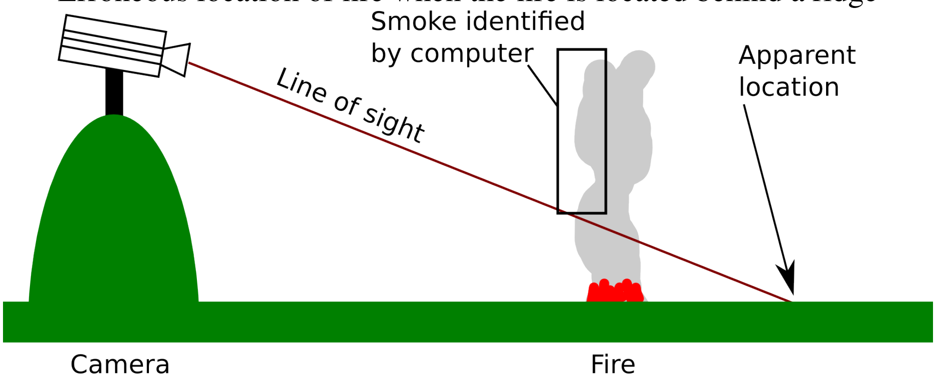
Detection of private burns in Victoria and NSW was inconsistent. In Tumut only 6 (15%) of the 41 private burns reported by cameras were detected by more than one system. In the Otways 18 (10%) of 181 burns were reported by both automatic systems. In the comparative trial at Tumut, less than 10% of burns reported by the tower operator were also detected by cameras. As many of the fires were at distances beyond the design characteristics of the cameras (approx 15 km radius) this is expected but again confirms the inferiority of the cameras to human vision.

False alarms were not a problem for either automatic system during this trial. Human operators of the systems successfully identified all false positives and did not report them.

The experimental design of this project tested each system as a whole, including not just the cameras and computers but also the human operators. Thus our design did not distinguish between fires which were missed because smoke was not detected by the computer algorithms and smoke which was detected but was not reported because the operator thought the alert was a



Erroneous location of fire when the fire is located behind a ridge



Erroneous location of fire when the base of the smoke plume is not correctly identified.

Three methods are used by the detection systems to locate fire in the landscape:

1. Triangulation (All systems): From the location of the fire in two or more camera images and the current headings of the cameras, the bearing of the fire relative to each camera is calculated. The location of the fire is calculated as the intersection of lines drawn along these bearings.
2. Pixel mapping (FireWatch, Forest Watch): From the location of the fire in an image and the current heading of the camera, a ray is projected into a mathematical model of the topography surrounding the tower. The point of intersection of the ray with the land is the location of the fire. Advanced calculations to detect near-misses on ridge lines may be used to deal with uncertainty due to the limited resolution of topographic models.
3. Targeting (EYEfi): The camera is oriented so that the fire is in the middle of the image. From the known orientation of the camera, a ray is projected into a mathematical model of the topography surrounding the tower. The point of intersection of the ray with the land is the location of the fire. Advanced calculations to detect near-misses on ridge lines may be used to deal with uncertainty due to the limited resolution of topographic models.

Where it can be used, the triangulation method is robust and location errors should be less than the size of the fire. The other two methods are subject to effects that may produce large errors:

- Topographic shadowing: If a fire is located behind a ridge, then the ray from the camera to the lowest visible part of the smoke column will be projected behind the fire.
- Mislocated smoke column: If detection algorithms do not correctly identify the base of a smoke column, then the fire will be located too far from the camera.

To avoid these problems all systems allow some manual adjustment of locations but this relies on the operator identifying that there is a problem. Errors of up to 18 km were observed in the present study.

Box 10.1: Two types of detection errors.

false alarm. As an additional exercise, FireWatch reprocessed their alert data after we provided information on locations and ignition times for research and operational burns. In this exercise, 10 of 16 unreported ignitions were associated with computer alerts which were dismissed by operators (Appendix A, similar analysis was not possible for the other systems and did not form part of the experimental design). This highlights the important of using skilled operators. We also recognise that all systems may have performed better in this trial had more skilled or experienced operators been employed. On the other hand, it is possible that the limitations of viewing the landscape through a camera are a greater constraint in correctly identifying smoke than operator experience.

Once fires were detected all camera systems were able to locate the burns with similar accuracy to the human observer in most cases. All systems made some gross errors (4–18 km) caused by targeting locations behind burns (see box 10.1). It is likely that in operational use camera operators with local knowledge would be able to identify and correct for these errors by correlating mapped detection locations with landmarks visible in the camera image.

Overall FireWatch performed slightly better than Forest Watch in terms of detection rate for known ignitions and number of private burns reported. Detection performance was at least partly a function of fire size and distance from the camera. Large prescribed burns were detected at long distances (up to 70 km) while smaller burns at moderate distances (10–20 km) were missed. Any statements about camera effectiveness at a particular distance need to be qualified by the size of fire that can be detected. Location accuracy was similar for all systems. The limited nature of the data set means it is not appropriate to calculate detection statistics in addition to the qualitative assessment already presented.

It is possible that in summer conditions, where point ignition fires would grow more rapidly than our research burns and produce smoke with different characteristics, the cameras might perform differently when detecting small fires (See section 7.3). However, the inconsistency of the detection of private burns suggests that only a limited improvement might be expected, and the results of the present study indicate that the cameras are very likely to perform worse than a human observer.

It is also possible that the detection algorithms used to process camera images would benefit from adaption and calibration to Australian conditions. For example atmospheric conditions, landscape appearance, and smoke characteristics all differ from other parts of the world. We note that the camera systems are subject to continuous development, including changes in detection algorithms which might affect future performance. Each company has provided up to date information on product capabilities to the Attorney General's department.

Given the poor performance relative to the human observer and the number of fires missed, the evidence presented in this study indicates that automatic camera detection systems are not yet a suitable replacement for staffed fire towers. However, use of camera systems for fire detection is not an all-or-nothing proposition. Even knowing that not all fires will be detected quickly, cameras might still be useful as a detection method in certain situations:

- To provide detection at times when towers are not staffed (i.e. at night),
- In remote locations where it is not possible to use human observers, or where travel times mean that towers are not open until late morning,
- In remote locations where it is accepted that some fires may grow to a large size before detection,

- To fill in blind spots in existing tower networks
- Working alongside human observers to provide detection, images, and other data for situational awareness.

Future developments in camera hardware and software may also improve the efficacy of the systems.

Fire management agencies currently use automatic lightning detection systems to track storm events. After a storm, fire detection by towers or aircraft is often used to detect any fires started by lightning strikes. EYEfi installations provide the capacity to detect lightning using an onboard sensor and to direct the camera to view lightning strikes for fire detection, however no detections were made by this method during this assessment due to lack of lightning activity, apart from some activity at the start of the trial which was used to calibrate the system. FireWatch and Forest Watch did not perform lightning detection during the trial but could be used to view locations which have been identified by a lightning detection system (e.g GPATS, currently used by agencies in Australia) by importing GIS shapefiles containing lightning detection locations.

10.2 Situational awareness

Tower mounted cameras can be used to collect information to develop situational awareness, including fire location and fire behaviour. Cameras on towers may be used alongside or instead of human observers. Advantages of using cameras on towers include:

1. Images can be recorded for documentation of fires (also possible for human observer using still or video camera and paper fire log)
2. Images can be viewed remotely in real time
3. Cameras can remain in place when a tower is threatened by fire and staff have vacated.

On the other hand, tower operators currently assist communication and coordination in the field by using radio to speak with Incident Management Teams (IMT), ground crews, and air crews. This capacity is likely to be limited for camera staff using 2D video cameras to view the landscape and possibly monitoring several cameras at once.

Mobile camera units[8] present another layer of information, allowing the tracking of the location of field units and sharing of images between field units and office staff. Mobile fire units were not tested during this trial.

Fire agency staff during this trial made extremely limited use of camera systems for monitoring fires. In the few instances where the systems were used by agency staff, it was to cross-check alerts received from one of the other systems. The lack of use by agency staff was because the burns conducted—and the single wildfire—were adequately supervised by field staff, or were private burns which required no supervision by the fire agency.

Based on discussions with agency staff, the sharpness of the high-definition FireWatch camera was good but black-and-white was limiting. For monitoring (not detection for which fixed views are preferred), being able to control and zoom the colour cameras made up for the lower resolution of the cameras used by Forest Watch and EYEfi. FireWatch can install colour cameras alongside the black-and-white sensor, so there are limited differences between the systems in

[8]Currently only offered by EYEfi.

this respect. Differences in how the systems are integrated into agency systems and operations are likely to be more important.

With changes in agency operating practices, it is possible that office staff could use camera systems to monitor prescribed and private burns across a district if this was shown to be useful. Had the trial covered a period of bushfire activity it is possible that more use would have been made of the systems to monitor fires and to investigate or verify reports from 000-calls by reverse look up (for those systems which have this feature). Finally, camera systems may be useful to provide situational awareness outside of fire season for other purposes, e.g. to monitor floods or landslides, etc.

10.3 Integration with agency operations

If camera systems are to be used for fire detection or situational awareness then several issues need to be considered:

- Trained staff need to be dedicated to operate the system for fire detection. In the same manner as tower operators, camera operators need to be able to distinguish false alarms, known safe smoke sources (e.g. prescribed burns), and wildfires to ensure only necessary alerts are passed on to fire managers. Staff in the Colac control centre found frequent alerts for safe fires (e.g. stubble burns) to be intrusive (this was a function of the trial design which required all fires to be reported). Local knowledge is also required to validate detection locations against landmarks, to avoid the errors observed in the detection sections of this report. Protocols for handover at shift change need to be developed to ensure that fires are not re-reported.
- If the cameras are used for situational awareness, then processes to extract information would need to be embedded in agency training and practice to ensure that the appropriate people have access to information from the cameras and understand it and make use of it. Each system uses different methods to distribute information (e.g. dedicated control centres with secondary computers to view alerts for FireWatch and Forest Watch vs distributed access model for EYEfi).
- The infrastructure that is used to access images and other information from the cameras is likely to make a difference to how useful they are for monitoring fires. Information of varying kinds about fires is required at different levels when fighting fires, from tactical information for sector commanders, to a strategic view of individual fires by IMTs, to an overview of all fires at state control centres. The map-based cloud access model used by EYEfi is likely to be better suited to fire monitoring to the control centre with secondary terminals model used by FireWatch and Forest Watch. This is because users at all levels can control the cameras and view images, obtaining the information they require without having to request information from a control centre. During the trial the control centre model worked well for fire detection and has also worked well in overseas applications of FireWatch and Forest Watch.
- Cameras, as with towers, are likely to view areas with differing tenure and fire management responsibilities across the landscape. Consideration needs to be given to responsibility for monitoring the cameras and for methods of distributing information between agencies. As with situational awareness, the different access models used by the systems are likely to be relevant.

- In Tumut, the tower normally communicates on an open radio channel. This means that field staff know about fires as soon as they are reported to the fire control office and can act quickly to deploy suppression resources and query the tower for more information before being directed to by the fire control officer–i.e. preemptive response. If a camera system replaced tower observers, this informal communication mechanism would be lost, with the potential for delays as detection and fire behaviour information is passed between camera operators in a central location, fire control rooms, and then to field staff.
- The notification methods tested in the trial (phone calls, SMS notifications, email reports) provided useful information about fires. In operational use, only methods with guaranteed delivery times should be used for initial alerting (i.e. not SMS or email as they may not be reliable). Follow up information (maps, images) are useful for confirming the nature of the alert and required response. These are most reliably provided by direct access to workstations or servers, either by being physically present or logging in remotely via computer networks.
- All systems rely on GIS data to place alerts and targets in a spatial context. The systems should use the same data that the rest of the fire agency uses. From the trial it is not clear whether static access (data is transferred to fire detection system servers periodically, used by FireWatch and Forest Watch during this trial) or dynamic access (system extracts data from state or agency databases, used by EYEfi) is preferred.
- The ability to access real-time spatial data (e.g. fire boundaries, vehicle locations) and to share data with other systems (e.g. fire spread models, community warning systems) may also prove useful. These features were not tested in this trial.

Each of the three systems uses different methods to address these issues and have their own limitations and unique capabilities. Any agency considering implementing a camera system needs to carefully consider how the features of these or other systems can address their needs for both fire detection and fire monitoring. While none of the systems tested are suitable as a sole fire detection and monitoring method, any of them may be useful if used in conjunction with other methods.

Finally, we note that not all capabilities of the systems were tested during this trial and that improvements have been made to some aspects since the trial was conducted.

11 Conclusions

All the camera systems tested were able to observe and locate fires during both day and night. However, detection by the camera systems was slower and less reliable than by a trained human observer. At present it is not possible to rely on cameras as a sole primary detection method and they are not a suitable replacement for trained fire observers. Cameras could be used to supplement other detection methods, particularly at night or in remote locations. The cameras could also be used to aid the gathering of situational awareness information and to add value to other data by integration with agency systems, for example burn planning, vehicle tracking, fire spread modelling, and community warnings.

The human camera operator is an integral part of all the camera systems. Skilled operators are required to decide whether computer generated alerts are fires or false alarms, and to validate fire locations against known landmarks. Staff at all levels of fire management practice would need training to make sure they understand what cameras can do and how to use information from the cameras in managing fires. Better detection results might in future be obtained using more experienced staff to supervise fire detection.

Both camera types tested (black-and-white and colour with night mode) were suitable for detection and monitoring during day and night. Under trial conditions, the FireWatch system performed better than Forest Watch at supervised automatic detection but both were outperformed by the human observer during the day. Different results might be obtained in summer conditions. EYEfi did not provide automatic smoke detection during the trial.

All camera systems could adequately locate fires once they were identified. Both methods used for single-camera location (pixel-mapping for FireWatch and Forest Watch, targeting for EYEfi) worked when the base of the smoke was identified correctly, and both introduced errors when the base of the smoke column was misidentified in an image or hidden behind a hill. All systems provide tools to allow a skilled operator to identify and correct these errors. Where it was used, multi-camera triangulation was the most reliable location method.

The fire monitoring capability was used in only a very limited fashion by agencies because of lack of wildfires during the trial and limited integration with agency operations. However, all systems showed potential for use in fire monitoring. Differences in how the systems are integrated into agency systems and operations are likely to be important.

Integration with agency infrastructure (primarily towers and IT systems) and working practices is feasible. All systems use a slightly different approach and the best choice of system would depend on the needs and capabilities of the agency deploying the cameras. The access models used by the different systems (cloud-based for EYEfi, local and remote servers for FireWatch and Forest Watch) will have an impact on how cameras could be used and should be considered in any deployment. The different capabilities of each system to link to agency databases and provide fire information to external systems should also be considered.

This study had three limitations. The field trial was conducted in autumn, so atmospheric conditions and fire behaviour were different from summer. Only one wildfire occurred, so the ability of the systems to provide information for situational awareness was tested in only a very limited way. The camera systems were of necessity not fully integrated with agency operations.

Future work to address these limitations could focus on two areas. Firstly, assessment of detection performance in peak fire season using research fires ignited under a range of burning conditions. This would follow the same methods used in this study but under conditions closer to those when earlier detection is critical, all three systems could be used in the evaluation. Secondly, a camera system could be integrated into agency operations during a fire season to fully test the operational potential of that system. This study would need to consider organisational and operational factors as well as technical features. Both areas of research would benefit from using updates to camera technologies described in the camera company submissions.

A Reanalysis of FireWatch alerts

After the completion of the field trial, the location and ignition times of research and operational burns were made available to the camera companies. FireWatch used this information to search the database of computer generated alerts for events which had been dismissed by operators as false alarms. For these alerts a report was provided to us in the same format as used during the trial. For the 16 burns not reported during the trial:

- 10 reports were correct alerts dismissed due to human error (burns 3, 4, 5, 6, 11, 19, 21, 22,23, and Herschell/Mairs in Sections 7 and 8). For some of the windrow burns we regard this dismissal as a correct operational judgement,
- 3 reports were smoke from other burns incorrectly attributed to missed burns (7, 12, Kennett River),
- 1 report was a false alarm that was nearby but upwind of a burn (2),
- 2 burns were not reported in the reanalysis (24, 31).

These results indicate that the important role of human operators discriminating between computer alerts that are false alarms and those which are fires is not always simple and requires skilled operators.

B Operational fire reporting form

CSIRO Sustainable Ecosystems- Bushfire Dynamics and Applications
Fire Detection Project
Operational Fire Observations

Date (dd/mm/yy):_____/_____/______	**Fire Name**
Fire agency:______________________	**Location** *(State grid reference, road name, localities)*: Map ref:______________________________ Lat /S:____________ Long/E:____________
Observer Name:	
Detection: Time (hh:mm):______________ How fire reported: □ 000 call □ Fire tower operator □ Detection Camera □ Aerial observation □ Other (specify):____________________	
Dispatch Time (hh:mm):____________	**Slope (°):__________** **Aspect:__________**
Travel Distance to Fire (km):________	**Observation:** □ Ground □ Aerial

Fire Behaviour Observations	
Arrival Time (hh:mm):	**Fire size at arrival time:** ________(ha) or (mxm):_______x_______
Flame characteristics: Height (m)______Angle (deg):________	
Convection column/Smoke (height, colour, direction, etc)	
Smoke Colour: □ White, □ Light gray, □ Medium gray, □ Dark gray, □ Black	
Smoke plume angle: □ Vertical, □ Leaning 60° into unburnt fuel, □ Leaning 30° into unburnt fuel, □ Leaning into burnt ground Estimate plume height: _________(m)	
Other comments on fire behaviour and smoke plume:	
Fire Photographs:	

Weather Conditions							
Time	**Temp**	**RH%**	**Wind speed (km/h)**	**Wind direction**	**Cloud cover**	**Fire Danger Index** Forest	 Grassland

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FUEL AND VEGETATION
□ **Grasslands**
Pasture type: □Eaten out pasture, □Grazed/cut pasture, □Natural grasslands Degree curing:______%
□**Eucalypt forest**
Bark Type: □Stringy, □Ribbon, □Platy, □Smooth Top tree height:_______(m)
Fuel hazard assessment
Bark fuel:_____; Elevated fuel:_____, Height:_____(m); Near-surface fuel:_____ Height: _____(cm), Surface fuel:______ Time since last fire (years):___________
□**Plantations**
□**Pine**: □0-3 years; □3-8 years; □8-13 years; □13-20 years (unthinned or unpruned) □13-20 years (thinned or pruned) □20+ years, □Logging slash Top Tree height:_____(m)
□**Hardwood:**; □0-3 years; □4-7 years; □8-10 years; □+10 years, □Logging slash *Surface grassy fuels:* □Present, □Absent Surface litter fuels: □Present, □Absent Top Tree height:_____(m)
□**Other fuel types:**
□Mallee shrub: Top height:_____(m)
□Heath fuels: Top height:_______(m)
□Other (please specify) Top height:______(m)
Fuel photographs and other comments:

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C Research data collection forms

FIRE BEHAVIOUR SHEET

Sheet:____of____

Site:	Date:	RHS/LHS obs:
Block:	Fire plot:	Fire behaviour observer:
Ignition start time: (hhmmss)	+ Time: (mmss)	= Ignition completion: (hhmmss)

Meteorological Conditions					
Time	Temp (°C)	RH (%)	Cloud (%)	Wind dir	Comments

Fire Behaviour Characteristics

	Fuel Layers Influencing Head Fire			Canopy Layers Crowning			Flame Characteristics			Comments	Tag thrown
Time (min)	SF	NSF	EF	EF	INT	OS	Height (m)	Angle (deg)	Depth (m)	UD=up-draught, DD=down-draught, C=crowning, smoke colour, fire whirls, S=spotting, SD=spotting distance (m), photo number etc.	(tag no. and time thrown)
00-02											
02-04											
04-06											
06-08											
08-10											
10-12											
12-14											
14-16											
16-18											
18-20											
20-22											
22-24											
24-26											
26-28											
28-30											
30-32											
32-34											
34-36											
36-38											
38-40											

PTO

	Fuel Layers Influencing Head Fire			Canopy Layers Crowning			Flame Characteristics			Comments	Tag thrown
Time (min)	SF	NSF	EF	EF	INT	OS	Height (m)	Angle (deg)	Depth (m)	UD=up-draught, DD=down-draught, C=crowning, smoke colour, fire whirls, S=spotting, SD=spotting distance (m), photo number etc.	(tag no. and time thrown)
40-42											
42-44											
44-46											
46-48											
48-50											
50-52											
52-54											
54-56											
56-58											
58-60											
60-62											
62-64											
64-66											
66-68											
68-70											
70-72											
72-74											
74-76											
76-78											
78-80											
80-82											
82-84											
84-86											
86-88											
88-90											

Comments:

CSIRO Dynamics and Applications
Fuel Assessment Form

Date: ______________Block:______________________
Fire Plot:_____ Line #:______ Transect Bearing:__________ (°)
Plot Location (GPS Reference: (WP:__________)
E/Lat:_______________________) (N/Long:__________________)
Map Grid Reference:
Aspect :______(°) Slope:______(°) Observer: ______________

Eucalypt Forests

Eucalypt Forest type: ☐Tall forest ☐Medium forest ☐Woodlands ☐ Plantations
Time since last burn: ________ (years) Plantation age :_______(years)

		1	2	3	4	5	6	7	8	9	10
Sufrace	Depth (mm)										
	FHS										
	PCS										
SurfuaceNear	Hieght (m)										
	FHS										
	PCS										
Elevated	Hieght (m)										
	FHS										
	PCS										
Overstorey	Hieght (m)										
	FHS										
	PCS										
Photo Number											
Direction Facing:		NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW
Photo Number											
Direction Facing:		NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW

Pine Plantations

Fuel complex: ☐PROD01 ☐PROD02 ☐PROD03 ☐ PROD04
☐PROD04T ☐PROD05 ☐PROD06

	Plot Number									
	1	2	3	4	5	6	7	8	9	10
Litter L layer depth (mm)										
Litter F-H layer depth (mm)										
Canopy base height (m)										
Total height (m)										
Photo Number										
Direction Facing:	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW
Photo Number										
Direction Facing:	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW

Grasslands

Pasture type: ☐Eaten out ☐Grazed/Mown ☐Undisturbed/Natural

	Plot Number									
	1	2	3	4	5	6	7	8	9	10
Degree curing (%)										
Mean top height (m)										
Photo Number										
Direction Facing:	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW
Photo Number										
Direction Facing:	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW	NE SW

Comments

Smoke Observations Sheet

sheet:___of ___

Date: Time:

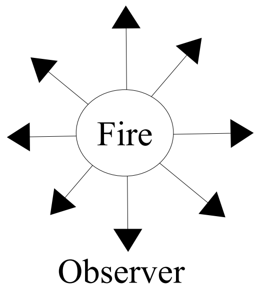
Site: Plot:

Location:

Observer:

Comments:

Relative smoke direction guide. →
Down means towards the observer



Time	Smoke seen	Smoke shape			Colour			Density			Rise angle				Direction	Height	Width
HH:MM	Y/N	Plume	Diffuse	Separating	White	Gray	Black	Transparent	Intermediate	Opaque	Horizontal	30	60	Vertical	Draw arrow	metres	metres

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