Scientifically-based monitoring project - final report:

Guidelines for ecosystem resilience monitoring, evaluation and reporting within the Victorian Bushfire Monitoring Program

Steve Leonard, Angie Haslem, Andrew Bennett, Michael Clarke

Contents

Acknowledgements

A number of DELWP staff made valuable contributions to this project, including from the MER unit: Andrew Clark, Shannon Devenish, Richard Hall, April Langerak, Thu Phan, Katie Taylor, Michelle Worsley and Romy Zyngier, and Landscape Evaluators including: Heather Adams, Evelyn Chia, Ellie Clark, Peta Cowie, Emily Doran, Hamish Martin and Natasha Schedvin. Thanks also to DELWP and Parks Victoria staff who assisted with pilot studies, attended workshops or otherwise contributed to the project.

Simon Watson, Graeme Newell and Matt White provided advice on survey design.

Josephine MacHunter and Katie Taylor provided comments on a draft of this report.

Acronyms

AM	Adaptive Management
ANEBRL	Alpine North-East Bushfire Risk Landscape
APZ	Asset Protection Zone
ARI	Arthur Rylah Institute
BACI	Before-After-Control-Impact
BMZ	Bushfire Management Zone
BOBRL	Barwon Otways Bushfire Risk Landscape
DBH(OB)	Diameter at Breast Height (Over Bark)
DELWP	Department of Environment, Land, Water and Planning
ECBRL	East Central Bushfire Risk Landscape
EFG	Ecological Fire Group
ERMER	Ecosystem Resilience Monitoring, Evaluation and Reporting
EVC	Ecological Vegetation Class
FOP	Fire Operations Plan
GL(M)M	Generalised Linear (Mixed) Model
GMA	Geometric Mean Abundance
GSS	Growth Stage Structure
HE	HawkEye
KEQ	Key Evaluation Question
LE	Landscape Evaluator
LEM	Landscape and Environmental Monitoring
LiDAR	Light Direction and Range
LMU	Landscape Management Unit
LMZ	Landscape Management Zone
LTU	La Trobe University
MER	Monitoring, Evaluation and Reporting
MQ	Monitoring Question
PPFM	Pre- and Post-Fire Monitoring
SC	Scientific Coordinator
SOP	Standard Operating Procedure
SW	State-wide (stream of ERMER)
TFI	Tolerable Fire Interval
VBMP	Victorian Bushfire Monitoring Program
VFMP	Victorian Forest Monitoring Program

Executive summary

The foundation of fire management planning by the Department of Environment, Land, Water and Planning (DELWP) is the Code of Practice for Bushfire Management on Public Land (the Code). Achieving the Code objectives requires DELWP to collect, analyse and interpret high quality data on how fire management affects bushfire risk and ecosystem resilience. DELWP's strategy for undertaking this task is encapsulated in the Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land (MER Framework), which outlines principles to guide development of the Victorian Bushfire Monitoring Program (VBMP).

The MER Framework situates the VBMP within an adaptive management (AM) context. Within AM, monitoring will only be successful if it generates better knowledge to improve management. A challenge for fire management in Victoria is to 'close the adaptive management loop' such that monitoring results are used to inform policy decisions and update management practices.

A central element of the MER Framework is a set of Key Evaluation Questions (KEQs). The KEQs form the basis for evaluating the impacts and effectiveness of management actions and strategies, as well as testing and improving the assumptions, models and metrics that underlie management decision making. Addressing these KEQs is therefore a primary aim for the VBMP.

This 'Scientifically Based Monitoring' project was commissioned by DELWP in 2015. The overarching aim of the project was to develop a strategy, design and methods for a monitoring program to address the ecosystem resilience KEQs contained in the MER Framework ('Ecosystem Resilience MER'/ERMER). Such a monitoring program would also provide data applicable to other fire management planning processes e.g. growth stage optimisation analyses.

We conducted a review of four large-scale fire and forest monitoring programs carried out by DELWP in the last decade and assessed the degree to which they have successfully completed the adaptive management cycle. This review indicated that effective leadership, clear identification of responsibilities and good communication amongst stakeholders were key to programs completing the AM cycle and hence informing management. These findings informed the subsequent development of the proposed ERMER program.

We undertook a process of 'unpacking' the ecosystem resilience KEQs in order to determine how best they can be addressed via monitoring. For most KEQs, it was also necessary to identify subsidiary monitoring questions (MQs). Monitoring questions are more precisely formulated questions that are more tractable to address by data collection and analysis. An important outcome of this component of the project was identifying that in essence all KEQs/MQs dealt with different facets of interactions amongst fire, biota and habitat. Identifying this 'relationship triangle' made designing a monitoring program to address KEQs much simpler. We formulated 'pathways' for addressing each KEQ, identifying the key components of the process leading from the KEQs to providing information to inform management. Monitoring design and methods were then developed to allow the KEQ pathways to be completed.

The proposed approach to ERMER is a 'two-stream' model. The *state-wide stream* consists of a centrally coordinated, systematic monitoring program that targets priority vegetation types (Ecological Fire Groups; EFGs), hence addressing the *Improvement KEQs*. The *regional stream* of ERMER will assess the more immediate effects of fuel management on biota, as per the *Impact KEQs*. In addition, the regional stream has the flexibility to examine how fuel management (and bushfire) affects species and ecological values of regional importance, as well as those otherwise not well represented in the broad scale state-wide surveys (e.g. threatened species). Cross-regional coordination of monitoring will be beneficial to avoid duplication and provide more extensive data sets. Both the state-wide and regional streams will combine to address *Effectiveness KEQs*.

The proposed sampling design for the state-wide stream of ERMER involves surveys of flora, vegetation structure, birds and ground-dwelling mammals at 200 sites within each priority EFG, with sites selected to encompass gradients of time since fire and inter-fire interval ('space for time' design). Monitoring within the regional stream will use a 'before-after-control-impact' (BACI) design to assess impacts of fuel management, as well as additional approaches tailored to address questions of regional significance. Guidelines for field methods and data analysis for each stream are outlined. We also outline processes for prioritising EFGs for monitoring, and for selecting sites for monitoring within the state-wide stream.

As indicated by the review of past monitoring programs, the success of the ERMER project will depend on strong oversight and coordination, including clear identification of responsibilities for carrying out the various program components and good communication amongst the program team and other stakeholders. These factors are key to the ERMER program producing results that can inform improved fire management, and hence successfully complete the adaptive management cycle.

We have also identified a need for a 'scientific coordinator' as part of the ERMER program team. The scientific coordinator will provide the capability to undertake sophisticated analyses and interpretation of data, as well as ongoing guidance on monitoring design, methods and analysis for both streams of the ERMER program.

In addition, the ERMER program will require robust data management systems, which ensure the integrity of data collected and make it readily available in formats that facilitate analyses, including for use in decision making processes such as growth stage optimisation. The MER unit is currently developing a database to meet this need.

The monitoring framework, design and methods outlined in this report will, if implemented, deliver information that can be used to inform improved fire management. However, as described in Chapter 2, the translation of information into management policy/practice is a critical step in the adaptive management cycle. Achieving this requires two elements: 1) a reporting process that ensures that monitoring results are communicated to the appropriate audiences within and outside DELWP in such a way as to make clear what elements of management require change, and what the nature of that change might be; 2) clear processes within DELWP for instigating management change when required. Given the importance of these elements we recommend that priority be given within DELWP to developing and establishing these processes.

Key recommendations from this project are:

- Implement the ERMER program based on a two-stream (state-wide/regional) approach outlined above.
- State-wide stream to consist of monitoring of flora, vegetation structure, birds and ground-dwelling mammals within priority EFGs. Sampling to consist of 200 sites per EFG, selected to encompass gradients of time since fire and inter-fire interval.
- Regional stream to use a BACI design to monitor the impacts of fuel management, plus address additional questions of regional significance.
- The MER unit and Landscape Evaluators to provide effective leadership of program to ensure all steps of AM cycle are completed. A 'scientific coordinator' will be an essential part of the

ERMER leadership team, providing ongoing guidance on monitoring design, data analysis and interpretation of results.
- Develop robust data management systems that ensure data integrity and availability.
- Explore and develop technological approaches to improve data collection efficiency.
- The MER unit and other stakeholders within DELWP give priority to developing the reporting process and processes for translating monitoring results into improved management.

1. Introduction

Background

The foundation of fire management planning by the Department of Environment, Land, Water and Planning (DELWP) is the Code of Practice for Bushfire Management on Public Land (2012; the Code). The code identifies two objectives for fire management:

- To minimise the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment. Human life will be afforded priority over all other considerations.
- To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage, and forest products.

In addition, DELWP's fire management is guided by the recommendations of the Victorian Bushfires Royal Commission (VBRC; Teague et al. 2010), which include:

- Recommendation 57: that DELWP report annually on planned burning outcomes in a manner that meets public accountability objectives, including publishing details of targets, area burnt, funds expended on the program and impacts on biodiversity.
- Recommendation 58: that DELWP significantly upgrade its program of long-term data collection to monitor and model the effects of its planned burning programs and of bushfires on biodiversity in Victoria.

Achieving the Code objectives and VBRC recommendations 57 and 58 requires DELWP to, amongst other things, collect, analyse and interpret high quality data on how fire management affects bushfire risk and ecological values. DELWP's strategy for undertaking this task is encapsulated in the Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land ('MER Framework'; 2015), which outlines principles to guide development of the Victorian Bushfire Monitoring Program (VBMP). The MER Framework and VBMP include monitoring, evaluation and reporting on the impacts of fire/fuel management activities on both bushfire risk to human life and property as well as effects on ecosystem resilience.

The MER Framework situates the VBMP within an adaptive management (AM) context. Adaptive management is a cyclical process that, by acknowledging uncertainties about the effect of management on ecological systems, provides a means for evaluating the outcomes of past management to improve knowledge, and refine future strategies ('learning by doing'; Walters and Holling 1990). Monitoring plays a central role in AM because it provides the data required to complete many steps in the cycle (Moir and Block 2001). If monitoring is undertaken within an AM context, it will be successful only if it serves to inform management/policy, or updates knowledge; this is a very rare occurrence globally (see review by Westgate et al. 2013). A challenge for fire management in Victoria is to 'close the adaptive management loop', such that monitoring results are used effectively to inform policy decisions and update management practices. This is an essential step in successful and effective monitoring, and for capitalising on past and future investments in fire monitoring.

A central element of the MER Framework is a set of Key Evaluation Questions (KEQs). The KEQs form the basis for evaluating the impacts and effectiveness of management actions and strategies, as well as testing and improving the models and assumptions that underlie management planning. Addressing these KEQs is therefore a primary aim for the VBMP.

Project outline

This ‘Scientifically Based Monitoring’ project was commissioned by DELWP in 2015. The overarching aim of the project was to develop a strategy, design and methods for addressing the ecosystem resilience KEQs contained in the MER Framework (‘Ecosystem Resilience MER’/ERMER. Note that the risk to life and property components of the VBMP were not within the scope of the project). The specific objectives of the project were:

1. To scientifically review and refine the Ecosystem Resilience component of DELWP’s existing Bushfire Monitoring, Evaluation and Reporting (MER) approach to determine its effectiveness and capability to report on bushfire management outcomes, as per the reporting requirements of the Code;
2. To identify and test options for refining the current approach to data collection to improve its efficiency and effectiveness for addressing the Ecosystem Resilience Key Evaluation Questions for bushfire MER;
3. To develop and document the evaluation approaches required to analyse the monitoring data to support consistent evaluation and reporting of management effectiveness and bushfire management outcomes.

The main activities undertaken to achieve these objectives consisted of:

1. A review of past major DELWP ecological monitoring programs, with a focus on identifying lessons to inform future monitoring
2. ‘Unpacking’ the ecosystem resilience KEQs to clarify the ecological relationships they encapsulate, and to determine the data and analytical methods required to address the KEQs
3. Developing a strategy, design and methods for collecting and analysing data required to address ecosystem resilience KEQs
4. Contributing to developing a reporting framework so that the results of monitoring and evaluation will more effectively inform fire management planning.

In addition, it is likely that the data generated by the monitoring program proposed in this report will have utility in fire management planning beyond addressing KEQs. In particular, data would be applicable to geometric mean abundance/growth stage structure (GMA/GSS) analyses. However, the proposed monitoring program was not designed expressly to address these additional processes and so will not necessarily be suitable in all contexts.

2. Fire monitoring and adaptive management: lessons for the Monitoring, Evaluation and Reporting Framework from past monitoring programs

We conducted a review of four large-scale (state-wide) fire and forest monitoring programs carried out by DELWP (including with partner organisations) over the last decade, and assessed the degree to which they have successfully completed the key stages involved in the adaptive management cycle. These programs consisted of: 1) the Pre and Post-Fire Flora Monitoring project, 2) the Landscape and Environmental Monitoring program (formally the Landscape Mosaic Burn project), 3) Project HawkEye, and 4) the Victorian Forest Monitoring Program. They represent major investments in monitoring, collectively costing over $10 million (in commissioned work alone), with some running for almost a decade. From this comparative assessment, we have identified the strengths of past programs, as well as factors limiting their success.

Methods and Results

A first step was to identify the key stages associated with the adaptive management cycle. Many papers have documented this framework (e.g., Allan and Stankey, 2009; Schreiber et al., 2004). We summarised the adaptive management cycle into a set of stages most relevant and applicable to future monitoring undertaken within ERMER (Figure 2.1). We also considered what constitutes successful completion of each stage, and the associated risks and opportunities should they not be satisfactorily undertaken (Table 2.1).

We identified nine broad stages that monitoring programs need to undertake to successfully complete the adaptive management (AM) cycle. The process of positioning these stages in relation to the AM cycle within the DELWP MER Framework (see Figure 2.1) highlighted the need for greater recognition of the 'change' and 'implementation' stages if ERMER is to be successful in closing the adaptive management loop. While these stages are not more important than preceding ones – the cyclical nature of the adaptive management framework means all stages must be completed – we suggest that fire monitoring will be more successful if greater attention is given to how results will translate into management change, and the implementation of such change.

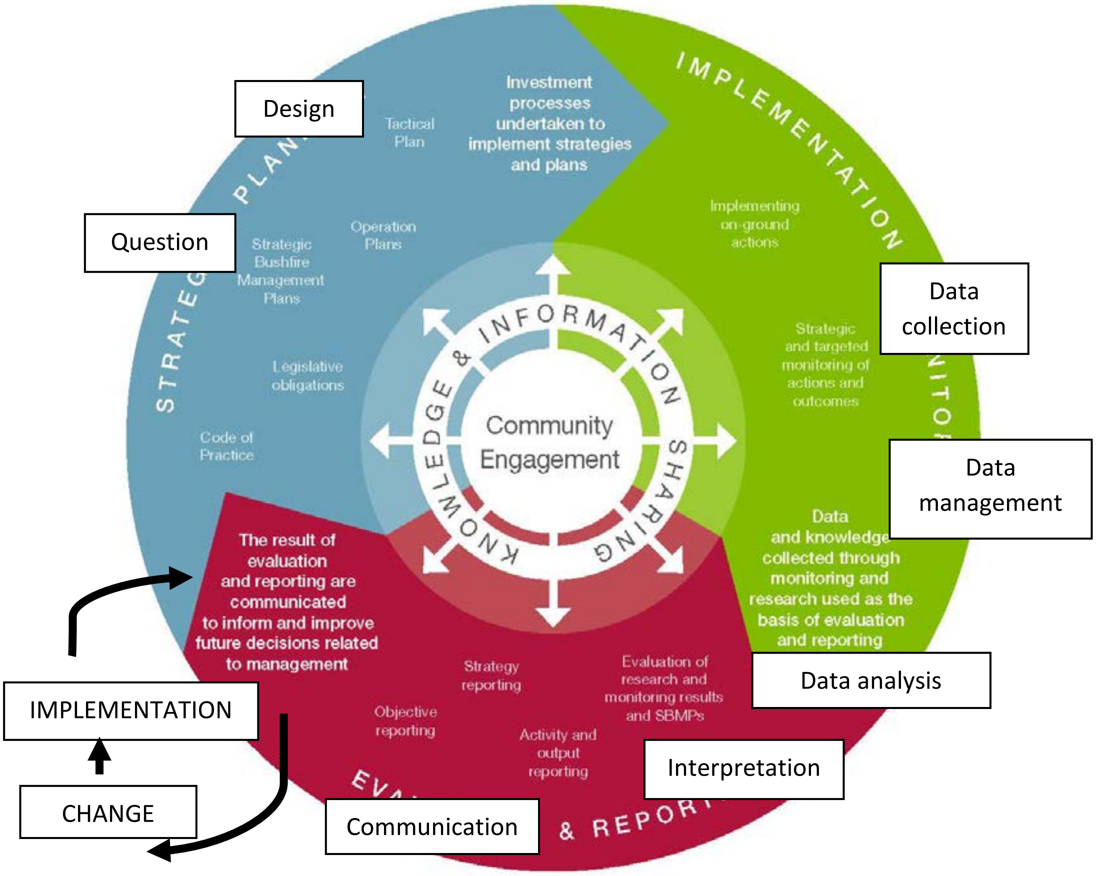


Figure 2.1. The adaptive management cycle as presented in the MER Framework (DELWP, 2015), including key stages that monitoring programs must incorporate to successfully complete the full adaptive management cycle.

Table 2.1. Nine stages of the adaptive management cycle, and a summary of the associated risks and opportunities for monitoring programs at each stage.

Stage of the AM cycle	**Attribute of a successful program**	**Risk – if action not carried out or done poorly**	**Opportunity – if done well**
Question	Question clearly defined, and related to management objectives	Program lacks direction; purpose poorly understood, link to management objectives unclear	Clarity of question/purpose informs design and execution of program, and ensures relevance to managers
Design	Survey design is robust and addresses question	Inappropriate design means question cannot be answered/inconclusive results	Data that addresses question will be collected appropriately
Data collection	Variables/metrics surveyed are relevant to question and consistently recorded	Question cannot be answered	Question can be answered
Data management	Data are quality checked, collated, well organised, clearly documented and available for analysis	Analysis is delayed or not possible	Analysis can be efficiently carried out; data can contribute to corporate databases and future analyses
Data analysis	Data are analysed using methods appropriate to design and aims	Lack of/inappropriate analysis mean no/ erroneous conclusions are drawn	Analysis provides useful answers to question
Interpretation	Results are interpreted with regard to management objective	Results fail to inform management	Implications of findings for management are clearly articulated
Communication	Results and findings are communicated to target audiences	Poor communication limits knowledge/ understanding of findings amongst audience	Good communication promotes understanding and uptake of findings
Change	Program outcomes are relevant to policy/practice development	Evidence for the need for change is insufficiently compelling to warrant changed practices.	Findings inform policy/practice development and managers are convinced of the need/value to change practices in light of new evidence
Implementation	Findings can inform practice, including future monitoring	Program does not close the AM loop; refinement of current management impossible/does not occur	Program closes the AM loop such that management is refined; knowledge gaps reduced

We employed two broad criteria to select monitoring programs for evaluation. First, as we were interested in understanding the link between monitoring and change in management, we focussed on monitoring undertaken within a management context (e.g. led or commissioned by DELWP). Second, we considered only programs undertaken at a large (e.g. state-wide) spatial scale. Biodiversity monitoring can be undertaken at a range of spatial scales. A plethora of small, 'targeted' monitoring programs have been undertaken in Victoria, often with the objective of informing management, but there are difficulties associated with extrapolating the findings of such (often question-driven) monitoring efforts to the larger regional or state-wide scale at which fire management and policy operates (e.g. Lindenmayer and Likens, 2010). Consequently, we limited our focus here to large-scale programs.

Based on these criteria, four monitoring programs were identified as being suitable for consideration in this assessment (Table 2.2). These projects were established to monitor the effects of fire on biodiversity, or forests more generally, they have been implemented since 2006, and they represent an investment of over $10 million (in commissioned work alone). They include: the Pre and Post-Fire Flora Monitoring program (PPFM), the Landscape and Environmental Monitoring program (LEM), Project HawkEye (HE: undertaken in three regions), and the Victorian Forest Monitoring Program (VFMP).

We then assessed the degree to which each monitoring program had completed the steps of the adaptive management cycle (Table 2.3), and summarised details of the governance structure of each program (i.e. which section of DELWP and/or other organisation had responsibility for completing adaptive management steps; Tables 2.2 and 2.4). To compile these data, we consulted people closely associated with each program, and reviewed published documents available for these programs. Results also draw on relevant insights gained during a workshop that involved people directly involved in ERMER planning (held at the Arthur Rylah Institute on August 6th, 2015).

Table 2.2. Key details of four, large-scale monitoring programs undertaken in Victoria. Abbreviations include: PPFM = Pre and Post-Fire Flora Monitoring; LEM = Landscape and Environmental Monitoring; HE = Project Hawkeye; VFMP = Victorian Forest Monitoring Program; PV = Parks Victoria.

Program	**Years of operation**	**Taxa monitored (number of sites)**					**Number DELWP regions encompassed**	**Cost to DELWP/PV***
		Vascular plants	Birds	Mammals	Habitat structure	Fuel		
PPFM	2006-2015	1171 (404 twice)					All	$1,017,290
LEM	2009-2014	273 (209 twice)	277 (212 twice)	216 (127 twice)	253 (158 twice)	213 (104 twice)	All	$4,000,000
HE Otways	2010-2014	41	45 (all repeat)	45 (all repeat)	45	45	1	$521,570
HE Mallee	2010-2014	248 (46 thrice)	484	25 (+ reptiles)	248 (46 thrice)	70	1	$688,305
Gippsland HE (A)~	2010-2014	132 (all twice)	124 (20 twice)	115	132 (DBH only)	132	2	~$1,000,000
Gippsland HE (B)~	2010-2014	25 sites	80 (surveyed 10 times)	104 sites (surveyed 4 times)	230 (66 surveyed twice)	150	2	$308,370
VFMP	2010 -	693 (once so far)			693 (once so far)		All	$3,300,000 ($550,000 pa)

* Costs presented here are under-estimates. All programs have included further work commissioned at unknown expense. For example, additional salary costs associated with Head Office personnel/protocol development (PPFM, HE), with the completion of 'sub-projects' (HE), or related to major in-kind contributions from partner organisations (HE); data collation and reporting (PPFM, LEM); prior funding (HE Gippsland, via LEM); statistical consultancy work (LEM).
~ HawkEye Gippsland comprised work associated with a previous fire-ecology research project (A) and region-based HE sub-projects (B); these components have been summarised separately.

Table 2.3. Summary of the degree to which four large-scale monitoring programs in Victoria have completed different components of the adaptive management cycle. Blue = stage completed, yellow = partially completed, red = not completed. Hatching = completed but not in relation to the original question/s the program was designed to answer.

Stage of the AM cycle/activity	PPFM	LEM	HE Otways	HE Mallee	HE Gippsland* A	HE Gippsland* B	VFMP
Question/design							
Is there a clearly defined question?							
Question relevant to policy?							
Design capable of answering question?							
Sampling regime sufficient to answer question?							
Data collection							
Were appropriate data collected?							
Were there rigorous protocols for data collection?							
Data management							
Data entered?							
Quality control?							
Meta data/documentation?							
Data collated ready for analysis?							
Data secured in state-wide database?							
Data analysis							
Have data been summarised?							
Can the data answer the question?							
Has analysis been undertaken?							
Interpretation							
Have results/summary been interpreted?							
Have results been peer-reviewed?~							
Communication							
Reporting?							
Answer question?							
Appropriate communication to stakeholders?^							
Recommendations							
Were any recommendations made?	a						
Did they address a policy issue?							
Change							
Change to future monitoring?							
Change to management practices?							
Change to policy?							
Implementation							
Plans to evaluate management change?							
Of policy change?							

* HawkEye Gippsland comprised work associated with a previous fire-ecology research project (A) and region-based HE sub-projects (B); these components have been summarised separately.

~ Peer-review is currently undertaken in a range of ways, including workshop/forum presentations and internal review of reports: all are less rigorous/more informal than the independent anonymous peer-review process that occurs when publishing in scientific journals.

^ Reports based on data summaries only (i.e. not answering monitoring question/s) are not considered appropriate communication.

[a] Recommendations related to improvements to future monitoring, and were applicable to this and other programs.

Table 2.4. Details of the governance structure of four large-scale monitoring programs in Victoria in relation to the adaptive management cycle. Abbreviations include HO = DELWP head office; SCID = (former) Strategy, Capability and Innovation Division; BD = Biodiversity Division; UM = University of Melbourne; LTU = La Trobe University; ARI = Arthur Rylah Institute; PV = Parks Victoria.

Stage of the AM cycle	**PPFM**	**LEM**	**HE Otways**	**HE Mallee**	**HE Gippsland**	**VFMP**
Commissioning unit	HO (SCID)	HO (SCID)	HO (SCID)	HO (SCID)	HO (SCID)	HO (SCID)
Program manager	HO (SCID)/ Regions	HO (SCID)/ Regions	HO (BD)	HO (BD)	HO (BD)	HO (SCID)
Scientific leadership	?/Regions	HO (SCID)	UM/Region	LTU/Region	ARI/Region	HO (SCID)
Question/design	HO (BD, SCID)	HO (SCID)	HO (BD), UM, Region	LTU, Region	ARI, Regions	HO (SCID, BD)
Data collection	ARI, Regions, PV	ARI, Regions	ARI, UM, Region, Contractors	LTU, Region	ARI, Regions, Contractors	Contractors
Data management						
Curated for analysis	Region	Region	Region/UM	LTU/Region	ARI/Regions	HO (SCID)
Curated for corporate database	ARI^	ARI^	HO (BD)	HO (BD)	HO (BD)	HO (SCID)
Data analysis	ARI^ (summary only)	ARI^ (summary only)	ARI^ (summary only)	LTU	ARI/Regions	HO (SCID)
Interpretation	ARI^	ARI^	ARI^	LTU/Region	ARI/Regions	HO (SCID)
Communication~	ARI^	ARI^	ARI^	LTU/Region	ARI/Regions	HO (SCID)
Recommendations	Not identified	Not identified	Not identified	LTU/Region	ARI/Regions	Not identified*
Change	Not identified	Not identified	Not identified	Region	Not identified	Not identified*
Implementation	Not identified	Not identified	Not identified	Not identified	Not identified	Not identified*

* The VFMP has not been in operation long enough to make recommendations, or complete the following stages.

^ These stages have been undertaken retrospectively as part of extra commissioned work.

~ Relates specifically to the production of reports containing program results/outcomes.

Insights from past monitoring programs

The following themes emerged from our assessment of past monitoring programs.

1. **Effective leadership is essential if monitoring programs are to be successful**. Program leaders are responsible for overseeing the completion of all tasks associated with each stage of the program, and ensuring they are delivered on time and to the required standard. This process will involve the co-ordination of a large number of people, who may change in identity over time, and so communication of expectations and progress is important for ensuring everyone is up-to-date with progress and any complications (see point 6 below). Appendix 1 contains an exemplar framework for identifying who holds the primary accountability, and who is a partner stakeholder, for each stage of the adaptive management cycle.

2. **Most programs encountered issues at the question/design stage, which often led to further problems at later stages in the cycle**. The overall outcome of monitoring programs is dependent on the success of these initial stages of question definition and sampling design. Lessons from past programs include:

- Questions need to be clearly defined and relevant to managers, and at a feasible scale for monitoring;
- Questions should be framed to address thresholds or degrees of change in key variables that will indicate successful management or a need for change in policy/practice.
- Monitoring sites must adequately replicate key 'management treatments' and include control sites where relevant;
- Sources of variation (e.g. vegetation type, topography, environmental gradients) other than the management treatment/s (e.g. planned fire) must be adequately sampled;
- Sufficient sites must be monitored to ensure sample size is not a limiting factor; either within treatments, or overall;
- Plan long-term programs with a realistic understanding of the ongoing availability of funds;
- Consider 'outlying' characteristics of sites that may limit the use of associated data (e.g. uncommon vegetation types, see third and fourth dot points above);
- Identify and record all essential data (e.g. fire data, habitat data).

3. **Success of the data collection stage depends on adequate training of field staff, clear communication of sampling protocols (e.g. via readily available Standard Operating Procedure and Work Instructions), and someone having responsibility for quality control to oversee this process**. The importance of experienced field personnel with good biological identification skills for the collection of consistent and accurate data cannot be overstated: the quality of monitoring data will depend on the experience of the field staff employed.

4. **Most past programs managed data well, at least for the purposes of the task at hand**. For many programs, a contributing factor in the success of this stage was allocating the tasks of data entry, vetting, documentation and ongoing management to a single person/small group. Inconsistencies in data collection methods and curation standards between programs can impede later meta-analyses (see Leonard et al. 2016). However a further consideration here is that, even if data have been quality-checked, collated, documented and stored in a database (i.e. meet criteria for success, as outlined in Table 2.1), they need to be made readily available to future users. This is

an area that could be improved, by developing a central database for biodiversity/fire-related monitoring data, collected as part of programs of all sizes (i.e. not only state-wide efforts).

5. **Data analysis and interpretation are critical stumbling blocks for many programs**. Access to analytical expertise with detailed ecological appreciation of the strength and limitations of the data was instrumental in projects that successfully completed this stage. However, failure in some programs was often associated with other factors (e.g., lack of personnel [HE Otways], poor data management [LEM]). The risk of failure was heightened when data analysis was seen as a separate commissioned task from that of study design and data collection. Notably, two of the four programs have not completed any data analyses in relation to their initial questions. Importantly, programs that do not successfully complete this step cannot progress to the subsequent stages in the adaptive management cycle with any confidence.

6. **Communication is critical to the success of monitoring programs and must be planned as part of program delivery**. Communication needs to be 'two way', with information being fed both 'up' and 'down' the management structure. Key communication pathways include:

- Policy <-> program sponsors <-> program team <-> regions. For monitoring programs to be successful, there must be engagement and buy-in from all levels of involvement, and at all stages of the program. Monitoring programs involve complex teams. Clearly identifying who is responsible and accountable for each stage of the program is critical for successful programs and productive corporate relations.
- Program sponsors <-> program team. Continual two way communication is essential for managing expectations. This is particularly important given monitoring programs often change over time (e.g., changes to monitoring questions, funding situations, political priorities) and success depends on all parties remaining committed to the project's goals.
- Program team <-> land/fire managers. Identify who can implement any change required, and communicate findings appropriately.
- Program team -> policy. Identify the pathway for information to be translated into policy.
- Dissemination of program outcomes. A range of forms of communication is recommended: scientific papers give credibility, and the peer review process enhances confidence in the quality and scientific rigour; fact sheets are good for diverse audiences. Reports and other program outcomes must be accessible to stakeholders.

7. **Programs have had variable success when it comes to initiating change**. Almost all monitoring programs have contributed to the refinement of monitoring efforts over time. This is a noteworthy success for DELWP, and a clear example of closing the adaptive management cycle in relation to monitoring actions specifically. However, there has been almost no demonstrable success in changing local practice or policy, and thus programs have not successfully achieved the implementation stage of the adaptive management cycle. An important factor here may be the general lack of identification of critical uncertainty in decision making that specifically links to alternative management actions. This is needed to identify the degree of change in monitored variables that triggers the need for policy/practice change. In addition, identifying policy change is difficult, for many reasons:

- Policy change depends on many factors outside the control of a particular program;

- Programs may contribute to policy by affirming the current position/underlying understanding;
- Programs can instigate important change, either in management practices or future monitoring, without leading to a change in policy.

Change takes time, and so may be yet to be realised. Notably, the monitoring program that has led to changes in local practice (HawkEye Mallee) benefitted from established relationships between researchers and regional staff developed over many years (also highlighting the importance of good communication pathways).

8. **There are some temporal considerations associated with monitoring that are important to recognise:**

- Program budgets must be adequate to support the program through to completion. This entails recognition in the planning phase of the importance of all stages of the adaptive management cycle, and allocation of sufficient funds and clear responsibilities accordingly;
- Program timelines (and budgets) must designate sufficient time to the tasks of data management and analysis: these steps are crucial to overall program outcomes, and the process of closing the adaptive management loop;
- Monitoring programs can take time to work through various issues associated with different stages of the cycle. Adequate time must be allowed for this to occur.
- Long-term datasets provide invaluable insights into the metrics targeted by monitoring, emphasizing the value of a long-term perspective to monitoring.

Box 2.1. Summary of insights from past monitoring programs.

Effective leadership is essential for successful monitoring programs, both in terms of program management (e.g., overseeing the completion of all stages to an acceptable standard), and scientific leadership to ensure a sound scientific basis for the program.

KEY INDICATORS OF SUCCESS:

1. Clarity of question(s), which clearly link to informing management decision making

Good communication with field staff who collect the monitoring data; training is imperative

2. Excellent data management, undertaken by a small group of people responsible for the entire process (e.g., collation, entry, vetting, documentation, storage and availability)

3. Explicit recognition of the importance of statistical analyses, and access to analytical expertise

KEY INDICATORS OF FAILURE:

1. Lack of clarity of responsibilities and accountabilities for each stage of the cycle

2. Poorly-defined monitoring question/s

3. Failure to account for other sources of variation (e.g., vegetation type, etc.) in program design

4. Insufficient data to answer question/s (e.g., insufficient number of sites or duration of sampling, key variables missing)

5. Poor communication/unproductive relationships between involved parties/stakeholders

Discussion

The MER Framework explicitly recognises the importance of undertaking fire monitoring within an adaptive management context (DELWP 2015). However, to maximise the potential for MER to lead to improved management, greater recognition of the importance of the 'change' and 'implementation' stages within the 'evaluation and reporting' section of the framework is required (see Figure 2.1). This will give greater emphasis to 'closing the adaptive management loop', a critical step for successful monitoring programs and ensuring maximum return on investment. Successful incorporation of the adaptive management framework into fire monitoring will mean that DEWLP's MER Framework is a world leader in this field.

Each stage of the adaptive management cycle involves distinct risks and opportunities. Risks threaten the overall success of a program, while many opportunities represent potential contributions that extend beyond the objectives of any given program. For example, monitoring data that are clearly documented and which have been collected using a well-designed sampling program will have long-term legacy value via contributions to future programs or research. Critically, the cyclical nature of the adaptive management framework means that the risks associated with any particular step have cascading effects that work in both directions. For example, risks associated with early steps of a monitoring program jeopardise all following steps, while risks associated with later steps of the cycle similarly threaten the ultimate success of the program, but also mean that investment in all preceding steps is wasted. The substantial investment in fire monitoring over the last decade (>$10 million on large-scale programs alone) highlights the need for future efforts to avoid risks and maximise opportunities.

This review of past monitoring programs in light of the adaptive management framework provides valuable insights to guide MER in the future. Fundamental to the success of all programs is effective leadership (both program leadership and scientific leadership), and a clear identification of who is responsible and accountable for each stage of the program. Having someone to coordinate all stages, and ensure all tasks are completed successfully is critical. Other insights can be distilled into seven indicators of success and failure (see Box 2.1). Most indicators relate to early steps in the cycle and so emphasize the importance of activities associated with collecting monitoring data: question definition, study design, data collection protocols, and data collation/management. Monitoring is often seen as a management action separate from scientific research (Lindenmayer and Likens, 2009), yet many steps in the adaptive management cycle are underpinned by scientific methodologies (Schreiber et al., 2004), and monitoring and research share common features that characterise their success (Lindenmayer and Likens, 2009).

The development and fostering of effective communication pathways is also of critical importance. In particular, engagement with stakeholders at every stage of the process is critical to the overall success of monitoring programs. Importantly, these insights are derived directly from programs undertaken by DELWP, and so provide recommendations that are highly relevant and specific to future MER efforts to be undertaken by DELWP.

Recommendations for the ERMER program

There is much room for improvement in the way in which monitoring programs are undertaken.

1. Monitoring programs depend on effective leadership and coordination. Assign clear responsibility and accountability for a) program coordination and delivery (including ensuring all stages are completed on time and to an acceptable standard), b) scientific leadership and guidance, c) engagement of stakeholders at all stages of the process.
2. Monitoring programs will be successful only if all stages are completed. Ensure upfront allocation of sufficient time and funds for the completion of all stages. In particular, more attention must be given to the stages of 'data analysis', 'interpretation', 'change', and 'implementation'.
3. Monitoring programs will not effectively inform management or contribute to knowledge gaps if results are not communicated. Reports must contain results that answer the original monitoring question/s, and so directly inform future management and policy.
4. Monitoring data needs to be well managed and accessible, both for the purposes of the MER program, as well other management decision making processes within DELWP.
5. Identify thresholds for key monitored variables that will trigger management action or review of policy. Monitoring needs to be able to detect change indicating if/when such thresholds are reached.

3. 'Unpacking' the Key Evaluation Questions

The Key Evaluation Questions (KEQs) set out in the MER Framework are a foundational element of the VBMP (see Appendix 2 for list of ecosystem resilience KEQs). The KEQs form the basis for (i) evaluating the impacts and effectiveness of management actions and strategies, as well as (ii) testing and improving the models and assumptions that inform management planning. The major focus of these latter 'Improvement' KEQs is testing the assumptions of and refining the three ecosystem resilience metrics used by DELWP in fire management planning (Tolerable Fire Interval, Growth Stage Structure, Geometric Mean Abundance of species; DELWP 2015)

While the KEQs broadly address key issues pertinent to the effects of fire management on ecosystem resilience, they required some 'unpacking' in order to determine how best they can be addressed via monitoring. The KEQ unpacking process was initially carried out at a workshop of DELWP staff and La Trobe University (LTU) researchers conducted in August 2015, with subsequent further refinement by the LTU project team.

The unpacking process included:

- Clarifying the ecological relationship(s) encapsulated in each KEQ
- Determining whether each KEQ focussed on the impacts of fire *events* or fire *regimes* (temporal scale)
- Determining the relevant spatial scale (e.g. regional, state-wide)
- Identifying primary response and predictor variables
- Identifying an appropriate approach to monitoring design (e.g. space for time, BACI)

For most KEQs, it was also necessary to identify subsidiary monitoring questions (MQs). Monitoring questions are more precisely formulated questions that encapsulate the attributes of KEQs yielded by the unpacking process, but which are more tractable to address by data collection and analysis. Initial work on identifying MQs was carried out by some regional MER teams in the course of formulating regional MER plans. While there was generally conceptual consistency in MQs across regional MER plans, there was some variation in the ways MQs were expressed. We selected MQs from the regional MER plans that best reflected the thrust of each KEQ, with some rewording for clarity where required, to create a 'standard' list of MQs. These MQs formed the basis of subsequent work (see below). The results of the KEQ unpacking and MQ formulation processes are shown in the 'Question' and 'Design' columns of the KEQ table given in Appendix 2.

An important outcome of this component of the project was to identify that, in essence, all KEQs/MQs dealt with different facets of interactions amongst fire, biota and habitat (Figure 3.1). Identifying this 'relationship triangle' made the design of a monitoring program to address KEQs much simpler. It indicated that most KEQs could be addressed by the same, fairly generic data sets, rather than separate data being required for each KEQ.

From here, we were able to formulate 'pathways' for addressing each KEQ: that is, the key components of the process leading from the KEQs to providing information for management (see Appendix 2). In addition to the information yielded by the KEQ unpacking process, these pathways include:

- identifying an approach to analysing data, including the type and general form of analytical models;

- focal results of analyses; key result metrics, and guidance on their presentation and interpretation;
- identifying reporting, scale (regional/state-wide), timeframe and audiences
- identifying the form of change to management required, if results indicate this is necessary

The monitoring design and methods outlined in succeeding chapters of this report have been formulated to allow the KEQ pathways to be completed (noting that KEQs 6 and 7 require dedicated research projects to properly address, which is beyond the scope of the proposed monitoring program outlined below).

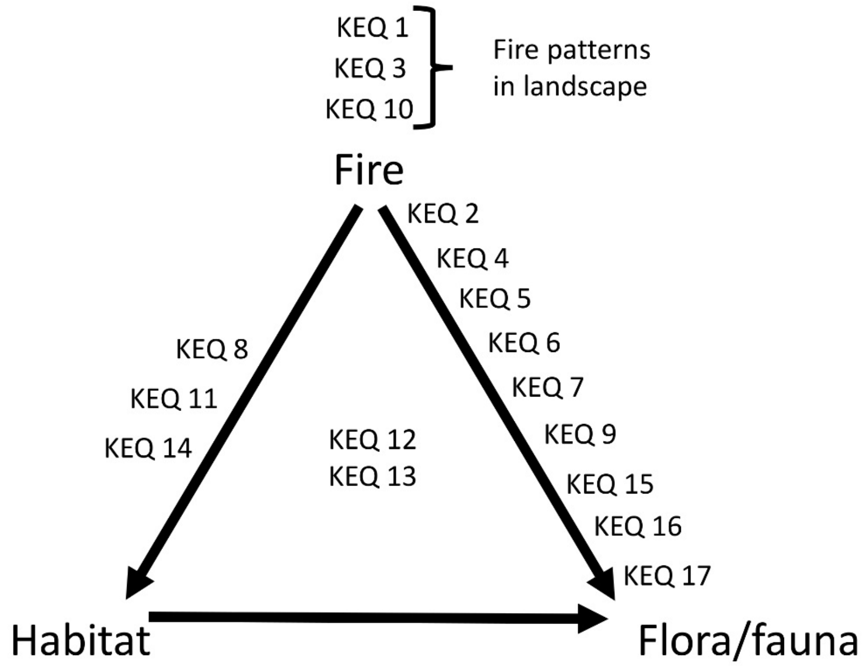


Figure 3.1. The triangle of ecological relationships and associated KEQs.

4. Proposed two-stream model for the ERMER program

Principles for coordination and design of monitoring

DELWP's Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land (MER Framework, DELWP 2015) outlines a number of principles for ensuring the quality of fire monitoring and the improvement of bushfire management. These principles include:

- **consistency**, defined as a "*state-wide approach…that follows an agreed set of standards and methods to enable a more meaningful interpretation of monitoring data collected from across the state*", and
- **quality and excellence** of "*data collected as part of monitoring activities must…be collected using methods based on the best available science*".

The review of past DELWP monitoring programs (Chapter 2) has shown that **effective leadership is a key determinant of the success of monitoring programs**. Leadership is required in terms of both program management and accountability, and ensuring a robust scientific approach is implemented throughout the program. A lack of such effective leadership was identified as a key reason for the failure of past monitoring programs to produce findings able to effectively inform management.

Alternative approaches to undertaking ERMER

We considered three alternative models for developing the ERMER program in light of the lessons learnt in the review of past monitoring programs (see Table 4.1). These three approaches differ in relation to the design of monitoring programs and features of their coordination, and can be summarised as follows:

1. Each region undertakes ERMER more or less independently, selecting monitoring questions (MQs) to address target key evaluation questions (KEQs), implementing monitoring (e.g. funding, designing program, collecting data, analysing data, interpreting results) and reporting on KEQs separately. This approach involves implementation/management of monitoring efforts and outcomes separately in each region, and reflects the status quo at the outset of the current project.
2. Each region addresses a consistent set of MQs at the same time. This may involve some coordination of efforts across regions, or regions working independently (as in Approach 1), or both.
3. Undertake ERMER in two distinct streams. A regional stream focusses on KEQs that address short-term, local-scale responses to fire. A state-wide stream involves establishing a state-wide network of sites for long-term fire monitoring to address KEQs that relate to fire regime attributes at larger scales. Oversight of the state-wide stream to be provided by a scientific coordinator.

Advantages and disadvantages of these approaches are given in Table 4.1. To summarise, the key weakness of Approaches 1 and 2 is that they involve devolving the management and

implementation of monitoring to six separate regions. The clear evidence from the experience of past monitoring programs is that this model compromises the potential for effective leadership and coordination, and hence has a high risk of failure to deliver effective monitoring outcomes.
We recommend that future fire monitoring within ERMER be based on a comprehensive state-wide network of long-term monitoring sites, managed and implemented by a scientific coordinator, in conjunction with focussed, regionally-based monitoring programs (Approach 3 in Table 4.1 below). This approach will provide an efficient and effective program for collecting data capable of answering almost all KEQs, and thus will address current management needs, while also providing the flexibility to address regional/local priorities. In addition, once established, a state-wide network of sites will represent a valuable resource for long-term fire ecology monitoring and research into the future. This approach is similar to that of the successful Victorian Forest Monitoring Program.

Advantages of a coordinated two-stream approach

- Efficiently provide data to address most KEQs, at the most appropriate spatial scale.
- Much simpler governance structure. This means there will be less potential for problems associated with unclear responsibilities, lack of accountabilities and communication failures, which have hindered past monitoring efforts (see Chapter 2)
- Will ensure greater consistency at all stages of the monitoring/adaptive management cycle; from design, sampling, data management and analysis to interpretation and reporting.
- Will avoid issues associated with differential capabilities/resources within different regions. Notably, it removes the need for strong statistical expertise in each region.
- Offers a more achievable and realistic role for Landscape Evaluators, with scope for them to contribute at both regional level and state-wide levels.
- **Overall, a much greater likelihood that the ERMER program will be successful in informing fire management policy and practice.**

Table 4.1. Advantages and disadvantages of alternative approaches to design and coordination of the ERMER program.

Approach	Advantages	Disadvantages
1. Each region selects monitoring questions (MQs) to address target KEQs and independently implements monitoring in each region.	• Regions can tailor MQs to own needs/priorities.	• Resource intensive (e.g. sites, effort, funds) to answer MQs on a region level. **Not cost-effective.** • **Selection of differing MQs across regions reduces potential for consistent state-wide reporting.** • **Inconsistent monitoring design/methods/data across regions.** • Will result in a 'scattergun' approach to new monitoring sites being added to the legacy database. **Reduced long-term value of new monitoring sites.** • Skill set to implement monitoring program and undertake analyses differs between regions, and may change over time (personnel turn-over). **Increased chance of failure to answer KEQs** • Past programs using this approach have had limited success. **Increased chance of failure for monitoring to address policy and management needs.**
2. All regions address a consistent set of MQs at the same time. May involve some coordination of efforts across regions, or regions working independently, or both.	• More consistent state-wide reporting. **Increased chance of monitoring that successfully addresses policy and management needs.** • Room for regions to interpret MQs in relation to focal species of interest to their region/local community. **Regions retain ability to target species of local importance.** • Coordination between regions provides greater efficiency and statistical power to answer MQs. **Increased efficiency and likelihood of success.**	• Resource intensive (e.g. sites, effort, funds) to answer MQs on a region level. **Not cost-effective.** • Skill set to implement monitoring program and undertake analyses differs between regions, and may change over time (personnel turn-over). **Increased chance of failure to answer KEQs.** • Past programs using this approach have had limited success. **Increased chance of failure for monitoring to address policy and management needs.**
3. Establish a comprehensive, state-wide network of sites for long-term fire monitoring to address multiple KEQs, to be managed by a central scientific coordinator. Region-level reporting on Impact KEQs; analyses and reporting for Effectiveness and Improvement KEQs carried out centrally.	• A carefully designed state-wide network of sites would have the capacity to answer most KEQs over time. **Effective design.** • Considerably more efficient sampling: fewer sites will be required; less duplication of effort. **Efficient approach.** • Central coordination provides opportunity for effective scientific leadership, program management, and analytical expertise. **Increased chance of success.** • Provide site network that has long-term value at state-wide level. **Long-term value of investment.** • Robust, systematic design provides more options for future data use (e.g. to answer different questions that may arise due to change in policy, management approaches, etc.). **Increased flexibility of monitoring data.** • Data collected will be of use in empirically identifying thresholds of concern to trigger management. **Contribution to other management questions.** • Reduces risks associated with inconsistencies between regions in terms of priorities, approaches, expertise, etc. **Reduced risk of failure**. • **Regions retain ability to target species/issues of local importance.**	• **Requires long-term commitment (though not necessarily more so than Approaches 1 and 2).** • **Resource intensive, though likely more efficient than Approaches 1 and 2**

5. Two stream model for ERMER: Implementation

As outlined in Chapter 4, we propose that the ERMER program be carried out as two 'streams'- region-based and state-wide (Table 5.1). It is envisaged that region-based monitoring is 'granular', focussing on Impact KEQs that address the immediate-short term effects of management actions (primarily planned burns). Monitoring may also be carried out at this level to address regionally specific issues.

State-wide monitoring addresses the more general and long-term relationships of biota/ecological values to fire regimes, as encapsulated in the Improvement KEQs. This stream would provide data to test current management models and metrics, and reduce uncertainty related to the outcomes of fire management for ecosystem resilience. The results of both monitoring streams are combined to address Effectiveness KEQs.

This chapter provides details of how the two ERMER streams can be implemented, and how they together address KEQs.

Region-based monitoring

Purpose

ERMER at the regional level will address Impact KEQs (1, 8, 9) and Effectiveness KEQs based on fire mapping (3, 10).

KEQs addressed

1, 3, 8, 9 10 (indirectly, Effectiveness KEQs 2, 11, 12)

Led by:

Landscape evaluator/region/MER unit

Description

KEQs 1, 3, 10: desktop analysis of fire mapping data to provide information on region/LMU status with regard to resilience metrics (Tolerable Fire Interval, TFI; Growth Stage Structure, GSS). For KEQs 8 and 9, field data collection on fauna, vegetation structure and habitat features within areas subject to planned burns, using a BACI design.

Region-based monitoring may also be carried out to address region-specific issues of management impacts on ecological values. Region-based monitoring could also focus on species that may be of interest in decision making, but are unlikely to be adequately sampled within the state-wide stream (e.g. rare/threatened species, arboreal mammals). In these instances it will be beneficial to coordinate monitoring across regions to avoid duplication of effort and develop more extensive data sets.

State-wide monitoring

Purpose

Address Improvement KEQs, providing more robust definitions of TFIs and growth stages, as well as providing empirical data on which to base GMA/GSS optimisation analyses, thereby increasing confidence in resilience metrics.

Led by:

Scientific coordinator/MER unit

KEQs addressed

4-7, 13-17 (indirectly, Effectiveness KEQs 2, 11, 12)

Description

A space-for-time design, sampling flora, fauna and habitat attributes across representative gradients of time since fire and fire interval within priority EFGs (see Chapter 7). Priority EFGs will be selected on the basis of attributes such as their extent, treatability with planned burning and current state of knowledge regarding fire-ecological relationships. The aim is to select the most important EFGs with respect to ecological fire management. It is anticipated that this design will include approximately 200 samples per EFG in total (see Chapter 7, Appendix 3). This network of sample sites will form the basis of ongoing long-term monitoring (i.e. monitoring recommended every five years). Where possible, it will incorporate existing legacy monitoring sites, but only where this does not compromise the robustness of the program.

It is inevitable that some of the selected sites will be burnt (either by bushfire or planned burn) at some point in the future. Employing a space for time experimental design, with careful selection of sites to represent gradients of time since fire and fire interval (see Chapter 8), will ensure the robustness of at least the initial round of monitoring (data will not be affected by sites being burnt *after* data have been collected). Prior to each subsequent round of monitoring it will be necessary to review the fire history status of sites within the target EFG(s) to determine whether recent fires have compromised the monitoring design (i.e. inadequate representation of fire regime gradients). If this were the case, options would include re-surveying sites, but re-framing analyses to examine shorter term impacts of burning and/or variation in fire intervals, or augmenting the site network with additional sites to 'restore' the original design.

The proposed sampling design will provide data to allow modelling of relationships of biotic responses (e.g. species occurrence/abundance, community composition, habitat attributes) to fire regime variables. These models will allow Improvement KEQs to be addressed and so help to refine definitions and application of resilience metrics. In addition these models will provide the capacity to predict the outcomes of planned burning and bushfires, and so allow the Effectiveness KEQs (2, 10, 11 and 12) to be addressed. These models can also be used prospectively to assess the likely outcomes of fire management scenarios, as well as to help identify critical thresholds of change in response variables.

Table 5.1. Division of KEQs between Regional and State-wide (SW) 'streams' of ERMER program. Effectiveness KEQs are addressed by combining the results obtained from each stream.

KEQ	KEQ	KEQ type	Monitoring type	Stream	Lead	Event/ regime	Method/required data	Use of outputs
1	How has fuel management changed the proportion of vegetation sitting below the minimum or above the maximum TFI?	Impact	Activity	Region	LE	Event	Desktop analysis; requires fire mapping	Assessment of current status of resilience metrics within LMU/Region/state (compared to goal/long term average)
3	Has the fuel management strategy maintained the desired amount of the landscape sitting within TFI?	Effectiveness	Management effectiveness			Regime		
10	How has the fuel management strategy changed the deviation from the goal growth stage structure?	Effectiveness				Regime		
8	How has the abundance of key habitat attributes changed as a result of fuel management?	Impact	Activity	Region	LE	Event	Before/after surveys of planned burn areas	Assess impacts of individual planned burns
9	How has fuel management changed the occupancy of fire sensitive species within their preferred habitat?	Impact						
2	How has the fuel management strategy maintained or improved populations of TFI-sensitive KFRS?	Effectiveness	Management effectiveness	Region /State-wide	SC/ LE	Event/ regime	Modelling of fuel management strategy outcomes using monitoring data from KEQs 8 and 9, combined with results from State-wide program.	Reporting on biodiversity impacts of fuel management strategies
11	How has the fuel management strategy effectively maintained key habitat attributes and critical growth stages for minimising the deviation from the goal growth stage structure?	Effectiveness						
12	Has the fuel management strategy contributed to the maintenance of populations of fire sensitive species across their distribution in Victoria, through the maintenance of appropriate growth stage structures?	Effectiveness						
4	Are KFRS that set minimum and maximum TFIs appropriate species for determining TFIs?	Improvement	Validation	State-wide	SC	Regime	Monitoring data collected at state-wide network of long-term monitoring sites; requires current fire mapping layers.	• Allow prediction of outcomes of management actions and strategies. • Better understanding of the ecological relationships that underpin current management models (e.g. TFI, GSS, GMA); • Reduce uncertainty around resilience metrics. • Empirical data on which to base GMA/GSS calculations.
5	How appropriate are the current TFIs for maintaining species composition and relative abundance within each EVD across the landscape?	Improvement						
6	Is the reproductive capacity of species that set minimum TFI consistent with the current TFIs?	Improvement						
7	Are the current thresholds for management action appropriate to avoid fundamental change in each EVD?	Improvement						
13	Are the availability of key habitat attributes reflected in the growth stages and linked to occurrence and abundance of species reliant on these attributes?	Improvement						
14	Do key habitat attributes regenerate as expected following fire?	Improvement						
15	Do the current EVD growth stage intervals reflect changes in the abundance of species over time?	Improvement						
16	Do the species response curves adequately predict the response of at-risk and fire sensitive species to fire?	Improvement						
17	Does the measured GMA of species match the modelled GMA of species derived from modelled species response curves?	Improvement						

Connection between monitoring streams: addressing Effectiveness KEQs

The Effectiveness KEQs (2, 3, 10, 11, 12) are those that most directly inform fuel management planning and address community interest in effects of management on biodiversity. These KEQs concern the effects of fire regimes at a 'landscape' scale; i.e. LMU/region (though results can be integrated to report at the state level). KEQs 3 and 10 are relatively simply dealt with via desk top analysis of fire mapping data. The remaining Effectiveness KEQs are more complex, as they require information on the biodiversity effects of fire *events* and fire *regimes* across the target landscape. These event and regime effects may be regarded as processes that play out at short and long time frames, respectively. Impact and Improvement KEQs address these processes. Impact KEQs (in particular 8 and 9) concern impacts of fire events, while Improvement KEQs address biodiversity relationships to fire regime attributes (interval, time since fire). Combining the results of both sets of KEQs provides the information required to address the Effectiveness KEQs (see Figure 5.1).

Impact KEQs 8 and 9 can be addressed by monitoring impacts of planned burns on biota and habitat, using a BACI design. We suggest that this monitoring be coordinated and carried out at the regional level. The Improvement KEQs are most efficiently and appropriately (from an experimental design perspective) addressed through a space-for-time approach, with sites selected to encompass gradients of fire interval and time since fire within target vegetation types (EFG). This approach constitutes the proposed state-wide monitoring program.

The results of these two sets of monitoring can be used to address Effectiveness KEQs 2, 11, 12 across a management landscape in the following way:

- Results from KEQs 8 and 9 indicate how the fuel management strategy has affected biodiversity in areas subject to recent planned burns (i.e. short term impacts of fire events).
- Results from Improvement KEQs allow biodiversity status (e.g. species/habitat abundances) to be modelled/predicted for the rest of the landscape (based on fire history attributes).
- Results from Improvement KEQs will also provide more robust definitions of TFIs and growth stages, as well as providing empirical data (response curves) on which to base GMA/GSS calculations, thereby increasing confidence in resilience metrics. This will be of immense value to fire planning in the future; empirically validating the expert models on which fire planning for ecosystem resilience is currently based will reduce uncertainty around predicted outcomes of planned burning.

Role of regional risk and evaluation teams

The proposed approach entails important roles for region-based risk and evaluation teams (specifically the Landscape Evaluators, Planned Burn Biodiversity Officers, and Risk Analysts) in relation to monitoring for ecosystem resilience (see Table 5.1). They will have primary responsibility for carrying out analyses for, and reporting on, KEQs that involve assessment of regional GSS and TFI status (1, 3, 10), applying the results of state-wide monitoring at a regional scale, and coordinating monitoring to address region-specific management issues. Landscape Evaluators will be responsible for:

- Data collection, analysis and reporting for KEQs 1, 3, 8, 9, 10.
- Coordination of region-specific monitoring (e.g. threatened species, community priorities).
- Assisting with coordination of state-wide monitoring within their region.
- Feeding regional data into a central database for curation and archiving.
- Region-level reporting on monitoring results.
- Facilitating the incorporation of monitoring results into management planning/practice.
- Consultation with, and feedback to, the scientific coordinator.

Ensuring the streams flow together: the importance of scientific coordination.

The review of past monitoring programs (Chapter 2) has emphasised the need for effective leadership and coordination to ensure success of the MER program. A crucial aspect of this is to ensure that the 'scientific' components of the program are executed well. These include: 1) ensuring consistent and sound decisions are made relating to monitoring design as sites are established; 2) oversight of data collection and data quality control; 3) data collation and management; and 4) statistical analysis and interpretation of results. This fourth component in particular will require a high level of technical expertise, combined with familiarity with the study systems, the data collected and the management context in order to interpret the analytical results (see Chapter 10). We suggest that these components be overseen/carried out by a 'scientific coordinator'. This role would involve:

- Coordination of state-wide site network and oversight/quality control of data collection
- Data collation and management, including documentation, database maintenance and ensuring integration with related analyses platforms such as the consolidated ecological module
- Data analysis to address state-wide KEQs
- Providing specialist advice and support regarding monitoring design, methods and data analysis and interpretation to MER unit and Landscape Evaluators
- Preparing state-wide MER reports
- Ensuring results/conclusions are fed back to regions to inform management
- Maintaining links with the broader scientific community, to ensure that the ERMER program is informed by the latest science (e.g. advances in analytical methods).

Experience from past monitoring programs (Chapter 2) suggests that these tasks are much more likely to be carried out successfully if responsibility is vested in one person or a dedicated team. Good examples are provided by the coordination of the VFMP program, and the excellent data management of the HawkEye project (undertaken by a single person). Past programs also show that there is high risk of failure if responsibility for monitoring programs is dispersed amongst several people/groups who also have other roles to fulfil. We recommend that the scientific coordinator role be carried out by a dedicated staff member within the MER unit (i.e. a person whose primary role is fulfilling the scientific coordinator role), or by engaging a research institution (e.g. ARI, university) 'on retainer', such that they take responsibility and oversight for carrying out this essential role. We strongly recommend against contracting out the role in a short term, piecemeal fashion (e.g. engaging a statistician on an ad hoc basis to analyse data). To be successful the role requires sustained engagement and familiarity with the ERMER program and related activities within DELWP.

The skills and experience required to carry out the scientific coordinator role include:

- Post-graduate degree (PhD) in ecology or related field
- Strong skills in experimental design and analysis
- Experience with a range of field methods, including understanding the practicalities/logistics of field surveys
- Excellent understanding of fire ecology, including responses of a range of taxa (plants and animals)
- Skilled at interpreting data in an applied setting (i.e. to inform management)
- Strong leadership skills
- Good communicator, able to engage effectively with all stakeholders
- Breadth of knowledge and skills; capable of 'turning their hand' to the range of issues and activities entailed within the ERMER program.

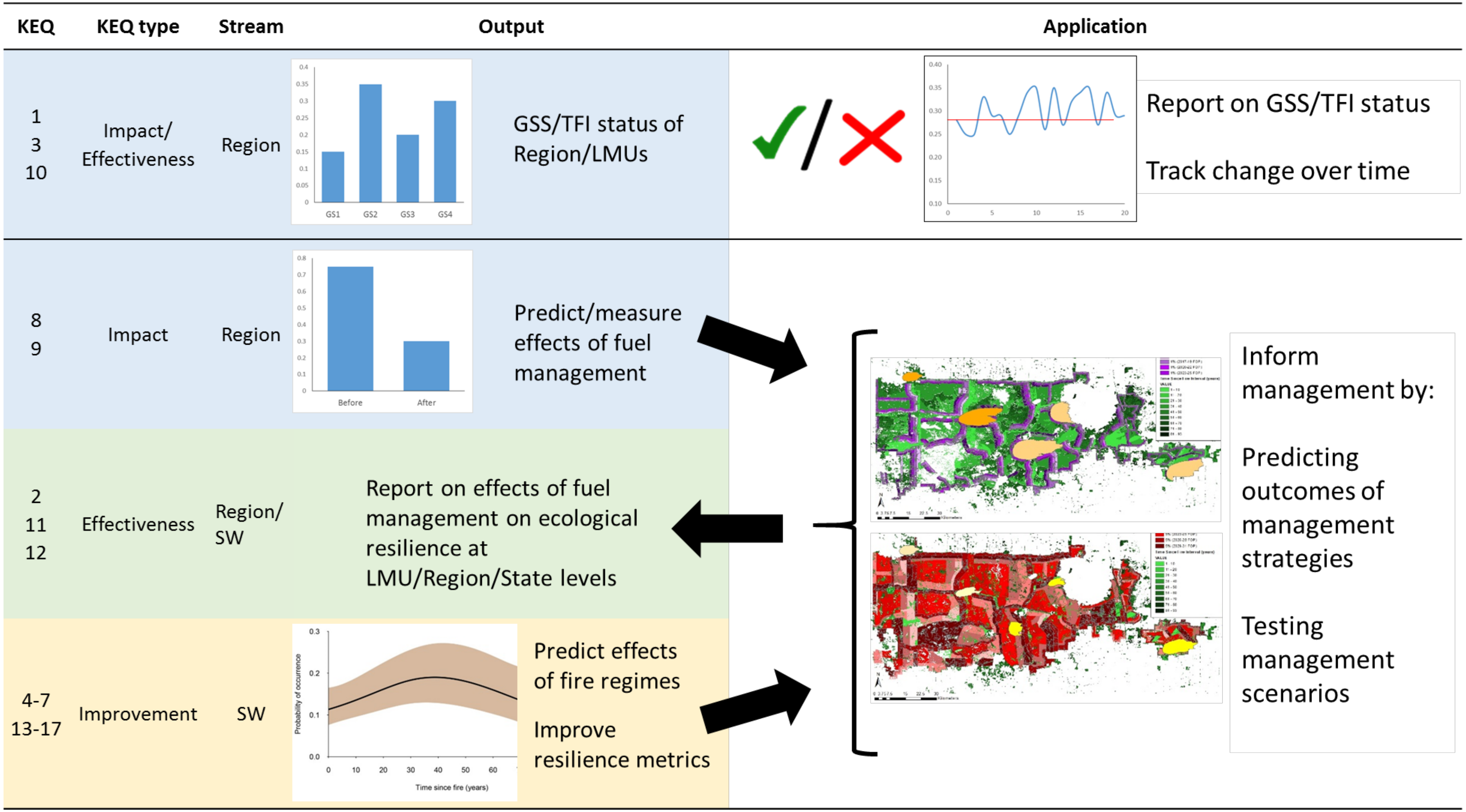


Figure 5.1. Relationship of the regional and state-wide ERMER streams to addressing Key Evaluation Questions.

6. Guidelines for regional field-based monitoring

As described in preceding chapters, the proposed model for the ERMER program consists of two 'streams'- region-based and state-wide. Regional monitoring focusses on Impact KEQs, as well as addressing questions/management issues of local significance. State-wide monitoring addresses the more general and long term relationships of biota/ecological values to fire regimes, as encapsulated in the Improvement KEQS. The results of both monitoring streams are combined to address Effectiveness KEQs.

This chapter provides basic principles to guide designing and carrying out monitoring within the regional stream of the MER program. There is an extensive literature on monitoring principles and practice (see References below), which provides a more in-depth examination of these issues.

With regard to field surveys, the regional stream of ERMER is mostly focussed on KEQS 8 and 9 i.e.:

KEQ 8: How has the abundance of key habitat attributes changed as a result of fuel management?

KEQ 9: How has fuel management changed the occupancy of fire sensitive species within their preferred habitat?

In the discussion below, 'fuel management' is assumed to take the form of planned burning, although the design principles and methods outlined would be applicable to examining the effects of other forms of fuel management.

Broadly speaking, we interpret these questions as concerning the **impact** of management actions (e.g. planned burning) on species or groups of species and habitat attributes (e.g. vegetation structure, large trees, logs) over **relatively short time frames** (≤ 5 years).

Though the focus here is on the effects of management actions as *events*, there is potential to consider these impacts in the context of underlying *regimes*. For example, it may be informative to compare the impacts of planned burns occurring after a long fire-free interval with similar burns at a short fire interval.

Similarly, regional monitoring may be used to assess the degree to which different fuel management practices differentially affect biodiversity values (e.g. comparing the effects of burns where fuel is raked from around large trees to those where it is not).

Case studies

In 2016, monitoring programs were initiated in three Bushfire Risk Landscapes (Alpine-North East, Barwon-Otways and East Central; work was carried out prior to BRL/region restructure in 2017). The process of designing, and the early stages of implementing these programs were recorded as case studies. The lessons learnt from these case studies have informed the general recommendations for monitoring contained in this document. Brief summaries of these case studies are given below.

Alpine-North East

The Alpine North-East (ANE) BRL has developed a monitoring program focussed on quantifying the effects of planned burning on the abundance of the Greater Glider (*Petauroides volans*) and hollow-bearing trees (critical habitat for Greater Gliders). The Greater Glider is a focus as this species was historically regarded as common, but more recent data suggest populations are in decline. In addition, planned burning may affect the Greater Glider by causing the loss of hollow-bearing trees, but this impact may be able to be reduced through mitigation measures (controlling burn coverage and intensity). The objectives of the monitoring are:

1. To determine the immediate, short-term impact of planned burning on the Greater Glider.
2. To determine the immediate, short-term impact of planned burning on hollow-bearing trees.
3. To evaluate the effectiveness of 'mitigation measures' recommended to mitigate the impact of planned burning on Greater Glider habitat.

Surveys are carried out using a BACI design, and consist of spotlight surveys of Greater Glider abundance (counts along transects) and recording the survivorship of hollow-bearing trees following planned burns. Pre-burn surveys were completed in Spring 2017. Planned burns are scheduled for Autumn 2018, after which post-burn surveys and assessments will be undertaken.

Barwon-Otways

Within the Barwon-Otways (BO) BRL, a number of areas of heathland were re-zoned from 'bushfire moderation zone' (BMZ) to 'asset protection zone' (APZ), as part of the BRL's risk reduction strategy. This change in zoning means that these areas will be subject to higher fire frequency than previously was the case. At a workshop in January 2017, it was decided that monitoring the effects on biota of this increase in fire frequency would be a priority. This monitoring program used existing sites and data from the Otways Hawkeye program, which had been set up several years previously to address a similar question, as well as capitalising on the University of Melbourne re-sampling associated sites in the same area at the same time using the same methods. This was possible because a number of Hawkeye sites were located in areas that had undergone a change in the fire management zoning of interest. Field surveys of vegetation structure and ground-dwelling mammals, using the same methods as the Hawkeye program, were carried out in autumn 2017.

East Central

Monitoring in the East Central (EC) BRL was also prompted by a concern over increased fire frequency due to re-zoning of burn units, in this case from landscape management zone (LMZ) to BMZ. The basic design for this monitoring was a BACI design, but also incorporating treatments of long and short intervals and large and small burn units within the burnt ('impact') treatment. Data collection was focussed on ground-dwelling mammals, in particular the endangered Smoky Mouse (*Pseudomys fumeus*) using camera traps, while also recording habitat structure at trap sites. Due to logistical constraints it was not possible to complete surveys within all the treatments during the initial survey round; however, six burnt sites and five controls were surveyed in late 2016. This pilot survey will be able to be expanded in subsequent survey seasons.

Lessons from case studies

Consultation with DELWP staff involved in these case studies provided a number of lessons, which are relevant to planning future regional monitoring. Key lessons include:

- Clear governance, roles and expectations need to be identified for the whole of the monitoring process including study design, determining methods, data collection, data management, analysis and reporting. Responsibility for these components should be determined at the beginning of the program.
- The need to determine processes and responsibilities for obtaining permits, animal ethics approval, OHS requirements etc.
- Ensure enough time is allocated for tasks. This includes explicitly allocating time/resources to data management, analysis and reporting.
- Start planning early. The year before field work is anticipated to occur is ideal.
- Where possible use consistent design and methods for similar taxa/questions across regions. This will require communication amongst regional teams.
- The need for regional data to be entered in a common database (i.e. for all regions and state-wide program), so data can be readily used to inform management beyond the region in which it was collected.

What to monitor

Determine priorities for monitoring

In many instances, monitoring will be initiated to address a perceived need to assess the effects of a particular management action or strategy (e.g. BOBRL case study) on biota/habitat generally. In other cases, concern or interest in a particular species or habitat feature will drive a need for monitoring (e.g. ANEBRL case study). Either case (or a combination of the two) may form the basis of designing a monitoring program.

Available resources will not allow monitoring of all issues/species/features that may be of interest within a region. Therefore, it will be necessary to prioritise monitoring activity and subjects. While it is beyond the scope of this document to set out a formal prioritisation process, the points below outline aspects to consider within three overarching 'themes'.

Organisational/political imperatives

- Priorities identified by regional/district staff
- Community interest
- Legislation (threatened species or other requirements to monitor/report)
- Reporting requirements

Ecological characteristics

- Potential to inform management

- Sensitivity of species/features to change (environmental/policy/management)
- Rarity; trajectory of abundance, conservation status
- Knowledge gaps; target little-known species/features
- Ecological interactions of potential targets (e.g. species/features that strongly affect other species/features)

Synergies and practicalities

- Existing management plans and actions
- Availability of existing sites/data
- Burn plans (FOP etc.)
- Logistics/resources
- Availability/knowledge of relevant fire history (mapping)

Define the question

Formulating a question that addresses the issue(s) of interest for monitoring is a key step in the monitoring process. A well formulated question will guide subsequent monitoring design and analysis. A 'good' question will also identify the response variable(s) and main predictor variable(s) of interest and encapsulate how their relationship may vary with variation in management. Within the DELWP MER Framework, a series of 'monitoring questions' have been developed at a regional level for this purpose, though in some cases these will need to modified to focus on particular species/features. Examples of the kinds of questions that may be relevant to addressing KEQs 8 and 9 are:

- What is the change in abundance of species X and habitat feature Y in response to planned burns in EFG A?
- Does post-burn abundance of species X and habitat feature Y differ between burns applied at short intervals compared to those applied at long intervals?

Having defined a question it is necessary to define the metrics for the response and predictor variables, plus any secondary predictors that may influence the relationship of primary interest.

Examples of variable and metrics likely to be relevant to region-based monitoring are given in Table 6.1.

Table 6.1. Examples of definitions and metrics for predictor and response variables

Predictors			
	Predictor	**Type**	**Metric(s)**
Primary predictors	Burn status	Categorical (binary)	- Burnt/unburnt (control)
	Fire interval	Continuous/categorical	- Years between fires (most recent, mean, minimum) - Within/below TFI
	Fire frequency	Continuous	- N fires over time
Secondary predictors*	EFG	Categorical	- EFG category
	Burn coverage	Continuous	- Percent burn cover
	Burn season	Categorical	- Spring/autumn
	TSF/growth stage	Continuous/categorical	- Years since last fire/growth stage
	Burn/patch size	Continuous	- area
	Presence/abundance of predators	Continuous/categorical	- presence/absence - count - reporting rate
	Topography	Continuous/categorical	- slope - aspect - topographic position
	Climate e.g. rainfall	Continuous	- annual/seasonal rainfall - rainfall anomaly (departure from average)
Responses			
	Response	**Type**	**Metrics**
Vegetation /habitat	Vegetation/habitat structure	Continuous	- Cover of plant life forms within height strata - Tree density - Tree DBH
	Hollow bearing trees	Continuous/categorical (binary)	- Density - Survivorship - Recruitment
Fauna	Bird/mammal species	Continuous/categorical (binary)	- presence/absence - count - reporting rate
	Bird/mammal community	Continuous/categorical (binary)	- diversity - composition
Flora	Plant species	Continuous/categorical (binary)	- presence/absence - cover
	Plant community	Continuous/categorical (binary)	- diversity - composition

*desirable to simplify design by controlling for, or stratifying by, these.

Monitoring design

In order to address questions of interest, it is critical to have an appropriate design for data collection. Sampling design must encompass the variables of interest (responses and predictors), while controlling or otherwise accounting for other drivers that may influence relationships. The sample size must be sufficient to allow robust statistical analyses and sampling needs to be logistically practical. Key factors to consider are listed in Table 6.2.

Table 6.2. Considerations for monitoring design.

Ecological considerations – what to measure?	
Ecological relationships(s) being addressed	Ensure the design will allow conclusions to be drawn regarding relationship/process of interest. Are the key variables being captured?
Control 'treatment'	In most cases a control will be required to provide a comparison against which to assess a treatment effect.
Nature of response/predictor variables	Are variables categorical, continuous etc.? What are their metrics? What is the range of variation within variables, and how much of this range is relevant?
Interactions with other drivers	Do the effects of other drivers need to be accounted/controlled for?
Spatial and temporal scale	What is the appropriate scale to consider relationships/effects? e.g. patch/landscape, months/years
Analytical considerations – how many samples?	
Expected effect size (=> required statistical power)	Effect size will likely need to be estimated based on expert opinion and/or existing similar data.
Level of replication required	Based on power analysis[1] or expert opinion/past experience.
Where and when to sample?	
Availability of 'treatments'	What range of burns and/or fire history are available or planned? How many sites/burn units possess attributes relevant to question?
Compatibility with past/existing studies/monitoring	Are there sites with existing data? Is it advantageous to incorporate these?
Logistics (personnel, resources, accessibility etc.)	What resources are available/required?
Seasonality	Does the season of treatment and/or survey matter?

[1] See Appendix 3 for results of power analysis indicating samples sizes required for generic analyses.

Design options

For the kinds of questions it is envisaged the regional stream will address, there are two basic approaches to survey design: space for time (chronosequence) and 'before-after-control-impact (BACI). These approaches, and their advantages and potential disadvantages are detailed below (Table 6.3). There is potential to combine these approaches for more complex questions/designs (see Figure 6.1, 6.2).

Table 6.3. Advantages and disadvantages of BACI and space for time sampling designs.

Approach	Implementation	Advantages	Issues
BACI	Sites/samples are assigned to treatments (e.g. burnt/unburnt) a priori. Surveys prior to application of treatment, and then at interval(s) afterwards.	• Robust 'experimental' approach • Potentially high level of control over treatments and other variables	• Takes time for any impacts/effects to emerge • Requires coordination to ensure design is applied/adhered to. • Design can be profoundly compromised by unplanned fire • Care required when interpreting immediate results (e.g. how to interpret change in response variables after fire: what level of change is acceptable/of concern?)
Space for time	Sites/samples are selected that meet criteria representing historical 'treatments' or a gradient in variable of interest (e.g. time since fire, fire interval).	• Provides information on impacts/effects relatively quickly. • Often is only practical option for long-term processes.	• Potentially less control over attributes of samples • Design potentially constrained by availability of sites meeting selection criteria

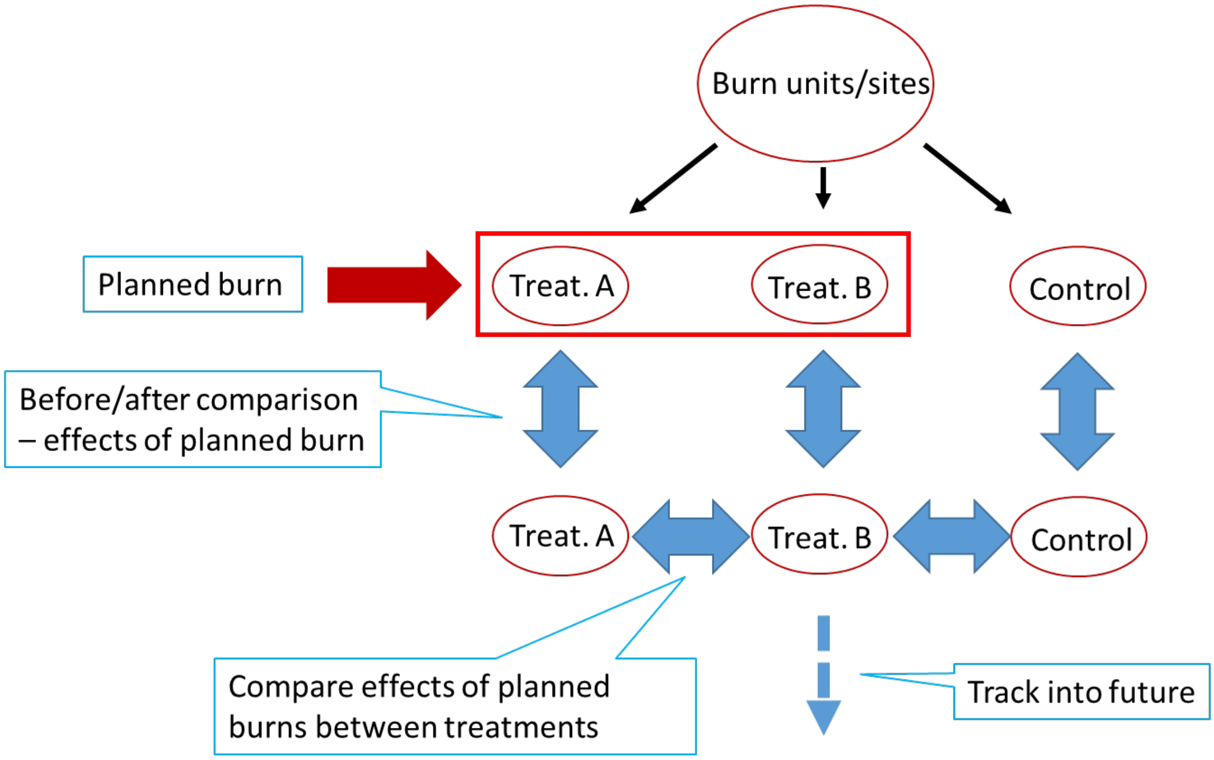


Figure 6.1. Example of BACI design incorporating different treatments of planned burn areas (e.g. predator control, measures to protect habitat trees, burn coverage). The controls (no treatment) provide a baseline for testing whether any change due to treatments is greater than change that may occur due to other processes such as natural environmental change.

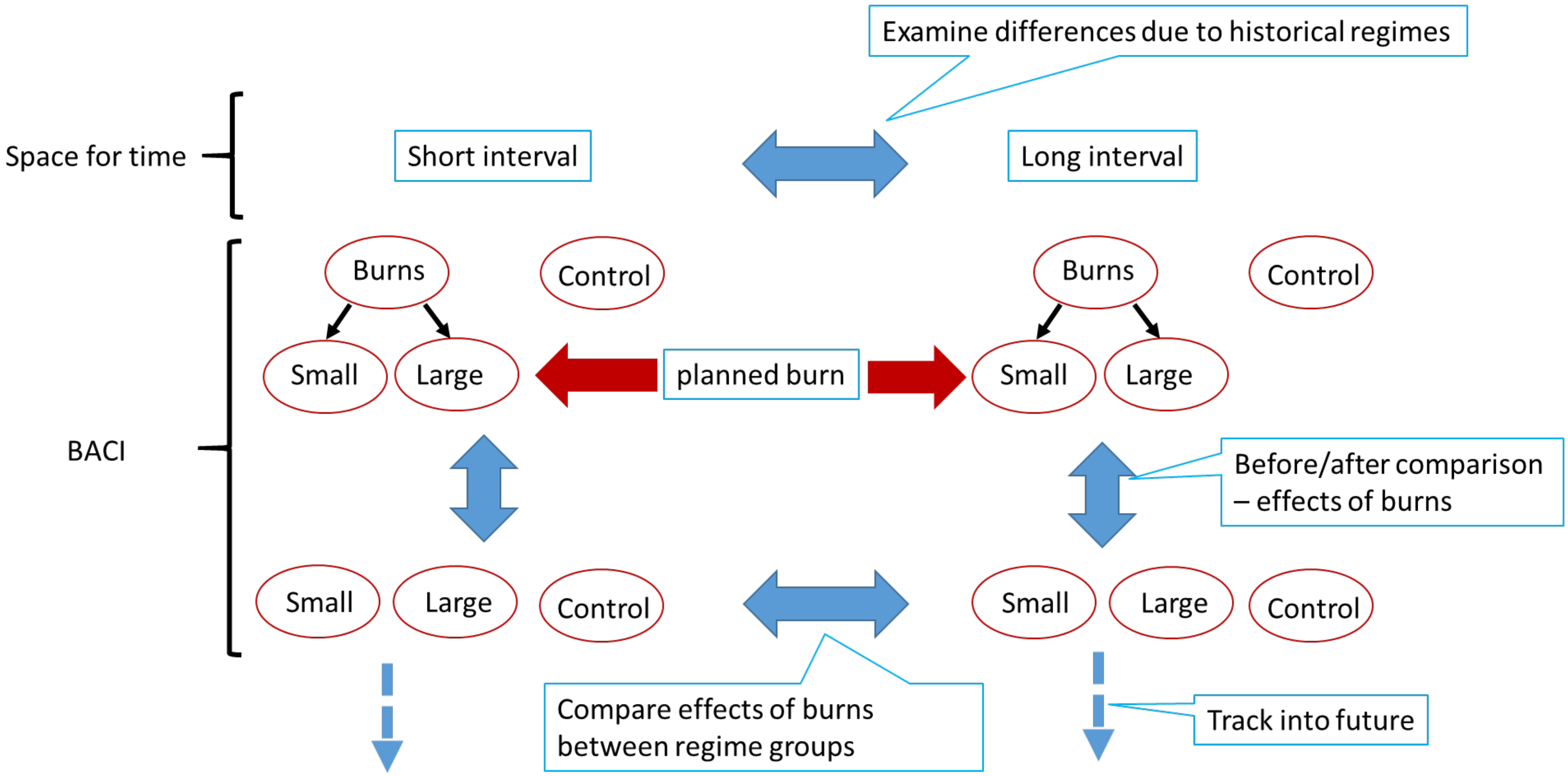


Figure 6.2. Example of monitoring design incorporating space-for-time and BACI elements to assess the impacts of small and large burns in the context of short and long fire intervals.

Methods

Methods for collecting data on flora, vegetation structure, birds and ground-dwelling mammals have been devised for use within the state-wide stream of the MER program (see Chapter 9). These methods should also be used in regional monitoring wherever possible (i.e. where they are suitable for addressing question of interest). The vegetation structure method requires botanical expertise (species identification). However, the method can readily be modified to be based on plant lifeforms, which would capture the same structural metrics as the full method (modification described in Chapter 9).

In some instances these 'standard' methods will not be suitable for addressing a question of interest, most obviously when taxa not covered by these methods are a focus (e.g. arboreal mammals). In these instances there are a number of factors to consider in choosing appropriate methods, including:

- Question and decision context being addressed
- Response/predictor metrics
- Resources (personnel/time/money)
- Equipment required
- Level of expertise required
- Compatibility with other programs/data sets

In determining which methods to use it would be useful to investigate recent monitoring/research programs that have examined similar questions/taxa; their methods may be able to be used or adapted. If in doubt regarding the suitability of methods, seek expert advice.

Data management

A robust data management system that ensures the long-term integrity, accessibility and usability of data is critical to the success of monitoring programs (Chapter 2). The DELWP MER unit is currently designing such a system for data collected within the state-wide stream of ERMER. This system should also include regionally collected data, which would facilitate using regional data in conjunction with that from the state-wide stream and/or other regions.

Analysis and reporting

Most questions will be able to be addressed using generalised linear models (GLMs). For designs that include spatial clustering of samples and/or a time component (e.g. paired designs, before/after comparisons), generalised linear mixed models (GLMMs) will be most appropriate. GL(M)Ms are a flexible approach that allow analysis of response variables with different distributions, and inclusion of categorical and continuous predictors (Table 6.4). It may be beneficial to seek specialist advice on analytical approaches and model formulation.

For the BACI design illustrated above (Figure 6.1), the form of a GLMM to test for an effect of treatment(s) would be:

Response ~ Treatment*time + (1|burn unit[1]/sample ID)[2]

Where:
Treatment = management action of interest e.g. burnt vs. unburnt (control)
Time = before/after treatment
Sample ID = identity of sample units that are surveyed before and after treatment
([1] include burn unit term if multiple samples within multiple burn units are included in sampling
[2] random component of mixed model, accounting for pairing/clustering of samples)

In this case, a significant treatment*time interaction would indicate the application of the treatment has resulted in a different outcome relative to the control; that is, that the treatment has had an effect because there is greater change through time than occurs for the control.

Table 6.4. Types of response variable and appropriate distribution for use in a GL(M)Ms.

Response type	**Example metric (from standard field methods)**	**Distribution/Type of GL(M)M.**
Continuous	Tree DBH, tree density[1]	Gaussian
Count	Number of bird species/individuals	Poisson
Binary	Presence/absence of species	Binomial (logistic regression)
Proportion/percentage	Species/lifeform cover	Logit transformation, Gaussian model

In some cases it may take several years to accumulate sufficient monitoring data to carry out formal statistical analyses. An interim measure may be to use descriptive statistics to identify trends or patterns in the data. An example would be to compare averages of a particular response variable before and after burning, or across treatment categories. Where sample sizes are small, results should be interpreted cautiously (this also applies when statistical analyses are used). However, such an approach may provide useful information to guide management.

Reporting

As discussed in Chapter 2, reporting the results of analyses of monitoring data is a critical step in informing future management. While is it is beyond the scope of the current project to devise a reporting process for ERMER, we have identified key components of the reporting process, applicable to both regional and state-wide streams of ERMER in Chapter 10. Other factors to consider with regard to reporting include:

- Statutory or organisational requirements
- Reporting cycle. Ensure information is available when it is needed, especially if required as inputs to subsequent activity.
- Audiences. Who requires what information? What is an appropriate format?
- Community/stakeholder needs

The DELWP MER unit is currently developing a reporting framework for the MER program.

Closing the loop – using results to inform management

Translating the findings of monitoring into management policy/practice ('closing the loop') is the aim of adaptive management. As seen in Chapter 2, the record of monitoring programs achieving this step is, at best, mixed. Often the failure of programs to lead to change reflects problems in preceding stages. Therefore the likelihood that monitoring will successfully inform management is increased by undertaking a robustly designed and systematic approach to monitoring, as outlined in this document. Again, it is beyond the scope of the current project to formulate a process for feeding monitoring results into management decision making. It is anticipated that progress towards developing such a process will be an outcome of the 'Ecological Model Consolidation' project currently being undertaken by ARI and University of Melbourne.

7. ERMER state-wide stream design

Objectives of the ERMER state-wide stream

The objective of the state-wide monitoring stream is to address the long-term relationships of biota/ecological values to fire regimes, as encapsulated in the Improvement KEQs. This stream will provide empirical data to test current ecosystem resilience models and metrics, and so reduce uncertainty related to the ecological outcomes of fire management. For example, data will be used to develop more robust definitions of tolerable fire intervals and growth stages, as well as providing empirical data (cf. expert opinion) on which to base calculations of geometric mean abundance and growth stage structure. The results from the state-wide monitoring stream will also contribute, in combination with results from regional monitoring, to addressing the Effectiveness KEQs.

Note there are two Improvement KEQs (KEQs 6 and 7) that are unlikely to be addressed using data collected during the state-wide stream (see Appendix 2). Both are questions that will be most efficiently and appropriately answered by targeted research projects. For example, KEQ 6 will require detailed field measurements of the reproductive output of individual plant species. The collection of such specific data at a state-wide scale is not logistically feasible.

Approach

We recommend a space-for-time design be employed to sample flora, fauna and habitat across gradients of time since fire and fire interval within target vegetation types (ecological fire groups: EFGs). Target EFGs will be selected on the basis of attributes such as overall extent and treatability with planned burning, with the aim of selecting the EFGs of greatest management relevance and capacity to reduce uncertainty in the outcomes of future management decisions (see Chapter 7).

On the basis of past system-wide research projects (e.g. Mallee Fire and Biodiversity Project, Foothills Fire and Biota Project) and power analysis (Appendix 3), we anticipate that data from approximately 200 sites from each EFG will be required to produce robust models of fire-biota relationships. Where possible, existing monitoring sites will be incorporated so as to maximise the value of existing and future datasets.

This network of state-wide sites will form the basis of ongoing long-term monitoring, with monitoring recommended at least once per decade at sites. Such long-term and large-scale data collection will provide a world-class monitoring program, which has the capacity to answer increasingly complex questions as data are amassed (e.g. examine interactions between fire and other drivers such as climate).

Implementation

We recommend that monitoring be undertaken on an EFG-by-EFG basis (though multiple EFGs could be surveyed concurrently), with, ideally, sampling within each EFG being completed within a single survey season. There are several benefits to this approach, compared with a strategy that sees the monitoring of some sites from each EFG every year:

- An EFG-by-EFG approach would comprise stand-alone, carefully designed ‘programs’ that together combine to form a state-wide network of sites for long-term monitoring. Approaching each EFG separately will enhance the potential for consistent scientific oversight of the entire process (from site selection to data collection to analysis and interpretation of results), a critical factor underpinning the success of the state-wide stream. This would also provide a way to account for EFG-specific factors that might require variations to implementation or methods across ecosystems, without loss of data consistency across the full network.
- Delivery of final outputs (e.g. empirical models, recommendations about current metrics) will be more efficient and timely, as progress of work in each EFG does not depend on that in other systems. Similarly, there is scope to focus work on priority systems, with those of lesser priority being dealt with later.
- Such an approach would provide greater flexibility in the process by which individual EFGs are undertaken/delivered. For example, some could be carved off into discrete research projects, while others could be undertaken by DELWP staff.
- Field surveys within given EFGs are more likely to be completed before unanticipated fires alter time since fire and/or fire interval gradients.

Prioritising Ecological Fire Groups for monitoring within the state-wide stream

The objective of the state-wide stream of ERMER is to provide empirical data to address the Improvement KEQs. These KEQs all centre around enhancing our understanding of the fire~biota relationships on which the conceptual models and management metrics (e.g. tolerable fire intervals, growth stages) underpinning fire management for ecological resilience are based. Tolerable fire intervals (TFIs) and growth stages (GSs) are both defined on the basis of vegetation type, as represented by Ecological Fire Groups (EFGs) (Cheal 2010).

Across Victoria, there are 35 mapped EFGs, ranging in cover from approximately 2,500 ha (Coastal-Grassland) to 1,720,000 ha (Grassy/Heathy Dry Forest; Figure 7.1). The process of selecting which of these EFGs to include in the state-wide stream of ERMER was based on three primary factors:

1. Coverage across the state. To ensure that results inform management across the broadest area possible.

2. ‘Treatability’ with planned fire. To ensure that results are of greatest relevance to management.

3. Representation in the public land estate. To ensure that results are of greatest relevance to management (and to reduce land-access issues for on-ground monitoring).

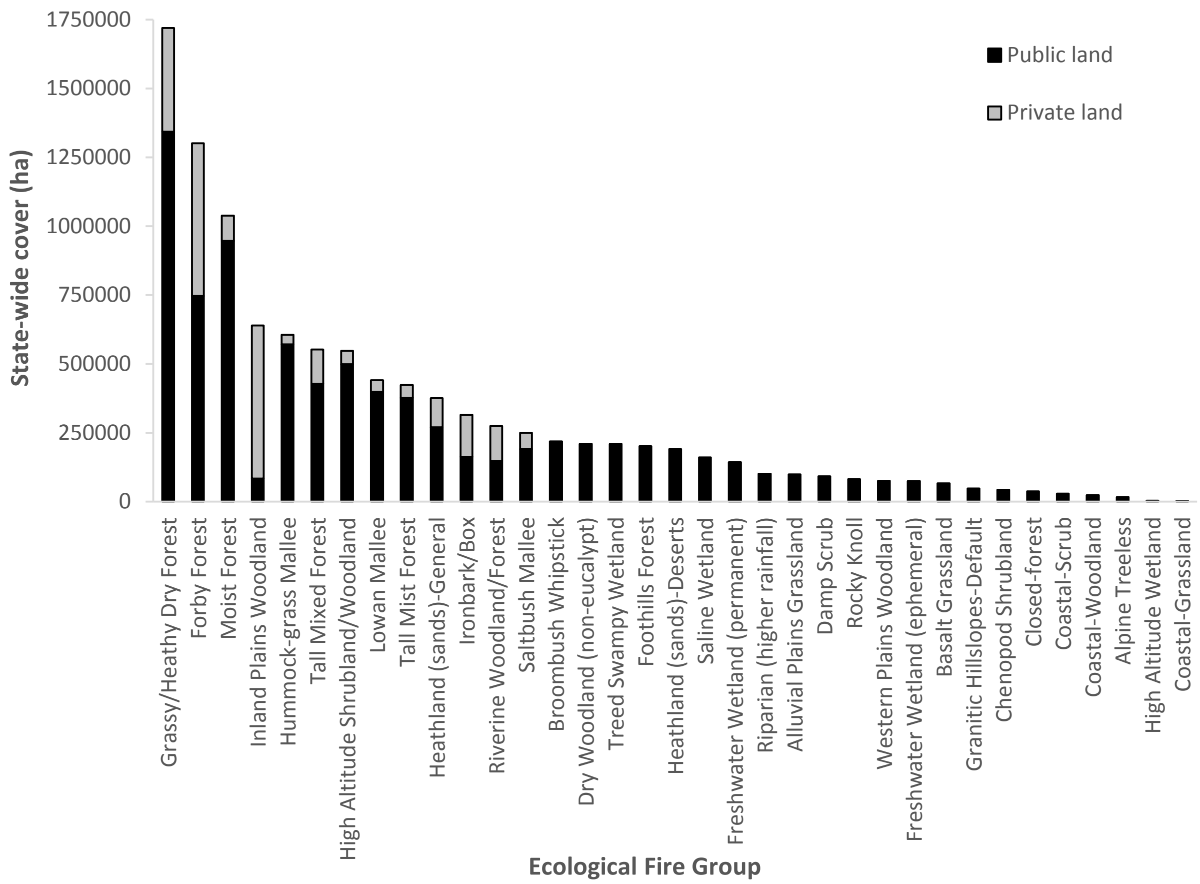


Figure 7.1. Overall cover of 35 Ecological Fire Groups mapped across Victoria. Relative cover on public (black) and private (grey) land is shown for those with cover >250,000 ha.

Based on these factors, a preliminary short-list of 10 priority EFGs was presented to DELWP staff for consultation. The shortlist included the top 10 EFGs, as based on their overall cover across the state, with the exception of Inland Plains Woodland. This EFG was excluded due to its highly fragmented nature, and predominant occurrence on private land (Figure 7.1, Table 7.1).

Feedback from landscape evaluators confirmed the exclusion of Inland Plains Woodland, and recommended the further exclusion of Tall Mist Forest and the inclusion of Foothills Forest and Heathland (sands)-Deserts (see Table 7.1). This resulted in a final list of 11 EFGs for state-wide monitoring that includes:

- Grassy/Heathy Dry Forest
- Forby Forest
- Moist Forest
- Hummock-grass Mallee
- Tall Mixed Forest
- Lowan Mallee
- Heathland (sands)-general
- Ironbark/Box
- Foothills Forest
- Heathland (sands)-Desert

- High Altitude
  Shrubland/Woodland

Collectively, these 11 EFGs comprise 69% of mapped native vegetation across the state (Figure 7.2), and all are regularly targeted for treatment by fuel reduction burns.

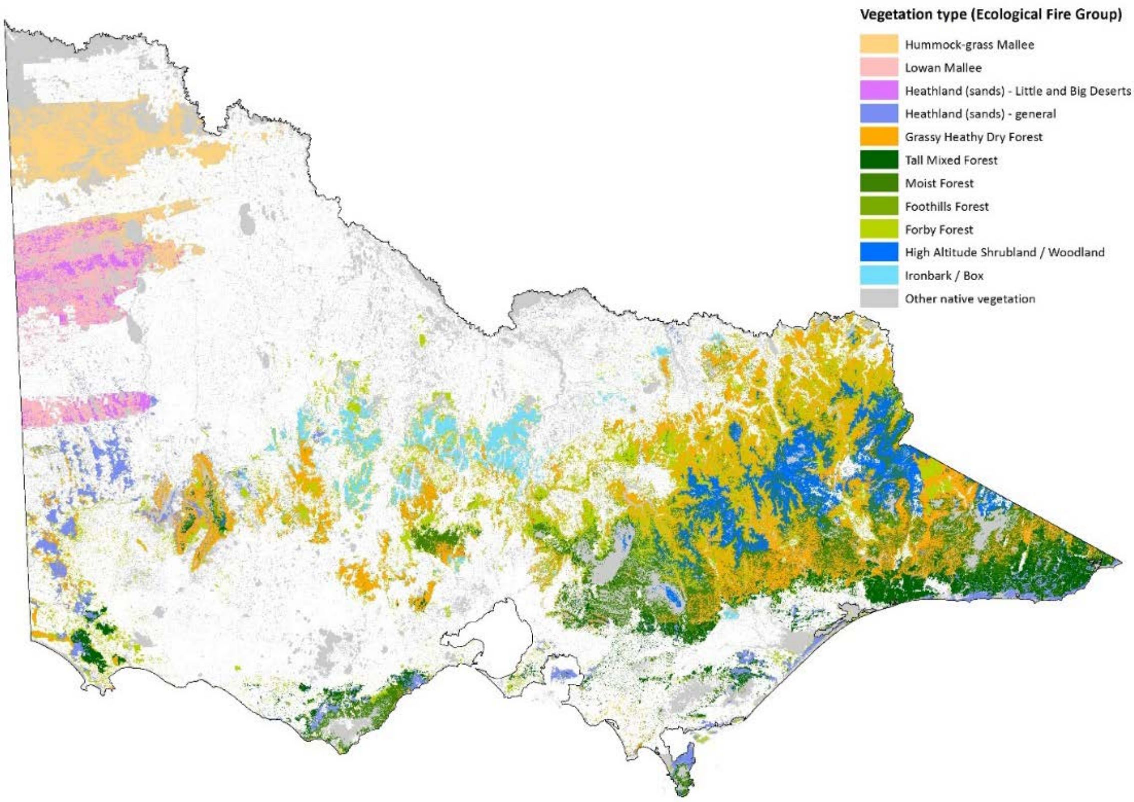


Figure 7.2. Distribution of 11 EFGs selected for monitoring within the state-wide stream of ERMER.

These 11 EFGs for state-wide monitoring vary widely in terms of existing empirical knowledge of relationships between fire and biota (as represented by Improvement KEQs) and past monitoring efforts. Good empirical understanding of fire-biota relationships already exists for five EFGs, such that additional monitoring at this stage would not greatly enhance or change current knowledge of associated ecosystem resilience metrics. These EFGs are Hummock-grass Mallee, and the four EFGs that collectively comprise the broader foothills forest system (Tall Mixed Forest, Moist Forest, Foothills Forest, Forby Forest). All have been the focus of considerable research attention (e.g. Mallee Fire and Biodiversity Project and Mallee Hawkeye; Foothills Fire and Biota project and contributing research projects). It is proposed that there is no need to monitor these EFGs in the first 'rotation' of state-wide monitoring.

Thus, monitoring within the state-wide stream of ERMER will target the following six EFGs as a matter of highest priority:

1. Grassy/Heathy Dry Forest,
2. Heathland (sands)-general,
3. Lowan Mallee,
4. Heathland (sands)-Deserts,
5. Ironbark/Box.
6. High Altitude Shrubland/Woodland

The prioritisation process to identify the order in which to monitor these EFGs considered a few factors: their spatial occurrence/distribution, and the fire history characteristics of each. We examined the time since fire (growth stage) and fire interval (TFI) gradients in each EFG to consider whether monitoring would yield adequate data to address the Improvement KEQs. For example, if the cover of a given EFG predominantly occurs in a single growth stage, this limits the capacity of resultant data to provide information about change in biodiversity *across* growth stages. Lastly, the potential for existing legacy sites to contribute to future monitoring was considered. Sites from legacy fire programs and the Victorian Forest Monitoring Program were examined to assess their potential suitability for inclusion within the state-wide ERMER site network. Preliminary selection criteria included: a) occurrence within the six priority EFGs, b) consistency of associated data with the state-wide ERMER methods (e.g. the PPFM indicator species, the HawkEye ground parrot survey, HawkEye weeds were all excluded due to the specific nature of field data collected), c) site access (e.g. VFMP sites listed as being 'difficult to access' or 'aborted' were excluded). Appendix 4 contains a summary of these assessments.

This process identified that, in most cases, it should be possible to ensure monitoring sites encompass relatively broad fire-regime gradients, although in some EFGs the availability of the oldest growth stage(s) is limited. The same is true for vegetation currently above the maximum tolerable fire interval. The notable exception is High Altitude Shrubland/Woodland, of which a large proportion was burnt in either 2003 or 2007 (see Appendix 4, Figure 2). Thus, because there is reduced potential to fully examine fire~biodiversity relationships over a range of fire ages and intervals, High Altitude Shrubland/Woodland is considered the lowest priority for monitoring out of the top six EFGs.

Of the remaining five EFGs, a second round of consultation with DELWP was undertaken. Based on this, it was determined that the first ('pilot') round of state-wide monitoring in ERMER would target Grassy/Heathy Dry Forest in the western region of Victoria.

Similar to Grassy/Heathy Dry Forest, the EFG 'Heathland (sands) – general' is broadly distributed across Victoria, occurring in relatively disjunct regions (see Appendix 4, Figure 6). To account for the influence of other environmental gradients (e.g. rainfall) on biodiversity across such large areas stratifying sampling within this EFG by geographic region (for example, west inland, Otways, and east coastal). All other EFGs (aside from those comprising the foothill forests) have more restricted distributions.

Prioritisation of monitoring within the remaining EFGs will depend on various considerations that could change over time. For example, the availability of funds, considerations about which region/s to focus on, status of existing knowledge about fire~biota relationships/ecological metrics, and intervening fire regimes. The steps outlined here provide a framework for undertaking this process in the future.

Table 7.1. Details of the 35 Ecological Fire Groups mapped across Victoria, including their proportional contribution to overall vegetation cover in the state, and inclusion in state-wide ERMER monitoring. Reasons for exclusion are given as relevant.

Ecological Fire Group	Prop^n of vegetation cover	Monitor at state-wide level?	Reason for exclusion
Grassy/Heathy Dry Forest	0.16	Yes	NA
Forby Forest	0.12	Yes	NA
Moist Forest	0.10	Yes	NA
Inland Plains Woodland	0.06	No	Predominately located on private land; patches highly fragmented
Hummock-grass Mallee	0.06	Yes	NA
Tall Mixed Forest	0.05	Yes	NA
High Altitude Shrubland/Woodland	0.05	Yes	NA
Lowan Mallee	0.04	Yes	NA
Tall Mist Forest	0.04	No	Not targeted for prescribed burning
Heathland (sands)-General	0.04	Yes	NA
Ironbark/Box	0.03	Yes	NA
Riverine Woodland/Forest	0.03	No	Patches highly fragmented and geographically dispersed
Saltbush Mallee	0.02	No	Low cover
Broombush Whipstick	0.02	No	Low cover
Dry Woodland (non-eucalypt)	0.02	No	Low cover
Treed Swampy Wetland	0.02	No	Low cover; reduced fire activity
Foothills Forest	0.02	Yes	NA (*included based on DELWP advice*: highly treatable and often burnt below TFI)
Heathland (sands)-Deserts	0.02	Yes	NA (*included based on DELWP advice*: closely intermixed with Lowan Mallee so managed together)
Saline Wetland	0.02	No	Low cover; reduced fire activity
Freshwater Wetland (permanent)	0.01	No	Low cover; reduced fire activity
Riparian (higher rainfall)	0.01	No	Low cover
Alluvial Plains Grassland	0.01	No	Low cover
Damp Scrub	0.01	No	Low cover
Rocky Knoll	0.01	No	Low cover; reduced fire activity
Western Plains Woodland	0.01	No	Low cover
Freshwater Wetland (ephemeral)	0.01	No	Low cover; reduced fire activity
Basalt Grassland	0.01	No	Low cover
Granitic Hillslopes-Default	<0.01	No	Low cover
Chenopod Shrubland	<0.01	No	Low cover
Closed-forest	<0.01	No	Low cover
Coastal-Scrub	<0.01	No	Low cover
Coastal-Woodland	<0.01	No	Low cover

8. Site selection – state-wide monitoring program

To address the Improvement KEQs, the design of the state-wide stream of ERMER involves stratifying sites on the basis of:

1) **vegetation type** (the unit on which resilience metrics are based: primary factor. Achieved by monitoring EFGs separately),
2) **fire age** (to represent growth stage/time since fire: primary factor), and
3) **fire interval** (to represent tolerable fire interval: secondary factor).

This section outlines a process for selecting sites on the basis of this broad design. It is anticipated site selection will be undertaken on an EFG-by-EFG basis, immediately prior to the monitoring of associated EFGs. This recommendation is made in order to reduce the potential for intervening fires to alter the fire history attributes of both the target EFG, and the already-selected sites.

In addition to the main stratifying factors of vegetation type, fire age and fire interval, a number of additional factors must be considered when selecting state-wide fire monitoring sites. Sites must be:

- within the target monitoring region (if relevant). For example, monitoring of a widely distributed EFG (e.g. Grassy/Heathy Dry Forest, Heathland (sands) – general) may be undertaken in two or more geographic regions, to reduce to influence of biogeographic factors on associated data
- on public land (to reduce issues with access for data collection),
- outside areas identified for planned burns in the current FOP (to avoid changes to fire age/interval before data collection)
- outside areas with mapped logging history (to reduce the impact of logging disturbance),
- outside designated Reference Areas (to accord with existing access restrictions)
- within patches of consistent EFG and fire history ≥ 5 ha in size (to avoid ecotones),
- distributed across the 'monitoring area' in a way that avoids spatial grouping of sites (overall, and of sites of similar fire history attributes). For example, avoid locating all sites burnt 0-5 years ago in the same fire scar/close to each other if alternative patches of 0-5 year old vegetation are available further away.
- at least 100 m from roads and tracks (to reduce disturbance and edge effects),
- at least 50 m from the edge of the vegetation/fire history patch boundary (where discernible: to ensure sites represent desired attributes and do not sample ecotones),
- at least 1 km away from other monitoring sites (for spatial independence).

The process for identifying potential (i.e. subject to ground-truthing in the field) monitoring sites that meet these criteria involves the following sequential steps (Figure 8.1):

1) summarise the fire age and interval attributes of the target EFG that is 'suitable' for monitoring (e.g. accounting for the first five criteria outlined above),
2) assess the attributes (e.g. EFG, fire age, fire interval, location) of existing legacy fire/forest monitoring sites to determine their suitability for inclusion in state-wide ERMER monitoring.
3) determine how to distribute the required number of monitoring sites (i.e. 200 per EFG, plus some extra 'back-up' sites) across the available fire-age gradient to capture as much

variation as possible. This step should consider suitable legacy sites (e.g. the outcome of step 2),

4) locate potential monitoring sites within patches of the requisite fire history attributes, for final ground-truthing in the field.

All these steps are desktop-based, however it is recommended that local input and ground-truthing of site attributes be sought prior to commencing monitoring to assess the likely suitability of potential monitoring sites. Each step is outlined in more detail below.

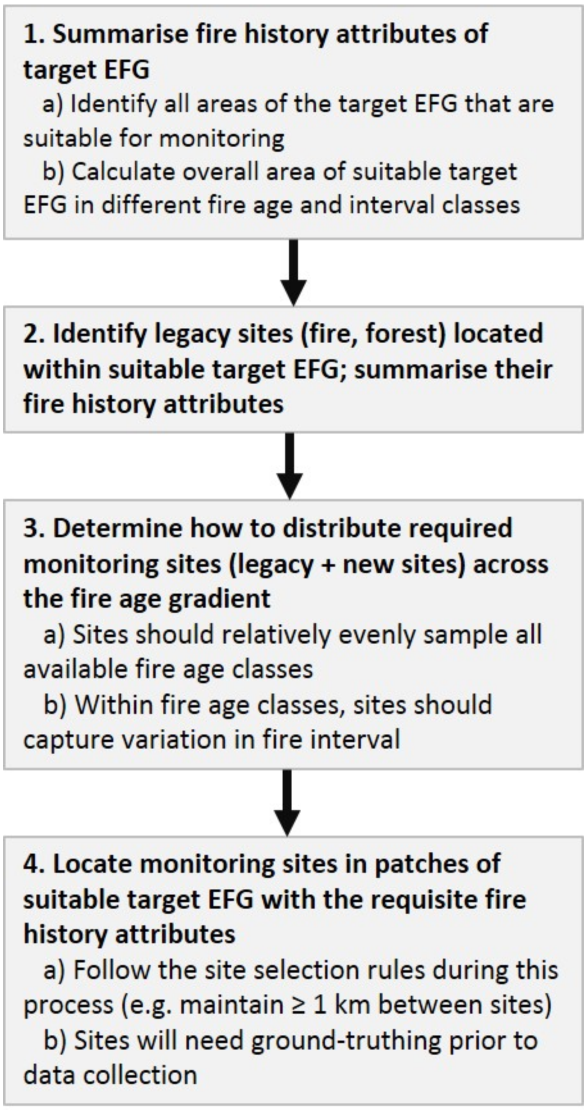


Figure 8.1. Summary of the key steps involved in selecting sites for monitoring within the state-wide stream of ERMER.

Step 1

Assemble the spatial data required to identify the parts of the target EFG that are suitable for establishing state-wide sites. Relevant layers will be those providing information on:

- vegetation type (i.e. EFG/EVC classes)
- fire history and planned burns (i.e. FireHAT, FOP layers)
- public land management (including Reference Areas)
- logging history

Using these layers, identify areas of the target EFG that: have a mapped fire history (i.e. sites with no recorded fires excluded), are on public land (but outside of Reference Areas), are outside of areas identified for future prescribed fire, and have no record of past logging activity. It may also be preferable to exclude some associated EVCs that have restricted/reduced cover, in order to minimise variability associated with vegetation and underlying environmental gradients (soils etc.). The resultant patches of the target EFG are those considered suitable for monitoring.

Summarise the fire age and interval attributes of the suitable target EFG, in terms of overall area and number of patches of different fire age and interval. This should be done using the latest version of FireHAT. Note that information on fire age (cf. LASTFIRE year) and the most recent fire interval may need to be calculated specifically. The area/number of patches of suitable target EFG should also be summarised into the following classes:

- fire age classes: 0-5 years, 6-10 years, 11-20 years, 21-30 years, 31-40 years, and so on until the maximum fire age.
- fire interval classes: below minimum TFI (for low intensity fire), within TFI, above maximum TFI, no interval data (e.g. for patches burnt only once). See Cheal (2010) for TFI values for all EFGs.

A procedure for automating this step has been created within ArcMap Model Builder (code provided to MER unit).

Step 2

Identify all existing legacy sites (past fire monitoring sites, and Victorian Forest Monitoring Program sites) that occur within the suitable target EFG, and determine their (current) fire age and most recent fire interval. Where possible, these sites should be prioritised for inclusion in the final set of potential monitoring sites.

Spatial proximity (i.e. <1 km between sites) may mean not all legacy sites can be included. In such cases, prioritise those that have sampled the greatest range of different taxa (e.g. birds/habitat/flora cf. flora). A lack of fire interval data may also mean legacy sites are excluded from consideration.

Step 3

To ensure data can address the Improvement KEQs, the set of monitoring sites must incorporate variation in both fire age and recent interval. Unless there are strongly under-represented fire age classes, such that these cannot be sampled as intensively as others, it is recommended that the overall number of monitoring sites (i.e. ~200 per EFG) be distributed evenly across the available fire-age classes. The recommended fire age-classes nominated to guide site selection are the same as those identified above (e.g. 0-5 years, 6-10 years, 11-20 years, 21-30 years etc.). These classes will provide for a range of encompassed variation in fire age, whilst also aligning reasonably well with the growth stages identified for different EFGs.

Fire age-class is the primary fire history attribute by which to stratify site selection; however, within each fire age-class, sites should also capture the available variation in most recent fire interval. As outlined above, it is suggested that fire interval classes be based on the tolerable fire intervals identified for each EFG (e.g. <minTFI, within TFI, > maxTFI). In addition, a fourth class will be required for areas (and legacy sites) for which there is only one mapped fire, and so no information on fire interval.

It is recommended that, at this stage, additional 'contingency' sites be selected within each fire age-class. This is to ensure that sufficient sites are identified during the desktop-based site selection process to cover the eventuality of some being deemed unsuitable in the field. Alternatively, additional sites may need to be identified whilst on-ground monitoring is underway, if additional sites are required.

Note that sites are not stratified by previous fire type (planned burn/bushfire), as adequately sampling both fire types would lead to a further increase in required sample size and in many instances would not be possible due to the vagaries of fire history. Fire type (or fire severity) can be included as a covariate in analyses.

The outcome of this step is a list of the number of monitoring sites to select in each fire age-class, after accounting for existing legacy sites (and including additional sites for field attrition, if desired).

Step 4

The primary factor on which site selection is stratified is fire age: Step 3 determined how many sites are to be selected within each fire age-class. Sites *within* each fire age class should be selected to encompass variation in fire interval classes (avoiding the 'no interval' class if possible). This final step involves identifying potential locations with the requisite fire age and interval attributes for the required number of sites. Sites will need to be ground-truthed to determine their suitability (accuracy of fire history and vegetation type, accessibility etc.) prior to monitoring and replaced with sites of similar EFG/fire history drawn from the pool of contingency sites identified in Step 3 if required.

It is recommended the process of site selection be done on a sequential basis, working from the fire age-class with least overall cover (likely to be the hardest in which to locate suitable sites) to the most common. Similarly, when ensuring sites in each age class represent all available interval classes, select sites in the class (most likely to be > max TFI) with least overall cover first.

Site selection rules:

The process of site selection will be guided by some rules, but most can be relaxed slightly if it allows for a more complete sampling of the fire gradients (i.e. ensures 'rarer' age/interval classes can be sampled).

- Fire-history patches should be at least 5 ha in size (to increase the likelihood of accurate vegetation/fire attributes in the field). Note this minimum patch-area rule relates to EFG patches, not the finer level of detail represented by EVCs.

- One site should be allocated to each fire-history patch (to help ensure data are independent).
- Sites of the same fire age-class should be distributed so as to maximise geographic spread across the extent of suitable target EFG (to avoid spatial clustering of sites of similar fire-age, and interval where possible).
- Sites should be at least 1 km apart (to ensure data are independent).
- Sites should be at least 50 m from the patch edge, where discernible (to avoid ecotones, and ensure sites represent the desired attributes).
- Sites should be at least 100 m from roads/tracks (to disturbance and edge effects).

It is anticipated that some sites may be moved (or determined to be unsuitable) following ground-truthing. It is highly recommended that the attributes of selected monitoring sites be assessed regularly throughout the process of ground-truthing and site selection, to ensure the final set of sites fulfils the original design.

9. ERMER field survey methods

The methods outlined in this chapter have been devised to provide the data required to address KEQs covered by the state-wide stream of ERMER. However, it would be advantageous to also use these methods for regionally-based monitoring as much as possible, so as to maximise consistency of data across both streams of the ERMER program. Note that more detailed versions of these methods (Work Instructions) have been submitted to DELWP; these documents, rather than the summary presented here, should be used in applying these methods in the field.

We propose that data collection for the state-wide component of the ERMER program be focussed on the following:

- Vegetation/habitat structure
- Flora
- Ground-dwelling mammals
- Birds

Focussing on these groups has several advantages:

- Provides data required to address KEQs
- Provides data on large number of fauna (and flora) species as required for GMA calculations (Sitters et al. 2018) and other decision making analyses
- Data can be collected with relatively simple, standard methods, that require minimal field infrastructure (cf. e.g. pitfall trapping for reptiles)
- There is a relatively large pool of people within and outside DELWP with expertise to identify flora, birds and mammals
- Previous fire-related monitoring/research programs in Victoria ('legacy' programs) have focussed on similar sets of taxa, hence there is potential to combine new and existing data sets
- Automated data collection is possible at present (camera trapping), or is likely to be in the near future (sound recorders, LiDAR; see below).

We recognise that other taxa are of ecological importance (e.g. invertebrates, reptiles, fungi). If desired, other groups could be surveyed as part of the regional stream of ERMER, or incorporated into state-wide ERMER in the future.

We recommend a quality assurance process is put in place to ensure the integrity of field collected data. In a large data collection program involving multiple observers, such as the state-wide stream proposed here, there is a risk of inconsistencies between observers introducing biases in data. In addition, there is always potential for measurement and recording errors in the field. Obviously, it would be beneficial to minimise these extraneous sources of variation in data. A good model for quality assurance in this context is the process used within the Victorian Forest Monitoring Program, which utilises field auditing (resurveying) of sites and desk top checking for errors and anomalies in data.

Methods

1. Site establishment

The network of state-wide ERMER survey sites is designed to encompass as fully as possible gradients of time since fire and fire interval within target vegetation types (EFGs). The initial identification of suitable sites will be based on DELWP vegetation and fire mapping. While every effort should be made to ensure that the fire history/vegetation attributes of sites are correct, sites will not necessarily have been ground-truthed prior to surveys being carried out. Therefore, it is important to verify site fire/vegetation attributes before commencing surveys.

A 'site' consists of an area ≥ 5ha of consistent fire history and EFG. The requirement for consistent EFG over 5ha can be relaxed for vegetation types that typically have environmentally constrained distributions (e.g. occur along gully lines or water courses) or where EFGs typically occur in a complex or mosaic (e.g. Forby Forest interspersed with damp forest along gullies). Similarly, variation in fire history within sites is permitted where this is typical of fire regimes within the system in question (e.g. unburnt gullies within burnt matrix). However, in these cases, EFG/fire history patch size must be sufficient to accommodate the sampling methods described below without sampling crossing a boundary into a different EFG/fire history.

Method:

- **Navigate to provided site coordinates**
- **Verify that site EFG and time since fire attributes (as per 'site' definition above) appear correct**. Visually check EFG and apparent time since fire over site (bearing in mind site definition above). For EFG see relevant EVD description (Cheal 2010). Time since fire is difficult to determine precisely on the ground, but major discrepancies between the mapped and actual time since fire of sites should be apparent through indicators such as bark charring, stem diameters and height of species that (re-)establish post fire and vegetation structure generally.
- **Record site attributes as per 'MER site establishment data sheet'**.
- **If site attributes appear correct, place site marker (metal stake) and record GPS coordinates (GDA 94).** This marker will form the '0' mark of the vegetation structure transect (see below), so ensure it is far enough from any vegetation type/fire history boundary to allow sufficient space (i.e. 100 m) for the transect.
- **If site attributes are not correct, relocate site to location with correct EFG/fire history attributes within same general area if possible, and mark as above.** If no 'correct' sites are available, record this on data sheet and do not proceed further with surveys at that site.

2. Flora and vegetation/habitat structure

Equipment:

- GPS
- 100 m tape
- Stakes

- Hammer
- Compass
- Clinometer
- Structure pole (~20 mm x 2 m wooden rod or similar)
- Tree callipers or diameter tape
- Clinometer/Vertex/height meter
- ‘Bottle opener’ dendrometer/wedge prisms/rod relascope
- Range finder
- Densitometer
- ERMER program vegetation structure and flora data sheets

From site marker (see above), extend tape measure 100 m parallel to contour (i.e. across, rather than up and down, slope). Ensure tape is as straight as possible. If deviations in line are unavoidable, mark bends with metal stake. Mark 100 m point with metal stake and record coordinates. Take photos looking along the transect from both the 0 and 100 m marks, and looking in the four cardinal directions (N, S, E, W) at these points.

Along transect, record data as per Table 9.1 below and ‘ERMER program vegetation structure data sheet’ (see Figure 9.2).

Record flora along transect as per Table 9.1 and ‘ERMER program flora data sheet’. For “minimum TFI” species (see list in associated Work Instruction document), record whether plants have reached reproductive maturity (i.e. have evidence of flower/seed production, or have reached size where this likely to have occurred) and the evidence observed to reach this conclusion (fruit/seed present, flowers present, size).

Flora surveys should be conducted in spring-early summer to maximise species visibility and when identification is likely to be easiest due to the presence of flowers.

Table 9.1. Variables recorded and methods for flora/vegetation surveys.

Variable	Unit	Method
Topography	Recorded at three points (0, 50 and 100 m) along the transect	
Slope	Degrees	Clinometer
Aspect	Degrees	Compass
Trees[1]	Recorded at three points (0, 50 and 100 m) along the transect	
Height of tallest live canopy tree within 25 m radius	Metres	Clinometer/Vertex/height meter
Height of tallest live sub-canopy[2] tree within 25 m radius	Metres	Clinometer/Vertex/height meter
DBHOB[3] of largest live tree within 25 m radius	Centimetres	Use diameter tape or callipers to measure stem diameter at 1.3m above ground.
Basal area[4] eucalypts	m2/ha	Angle count using dendrometer/wedge prism/rod relascope
Basal area non-eucalypts	m2/ha	Angle count using dendrometer/wedge prism/rod relascope
Basal area dead trees	m2/ha	Angle count using dendrometer/wedge prism/rod relascope
Tree density (point-centred quarter method Figure 9.1)	Stems/ha	Distance to nearest tree (live or dead) within each quadrant of cross aligned parallel/perpendicular to transect. If no tree is present with 25 m of sample point in any quadrant, record quadrant as 'empty'. For multi-stemmed trees record distance to main stem (i.e. below split), or centre of clump of stems for mallee form trees
Overstorey DBHOB	Centimetres	DBHOB at 1.3 m of the two nearest trees within each PCQ quadrant within 25m of sample point.
Hollows	P/A	Presence or absence of visible hollows in the eight trees measured for DBH. Classify as **B**asal or **E**levated (in upper stem/branches) or **N**one.
Log cover	Centimetres	Intercept of logs beneath transect (i.e. sum of transect length covered by logs)
Log number	Count	Count of logs (total and hollow) intercepted by transect, allocated to diameter classes: small = 10-20cm, medium = 20-40cm, large = ≥40cm In mallee: small = 5-10cm, medium = 10-20cm, large = ≥20cm Record logs that are connected (e.g. large branches of a fallen tree) as separate logs.

Table 9.1 cont.

Species/vegetation cover	Recorded at 33 locations spaced every 3 m along the transect using structure pole (200 x ~1.5 cm)	
Ground cover type	P/A	Within categories: bare, litter, moss/lichen, rock, CWD, log
Litter depth (if ground cover is litter)	Centimetres	Measured to nearest cm at each of the 33 sampling points where vegetation cover is measured
Species/vegetation cover	P/A	Record species touching pole within height strata. Only record one touch per species per height stratum at each sample point, even if a species touches more than once in that stratum. Also record elevated dead material (excluding logs) as part of this survey. Height classes = 0-20cm, 20-50cm, 50-100cm, 100-200cm, 200-400cm[5] Species converted to life categories at data entry stage Life forms = Fern, forb, grass, graminoid, shrub, tree
Sub-canopy	P/A	Whether or not vegetation is visible above the crosshairs of a densitometer. Record species.
Canopy	P/A	Whether or not vegetation is visible above the crosshairs of a densitometer. Record species.
Additional plant species	P/A	Record species present within 2 m wide band along right hand side of transect (looking from 0-100 m) that were **not** recorded in pole intercept survey above.

[1]'Tree' for this component of the survey means trees with stem diameter > 10cm (i.e. exclude seedlings/saplings), except in mallee vegetation, where stems of all sizes are included.
[2]'sub-canopy' = trees/shrubs in height range between 4m and base of canopy layer. Note that in mallee and similar vegetation the canopy layer may be <4m, and would be recorded as such (i.e. no sub-canopy would be recorded).
[3]for DBHOB measurements of multi-stemmed trees (stems diverge below 1.3m), measure all stems and assign records to single tree (i.e. one tree, but several DBHs recorded). For mallee form trees, if more than five stems are present, randomly select five for measurement.
[4]for basal area measurement of multi-stemmed trees: if split occurs above ground, assess stem below split; if split is at or below ground level e.g. mallee form trees, assess each stem individually
[5]visually estimate 'touches' in 200-400 cm range above top of pole.

Definitions:

Hollow (tree) = cavity in tree >20 mm diameter that appears to extend beyond the surface of bark/wood (i.e. has some 'depth' such that it could shelter a bird or mammal), or fissure extending beyond outer surface into interior of tree.

Hollow (log) = as per above and/or ends of log are open

Litter = dead plant material (leaves twigs etc.) up to 1 cm diameter on ground

Coarse woody debris (CWD) = woody material 1-10 cm diameter on ground (1-5 cm in mallee vegetation)

Log = tree branches and stems > 50 cm in length and >10 cm diameter (> 5cm in mallee vegetation)

Note: Modification of flora survey to record plant life-form cover

While plant species cover is required for state-wide stream surveys, and desirable for regional stream surveys, there is potential that for regional-stream monitoring, depending on the question being addressed, only data on plant life-form cover will be required. Alternatively, personnel with expertise to carry out full floristic surveys may not be available. In these cases the floristic survey can be modified to record plant life-form cover. To do this, use a structure pole at 3 m intervals along the transect as for floristic survey, but record *lifeforms* touching the pole (Life forms = Fern, forb, grass, graminoid, shrub, tree). As with plant species, only record one touch per lifeform per height class. This modified method will provide lifeform cover data consistent with that obtained from the full floristic survey i.e. lifeform cover data recorded by either method can be combined.

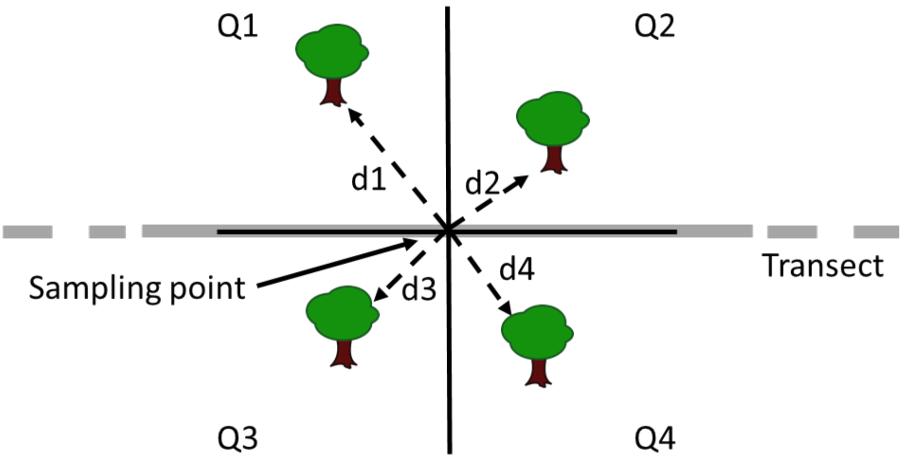


Figure 9.1. Point-centred quarter method for estimating tree density. Sampling cross located at sampling points at 0, 50 and 100 m along transect. Measure distance to nearest tree (d1-d4) in each quadrant (Q1-Q4). Mean of distances is proportional to tree density. If no tree is present with 25 m of sample point in any quadrant, record quadrant as ‘empty’.

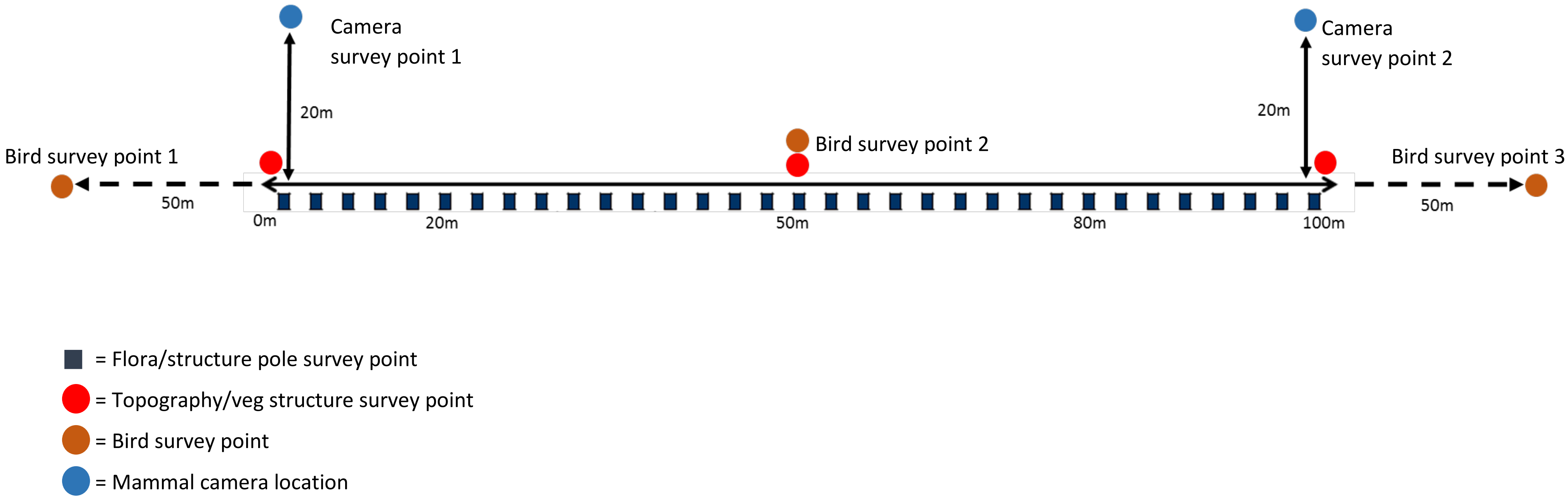


Figure 9.2. Schematic diagram of monitoring site.

3. Ground-dwelling mammals

Equipment:

- Reconyx HC500/550 cameras
- Batteries
- SD cards
- Bungee cord or similar to attach cameras to trees/stakes
- Python locks
- Bait holders (5 x tea infusers or 1 x vented PVC pipe per herbivore camera; 1 x vented PVC pipe and 1 x wire mesh cage per predator camera)
- Bait (herbivores: rolled oats, peanut butter, golden syrup, vanilla essence; predators: blood and bone, tuna oil)
- Stakes (2x per site for bait stations, plus additional as required for cameras)
- Hammer
- GPS
- DELWP MER program ID tags
- Small white board and marker
- ERMER program camera survey data sheet

Camera deployment

Deploy two infra-red motion-detecting cameras (recommend Reconyx HC500/550 or similar) per site for 21 days. Place cameras at approximately the 0 m (point 1) and 100 m (point 2) points of the transect (offset 20 m to the left of the transect, looking from 0-100 m) used for vegetation and floristic surveys (Figure 9.2). Record coordinates of camera points. The camera at point 1 will be baited to attract primarily herbivorous/omnivorous mammals and use a white flash for photographs (use Reconyx HC 550), while the camera at point 2 will target predators and use infra-red flash (use Reconyx HC 500).

Attach cameras to a tree (or stake if no conveniently located trees) using a bungee cord or similar, at 50 cm above the ground, oriented towards the south to reduce false triggers resulting from direct sunlight (Figure 9.3). Secure camera with python lock or similar. Attach DEWLP MER program ID tag to camera.

Bait cameras as follows:

- Herbivore cameras (point 1): five tea infusers or vented PVC pipe bait holder (use same bait holder and volume of bait i.e. approximately five teaspoons for all sites) containing mix of rolled oats, peanut butter, golden syrup and vanilla essence. Attach bait holder(s) to a stake at approximately 40 cm above the ground and 1.7 m from the camera.
- Predator cameras (point 2): mix of blood and bone and tuna oil, secured within PVC pipe bait holder or similar. Attach bait to a stake at approximately 1 m above the ground and 3 m from the camera.

Angle the camera slightly downward so it captures the base of the bait station stake in the middle of the frame, to ensure a consistent field of ‘detection’ as a function of the camera to bait station distance. The base of the stake should be centre-frame or just below centre frame in order to maximise detections of small species. Use wedges or objects such as short sticks or rocks wedged behind the camera to adjust camera orientation. Remove any vegetation or other obstacles within the camera field of view that may obscure animals in photographs and/or cause false triggers of camera.

To test if the camera is positioned correctly, arm the camera, move your hand from side to side several times in front and behind the base of the bait station, and to both sides of the bait station. Turn off the camera, remove the SD card and view the images in a hand-held digital camera. Re-insert the SD card in the remote camera, delete the images, adjust the camera position and repeat the exercise as necessary

Set cameras to take photographs 24 hours per day with the following settings: highest sensitivity and resolution with five shots per trigger, no interval between photos or triggers. Once each camera is set up, use it to take a photograph of a small whiteboard or similar on which is clearly written: site ID, survey point ID, date, camera ID, SD card ID, and recorders name(s).

Record details of camera deployment as per 'ERMER program camera survey data sheet'.

Camera recovery

Approach the camera from the front to trigger a 'capture' sequence. This indicates the end of the sampling period when analysing the camera photos back at the office.

Open the remote camera unit and check the display for the current capture sequence. If the screen is blank move your hand in front of the sensor to trigger a sequence. If the display is still blank, switch the camera off and on again to determine whether the camera is operational. It is important to confirm whether or not the camera was operational for the whole survey period. If there is no capture sequence on recovery of the camera it makes it impossible to know whether the camera was operational for the full deployment period. For example if the last image occurs in week 2, this could reflect either no animals at the site post week 2 or a camera malfunction sometime post this time.

Cross check that the camera, SD card and site information match the deployment data sheet. Record whether camera was operational at recovery (as per above).

If the bait station is missing have a look around to recover the bait station. Record if bait station is missing or any other site conditions that may have changed since setting the camera.

Record details of camera recovery as per 'ERMER program camera survey data sheet'.

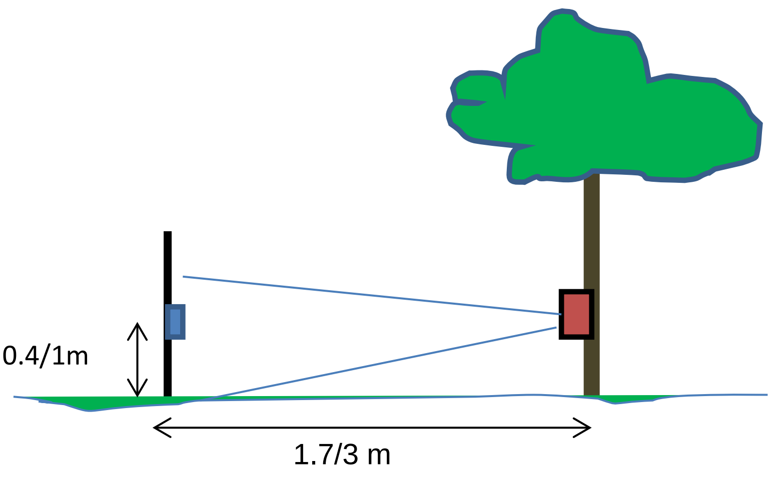


Figure 9.3. Camera set up. = bait station; = Camera

4. Birds

Equipment:

- Binoculars
- Range finder
- GPS
- ERMER bird survey data sheet

Bird surveys will consist of three seven minute point counts, carried out four times per site. Each point count is focussed on a 46 m radius circular 'plot' (Figure 9.3). The survey area and duration of the three point counts combined (~2 ha, 21 minutes) approximates the survey effort of the widely used 20 minute 2ha search method (Loyn 1986). The point count method recommended here will allow estimation of species detectability and hence more robust estimation of species presence/absence and abundance. It also has benefits with regard to repeatability (easy to ensure future surveys are carried out precisely at the same locations) and logistics (observers do not need to traverse potentially rugged terrain while observing birds).

Each survey (i.e. set of three point counts per site) should be carried out by a single observer, but if multiple observers are available, the four surveys per site should be shared amongst them (i.e. all four surveys at a site should not be carried out by the same person). In addition the four surveys should be carried out on different days and at different times (i.e. equal mix of morning/afternoon surveys within each site).

Surveys should be carried out in spring-early summer (September-December) when bird activity and species presence peaks, with the four surveys per site spread across this period. Surveys should not be undertaken when the temperature is >30°, during rain or when wind speed exceeds 38 kmh^{-1} (Beaufort scale 5, fresh breeze).

The three point counts per survey will be carried out at the 0, 100 and 200 points of a 200m transect centred on the 100m vegetation transect described above (Figure 9.2, 9.4). For each point count, record site, date, time, point count number/location and weather conditions as per 'ERMER bird survey data sheet'. Record all bird species seen and/or heard and the distance band in which they occur (0-5m, 5-10m, 10-15m, 15-25m, 25-46m, >46m ; use a range finder to assist with accuracy). Estimate abundance for both visual and aural observations, taking care not double count birds (e.g. if an individual is initially heard and subsequently comes into view, do not record as separate observations; if the same individual/s is both seen and heard, it/they should be recorded as 'seen'). Similarly, do not double count individuals that occur in more than one point count. Only include birds that are using habitat within the site (e.g. foraging, perching, nesting) or are actively engaged in foraging overhead (e.g. aerial insectivores). Birds that simply fly over the site should be recorded as incidental records.

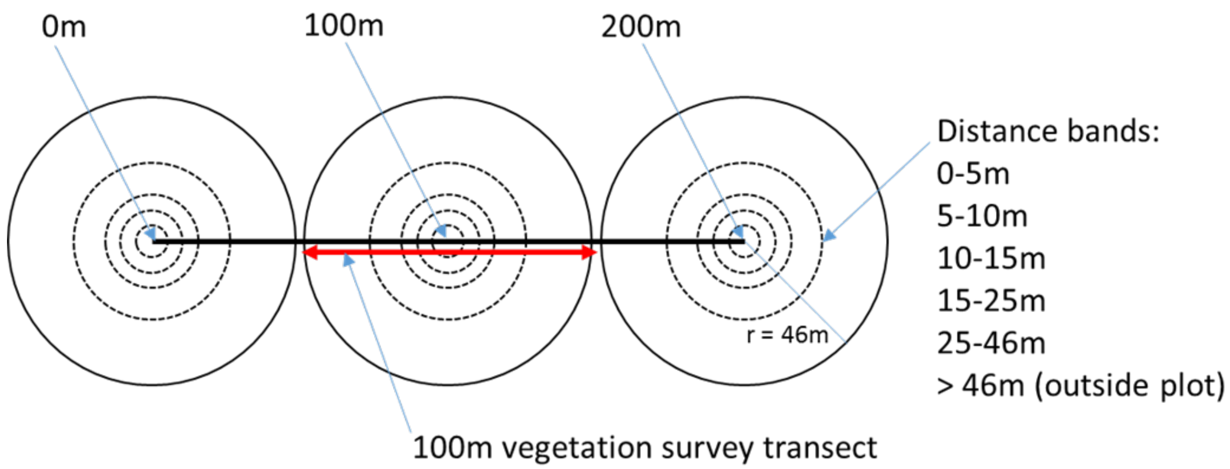


Figure 9.4. Layout of bird point surveys within a site.

Future survey options

Vegetation structure

LiDAR

Aerial or ground-based LiDAR (Light Direction and Ranging) has great promise as a method for efficiently recording vegetation structure data (e.g. cover within height strata, tree height, density and diameter) and is likely to become a commonly used technique within the next decade.

The main advantage of this approach is that it can rapidly acquire fine-grained data on vegetation structure. It would also allow structure to be characterised over patch-landscape scales, rather than at plot scale as with traditional techniques.

One disadvantage of LiDAR is the relatively high cost of acquiring data and/or buying equipment (e.g. ~$25K for a handheld ground-based unit), though cost is likely to decrease rapidly over time. LiDAR also does not (at this stage) allow cover of different lifeforms/components to be derived; cover measurements are simply total vegetation cover, though this can be split into various height strata. Similarly, it does not provide information on species composition or abundance. However, it may be possible to use LiDAR data in conjunction with manually collected data to produce models or 'rules of thumb' to infer what cover in different strata represents (e.g. in Foothills Forest, most cover in the 1-4 m range is shrubs). In addition, protocols and workflows for processing data to provide metrics relevant to the MER program are yet to be determined, and it may require a dedicated project to do this.

We recommend that initial surveys within the ERMER program be based on the 'traditional' methods outlined above. It would be beneficial to acquire LiDAR data/equipment and conduct trials on sites surveyed manually, which would allow the data collected by the different methods to be compared and inform development of LiDAR-based methods for future use.

Birds

Sound recorders

Like LiDAR in the case of vegetation structure, sound recorders hold the promise of dramatically improving data collection efficiency. DEWLP staff have conducted a trial of recorders (recording for five minutes three times per day for 18-21 days) compared with a standard survey technique (2 ha, 20 minute search; L. Bluff pers comm.). With regard to detecting species, the main findings were:

- Across the combined dataset, 55 species were detected by both methods, 3 species were detected by standard surveys but not recorders, and 26 species were detected by recorders but not standard surveys.
- Recorders detect more species per person-hour and per dollar, taking both field and desk time into account.
- A fixed cost survey designed around recorders would achieve a higher degree of site-level completeness across a larger set of sites.
- A hybrid method combining analysis of ~9 sound files with two standard surveys per site would be approximately the same cost as three standard surveys per site, but would double the count of species detected per site.

Recorders also performed similarly to the standard method in providing an estimate of relative abundance.

While recorders markedly reduced time spent in the field, processing data (i.e. determining what species have been recorded) remains a major and specialist task. While work is currently underway on automating bird call recognition, it appears that this is still some way from being operational.

We recommend that sound recorders be deployed at ERMER sites in coming field seasons (in conjunction with camera traps would probably work well), using similar methods to the previous trial. Data collected could be compared to that collected manually to augment the previous trial. Alternatively, even if the recorder data were not used immediately, and were simply stored until personnel or an automated method were available for processing, with the set up cost being negligible (if deployed at same time as cameras), it would still be worthwhile to carry out recorder surveys.

10. Analysis and reporting

This chapter provides an overview of the process of using monitoring data to answer MQs/KEQs, and evaluate the management implications of results. The steps below outline a general approach to data analysis and reporting. Details of analysis approach, results interpretation, evaluation and reporting for each KEQ/MQ are given in the 'data analysis', 'results', 'interpretation', 'reporting' and 'change' columns of the KEQ table in Appendix 2.

Note that we have deliberately not provided detailed protocols or 'recipes' for data analysis (in the form of analysis code etc.). This is because of the complexity of the analyses that will be required, and the likelihood that question and dataset-specific decisions will be required during the course of analyses. Answering most KEQs will require analysis of multiple response variables (e.g. species). While it is possible to identify a general analysis approach for each KEQ (as in Appendix 2), different response variables are likely to require variations on the general approach depending on the nature of the data. Obtaining robust results will involve iteratively fitting various forms of models and checking results and model diagnostics until the most appropriate model is identified. Having produced a 'correct' (i.e. statistically appropriate) model, it is then necessary to interpret the results both statistically (e.g. "How strong is a relationship/effect?" "What is the predictive power of the model?"), as well as in terms of sensibility (i.e. "Does the result accord with our understanding of the system?"). These processes require specialist input from a person or team experienced in ecological modelling and with good knowledge of the relevant ecosystems. This would be a key part of the 'scientific coordinator' role outlined above (Chapter 5). A 'recipe book' approach to these analyses runs a high risk of producing unreliable models and hence drawing flawed conclusions. However, notwithstanding this, the process of analysing the initial data sets collected within the ERMER program are likely to provide valuable guidance for subsequent analyses. Therefore, we recommend that these initial analyses be carried out as a dedicated 'pilot study', with processes and outcomes well documented such that they may inform future work.

Analysis, evaluation and reporting steps

1. **Revisit management objective, KEQ and MQ underpinning the collection of monitoring data.**

Clarity as to the objective of the analysis process (i.e. the question) will help keep analyses focussed.

2. **Identify best analytical approach**

Analytical approaches that are likely to be most applicable to each KEQ are identified in Appendix 2. These mostly consist of some form of Generalised Linear/Additive (Mixed) Model. Other approaches, such as boosted regression tree analysis and multivariate approaches, may also be useful for some KEQs.

3. **Assemble required data**

The primary response and predictor variables relevant to each KEQ/MQ are given in the 'Data' column of Appendix 2. Other predictor variables (co-variates) may also need to be included in analyses. Site/field data metrics relevant to each KEQ are shown in Appendix 5. Data will need to be extracted from the central MER database and assembled in spreadsheet(s) or similar in a format appropriate for input into analysis. A common format is a matrix with samples/sites as rows and predictor and response variables as columns. Checking of data, for completeness and any likely errors, is a critical requirement and is especially important when data collection and analysis is carried out by different people, as will be the case here.

4. **Preliminary data exploration**

This step involves further data assessment and manipulation, such as:

- finalising which variables (predictor and response) to include in analyses. For example, which species have adequate data for statistical analyses; which species to include in multivariate analyses; is it necessary to include covariate predictors in models?
- checking that data meet the assumptions of the analytical approach (e.g. independence, distributional requirements, variance considerations, collinearity);
- considering the need for data transformations, standardisations;
- deciding on model specification (e.g. linear or non-linear relationships, interaction terms required).

5. **Undertake data analyses**

This step may involve a few iterations before data analyses are finalised. Code for undertaking analyses will be required, as is expertise in using statistical packages and interpreting results. Analysis process, including code, should be documented for quality assurance and to inform future analyses.

6. **Sensibility check of results**

Consider whether results make ecological sense, answer the original question, inform the management issue, or could be examined in a different way. Several iterations of steps 2 to 6 may be required before analyses and results are finalised. This is to be expected, and must be factored into the time allocated for the completion of this stage.

7. **Interpret results**

Evaluate what the results mean in relation to the management issue and KEQ being addressed.

8. **Compare results of management threshold for change**

Ideally there will be an *a priori* defined threshold to trigger management change that results can be compared to. This will not always be the case, and in such situations, it will be a matter of considering results in light of the management objective they inform, and deciding whether results provide evidence to warrant updated management/conceptual models.

9. **Reporting**

This step involves collating outputs of steps 5-8 to provide a clear summary of results and their implications with regard to management actions. This may include:

- presentation of results (tables, graphs, summaries of data, etc.)
- evaluation of what results mean in light of management issue and KEQ
- assessment of whether management threshold has been crossed.

The KEQ pathways (Appendix 2) provide guidance on reporting for each KEQ.

10. Make recommendations for future management based on results

This step is the culmination of all preceding steps. Monitoring will have greatest value if it provides knowledge that leads to improved future management. Recommendations may involve changes to management practice, knowledge to underpin current management (e.g. revision of performance measures used to evaluate management options), or policy. Recommendations may not lead to changed future management if they affirm current practice/knowledge. Recommendations must be communicated effectively to those responsible for implementing suggested changes.

11. Conclusions and recommendations

This report outlines an approach to addressing the ecosystem resilience KEQs set out in the MER Framework, and hence strengthening the base of empirical information underlying fire management in Victoria.

The central feature of the proposed approach is a ‘two-stream’ model for ERMER. The state-wide stream consists of a centrally coordinated, systematic monitoring program targeting priority EFGs. While being a major undertaking, the state-wide stream represents an efficient means of collecting the large amount of empirical data required to elucidate the relationships of biota to fire regimes, and hence address the Improvement KEQs.

Alongside the state-wide stream, the regional stream of ERMER will collect data to assess the more immediate effects of planned burning and other forms of fuel management on biota, as encapsulated in the Impact KEQs. In addition, the regional stream has the flexibility to examine how fuel management (and bushfire) affects species and ecological values of regional importance as well as those otherwise well represented in the broad scale state-wide surveys (e.g. threatened species). Both the state-wide and regional streams will combine to address Effectiveness KEQs.

As indicated by our review of past monitoring programs (Chapter 2), the success of the ERMER project depends on strong oversight and coordination. This should include clear identification of responsibilities for carrying out the various program components and good communication amongst the program team and other stakeholders. These factors are key to the ERMER program producing results that can inform improved fire management, and hence successfully complete the adaptive management cycle.

We have also identified a need for a ‘scientific coordinator’ as part of the program team. The KEQs pose complex questions regarding biota-fire relationships and so will require robust data management systems, sophisticated analyses and careful interpretation of results to be addressed. A scientific coordinator will provide the capability to undertake these tasks, as well as ongoing guidance on monitoring design, methods and analysis for both streams of the ERMER program.

Next steps

The monitoring framework, design and methods outlined in this report will, if implemented, deliver information that can be used to inform improved fire management. However, as described in Chapter 2, the translation of information into management policy/practice is a critical step in the adaptive management cycle, and one that in the past has proved difficult. Two elements are required here: 1) a reporting process that ensures that monitoring results are communicated to the appropriate audiences within and outside DELWP in such a way as to make clear what elements of management require change, and what the nature of that change might be; 2) clear processes within DELWP for instigating management change when required. We understand that the MER unit and Ecological Model Consolidation projects are, respectively, currently working on addressing these needs. Given the importance of these elements we suggest that this work be prioritised and continued as required.

Recommendations

To summarise, key recommendations stemming from this project are:

- Implement ERMER program based on two-stream (state-wide/regional) approach outlined above.
- State-wide stream to consist of monitoring of flora/vegetation, birds and ground dwelling mammals within priority EFGs. Sampling to consist of 200 sites per EFG, selected to encompass gradients of time since fire and inter-fire interval.
- Regional stream to use BACI design to monitor impacts of fuel management, address additional questions of regional significance and collect data on species not well represented in state-wide data sets (e.g. threatened species).
- A 'scientific coordinator' be appointed within the ERMER leadership team, to provide leadership on the implementation of this program, monitoring design, data analysis and interpretation of results.
- Implement robust data management systems that ensure integration of state-wide and regional monitoring data and the ready availability of these data for analyses both for the purposes of the MER program and more broadly within DELWP.
- Landscape Evaluators to provide effective local leadership of ERMER including implementing regional stream and communicating and promoting implementation of findings.
- Explore and develop technological approaches to improve data collection efficiency.
- MER unit and other stakeholders within DELWP to continue to develop reporting process and processes for translating monitoring results into improved management.

References

Allan, C. and Stankey, G.H. (2009) *Adaptive Environmental Management: A Practitioner's Guide.* CSIRO, Melbourne, Victoria, Australia.

Allen, C. and Gunderson, L.H. (2010) Pathology and failure in the design and implementation of adaptive management. *Journal of Environmental Management* 92:1379-1384.

Cheal, D., 2010. *Growth Stages and Tolerable Fire intervals for Victoria's Native Vegetation Data Sets.* Fire and Adaptive Management Report No. 84. Department of Sustainability and Environment, East Melbourne, Victoria, Australia.

Cundill, G. and Fabricius, C. (2009) Monitoring in adaptive co-management: towards a learning based approach. *Journal of Environmental Management* 90:3205-3211.

Department of Environment, Land, Water and Planning (2015) *Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land*. Department of Environment, Land, Water and Planning, East Melbourne, Victoria, Australia.

DEWLP (2015) DELWP Policy Position – Measuring Ecosystem Resilience in Strategic Bushfire Management Planning. Department of Environment, Land, Water and Planning, Melbourne.

DSE (2012) *Code of Practice for Bushfire Management on Public Land*. Department of Sustainability and Environment, Melbourne.

Field, S.A., O'Connor, P.J., Tyre, A.J. and Possingham, H.P. (2007) Making monitoring meaningful. *Austral Ecology* 32:485-491.

Gibbs, J.P., Droege, S. and Eagle, P. (1998) Monitoring populations of plants and animals. *BioScience* 48:935-940.

Gregory, R., Ohlson, D. and Arvai, J. (2006) Deconstructing adaptive management: criteria for applications to environmental management. *Ecological Applications* 16: 2411-2425.

Legge, C.J and Nagy, L. (2006) Why most conservation monitoring is, but need not be, a waste of time. *Journal of Environmental Management* 78:194-199.

Leonard, S., Bruce, M., Christie, F., Di Stefano, J., Haslem, A., Holland, G., Kelly, L., Loyn, R., MacHunter, J., Rumpff, L., Stamation, K., Bennett, A., Clarke, M. and York, A. (2016) *Foothills Fire and Biota, Fire and Adaptive Management Report no. 96.* Department of Environment, Land, Water and Planning, Melbourne.

Loyn, R.H. (1986). The 20 minute search - A simple method for counting forest birds. *Corella* 10: 58-60.

Lindenmayer, D.B. and Likens, G.E. (2010) The science and application of ecological monitoring. *Biological Conservation* 143:1317-1328.

Lindenmayer, D.B., Burns, E., Tennant, P., Dickman, C.R., Green, P.T., Keith, D.A., Metcalfe, D.J., Russell-Smith, J., Wardle, G.M., Williams, D., Bossard, K., Delacey, C., Hanigan, I., Bull, C.,M., Gillespie, G., Hobbs, R.J., Krebs, C.J., Likens, G.E., Porter, J. and Vardon, M. (2015) Contemplating the future: acting now on long-term monitoring to answer 2050s questions. *Austral Ecology* 40:213-224.

Lovett, G.M., Burns, D.A., Driscoll, C.T., Jenkins, J.C., Mitchell, M.J., Rustad, L., Shanley, J.B., Likens, G.E. and Haeuber, R. (2007) Who needs environmental monitoring*? Frontiers in Ecology and Environment* 5:253-260.

Moir, W.H. and Block, W.M. (2001) Adaptive management on public lands in the United States: commitment or rhetoric? *Environmental Management* 28: 141-148.

Nichols, J.D. and Williams, B.K. (2006) Monitoring for conservation. *Trends in Ecology and Evolution* 21:668-673.

Schreiber, E.S.G., Bearlin, A.R., Nicol, S.J. and Todd, C.R. (2004) Adaptive management: a synthesis of current understanding and effective application. *Ecological Management and Restoration* 5: 177-182.

Sitters, H., Di Stefano, J., Wills, T., Swan, M. and York, A. (2018). Survey design for precise fire management conservation targets. Ecological Applications 28: 35-45

Teague, B., McLeod R, Pascoe, P, 2010. *2009 Victorian Bushfires Royal Commission: Final Report*. Parliament of Victoria, Melbourne.

Walters, C.J. and Holling, C.S. (1990) Large-scale management experiments and learning by doing. *Ecology* 71:2060-2068.

Westgate, M.J., Likens, G.E. and Lindenmayer, D.B. (2013) Adaptive management of biological systems: a review. *Biological Conservation* 158:128-139.

Yoccoz, N.G., Nichols, J.D. and Boulinier, T. (2001) Monitoring of biological diversity in space and time. *Trends in Ecology and Evolution* 16:446-453.

Appendix 1. Framework for identifying responsibilities for each stage of the adaptive management cycle.

	Lead [a]	Partner [b]	Implement [c]	Agree [d]	Communicate [e]	Use/manage [f]	Know [g]
Commissioning unit							
Program manager							
Scientific leadership							
Question/design							
Define clear question							
Ensure question is policy/management relevant							
Identify question-specific management thresholds*							
Design monitoring program to answer question							
Design sampling regime to answer question							
Data collection							
Collect appropriate data to answer question							
Enforce rigorous protocols for data collection							
Data management							
Enter data							
Check data/ensure data of high quality							
Document relevant metadata							
Collate data ready for analysis							
Ensure data secured in state-wide database							
Data analysis							
Summarise data							
Undertake analyses to answer question							
Interpretation							
Interpret results in relation to question							
Undertake peer-review of methods/results							
Communication							
Produce report that answers question							
Communicate results in other ways^							
Recommendations							
Make recommendations related to the question							
Change							
Approve change to future monitoring							
Approve change to management practices							
Approve change to policy							
Implementation							
Evaluate management change							
Implement policy change							

[a] Lead decision maker/accountable for deliverable (Level 1)
[b] Participant in decision making/has discussed with and agreed strategy with Lead (Level 2)
[c] Owns and manages the process of delivery (Level 3)
[d] Must gain the agreement of this person/s or unit/s (Level 4)
[e] Disseminates information, etc.

[f] End point recipient/doer/user of the knowledge to deliverer of the management action
[g] Must know about the decision and implementation
* Thresholds in monitored variables (e.g. level of change, degree of departure from baseline) that trigger management action or review of policy
^ Other forms of communication to disseminate results may include workshops, presentations, fact sheets, scientific papers

Appendix 2. KEQ pathways

See accompanying excel file worksheet ‘KEQ pathways’. This spreadsheet outlines the end-to end process for addressing KEQs.

Appendix 3. Power analysis

Power analysis was undertaken to determine the sampling effort required to produce reliable models within the proposed ERMER program. This analysis was carried out primarily with a focus on the state-wide stream of ERMER, but the results are also applicable to similar regional-based monitoring. We undertook simple power analyses for GLMs using the R package pwr (Champely et al. 2017). It is anticipated the GLMs will be the primary type of modelling used for state-wide data analysis. Due to the large number of potential response variables within the proposed ERMER data sets, it was not possible to examine the power of particular models. Instead, analyses were carried out across a range of hypothetical R^2 (0.05-0.3) values and numbers of predictors (1-3), with target power value held at 0.8 and P-value 0.05 (Table 1).

Results of these analyses indicate that while relatively strong relationships (higher r^2 values) are likely to be detected with sample sizes of 30-50, weaker relationships require 150-200 samples for reliable detection. As biota-fire relationships typically tend to be at the weak end of the spectrum, this suggests that a sample size of ~200 is required to model such relationships.

Table 1. Results of power analysis of hypothetical GLMs.

R^2	Effect size (f^2)	N predictors	Power	P	Required sample size (N)
0.05	0.05	1	0.8	0.05	151
0.1	0.11	1	0.8	0.05	73
0.2	0.25	1	0.8	0.05	34
0.3	0.43	1	0.8	0.05	21
0.05	0.05	2	0.8	0.05	196
0.1	0.11	2	0.8	0.05	90
0.2	0.25	2	0.8	0.05	41
0.3	0.43	2	0.8	0.05	26
0.05	0.05	3	0.8	0.05	222
0.1	0.11	3	0.8	0.05	104
0.2	0.25	3	0.8	0.05	47
0.3	0.43	3	0.8	0.05	28

To further examine required sample sizes, we performed post-hoc power analyses on GLMMs of the probability of bird species occurrence in relation to time since fire in Forby Forest and Moist Forest EFGs (Table 2), using the R package simr (Green and MacLeod 2016). The EFGs differed in sample size (Forby = 154, Moist = 130). For Forby forest, two out of six models were found to have power greater 0.8, while for Moist forest none of the four models had power of 0.8. While this analysis should be interpreted cautiously due to the small number of models considered, it further suggests that sample sizes greater than 150 are required to have the potential to reliably model biota-fire regime relationships.

On the basis of these analyses, as well as our prior experience in modelling biota-fire relationships, we recommend a survey effort of 200 sites per EFG for the state-wide component of ERMER.

It is worth noting that for a given sample size, analytical power can be increased by using a higher threshold for statistical significance than the conventional 0.05 (e.g. 0.1). This may be useful when trying to detect the often weak effects of fire regimes on biota. This approach would also have the advantage of being more precautionary, in that there is less chance of erroneously concluding that there is no effect of fire regime on the response of interest.

Table 2. Results of post-hoc power analysis of GLMMs

		Co-efficient	P	Power	R^2m	R^2c
Forby forest	Aust. king parrot	0.02	0.01	0.59	0.06	0.16
N = 154	Laughing kookaburra	0.03	0.00	0.93	0.11	0.35
	East. yellow Robin	0.02	0.00	0.44	0.05	0.36
	Spotted pardalote	-0.03	0.00	0.87	0.14	0.14
	Striated pardalote	0.01	0.08	0.16	0.01	0.30
	Flame robin	-0.05	0.02	0.72	0.32	0.32
Moist forest	East. spinebill	0.01	0.04	0.17	0.02	0.05
N = 130	East. yellow Robin	0.03	0.00	0.73	0.16	0.16
	Golden whistler	0.02	0.01	0.43	0.08	0.08
	Crescent honeyeater	0.03	0.01	0.46	0.08	0.61

Champely, S. (2017). pwr: Basic Functions for Power Analysis. R package version 1.2-1. Available at: https://CRAN.R-project.org/package=pwr

Green, P. and MacLeod, C.J. (2016). simr: an R package for power analysis of generalised linear mixed models by simulation. Methods in Ecology and Evolution 7: 493-498.

Appendix 4. Summary of fire history information for six priority EFGs for state-wide monitoring

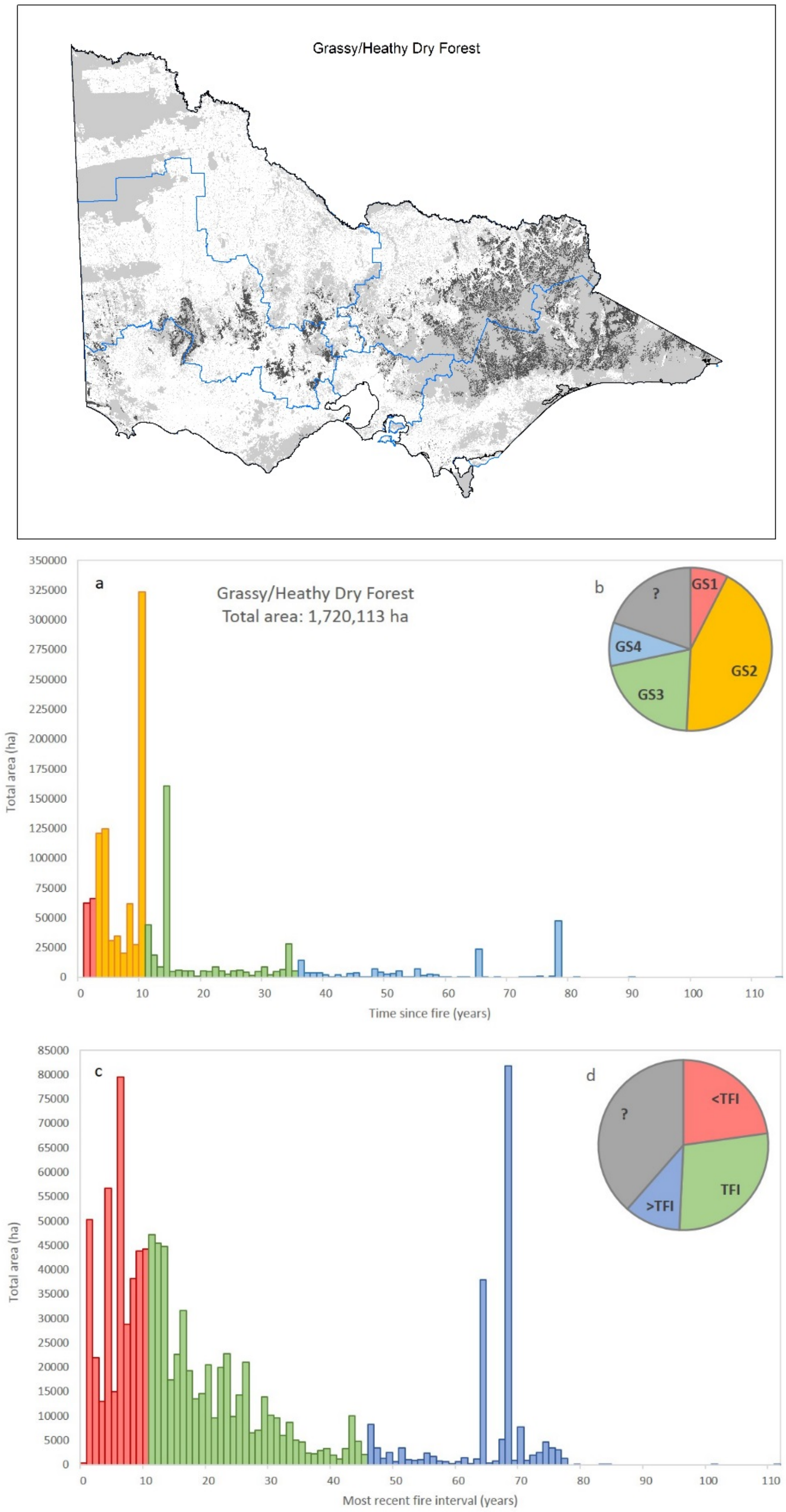
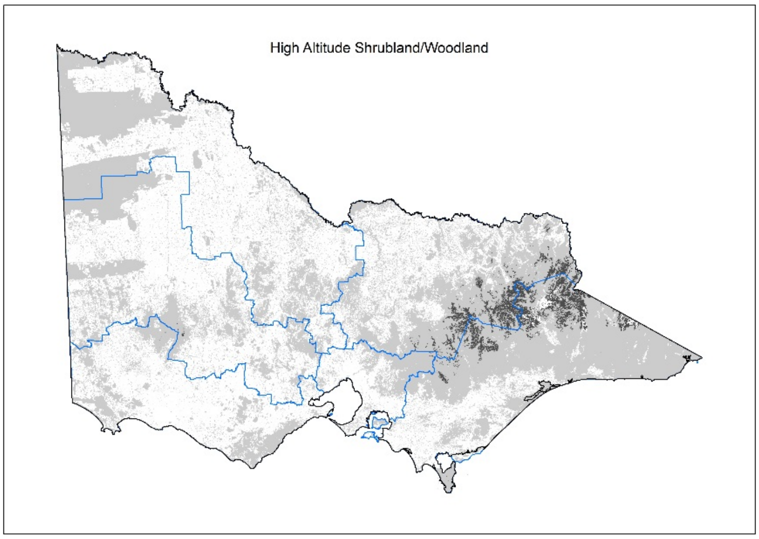


Fig. 1 Distribution and summary of the fire history of Grassy/Heathy Dry Forest, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1

(early) 0-2.5 years; GS2 (young) 2.5-10 years; GS3 (mature) 10-35 years; GS4 (late) 35-9999 years. Tolerable Fire Intervals are as follows: min TFI 10 years, max TFI 45 years.



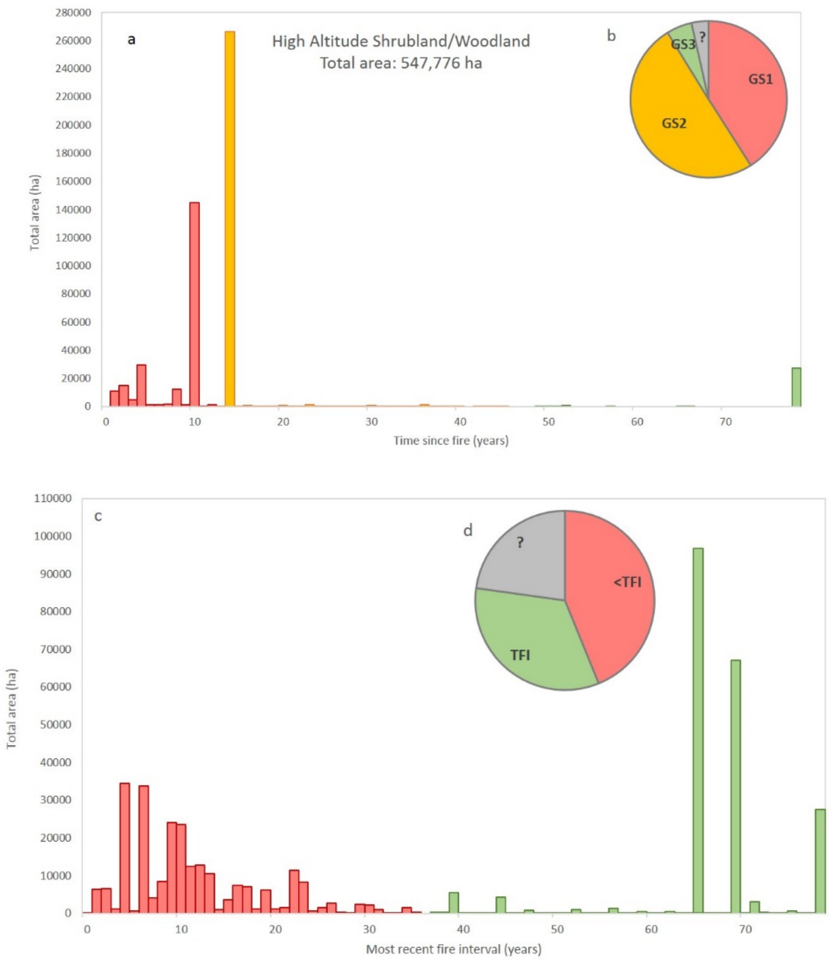


Fig. 2 Distribution and summary of the fire history of High Altitude Shrubland/Woodland, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1 (early) 0-12 years; GS2 (young) 12-45 years; GS3 (mature) 45-85 years; GS4 (late) 85-9999 years. Tolerable Fire Intervals are as follows: min TFI 35 years, max TFI 125 years.

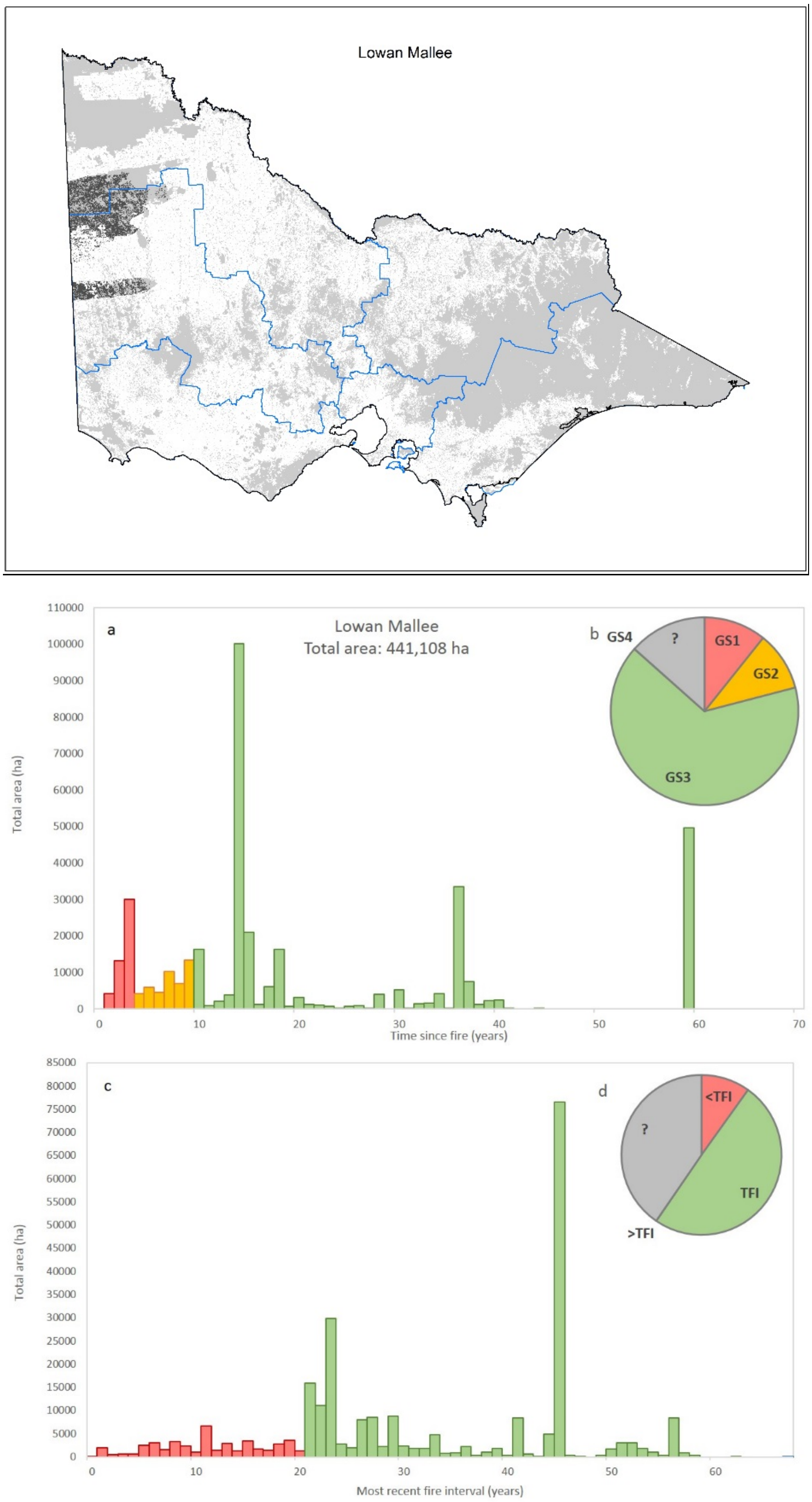


Fig. 3 Distribution and summary of the fire history of Lowan Mallee, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1 (early) 0-3 years; GS2 (young) 3-9 years; GS3 (mature) 9-60 years; GS4 (late) 60-9999 years. Tolerable Fire Intervals are as follows: min TFI 20 years, max TFI 65 years.

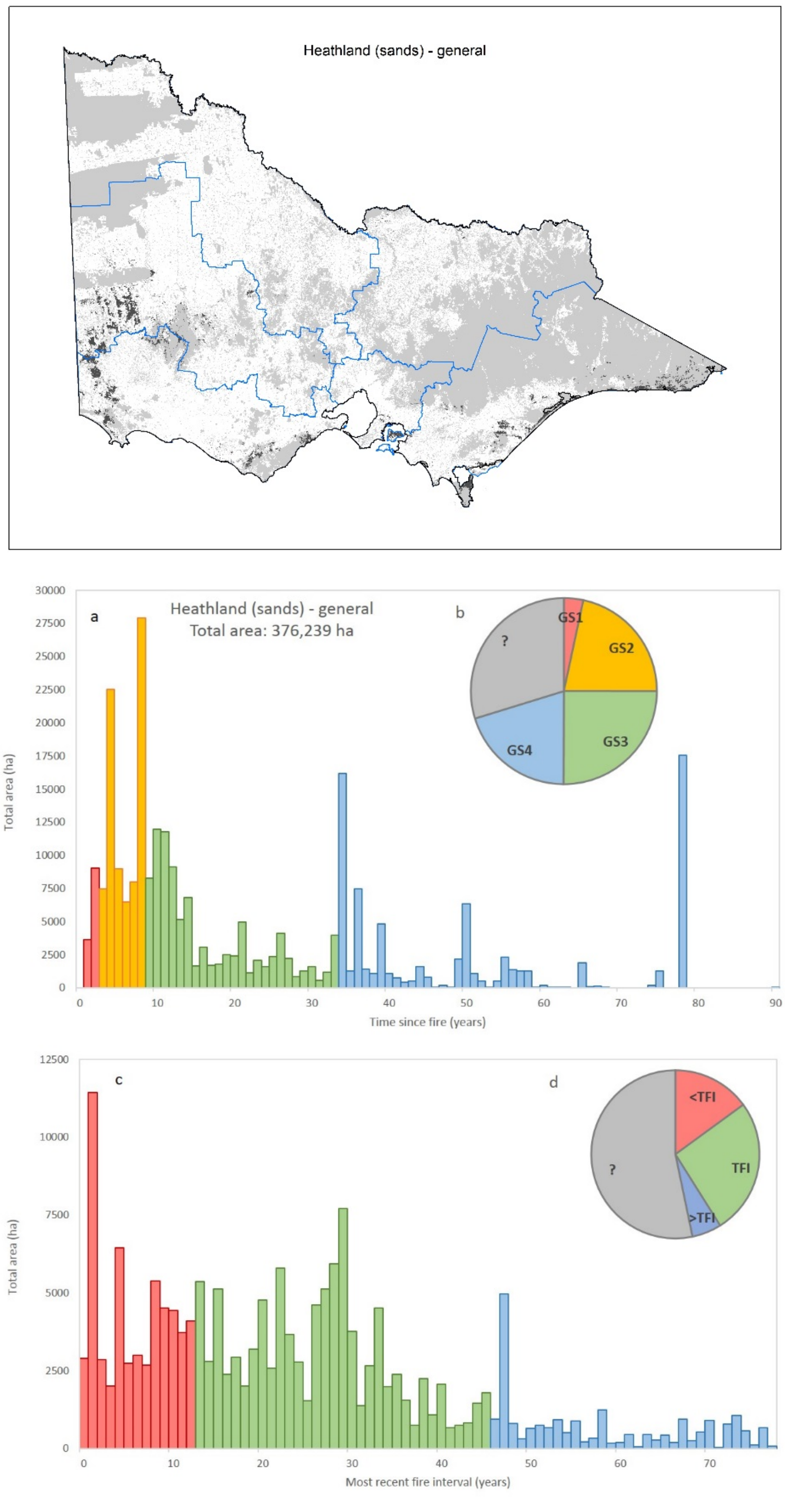


Fig. 4 Distribution and summary of the fire history of Heathland (sands) - General, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1 (early) 0-2.5 years; GS2 (young) 2.5-8.5 years; GS3 (mature) 8.5-33.5 years; GS4 (late) 33.5-9999 years. Tolerable Fire Intervals are as follows: min TFI 12 years, max TFI 45 years.

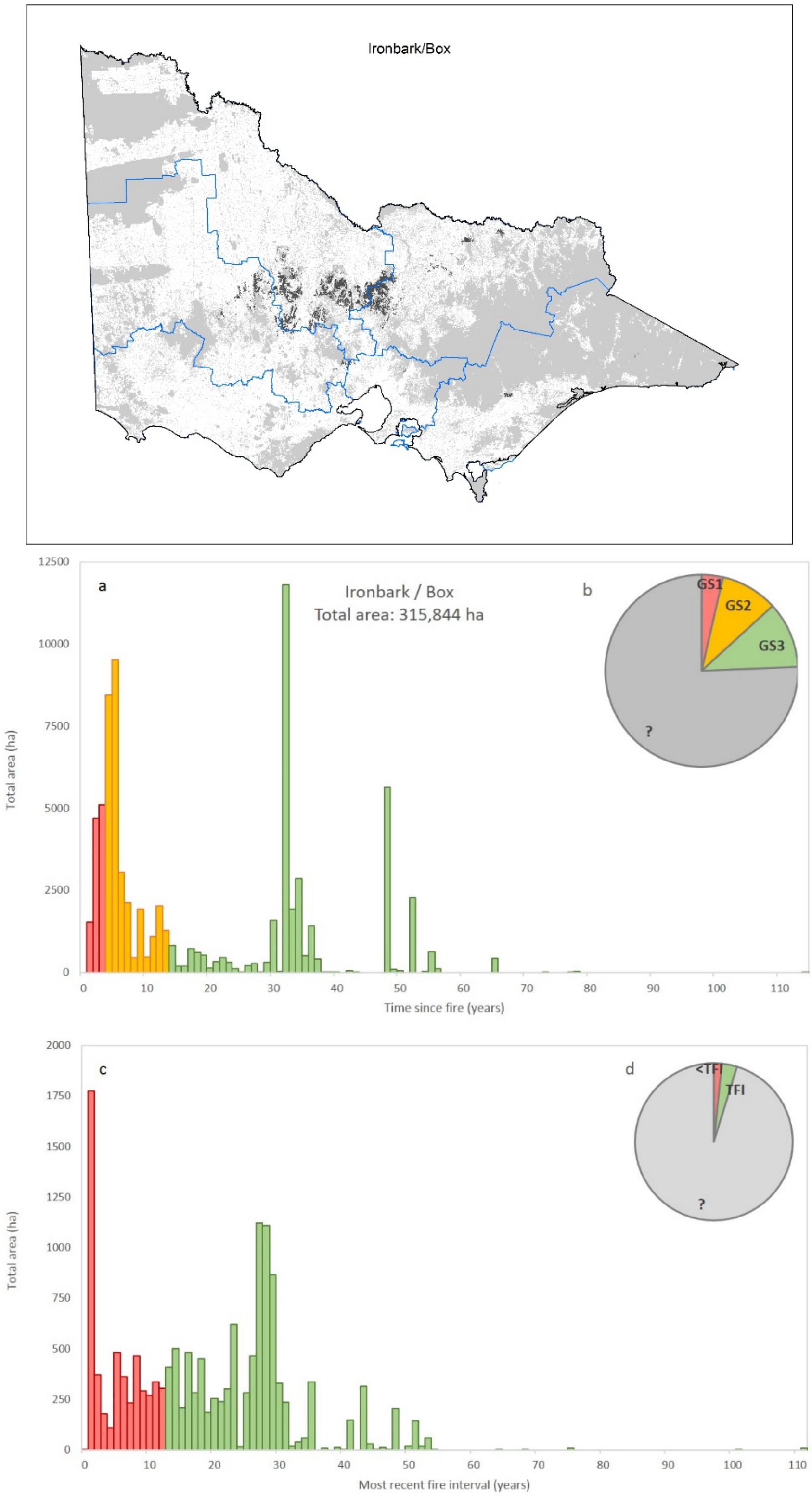
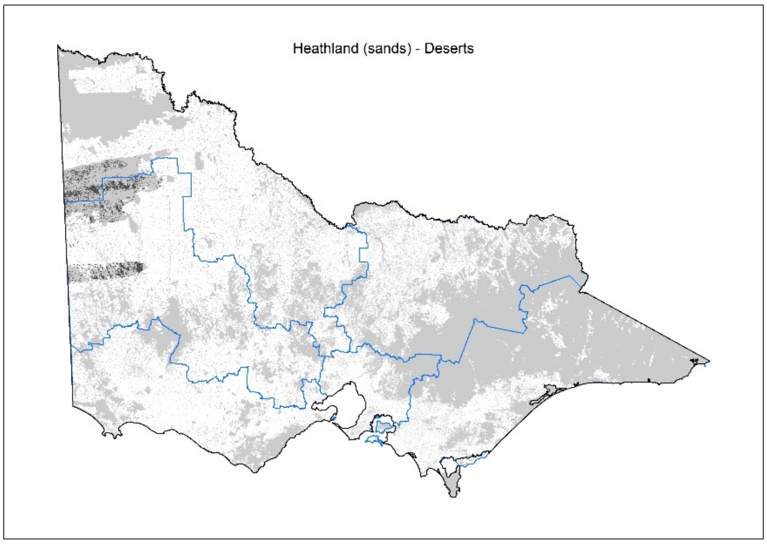
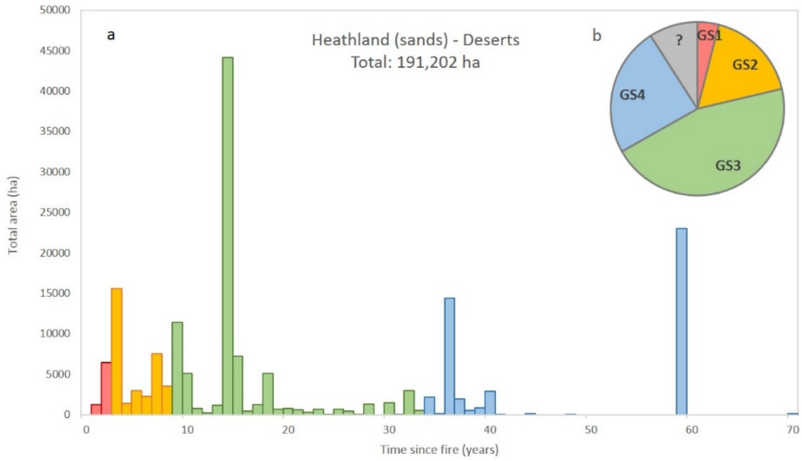


Fig. 5 Distribution and summary of the fire history of Ironbark / Box, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1 (early) 0-3 years; GS2 (young) 3-13 years; GS3 (mature) 13-140 years; GS4 (late) 140-9999 years. Tolerable Fire Intervals are as follows: min TFI 12 years, max TFI 150 years.





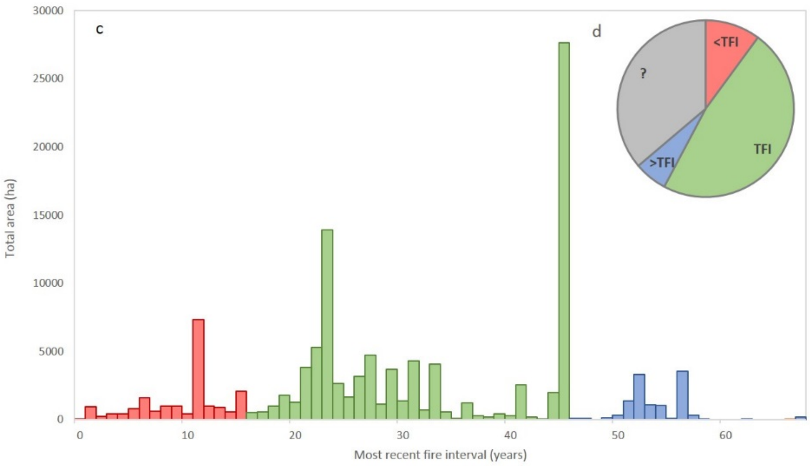


Fig. 6 Distribution and summary of the fire history of Heathland (sands) - Deserts, including: the distribution of overall area in relation to fire age (in years (a) and growth stage classes (b)) and most recent fire interval (in years (c) in tolerable fire interval classes (d)). Growth stages (based on four-class groupings provided by ARI) are as follows: GS1 (early) 0-2.5 years; GS2 (young) 2.5-8.5 years; GS3 (mature) 8.5-33.5 years; GS4 (late) 33.5-9999 years. Tolerable Fire Intervals are as follows: min TFI 15 years, max TFI 45 years.

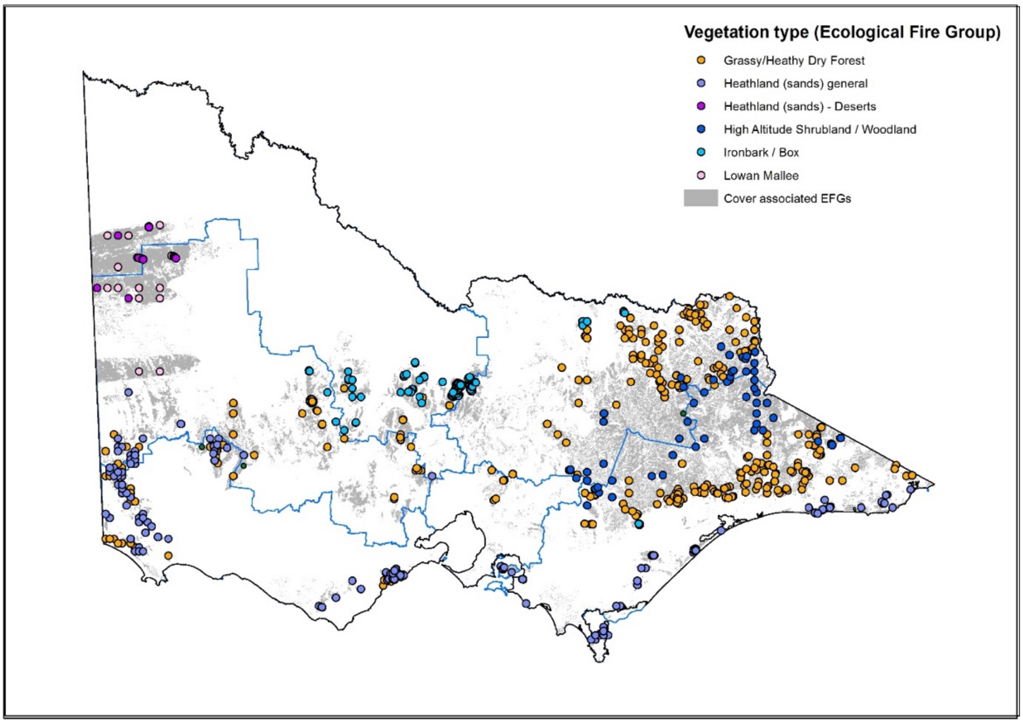


Fig. 7 Distribution of 1015 legacy/forest monitoring sites potentially suitable for inclusion in state-wide stream of ERMER. Further assessment will be required at the time of final site selection for each EFG.

Table 1. Summary of the number of (potentially suitable) sites sampled in each priority EFG by different legacy fire/forest programs.

EFG	**Box-Ironbark Exp Burn Project**	**Gippsland Retro**	**HE Gippsland**	**HE Otway**	**LEM**	**PPFM**	**VFMP**	**Total**
Grassy/Heathy Dry Forest	19	60	27	3	67	117	111	**402**
Heathland (sands)-general		1	1	31	10	58	77	**178**
Heathland (sands) - Deserts					16	5	3	**24**
High Altitude Shrubland / Woodland		1			18	8	34	**61**
Ironbark / Box	244					59	20	**322**
Lowan Mallee					12	1	12	**25**
Total	**263**	**62**	**28**	**34**	**123**	**248**	**257**	**1015**

Appendix 5.

State-wide data variable relationships

See worksheet ‘SW variable relationships’ in ‘MER final report excel appendices’. This spreadsheet shows how variables for which data will be collected during the ERMER state-wide program relate to each other as response/predictor variables in models. Note that models may also include additional variables, as required.