

Framework for Using and Updating Ecological Models to Inform Bushfire Management Planning

Final report



Policy and Planning Division, Forest, Fire and Regions

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Executive Summary

Effectively managing the risks of fire to ecosystem resilience and threatened species is a core commitment of Victoria's Safer Together policy. Through collaboration with Department of Environment, Land, Water and Planning, and its partner agencies, the project team have developed a decision-making framework, including a Fire Analysis Module for Ecological values (FAME), to facilitate more effective and transparent consideration of ecological values in strategic fire management decisions.

Project Aims

In BNHCRC Emergency Risk Project 1 (ERP1) we aimed to develop a consolidated framework that describes the development and application of ecological models (including for ecosystem resilience and threatened species) to inform strategic bushfire management planning. Importantly, this project was focused on developing a framework developed with high levels of stakeholder consultation, such that the resulting framework is tailored for its application, and sensitive to the current re-development of Strategic Bushfire Management Planning (SBMP) guidance. Our specific aims were to:

- Develop a decision framework that describes the development and application of ecological models (including for ecosystem resilience and threatened species) to inform SBMP.
- Develop a Fire Analysis Module for Ecological values (hereafter FAME) that integrates existing ecological data and models into a single platform. FAME will enable a more user-friendly approach to undertaking ecological risk assessments to support SBMP.

The decision-making framework

We used a structured decision-making framework to guide decision makers and stakeholders on how to better use ecological models and metrics to inform a strategic planning process. Structured decision-making describes both the process of deconstructing decisions into various common components, and the broad set of tools used, and is designed to aid logical and transparent decision-making.

This approach was designed to facilitate the application of FAME, and to align with the current SBMP process, which also draws on the structured decision-making framework.

FAME brings together existing ecological data and models into a single platform to support SBMP decisions. To ensure the module was tailored to user requirements, the module was developed in close collaboration with end users in DELWP Forest and Fire Regions risk and evaluation teams, the Monitoring, Evaluation and Reporting Unit and the Forest and Fire Assessment Unit.

FAME allows users to analyse and evaluate the impact of different fire management strategies on ecological objectives, and automates documentation of (i) data inputs, (ii) key decision points undertaken as part of the analyses and (iii) standard outputs. FAME is designed to provide transparency and consistency in analytical approaches and outputs.

Why is the decision framework and FAME needed?

Collaboration with stakeholders identified constraints and impediments in considering ecological values in SBMP decision-making (Appendix 1). The main issues were:

- Some of the ecological metrics (performance measures) were perceived to be inadequate by some internal and external stakeholders and were not consistently used to guide strategic bushfire management at the regional level.
- A lack of guidance in the Code (DSE 2012) regarding which ecological metrics should be considered to inform the selection of a preferred fire management strategy.
- Limited integration of the methods to analyse risk to ecosystem resilience and threatened species to guide fire management decisions.
- Disjointed curation and access to the ecological data and models, making it difficult to use the most up to date information to support decision-making.

- The need to identify knowledge gaps in information regarding ecosystems, plants and animals (including threatened species) to better inform strategic research investment and monitoring prioritisation.
- No process to guide how new data collected through monitoring and research will be used to update the ecological models used in decision-making.
- In addition, there was limited consideration of how uncertainty in data could influence decision-making; in particular, how uncertainty connects to decision maker's risk tolerance of undesirable outcomes.

Case study insights

We conducted two case studies in collaboration with DELWP's regional risk and evaluation teams in the Gippsland and Metro regions. This enabled us to develop and test the framework for applying ecological models and metrics as part of a real-world application of strategic bushfire management planning. We demonstrated a participatory and iterative approach through workshops with regional and cross agency project partners.

The case studies also provided an early opportunity to test a beta version of FAME, to model the consequences of alternative strategic fire management plans on ecological values. The development of the decision-making framework, with FAME, facilitated a more streamlined approach to risk assessment, and provided greater transparency in the decision-making process.

Feedback from the Gippsland team indicates the main benefits of this approach are:

- Identifying the core elements of the decision context, such as who is involved in the planning and decision-making.
- Providing a clear link between values (objectives) and metrics (performance measures).
- Demonstrating a participatory approach to trade-offs which supports the application of DELWP's Community Charter.

In the Metro region we were involved in implementing the consolidated analysis code (i.e. that underpins FAME) for three management scenarios, to explore the consequences for related changes in ecological objectives. We also assisted in facilitating two expert workshops, to develop the alternative management scenarios, and validate the findings generated by FAME.

In the Barwon South-west region, FAME was again used to run eleven different fire scenarios and evaluate them in relation to ecological objectives. This information was then applied by the Barwon South-west region within a structured decision-making framework, including a participatory approach to investigating trade-offs between ecological and other values.

Key Outcomes

We carefully reviewed and streamlined thousands of disjointed files, comprising data, models and scripts for analysis, into a single platform for end-to-end risk assessment of ecological values, i.e. FAME. In doing so we balanced the need for a unified and flexible approach between DELWP regions. FAME will improve the accessibility and transparency of ecological risk assessment. This will enhance DELWP's commitment to a community centered approach through access to better and timely information about the consideration of ecological values in bushfire management.

We also developed the decision framework in which FAME resides. The framework is a step by step process that provides a line of sight between the context of decisions (bushfire management), ecological values and transparent evaluation of impacts of alternative strategies on those values in concert with other values such as life and property.

We navigated the intrinsically complex decision context of SBMP by drawing on the core principles of structured decision-making. This included a collaborative approach where project partners and stakeholders were identified as part of the first stage of the project. Engagement occurred throughout the project; in workshops, regional networks (risk and evaluation teams), with FFR policy leads, Biodiversity Division staff, Parks Victoria and CFA, and researchers working on related projects. This approach was crucial in ensuring our work facilitated relevant and flexible applications of SBMP.

Next steps

Implementation of the decision framework and FAME requires:

- Ongoing user support, including cloud computing to enable reliable regional access
- Curation of FAME and related datasets, particularly those in the Victorian Bushfire Monitoring Program Database, to support timely data updates to field data to improve decision-making

- Implementation of a process to calibrate and combine state-wide monitoring data with legacy data, including field and expert-derived data sources. Recent approaches using Victorian Biodiversity Atlas data to replace expert judgement of species' response has been identified by DELWP risk and evaluation teams as a high priority for further exploration (see Case study)
- Development of agreements and a curated process to access relevant data arising from university research, where survey methods are compatible
- Development of an analytical approach to incorporate flora-based performance measures, with animal-based performance measures (i.e. to create a 'biodiversity' performance measure that captures impacts on both flora and fauna)
- Development and implementation of an approach to incorporate uncertainty for all (Code) performance measures, to support i) exploration of critical uncertainties to inform targeted monitoring efforts, and; ii) allow decision makers to exercise their risk attitude, or tolerance to uncertainty, when deciding on preferred management strategies.
- Curation of the decision framework, including exploration, documentation and review of i) the suitability of the performance measures and data; ii) the results of any updates to critical uncertainties, and; iii) any changes in the decision context that may alter the way in which data is being applied, such as the inclusion of ecological values on private land, time frames, spatial scales etc.
- Development of a process to prioritise the key evaluation questions from the Victorian Bushfire Monitoring Program (DELWP 2015a) to target critical uncertainties from the SBMP decision-making process.
- Development of a better understanding of the needs and aspirations of Aboriginal communities in fire management, including: the specification of ecological objectives, and to improve the link between Aboriginal fire management practices and the ecological data used for fire management decisions.

The objectives and associated performance measures for evaluating impacts to ecological values from fire management were developed in close collaboration with stakeholders. However, they are yet to be endorsed by the DELWP governance processes. This is needed to ensure the ecological objectives and performance measures consider

broader community expectations beyond those of project stakeholders. This broader review process is well beyond the scope of the project but is a critical step to ensure community trust and successful adoption of the ecological objectives and performance measures.

Future applications

FAME was designed to assist with strategic decisions at the regional scale. There is potential to refine the module to provide the information necessary to inform finer-scale regional fuel operations plans, or broader scale applications such as the state-wide fuel management report. As part of an approach to decision-making which focuses on community engagement and participation, it is crucial to have a clear narrative about the predicted response of ecological values under different fire management scenarios. To this end, a useful next step in the application of FAME and the decision framework could involve testing by interested members of the community. This testing process could involve exploration of multiple management strategies under different climate/fire scenarios. To facilitate a participatory decision-making process with community stakeholders, we also recommend further development of the FAME shiny app to incorporate the selection of other objectives (e.g. life and property) to support exploration of trade-offs.

Last, as DELWP moves towards a process of Integrated Forest and Fire management, further research is needed to develop a decision-making framework and analytical tools which incorporate interactions between other management levers (e.g. timber harvesting and/or pest management), other environmental drivers (e.g. climate change, drought) and landscape context issues (e.g. fragmentation of habitat).

Glossary

BNHCRC	Bushfire Natural Hazards Cooperative Research Centre
FFRA Unit	Forest and Fire Risk Assessment Unit
DELWP	Department of Environment, Land, Water and Planning
EFG	Ecological Fire Group
ERP1	Emergency Risk Project 1
FAME	Fire Analysis Module for Ecological values
FRAC	Fauna Relative Abundance Calculator
GMA	Geometric Mean Abundance
GSO	Growth Stage Optimisation
KFRS	Key Fire Response Species
MER	Monitoring Evaluation Reporting
PBBO	Planned Burning Biodiversity Officer
SDM	Species Distribution Model
SBMP	Strategic Bushfire Management Plan
SOP	Standard Operating Procedure
TFI	Tolerable Fire Interval
TSF	Time Since Fire
VBA	Victorian Biodiversity Atlas
VBMP	Victorian Bushfire Monitoring Program

Introduction

Policy drivers

Building the health of Victoria's environments is a central tenet of Victoria's Safer Together policy, which outlines the State's approach to managing bushfire risk. With respect to building the health of the environment, the primary objectives of bushfire management on Public land in Victoria are two-fold:

- to minimise the impacts of major bushfires on the environment
- to maintain or improve ecosystem resilience.

The entire objectives are outlined in the Code of Practice for Bushfire Management on Public Land 2012 (hereafter The Code).

The integration of science into bushfire management policy and decision-making, and the adoption of a strategic, risk-based approach to planning are critical to achieving the above objectives. To achieve this, the Department of Environment, Land, Water and Planning (DELWP) undertakes strategic planning to guide fuel management activities. Specifically, DELWP uses the strategic planning process to i) identify values to be protected from bushfire, ii) assess bushfire risk to those values, iii) develop strategies to enable capacity building to manage risks, and iv) identify a preferred approach to assess bushfire risk.

Throughout this document, it is acknowledged that DELWP is currently developing new guidance for the process of making strategic bushfire management decisions.

Project aims, research questions and outputs

In this project, our aim was to:

- Develop a decision framework that describes the development and application of ecological models (including ecosystem resilience and threatened species) to inform strategic bushfire management planning.
- Develop an ecological module (FAME) that integrates existing ecological data and models into a single platform. This will enable a more user-friendly approach to undertaking ecological risk assessments to support SBMP decision-making.

Importantly, our focus was to develop FAME and the associated decision framework with high levels of stakeholder consultation, to ensure the approach was tailored to its anticipated real-world application, and sensitive to the current re-development of strategic planning guidance.

To develop a strategic planning decision framework, the following questions need consideration. These questions were addressed via a series of Outputs (Table 1):

- What are the current decision-making processes used in strategic planning across the six Forest and Fire Regions (hereafter the 'regions') in Victoria?
- What is the role of ecological objectives in strategic planning?
- What are the ecological objectives for strategic planning and how can these objectives be measured?
- Which data processing and analytical techniques are most suited to support the assessment of risk to ecological objectives?
- How do we predict ecological responses to fire to inform fuel management decision-making at the strategic planning level?
- What knowledge and training are needed by decision makers and practitioners to evaluate risk to ecological objectives as part of strategic planning?

This report is a brief synthesis of key messages from the project outputs (outlined in Table 1). The project outputs are provided in the Appendices.

Table 1: List of project outputs for Emergency Risk Project 1

Output #	Description	Details
1	Revised project plan (Appendix A)	A workshop was held with the DELWP policy lead(s), regional contacts (such as Planned Burning Biodiversity and Landscape Evaluators) and Policy and Planning Division contacts (FFRA Unit, MER Unit, Policy and Planning Unit). Our primary aim was to design the project to address the right decision context. We sought to: <ul style="list-style-type: none"> i. Specify the roles, responsibilities and needs of key stakeholders involved in the process; ii. Clarify the spatial and temporal scale over which decisions will be made e.g. state-wide vs. Bushfire Risk Landscapes vs. burn units, public vs. private land, yearly fire plans vs. decade-long projections; iii. Clarify the legal and policy context under which the framework sits, the trigger for this proposal, and any decisions linked to this process; iv. Elicit the constraints that may limit decisions and need to be incorporated into the modelling framework; v. Clarify the objectives and metrics/performance measures underpinning the framework.
2	Ecological models	Through interviews and workshops with key subject matter experts, we sought to understand and document:
3	Threatened species models	<ul style="list-style-type: none"> i. The information required of the models within the decision context (i.e. clarify the information required to inform the performance measures and decision-making);
4	Supporting documentation for ecological and threatened species models, and outline of gaps (Appendix E)	<ul style="list-style-type: none"> ii. The types of models and data that are available that can provide this information; iii. The suite of ecological models and data within the scope of this project; iv. The current limitations of these models and data sources, and; v. The processes or guidance already in place in terms of data management and model output.
5	Conceptual framework (Appendix B)	This output is essentially derived from the steps outlined in Figure 1. We collaborated with our case study region to address each of the steps in this project, including: <ul style="list-style-type: none"> i A problem statement, clearly outlining the decisions to be made, ii A clarification of the management objectives (i.e. from The Code) and the associated performance measures (Appendix A) relevant to the region. iii A demonstration of how the existing ecological metrics, informed by ecological models and data, can be utilised to understand the consequences of implementing various alternative management (planned burning) scenarios, in relation to the objectives (Appendix E). iv An example of method(s) for addressing trade-offs between multiple objectives (Appendix B). v The role of MER in updating the data and models in the framework to reduce critical uncertainties in decision-making (Appendix C).
6	Ecological resilience model code and shiny app (FAME) (To be curated by DELWP MER and FFRA Units)	<p>Involves development of database architecture and associated scripting and front end (R) to enable more efficient analyses of ecological risk to ecosystem resilience and threatened species. The model outputs are tied to the objectives and performance measures outlined by the stakeholders.</p> <p>We developed a Graphical User Interface using open source code (Shiny Web Application Framework) to house key components of the consolidated module. This is essentially a system designed to enhance the efficiency and ease of use, to enable a more streamlined approach for using models to inform decision-making, that allows incorporation of local priorities and knowledge without compromising essential steps that require manual input.</p>

Output #	Description	Details
7	Supporting documentation (Appendix D)	The consolidated module documentation has been developed after consultation with practitioners, to ensure it recognises the requirements of users. We are liaising with the DELWP Policy lead so that the documentation can be readily integrated into current DELWP systems, processes and curation requirements. The documentation will include a data workflow that has well defined inputs, outputs and purposes. Testing of the technical guidance will be undertaken as part of training users of the consolidated module (FAME).
8	Documented process map for monitoring (Appendix C)	The issues with the technical process of using ecological models, data and metrics to support strategy selection are the primary focus for this output. Our aim was to: <ul style="list-style-type: none"> i Identify the issues relating to performance measures, and / or the data that underpins them; ii In detail, unpack a process for addressing some of the key issues with performance measures and data; iii Highlight ways to address some of the remaining issues with performance measures and data; iv Summarise the issues and solutions in a process map.
9	Case study (see Case Study in this report, and Appendix B)	We provided support for the implementation of the conceptual framework for developing and applying the ecological metrics to inform strategic planning through a case study within a DELWP region. This report provides a summary of that work.
10	Seminar	A final seminar was undertaken (22 nd May 2019) to outline the application of the Fire Analysis Module for Ecological values (FAME) in relation to bushfire management decision-making.
11	Training	Detailed information about the mechanics of FAME was provided as part of a one-day training / workshop on 24 th April 2019 to DELWP staff who are more involved in the technical side of the process of analyses of risk to ecosystem resilience (staff from statewide and regional risk and evaluation team).

The decision framework

Approach

The focus of BNHCRC Ecological Research Project 1 (ERP1) is to develop a Fire Analysis Module for Ecological values (FAME) that is as flexible as possible in the face of current revisions to the guidance for the strategic bushfire management planning process, and relevant to multiple regions which differ in their approach to identifying preferred strategies.

We used a structured decision-making framework (Figure 1, Gregory *et al.* 2012) to work through the research questions, and guide decision makers and stakeholders on how to better use ecological models and metrics to inform a strategic planning process. This approach was designed to inform the modelling component of this project (i.e. FAME), and to align with the current Strategic Bushfire Management Planning (SBMP) planning process, which also draws on the structured decision-making framework. Structured decision-making describes both the process of deconstructing decisions into various common components, and the broad set of tools used, and is designed to aid logical and transparent decision-making (Figure 1; Gregory *et al.* 2012).

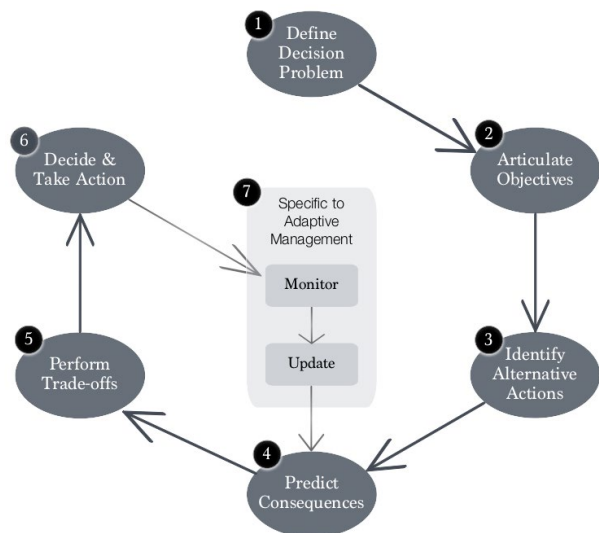


Figure 1. The structured decision-making framework refers to both the steps, and the suite of tools used to address those steps (Gregory *et al.* 2012). FAME facilitates the prediction of consequences for ecological objectives (i.e. Step 4).

Breaking down a decision and analysing each step separately helps people to logically process, understand and communicate complex decisions. This approach is particularly valuable for decisions that involve trade-offs between multiple competing objectives, uncertainty surrounding the available

management options, and/or high uncertainty about the consequences of management. This process can help clarify where uncertainty exists in the data and recognise when uncertainty influences a management decision. Importantly, the approach disaggregates scientific data from values, which can mitigate against biases associated with unstructured judgements (e.g. anchoring, status quo bias, zero-risk bias; Addison *et al.* 2013).

The decision-making framework was developed in conjunction with PBBOs and the policy leads (Appendix B), and we worked through the following:

- Problem statement (Step 1, Figure 1): Provided guidance for developing a problem statement relevant to the region's decision context. An important driver of decision context is The Code which includes the principle that bushfire management be undertaken at the landscape scale, and that there will be clearly articulated landscape-level objectives, which encourage land and fire agencies to work together to achieve the objectives of the Code.
- Objectives and performance measures (Step 2, Figure 1): were elicited in the initial stages of the project, and with input from stakeholders, were refined over time (Table 2). Note we offered flexibility in the choice of performance measures, for each objective. Regions can choose the relevant performance measures for analysis of trade-offs, but all measures are calculated and reported in FAME. Further review of the framing of objectives as declines rather than increase is highly recommended (see next steps).
- Alternative management strategies (Step 3, Figure 1): we did not give specific guidance for developing or selecting alternative strategies, nor predict the consequences of actions beyond planned burning strategies. This step was left largely to PBBO's, with some guidance provided in Appendix B.
- Consequences (Step 4, Figure 1): Code to integrate ecological models and data was developed (i.e. to create FAME), and used by three regions (Gippsland, Metro and South-West) in the process of developing their Strategic Bushfire Management Plans. In some cases, regional data from the VBMP database was used to assist in assessing the consequences of alternative strategies.
- Trade-offs (Step 5, Figure 1): A brief example of different ways to address trade-offs between multiple objectives is provided in Appendix B.

One method was demonstrated during a workshop with the Case Study region, which was implemented by the Region in their SBMP process.

- Monitoring, Evaluation and Reporting (MER) (Step 7, Figure 1): An introduction to the role of MER in updating the data and models in the framework to reduce critical uncertainties in decision-making is provided in Appendix B. A process map to highlight some of the key issues and solutions to resolving uncertainty in data is provided in Appendix C.

The specific examples in the conceptual framework (Appendix B Output 5: Conceptual framework) were developed in consultation with the Gippsland region.

In the following section, we outline the nature of our involvement with the Gippsland and Metro regions, and highlight the different approaches used by the regions when implementing the SBMP process (Table 3). This summary provides an opportunity to compare different decision-making approaches, and highlights the benefit of developing a flexible module, and decision-making framework.

Case studies

Gippsland

The Gippsland Region is developing a strategic plan to guide selection of management strategies that will best manage risk to a range of values potentially impacted by bushfire on public and private land, until 2050. It should be noted that analysing (modelling) risk to objectives/values for private land contexts is not currently feasible, and the private land context is being addressed in a parallel process.

Important values include protecting the lives and health and wellbeing of community and staff involved in fire management, and minimizing the risk to environmental values, economic values, infrastructure, contemporary and cultural history.

The SBMP process is being delivered in Gippsland by a planning team with representatives from the CFA, Parks Victoria, Local Government and DELWP. The Gippsland team ran a series of workshops with their key stakeholders, to progress through the structured decision-making framework and arrive at a preferred strategy for fuel management (subject to further consultation).

The ERP1 team's role began prior to the SBMP workshops. The team demonstrated an approach to implementing the steps of structured decision-making (to supplement existing Safer Together

guidance), with key stakeholders from the Gippsland risk and evaluation team (Appendix B). The team also assisted with the analysis of consequences stemming from alternative strategies, using a beta version of the module (FAME).

Metro

The Metro Region is in the process of identifying a 40-year strategic bushfire management plan for public land, specifically for their Land Management Zone (Zone 3). Zone 3 is managed solely for ecological objectives, as risk reduction targets for life and property in Metro are already achieved within the other (Asset Protection and Bushfire Management) zones.

The Metro planning team identified several ecological values and objectives for Zone 3, along with their associated performance measures in collaboration with stakeholders. It was recognised that whilst the overarching objectives are consistent across the region, the location of different ecological values varied across the Metro region, and management alternatives may differ depending on the location of values. As such, within Zone 3 there were three planning units identified: forested areas, grassland areas, and French Island.

Guidance from the ERP1 team was sought for subsequent steps in the structured decision-making process. For instance, it was recognised that decisions about a 'preferred' management plan are difficult because i) there are multiple values, and stakeholders will prioritise those values differently; ii) there are many alternative plans that could be explored in relation to those values, and; iii) there are knowledge gaps for some values and planning units that hamper the prediction and evaluation of the consequences of fire management.

Our involvement with the Metro region differed to Gippsland, in that we were involved in i) facilitating the development of ecologically focused management alternatives with experts; ii) assisting with the analysis of the consequences, using a beta version of FAME; iii) facilitating review of the outcomes of the consequences analysis with experts, to explore a preferred management alternative, and iv) facilitating exploration of a preferred management alternative, for instances where data was lacking.

Table 2: Revised fundamental objectives and performance measures for the ERP 1 decision framework. A user can choose as many fundamental objectives as relevant from 1-5, **but only one performance measure** for each objective can be chosen for trade-off analysis. A report for all objectives and measures is generated from the Fire Analysis Module for Ecological values (FAME). The relevant spatial or temporal scale is not specified in this table but will be defined in the module. ¹Work by Tracey Regan informs the ‘significant impact’ thresholds, which is based on threat status (MacHunter et al. 2018). ²Iconic landscapes or species may or may not be threatened but are particularly valued by stakeholders (e.g. koalas or high profile threatened species). They are socio-ecological objectives that can be calculated using the module. ³At this stage the project team envisages that Ecological Fire Groups (EFGs) and fauna will be available as specified below, however work is still underway as to the feasibility of including flora as part of performance measures 9-14 (this includes both conceptual basis of including flora and technical process).

FUNDAMENTAL OBJECTIVES	DIRECTION	PERFORMANCE MEASURES
1. Avoid decline in the persistence of ecosystems	Less is better	1. Cumulative area across EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);
		2. Cumulative area across EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		3. The proportion of minimum TFI species across ecosystems that decline in abundance by $x\%^{1}$.
2. Avoid decline in the persistence of iconic ² landscapes	Less is better	4. For examining the set of iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);
		5. For examining the set of iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		6. For examining one or more individual iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);
		7. For examining one or more individual iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		8. The proportion of minimum TFI species across iconic EFGs that decline in abundance by $x\%^{1}$.
3. Minimise decline in the persistence of all plant and animal species with data ³	Less is better	9. Proportion of faunal and flora species that are significantly impacted (e.g. decline by $x\%^{1}$ in relative abundance, occupancy, or extent).
		10. Number of significantly impacted faunal and flora species (e.g. decline by $x\%^{1}$ in relative abundance, occupancy, or extent).
		11. Level of decline in geometric mean abundance of all faunal and flora species
4. Minimise decline in the persistence of threatened species	Less is better	12. Number of significantly impacted threatened species with data ³ (e.g. decline by $x\%^{1}$ in relative abundance, occupancy, or extent).
5. Minimise decline in the persistence of iconic ² species	Less is better	13. For examining a group of iconic species: Number of significantly impacted iconic species (e.g. declining by more than $x\%^{1}$ in abundance, occupancy, or extent over the duration of the strategy).
		14. For examining one or more individual species: % declines in abundance, occupancy, or extent over the duration of the strategy.

Table 3: Case study comparison, in relation to the steps of structured decision-making.

Step	Gippsland	Metro
Spatial and temporal scale	All fuel management zones / 30-year Strategy (i.e. to 2050)	Landscape Management Zone only / 40-year Strategy (to 2060) Zone was divided into three planning units: French Island, forested areas and grassland areas.
Objectives	Social, economic and ecological objectives: <ul style="list-style-type: none"> - Minimise human life loss serious injury - Minimise social, livelihood economic disruption - Minimise disruption to essential services and critical infrastructure - Minimise loss of community and cultural assets - Minimise decline in native plant and animal populations 	Ecological objectives only: <ul style="list-style-type: none"> - Maximise persistence of communities - Minimise decline in threatened communities - Maximise persistence of species - Minimise decline in iconic (threatened) species
Alternatives	Stakeholders identified key strategy variables (Amount of fuel treatment, Spread of fuel treatment, Human/ Ecological weighting, and Equality/ Efficiency). The Gippsland Planning team developed 11 options (each with 5 replicates) which varied according to the variables.	Facilitated workshops (and follow up meetings) with experts to generate alternatives and constraints.
(Ecological) Consequences	Utilised the Fire Analysis Module for Ecological values (FAME), and incorporated VBA data. Future Fire Occupancy expert data not used.	For forested areas and French Island, utilised the Fire Analysis Module for Ecological values (FAME), and incorporated Future Fire Occupancy expert data, plus current (field or modelled) data on iconic threatened species. Qualitative expert opinion was used for grasslands and to supplement French Island data.
Trade-offs	Stakeholders asked to directly rank alternatives and undertake a quantitative trade-off (swing weighting) process. Further discussion was held to make a final decision on whether to endorse, accept or oppose each of the alternative strategies.	The consequences identified an optimal strategy for forests, which was validated with experts in a facilitated workshop. During the workshop, a preferred strategy was discussed and refined for French Island and grasslands (i.e. holistic approach to reach consensus).
Make decision	The next step in this process involves checking for operational feasibility and further refinement with stakeholders.	The next step in this process involves checking for operational feasibility and further refinement with stakeholders.
Dealing with uncertainty	Consequences were run using one climate/wildfire scenario only, and analysis did not incorporate uncertainty bounds. Some data (i.e. TFI) was not utilised at all because of a lack of trust in the data. To incorporate uncertainty, five replicates of each alternative strategy were generated and then averaged to provide data for the consequence tables.	Consequences were run using one climate/wildfire scenario only, and available evidence was used (i.e. no uncertainty bounds). Metro referred to experts to validate consequences, as there was no other way to gauge whether a preferred strategy would change under uncertainty.

a. TFI: Tolerable Fire Interval

b. VBA: Victorian Biodiversity Atlas

Fire Analysis Module for Ecological values (FAME)

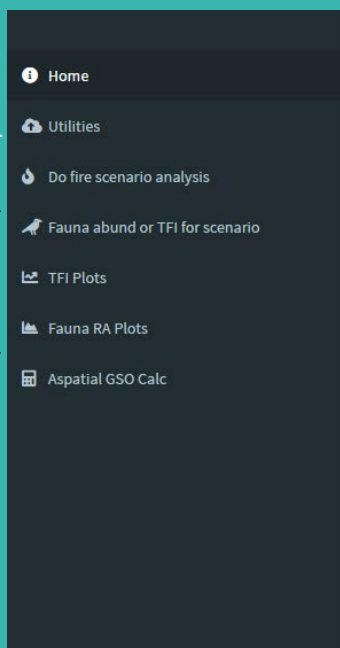
This section provides a brief introduction to the Fire Analysis Module for Ecological values (FAME) that supports the decision framework for considering ecological values in SBMP. Further details about the data and scripts which underpin the module are provided in Appendix D.

Purpose

The purpose of FAME is to improve decision making through access to better information as part of ecological risk assessment. The module provides a more integrated and user-friendly approach to undertaking ecological risk assessments to support SBMP decision-making. The module provides streamlined access to data and scripts in a single analysis environment. This improves transparency in the process through automated documentation of (i) data inputs, (ii) key decision points undertaken as part of the analyses and (iii) standard outputs to provide consistency in approaches across the state.

Key steps in FAME

Prior to analysis in FAME combine future fire regimes with existing fire history using ARCGIS tool to generate the “raw fire sequence shapefile” (detailed instructions in Appendix D).



Fire Analysis Module for Ecological values



1. Upload files into module (Utilities page)
 - a. Raw fire sequence shapefile
 - b. Custom footprint of analysis (optional)
 - c. Custom species list (optional)
2. Select scenario to undertake fire history analysis (FireHat)
 - d. Select fire sequence to analyse
 - e. Select analysis footprint (user defined, FFR region or state-wide)
 - f. Other option
3. Load scenario and undertake relative abundance or TFI calculations
 - g. Choosing baseline (for relative abundance)
 - h. User defined species list
 - i. Map generation
4. Aspatial GSO calculations (see Appendix D)
5. Download
 - j. csv files of RA and / or maps (Figure 2)
 - k. R data file – meta data re input data and all choices for this analysis

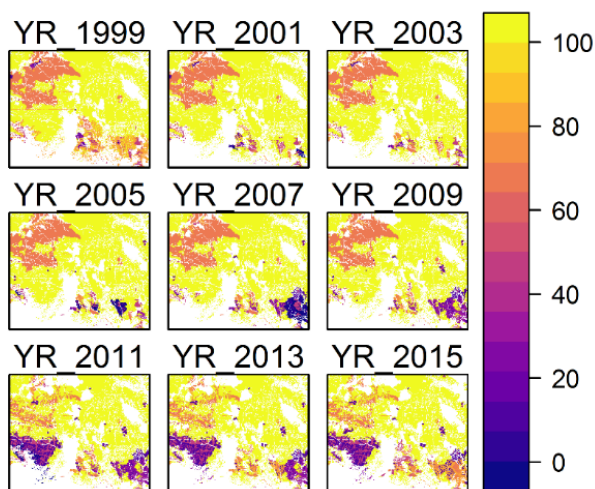


Figure 2: Spatially explicit models of species relative abundance (scaled 0-100%) with fire history allow calculation of change in species' abundance in any management area. This example shows changes in the modelled relative abundance of the Pilotbird in the Central Highlands 1999 to 2015

Overarching principles of the module

The module was developed in close collaboration with end users in DELWP Forest and Fire Regions risk and evaluation teams, the Monitoring, Evaluation and Reporting Unit and the Forest and Fire Assessment Unit. Guiding principles in the development of the module were:

- *Flexibility*
- *Future proofing*
- *Improving speed of analysis*
- *Accessibility to wider user group*
- *Quality assurance*
- *Single source of inputs*
- *Standard format for outputs*
- *Tailored to user requirements*
- *Consistency in analysis*
- *Transparency of analysis and outputs*

Users of the module

Currently DELWP has six Forest and Fire Regions each comprising Risk and Evaluation teams who lead the risk assessment process for SBMP. The core users of the module are the Biodiversity Officers in the Risk and Evaluation team who have the requisite skills to develop and review spatial and aspatial data inputs including fire history and biodiversity information. While the module was

designed primarily to support SBMP it may also be applied at the state-wide level and therefore could also be used by staff (with appropriate training) in MER and FFRA units as part of state-wide reporting (e.g. for the Fuel Management Report). Outputs from the module could support SBMP discussions with non – technical stakeholders. Further work would be needed to make the module itself more widely available (e.g. for non-technical stakeholders) to undertake scenario analyses.

How was the module developed?

Stocktake and consolidation of input datasets

Datasets used in prior ecological risk assessments were identified in collaboration with end users of the module. We then reviewed these datasets for their usefulness in supporting performance measures for SBMP (Table 2 in Case study section above).

Several spatial layers were identified as critical to supporting analyses. These included fire history, species' Habitat Distribution Models (HDMs) and Ecological Fire Groups (EFGs). Spatial datasets were standardised to ensure all rasters were the same size and aligned with each other. Exploration of analysis methods using unthresholded models were explored but remain unresolved due to issues with using ranked data for performance measures. Related work investigating choice of HDM thresholds for threatened species had too few responses to warrant changing the set of HDMs (MacHunter et al. 2018). Hence, the existing thresholds are used for the module (95se HDMs for non-threatened species and expert adjustment for threatened species).

Existing categories for vegetation growth stages (Cheal 2010) which are binned into blocks of time (0.5 up to more than 100 years) were recast into single years since fire. This approach enables future classifications of growth stages based on new knowledge. Another advantage of recasting the data in this way is an increase in computational speed stemming from use of integer values (years) versus categorical values (growth stages).

A stocktake of data about post-fire species' response to vegetation change included both expert opinion and field data from legacy fire monitoring programs. Further details of the data stocktake are provided in Appendix E. Due to access issues with the VBMP database it was not possible to embed a direct link between VBMP field data and the module. However, while there are intentions to resolve this issue, the input data file for species responses to fire was transformed into a format which supports

updates from field derived data. This is intended to provide flexibility in data inputs and allow for updating with future data sources. In the longer term it is envisaged that data generated from the statewide fire monitoring program (Leonard et al. 2018), led by the MER unit, will be incorporated into the module according to the methods outlined in Output 8 (see Appendix C). In the interim, the long format data file can also accommodate user preferences for alternative data sources (see case study using Victorian Biodiversity Atlas derived data on fauna responses to time since fire).

Further investigation is required to assess how flora can be integrated into the relevant performance measures in Table 2. This includes the conceptual basis of including flora which should account for the mechanism of species persistence (which varies between obligate seeders and vegetative resprouters), and how to correctly account for the seed bank. Once the conceptual basis is resolved, the technical process would need to be determined accordingly. Further details about methods for exploring issues regarding choice of performance measures is provided in Appendix C.

Stocktake of how data were being analysed and code consolidation

We consulted with end users to identify existing analysis tools used for ecological risk assessment. These included the FireHat tool (to transform fire history information), FRAC tool (Fauna Relative Abundance Calculator - aspatial analysis of EPBC species), FFO (Future Fire Occupancy; archived database of expert opinion), GSO (Growth Stage Optimisation, which generates the growth stage structure that results in the maximum value of GMA) code incorporating uncertainty (Sitters et al. 2018) and multiple data types, ArcGIS tool and various pieces of R and python code that have been used for state-wide bushfire management reporting (e.g. for the DELWP Fuel Management Report).

Consolidation of code involved substantial revision of scripts to streamline the analysis process. Consolidating these disparate sources into one open-source platform supports a more cost-effective approach that is not reliant on licensing costs. The open source R platform also has the advantage of seamless integration with a browser-based Graphical User Interface (GUI). GUIs have the advantage of improving user accessibility as the complexity of the analysis underlying the module requires highly specialist skills. The GUI enables a wider selection of users that can undertake complex risk analysis without having knowledge of

specialised programming languages such as R. Note that the first stage in the consolidation of fire sequences / scenarios into a single shapefile still requires user knowledge with ARCPy (a Python site package for performing GIS functions available in ArcGIS). Other R and Python approaches were explored but found to be several orders of magnitude slower so the ARCPy scripts were retained.

Development of new analytical methods

The existing methods for evaluating changes in species abundance were difficult to translate into an operational setting (i.e. for burn planning). To address this issue, we developed a spatially explicit routine to automate analyses for all available species with fire response data. Unlike the aspatial GSO, the spatial GSO does not capture uncertainty (using the bootstrapping approach, see Porigneaux et al. 2017, Sitters et al. 2018) from underlying fire response data. However, if desired it would be possible to run the spatial analyses and input lower and upper confidence intervals along with mean values.

Another constraint in the spatial approach relates to gaps in the data on species' response to fire. These data gaps limit the analyses to only show change in species abundance for EFGs that are subject to planned fire. In some regions, extensive areas comprise EFGs that are subject to bushfire (not planned fire) and should also be accounted for. One method of addressing this could be to report at an EFG level (rather than at a regional level) though it would add considerable complexity to interpretation.

Future refinements

Several iterations of the code were undertaken to speed up the process, thereby reducing analysis time and minimising associated costs with cloud computing. This work has enabled analyses to include a state-wide spatial footprint and/or faster calculation of multiple future fire scenarios. Areas to explore to improve the code include (while also considering impact of R updates):

- Ability to provide outputs at small (burn) units
- Incorporation of the R package *velox* to increase the speed of reading and writing rasters, and manipulation of the arrays within.
- Ability to run code as a batch process rather than via a GUI.
- New functionality on the GUI e.g. interactive chart outputs.

Discussion and Recommended Next Steps

What worked

Complex decisions are characteristic of natural resource management (NRM). They often involve high levels of uncertainty across large temporal and spatial scales, competing objectives and numerous stakeholders. These factors contribute to different priorities regarding the desirable balance within ecological objectives including different plants, animals, communities, or other related entities such as old trees. Furthermore, NRM decisions involve other objectives such as minimizing cost, or risk to life and property, which may constrain achievement of ecological objectives.

We navigated the intrinsically complex decision context of SBMP by drawing on the core principles of structured decision-making (Gregory et al. 2012). This included a collaborative approach where project partners and stakeholders were identified as part of the first stage of the project. Engagement occurred throughout the project; in workshops, regional networks (risk and evaluation teams), with FFR policy leads, Biodiversity Division staff, Parks Victoria and CFA, and researchers working on related projects. This approach was crucial in ensuring our work was tailored to the decision context of Strategic Bushfire Management Planning (SBMP). For instance, we were able to identify and explore common themes and sticking points in the use of ecological data and models in decision-making, such as issues with existing ecological metrics (such as GMA) being challenging to explain to external and internal stakeholders.

Structured decision-making provides a classification of objectives (strategic, process, fundamental and means objectives) that was valuable in guiding discussions about what factors are important in decision-making. We worked with project partners using an iterative approach to the refinement of existing ecological objectives, and for the development of new ecological objectives. This provided a common understanding of the different types of objectives, and how and when they should be applied in the decision-making process (Appendix B). An iterative approach was important to clarify and resolve ambiguity (i.e. wording and meaning) with objectives and performance measures, which could impact evaluation and interpretation of alternative actions. For example, calculating an “area below TFI” or “burnt below TFI” will result in different views of the consequences

associated with alternative future fire regimes. Uncertainty in the conceptual model underpinning Tolerable Fire Intervals (TFI) about the characteristics and thresholds of fundamental ecosystem change also generated discussion about the associated performance measure: the *number of times* “burnt below TFI”. Having time in the project to clarify the meaning and suitability of performance measures was crucial in arriving at an acceptable and relevant suite of performance measures to include in FAME.

Project workshops revealed the need for flexibility in the use of DELWP resilience metrics for decision-making. That is, all performance measures (Table 2) are available for *reporting*, but regions have the choice of one performance measure per objective for *decision-making* (i.e. *analysis of trade-offs*). The choice may be dictated by data availability, communicability, stakeholder preferences etc. At a statewide level, TFI and GMA were generally viewed as adequate for tracking broad trends in ecosystem resilience. However, in the context of decision-making, GMA was not preferred by most regions (i.e. to date, used by only two out of six of the regions in the SBMP process). Instead, a metric closely related to GMA – the number of species declining by a threshold amount - was used by five of the six regions for decision-making involving trade-offs. Calculating the number of species declining may be derived by decomposition of the multispecies result (GMA) from GSO into single species effects (Chick 2018). Alternatively, a simple comparison of species’ abundance under different scenarios (i.e. not involving GSO or GMA) can be used to calculate the number of species declining. The thresholds varied according to threat status, and were developed in a separate structured participatory process (MacHunter et al. 2018). In comparison to GMA, the species threshold performance measure was considered to be more intuitive and meaningful to community stakeholders for evaluating alternative strategies involving trade-offs with non-ecological values. Differences in the suitability of ecological objectives also varied between regions. For instance, Gippsland used a single objective inclusive of all species, whereas in the Metro and the South West regions, declines of (multiple) iconic species were also considered as additional objectives.

Initially our project was to focus on one case study region, but work undertaken in a related project enabled us to test an earlier version of FAME with multiple regions. This presented another opportunity to understand common issues and new approaches being developed and trialled in the regions, such as replacing existing data (based on expert judgement) with VBA derived data (Gippsland, South-West), and

using qualitative data when empirical data were lacking (Metro). The case studies also demonstrated variation in the scale of analyses between regions.

In summary, this highlights the critical need for flexibility in decision support tools, to cater for regional differences in the decision-making process.

Key lessons

- We applied a collaborative approach throughout this project. Our focus on end-user requirements combined with close collaboration with DELWP policy leads was crucial to successfully tailoring this research to relevant and flexible applications of strategic bushfire management planning.
- We refined existing ecological objectives and performance measures using an iterative approach. This helped to reduce ambiguity of terms and clarify the role of different types of objectives in the decision-making process (Gregory *et al.* 2012). It would be useful to revisit the final suite of objectives (and associated performance measures) with non-technical stakeholders to evaluate whether they are understood, and/or capture objectives of interest. There is an immediate need to review the objectives, performance measures and associated significant impact thresholds as part of DELWP governance processes, which should consider broader community expectations and the Guideline for Matters of National Significance. In particular, the framing of ecological objectives, which currently focus on minimising declines rather than maximising increases in ecological outcomes, should be a priority for review.
- In the development of the Fire Analysis Module for Ecological values (FAME) and decision framework, we endeavoured to balance the need for a unified approach between regions, whilst allowing for flexibility to account for different stakeholders and data availability.

Reviewing issues with data, performance measures and uncertainty

DELWP has made progress defining the ecological objectives and performance measures for strategic planning. These objectives were specified early in the ERP 1 project (Appendix A) and been iteratively revised as part of subsequent review by policy leads and project stakeholders (Table 2, Case Study section). However, there are issues and gaps with the process that impede decisions about development, identification and assessment of preferred management strategies. These issues and gaps can be described in relation to (i) issues with the decision-making process, and (ii) issues with the

technical process of implementing ecological models to support bushfire management planning.

In the initial stages of the ERP1 project, a workshop was held with relevant stakeholders to develop a shared understanding of the constraints and issues with the current decision-making process as it relates to inclusion of ecological objectives, and the technical (modelling/data/tools) process (Appendix A

Output 1: Project Plan). The issues with the specification and use of performance measures and data to support strategy selection are the primary focus for this part of the discussion.

The data related issues can largely be synthesised into three themes:

1. Adequacy of the performance measures used to represent the objectives;
2. Adequacy of data underpinning the performance measures, e.g. data quality, data gaps, and;
3. Lack of process for integrating and updating ecological models with new data collected through MER and research.

We explored these themes in a dedicated workshop which brought together the policy leads and key researchers with expertise in applied research for fire management, or in developing decision support tools. The findings of this workshop formed the basis of Output 8 (Appendix C Output 8: Process map) and key points from this work are highlighted below.

We developed a decision tree (or process map, Figure 3), to aid diagnosing and targeting solutions for many of the issues raised throughout this project. In this figure, we highlight four steps a risk or data analyst (i.e. PBBO) should take when navigating the choice of performance measures (Table 2) and associated quality of evidence (data), to support decision analysis.

- Step 1 – are the performance measures adequate?
- Step 2 – is data collection or revision of the performance measure required to proceed with analysis?
- Step 3 – is the quality of evidence (data) adequate?
- Step 4 – is critical uncertainty present (i.e. adaptive management warranted)?

In essence, we advocate that structured decision making be used to first examine whether uncertainty or issues with the performance measures impedes the choice of a preferred management strategy. However, we recognise that in many cases decision analysis cannot proceed until issues are resolved. In either case, using the framework allows a user to pinpoint where the issues with the measures or data lie, such that targeted solutions can be applied to support future iterations of the analysis. It is recommended that PBBO's have a platform for documenting issues, to facilitate improvements to FAME and the supporting decision framework.

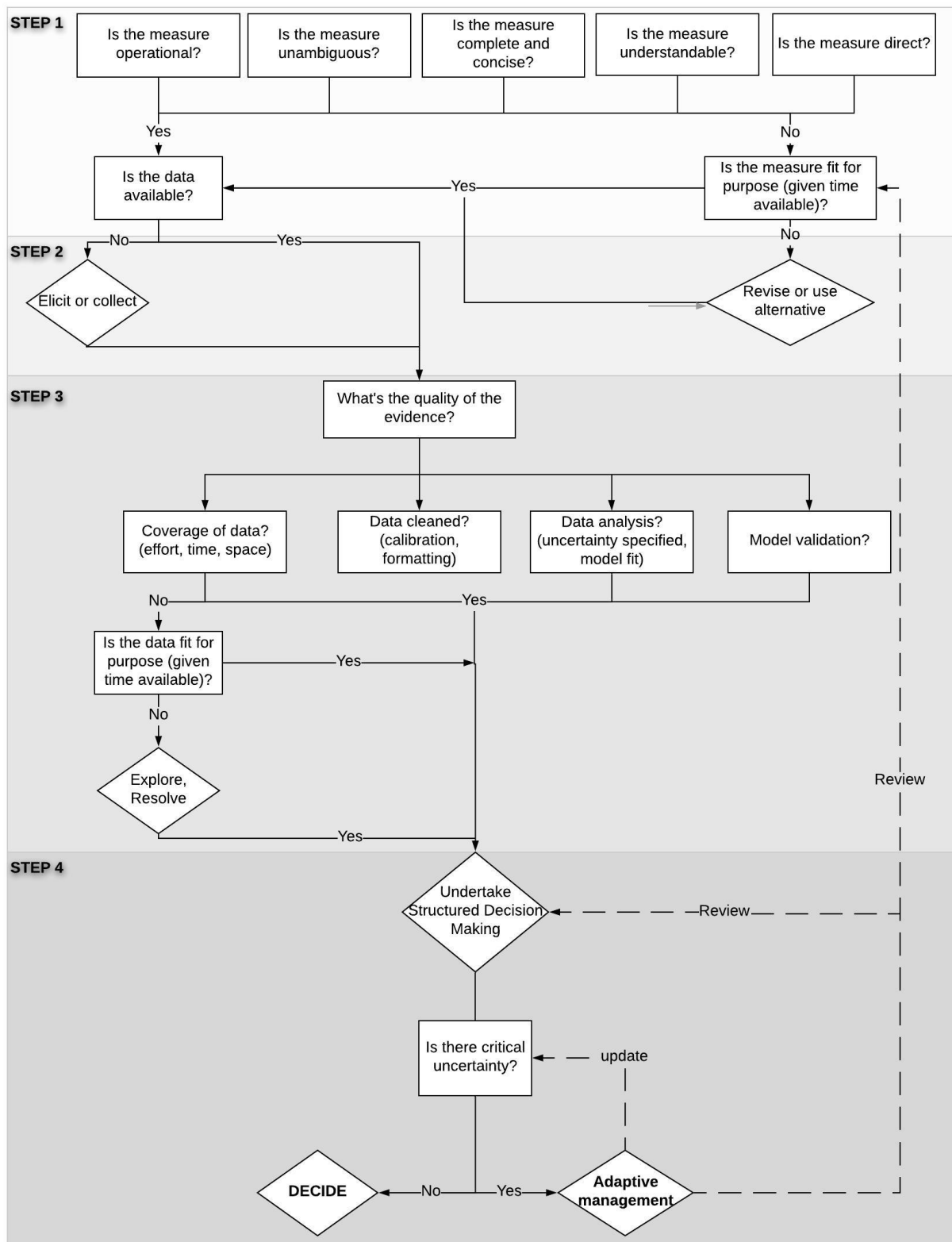


Figure 3 A decision tree, or process map, which provides a guide for diagnosing and summarising the issues with performance measures and data, to accompany suggested solutions to these issues (e.g. Table 5, and Appendix C). It is recommended that PBBO's have some kind of platform for recording and documenting issues, to facilitate improvements to FAME and the supporting decision framework.

Adequacy of performance measures used to represent the objectives

For various reasons outlined below, some performance measures (metrics) were considered inadequate and were not used to guide strategy selection. 'Adequacy' is related to:

- The links and logic between the ecological models and metrics, and the Code objective and the values it represents, have not been well articulated. Thus, the current measures do not always directly measure (or 'represent') the objectives or may be insensitive to bushfire management interventions.
- Difficulties in interpretation of the performance measures (e.g. measures may not be direct, natural measures, or are difficult to define).
- Difficulties in communicating meaningful outcomes of Strategies on ecological objectives to decision makers and other stakeholders, which is in part due to ambiguities, and a lack of specification of what is a 'good' or desired outcome.

Figure 3 highlights a process for diagnosing issues with performance measures, based on criteria posed by Gregory *et al.* (2012). Examples of these issues in relation to the criteria, as identified in the ERP1 project, are found in Table 4.

One of the primary issues with performance measures to assist decision-making was the lack of clarity between Time Since Fire (TSF) and species responses (Table 4). Details about a potential process to solve this issue is provided in Appendix C, and a summary is provided here:

1. Improve the process of validating the TSF model: build this into the workflow for updating data in Victorian Bushfire Monitoring Program (VBMP) database
2. Identify key fire attributes in different EFGs (and/or for different species) that are required in data collection efforts. These are the conceptual models (i.e. to elicit) that represent hypotheses about EFG/species responses to fire regimes and can help to stratify sampling.
3. Consult multiple experts (e.g. regional staff, other ecologists), to explore whether there are competing conceptual models that need to be considered. Key areas for investigation include effects of fire severity, extent, season, frequency patchiness and interactions, but further discussion is needed to understand and prioritise these.
4. Identify critical model needs: e.g. For a certain species, identify what aspect, within the fire regime, is a critical knowledge need. The aspects should be evident from the development of the conceptual models.
5. Sensitivity analysis: identify sensitivity of species to Time Since Fire for the different EFGs/ regions, then monitor species responses following fire.
6. Use data to develop the species distribution models, species trajectory, GMA, and the effects of fire management.

Table 4 Examples of some of the issues with performance measures that are used in strategic bushfire management planning. This table is modified from Appendix C.

Some of the desired attributes of performance measures (direct from Gregory <i>et al.</i> 2012)	Key examples
<p>Complete</p> <p>The performance measure covers the range of possible consequences for the corresponding objective</p>	<p>Geometric Mean Abundance currently captures fauna, but not flora, despite the objectives specifying that both are to be considered.</p>
<p>Unambiguous</p> <p>A clear relationship exists between consequences and descriptions of consequences using the performance measure.</p>	<p>Lack of clarity in relationship between time since fire and species response (i.e. there may be other elements of the fire regime, or environmental predictors that explain species response).</p> <p>Geometric Mean Abundance (GMA): Several studies have evaluated the properties of GMA and while it meets certain aspects of ecological resilience in principle, whether other metrics and models are more suitable is not known. This will depend on how resilience is defined, how the different metrics capture that definition, and how robust they are to uncertainty (e.g. Giljohann <i>et al.</i> 2015)</p> <p>Tolerable Fire Intervals (TFI) are intended to capture the needs of the most fire-sensitive plant species by specifying intervals that will enable them to survive. Studies have shown that many system attributes (other than persistence of plant species) are not accommodated by the current TFI intervals.</p> <p>Use of proportions in performance measures 3, 8 and 9 (Table 2) compromise the ability to make meaningful trade-offs, unless they are accompanied by absolute statements of the number of minimum TFI spp, or number of species with data.</p>
<p>Understandable</p> <p>Consequences and value trade-offs made using the performance measure can readily be understood and clearly communicated.</p>	<p>It is difficult to conceptualise what a meaningful change in geometric mean abundance is, which makes it difficult to use it in a participatory trade-off analysis (like swing weighting).</p>
<p>Direct</p> <p>The performance measure levels directly describe the consequences of interest. Value judgements can reasonably be made.</p>	<p>Tolerable Fire Intervals are calculated on the basis of flora, but the relevant objective is a measure of ecosystems more broadly (i.e. plants and animals)</p> <p>There is an assumption that probability of occurrence as a function of time since last fire translates to relative abundance in different successional growth stage structures, which has not been tested for all species.</p> <p>The survey methods used do not provide a direct measure of abundance (e.g. camera traps).</p>

Adequacy of data underpinning the performance measures

Issues identified with the quality of evidence to support decision-making for fire management are synthesised in Appendix C. Key data issues fall under four main themes: completeness of the data, formatting problems, the representation and exploration of uncertainty, and data calibration problems. These issues and potential solutions are provided in Table 5. Below, we summarise two of the key issues with uncertainty in the data: the ability

to explore critical uncertainty, and the reliability of the data derived through expert judgement.

Modelling Consequences and Understanding Critical Uncertainty

In some cases, a decision maker is not able to determine which management strategy is preferred or ‘optimal’ because of the uncertainty underpinning the response variables to alternative strategies. This uncertainty is referred to as ‘critical

uncertainty' because it impedes the choice of a preferred strategy.

If uncertainty is accounted for in a consequence table, a user would be able to start investigating the possible sources of critical uncertainty in the decision process, and decision makers would be able to exercise their attitude to risk. That is, does the preferred alternative change for a given objective when considering the lower bound, upper bound or nominal consequence estimate? An analysis of trade-offs can help differentiate whether a strategy is preferred, despite this uncertainty. If so, monitoring to resolve uncertainty is not required. However, if it is not possible to differentiate between strategies due to uncertainty, then further investigation is warranted to determine whether there is justification for an adaptive management program. Note, without uncertainty included for all objectives (including life/property), or the exploration of different climate/fire strategies, it is not possible to determine whether uncertainty is 'critical' for any given strategy.

To allow for identification of critical uncertainty (i.e. if resolved through monitoring, would result in improved management decisions), and to allow decision makers to exercise their risk attitude when making decisions in the face of uncertainty, it is crucial that further work is done to incorporate uncertainty into data that supports all objectives, including life and property. As per Figure 3, we advocate that even in the absence of uncertainty estimates, a structured decision-making process can be run to explore whether a preferred alternative can be identified and has the support from all stakeholders. This process can provide a target for where uncertainty estimates are most needed (e.g. in regions where a lack of uncertainty, or trust in the data, is a problem). As per the process in the Metro region (Table 3), experts were used in the process to explore consequence estimates and flag any data issues if the selected alternative was questionable. This is a form of model validation.

Last, we advocate for the development of a process to link the Key Evaluation Questions (Leonard et al. 2018) to the SBMP decision-making process. It is anticipated that this will involve a process of prioritising Key Evaluation Questions in relation to critical uncertainties by exploring a Value of Information analysis (Canessa et al. 2015).

Data derived through expert judgement

Discussions with stakeholders during the project highlighted that the issues with the available performance measures and data varied markedly between regions. This was particularly evident through working with the case study regions (Table

3). The important question is, when do those issues become a problem for decision-making? Uncertainty does not even have to be 'critical' in the technical sense, if a decision cannot proceed because stakeholders lack confidence in the performance measure or data and refuse to use them for those reasons.

Stakeholders have concerns with data derived from expert judgement as it was not designed for a quantitative application and may be unsuitable for ecological risk assessment. This is due to issues with accuracy and false precision which lead to markedly different conclusions about the mix of vegetation growth stages that will maximise biodiversity in comparison to field-based data (Giljohann et al. 2018).

To address data needs, DELWP is commencing a new long-term statewide monitoring program of field data collection (Leonard *et al.* 2018). Incrementally over the next 3-10 years, field data will be analysed and available in FAME. It is envisaged this field derived data will provide greater accuracy and stakeholder acceptability than existing data derived from expert judgement. However, in the interim there remain issues in terms of improving the quality of the existing expert data to support current decision-making processes and understanding whether the field data has adequate spatial and temporal coverage. New questions arise – should the existing expert data be replaced, or should the two data sources be integrated, and how (Giljohann et al. 2018)? Below, we outline an approach that was developed in Output 8 to improve trust and reduce uncertainty in the existing expert data, and to update models with new data, when it arises:

1. Clarify to stakeholders how the existing expert data was collected (i.e. attempt to deal with the miscommunication issue)
2. Do you need more field data? Validate and calibrate (existing) expert data with field data.
3. What are the concerns with the data? Use the decision tree (Figure 4) as the basis for consultation with stakeholders, to undertake a (form of) sensitivity analysis to target calibration and data collection efforts.
4. Where required, re-do expert elicitation, guided by the sensitivity analysis.
 - Develop conceptual models (hypotheses) relating to the key drivers of species abundance in space and time. Use multiple experts and investigate whether there is a consensus model (i.e. everyone is on the

- same page), or different (competing) causal models exist.
 - Undertake a structured expert elicitation process (IDEA protocol – Identify Discuss Evaluate Aggregate, Hemming *et al.* 2018): Using the models, develop a series of questions that relate to eliciting species trajectories to underpin the IDEA protocol (Hemming *et al.* 2018).
- 5. Integrate field data with expert data
 - Update data over time using Bayesian updating approaches (Murphy *et al.* 2018)
 - Document assumptions: infer to areas with data gaps; use space for time substitution and use experts to validate
 - Use bias correcting approaches to account for different survey methods (Giljohann *et al.* 2018).
- 6. Review: Do you need more field data, and where? Validate and calibrate new expert data with field data.
- 7. Evaluate decisions (i.e. choice of strategies), using all data types
 - Use field data only
 - Use expert only (weighted)
 - Use integrated data – Bayesian updated

Table 5. Examples of some of the issues with data that are used to inform the performance measures for strategic bushfire management planning and possible methods to address the issues. This table is modified from Appendix C.

Data issues	Examples	Potential solutions
Completeness	Data collection skewed to some species (mainly birds, mammals, flora), EFGs/ regions No true absence data collected	Prioritize critical uncertainties, elicit data using IDEA protocol (Hemming <i>et al.</i> 2018), and collect data to test/update expert judgement
Formatting	Expert or field data available, but not in an accessible format	Model field-collected data where necessary, insert field data in Victorian Bushfire Monitoring Program database, and develop scripts to include modelled values and their confidence intervals in FAME.
Uncertainty	<p>Estimates of relative abundance are largely point estimates in each growth stage with no understanding of the reliability or confidence the expert has in their judgements.</p> <p>There is inherent uncertainty in the choice of habitat distribution model and the environmental variables that are used as predictors in the habitat distribution model</p> <p>There are no uncertainty bounds presented for the data, which precludes identification of critical uncertainty (to target monitoring), and ability to exercise risk attitude when making decisions based on the data.</p> <p>There is no uncertainty presented as a result of exploring plausible fire/climate scenarios, nor any estimates for the likelihood of those different scenarios. It is not possible to i) explore whether a preferred management strategy would alter under uncertainty (i.e. critical uncertainty), ii) for a decision-maker to exercise their risk attitude, based on the likelihood and consequences of those different scenarios.</p>	<p>Prioritize critical uncertainties, elicit data using IDEA protocol (Hemming <i>et al.</i> 2018), and collect data to test/update expert judgement</p> <p>Document model selection and conceptual model(s) underpinning predictor selection, identify competing conceptual models (expert judgement), evaluate competing conceptual models (field, longer term).</p> <p>Elicit bounds using IDEA protocol (Hemming <i>et al.</i> 2018), with uncertainty, and/or collect data to test/update expert judgement.</p> <p>Explore the consequences of management alternatives under different climate/fire scenarios. Explore critical uncertainty (i.e. a change in preferred strategy). Model or estimate (IDEA protocol) the likelihood of each scenario (i.e. to facilitate a risk assessment).</p>

Data issues	Examples	Potential solutions
Calibration	Monitoring data with different survey methods/ data collection has not been calibrated. For example, field data collected using various methods not calibrated (e.g. pitfall vs Elliot traps vs etc.); Expert and field data not calibrated	Search literature for how to calibrate different data types, ask experts to calibrate data, partition analysis to only use single or calibrated survey techniques, undertake field calibration (longer-term)

Key lessons

- It is evident that there are issues compromising confidence in the performance measures and data. In ERP1, we:
 - provided a decision tree, or process map, to assist stakeholders to diagnose and summarise the issues with performance measures and data during their decision-making process (Figure 3),
 - provided some accompanying guidance for solutions to explore and resolve these issues (Appendix C).
- Two issues in particular were found to cause impediments to the decision-making process: the lack of clarity between Time Since Fire (TSF) and species responses, and the need to update or replace data derived from expert judgment regarding species' response to TSF.
- Solutions highlight the importance of developing conceptual models with experts as an initial step in clarifying uncertainty, prioritising where improved information is most critical to resolve, and utilising structured expert elicitation where necessary (i.e. as an interim measure, prior to collection and validation with field data).
- It is critical that further work is done to incorporate uncertainty into data that supports all objectives, including life and property. This allows for identification of critical uncertainty to target monitoring efforts and allows decision makers to exercise their risk attitude when making decisions in the face of uncertainty.
- To target existing data collection efforts to resolve critical uncertainties, it would be worthwhile developing a process to document issues with data or measures arising from the SBMP process (i.e using Figure 4), and prioritise the key evaluation questions from the monitoring program.

Reviewing the decision framework

Core decision steps

The decision framework for applying ecological objectives in strategic bushfire management planning is a critical step in improving consideration of ecological values by stakeholders and decision makers. To develop the framework for this project we applied the core steps and principles of structured decision-making (Figure 1) which are particularly useful for complex natural resource management decisions which involve competing objectives, high uncertainty, and high levels of scrutiny by stakeholders. Structured decision making

is designed to aid logical, repeatable and transparent decision making. The focus is on using participatory, values focused approaches, to ensure stakeholders are engaged, and aware of other perspectives throughout the process. In the Case Study section of this report we step through the application of the decision framework as part of Strategic Bushfire Management Planning in the Gippsland and Metro regions. This will be used as the basis for training the risk and evaluation teams in the use of FAME (Output 11).

In this project, we applied the steps of structured decision-making to navigate the consideration of ecological values in strategic fire management decisions. We recommend application of the core steps and principles of structured decision-making for other decision contexts (e.g. finer scale decision making for fuel operation plans or broader applications as part of statewide reporting). Stepping through these related decision contexts is likely to reveal similar information to that associated with strategic bushfire management planning. However, it should not be assumed that the suite of performance measures / ecological objectives will necessarily directly map on to the other decision contexts. Application of the decision framework will require each step to be reviewed in new decision contexts.

In addition, if this approach is to be expanded to other contexts, it may be useful to consider the application of frameworks like the Vic Gov Outcomes Architecture (Victorian Government 2019) in helping to achieve a level of consistency in language regarding performance measures / metrics / indicators etc.

Double loop learning

As well as resolving uncertainty through monitoring (i.e. single loop learning), it will be necessary to allow stakeholders to refine the decision context over time (i.e. double loop learning), which may result in required changes to the module. Examples may include:

- Further development or addition of objectives - currently, all objectives are specified to explore 'minimising' impact to ecological objectives, which does not allow for exploration of which

alternatives might 'maximise' ecological outcomes. This was a decision made by stakeholders which reflects their dominant risk attitude in the face of trade-offs with other objectives. However, subsequent iterations of the module could also allow users to explore maximising ecological outcomes.

- Further development or addition of performance measures – as **above**, there are suggestions to revise performance measures which are indirect, incomplete or ambiguous measures of the objectives.
- Altering the spatial scales under consideration in the decision context.
- Altering the timeframes under consideration in the decision context – for instance, further guidance may be given to the issue of exploring shorter (i.e. 3 year) vs longer (i.e. >30 year) timeframes when exploring ecological consequences. It is likely that focusing on short-term consequences may be suboptimal in terms of longer-term outcomes. This issue stems from changes in habitat over time where shorter term spatial arrangements of habitat (growth stages) may compromise the achievement of distribution of habitats in the future.
- As part of DELWP's Aboriginal Inclusion Plan 2016-2020, future work is needed to develop a better understanding of the needs and aspirations of Aboriginal communities and opportunities to support Aboriginal science by including revised data and culturally relevant ecological metrics in FAME.

Key points

- Structured decision-making (Gregory *et al.* 2012) provides a flexible and robust approach to navigating complex decisions such as SBMP. Its core steps include:
 1. defining a decision context, 2. developing objectives, 3. developing alternatives, 4. determining consequences, 5. evaluating trade-offs, 6. selecting a preferred option, 7. undertaking monitoring to resolve critical uncertainties, and updating preferred action if needed
- We recommend that double loop learning is built into a review process, to support longer term evaluation and improvement of the decision framework.

Implementation of FAME and framework

For the module and decision framework to provide sustained support to end-users and decision makers, it is vital that both are provided with proper curation. Further testing and refinement of the module needs to be coordinated, and any glitches in either access or implementation of the module addressed. Currently it is envisaged that curation of the Fire Analysis Module for Ecological values (FAME) and decision framework is undertaken at a statewide level within Knowledge and Planning Branch of DELWPs Forest Fire and Regions Group. The most immediate issue to resolve is regional access to FAME through a cloud computing environment such as Amazon Web Service (AWS). It is anticipated that connection issues and compatibility with DELWP Information Technology security will need to be managed on an ongoing basis. As well as establishing a timeframe for iterative updates to the data, a time-frame for revisiting the decision context should be established, with time allocated for any necessary changes to the module.

While FAME and the decision framework were tailored to a regional decision-making context, there is strong potential for application at other spatial scales, such as for scheduling burns as part of FOP or at a statewide scale as part of the Fuel Management report. Other refinements to FAME include new script to step users through all stages of a structured decision-making process, including consequence tables and associated trade-off analyses, to provide a complete end to end decision-making process. This will better support community at the centre of decision-making and provide a repeatable and transparent approach.

Future work exploring trade-offs

Currently, users can analyse the consequences of management alternatives on ecological objectives (i.e. FAME), but allowing for users to model the consequences of other objectives would allow investigation of:

- The alternative that performs best or worst for each objective.
- The presence of a dominant alternative; that is, a clear winner, that outperforms other alternatives on all objectives.

- Any dominated alternatives, or practically dominated alternatives. That is, alternatives that are consistently outperformed by another alternative, or alternatives that have unacceptable performance for any objective(s).
- Any redundant measures. That is, those performance measures that do not vary (substantially) across the alternatives. This indicates that either the alternatives need revising, the performance measure needs revising (i.e. it is insensitive), or that this objective does not contribute further in the analysis of the decision (i.e. even if an important value; Gregory *et al.* 2012).

Expanding the module to allow for exploration of the consequences of fire management alternatives for all objectives can allow a user to simplify the decision context (i.e. narrow down the list of alternatives or objectives under consideration) or better understand where there are critical uncertainties or trust issues in the data, or where trade-offs are necessary.

Determining the most appropriate fuel management strategy is likely to require trade-offs between competing objectives (e.g. life and property values vs. environmental values), as it is uncommon to find a shared dominant alternative. This clearly presents considerable challenges for strategic bushfire management planning, both in relation to the difficult nature of the trade-offs, and the involvement of community in the decision-making process. In ERP1, we explored trade-off methods with the Gippsland region (Output 5), who then went on to implement a participatory approach to analysing trade-offs in their SBMP process. These methods are similar to those trialled in the Strategic Bushfire Risk Assessment & Strategy Selection (SBRASS) Project (DELWP 2015b).

In addition to providing clear guidance and options for regions to undertake an analysis of trade-offs, there is an obvious next step to expand the module to allow users to undertake a quantitative analysis of trade-offs. Work has already been done to explore a prototype shiny app by the ERP1 team, which could be expanded and refined for this decision context.

Key points

- Proper curation of the analysis module and decision framework is fundamental to their timely and appropriate application. Curation should include any updates to input data, responsibility for user access, troubleshooting and user support.
- A timeframe should be established for stakeholders to revisit the decision context and make any necessary changes to the FAME module.
- Currently the analysis module is 'tuned' to strategic bushfire management planning. Future enhancements include tuning or modifying the analysis module to enable related ecological analyses for local and statewide scales. This would be valuable in providing efficiencies in data management and support better integration in how ecological values are considered at different levels of bushfire management planning.
- Other improvements include additional guidance and functionality to the module to enhance community engagement.
- A process for trade-offs needs to be clearly articulated and could be incorporated into the module to facilitate a transparent approach to decision-making for multiple objectives.
- To support a decision framework, the module could be expanded to model and report on the consequences of alternative management strategies on other (non-ecological) objectives that could be housed within the web-based graphical user interface.

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Appendix A Output 1: Project Plan

Executive Summary

The State's new approach to managing Bushfire Risk, Victoria's 'Safer Together' Policy, is focused on improving the health of Victoria's environment. With respect to encouraging healthy environments, the dual objectives of bushfire management on Public land in Victoria are minimising the impacts of major bushfires on the environment and maintaining or improving ecosystem resilience. Strategic bushfire management plans (SBMP) guide fuel management activities by identifying strategies that protect key ecological values from bushfire and minimising the impacts of planned burning. A pathway to implementing SBMP's has been identified by DELWP, and ecological models resulting from extensive research into the response of flora and fauna to fire are integral to this process. However, there remain significant knowledge and implementation gaps impeding the use of the ecological models and metrics in decision-making.

In this project we aim to develop a consolidated framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species to facilitate effective decision-making. The project will bring together a suite of ecological models into a world-class and user-friendly system to enhance bushfire management, research investment and monitoring

Introduction and Context

Policy drivers

Building the health of Victoria's environments is a central tenet of Victoria's Safer Together policy, which outlines the State's approach to managing bushfire risk. With respect to building the health of environments, the primary objectives of bushfire management on Public land in Victoria are two-fold:

- (i) to minimise the impacts of major bushfires on the environment
- (ii) to maintain or improve ecosystem resilience.

The entire objectives are outlined in the Code of Practice for Bushfire Management on Public Land 2012 (The Code).

The integration of science into bushfire management policy and decision-making, and the adoption of a strategic, risk-based approach to planning are critical to achieving the above objectives. Therefore, Department of Environment, Land, Water and Planning (DELWP) undertakes strategic planning to guide fuel management activities. Specifically, DELWP use the strategic planning process to i) identify values to be protected from bushfire, ii) assess bushfire risk to those values, iii) develop strategies to enable capacity building to manage risks, and iv) identify a preferred approach to assess bushfire risk. Throughout this document, it is acknowledged that DELWP is currently developing new guidance for strategic bushfire management planning.

Policy implementation questions

How can we design a decision framework for DELWP to apply data and models to assess the potential impacts of alternative strategies on ecological values to develop bushfire management strategies that:

- Is built on an understanding of the existing and developing decision-making frameworks
- Incorporates a preferred suite of ecological objectives and associated performance measures and metrics to support evaluation and reporting of ecological values as part of strategic planning.
- Includes relevant ecological data, models and metrics currently used to inform decision-making at the strategic level.
- Provides an integrated analysis tool to support a consistent approach to the assessment of bushfire management.
- Demonstrates a process to identify and prioritise critical uncertainties in ecological data to guide research investment and monitoring

Research approach

We will use a structured decision-making (SDM) framework (Figure 1; Addison, Rumpff et al 2013) to guide decision makers and stakeholders on how to better use ecological models and metrics to inform a strategic planning process. It is important to note that we are primarily using the steps of a SDM framework to ensure the modelling component of this proposal is fit for purpose (i.e. bushfire management) – it is the role of decision makers and government to apply such a framework.

A structured decision-making process involves an organised analysis of a problem, focused explicitly on addressing the objectives of those involved in the decision-making process (i.e. as per the objectives outlined in The Code). This approach is well suited to supporting ecological risk assessments where there is a backdrop of potentially competing objectives such as the conservation of species with different requirements. Structured decision-making provides a systematic, rational and transparent platform for synthesizing existing knowledge and uncertainty, and exploring the consequences of management alternatives, such as the amount and configuration of planned burning, in relation to The Code objectives.

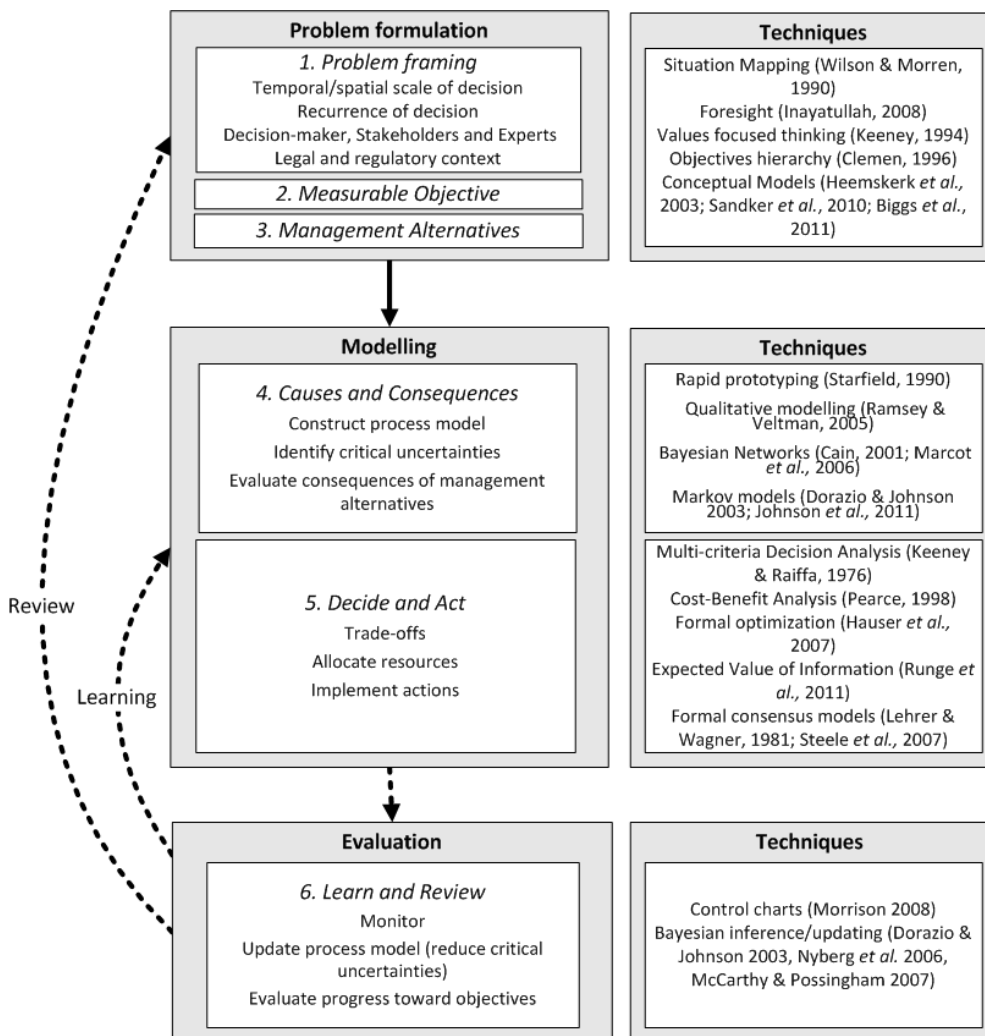


Figure 4: The Structured Decision-Making framework (from Addison, Rumpff et al 2013), which outlines a number of steps and associated tools and techniques that can assist adaptive management and decision-making. Dashed lines indicate feedback loops.

Project Details

History

DELWP has made progress defining the ecological objectives and metrics for strategic planning (e.g. developing ecological models and metrics through research, developing risk analysis tools, and establishing a MER framework). However, there are issues and gaps with the process that impede decisions about development, identification and assessment of preferred management strategies. These issues and gaps can be described in relation to issues with the decision-making process, and issues with the technical process of implementing ecological models to support bushfire management planning (as described in Workshop 1 Report and synthesized below). Whilst the following list is comprehensive, it is acknowledged that many of the issues raised are beyond the scope of this project. This project will be focused on developing a framework to integrate ecological data and models to inform the strategic bushfire management planning across regions. However, understanding issues with the decision-making process is critical to understanding the decision context across the regions. This understanding, along with close stakeholder consultation, provides the basis for developing flexible decision support tools that are fit for purpose, and are sensitive to the current re-development of strategic-level planning guidance.

The issues with the decision-making process are described as follows:

- i) There is no clearly defined process by which ecological values are considered with other values in the Code to inform the selection of a preferred management Strategy. As a result, the process varies across regions (Figure 2), and:
 - a. Ecological objectives are either not specified, incomplete (i.e. missing), or not accounted for in the development of the Strategies,
 - b. Trade-offs involved in Strategy selection by the ACFO are not explicit.
- ii) Guidance on how and whether community input should be incorporated into the development and selection of the strategy is lacking.
- iii) There is no clear process to develop the Strategy in relation to constraints around risk reduction targets, and area burnt targets.
- iv) The process aligning the Fire Operations Plans with the Strategic Bushfire Management Plans (in relation to ecological values) is highly variable across Regions.
- v) There are a lack of ecological focused state-wide objectives guiding constraints for Strategy development at the regional level.
- vi) There is no process to guide the selection of alternative management strategies that aim to address multiple objectives, nor multiple threats.

The issues with the technical process of using ecological models, data and metrics to support strategy selection are the primary focus for this project, and are described as follows:

- vii) The metrics (performance measures) are not 'adequate', and so are not used to guide strategy selection at the regional level. 'Adequacy' is related to:
 - a. Confidence in model outputs is compromised because there is no current method for identifying critical knowledge gaps (i.e. updating would result in an improved decision)
 - b. The links and logic between the ecological models and metrics and the Code objective and the values it represents have not been well articulated. Thus, the current measures do not always directly measure (or 'represent') the objectives or are insensitive to bushfire management interventions.
 - c. Difficulties in interpretation of the performance measures, due to a lack of specification of desired outcomes.
 - d. Difficulties in communicating meaningful outcomes of management Strategies on ecological objectives to decision makers and other stakeholders.

- viii) The ecological models have not been consolidated and don't fit together in a logical or consistent way;
- ix) The ecosystems and species where models are lacking have not been identified and this is required to inform research investment and monitoring prioritisation;
- x) Threatened species data have not been collated at a state-wide scale, and gaps have not been identified.
- xi) Current methods to analyse risk to ecosystem resilience and assess planned burning and bushfire impacts on threatened species are not integrated;
- xii) There is no process to describe how new data collected through MER and research will be used to update the ecological models and risk assessment methods.

Research question/s and context:

In this project we aim to develop a consolidated framework that describes the development and application of ecological models (including ecosystem resilience and threatened species) to inform strategic bushfire management planning. Importantly, this project will be focused on developing a framework developed with high levels of stakeholder consultation, such that the resulting framework is fit for purpose, and sensitive to the current re-development of strategic planning guidance.

To develop a strategic planning decision framework the following questions need consideration:

- What are the current decision-making framework/s used in strategic planning across the different regions?
- What is the role of ecological objectives in strategic planning?
- What are the ecological objectives for strategic planning and how can these objectives be measured?
- Which data processing and analyses techniques are most suited to support the development and implementation of assessing risk to ecological objectives as part of strategic planning processes such as strategic planning?
- How do we predict ecological responses to fire to inform fuel management decision-making at the strategic planning level?
- What knowledge and training is needed by decision makers and practitioners to evaluate risk to ecological objectives as part of strategic planning?

This project complements current work undertaken by the project consortium (see next section "Linkages to other research"). Our work also builds on:

- the *SBRASS* project which also used structured decision-making as part of Strategic Bushfire Management Planning in the Barwon Otways Bushfire Risk Landscape (DELWP 2015b). We will further this approach by focusing more on the development of ecological objectives and performance measures for SBMP.
- a report commissioned by DELWP regarding "*Review of resilience concepts and their measurement for fire management*" (McCarthy 2011). We will extend this work by utilising the current metrics but reviewing whether there are alternative ways of using the metrics to provide alternative performance outputs if necessary (see issue vii above). We will also note, but not develop, where objectives have been identified that do not currently have any metric or measure available (see Workshop 1 report). Having measures or outputs that assist users understand the performance of objectives is necessary when it comes time to make trade-off decisions within the current and proposed strategic decision-making process.

- The “*Foothills Fire and Biota*” project which examined responses of vegetation structure, floristic composition, bird abundance (within guilds,) and mammals, to fire regime attributes and a range of environmental variables (Leonard et al. 2016). We will extend this work by evaluating the suitability of these ecological models for the consolidated ecological module
- Several related research projects applying ecological resilience models and metrics (GMA, TFI) as part of bushfire management risk assessment (e.g. Watson et al. 2012, Muir et al. 2014, Sitters et al. 2014, Giljohann et al. 2015, Kelly et al. 2015, York and Friend 2016). We will extend this work by evaluating the feasibility of GMA and TFI in the current and proposed SBMP decision-making process.

Linkages to the other research

Several members of the ERP 1 project team are currently working on closely related projects. This will provide close integration and leverage where possible with ERP 1. There are three broad areas of potential integration and leverage:

1. *Decision support tools*

- Nature Kit / Strategic Management Prospects (Knowledge and Decision Systems, Arthur Rylah Institute (ARI))
- Decision support system (Integrated Forest & Ecosystem Research (IFER)) e.g. initial knowledge sharing about projects in Oct 2017 attended by JM, LR, TW and several members of the IFER team. Intention to share our respective project plans later in 2017.
- Spatially explicit solutions for managing fire and biodiversity (University of Melbourne (UoM), La Trobe University (LTU)) e.g. JM, LR attending project workshop 20/11/2017 being led by KG & LK.

2. *Models and data about species, habitat and fire regime*

- Foothills fire and biota (LTU, UoM, ARI)
- Flora, fauna, habitat attributes and vegetation growth stages in Victorian Tall Wet Forest (IFER)
- Using fire to manage biodiversity in fragmented landscapes in South West (UoM, ARI)
- Flora key fire response species and TFI (ARI, PV, DELWP)

3. *Refining tools and data*

- Fire vulnerability mapping
- Resilience metric sensitivity analysis and GSO in fragmented landscapes IFER (Sitters et al.)
- Scientifically-based monitoring project (MER research project - LTU)
- Refinement of EPBC Assessment process and ecological resilience technical method (ARI)

Key outputs

1. *Develop a detailed project plan*

Central to our project is using a focused workshop to build a clearer understanding of the fire management decision context in Victoria with DELWP and relevant stakeholders. In collaboration with the DELWP policy lead, regional contacts (such as Planned Burning Biodiversity and Landscape Evaluators) and SCI Division contacts (BRAU, MER Unit, Policy and Planning Units), we held a two-day facilitated workshop to clarify the decision context underpinning the framework for bushfire management in Victoria.

Using structured facilitation techniques, we have developed a formal articulation of the decision context (as a problem statement), including the scope and bounds of the project. We also used objectives hierarchies to

clarify the objectives and metrics relevant to this decision context. These exercises enable a shared understanding between the project team and stakeholders, and provide the context for the project plan.

The workshop enabled:

- vi. Specification of the roles, responsibilities and needs of key stakeholders involved in the process;
- vii. Clarification of the spatial and temporal scale over which decisions will be made e.g. state-wide vs. Bushfire Risk Landscapes vs. burn units, public vs. private land, yearly fire plans vs. decade-long projections;
- viii. Clarification of the legal and policy context under which the framework sits, the trigger for this proposal, and any decisions linked to this process;
- ix. Elucidation of constraints that may limit decisions and need to be incorporated into the modelling framework;
- x. Clarification of the objectives and metrics/performance measures underpinning the framework.

During this workshop, we sought clarification of how data, models and metrics are currently used to inform strategic-level decision making around bushfire management. This information was used to frame the decision context - using the structured decision-making framework described in Figure 1 (see Output 5). The potential to incorporate other levels of planning (operational and tactical) was also discussed. This information was used to refine the project plan, in collaboration with DELWP policy staff, and will be used to define the context underpinning the project.

2. Collation of ecological models and metadata; and
3. Collation of threatened species fire response data, species distribution models and associated metadata.
4. Documentation for the collated ecological models and threatened species data, including a synthesis of current knowledge, a list of ecosystems for which models have not yet been developed, and outline of threatened species data gaps.

The collation of ecological models (Output 2) and threatened species data (Output 3) will start with a series of interviews, and a workshop (separate to that undertaken for refining project plan) with key DELWP staff members (i.e. those undertaking analyses of risk to ecosystem resilience and threatened species) and subject-matter experts to understand:

- vi. What information is required of the models within the decision context (i.e. clarify the information required to inform the performance measures and decision making);
- vii. What types of models and data are available that can provide this information;
- viii. What is the suite of ecological models and data within the scope of this project;
- ix. What are the current limitations of these models and data sources, and;
- x. What processes or guidance is already in place in terms of data management and model output.

These questions form the knowledge gaps presented in Table 2. A subsequent interim report will present the findings of this work which is a key step in efficiently collating the appropriate models and data. We expect some of these questions (especially i.) will also be addressed in the first workshop (Output 1).

We envisage the need to generate an influence diagram or a qualitative version of a process model to explore what elements of environmental variation are critical to decision making. This will involve meetings / interviews with project team researchers and practitioners (such as Planned Burning Biodiversity Officers and Landscape Evaluators) to establish which environmental gradients (e.g. climate), ecological interactions (e.g. fire and predation) and management actions (e.g. Fire Zoning) are necessary to support analyses of risk to ecosystem resilience and threatened species.

The interviews will build on state-wide approaches to gap analysis recently devised to support Monitoring Evaluation and Reporting (MacHunter et al, 2015) and related work in the Scientifically-based Monitoring

(MER) Project to develop formal criteria to identify knowledge gaps. This will be explored further as part of Output 8 to determine if these gaps matter.

Once criteria for identifying “data gaps” are defined, the relevant databases (e.g. VBMP database which houses fire legacy monitoring data, Future Fauna Occupancy database and Flora Vital Attribute database) will be queried to generate summaries of knowledge gaps e.g. that relate to species fire response (including threatened species) according to fire severity, vegetation type, growth stage (mainly fauna) / fire interval (mainly flora) and relevant environmental gradients / interactions. This will distinguish between expert elicited opinion, vs. empirical data (modelled values or raw data).

As in Table 2, we foresee each of the key tasks will be reported on to provide an understanding of the data requirements (within the overarching decision context), the current state of knowledge in relation to that data (i.e. ecological models and threatened species data), and a list of data gaps for both ecosystems and threatened species. This interim report will draw on research currently being undertaken in the Scientifically-based Monitoring (MER) Project and the Spatial Solutions Fire Ecology Project, as well as informing future data collection efforts within the MER framework.

Table 6: Knowledge gaps that will be addressed to inform collation of ecological models and threatened species data used in analysis of risk to ecosystem resilience

Steps to address knowledge gaps	Task
Which information? Clarify the use of data and models within the bushfire management decision context, and understand the requirements of data and ecological models to support decision making	Communicate and clarify the role of data and models within the decision context (i.e. metrics for objectives), and develop criteria to assess whether the data are ‘fit for purpose’. Outline rationale for baseline requirements or criteria for data and ecological models to evaluate risks to ecosystem resilience.
Which species? What is the existing criteria for selection of species and traits that underpin analyses of risks to ecosystem resilience?	Document existing guidance for analyses of risks to ecosystem resilience relating to species selection and data type (e.g. expert judgments vs. empirical data).
Which data/models? What is the suite of ecological models and data within the scope of this project (e.g. Species Distribution Models, Ecological Fire Groups, species fire response, growth stages)?	Provide an understanding of the current data sources, and a rationale for inclusion of other ecological models for analyses of risk to ecosystem resilience.
Other data? What are the current and potential data sources not already available in current DELWP databases	Identify the feasibility and steps needed to incorporate new data (particularly relating to threatened species) into DELWP databases e.g. related to the VBMP Data Management project.
Data management? What guidance and metadata already exists for those data and models, and how that aligns with current DELWP metadata standards	Provide recommendations about suitable data manager/s for each dataset to provide a more consolidated approach to the curation of datasets.

5. Description of the conceptual framework for developing and applying the ecological models (as part of analysing risk to both ecosystem resilience and threatened species) to inform strategic bushfire management planning.

This output is essentially derived from the steps outlined in above section “Research approach”. As per Table 1 we envisage a workshop / consultation with stakeholders involved in the planning process (i.e. reps from Regional Forest and Fire Planning Managers, Risk & Evaluation teams, and ACFO from case study region, plus reps from BRAU, Planning, MER), but focused in the case study region. Again, our focus is on developing an ecological resilience module that is fit for purpose, as flexible as possible in the face of current revisions to the guidance for the strategic planning process, and relevant to multiple regions which differ in their approach to identifying preferred strategies (i.e. Workshop 1 report). As such, it is important we get the perspective of decision makers, so we can discuss any preferences regarding decision-making frameworks used in the strategic planning process. We have shifted the focus of the workshop associated with this output to be case-study specific, with representatives from MER, Planning and BRAU invited. We are focusing on the case study region to maximise engagement, within the available budget.

This will be synthesized in a report outlining this framework (see Figure 1) and would address each of the steps in this project, including:

- A problem statement, clearly outlining the decisions to be made,
- A clarification of the management objectives (i.e. from The Code) and the associated performance measures (Output 1) relevant to the region. We can explore whether inclusion of objectives other than those specified in The Code (i.e. cost, social objectives) is appropriate given the planning context within the region.
- A demonstration of how the existing ecological metrics, informed by ecological models and data, can be utilised to understand the consequences of implementing various alternative management (planned burning) scenarios, in relation to the objectives (Outputs 2, 3, 4).
- An example of method(s) for addressing trade-offs between multiple objectives (Output 5). There are a number of methods available to address trade-offs (including an optimisation approach, or multi-attribute analyses, see Figure 1) and we will explore the appetite and preference from the case study region.
- The role of MER in updating the data and models in the framework to reduce critical uncertainties in decision making (Output 8).

This report i.e. Output 5 will be revised / expanded if necessary following Output 9 (the case study) to incorporate any learnings from that process.

6. Consolidate existing ecological models and data into a single system of analysis as an ecological resilience module (code, etc.). This will have linkages with current and emerging optimisation (e.g. Woodstock) and ecosystem process assessment models (e.g. LANDIS).

This will involve development of database architecture and associated scripting and front end (in python and / or R) to enable analyses of ecological risk to ecosystem resilience and threatened species to be addressed within the decision context to take place in a more efficient fashion (see step 5). The project team in consultation with DELWP policy lead and regional stakeholders will develop criteria for the ecological resilience module and user requirements for its application.

The complexity of the integration of ecological models will depend on the type, quality and availability of the data sources, which we anticipate will be quite variable. Complexity also depends on the extent to which the process can be automated whilst allowing for critical decision steps to be undertaken manually. Essentially this would distinguish components of the integration that can be batch processed and automated according to prior assumptions about generic approaches. For example, the selection of fire severities to represent the application of planned fire in a model could be determined a priori and therefore become an automated decision step as part of growth stage optimisation analyses. The decision context for analyses of risk to

ecosystem resilience will also directly impact components and analyses of this module. For instance, if integration / optimisation of TFI and GMA are expected to be undertaken as part of the module, or individually retained to inform multi-criteria decision analysis.

Research projects are already underway in themes relating to analyses of risk to ecosystem resilience e.g. Spatial Solutions Fire Ecology Project (Kelly et al), applying growth stage optimisation in fragmented landscapes (York et al), LANDIS (IFER) – and consultation with these project teams will be undertaken to adopt the latest thinking in biodiversity indices and fire simulations in the context of the module.

Considering the complexity of the coding underpinning the various aspects of analyses of risk to ecosystem resilience, combined with the varying modelling capabilities of practitioners, we believe a platform is needed comprising an accessible user interface to overlay a system of streamlined data flows for ease of analyses. To this end, we will explore the utility of a Graphical User Interface using open source code (Shiny Web Application Framework) to house key components of the consolidated module. This is essentially a system designed to enhance the efficiency and ease of use for executing a series of complex computational or data manipulation steps. This approach will enable a more streamlined approach for using models to inform decision making without compromising essential steps that require manual input to reflect and incorporate local priorities and knowledge. Additional work could be undertaken to incorporate visualisation tools as part of the outputs of the consolidated module (e.g. figures of growth stage structures or projections of GMA forwards in time (or back-casting through time), but is outside the scope of this brief.

7. Supporting documentation for the ecological resilience module, including descriptive material of the module and technical guidance on its application.

The consolidated module will be documented in consultation with practitioners to ensure it recognises the requirements of users. We will liaise with the DELWP Policy lead so that the documentation can be readily integrated into current DELWP systems, processes and curation requirements. The documentation will include a data workflow that has well defined inputs, outputs and purposes. Testing of the technical guidance will be undertaken as part of training users of the ecological module.

8. Process map to outline how to identify and prioritise uncertainty in decision making

Following a request from the PCB we have scaled back this output from the original project proposal to allow reallocation of resources for training. In terms of an approach this process map would largely be generated without high levels of stakeholder input. Essentially, we would be drawing on best practise principles of how to identify and address critical uncertainty in decision making, i.e. in those cases where it is not possible to distinguish between strategies because of uncertainty in the consequences related to ecological objectives.

- We envisage that the approach would involve a short workshop with project team researchers (Mick McCarthy, Terry Walshe, Luke Kelly, Kate Giljohan, Tracey Regan, Libby Rumpff, Josephine MacHunter) and BRAU/MER policy lead to identify various options and a pathway forward. We will focus on using tolerable fire interval (TFI) data as an example throughout the workshop.

The following questions will be addressed as part of this output:

- How to elicit structured data from experts, with uncertainty, when new data is lacking (i.e. if data is required from a private land context) or existing information is uncertain.
- How to set decision thresholds (or triggers) when monitoring data is incorporated into the decision-making process. It should be noted that the setting of decision triggers will involve judgements on the tolerance for uncertainty.
- How to identify critical uncertainties in ecological data, as a focus for monitoring efforts.

This workshop and outputs would be tailored to a specific data focus, like TFI. We will not consider all the elements of the ecological data, tools and models underpinning the decision framework.

9. Documented case-study on the application of the framework.

We will provide support for the implementation of the conceptual framework for developing and applying the ecological metrics to inform strategic planning through a case study within a DELWP region. Potential case study locations have been evaluated through availability of essential data inputs in consultation with the DELWP policy lead and identified Gippsland Region as the preferred location for this work. We will liaise with the DELWP policy lead and regional stakeholders to form a working group to undertake a participatory implementation of the decision-making framework. No budget is available for workshops within this proposal, but strong interest in a collaborative and participatory approach to undertaking the planning process has been noted by the region. The project team is supportive of this approach, as it will help ensure the module and framework are well tested and fit for purpose. As such, the workshop identified in Output 5 has now been tailored to the case study region, with invitation to other DELWP stakeholders to attend (i.e. MER, BRAU and Planning team reps).

10. Final seminar

The final seminar will be undertaken to outline the application of the ecological resilience module in relation to bushfire management decision making. The two-hour seminar will be participatory in nature and will provide an excellent opportunity to obtain additional feedback from key stakeholders to assist with project evaluation.

11. Training workshops

Detailed information about the mechanics of the ecological resilience module will be provided as part of 1 day training / workshop to DELWP staff who are more involved in the technical side of the process of analyses of risk to ecosystem resilience (PBBOs and data managers) and MER (Landscape Evaluators). A separate 1-2 hours workshop will be provided to decision makers (ACFOs & Regional manager) to explain the framework, and run through (demonstrate) case study findings (providing they have already attended the Final Seminar -Output 10).

Outcomes

- Improved understanding by SCI Division and regional staff about the variation in decision making approaches across the different regions and impediments to this process.
- Improved / streamlined access to ecological models and data to support ecological analyses and metrics to inform strategic planning (subject to internal systems being in place e.g. VBMP databases and BRAU).
- Improved evaluation of risks to ecosystem resilience and threatened species as part of strategic planning to support more effective decision making.
- Improved capability of staff in Risk and Evaluation teams in using tools to support ecological analyses and metrics to inform strategic planning.
- Improved allocation of DELWP resources and prioritisation of MER projects / programs through application of a process to identify critical uncertainties in strategic planning.
 - Note: all of the outcomes listed above are partly contingent on DELWP adopting the recommended processes.
- Stronger collaborations between related research projects.

Success measures

Success for this project will be measured by the delivery of the 11 outputs above. Immediately the project team's success will be demonstrated by the willing collaboration by DELWP staff in workshops.

Medium to long term success will be measured by the extent to which DELWP utilise this framework within their strategic and operational bushfire fire management planning.

Success throughout the project will be demonstrated through productive collaboration within our project team and more broadly with researchers on related projects.

Collaboration and potential Interdependencies

The main collaborators in this project are DELWP staff within SCI Division and the regions. This is critical to ensure the outputs for this project developed to integrate with the systems, tools and processes already in place.

This first workshop was undertaken in October 2017 and involved representation from PV and DELWP regional staff and statewide staff from SCI, and Biodiversity Divisions. Follow up meetings with DELWP policy leads, MER unit and Planning unit was undertaken to revise the project scope. Feedback from the workshop report from the participants is anticipated to occur later in November 2017.

A similar representation of DELWP staff is anticipated for workshop 2 to discuss the current ecological models. We envisage that a series of one on one meetings will also be involved with other members of the ERP 1 project team, particularly those in the La Trobe Uni (Steve Leonard & Angie Haslem) and other taxonomic experts at ARI.

For workshop 3 we anticipate that representation of the decision makers from our case study region will be critical to identify the pros and cons of different decision-making frameworks as part of SBMP.

Workshop 4 will draw on expertise within the project team to map key elements of uncertainty in the decision-making process and we also anticipate involvement with the BRAU and MER teams to better understand existing processes in place.

Members of the project team will contribute to workshops, meetings etc. for related projects as required. For example, Steve Leonard, Libby Rumpff and Josephine MacHunter recently attended a related workshop regarding the development of scenarios for fuel management as part of the Spatial Solutions project. We are meeting with the broader ERP 1 project team in December 2017 to discuss synergies and linkages to help identify opportunities to contribute to related projects. We also envisage ongoing discussion with the IFER Decision Support Tool project particularly in relation to the potential integration with emerging tools such as FROST being developed in related work.

Work undertaken as part of the ARI-SCI project regarding updating GSO analysis will be integrated into the consolidated ecological module.

A project fact sheet is currently being developed to inform the wider community as well as internal DELWP staff that aren't directly involved in project meetings / workshops.

Supplementary material: Outcomes report from ERP 1 Workshop 1

Date: 25-26th October, 2017

Location: ARI Conference room, 123 Brown St Heidelberg

Prepared by: Libby Rumpff and Josephine MacHunter

KEY SUMMARY POINTS

- This workshop was the first in a series aimed at developing a participatory, iterative and consolidated decision framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species, to facilitate effective decision making for bushfire management planning in Victoria.
- The aim of the workshop was to develop a shared understanding of the decision context, the constraints to both the current decision-making and technical (modelling/data/tools) process, and a clarification of the objectives and performance measures underpinning decision making.
- A problem statement was developed collaboratively with the workshop participants over the course of the 2 days. This involved i) understanding the current processes by which decisions are made at the Strategic and Operational level across the Regions, ii) who is involved in planning and decision-making; iii) how ecological objectives fit with this process; iv) the impediments to the application of ecological models and metrics to the decision process, and; v) what workshop participants thought was needed to improve the decision-making process.
- There were 12 different issues identified which impede either the decision-making process, or the technical implementation of ecological data/models.
- Six fundamental ecological objectives were identified, which were environmental, socio-ecological or organisational in nature.
- At this stage, 13 potential performance measures have been identified that could be used in the decision-making framework.
- The project team have used the outcomes from the workshop as the basis of a refined Project Plan.

BACKGROUND

Victoria's *Code of Practice for Bushfire Management on Public Land* specifies that fire management aims to achieve the dual objectives of minimising the impacts of major bushfires on life, property and the environment, and maintaining or improving ecosystem resilience. Strategic bushfire management plans (SBMP) guide bushfire management activities by identifying strategies that achieve both objectives. A pathway to implementing SBMP's has been identified by DELWP, and ecological models resulting from extensive research into the response of flora and fauna to fire are integral to this process. However, consultation with stakeholders has highlighted that the current approach to applying ecological data and models to support fuel management decision making is limited by several knowledge and implementation gaps.

BNHCRC Ecological Research Project 1 (*Using, updating and integrating ecological models into a decision framework to inform bushfire management planning*) aims to develop a consolidated decision framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species to facilitate effective decision making. The project aims to bring together a suite of

ecological models into a world-class and user-friendly system to enhance bushfire management, research investment and monitoring.

Central to our project is building a clearer understanding of the fire management decision context in Victoria, to ensure the framework and tools are 'fit for purpose'. To this end, the first step in this project was to hold a workshop with DELWP and relevant stakeholders (see 'Attendees') to develop a shared understanding of the decision context, the constraints to both the current decision-making and technical (modelling/data/tools) process, and a clarification of the objectives and performance measures underpinning decision making. The project team have used the outcomes from the workshop as the basis of a refined project plan. A version of this report will be sent to participants for review and feedback.

THE APPROACH

The decision framework developed within the ERP1 project will be based upon the tools and steps of structured decision making (SDM, Figure 1; Gregory *et al* 2012). SDM describes both the process of deconstructing decisions into various common components, and the broad set of tools used, and is designed to aid logical and transparent decision making (Figure 1; Gregory *et al* 2012, Garrard *et al.* 2017).

Breaking down a decision and analysing each step separately helps people logically process, understand and communicate decisions. This approach is particularly valuable for complex decisions that can involve multiple competing objectives, uncertainty surrounding the available management options, and/or high uncertainty about the consequences of management. The process of analysing decisions can also help clarify where uncertainty exists in the data, and also recognise when uncertainty influences a management decision. Importantly, the approach disaggregates scientific data from values, which can mitigate against biases associated with unstructured judgements (Addison *et al.* 2013).

The project's first workshop was designed to enable a shared understanding of the context, constraints and impediments to decision making between the project team and stakeholders, to provide the context for the project plan. The two days were largely focused on:

- I. Refining a problem statement that identifies the scope and scale of the decision at hand (Step 1; Figure 1).
- II. Further developing/refining (measurable) objectives (Step 2; Figure 1).

Substantial attention was given to these steps because the quality of any decision framework rests largely on the extent to which the management objectives capture the key considerations of the problem context. In the workshop, the research team also aimed to elicit information which would assist with the compilation of ecological models and data, which will be used in the framework to examine the 'consequences' of alternative planned burning strategies on ecological objectives (Steps 3 and 4: Figure 1). As such, we spent some time:

- III. Clarifying how data, models and performance measures are currently used to inform decision making for strategic bushfire management planning.

Further investigation regarding the use of ecological models and data will be undertaken as part of subsequent meetings / workshops with the MER Unit and Risk and Evaluation Teams.

These steps are outlined in more detail below in a discussion of the findings of the first workshop (i.e. Sections 1-3, below). This report is designed to recap the process from the workshop and provide a summary of findings.

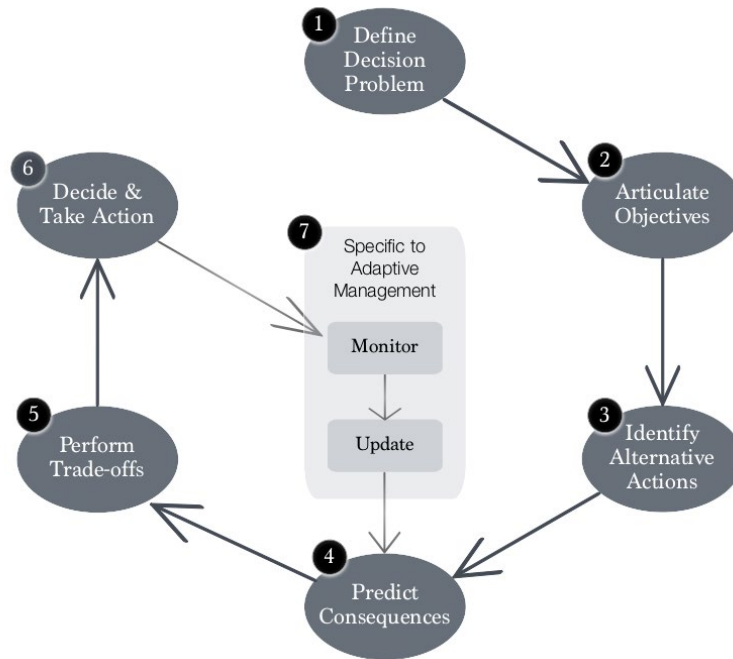


Figure 1. The structured decision making framework refers to both the steps, and the suite of tools used to address those steps. This figure is taken directly from Garrard *et. al.* (2017). In the workshop the focus was on the first two steps.

1. THE DECISION CONTEXT

The first step in SDM involves clarifying the decision context with workshop participants, to gain a clear and common understanding of the question(s) at hand. The primary aim of this step is to clearly and succinctly define what decision(s) are being made and why, and how the decision is related to other prior or anticipated decisions. Roles and responsibilities within the decision should be clearly established, including identification of the ultimate decision maker. Stakeholders and key technical experts need to be identified, and their role in the decision process defined. In this step, it is also important to identify the constraints within which the decision will be made. These might include, for example, legal constraints, minimum performance requirements for selected outcomes, or other constraints that have been established through a prior decision process.

The decision context can be encapsulated in a problem statement, which is a succinct articulation of the problem. This helps bound the decision and ensures that all participants involved in contributing to the decision are on the same page. Ultimately, the aim is to clarify the scope for ERP1 such that the decision framework with ecological model consolidation is ‘fit for purpose’.

A problem statement was developed collaboratively with the workshop participants over the course of the 2 days. This involved i) understanding the current processes by which decisions are made at the Strategic and Operational level across the Regions, ii) who is involved in planning and decision-making; iii) how ecological objectives fit with this process; iv) the impediments to the application of ecological models and metrics to the decision process, and; v) what workshop participants thought was needed to improve the decision-making process. It is worth noting that the problem statement is currently long, as it aims to capture the complexities and issues with the decision-making process. If necessary, this statement will be refined over the life of the project, with input from workshop participants.

The problem statement

Consultation with stakeholders (including PBBOs, members of the ERAWG, and several business units within SCI Division and FFR) has highlighted that the current approach to applying ecological data and models to support fuel management decision making is limited by several factors. Many of these issues were outlined in a Capability Plan for Ecological Risk Assessment (BRAU, 2016), which is a long-term strategy which outlines specific actions to help streamline ecological risk analyses to ensure outputs can effectively inform bushfire management planning.

Although DELWP has made progress defining ecological objectives and measures, developing ecological models through research, developing risk analysis tools, and establishing a MER framework, there are issues and gaps with the process that impede decisions about development and identification of regional Strategies. These issues and gaps can be described in relation to (i) issues with the decision-making process, and (ii) issues with the technical process of implementing ecological models to support bushfire management planning.

The issues with the decision-making process are described as follows:

- I. There is no clearly defined process by which ecological values are considered with other values in the Code to inform the selection of a preferred management Strategy. As a result, the process varies across regions (Figure 2), and:
 - a. Ecological objectives are either not specified, incomplete (i.e. missing), or not accounted for in the development of the Strategies,
 - b. Trade-offs involved in Strategy selection are not explicit.
- II. Guidance on how and whether community input should be incorporated into the development and selection of the strategy is lacking.
- III. There is no clear process to develop the Strategy in relation to constraints around risk reduction targets, and area burnt targets in operational delivery.
- IV. The process aligning the Fire Operations Plans with the Strategic Bushfire Management Plans (in relation to ecological values) is highly variable across Regions.
- V. There are a lack of ecologically focused state-wide objectives guiding constraints for Strategy development at the regional level.
- VI. There is no process to guide the selection of alternative management strategies that aim to address multiple objectives, nor multiple threats.

The issues with the technical process of using ecological models, data and metrics to support Strategy selection are described as follows:

- VII. The metrics (performance measures) are not 'adequate', and so are not used to guide strategy selection at the regional level. 'Adequacy' is related to:
 - a. Confidence in model outputs is compromised because there is no current method for identifying critical knowledge gaps (i.e. updating would result in an improved decision)
 - b. The links and logic between the ecological models and metrics and the Code objective and the values it represents have not been well articulated. Thus, the current measures do not always directly measure (or 'represent') the objectives, or are insensitive to bushfire management interventions.
 - c. Difficulties in interpretation of the performance measures (i.e. measures may not be direct, natural measures, or are difficult to define).
 - d. Difficulties in communicating meaningful outcomes of Strategies on ecological objectives to decision makers and other stakeholders, which is in part due to a lack of specification of what is a 'good' or desired outcome.

- VIII. The ecological models have not been consolidated into a user-friendly, logical, and consistent framework/module;
- IX. The ecosystems and species where models are lacking have not been identified and this is required to inform assessment, research investment and monitoring prioritisation;
- X. Threatened species data have not been collated at a state-wide scale, and gaps have not been identified.
- XI. Current methods to analyse risk to ecosystem resilience and assess planned burning and bushfire impacts on threatened species are not integrated;
- XII. There is no process to describe how new data collected through MER and research will be used to update the ecological models and risk assessment methods.

These are issues which relate to bushfire management planning at a state, regional and operational level, and the ERP 1 project will focus on developing a decision framework that is sensitive to, but does not integrate decision making at all scales. The ERP1 project will focus on the identification of longer-term (i.e. 40 year) Strategies at the regional level, as the integration of ecological models at this scale is deficient, there is good alignment with current internal processes (i.e. DELWP Planning process review) to redress this deficiency, and because decisions around the shorter-term (1-3 year) fuel operational plans (FOP) should flow from the Strategic process. Where possible, the research team will highlight the extent of the alignment with the FOP process. Though future strategies will relate to bushfire management on both private and public lands, the ERP 1 project will first focus on decision-making for public lands.

In each region, the Assistant Chief Fire Officers (ACFOs) are responsible for endorsing the Strategies, and in the future, final approval of the Strategy will be given by a multi-agency Bushfire Management Planning Committees. Regional Risk and Evaluation Teams and the community are involved in guiding the generation and selection of the final Strategy, but this involvement varies across regions. The dotted lines refer to where monitoring does, or may, occur to inform the decision-making process. Given the issues and variation in regional decision-making processes (Figure 2), there is recognition that the current process for Strategy development and identification at the regional level requires a:

- Transparent, flexible and long-term decision-making process, with articulation of trade-offs between ecological, social and economic objectives;
- Improvements in the articulation of performance measures, models and data to support decision-making
- Clear articulation of the different roles and responsibilities of Department of Environment, Land, Water and Planning staff and community in the decision-making process, and;

Relevant to this project is developing and demonstrating a flexible process for consolidating ecological data, tools and models to evaluate the consequences of different management strategies to inform trade-offs involved in selection of a preferred Strategy. Analysis of consequences and trade-offs requires prior articulation and definition of i) the strategic-level ecological values and objectives underpinning relevant policy (e.g. the Department's 'Code of Practice for Bushfire Management on Public Land', 'Victoria's Safer Together' policy), legislation (e.g. the EPBC and FFG Acts), and other stakeholder values; ii) the performance metrics used to evaluate progress toward these objectives, and; iii) guidance for the development of alternative fire management strategies and scenarios that are to be evaluated in the decision-making process.

It is recognised that the 'Strategic Bushfire Management Planning Process' is currently under review, and being revised to be multi-agency and cross tenure. Changes to the process are reflected in the 'Technical Methods Reference Document', and the timing of the ERP1 project is such that there is an opportunity for the outcomes of this project to inform the review process.

The aims of this project are to develop, document, test and explain an overarching framework that:

- I. Provide guidance on defining the ecological objectives and measures underpinning the Code objectives, and other relevant values,

- II. Enables existing ecological models to input to a streamlined ecological module, to facilitate analyses of the consequences of alternative management strategies in relation to ecological values,
- III. Provides guidance and recommendations on how the models could be managed such that they can be used to inform decision making at the Strategic level, and;
- IV. Provides a process map to outline how to identify and prioritise uncertainty in decision making.

The project will also involve training of relevant staff in Risk Evaluation Teams in use of the decision-making framework and the ecological module that sits within it. A related information session will be provided to decision makers in the use of the decision-making framework.

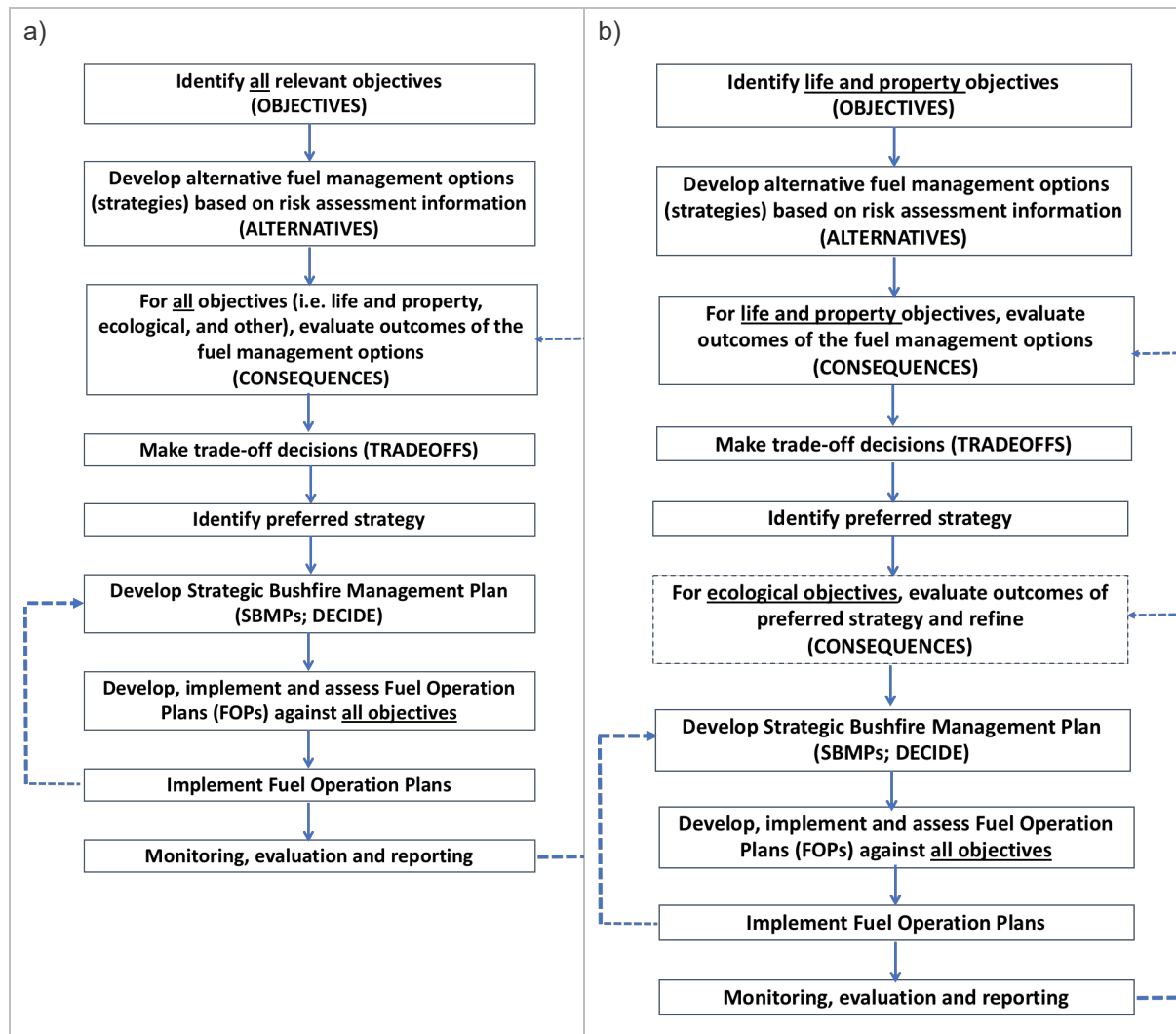


Figure 2. A summary of the differences between decision-making processes relating to selection of a preferred Strategy across regions. Figure a) highlights that ecological objectives (and associated metrics) are considered together with life and property, and other objectives throughout the process of deciding on a preferred Strategy (i.e. Barwon-Otways BRL region, SBRASS project). In b), the preferred Strategy is driven by life and property objectives, and ecological objectives are either used to refine the preferred Strategy (e.g. South-West BRL region), or considered only in the development of fuel operation plans (e.g. Alpine and Greater Gippsland BRL region).

2. OBJECTIVES

Capturing the things ‘we’ care about, our values, is integral to any decision-making process (Keeney 1992; Gregory et al 2012). To aid decision-making, values are translated into specific, measurable statements that describe what is to be achieved. These statements are called objectives.

Fundamental objectives state the primary reason for the decision (Runge 2011), and guide the rest of the decision analysis. These are differentiated from means objectives (which specify the means to achieving the fundamental objectives), process objectives (which specify the way a decision might be made) and strategic objectives (which are strategic priorities of the organization that govern all decisions). Once established, objectives form the basis for developing and evaluating alternative courses of action for management. To aid analysis, care must be taken to ensure that fundamental and means objectives are well defined, not confused (i.e. double counting of objectives), and that objectives are preferentially independent (i.e. the preference for objective ‘x’ does not depend on that of objective ‘y’). This is important when considering later steps in the analysis.

Developing measurable objectives was achieved through 6 steps (adapted from Gregory et al. 2012):

- I. Individually brainstorm an initial list of objectives (i.e. “What do you want to achieve/avoid with management?”)
- II. Separate means, process and strategic objectives from fundamental objectives using the WITI (“Why is that important”) test (Clemen 1996)
- III. Build group objective hierarchies to represent the relationship between objectives, and discuss.
- IV. Compile and define a list of fundamental objectives from the group
- V. Discuss which performance measures could be assigned to each objective

Note, we also asked participants to tell us their process objectives (i.e. “What do you want to achieve/avoid with the decision-making process?”), but this was to obtain further detail to aid development of the problem statement.

There are several important points to note in objective setting. First, we acknowledge that there are already objectives set out in the Department’s ‘Code of Practice for Bushfire Management on Public Land’, ‘Victoria’s Safer Together’ policy, and relevant legislation such as the EPBC and FFG Acts. In this process, we consider these ‘strategic-level’ objectives, which need to be defined as they are often statements that include multiple values. For example, the second Code objective is “To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products”.

Second, it is intended that the list of objectives developed in this workshop (and in subsequent review) will provide the basis for the decision framework. However, we will seek to understand the values of other key stakeholders (e.g. ACFO’s) to refine this list.

Below, we differentiate and explore the management objectives that underpin the Strategic Planning process.

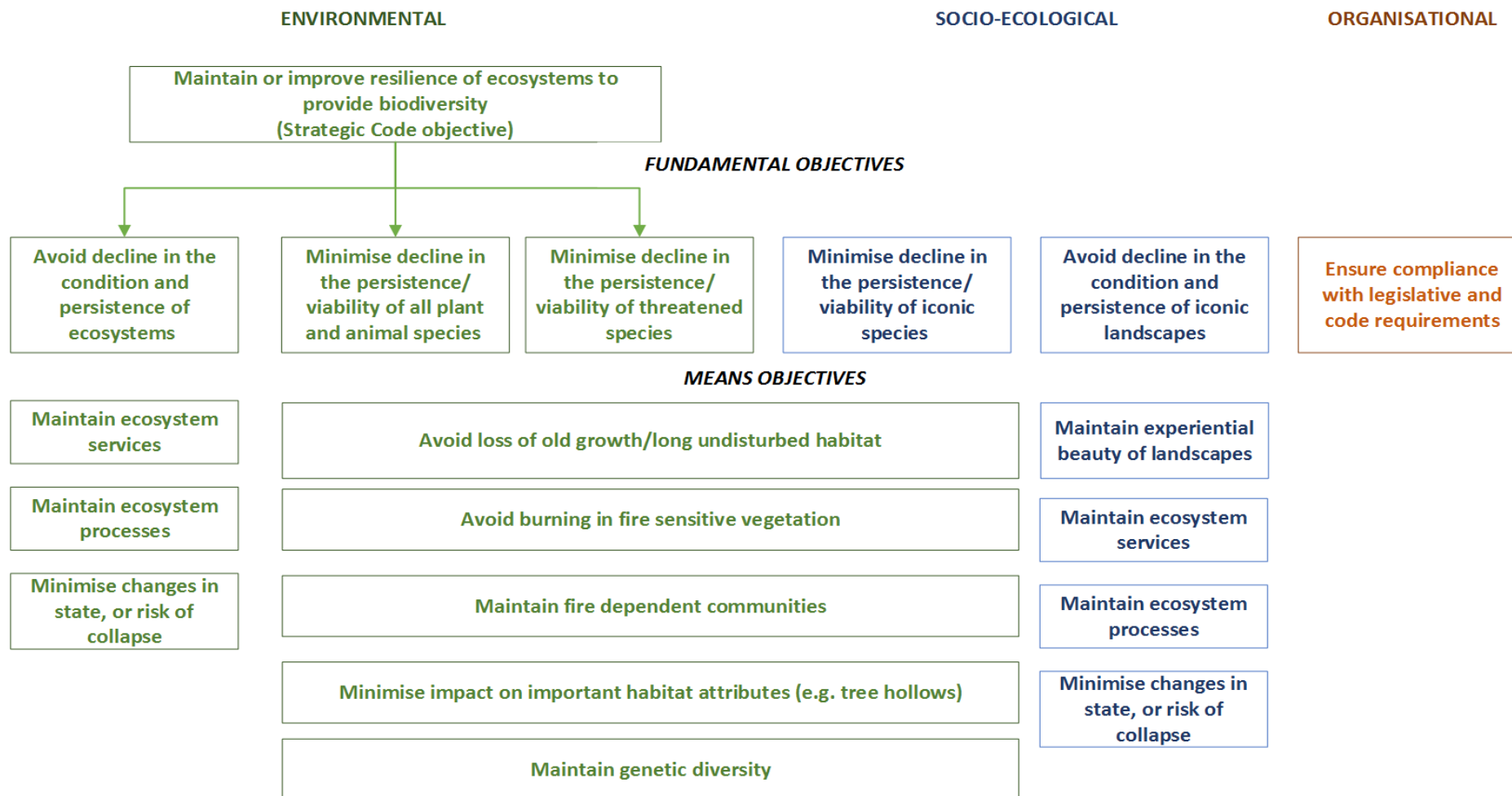


Figure 3. The initial prototype of the group objectives hierarchy, which is a collation of fundamental objectives highlighted by workshop participants

3. PERFORMANCE MEASURES

In the workshop, we started the process of understanding current or potential future performance measures for each objective. Performance measures are specific metrics that allow the analysis of the impact of a number of alternative management and monitoring plans on objectives. Good performance measures are clear and concise, unambiguous, understandable, direct and operational (Gregory et al. 2012). This is critical because they define how an objective is to be interpreted and evaluated in the decision context. Thus, measures that can be understood and implemented by a range of stakeholders (including the community), and help monitor progress toward the objectives of the Strategy, are invaluable. The need for well-defined and understood measures (particularly by community stakeholders and decision makers) was identified as a critical issue in the integration of ecological objectives into the decision-making process (see *Problem Statement*).

Developing performance measures is a difficult task, and further discussion is needed regarding the benefits and disadvantages of alternative measures, and the definition of measures at an appropriate spatial and temporal scale. Time was limited in the first workshop, and it will be necessary for this project to work toward selecting a performance measure for each objective. This selection will be based on further consultation and an understanding of data availability (to be confirmed later in the project), and then detail and advice will be provided on where further development of measures is required. It may be possible to offer flexibility in the choice of performance measures for each region (i.e. where multiple measures exist for an objective), but this also needs to be discussed.

A summary of the performance measures is found below in Table 1. At this stage, these measures are not specific to a particular spatial or temporal scale.

NEXT STEPS

When we have consolidated your comments on this Workshop 1 report, we will be drawing on this information and updating it as part of other project outputs.

The next task will be looking at the models and data that is needed and available, and where there are gaps in information. This will involve another workshop with DEWLP staff, which will also involve clarification of performance measures.

Table 1. A list of current and potential performance measures that could be relevant to the different fundamental objectives. At this stage, none of these measures are specific to a particular spatial or temporal scale. Note that performance measures in bold have never been implemented (i.e. potential) within the bushfire management context, and will require further development beyond this project.

OBJECTIVES	CURRENT AND POTENTIAL PERFORMANCE MEASURES
<p>AVOID DECLINE IN THE CONDITION AND PERSISTENCE ECOSYSTEMS</p> <p>AVOID DECLINE IN THE CONDITION AND PERSISTENCE OF ICONIC LANDSCAPES</p>	<p><i>Tolerable fire interval</i></p> <p><i>Proportion of total area currently below minimum TFI</i></p> <p><i>Proportion of total area currently above maximum TFI</i></p> <p><i>Annual and cumulative area (total and proportion) of each EFG in landscape burnt while below minimum TFI</i></p> <p><i>Variation in inter-fire periods over time across a landscape and within each EFG</i></p> <p><i>Deviation between the ecological goal and observed vegetation growth stage structures</i></p> <p><i>Change in area (IUCN)</i></p> <p><i>Change in extent of occurrence (IUCN)</i></p> <p><i>Changes in abiotic and biotic components of the ecosystems (IUCN)</i></p>
<p>MINIMISE DECLINE IN THE PERSISTENCE OF THREATENED SPECIES</p> <p>MINIMISE DECLINE IN THE PERSISTENCE OF ALL PLANT AND ANIMAL SPECIES</p> <p>MINIMISE DECLINE IN THE PERSISTENCE OF ICONIC SPECIES</p>	<p><i>Minimise number of threatened species declining by more than 5% (in abundance, occupancy, extent) over the duration of the strategy. Consider this measure also at the population level.</i></p> <p><i>Geometric Mean Abundance (GMA) of all species (currently only fauna data used)</i></p> <p><i>Geometric Mean Abundance (GMA) of Key Fire Response Species (currently only fauna data used)</i></p> <p><i>Minimise the number of KFRS (currently only fauna species used) that decline by 20% (in relative abundance, occupancy, extent).</i></p> <p><i>Minimise the number of flora (minimum TFI species) that decline by 20% in (relative abundance, occupancy, extent).</i></p> <p><i>Vegetation growth stage structure (proportional change in GMA between target and observed growth stage structures)</i></p> <p><i>Tolerable fire interval (area below minimum, area above maximum, area burnt while below min TFI)</i></p>
<p>ENSURE COMPLIANCE WITH LEGISLATIVE AND CODE REQUIREMENTS</p>	<p><i>Yes, No</i></p> <p><i>Opportunity cost in the number of threatened species declining (in abundance, occupancy, extent) over the duration of the strategy.</i></p>

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Appendix B Output 5: Conceptual framework

Workshop examples from Case-study region
Workshop 3 held 1st May, 2018
Bairnsdale RSL, Forge Creek Rd, Bairnsdale
Prepared by Libby Rumpff and Josephine MacHunter

Summary

Context

The *Code of Practice for Bushfire Management on Public Land* specifies that fire management aims to achieve the multiple objectives of minimising the impacts of major bushfires on life, property and the environment, and improving ecosystem resilience. The Safer Together policy (2015) advocates the use of the latest science, data and technology to make sure management actions are targeted at reducing bushfire risk and protecting values such as ecosystem system resilience. A key area of research is to reduce uncertainties and knowledge gaps in modelling the consequences of fire management on multiple values. There also exists implementation gaps in risk assessment of ecosystem resilience to support strategic bushfire management planning (SBMP) highlighting the need for a decision framework to better support this process. BNHCRC Ecological Research Project 1 (***Using, updating and integrating ecological models into a decision framework to inform bushfire management planning***) was commissioned by DEWLP to bring together a suite of ecological models into a world-class and user-friendly system to enhance fire management, research investment and monitoring.

Aims

This report (Output 5 of ERP 1) aims to develop a consolidated decision framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species to facilitate effective fire management decision-making.

Findings

This report describes the next iteration of a decision framework to support the ecological models. In this report, we provide:

- Guidance for developing a problem statement, clearly outlining the decisions to be made (with an example from the Case study region).
- A clarification of the management objectives (i.e. from The Code) and the associated performance measures that might be relevant to the regions for SBMP.
- A demonstration of how the existing ecological metrics, informed by ecological models and data, can be presented to understand the consequences of implementing various alternative management (planned burning) scenarios, in relation to the objectives.
- An example of ways to address trade-offs between multiple objectives.

A brief introduction to the role of MER in updating the data and models in the framework to reduce critical uncertainties in decision-making (noting this is expanded in Output 8 of ERP 1).

Management implications

This iteration of the decision framework, which is based on the core steps of a Structured Decision-Making approach, provides guidance that can support SBMP. This report includes a case study from the Gippsland Region that can be used as a reference for DELWP Risk and Evaluation teams in other Regions to help frame the decision context, objectives and performance measures for their SBMP. Guidance is also provided for regional staff (Risk and Evaluation teams, Regional Managers Forest and Fire Planning) for later stages in the decision-making process for SBMP which could be incorporated into the guidance for SBMP being developed by the Planning Unit within the Forest, Fire and Regions group.

Background

Victoria's *Code of Practice for Bushfire Management on Public Land* (the Code) specifies that fire management aims to achieve the dual objectives of minimising the impacts of major bushfires on life, property and the environment, and maintaining or improving ecosystem resilience. More recently the Safer Together (2015) policy platform sets out the direction for bushfire management in Victoria. The four pillars of Safer Together are: (i) the use of science and technology to reduce uncertainty in models and data; (ii) working in partnership with the land managers and emergency management sector; (iii) involving local communities in decision-making about bushfire management all year round and (iv) understanding how and where bushfires spread.

Strategic bushfire management plans (SBMP) guide bushfire management activities by identifying strategies that seek to protect multiple values. A pathway to implementing SBMP's has been identified by DELWP, and ecological models resulting from extensive research into the response of flora and fauna to fire are integral to this process. However, consultation with stakeholders has highlighted that the current approach to applying ecological data and models to support fuel management decision-making is limited by several knowledge and implementation gaps.

BNHCRC Ecological Research Project 1 (***Using, updating and integrating ecological models into a decision framework to inform bushfire management planning***) aims to develop a consolidated decision framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species to facilitate effective decision-making. In this project we aim to bring together a suite of ecological models into a world-class and user-friendly system to enhance bushfire management, research investment and monitoring. The focus is on developing an ecological resilience module that is fit for purpose, as flexible as possible in the face of current revisions to the guidance for the strategic bushfire management planning process, and relevant to multiple regions which differ in their approach to identifying preferred strategies.

This report (Output 5 of ERP 1) provides a description of the conceptual framework for developing and applying the ecological models (as part of analysing risk to both ecosystem resilience and threatened species) to inform strategic bushfire management planning.

It essentially describes the steps outlined in the structured decision-making framework (Figure 1). The report is based on the findings from workshop 1 (see Appendix 1 for workshop 1 report) and workshop 3 of ERP 1. The specific examples in this report were developed in consultation with the Gippsland region (i.e. the case study region, workshop 3).

This report includes:

- Guidance for developing a problem statement, clearly outlining the decisions to be made (with an example from the Case study region)
- A clarification of the management objectives (i.e. from The Code) and the associated performance measures (Workshop 1) that might be relevant to the regions.
- A demonstration of how the existing ecological metrics, informed by ecological models and data, can be presented to understand the consequences of implementing various alternative management (planned burning) scenarios, in relation to the objectives.
- An example of ways to address trade-offs between multiple objectives.
- A brief introduction to the role of MER in updating the data and models in the framework to reduce critical uncertainties in decision-making (noting this is expanded in Output 8).

Project approach

The decision framework developed within the ERP1 project is based upon the tools and steps of structured decision-making (SDM, Figure 1; Gregory *et al* 2012). SDM describes both the process of deconstructing decisions into various common components, and the broad set of tools used, and is designed to aid logical and transparent decision-making (Figure 1; Gregory *et al* 2012, Garrard *et al*. 2017).

Breaking down a decision and analysing each step separately helps people logically process, understand and communicate decisions. This approach is particularly valuable for complex decisions that can involve multiple competing objectives, uncertainty surrounding the available management

options, and/or high uncertainty about the consequences of management. The process of analysing decisions can also help clarify where uncertainty exists in the data, and also recognise when uncertainty influences a management decision. Importantly, the approach disaggregates scientific data from values, which can mitigate against biases associated with unstructured judgements (e.g. anchoring, status quo bias, zero-risk bias; Addison *et al.* 2013).

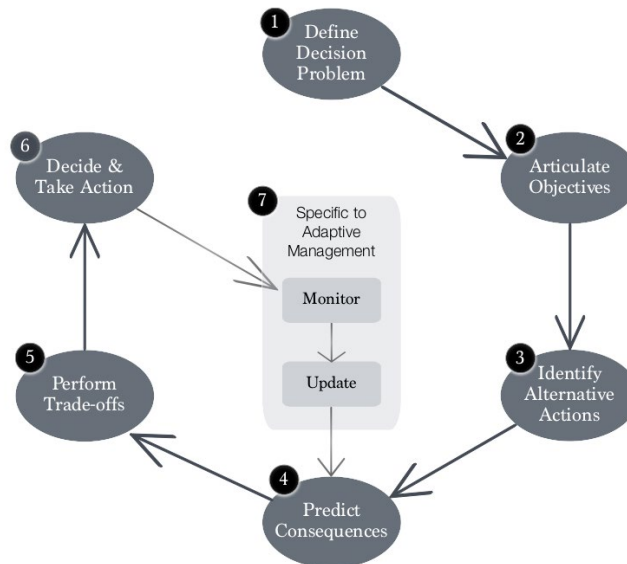


Figure 1. The structured decision-making framework refers to both the steps, and the suite of tools used to address those steps. This figure is taken directly from Garrard *et al.* (2017). In the workshops the focus was on the first two steps.

The decision context

The first step in SDM involves clarifying the decision context with the relevant stakeholders. The primary aim of this step is to clearly and succinctly define what decision(s) are being made and why, such that everyone has a shared understanding of the problem at hand. Importantly, bounds on the problem are established by identifying spatial, temporal, organizational, legal, and relevant constraints. These might include, for example, legal constraints, minimum performance requirements for selected outcomes, or other constraints that have been established through a prior decision process. Roles and responsibilities within the decision should be clearly established, including identification of the ultimate decision maker. Stakeholders and key technical experts need to be identified, and their role in the decision process defined.

The decision context can be encapsulated in a problem statement, which is a succinct articulation of the problem. This helps bound the decision and ensures that all participants involved in contributing to the decision are on the same page.

In workshop 1, a broad problem statement was prepared with participants (see Appendix 1). Developing the problem statement involved i) understanding the current processes by which decisions are made at the Strategic and Operational level across the Regions, ii) who is involved in planning and decision-making; iii) how ecological objectives fit with this process; iv) the impediments to the application of ecological models and metrics to the decision process, and; v) what workshop participants thought was needed to improve the decision-making process.

It is worth noting that the original problem statement was long, as it aimed to capture the complexities and issues with the decision-making process, to aid the project leaders design the ERP1 project to account for, or be cognisant of as many of the issues as they could such that the decision framework with ecological model consolidation is ‘fit for purpose’. The problem statement also serves as a record of the technical and decision process issues, such that continued improvements to the process can be made beyond the ERP 1 project.

Guidance for developing problem statements

In this report, we present a method for developing regional specific problem statements, with the relevant stakeholders. Guidance was provided by Regan, T and MacHunter, J as part of a cross agency workshop delivered in 13/4/2018). Relevant questions and points to work through include:

- **What is the trigger?** Why does a decision need to be made? Why does it matter? What are the problems? What is the decision(s) to be made?
- **Identify the decision maker(s)** Is this a cross agency arrangement? If so, what are the arrangements for resolution on the decision?
- **Identify other key players and their roles in the decision process:** decision implementers & stakeholders, technical experts, community, other agencies
- **Frequency & Timing** - How often will the decision be made? When? Are other decisions linked to this one?
- **Scope** - How large, broad, complicated is the problem/decision? What is the relevant spatial scale? Are there multiple land tenures to deal with?
- **Outcomes** – Roughly, what are the desired outcomes? What are you hoping to achieve?
- **Actions** – Briefly, summarize the kinds of actions or strategies that are relevant to this context?
- **Constraints** - Legal, financial, political, 'minimum performance'. Perceived or real constraints?
- **Uncertainty** – Is there an initial awareness of which uncertainty is impeding the decision process? What is it?

Example (draft) problem statement (from Gippsland region)

Under the Safer Together project 2.3 of the Safer Together Program, the Gippsland Region are undertaking a strategic planning process to develop and select management strategies that will best minimize risk to a range of values potentially impacted by bushfire on public and private land. Alternative management actions will primarily include different arrangements and rotations of planned burning. Further management actions, such as improved roading and community risk understanding, may also be considered in broader strategy development. The risk assessment process used for assessing planned burning strategies will be modelled to 2050.

Fundamental values and fundamental objectives for fire management in Gippsland have been set by fire sector and land management agency staff within Gippsland. The fundamental values are:

- Human Life
- Wellbeing: individual, social, cultural
- Nature: biodiversity and ecosystem function

The fundamental objectives for fire management in Gippsland are to:

- Minimise human life loss and serious injury
- Minimise social, livelihood and economic disruption
- Minimise disruption to essential services and critical infrastructure
- Minimise loss of community and cultural assets
- Minimise decline in native plant and animal populations

It is acknowledged that achieving some of the fundamental objectives may be at the cost of other objectives, and that some actions undertaken to achieve these objectives may impact on fundamental values. Within the planning process there is also recognition that the current capture of potential impacts of bushfire and fire management is heavily reliant on modelled data. In addition, most available ecological data to guide risk assessments is limited to expert opinion about impacts on terrestrial systems, on public land. The information available for aquatic systems and private land is currently deficient.

The Regional Strategic Fire Management Planning Committee is the owner of the strategic fuel management decision-making process. At a regional level, the Assistant Chief Fire Officer (ACFO)

will sign off on the strategic plans relevant to the management of public land, but decisions may proceed to the Chief Fire Officer at the State level for final approval. Currently, the process for developing strategies in the private land context has not been decided, and discussions with the CFA and Local Government Agencies is ongoing, regarding the scope of strategies and the format of the decision process.

The Code of Practice includes the principle that bushfire management be undertaken at landscape scale, and that there will be clearly articulated landscape-level objectives, which encourage land and fire agencies to work together to achieve the objectives of the Code. As well as meeting objectives under the Code, there are other legislative considerations, as specified under the Forests Act, Cultural Heritage Act, the Environmental Protection and Biodiversity Conservation Act (EPBC), and the Flora and Fauna Guarantee Act (FFG). It should be noted that guidance relating to the role of the State and Federal Environment Ministers in making fire management decisions (impacting on the status and management of EPBC and FFG listed species and communities) is lacking. This means that, when trade-offs between conflicting objectives are made through the SBMP processes, these cannot be viewed as solutions to legal requirements, or as a resolution of conflicts between pieces of legislation.

The process for stakeholder engagement is still in development, but relevant stakeholders who may be included in the strategic planning process over include more than 16 agencies* such as Parks Victoria, CFA and DELWP (those with regional planning roles), local government representatives, Traditional Owners, Regional Strategic Fire Management Planning Committees, and online consultation with the broader community via the Engage Victoria website.

*Agencies potentially involved in stakeholder engagement for development of the Gippsland SBMP

- Bass Coast Shire
- City of Latrobe
- Country Fire Authority
- DELWP
- East Gippsland Water
- Emergency Management Victoria
- Gippsland Water
- Gunaikurnai Land and Waters Aboriginal Corporation
- HVP Plantations
- Melbourne Water
- Parks Victoria
- Shire of Baw Baw
- Shire of East Gippsland
- Shire of Wellington
- South Gippsland Shire Council
- South Gippsland Water
- Southern Rural Water
- VicForests

Measurable objectives

Capturing the things ‘we’ care about, our values, is integral to any decision-making process (Keeney 1992; Gregory *et al* 2012). To aid decision-making, values are translated into specific, measurable statements that describe what is to be achieved. These statements are called objectives, and these are developed in the second step of a Structured Decision-Making process. Fundamental objectives state the primary reason for the decision (Runge 2011) and guide the rest of the decision analysis. These are differentiated from means objectives (which specify the means to achieving the fundamental objectives), process objectives (which specify the way a decision might be made) and strategic objectives (which are strategic priorities of the organization that govern all decisions). Once established, objectives form the basis for developing and evaluating alternative courses of action for management. To aid analysis, care must be taken to ensure that fundamental and means objectives are well defined, not confused (i.e. double counting of objectives), and that objectives are preferentially independent (i.e. the preference for objective ‘x’ does not depend on that of objective ‘y’). An example of double counting would be to ‘maximize the habitat of threatened species X’, as well as ‘maximize the persistence of threatened species X’. Both double counting and preferential independence are important in the analysis of trade-offs (see Section 5, Tradeoffs).

There are several important points to note in objective setting. First, we acknowledge that there are already objectives set out in the Department’s ‘Code of Practice for Bushfire Management on Public Land’, ‘Victoria’s Safer Together’ policy, and relevant legislation such as the EPBC and FFG Acts. In this Structured Decision-Making framework, we consider these ‘strategic-level’ objectives, which need to be defined as they are often statements that include multiple values. For example, the second Code objective is “To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products”.

It is intended that the list of fundamental environmental objectives presented below (Table 1), as developed in the first workshop, will be reflected in the Strategic Bushfire Management Planning guidance, and provide the basis for the decision framework. It should be noted that i) regions will not have to select all fundamental objectives if they are not applicable for trade-off analysis in the planning process, but the risk assessment module developed in this project can report on the impacts of alternative strategies on all potential ecological objectives, and; ii) the wording may be refined with further consultation from regions and other key stakeholders (e.g. ACFO's).

Guidance for setting objectives

Developing measurable objectives is achieved through 6 steps (adapted from Gregory *et al.* 2012):

1. Individually brainstorm an initial list of objectives (i.e. "What do you want to achieve/avoid with management?")
2. Separate means, process and strategic objectives from fundamental objectives using the WITI ("Why is that important") test (Clemen 1996)
3. Build a group objective hierarchy to represent the relationship between objectives and discuss.
4. Compile and define a list of fundamental objectives from the group
5. Discuss which performance measures could be assigned to each objective

As part of Workshop 3, a modified version of the above was run with the case study region, prior to the multi-stakeholder Safer Together objectives setting workshop (in June 2018). From Table 1, the following objectives were identified in Workshop 3:

1. Avoid decline in the persistence of (self-perpetuating) ecosystems
2. Minimise decline in the persistence of (non-threatened) plant and animal species
3. Minimise decline in the persistence of threatened species.

In the June 2018 Safer Together objectives setting workshop for the Gippsland region, Objectives 1 and 3 were not specified. There was some discussion at the ERP1 workshop 3 whether 'Minimise decline in the persistence of all plant and animal species' was the only objective required in an analysis of trade-offs with other objectives. This was in part due to issues with the current suggested metrics (and performance measures) for Objective 1, and uncertainty whether the threat status of species necessitated a separate fundamental objective. Similarly, maximising the 'condition' of communities and ecosystems was highlighted as a fundamental objective in the ERP1 workshop 3, but it was recognised that the current performance measures did not capture 'condition' so it was not considered further.

We did not focus on social objectives at the ERP 1 workshop 3, but it was acknowledged that 'Increasing community wellbeing' is a social objective related to environmental values.

Performance measures

Performance measures are specific metrics that allow the analysis of the impact of alternative strategies on objectives. Good performance measures are clear and concise, unambiguous, understandable, direct and operational (Gregory *et al.* 2012). This is critical because they define how an objective is to be interpreted and evaluated in the decision context. Thus, measures that can be understood and implemented by a range of stakeholders (including the community) and help monitor progress toward the objectives of the Strategy, are invaluable. The need for well-defined and understood measures (particularly by community stakeholders and decision makers) was identified as a critical issue in the integration of ecological objectives into the decision-making process (see Appendix One, the ERP 1 Problem statement).

Feedback on selecting relevant performance measures for each objective is ongoing, and it is clear there is dissatisfaction with some of the ecological metrics. There is recognition that:

- The tolerable fire interval (TFI) data cannot be tested and updated, and some regions are seeking a better, more direct measure of ecosystem/landscape decline (persistence and condition).
- The term 'ecosystem' requires better definition to capture people's understanding. For instance, in Workshop 3 it was highlighted that the performance measures for Objectives 3-6 (Table 1) were seen to better reflect an 'ecosystem' measure, rather than TFI. It would be tempting to use the same model output (performance measure) to represent multiple objectives. However, different fundamental objectives need to have different measures for any analysis or discussion of trade-offs to work (see Section 5), as using the same measure does not allow discussion/analysis of whether one objective should be weighted more highly than the other. If data or model outputs are not available for all objectives, structured expert elicitation is warranted (see Hemming et al. 2018).
- Measures involving Key Fire Response species are proxy measures, as they are selected as representatives of 'all' species. Similarly, data is not available for 'all' plant species.

Review of the measures will be based on further consultation with DELWP staff. It is anticipated that the consolidated analysis module can offer flexibility in the choice of performance measures for each region (i.e. where multiple measures exist for an objective).

Table 1. The list of ecological objectives and performance measures. A user can choose as many objectives as relevant from 1-6, but only one performance measure for each objective can be chosen for trade-off analysis. A report for all objectives and measures will be generated. The relevant spatial or temporal scale is not specified in this table but will be defined in the module. * Work by Tracey Regan informs the ‘significant impact’ thresholds, which is based on threat status. # iconic landscapes or species that are not threatened but valued by stakeholders for another reason (e.g. koalas): they are socio-ecological objectives that can be calculated using the module.

Number	Fundamental objectives	Preferred direction	Performance measures
1	Avoid decline in the persistence of ecosystems	Less is better	Choose one of: <ul style="list-style-type: none"> ○ Cumulative area of each EFG in landscape burnt outside TFI range (choose threshold for number of times burnt); ○ Cumulative area of each EFG in landscape burnt below TFI range (choose threshold for number of times burnt); ○ The proportion of minimum TFI species across ecosystems that decline in abundance by 20%*.
2	Avoid decline in the persistence of iconic# landscapes	Less is better	Choose one of: <ul style="list-style-type: none"> ○ Cumulative area of each iconic EFG in landscape burnt outside TFI range (choose threshold for number of times burnt); ○ Cumulative area of each iconic EFG in landscape burnt below TFI range (choose threshold for number of times burnt); ○ The proportion of minimum TFI sp across ecosystems that decline in abundance by 20%*.
3a	Minimise decline in the persistence of non-threatened plant and animal species; or	Less is better	Choose one of: <ul style="list-style-type: none"> ○ Proportion of significantly impacted least concern faunal (KFRS) and flora species (e.g. decline by 20%* in relative abundance, occupancy, extent). ○ Geometric mean abundance of least concern faunal (KFRS) and flora species
3b	Minimise decline in the persistence of all plant and animal species		<ul style="list-style-type: none"> ○ Proportion of significantly impacted faunal (KFRS) and flora species (e.g. decline by 20%* in relative abundance, occupancy, extent). ○ Geometric mean abundance of all faunal (KFRS) and flora species
4a	Minimise decline in the persistence of threatened species; or	Less is better	Number of significantly impacted threatened faunal and flora species (e.g. decline by 20%* in relative abundance, occupancy, extent).
4b	Maximise compliance with legislative requirements		As above
5	Minimise decline in the persistence of iconic* species	Less is better	Number of significantly impacted iconic species (e.g. declining by more than 20%* in abundance, occupancy, extent over the duration of the strategy).
6	Maximise compliance with code requirements	More is better	Ecological objectives explicitly considered in strategy selection (Yes = 1/No = 0)

Alternatives

Management alternatives focus directly on achieving objectives, and may involve varying the type, intensity and timing of actions across sites. Management alternatives is a broad term used in Structured Decision-Making. Management alternatives may consist of actions, or strategies. Actions are individual, discrete activities (e.g. a planned burn). A strategy is a combination of different actions (e.g. undertake pest control, planned burn, community education programs etc).

There is significant value in investigating the impact of different management alternatives in relation to the key management objectives, to gain an understanding of why it may be more beneficial to implement one management alternative over another (Gregory et al. 2012).

In this project, we are not giving specific guidance for selecting alternative strategies, nor are we able to predict the consequences of actions beyond planned burning strategies. However, once objectives are established for a region, these should act as a guide for the development of management strategies. That is, focus should be given to developing alternatives that would best meet all objectives, as opposed to developing alternative strategies that may maximise individual objectives, but not perform well across all relevant objectives. The 'Do nothing' and/or 'Status Quo' alternative should always be included as a point of comparison, to ensure it is worth changing management strategies.

In addition, the initial risk assessment stage of the Strategic Bushfire Management Plans is a useful platform for identifying hazards relevant to the region, and designing strategies that incorporate actions that minimise the impact of these hazards.

Consequences

Estimates of how the management strategies are expected to influence each of the performance measures allow you to compare the effectiveness and efficiency of different alternative management strategies, and identify redundant objectives (i.e. those that do not vary in relation to the alternatives at hand). That is, a model that describes the consequences of the planned burning strategies on the objectives important to the decision.

This project is focused on consolidating ecological models and data to present the consequences for ecological objectives, for each alternative. In the ecological analysis module, the consequences for ecological objectives will be calculated and presented as a consequences table (i.e. Table 2). The role of the consequence table to provide a (quantitative) means to explore the relative performance of each alternative, and the key uncertainties and potential trade-offs associated with this decision context.

Guidance for exploring the consequence table

In a consequence table, a user can investigate:

- The alternative that performs best or worst for each objective.
- If there is a dominant alternative. That is, a clear winner, that outperforms other alternatives on all objectives.
- If there are dominated alternative, or practically dominated alternatives. That is, alternatives that are consistently outperformed by another alternative. Or, alternatives that have unacceptable performance for any objective(s). Note Alternatives 1 and 3 are dominated by Alternatives 2 and 4 (Table 3).
- If there are redundant measures. That is, those performance measures that do not vary (substantially) across the alternatives. This indicates that either the alternatives need revising, the performance measure needs revising (i.e. it is insensitive), or that this objective is does not contribute further in the analysis of the decision (i.e. even if an important value). Note the 'sense of place' constructed measure is a redundant measure (Table 3).

- If uncertainty is accounted for in a consequence table, a user would be able to start investigating the possible sources of critical uncertainty in the decision process. That is, does the preferred alternative change for a given objective when considering the lower bound, upper bound or nominal consequence estimate? An analysis of trade-offs (see following section) can help differentiate whether a strategy is preferred, despite uncertainty. If so, monitoring to resolve uncertainty is not necessarily required, but may be undertaken for other reasons (i.e. reporting/ auditing, as a trigger for management, communication etc). However, if it is not possible to differentiate between strategies considering uncertainty, then further investigation is warranted to determine whether there is justification for an adaptive management program. Note, uncertainty will be available for some outputs from the consolidated ecological module to include in a consequence table, but without uncertainty included for all fundamental objectives (including life/property) it is not possible to determine whether uncertainty is 'critical' for any give strategy.

Table 2. Consequences for objectives, against alternative fire management strategies. Note that only the ecological objectives will be auto-populated in the consequence table within the module, but users could have the opportunity to manually enter the consequences of different objectives, in order to simplify objectives.

Objectives (performance measures)	status quo A1	Alternative 2	Alternative 3	Alternative 4
	nominal	nominal	nominal	nominal
Human Life Loss (Expected House Loss over 40 years)	53	39	53	36
Faunal species decline (Number of species with a 20% or greater decline over 40 years)	12	3	14	12
Sense of place (Constructed Scale (0-100) 100 representing nirvana. 0 representing no social cohesion)	66	67	66	66
Economic loss to public property (Expected Cost over 40 years (millions))	16	11	16	11

Table 3. The simplified consequence table. Scores shaded in dark orange do not have to be considered further in the analysis of trade-offs. For example, Alternatives 1 and 3 are dominated (outperformed) by Alternatives 2 and 4, and the constructed scale for ‘sense of place’ is a redundant measure. After removal of Alternatives 1 and 3, ‘expected cost’ does not vary over Alternative 2 and 4, thus is also redundant. The table is thus simplified to show a trade-off between species decline (number of species with a $\geq 20\%$ decline over 40 years) and Human life loss (Expected house loss over 40 years).

Objectives (performance measures)	status quo A1	Alternative 2	Alternative 3	Alternative 4
	nominal	nominal	nominal	nominal
Human Life Loss (Expected House Loss over 40 years)	53	39	53	36
Species decline (Number of species with a >20% decline over 40 years)	12	3	14	12
Sense of place (Constructed Scale (0-100) 0 representing no social cohesion)	66	67	66	66
Economic loss to public property (Expected Cost (millions) over 40 years)	16	11	16	11

Trade-offs

Determining the most appropriate fuel management strategy is likely to require trade-offs between competing objectives (i.e. life and property values and environmental values are often deemed 'competing'), as it is rarely possible to find a dominant alternative. This problem requires the decision-maker/s to make a call on what is more important or valued. Different people involved in a decision will have different perspectives on what is a good alternative, and what exactly is meant when we speak of 'desirable' outcomes. Difficult decisions will often involve (a) contested stories of cause-and-effect underpinning judgments of how well each alternative will perform against each objective and (b) divergent value judgments on the relative importance of each objective. This presents a considerable challenge within the context of strategic bushfire management planning and Safer Together which advocates that "we will involve local communities in decision-making about bushfire management". The extent to which the community is involved in trade-offs is yet to be specified in SBMP guidance. In the next section we provide guidance on different approaches to making trade-offs

Note that within the ecological module, the decision to incorporate trade-off analysis is yet to be decided. If included, it would require users to manually enter the consequences of non-ecological objectives.

Guidance for exploring trade-offs

There are different approaches to examining trade-offs (see Goodwin and Wright 2009; Gregory et al. 2012; Conroy et al 2013), and a couple of these were explored within the workshop with the Gippsland region, using a mock example with competing objectives. As a first step, we asked participants to examine the consequence table and directly rank alternatives i.e. a more 'holistic' consideration of trade-offs. Results were collated (anonymously) and presented to the group. This can be a useful step to first explore differences in opinions about preferred alternatives, to gauge the level of 'support' for different alternatives as a basis for discussion (i.e. is further analysis needed?).

It should be noted that the quality and consistency of individual judgements can be improved using quantitative approaches, to ensure assessments are performance based. The quantitative approaches discussed were as follows:

1. Individuals undertake a quantitative trade-off analysis (see method below), and as above, results are presented as the basis for exploring and discussing similarities or differences in preferred alternatives. Alternatively, instead of all individuals involved in strategy selection undertaking the exercise, the decision maker/s could do so. Note the approach taken in the workshop was to initially rank alternatives, then undertake a quantitative approach – this is referred to as a generalized multi-method trade-off approach (Gregory et al 2012).
2. Another method discussed included an optimisation approach, which (mathematically) searches for the alternative set of actions that maximises or minimises a specified objective(s), whilst constraining the other objectives to a desired or acceptable value. Note, the ability to undertake spatial optimisations is at present restricted by development of analysis method, computational power, and data.
3. To understand the preferences of the broader 'community' in each region (those stakeholders not directly involved in strategy selection), a preferences survey could be undertaken to determine/explore the weightings placed on objectives. For different methods see Goodwin and Wright 2009; Mitchell and Carson 2013. This approach was not discussed at the regional workshop.

Quantitative trade-off method presented in the workshop

Quantitative approaches such as multi-attribute trade-off methods can improve the quality and consistency of individual judgements and ensure assessments are performance based. A multi-attribute trade-off (utility) approach involves assigning weights to the different objectives. Assigning weights should involve consideration of both how important the objective is (which can vary from person to person), and the degree

to which that objective changes across the alternatives on offer. As in, explicit consideration should be given to how much one objective could reasonably be sacrificed to achieve specific amounts of other objectives.

In the Gippsland workshop (3), we used a multi-attribute method known as swing weighting (von Winterfeldt and Edwards 1986). The swing weight method involves showing participants the best and worst consequence estimate for each objective and asking for a rank and weight to be assigned (Table 4). The rank reflects the order in which you would swing (change) each objective from worst estimate to best estimate. The weights reflect how valued the objectives are, in relation to the first ranked objective (with 100 being most valued and 0 being no value). The swing weighting task was undertaken in the workshop by all workshop participants.

A weighted additive model was then used to evaluate the management alternatives by generating decision scores (V_i , Figure 2). This involves aggregating the consequence estimates and weights, following:

$$\text{Equation 1.} \quad V_i = \sum_{j=1}^n w_j x_{ij}$$

where w_j is the normalised weight assigned to objective j , and x_{ij} is the normalised consequence for alternative a_i on objective j . The consequence estimates (x_{ij}) are normalised (on a scale of 0–1) across the entire range of the estimated consequences of each objective, using:

$$\text{Equation 2.} \quad x_{ij} = \frac{x_i - x_{\min(\text{pessimistic})}}{x_{\max(\text{optimistic})} - x_{\min(\text{pessimistic})}}$$

where, $x_{\max(\text{optimistic})}$ is the maximum optimistic estimate $x_{\min(\text{pessimistic})}$ is the minimum pessimistic estimate across all ecological scenarios.

Table 4. Ranking and weighting of objectives (with the weights provided as an example only, not from workshop participants). Note, the following table assumes the consequence table has not been simplified (i.e. Table 3)

	worst	best	rank	weight	normalised
Human Life Loss (Expected House Loss over 40 years)	53	36	2	80	0.40
Species decline (Number of species with a >20% decline over 40 years)	14	3	1	100	0.50
Sense of place (Constructed Scale (0-100) 0 representing no social cohesion)	66	67	4	0	0.00
Economic loss to public property (Expected Cost (millions) over 40 years)	16	11	3	20	0.10
					1.00

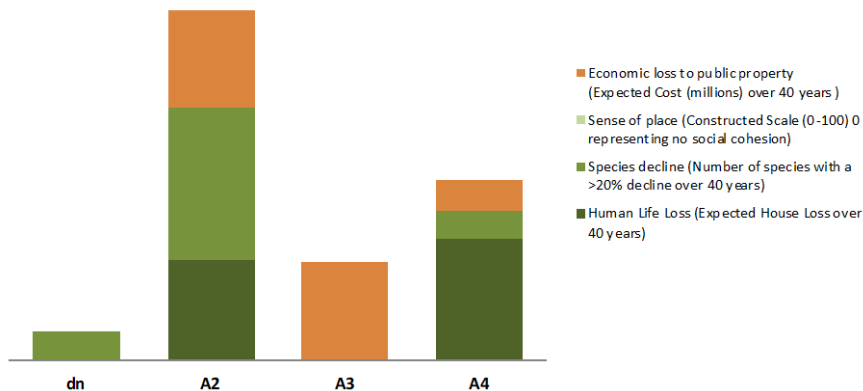


Figure 2. The overall decision scores, which indicates Alternative 2 as the highest performing alternative. The coloured bars highlight the contribution of each objective to the total decision scores.

As mentioned above ('Consequences'), during trade-off analysis explicit consideration should be given to the estimates of uncertainty provided to allow a user (decision maker/s) to exercise their risk attitude when selecting a preferred alternative. Even though it is not anticipated that uncertainty will be available from all model outputs (i.e. only the nominal scores will be calculated for many performance measures – Figure 2), we expand on an approach to consider uncertainty further here (in anticipation of data being collection through the Victorian Bushfire Monitoring Program that will provide necessary input data). The weighted additive model can be used to generate three estimates for each management alternative i) a nominal decision score (based on the best guess); ii) a lower bound decision score (based on the pessimistic estimates); and, iii) an upper bound decision score (based on the optimistic estimates). Figure 3 highlights the variation in decision scores, accounting for uncertainty that has been added to the consequence table (i.e. to Table 2, but not shown). A risk-taking decision maker may select the preferred alternative under the upper bound, or optimistic scenario, and a risk-averse decision-maker may select the alternative that avoids the worst-case scenario (i.e. the preferred alternative using the lower bound estimates). Selecting the alternative with the highest nominal decision score (i.e. using best estimates) and ignoring uncertainty implies a risk neutral attitude (Chankong and Yacov 1983). Figure 3 still highlights Alternative 2 is preferred using nominal scores (as in Figure 2). However, Alternative 4 has the highest upper bound, and the highest lower bound. Thus, the uncertainty in this (constructed) example could be considered 'critical' to resolve.

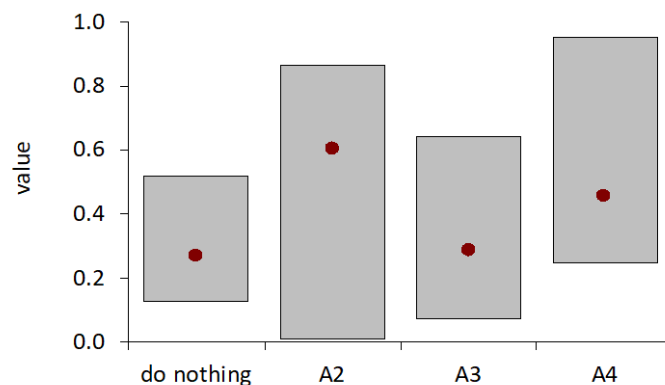


Figure 3. A summary of overall decision scores, accounting for uncertainty in the consequence table. Red dots represent a nominal decision score (based on the best guess); box around each score encompass a lower bound decision score (based on the pessimistic estimates) and an upper bound decision score (based on the optimistic estimates). The horizontal axis shows a no action / “do nothing” scenario in comparison to alternative scenarios (A2,3,4). The vertical axis is the (unitless) decision score, calculated using the weighted additive model (see Equation 1, above).

Project next steps

Next steps in ERP 1 include:

- Documentation of collated ecological and threatened species models (Output 4).
- Integrating the ecological models into an ecological module and developing the user interface (shiny-app) to support the decision framework (Output 6).
- Developing a documented process map for monitoring (Output 8)

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Appendix C Output 8: Process map

A process for dealing with uncertainty for fire management decisions

Outcomes report from Workshop 4, held 26th October, 2018
Room G26, BioSciences 1, University of Melbourne, Parkville

Prepared by Libby Rumpff, Josephine MacHunter and Kate Cranney

Introduction

Background

Fire management aims to achieve two objectives according to the *Code of Practice for Bushfire Management on Public Land* for Victoria (the Code): to minimise the impacts of major bushfires on life and property, and to maintain or improve ecosystem resilience. Regional risk and evaluation teams in the Victorian Government create Strategic Bushfire Management Plans (SBMPs) to guide bushfire management activities by outlining strategies that achieve both objectives.

The Victorian Department of Environment, Land, Water and Planning (DELWP) has identified a pathway to implement SBMPs, and ecological models are integral to this pathway. Ecological models are based on extensive research into the response of flora and fauna to fire; however, stakeholders have highlighted that knowledge and implementation gaps limit our current approach of applying ecological data and models to support fuel management decision-making. Through the BNHCRC Ecological Research Project 1 (*Using, updating and integrating ecological models into a decision framework to inform bushfire management planning; ERP 1*), the project team are leading an investigation into these issues, and providing solutions for DELWP.

The primary aim of ERP 1 is to create a consolidated decision framework for applying ecological models and metrics to manage risks to ecosystem resilience and threatened species, to facilitate effective decision-making. In this project we aim to bring together a suite of ecological models into a world-class and user-friendly system to improve bushfire management, research investment and monitoring.

A core part of ERP 1 is analysing the tools and approaches used to deal with (identify and prioritise) the type of uncertainty that affects decision-making for fire management. We are particularly focused on the types of uncertainty that are critical to decision makers—in this context, that means that a decision maker is not able to determine which fire management strategy is preferred or 'optimal', because of the uncertainty underpinning the response of the ecological objectives to fire management strategies.

Structured Decision-Making

A key component of ERP 1 is developing a structured decision-making (SDM) framework (Figure 5) to guide decision makers and stakeholders on how to better use ecological models and metrics to inform a strategic planning process. We are using the SDM framework to ensure the modelling component of this proposal is relevant to the decision context (i.e. bushfire management)—it is the role of decision makers and government to apply such a framework.

A structured decision-making process involves an organised analysis of a problem, focused explicitly on addressing the objectives of those involved in the decision-making process (i.e. as per the objectives outlined in The Code). This approach is well-suited to supporting ecological risk assessments where there is a backdrop of potentially competing objectives such as the conservation of species with different requirements. Structured decision-making provides a systematic, rational and transparent platform for synthesizing existing knowledge and uncertainty, and exploring the consequences of management alternatives, such as the amount and configuration of planned burning, in relation to The Code objectives.

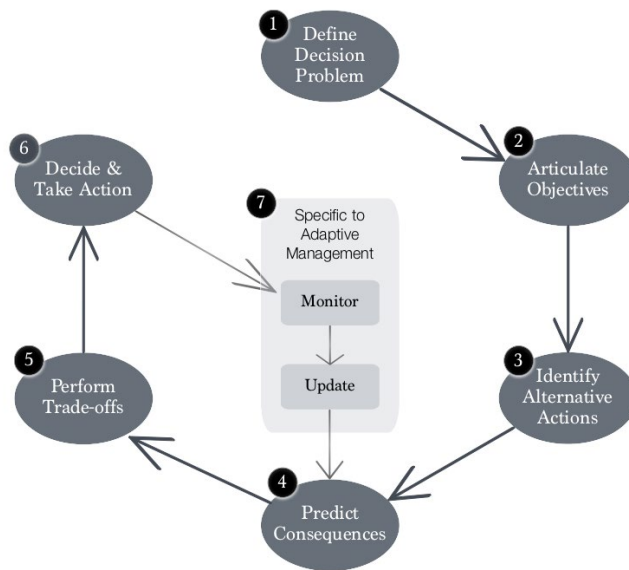


Figure 1: The structured decision-making framework refers to both the steps, and the suite of tools used to address those steps. This figure is taken directly from Garrard et al. (2017).

Output 8 Context

DELWP has made progress defining the ecological objectives and performance measures for strategic planning. These objectives were specified early in the ERP 1 project and been iteratively revised as part of subsequent review by policy leads and project stakeholders (see Appendix 1. List of fundamental objectives and performance measures). However, there are issues and gaps with the process that impede decisions about development, identification and assessment of preferred management strategies. These issues and gaps can be described in relation to issues with the decision-making process, and issues with the technical process of implementing ecological models to support bushfire management planning.

The issues with the technical process of using ecological models, data and metrics to support strategy selection are the primary focus for this output. The issues were initially explored in workshop 1 of this project and synthesised in a previous report (Output 5). In this report we classify the problems into three broad issues:

- i) Specification of performance measures;
- ii) The type and quality of data that is used to calculate the measures, or;
- iii) Both the specification performance measures and the underlying data

These issues lead to uncertainty around the robustness of the performance measures and their ability to estimate the consequences of alternative management strategies (Figure 1). In some cases, a decision maker is not able to determine which fire management strategy is preferred or ‘optimal’ because of the uncertainty underpinning the response of the ecological objectives to fire management strategies. This uncertainty is referred to as ‘critical uncertainty’ because it impedes the choice of a preferred strategy. However, we recognise that this uncertainty does not even have to be ‘critical’ in the technical sense, if a decision cannot proceed because stakeholders lack confidence in the performance measure or data and refuse to use them for those reasons.

Aims

For Output 8, we aim to:

- i) Identify the issues relating to performance measures, and / or the data that underpins them;
- ii) In detail, unpack a process for addressing some of the key issues with performance measures and data;
- iii) Highlight ways to address some of the remaining issues with performance measures and data;
- iv) Summarise the issues and solutions in a process map

Approach

Key Steps

The steps used to identify key issues, develop solutions and summarise in a process map was to:

1. Review the scientific literature regarding types of lines of evidence, uncertainty and interaction with decision-making
2. Summarise and classify information from previous ERP1 workshops and meetings with DELWP risk and evaluation teams about problems hindering the applications of ecological values in decision-making
3. Conduct a workshop to unpack some of the problems in more detail
4. Develop a process map to guide future work to explore and resolve issues with performance measures and/or data.

The Workshop

We held a one-day workshop (see Appendix 2. Workshop agenda) in October 2018 at Melbourne University, to bring together the policy leads for this project and key researchers who have expertise in applied research for fire management, or in developing decisions support tools (or both; see see Appendix 3. Workshop participants).

We asked workshop attendees to draw on best practise principles of how to identify and address uncertainty in decision-making. We spent some time discussing different problems together, focusing on performance measures and data that are specific to fire management, but can be thought about more broadly. We then started thinking about ways we could both explore or resolve a subset of these problems in greater detail in smaller teams.

For a subset of problems, groups were posed the following questions:

Question 1: How would you explore if this is a problem?

- What type of fire management knowledge gap or uncertainty is this? i.e. give us some details in relation to Strategic Bushfire Management Planning
- What is the problem with the measure (e.g. non-direct)
- What is the source of the uncertainty (e.g. measurement etc.)

Question 2: How would you explore and resolve it?

- Explore: how do you know it's a problem?
- Draw the process out to resolve the problem (and explore if necessary). Any alternatives approaches? i.e. would you apply different tools/ approaches depending on the context? Or, do you have high and low budget options?

Key Findings

Literature review

Hierarchy of lines of evidence

To determine what is the best information to support decision-making first requires evaluation of the evidence used to support the decision. Work undertaken by Pullin and Knight (2003) provides a useful hierarchy of quality of evidence to support decision-making in conservation:

1. Strong evidence obtained from at least one properly designed; randomised controlled trial of appropriate size.
2. Evidence from well-designed controlled trials without randomisation.
3. Evidence from a comparison of differences between sites with and without (controls) a desired species or community.

4. Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
5. Judgements of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees (note after Pullin and Knight (2003), best practise approaches to expert elicitation using IDEA protocol have been developed (See Hemming *et al*, 2018).
6. Evidence inadequate owing to problems of methodology e.g. sample size, length or comprehensiveness of monitoring or, conflicts of evidence.

These steps help planners to address the lack of evidence rather than simply carrying on with the status quo. This hierarchy of evidence is most suited to where the fact of the matter is desired and recommends a properly designed study is preferable to expert judgement. However, where shorter term solutions are needed, expert judgement can be useful as an interim approach and later validated with field studies. For example, it will take many years to sample all the elements deemed important to influence species' persistence (rainfall, predation, interactions with various aspects of fire regime) so expert judgement has merit in providing information to help guide decisions in the shorter term.

Within this hierarchy requires elicitation of tolerance to uncertainty. In most cases scientific convention assumes 95% confidence in models is sufficient (e.g. this is commonly reported as statistically significant effect). However, decision makers may vary in their tolerance to model uncertainty and this risk tolerance needs elicited to ensure appropriate models can be developed. Further considerations in interpretation and application of confidence intervals (including ecological versus statistical significance) is summarised in Fidler *et al.* (2018).

Common problems with performance measures

To analyse a decision, we need a set of objectives and alternative ways to meet those objectives. We also need to measure each objective, so that we can evaluate the consequences of alternative management strategies, to support making value trade-offs between achieving relatively more or less on different objectives (Keeney and Gregory 2005). A performance measure—also known as an attribute, criterion or metric—is the way we measure objectives. For example, for the objective “Minimise decline in the persistence of all plant and animal species”, one performance measure could be the ‘proportion of significantly impacted faunal and flora species (where ‘significantly impacted’ refers to a specific decline, x %, in relative abundance, occupancy, or extent).

There are different types of performance measures: natural attributes, constructed attributes (e.g. a scale or index, like GMA), and proxy attributes (e.g. TFI) (Keeney, 1992). Ideally, a performance measure will have the following five properties, as outlined in Keeney and Gregory 2005. Performance measures should be:

1. **Unambiguous**—A clear relationship exists between consequences and descriptions of consequences using the performance measure.
2. **Comprehensive**—The performance measure levels cover the range of possible consequences for the corresponding objective, and value judgments implicit in the performance measure are reasonable.
3. **Direct**—The performance measure levels directly describe the consequences of interest.
4. **Operational**—In practice, information to describe consequences can be obtained and value trade-offs can reasonably be made.
5. **Understandable**—Consequences and value trade-offs made using the performance measure can readily be understood and clearly communicated.

Clearly, using a natural and direct measure is ideal to adequately represent the objective (Gregory *et al* 2012), but the use of proxies and constructed scales is sometimes necessary when a performance measure is multifaceted or difficult to measure, or data is unavailable. However, stakeholders have recognised that some of the current performance measures are not adequate for use in decision-making, in that:

- the current measures do not always directly measure the objectives or are insensitive to bushfire management interventions (i.e. are proxy measures). An example is the use of tolerable fire intervals to represent the localised declines or losses of species that are most sensitive to fire because of too-frequent or infrequent fires.

- There are difficulties in communicating meaningful outcomes of management fuel management strategies on ecological objectives to decision makers and other stakeholders. An example is the use of the geometric mean abundance, an index, to represent ecosystem resilience, when stakeholders are not familiar with these concepts.

What types of uncertainty may be present in data?

As well as issues with performance measures, there can also be issues with uncertainty around the data and the models used to calculate the performance measures. Researchers (Regan *et al* 2002) have classified uncertainty into two broad categories—epistemic and linguistic uncertainty—and several subcategories (We do this to frame the issues in a broader context of uncertainty to guide some of the proposed solutions to current issues and provide a template for when new problems are identified in the future.). It is apparent that these different types of uncertainty are relevant to the various issues associated with the data and performance measures. For example, one of the common issues raised with data is a function of epistemic uncertainty, where the accuracy of expert judgement is in question because uncertainty is not specified, and the expert (subjective) judgement has not been validated. In [Table 2](#) we summarise many (but not all) of the issues with performance measure or data in relation to these different forms of uncertainty along with some of the issues with performance measures. We do this to frame the issues in a broader context of uncertainty to guide some of the proposed solutions to current issues and provide a template for when new problems are identified in the future.

Table 1: A summary of the different types of uncertainty and general solutions to address

Problem Type	Examples	Potential solutions
Epistemic uncertainty	Arises due to incomplete knowledge. There is a fact of the matter, but the true value is not known with accuracy or precision.	
Measurement error	Results from imperfections in measuring equipment and observational techniques and includes operator error and instrument error	Increase measurements. Statistical techniques, confidence and credible intervals
Systematic error	The result of bias in the measuring equipment or the sampling procedure. It is formally defined as the difference between the true value of the quantity of interest and the value to which the mean of the measurements converges as sample sizes increase. Unlike measurement error, it is not (apparently) random and, therefore, measurements subject to systematic error alone do not vary about a true value.	Recognise the bias and remove it
Natural variation	The fluctuation in the parameter due to environmental factors. This occurs in systems that change (with respect to time, space, or other variables) in ways that are difficult to predict. Inherent randomness in a system occurs not because of our limited understanding of the driving processes and patterns, but because the system is, in principle, irreducible to a deterministic one.	Probability distributions, intervals
Model uncertainty	A result of our representations of physical and biological systems. Models may be based on diagrams, flow charts, mathematical representations, computer simulations, and many others. Model uncertainty arises in two main ways. First, usually only variables and processes that are regarded as relevant and prominent for the purpose at hand are featured in the model. The second way model uncertainty arises is in the way constructs are used to represent observed processes.	Validation, revision of theory based on observations, model averaging
Subjective judgement	Uncertainty due to subjective judgment occurs as a result of interpretation of data. This is especially the case when data are scarce and error prone.	Validate or replace with empirical estimates. Structured elicitation methods. Subjective probabilities and degrees of belief
Linguistic uncertainty	Linguistic uncertainty results from our use of language and can be classified into five distinct types: (1) Vagueness (2) Context dependence (3) Ambiguity (4) Indeterminacy of theoretical terms and (5) Underspecificity. Of these, vagueness is considered the most important for practical purposes.	(1) Thresholds, fuzzy sets (2) Specify context (3) Clarify meaning of ambiguous terms (4) .. (5) Specify all aspects of the subject of interest

A summary of the key issues underpinning the performance measures and data used to calculate the ecological impacts of fire management strategies

Problem Type	Examples	Potential solutions
Incomplete or patchy data: Performance measure is not comprehensive Epistemic uncertainty: Incomplete knowledge and potentially systematic errors	Data collection skewed to some species (mainly birds, mammals, flora) Data collection skewed to some EFGs/ regions	Short-term: Identify key species/areas and elicit data using IDEA protocol (Hemming <i>et al</i> 2018) Long-term: Collect data and update expert judgement
Data/ expert judgement doesn't specify uncertainty around the estimate, or confidence level Epistemic uncertainty: Subjective judgement	Estimates of relative abundance are largely point estimates in each growth stage with no understanding of the reliability or confidence the expert has in their judgements.	Short-term: Elicit data using IDEA protocol (Hemming <i>et al</i> 2018) Long-term: Collect data and update expert judgement
Epistemic uncertainty: Model uncertainty	There is inherent uncertainty in the choice of habitat distribution model and the environmental variables that are used as predictors in the habitat distribution model	Short-term: Document model selection and conceptual model(s) underpinning predictor selection. Short/mid-term: Identify competing conceptual models (expert judgement) Long-term: Evaluate competing conceptual models (field)
Performance measure is ambiguous Epistemic uncertainty: Model uncertainty	Lack of clarity in relationship between time since fire and species response (i.e. maybe other elements of fire regime, or environmental predictors that explain species response).	See Problem 1 below
Performance measure is ambiguous Linguistic uncertainty: Ambiguity, vagueness	Estimates of relative abundance were not elicited in a structured process so may also reflect many linguistic uncertainties	Short-term: Elicit data using IDEA protocol (Hemming <i>et al</i> 2018) Long-term: Collect data and update expert judgement
Epistemic uncertainty: Measurement error	Monitoring data has not been calibrated with respect to the different survey methods/ data collection e.g. Field data collected using various methods, not calibrated (i.e. pitfall vs Elliot traps vs etc.); Expert and field data not calibrated	Short-term: Search literature for how to calibrate different data types Short-term: Ask experts to calibrate data Short-term: Partition analysis to only use single or calibrated survey techniques Long-term: Undertake field calibration See Problem 2 below
The performance measure is indirect Epistemic uncertainty: Model uncertainty	Assumption that probability of occurrence as a function of time since last fire translates to relative abundance in different successional growth stage structures has not been tested. Survey methods do not provide a direct measure of abundance (e.g. camera traps).	Short-term: Assume occupancy = abundance Short-term: Only use occupancy if species is rare Short-term: Search literature to address problem Long-term: Investigate assumptions (field) and use different survey technique, if necessary

Problem Type	Examples	Potential solutions
Incomplete or patchy data: The performance measure is not comprehensive Epistemic uncertainty: Systematic or Measurement error	No true absence data collected	Short-term: Camera data can be used to infer information about absence Short/mid-term: Test: 20 min / 2 ha counts data can be used to infer information about absence Short/mid-term: Generate species list for each survey point using HDMs. Then, if not detected assume absent Long-term: Test assumptions (field)
No data to calculate performance measures Epistemic uncertainty: from incomplete knowledge	Expert or field data available, but not in accessible format	Short-term: Model field collected data where necessary Short/mid-term: Insert field data in Victorian Bushfire Monitoring Program database to accept modelled values and confidence intervals
Measure may be ambiguous, not understandable, or operational Epistemic uncertainty: Model uncertainty	Geometric Mean Abundance (GMA): Several studies have evaluated the properties of GMA and while it meets certain aspects of ecological resilience in principle, whether other metrics and models are more suitable is not known. This will depend on how resilience is defined, how the different metrics capture that definition, and how robust they are to uncertainty (e.g. Giljohann <i>et al.</i> 2015) Tolerable Fire Intervals (TFI) are intended to capture the needs of the most fire sensitive flora species by specifying intervals that will enable them to survive. As part of an adaptive management approach these intervals were adopted as part of DELWPs ecosystem resilience measures to help maintain the structure, function and composition of ecosystems. Studies have shown that many attributes are not accommodated by the current TFI intervals.	Long-term: investigate how different resilience metrics capture the stated definition, and how robust they are to uncertainty

In consultation with the policy leads and workshop participants, we decided to focus on outlining solutions for three of the issues above:

1. Model Uncertainty: lack of clarity between Time Since Fire (TSF) and species response
2. Subjective Judgement: How to evaluate and integrate expert field data
3. How do you evaluate a good metric?

A process for exploring and resolving each of the issues is provided below.

Problem 1 Model uncertainty: lack of clarity between time since fire and species response

Question 1: How would you explore if this is a problem?

1.1 What type of fire management knowledge gap or uncertainty is this? i.e. give us some details in relation to Strategic Bushfire Management Planning

Time Since Fire (TSF) is the sole measure of fire regime, but there are problems with this. Firstly, only three Ecological Fire Groups (EFG's) in Victoria (Mallee, heathland and grasslands) where TSF explains a large proportion of species' responses to fire. In other EFGs TSF is not a good predictor of species responses because fires tend to occur at lower severities and site-specific factors are more influential. Other limitations of TSF as sole predictor of species responses include:

- Lack of consideration of fire intensity, extent, seasonality, frequency, patchiness
- Site specific interactions (e.g. hollow-bearing trees, climate) and other drivers of species distributions and abundance
- Other broader interactions such as climate and predation

This results in estimates of species responses that are only weakly predicted by TSF. Predictions include large error bounds around relative abundance of species, which makes decision-making tricky *and* this underpins all current GMA metrics. One example is the model for Mallee emu-wren which does not have all those interactions in the model.

1.2 What is the problem with the measure (e.g. non-direct)

It's not comprehensive:

- TSF doesn't include other interactions
- Species Distribution Models (SDM) and GMA only showing species that have sensitive responses e.g. KFRS
- No spatial variation with TSF
- Technical constraints (e.g. data management and methods for standardised analyses) have hindered the use of field data resulting in high dependence on expert-elicited data

But it **is** understandable - that's why people use TSF so often!

1.3 What is the source of the uncertainty (e.g. measurement etc.)

Model uncertainty – field data has shown that TSF isn't a good predictor for all species in all EFGs, particularly forested EFGs (Leonard *et al* 2016).

Question 2: How would you explore and resolve the problem?

2.1 Draw the process out to resolve the problem (and explore if necessary). Any alternative approaches? i.e. would you apply different tools/ approaches depending on the context? Or, do you have high and low budget options?

Explore: how do you know it's a problem?

- When models do not give you any useful resolution e.g. species show no difference whether it is 5 or 100 years since fire (i.e. species appear to be insensitive to TSF), when you know or believe they are sensitive to fire.
- Risk analysts have lost trust in the TSF model outcome because (i) they have local knowledge and observation of system; and /or (ii) field data that shows other factors are more influential.
- It is challenging to explore this issue (i.e. with data) because there are not enough replicates in the environment of all features of the fire regime (severity, TSF, interval, patchiness etc).

Resolve: how would you resolve this issue?

1. Identify critical knowledge needs using the process outlined below.
2. Improve the process of validating the TSF model: build this into the workflow for updating data in Victorian Bushfire Monitoring Program (VBMP) database
3. Identify key fire attributes in different EFGs (and/or for different species) that you need to collect data about. These are the conceptual models that represent hypotheses about EFG/species responses to fire regimes and can help here to stratify sampling. Consult multiple experts (i.e. regional staff, other ecologists etc), to explore whether there are competing models that need to be explored. In this workshop the key areas for investigation include effects of fire severity, extent, season, frequency patchiness and interactions but further discussion is needed to prioritise these.
4. Identify *critical* model needs: e.g. For a certain species, learn what aspect, within the regime, you need to know about. The aspects should be evident from the conceptual models developed in above step (3)
5. Sensitivity analysis (sensitivity to TSF): identify for the different EFGs/ regions, then monitor species responses following fire.
6. Use data to develop the species distribution models, species trajectory, GMA, and the effect of fire management

How well does your process perform? What are the benefits and limitations (e.g. in terms of time, money, precision, accuracy, comprehensiveness, evidence-based decision-making, reputation, etc.) Do you need to explore this first, or assume it's a problem for decision-making?

1. DELWP is investing in fire severity mapping so the mapping will improve with time.
2. Monitoring program is supposed to provide this information (to validate the TSF model) but we need quality data (see section above "Hierarchy of lines of evidence"). The Victoria Bushfire Monitoring Database has been developed to address current data accessibility and storage issues. The next step is to deal with how to combine expert judgment and field data (but see Problem 2). Also, whilst DELWP has standardised operating procedures for field surveys, there is still the issue of how to calibrate data that comes from different sources (from Elliot trap, camera, etc, different survey types – Table 2). There are also detection issues for rare species, and comprehensive (field) abundance data is lacking. It is acknowledged that field data is costly, and expert data is required in the meantime.
3. Collecting field data is expensive and takes a long time. Also, there is a risk data collection goes too far (i.e. overkill), which is why a sensitivity analysis is crucial.
4. Expert judgement provides the conceptual models which help identify the relevant factors within the fire regimes (i.e. targeted sampling). Recognition that there may be different and/or competing models for different species or regions which can be tested.
5. The participatory approach to building and testing models with multiple experts is good for buy-in. High staff turn-over can cause issues in terms of getting people on board with the process, but this works to develop a culture of cooperation.
6. Use expert elicitation until field data is collected (and integrated), using a structured approach to incorporate uncertainty (i.e. IDEA protocol; Hemming *et al* 2018)
7. This approach is already underway at DELWP, but there are questions about data accuracy. For instance, the power to detect species we care about (rare and threatened) is difficult, so space for time substitution doesn't work well. There is the possibility of exploring a trait-based analysis, to look at the response of species with similar traits. This still requires lots of data.

Summary: Model uncertainty – lack of clarity between TSF and species responses

Already happening:

- Fire severity mapping
- Vic Ecosystem Resilience Monitoring Program (2200 sites comprising 200 in each of 11 EFG's)
- Standardised Operating Procedures (SOP) for field surveys / monitoring
- Vic Bushfire Monitoring Database

Low-hanging fruit

- Make SOP available on DELWP website and communicate to other agencies and research institutions collecting relevant data
- Include regional data in Victoria Bushfire Monitoring Database (need guidelines for this – how to incorporate different datasets, including historical data). This work is underway and planned to be business as usual by late 2019.

Medium-term

- Identify model sensitivity (build fully deterministic conceptual model) *then* tweak parameters
- Expert elicitation (including PBBOs) to identify key habitat attributes and environmental variables such as rainfall and topographic position for each EFG
- Develop state and transition models for EFGs

Longer term

- Incorporate improved knowledge from VERMP (part of Victorian Biodiversity Monitoring Program)
- Build species-level models with better data, including interactions between the fire regime, environmental co-variates, and other management actions.

Problem 2 How to evaluate and integrate expert field data subjective Judgement

What's the problem?

What type of fire management knowledge gap or uncertainty is this? i.e. give us some details in relation to Strategic Bushfire Management Planning

Expert data is currently used to develop measures of relative abundance. The expert data was collected for a different purpose (i.e. to provide a qualitative / conceptual view of how species' respond to fire), so the data is not at the relevant spatial or temporal scale for this decision context. In addition, few experts were consulted, and the data was not collected in a structured way, so there are potentially issues of overconfidence and linguistic ambiguity in the data. Many of the species do not have uncertainty bounds specified. Given the above issues, there are trust issues with the data, because users are not always confident the data is accurate or precise. A long-term program of field collection is underway, and though many have higher confidence in this data, there are still issues in terms of spatial and temporal coverage and replication. A new issue arises – should the two data sources integrated, and how?

What is the problem with the measure (e.g. non-direct)

Issues around ambiguity and comprehensiveness

What is the source of the uncertainty (e.g. measurement etc.)

Measurement error, linguistic ambiguity

How would you explore and resolve the problem?

2.1 Draw the process out to resolve the problem (and explore if necessary). Any alternative approaches? i.e. would you apply different tools/ approaches depending on the context? Or, do you have high and low budget options?

Options:

- A. Gold standard: The long-term solution, where the entire process is fully funded.

- B. Funds are allocated in a piecemeal way (i.e. only parts of the problem can be tackled at any one time, with next steps dependent on ongoing funding).

A. Gold standard (well-funded, long-term solution)

1. What are the concerns with the data? A form of sensitivity analysis

Evaluate inputs, across EFGs and taxa.

- a. First, focus on regions where you know confidence or trust in the expert data is poor (i.e. data is insensitive, despite evidence or contrary belief), or where field data is not available, or where you know that the relative abundance data is influential in driving decision-making.
 - b. Identify regions which are not clearly driven by either Time Since Fire (GSS) or existing habitat models (SDMs) (e.g. many foothills EFGs may be more sensitive to other aspects of fire regime)
2. Clarify how expert data was collected with users (i.e. attempt to deal with the miscommunication issue)
3. Re-do expert elicitation, guided by sensitivity analysis (1)

- a. Develop conceptual models (hypotheses) using multiple experts (as per Problem 1), and investigate whether there is a:
 - b. A consensus model i.e. everyone is on the same page, or
 - c. There are different (competing) causal models e.g. experts can't agree
 - d. Note, conceptual models relate to the key drivers of species abundance in space and time (i.e. fire, climate, predators etc). These could be developed for trait groups (i.e. general models) and then evaluated (parameterised) with regard to spatial context.
 - e. Undertake a structured expert elicitation process (IDEA protocol – *Identify Discuss Evaluate Aggregate*, Hemming *et al* 2018).
 - i. Using the models, develop a series of questions to underpin the IDEA protocol (Hemming *et al* 2018). Ensure questions relate to eliciting species trajectories.
 - ii. Ask calibration questions of multiple experts (i.e. to explore accuracy and precision of individuals)
 - iii. Implement IDEA Protocol and aggregate group averages for decision analysis.
4. Integrate field data with expert data
- a. Update data over time using Bayesian updating approaches
 - b. Document assumptions: infer to areas with data gaps: use space for time and use experts to validate.

5. Do you need more field data? Validate and calibrate expert data with field data

Note, this really should be also attempted prior to re-eliciting the expert judgement (3), but with the original expert data. It is important to note that the conceptual modelling step is required here, because both data sets (field and expert) could be flawed. The options are to:

- a. Do a sensitivity to uncertainty analysis (i.e. add bounds to data, as per case study in MacHunter *et al* 2016, page 25)
 - b. Add bounds to data, by revisiting experts (for example)
6. Evaluate decisions (i.e. choice of strategies), using all data types
- a. Use field data only

- b. Use expert only (weighted)
- c. Use integrated data – Bayesian updated

B. Shorter-term (piece meal funding). This is more of an exploration of the scale of the problem, but only for a couple of species.

Steps 1 and 2, as per above

1. Do you need more field data? Validate and calibrate expert data with field data

The options are to:

- a. Do a sensitivity to uncertainty analysis (i.e. add bounds to data, as per case study in MacHunter *et al* 2016, page 25)
 - b. Add bounds to data, by revisiting experts (for example)
2. Additional option if funding permits: Elicit new data using IDEA protocol, for upcoming season (to get feedback), and for a variety of scenarios that vary in threats/drivers, to interrogate with past data.
 3. Demonstrate Bayesian updating

It is also possible to explore the problem first, and demonstrate the gold standard approach, but just using a couple of case study species. For example:

1. Choose a fire sensitive common/widespread species and a species that is more restricted in number/location, both of which have TFI expert data, long-term data, and also have future data planned for collection.
2. (3a) Develop conceptual models – what are the drivers for this species (e.g. climate, cats, fire etc). Interrogate the field data in relation to the conceptual model i.e. did it cover a variety of the drivers?
3. Do you need more field data? Validate and calibrate expert data with field data. The options are to:
 - a. Do a sensitivity to uncertainty analysis (i.e. add bounds to data, as per case study in MacHunter *et al* 2016, page 25)
 - b. Add bounds to data, by revisiting experts (for example)
4. Additional option if funding permits: Elicit new data using IDEA protocol, for upcoming season (to get feedback), and for a variety of scenarios that vary in threats/drivers, to interrogate with past data.
5. Demonstrate Bayesian updating method.

How well does your process perform? What are the benefits and limitations (e.g. in terms of time, money, precision, accuracy, comprehensiveness, evidence-based decision-making, reputation, etc.) Do you need to explore this first, or assume it's a problem for decision-making?

The gold standard approach works really well for both exploring and resolving the problem. It's potentially expensive but provides a longer-term solution, and the first sensitivity analysis should be used to target efforts. One of the issues might be cognitive burden on the experts (where they are required to estimate the effect of numerous scenarios/factors), which is why it could be useful to explore whether the decision is sensitive to uncertainty in a particular parameter before proceeding with expert elicitation. A participatory approach to eliciting information from experts might help with trust issues with the data and facilitate sharing of data and knowledge.

Problem 3 How do you evaluate a good metric

Question1: What's the problem?

1.1 What type of fire management knowledge gap or uncertainty is this? i.e. give us some details in relation to Strategic Bushfire Management Planning

There are different cause and effect models underpinning the performance measures. That is, experts have a different perception of what the metrics mean, or the performance measures are proxies (non-direct) measures of the objective. These are both a form of model uncertainty (epistemic uncertainty) e.g. we care about plants, animals and ecosystems but use TFI and / or relative abundance and / or GMA as a proxy / performance measure.

1.2 What is the problem with the measure (e.g. non-direct)

- Model is not direct
- Different cause and effect models underpin GMA and TFI
- Potentially double counting e.g. we do not yet know how to combine two performance measures together e.g. GMA and TFI

1.3 What is the source of the uncertainty (e.g. measurement etc.)

- Model uncertainty

Question 2: How would you explore and resolve it?

2.1 Draw the process out to resolve the problem (and explore if necessary). Any alternative approaches? i.e. would you apply different tools/ approaches depending on the context? Or, do you have high and low budget options?

- Combine various models
 - e.g. TFI and GMA into one super model as otherwise we are potentially trading off between models.
 - Use pareto optimisation (Driscoll, et al. 2016). This would enable units of GMA and TFI to be comparable. But would need to elicit judgements of how much we care about GMA and TFI (which is potentially making trade-offs prior to the evaluation of consequences?).
- Explore alternative approaches / performance measures
 - e.g. IUCN Redlist weighted mean of number of individuals in each threat / status class (and it is worth exploring whether University of Queensland researchers are doing work on this for Australian species). This approach would address concerns about the oversimplification of TSF as the main cause of population changes (ignoring other aspects of fire regime, climate and predation etc.). Also, can use different lines of evidence in IUCN for projected changes in abundance / occupancy e.g. PVA, Abd of mature individuals, trends, area of occupancy (e.g. TFI sensitive species), combination or data deficient. Choose the result with biggest declines if more than one line of evidence.
- To test some of these metrics we could conduct a retrospective study where we know the fate of the species prior to the decline and test the performance of the metric to detect these declines (see Keith *et al*, 2004)
 - Model hypothetical species where you know the truth and include uncertainty and see how well metrics were able to cope with uncertainty that was used to do the assessment (Rueda-cediel *et al*, 2015)
 - Credibility – weight probability into occupancy and abundance
 - But IUCN loses information through categorisation into threat classes, i.e. the information could still be extracted but IUCN categorisation means that you don't know if a species is very close to the upper or lower end of the boundary of a threat category.

- Use a trait-based approach to decide which species most need data for IUCN assessment. Investigated trade-off between time to collect data and full IUCN assessment or machine learning approach (Bland *et al* 2017).

How well does your process perform? What are the benefits and limitations (e.g. in terms of time, money, precision, accuracy, comprehensiveness, evidence-based decision-making, reputation, etc.) Do you need to explore this first, or assume it's a problem for decision-making?

- IUCN categories
 - in terms of precision the IUCN approach has wide bounds on extinction risk categories. See published literature on this but complex to apply in practice (so maybe not feasible in shorter term).
 - Time: likely to be more than 6 months to explore feasibility of IUCN approach
 - Accuracy: different lines of evidence so can explore consistency between different approach
 - Comprehensiveness: many species likely to be data deficit
 - Reputation: likely to be improved as used as IUCN is used internationally
 - Evidence based: yes – uses well established methods
- Combining TFI and GMA
 - Precision
 - Time: discrete piece of work to develop method (< 6months)
 - Accuracy: building performance measure through combining other performance measure so will be difficult to unpack this clearly
 - Comprehensive: quite good as taking into account both flora and fauna
 - Reputation: not sure this approach will have community / risk analyst support
 - Evidence based: not sure

Do you need to explore this first, or assume it's a problem for decision-making?

There is a need to explore what is or isn't working e.g. GMA is good for trend tracking and has good theoretic and some field observations to support its application, but it doesn't have broad appeal for decision-making. Alternatively, GMA issues could be considered an implementation problem, which largely stems for data inputs and other factors such as lack of consideration of interactions (see discussion in Problem 1 around interactions from other elements of fire regime, climate change etc.). This requires further consultation with those using GMA (i.e. PBBO's and their stakeholders)

Summary: A Process map

The following decision tree (Figure 2) was constructed as a summary of the different issues outlined in this report, and a guide for the different solutions suggested. This draws on previous workshops with project team and DELWP collaborators (Table 2) which explored issues with performance measure or data.

The process map is not designed to provide a comprehensive set of solutions. Rather, we have provided some solutions in detail (Problems 1-3) and others briefly (Table 2). Where new problems are identified in the future we recommend identification of the problem type and general treatments (see Table 1).

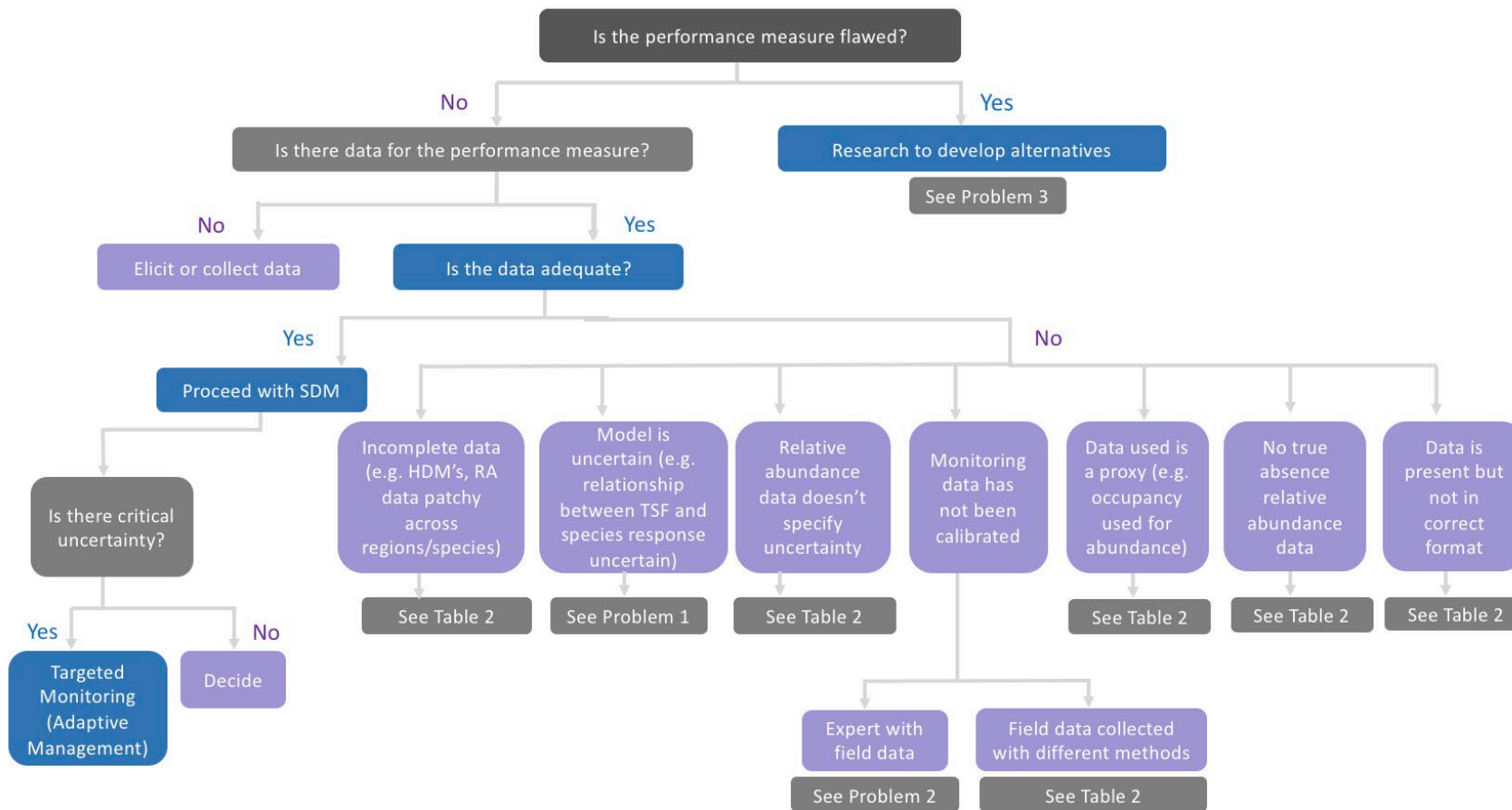


Figure 2: Process map. Note, that this process map has been updated in preparation for publication, and is included for reference in Figure 6.

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Appendix D Output 7: Supporting documentation

Fire Analysis Module for Ecological values



Version control

Version	Author	Changes	Date
V0.5	N. Amos	First draft	8/4/2019
V0.9	J. MacHunter	Review and minor edits	10/4/2019
V0.99	J. MacHunter	Added GSO documentation from inputs doc	17/4/2019
V1.0	N. Amos	Appendix added with inputs and outputs and revision from previous comments addressed	23/04/2019
V1.01	N. Amos	Minor update to reflect changes to TFI outputs following training workshop and addition of shutdown utility	9/05/2019

User Manual

Glossary

TFI – Tolerable Fire Interval
BBTFI – Burnt Below Tolerable Fire Interval
EFG – Ecological Fire Group
HDM – Habitat Distribution Model
GSO – Growth Stage Optimisation
GUI – Graphical User Interface

Introduction

This software provides a Fire Analysis Module for Ecological values (henceforth FAME). The body of this manual should be read in conjunction Appendix 1 which provides details on the structure of the input and output files required by the module, and the values calculated in the outputs.

The module allows for the spatial analysis of fire sequence information from an input file of individually dated fire footprints. This data is analysed in conjunction with fauna habitat distribution models (HDM) and vegetation maps of Ecological Fire Groups (EFG sensu Cheal 2010) of vegetation (and associated lookup tables) to allow calculation of the metrics to evaluate the impacts of fire on ecological values (Table 2, ERP 1 Final Report, p12). At this stage FAME is scripted to provide Tolerable Fire Interval status of vegetation, and changes in modelled abundance of vertebrate fauna species. The conceptual basis and method for evaluating flora species requires further investigation before it will be possible to incorporate into FAME (ERP 1 Final Report, p16).

The module also incorporates the aspatial vegetation growth stage optimisation (GSO) tool, written in R, that extended scripts developed by Sitters et al. (2018) and then subsequently revised by Paul Moloney at ARI which enabled greater flexibility in decision rules regarding input data for species responses to fire (Porigneaux et al. 2017).

FAME provides a Graphical User Interface (GUI) via a web browser which connects to a server where the analysis occurs. FAME facilitates exploration of fire scenario options for users with minimal experience with command line or script-based analyses.

Workflow

The workflow consists of six stages. The preparatory stage occurs on a local desktop computer and next four stages on the remote server. The final stage occurs involves both the remote server and a local desktop computer. A brief overview of each stage is provided below followed by more detailed instructions in the following sections.

1. Data preparation
 - Collate input files and save to desktop computer
 - Combine the future fire scenario with past fire history and clip the data to the region of interest. This process is undertaken on a local desktop computer in ArcMap v10.3 (or later version).
 - Upload this dataset to the FAME server.
2. Fire sequence analysis in FAME
 - Carry out fire history analysis on the server
3. Fauna relative abundance (RA) following fire: and.
 - Combine the fire scenario outputs from stage one, vegetation mapping (EFG), species' habitat distribution models (HDMs) for vertebrate fauna and lookup tables of the predicted effect time since fire and EFG on the relative abundance of each species (within the area identified as its potential range by the HDM).
4. Tolerable fire interval (TFI) analysis.
 - Combine the fire scenario outputs from stage one with vegetation mapping and TFI values for the EFGs (Cheal 2010) to output summaries, and if desired raster maps of the annual status of vegetation age relative to TFI.
 - Identify those areas where there are inter-fire intervals that have and /or will result in an area being Burned Below TFI (BBTFI) one or more times.
5. Aspatial Growth Stage Optimisation for Fauna Species.

- A separate process provides for aspatial optimisation for determining the ideal distribution of growth stages for EFGs in a defined area that will maximise the Geometric Mean Abundance (GMA) of species. This is determined by the lookup of species' relative abundance with growth stage and EFG, and a list of species occurring in the area of interest.


6. Down results of FAME

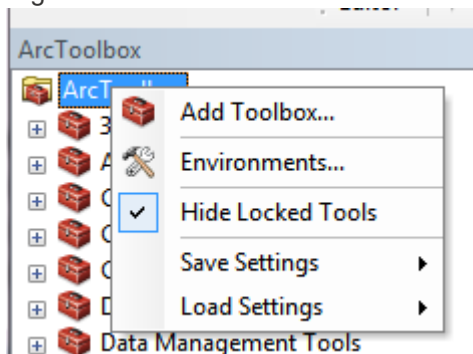
Stage one: Data preparation

Setting up files on your local desktop PC

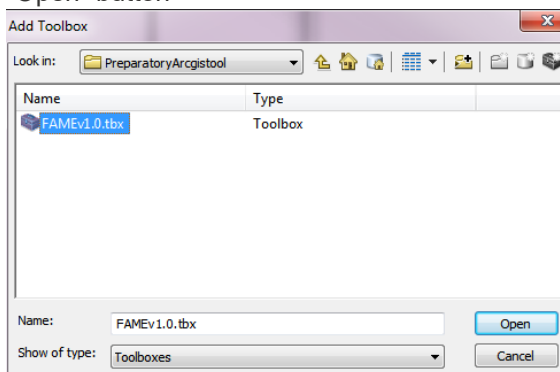
- Generate a folder for input files on your local desktop PC
- Save and prepare FireScenario which is the fire scenario shapefile formatted as described in the Appendix 1.
- Decide on the area of analysis. You should select a polygon that is as small as possible given your area of interest for the analysis as this will speed all further processing steps. The default options are the FFR regions in the LF_DISTRICT layer in the CGDL database. A local copy of this is made for use in the tool and called LF_REGIONS.shp. The polygon(s) for the FFR regions should be selected from this file. If you wish to select a different area of interest, then an ad-hoc polygon shapefile must be generated and saved locally.
- Fire History should be accessed via most recent version on CDSL or document alternative fire history data including relevant metadata (if that is used).
- Save relevant files on PC according to formats specified in the document Appendix 1

Initial setup in ARCGIS (the following steps a-e only need to occur once)

- Open ArcMap on your computer.
- Click the toolbox icon  on the ribbon to open the toolbox window.
- Right click on "ArcToolbox" and select "Add Toolbox"



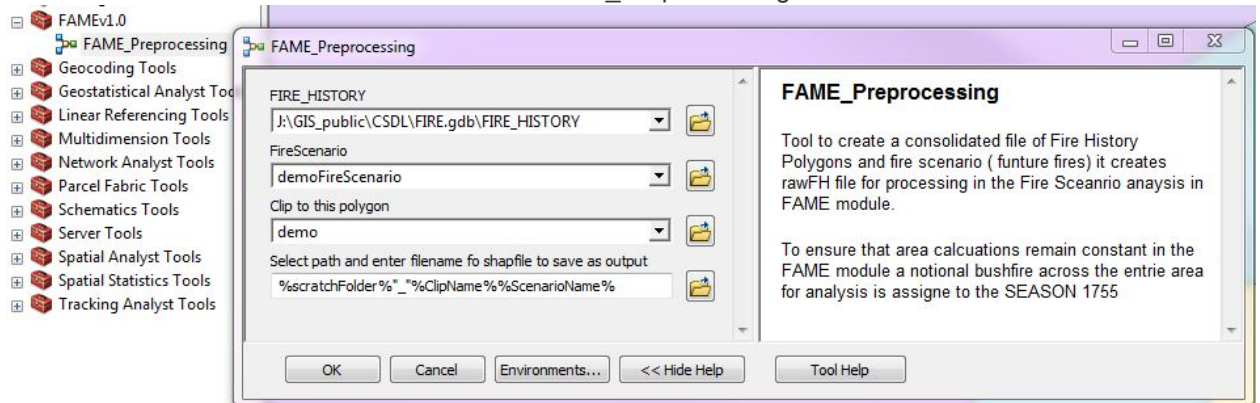
- Navigate to the location where you have the FAME toolbox saved, select the toolbox and click the "Open" button



- This will add the toolbox to your project. Save the project file. This file can then be opened in future when you need to pre process fire scenarios for FAME.

Preprocessing fire scenarios

- a. Click on the FAME toolbox then double click on “FAME_Preprocessing”



- b. The resulting dialog box requires 4 inputs
- FIRE_HISTORY: this will generally be the current corporate fire history layer, it can be selected from your normal access point for the corporate library, however if you are doing many iterations of pre-processing step, you may wish to make a local copy to speed the pre-processing read time.
 - FireScenario, the fire scenario shapefile formatted as described in the Appendix 1.
 - A polygon to clip the output file to. You should select a polygon that is as small as possible given your area of interest for the analysis as this will speed all further processing steps. The default options are the LF_REGIONS, which can be selected from LF_REGIONS.shp, which is saved in the same directory as the FAME toolbox. If you wish to select a different area of interest, then an ad-hoc polygon shapefile must be selected.
 - The name and location for the output fire scenario file. Make this filename unique and meaningful to you as this name is used to provide the base name for outputs of the FAME analysis. By default the output file will be given the name of the clip polygon (or just “LF_REGION” if the default regions are used) concatenated with the Fire Scenario Name. It is suggested that you enter a file name following using the following convention Region(name)_LMU(name)_Scenario(number)_version(number).shp
- c. Click the OK button in the dialog box to run the tool.

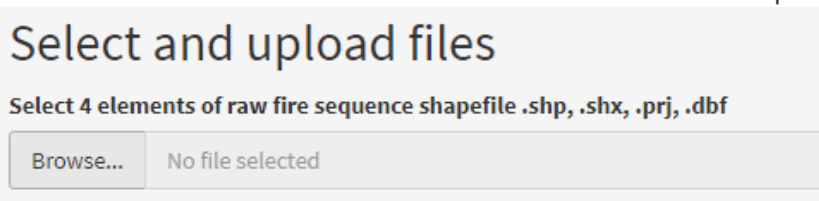
Stage two: Fire sequence analysis in FAME

This analysis provides the unique sequence of fires at any location. It results in a polygon dataset where each polygon has a unique fire sequence which comprises all preceding inter fire intervals and associated fire types (bushfire / planned burn). The analysis also maps time since fire for every year of the analysis into the same polygon dataset. These analyses have consolidated and improved previous approaches using the DELWP tool known as FireHAT.

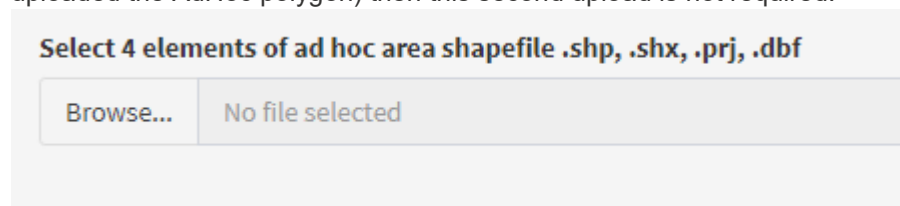
- a. Open the FAME module home page in your web browser (Chrome is preferred, but should work OK with FireFox and ie explorer) current url is: http://13.239.176.47/shiny/rstudio/FAME_1.0/.



- b. Select the utilities tab in the bar on the left of the screen
the Utilities tab provides for upload and download of files from the server, as well as creation of draft species lists and area specific data input files for the aspatial GSO analysis (see below).
- c. Click the Browse... button under “Select 4 elements of raw fire sequence



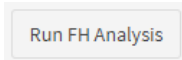
select the four files that comprise the shapefile for the scenario that you created in stage one. If you used an AdHoc shapefile to clip you need to use the second item on this tab to upload that as well. If you are doing an analysis based on LF_Regions, or statewide (or have previously uploaded the AdHoc polygon) then this second upload is not required.

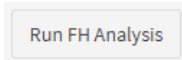


- d. Switch to the “Do fire scenario analysis” tab. Here you need to make several selections before running the Fire Scenario Analysis For all except “Fire scenario shapefile” and “Choose a Region” default values are set. You must therefore select these first two settings and decide whether the default values for the remaining three options are appropriate for your analysis. Purpose of each setting is tabulated below.

Setting name	Purpose	Values
Fire scenario shapefile	The fire sequence (combination of fire history and future fire scenario) to be analysed.	Shapefile produced in the preparatory ARCGIS tool and uploaded to module
Choose a Region	Sets the boundary of the analysis. Analysis should be restricted to only the area of interest to minimise computation time. Usually this boundary should correspond to the clipping boundary used in the ArcGIS preparatory to create the fire sequence for analysis, however the analysis will still run if these boundaries differ (if they overlap each other). Areas outside the clipping of the Fire Scenario will be set to “NA”. If the region chosen is within the Fire Scenario area clipped, the analysis will be restricted to the region chosen.	Whole of State (Default) Ad Hoc polygon (user-provided shapefile in VG94 projection of the boundary of the region of interest) or One of the DELWP Forest and Fire Regions (FFR) "BARWON SOUTH WEST "=1, "GIPPSLAND "=2, "GRAMPIANS "=3, "HUME "=4, "LODDON MALLEE "=5, "PORT PHILLIP "=6,
Raster Resolution	Sets the resolution used for analysis, this is important in determining memory requirements and processing speed. Use of 75m raster increases processing and memory requirements ~10x	225 m (default) 75 m
Restrict Analysis to Public Land	The analysis can be carried out across both public and private land, however	Yes (Default) No

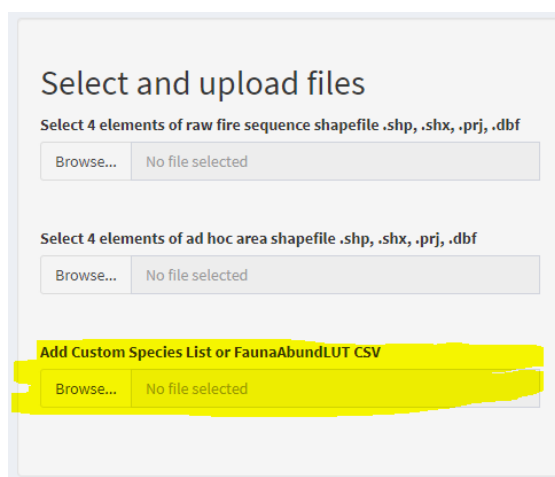
Setting name	Purpose	Values
	fire history is much less complete for private land.	
Other and Unknown fire value	Fire history may contain fires of unknown type, you need to decide how to treat these in the analysis. They may be treated as either a bushfire or a burn, or alternatively areas with an unknow fire type may be treated as “NA” values. If the latter is chosen then TFI status, and relative abundance for the cell cannot be calculated based on that fire.	Bushfire (Default) Burn NA
First season for analysis output	Start the analysis at the first season which may be of interest, this reduces processing time, particularly in the Relative abundance calculations (that loop year by year). Calculations occur for each season from the first chosen to the maximum season value in the fire sequence.	1980 (default) Any season after the first season in the fire sequence file provided



- e. When you are happy with the settings press the  button. A spinner will be displayed while the analysis is undertaken, and an animation of a burning fire will appear to the left of the screen while the server is busy processing your data. Depending on the size of the area, and complexity of the fire scenarios you have chosen this process may take from a few seconds (for a few thousand hectares and a few hundred fires) to an hour or more (for a statewide analysis with ~100,000 fires) to run. A green tick will appear to the right of the button and disappear again after 5 seconds when the processing has completed. FH analysis rdata and shapefiles will be created at the conclusion of the process. The content of the files is described in the outputs document.

Stages three and four: Spatial TFI and Fauna Abundance Calculations

- a. Select the “Fauna abund or TFI for scenario” tab. To run these analyses, you need to use a previously calculated FH analysis, if you are doing this immediate following stge 2 (above), then the FH analysis you have just created will be loaded automatically. If you wish to select a different FH analysis or have prepared the FH analysis previously you will need to select this in the “FH analysis to use” dropdown at the top of the screen. The FH analysis loaded is displayed below this box.
- b. If you wish to use a custom species list or custom relative abundance lookup table the .csv files for these (given unique and identifiable names) must be uploaded before proceeding to the analysis. This is done using the upload custom option on the “Utilities” tab upload box.



Fauna abundance calculations

a. There are four options to select, all have a default value.

Setting name	Purpose	Values
Enter start and end of abundance baseline period	Set the seasons to be used to calculate the baseline relative abundance used to calculate % change from baseline. It can be a single year or a range of years.	Defaults "First season for analysis output". Any value between this and the maximum season in the analysis can be chosen Note the start season for the baseline must be equal to or greater than the default "First season for analysis output". For a single year chose the same value for start and end, for a range select a higher value for the end
Use default or custom species list	The default is to calculate species responses for all species that have relative abundance data, and to plot relative abundances Rasters for all the species that have RA calculated (as an option). Reducing either of these lists to the species of interest in the region only will significantly reduce calculation times and make outputs easier to handle.	Default: Standard species list (all species that have RA data available are calculated whether or not they occur in the region of interest). Alternative values: Uploaded manually edited draft species list produced using the "create draft species" list utility in the app
Use default or custom relative abundance	Where sufficient field data is available the expert opinion data may be replaced with models based on this field data. In other cases, there may be regional variations in responses that are not addressed in the statewide data. Further the current FFO data only addresses treatable EFGs. Ideally as the available curated response data improves the default dataset would be updated to these values	Default relative abundance uses statewide expert opinion data of relative abundance for each growth stage and EFG and firetype available (previously known as the FFO dataset). If custom values are choosing a dropdown box will appear to select the relevant .csv file (which has previously been uploaded to the server).
Make relative abundance rasters	Whether to output individual Species x Season relative abundance rasters. These provide the spatial view of changes in abundance for each taxon through the fire sequence, however they increase the computation time.	No (default for more rapid computation). Yes (if spatial output is desired). You can then select whether you wish to create rasters for all years or only some. If you chose some, then a further dropdown appears where you select the year(s) to create.

b. When you are satisfied with your settings you can run the calculations by pressing the:

Run fauna relative abundance calculations

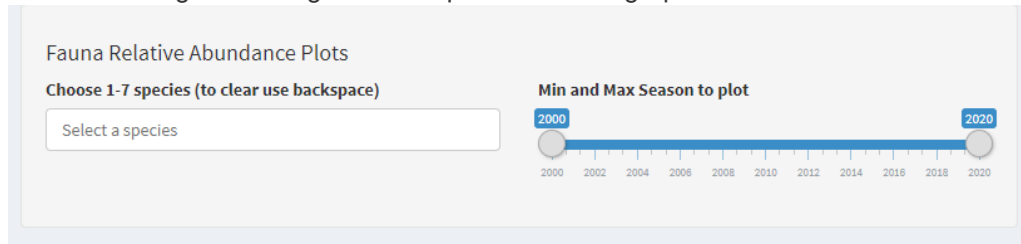
at the bottom left of the tab. **The browser window must be left open while the calculations occur.** When the calculations have completed the app will automatically switch to the "Fauna RA plots" tab.

Note: This is the lengthiest calculation, it will increase in duration with, number of species selected in your list, number of years in the scenario, whether or not rasters are output and increasing size of the area of interest. A run for a few species, for a

small region (e.g. Port Philip) with no raster output may take a few minutes to run at 225m resolution. A run for all available species for the whole state outputting all rasters at 225m resolution will take 4 hours or more. At 75m the speed is approximately 10x longer and is constrained to only a portion of the state by available RAM. The maxima at 75m have not been tested.

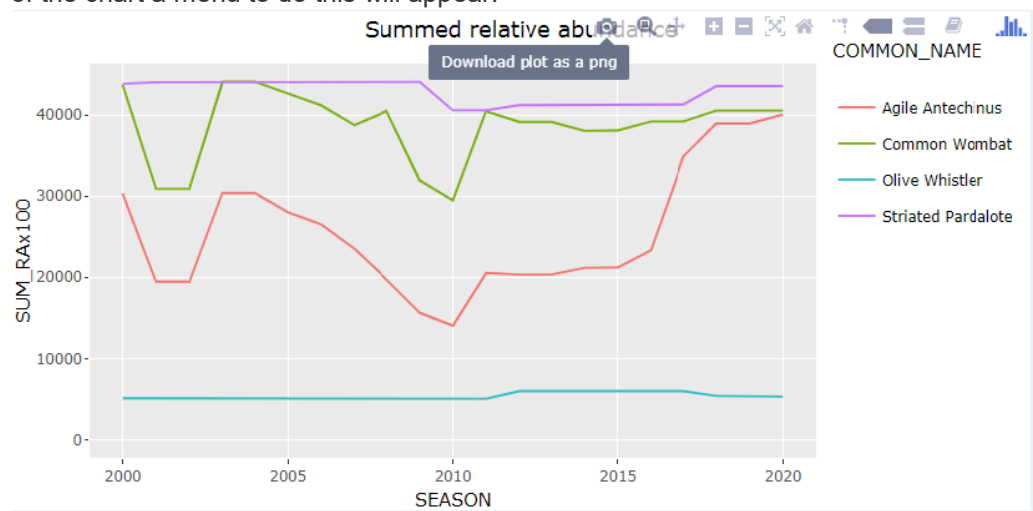
Fauna RA plots

- c. The RA plots widow displays a single plot on which the user can chose to display the summed relative abundance across the region of interest over time for 1-7 species. Initially no taxa are shown. The user must select them from the top left drop down box. The user can also use the slider on the right to change the time period that the graph covers.



Once species have been selected, they are displayed with the legend indicating the name of each selected. To remove a species, use the arrow cursors and bispase in the dropdown box.

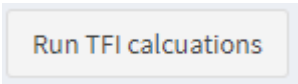
- d. The chart can be copied and downloaded as a .png graphic – if you hover the mouse over the top of the chart a menu to do this will appear:



TFI calculations

- a. A single choice is required before calculating TFI status and BBTFI results. Whether or not to output individual TFI rasters for each SEASON – to do so incurs a small extra computation time. The Two BBTFI raster maps are output automatically.

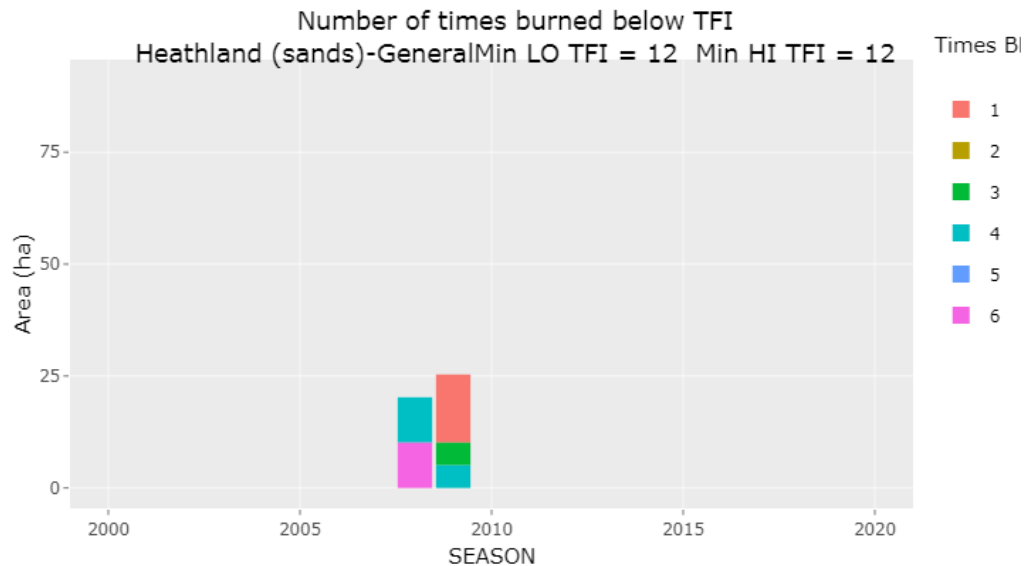
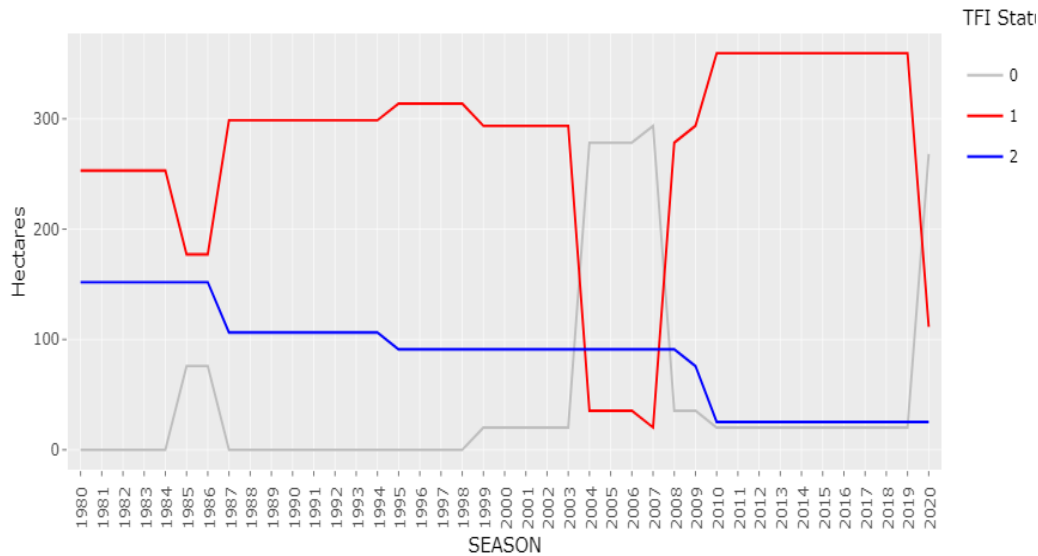
Run TFI calculations

- b. To run the calculations, press the bottom centre button . This calculation may take c considerable time (half an hour or more if a large areas is being calculated – but considerably less time than the corresponding fauna RA calculations. **The browser window must be left open while the calculations occur.** On completion of the calculations the app will automatically switch to the “TFI plots” tab.

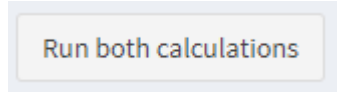
TFI plots

- c. The TFI Plots tab contains two interactive plots, the upper plot displays the area of an EFG within (0), below(1) minimum and above maximum(2) TFI in each SEASON of the analysis, the lower plot displays the area BBTFI, in each SEASON. The EFG and the time period to display are selected using the dropdown and slider at the top of the tab. Only a single EFG may be displayed

at a time.



d. Alternatively, if you want to run both TFI and Abundance calculations select to



on bottom right of the tab. **The browser window must be left open while the calculations occur.** In this case you may need to switch to either of the graphical output tabs for these calculations manually.

Stage five: Growth stage optimisation in Shiny

This document is a guide to using the growth stage optimisation (GSO) tool from the FAME v1.0 shiny app.

File formatting

There are several files that you need to create in Excel to run the GSO in R. Currently these files are in either .csv (comma separated value text files) or Microsoft Excel (.xlsx) formats as noted below. It is desirable that each xlsx worksheet will ultimately be replaced by a corresponding .csv file. This has not been completed in as part of ERP1. They require that you use the same headers and name endings otherwise errors in the code may occur. (the name can be prefixed with individual details of the file, for instance the LMU name),

Please note that **R is case sensitive**. The files should be stored in **./GSOinputs**". This is taken care of by uploading them to the shiny server from the app interface.

The first .csv file required is ends with "Spp_EFG_LMU.csv" which can be generated using the utility in the FAME module on the utilities tab. The file includes the species that might be expected to be found in each EFG within the LMU (and will need manual validation of the species included) it has the form,

	A	B	C	D	E	F
1	COMMONNAME	EFG_NO	EFG_NAME	ha	val	lmu
2	Agile Antechinus	2	Coastal-Woodland	276.0757671	1	1
3	Australasian Bittern	2	Coastal-Woodland	335.5328589	1	1
4	Australasian Gannet	2	Coastal-Woodland	698.7336025	1	1
5	Australasian Grebe	2	Coastal-Woodland	2800.40011	1	1
6	Australasian Pipit	2	Coastal-Woodland	6636.844965	1	1
7	Australasian Shoveler	2	Coastal-Woodland	2640.063383	1	1
8	Australian Bustard	2	Coastal-Woodland	4629.470403	1	1
9	Australian Hobby	2	Coastal-Woodland	6515.520094	1	1
10	Australian Magpie	2	Coastal-Woodland	5102.674173	1	1
11	Australian Pelican	2	Coastal-Woodland	35.04913084	1	1
12	Australian Pratincole	2	Coastal-Woodland	51.7390457	1	1
13	Australian Raven	2	Coastal-Woodland	3579.263168	1	1
14	Australian Shelduck	2	Coastal-Woodland	165.6663107	1	1

The second file required "LMU Area.csv" has the total area of each EFG within the LMU, with its EFG name and number.

	A	B	C
1	EFG_NO	EFG_NAME	Area
2	6	Heathland (sands)-General	10000.00
3	7	Grassy/Heathy Dry Forest	20000.00

The file ending "LMU_Scenarios.csv" has the information about the scenarios to be compared. The "PercLandscape" column is the proportion of that EFG in that GS. Therefore, they need to sum to 1 for an EFG within each scenario. For instance, in EFG 6 in the 2017 (current) scenario the proportions are 0.04, 0.06, 0.42 and 0.48, which add up to 1 (or 100%).

	A	B	C	D	E	F
1	EFG_NO	EFG_NAME	BGS_NAME	BGS_ID	Scenario	PercLandscape
2	6	Heathland (sands)-General	Juvenile	1	2006	0.075204844
3	6	Heathland (sands)-General	Adolescent	2	2006	0.180491625
4	6	Heathland (sands)-General	Mature	3	2006	0.744303531
5	6	Heathland (sands)-General	Old	4	2006	0
6	6	Heathland (sands)-General	Juvenile	1	2017 (current)	0.04
7	6	Heathland (sands)-General	Adolescent	2	2017 (current)	0.06
8	6	Heathland (sands)-General	Mature	3	2017 (current)	0.42
9	6	Heathland (sands)-General	Old	4	2017 (current)	0.48
10	6	Heathland (sands)-General	Juvenile	1	Strategy 1	0.13
11	6	Heathland (sands)-General	Adolescent	2	Strategy 1	0.11
12	6	Heathland (sands)-General	Mature	3	Strategy 1	0.34
13	6	Heathland (sands)-General	Old	4	Strategy 1	0.41
14	6	Heathland (sands)-General	Juvenile	1	Strategy 2	0.17
15	6	Heathland (sands)-General	Adolescent	2	Strategy 2	0.32
16	6	Heathland (sands)-General	Mature	3	Strategy 2	0.21
17	6	Heathland (sands)-General	Old	4	Strategy 2	0.3
18	7	Grassy/Heathy Dry Forest	Juvenile	1	2006	0
19	7	Grassy/Heathy Dry Forest	Adolescent	2	2006	0

The next required is “ObsData.csv”. This contains the observational data, with each row containing the observations for one species at one survey site.

	A	B	C	D	E	F	G	H	I
1	SurvID	SurveyMethod	VBA_CODE	COMMON_NAME	EFG_NO	TSF	FireType	Response	DIVNAME
2	FBB_0984	Bird1	10235	Australian Hobby	7	4.58	Low	0	Birds
3	FBB_0985	Bird1	10235	Australian Hobby	7	20	Low	0	Birds
4	FBB_0986	Bird1	10235	Australian Hobby	7	30	Low	0	Birds
5	FBB_0987	Bird1	10235	Australian Hobby	7	NA	NA	0	Birds
6	FBB_0988	Bird1	10235	Australian Hobby	7	4.67	Low	0	Birds
7	FBB_0989	Bird1	10235	Australian Hobby	7	27	Low	0	Birds
8	FBB_0994	Bird1	10235	Australian Hobby	7	20	Low	0	Birds
9	FBB_0995	Bird1	10235	Australian Hobby	7	26	High	0	Birds
10	FBB_0996	Bird1	10235	Australian Hobby	7	1.75	Low	0	Birds
11	FBB_0997	Bird1	10235	Australian Hobby	7	8	High	0	Birds
12	FBB_0998	Bird1	10235	Australian Hobby	7	4	High	0	Birds
13	FBB_0999	Bird1	10235	Australian Hobby	7	72	High	0	Birds
14	FBB_1004	Bird1	10235	Australian Hobby	7	39	Low	0	Birds
15	FBB_1005	Bird1	10235	Australian Hobby	7	25	Low	0	Birds
16	FBB_1006	Bird1	10235	Australian Hobby	7	16	High	0	Birds
17	FBB_1007	Bird1	10235	Australian Hobby	7	NA	NA	0	Birds
18	FBB_1008	Bird1	10235	Australian Hobby	7	39	Low	0	Birds
19	FBB_1009	Bird1	10235	Australian Hobby	7	13	Low	0	Birds
20	FBB_1010	Bird1	10235	Australian Hobby	7	5	Low	0	Birds
21	FBB_1011	Bird1	10235	Australian Hobby	7	31	Low	0	Birds
22	FBB_1016	Bird1	10235	Australian Hobby	7	29	High	0	Birds
23	FBB_1017	Bird1	10235	Australian Hobby	7	29	High	0	Birds
24	FBB_1018	Bird1	10235	Australian Hobby	7	20	High	0	Birds

Options for GSO in Selected in shiny app

The shiny app provides a single screen GUI to select the four.csv file required and select all the settings required for t GSO to be run (these were previously handled by editing the text in the R file). The options are given in the table below.

Shiny GSO GUI

Aspatial GSO Input Selections

Select GSO input tables

Select Spp_EFG_LMU.csv file

LMU_Area.csv file

LMU_Scenarios.csv file

ObsData.csv file

Analysis options

Please note all inputs are case sensitive, do not include any spaces

Low or High fire type.

baseline for comparisons. You need to use a name as specified in the scenarios spreadsheet or "Optimisation"

Which fauna classes to use NA for all

Select rule to use

weight for option 2

Number of iterations to run

Number of simulations to generate 95% CI7

GSO Options

Option	Name in R	Options
Most recent fire type	FireType	"Low" or "High"
The scenario to use for comparisons	Comparison	This will depend on which scenario you want to set for comparisons, and what you called your scenarios. If you want to use the optimised solution, then type "Optimisation".
Which combination of data to use. Options range from exclusive use of expert opinion or observational data to various combinations of both. See Porigneaux et al. (2017) for what each option means.	Rule	"Rule0", "Rule1", "Rule1a", "Rule1b", "Rule1c", "Rule2", "Rule2a", "Rule2b", "Rule2c", "Rule3", "Rule3a", "Rule3b" or "Rule3c"
The weight to use when combining expert opinion and observational data if using "Rule2".	dWt	A number between 0 and 1, with 0 meaning no weight goes to the survey data (effectively "Rule0") and 1 meaning all weight goes to survey data (where available, effectively "Rule1").
The number of times we resample from the data to estimate the abundance index.	nrep	Number greater than 0. Default is 100.
The number of times we simulate the process, used to generate 95% confidence intervals.	nsim	Number greater than 0.

Background to decision rules in aspatial GSO

A workshop in July 2017 with researchers, policy and PBBOs concluded that the best way to use observational data and expert opinion in combination is not yet settled, and potentially different for different objectives and scenarios. Hence, some decisions still need to be made as to how the expert opinion and observational data should be combined. Currently there are 9 options:

- Rule 0 uses only the expert opinion;
- Rule 1 uses the mean of the observational data where available, and the expert opinion otherwise;
 - Rule 1a is similar to Rule 1, but uses the maximum instead of the mean;
 - Rule 1b is similar to Rule 1, but uses the median instead of the mean;
 - Rule 1c is similar to Rule 1, but uses the upper quartile instead of the mean;
- Rule 2 uses a weighted average of the mean of the observational data and the expert opinion where available, and the expert opinion otherwise.
 - Rule 2a is similar to Rule 2, but uses the maximum instead of the mean;
 - Rule 2b is similar to Rule 2, uses the median instead of the mean;
 - Rule 2c is similar to Rule 2, uses the upper quartile instead of the mean
- Rule 3 uses the mean of the observational data does not use the expert opinion. Please note this will restrict the model to EFG GS with observational data, and may therefore have a vastly reduced number of species considered.
 - Rule 3a is similar to Rule 3, but uses the maximum instead of the mean;
 - Rule 3b is similar to Rule 3, uses the median instead of the mean;
 - Rule 3c is similar to Rule 3, uses the upper quartile instead of the mean

Where expert data is used together with observational data the former needs to be recast into a scale that is comparable to observational data, e.g. with birds a commonly used method is a 20 minute / 2ha count. Currently, this recasting has been done for birds only (as part of testing these new methods). Further work is needed to check if the recast values are sensible as well as recasting data for other taxonomic groups e.g. mammals and reptiles. In the interim the expert estimations in the ordinal scale

have been assumed to satisfy numerical scale characteristics but biometric advice suggests this is highly problematic. The main issue is that one of the assumptions of GMA is that the data on species' relative abundances are linearly related but this may not be satisfied with ordinal data as it could be any non-linear shape.

Considerations and decision points

- Are there sufficient numbers of species to provide a robust GSO if just using observational data?
- What analysis rule will be applied, including any weighting of observational data versus expert opinion. In general, the mean will be an appropriate choice to summarise the observational data. However, when the species of interest are rare in the environment, but are abundant when they are present, the maximum or upper quartile may give a better indication of the value of each GSO. When the species of interest have non-zero observations for at least half the observations, the median could be used, to be more robust to large outliers than the mean.

Running the GSO

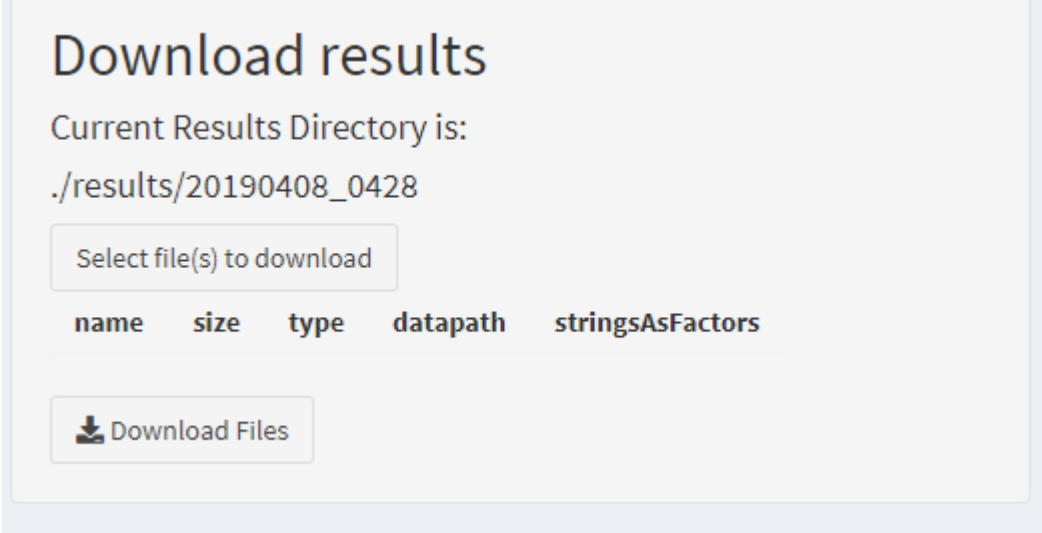
Once the data files are saved in the folder “./GSOInputs” and the model options are selected in the second coloured box the GSO is ready to run. To run the model, you just need to click the “Run GSO button at the bottom left of the GDSO shiny app window.

Note: this process may take some time depending on the amount of observational data, number of simulations required and the speed of the computer.

Once the analysis has run two files will be created. “GSO_Analysis_Output.docx which can be used as the basis of a report. It documents the options used, including model choices, EFGs and species used and produces some tables, plots and comparisons. A file “GSO Species Changes.csv” is also created to store the change in abundance index for each species and scenario. Note these files will be overwritten if the “Run GSO” button is pushed again.

Stage six: Downloading results from the module

- a. Downloading results is handled from the “Download results” box at the bottom right of the Utilities tab:



Download results

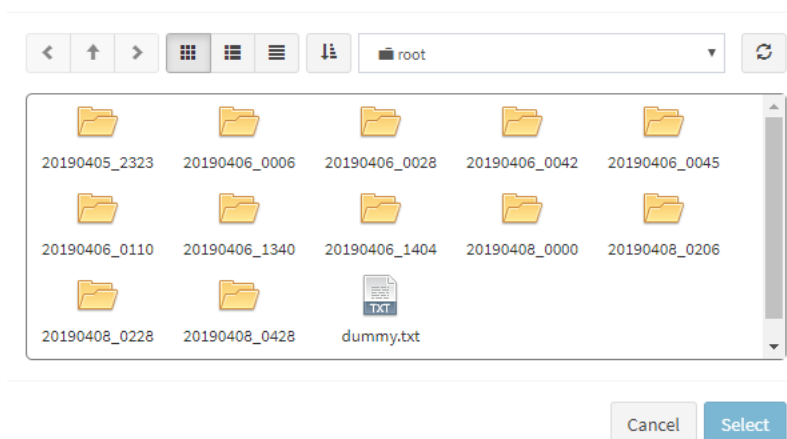
Current Results Directory is:
./results/20190408_0428

Select file(s) to download

name	size	type	datapath	stringsAsFactors
------	------	------	----------	------------------

Download Files

Click on the Select (files) to download button to open a download dialog box:



this opens a file browser window, which will display all the directories of results data on the server, plus a file called dummy.txt. Each session of FAME creates a results directory named <YYYYMMDD_HHMM> (numerical date time to the nearest minute) when the session is opened. All results are housed in this directory.

The “Download Results” box provides the results directory name for the current session for easy identification.

If you wish to download all results from the current session select this directory in the file browser window along with the “dummy.txt” file (this last step is necessary because the browser will only download a directory when a file is also identified for download – you will simply ignore the dummy .txt file after download).

Alternatively you can browse the contents of the individual download directories and select files and directories therein for download.

When finished selecting, press the select button ant the bottom right of the file browser window.

- b. The Download results box will then display the list of files (or directories containing files) that you have selected for download. To complete the process click the “Download files” button at the bottom of the box. This will zip your selection and download to a file named output.zip in your local downloads directory. From here it can be unzipped, and the contents examined. Details of the structure and content of each of the files in the downloads directory is given in FAMEv1.0_Inputs_Outputs.doc

Additional utilities

Shut Down Server

You can shut down the server when running on AWS the utilities page has a button on the bottom left of the utilities tab. This will shut down the server, **any data that has not been downloaded will be lost**. This button is provided to save running costs when the server is not in use.

WARNING BUTTON BELOW WILL SHUT DOWN SERVER

Make sure you have downloaded all your data first

Shut Down Server

Draft species list

The Utilities page includes an option to create a draft species list – this also estimates the proportion of the species range within the area of interest.

Create draft species lists

Choose an area for species list

WHOLE OF STATE

Restrict analysis to Public Land

Yes

No

Run draft species list

Run Spp EFG LMU for list for GSO

This is useful if you are unsure which species it may be appropriate to include in your analysis. It should only however be considered as a starting point for a custom list – the proportion of the range is based on the number of cells of the 225m binary HDM for the species in the area of interest, and may be further restricted to those on public land only. To run this tool select the previously uploaded polygon for the area of interest, or one of the LF_Regions, chose whether or not to calculate only the proportion occurring on public land, and press the Run draft species list Button. This file can be downloaded using the download procedure described above. You can then edit the “Include” and Make Raster columns as required to finalise your custom species list. This should be renamed, and uploaded to the module for further processing.

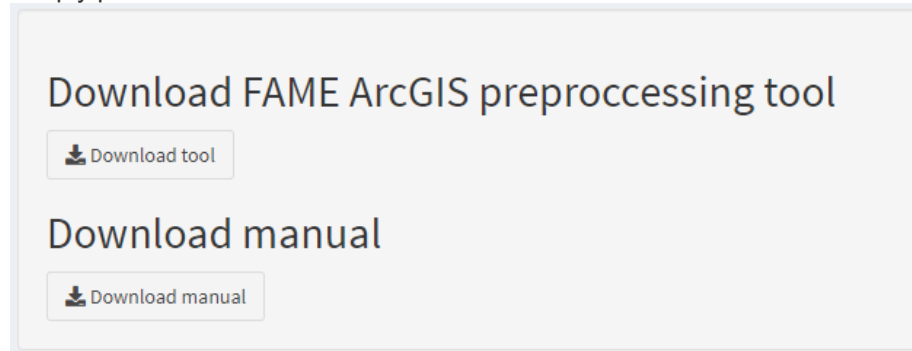
EFG_AREAS and spp_EFG_LMU files

Two further files required to run the aspatial GSO calculations the EFG_AREAS and spp_EFG_LMU files are also calculated by this Utility , press the “Run Spp EFG LMU for region to create these files. They are downloaded in the same way. At the moment they may require manual editing or addition to the field names before use in the GSO module.

Download of manual and ArcGIS Pre-processing tool.

The utilities page includes buttons to download and view the Manual for the app, and the pre-processing tool and associated files, including an AcrMAP project file (.mxd) with a demo dataset loaded.

Simply push the buttons on the bottom left of the utilities tab to download these files.



Appendix 1 Inputs/Outputs for FAME

ARCGIS/ Windows pre-processing:

Pre-processing of the input fire history polygons is required in ArcGIS, this creates a file that is then loaded to the server for processing.

Hardware and software requirements:

Windows 7 or 10 PC with ARCGIS 10.3.1, 8GB ram.

Inputs

Code

ArcMap v10.3 toolbox "FAMEv1.0.tbx"

Data Files

Two fire sequence polygon datasets (either shapefiles or file geodatabase) in VICGRID94 projection, one giving the fire history (ie past fire events) and the other giving a future fire scenario. The Template is based on the required fields from the corporate FIRE_HISTORY dataset. In each dataset the polygons must have at least the attributes SEASON and FIRETYPE (Table1). Other attributes can be present in the attribute table, they will be deleted from the output.

Each combination of fire SEASON and FIRETYPE must be represented by a separate polygon (ie each polygon may only have one SEASON and FIRETYPE).

Field Name	Permissible values	Datatype	Length
SEASON	4 digit year value for the SEASON of the fire event >=1755	SHORT INTEGER	
FIRETYPE	"BURN","BUSHFIRE","OTHER","UNKNOWN"	STRING	50

Table 1. Required attribute fields for Fire History and Fire Future input feature classes.

A polygon shapefile containing polygon(s) to be selected as the boundary of the analysis area to be clipped from FireHistory and FireScenario above. Either an Adhoc polygon created by the user or polygon(s) selected from the supplied LF_REGIONS.shp which is a local copy of the LF_DISTRICT layer in the CGDL database.

Outputs

Shapefile with same fields (SEASON, FIRETYPE) as the input file, combining all the fire events into a single file clipped to the boundary selected.

Inputs

Directory structure

All files (inputs and outputs) should be located in a single main (root)directory, and subdirectories thereof. Files are shown below with their unix “dot notation” to indicate their location in this root directory The subdirectories contained in this main directory (./) are :

```
./AdHocPolygons
./CustomCSV
./FH_Outputs
./GSO
./GSOInputs
./HDMS
./HDMS/225m/BinaryThresholded
./HDMS/225m/BinaryThresholded
./InputGeneralRasters
./rawFH
./ReferenceShapefiles
./ReferenceTables
./results/<YYYYMMDDHHMM>
```

Subdirectories of the results directory are created each time the application is started, these are given the name of the numeric datetime string at their creation. Note that on AWS these times will be UTC not local time.

```
./www
```

Files for spatial relative abundance TFI an BTFI calculations

Fire History Shapefile

Output File shapefile from Stage 1. Shapefile of selected polygons defining boundary for Ad Hoc study area boundary, if required. This file should be placed in the directory ./rawFH

R script files.

```
./TFI_functionsShiny.r
./EcoResFunctionsShiny.r
```

These two files contain all the r functions used in calculations. The purpose individual functions are briefly described in the file themselves.

```
./global.r
./server.r
./ui.r
./disableWhenRunning.js
./ButtonDisableHelpers.r
```

These five files are the constituent files required to run the shiny app – the global file provides setup and loads the functions and required r packages. The ui provides the user interface for shiny and the server serves data and outputs to the UI and saves results to disk. The last two files provide javascript and a number of functions which disable buttons in the interface while processing is running, and provide basic return of error messages to the ui if a process fails to complete. These last two files were sourced and adapted from examples found in web help groups.

```
./makeHDMVals.r
```

This file is provided for reference it is used to convert the HDM rasters (p106) into sparse matrices for use in the module

Reference / Lookup Tables

./ReferenceTables/DraftTaxonListStatewidev2.csv

List of fauna HDM rasters (577) includes VBA species #, threat status, taxonomic divisions

Field Name	Details
TAXON_ID	VBA 2016 Taxon ID for the species
HDMPATH	The Path to the 225m version of the HDM for the species
ShortName	for internal use only
Include	Whether or not the species should be included in the analysis
MakeRasters	Whether or not abundance rasters should be made if the option is selected in the UI
COMMON_NAME	VBA common name for the species
NAME	VBA systematic name for the species
DIVNAME	The broad taxonomic division (class) that the species is in
FFG_ACT_STATUS	Conservation status under <i>the Flora and Fauna Guarantee Act 1988</i>
EPBC_ACT_STATUS	Conservation status under the Commonwealth <i>Environmental Protection and Biodiversity Conservation Act</i>
VIC_ADVISORY_STATUS	Conservation status in the DELWP advisory list of threatened Fauna.
SigThreshold.x	significant threshold for impact based on Vic Advisory conservation status
SigThreshold.y	significant threshold for impact based on EPBC conservation status
CombThreshold	Combination of the above two fields to give threshold used in calculations of charges in relative abundance tables

./ReferenceTables/EFG_EVD_TFI.csv

Look up of TFI parameters for EFGs csv copy of Lookup in CGDL "EFG_EVD_TFI"

Field Name	Details
OBJECTID	Object_ID for ArcGIS table (not used)
EFG_NUM	EFG Number,99 for no EFG
EFG_NAME	EFG Name
EVD_NUM	EVD Number (Not Used)
EVD_NAME	EVD Name (Not Used)
MIN_LO_TFI	Minimum TFI(Tolerable Fire Interval) (integer years) for low intensity fire
MIN_HI_TFI	Minimum TFI (integer years) for high intensity fire
MAX_TFI	Maximum TFI (integer years)

./ReferenceTables/OrdinalExpertLong.csv

Long table format of species responses based on expert opinion

Field Name	Details
COMMON_NAME	Common Name of Fauna Taxon (same as VBA 2016)
FireType	Low or High (intensity)
EFG_GS	Composite String of EFG number and growth stage (not used)
Abund	Relative abundance for the EFG and growth stage Numeric 0-1 or NA for absent or no-data

EFG_NO	EFG Number
GS4_NO	Growth stage (4 classes) 1:4
VBA_CODE	VBA TAXON_ID

./ReferenceTables/EFG_TSF_4GScorrectedAllEFGto400yrs.csv
Growth stage to TSF lookup

Field Name	Details
EFG_NO	EFG Number
EFG_NAME	EFG Name
GS4_NO	Growth stage (4 classes) 1:4
Start	Start of growth stage (from source data, not used) age in years
End	End of growth stage (from source data, not used) age in years, end age is equal to start age of next GS
startInt	Integer values for GS4_NO 2:4 startInt=Start+1 to create exclusive ranges
endInt	endInt= integer version of End
YSF	Age of vegetation in Years (0-400) "Years Since Fire"

./ReferenceTables/HDMSums225.csv
Total # of thresholded cells of each HDM

Raster files used in calculations

./InputGeneralRasters/EFG_NUM_225.tif
./InputGeneralRasters/EFG_NUM_75.tif
Rasters of EFG number for the state.
./InputGeneralRasters/IndexVals225.tif
./InputGeneralRasters/IndexVals75.tif
Rasters providing a sequential index number for each cell in the state.
./InputGeneralRasters/LF_REGION_225.tif
./InputGeneralRasters/LF_REGION_75.tif
Rasters providing numbered cells (1:6) for the six DELWP fire regions in the state.

Thresholded Rasters of HDMs at 75m and 225m pixel size and associated R sparse arrays

./HDMS/225m/BinaryThresholded/<Common_Name>_SppXXXXX_Thresholded_Binary.tif
./HDMS/225m/BinaryThresholded/<Common_Name>_SppXXXXX_Thresholded_Binary.tif
There are two directories of HDM files, one for each resolution stored as subdirectories of ./HDMS. The file names in each directory are identical. File names follow the format <Common_Name>_SppXXXXX_Thresholded_Binary.tif where <Common_Name> is the Common Name of the species and XXXXX is the TAXON_ID used in the Victoria Biodiversity Atlas(VBA) as of April2016, with _ replacing spaces between names. There are currently 577 taxa covered by these files (Appendix 1). These rasters are summarised into the sparse matrices (below), they are not used directly in the module.

./HDMS/ HDMVals225.rdata
./HDMS/ HDMVals75.rdata

In addition to the rasters there are two R data files (one for each resolution) these each contain a single r object – a sparse binary matrix of 577 columns each column represents the footprint of the 577 binary HDMs the column name for each column is the VBA TAXON_ID for the species. the rows of these rasters are indexed to ./InputGeneralRasters/IndexVals225.tif and ./InputGeneralRasters/IndexVals75.tif. The R script to generate these sparse matrices is

./makeHDMVals.r. These sparse arrays provide faster loading and look-up of the HDM footprints and are used instead of the HDM rasters themselves in the module.

Graphics files used in the UI

- ./www/ajax-loader.gif
Loader animation – open source
- ./www/FAME.png
- ./www/08732250_before_after_2014_fire.jpg
Header text and image on the home screen
- ./www/Fire-animation.gif
- ./www/LinktoCreativeCommonsWikiFor Fire Animation.gif.txt
Gif animation displayed when processing is occurring, and text file giving details of creative commons licence location.

Input settings

In addition to the input files there are a number of settings that must be, or can optionally be, chosen before running the Spatial Relative Abundance, and TFI calculations.

Setting name	Purpose	Values
Fire Scenario Analysis		
Fire scenario shapefile	The fire sequence (combination of fire history and future fire scenario) to be analysed.	Shapefile produced in the preparatory ARCGIS tool and uploaded to module
Region for analysis	Sets the boundary of the analysis. Analysis should be restricted to only the area of interest to minimise computation time. Usually this boundary should correspond to the clipping boundary used in the ARCGIS preparatory tool to create the fire sequence for analysis, however the analysis will still run if these boundaries differ (as long as they overlap each other. Areas outside the clipping of the Fire scenario will be set to NA. If the region chosen is within the Fire Scenario area clipped, the analysis will be restricted to the region chosen.	Whole of State (Default) Ad Hoc polygon (user-provided shapefile in VG94 projection of the boundary of the region of interest) or One of the DELWP Fire regions "BARWON SOUTH WEST "=1, "GIPPSLAND "=2 , "GRAMPIANS "=3, "HUME "=4, "LODDON MALLEE "=5, "PORT PHILLIP "=6,
Raster Resolution	Sets the resolution used for analysis, this is important in determining memory requirements and processing speed. Use of 75m raster increases processing and memory requirements ~10x	225 m (default) 75 m
Public Land Only	The analysis can be carried out across both public and private land, however fire history is much less complete for private land.	Yes(Default) No
Other and Unknown fire value	Fire history may contain fires of unknown type, you need to decide how to treat these in the analysis. They may be treated as either a bushfire or a burn, or alternatively areas with an unknown fire type may be treated as "NA" values. If the latter is chosen then TFI status, and relative abundance for the	Bushfire (Default) Burn NA

Setting name	Purpose	Values
	cell cannot be calculated based on that fire.	
First season for analysis output	Start the analysis at the first season which may be of interest, this reduces processing time, particularly in the Relative abundance calculations (that loop year by year). Calculations occur for each season from the first chosen to the maximum season value in the fire sequence.	1980 (default) Any season after the first season in the fire sequence file provided
Spatial TFI and Relative abundance calculations		
Enter start and end of abundance baseline period	Set the seasons to be used to calculate the baseline relative abundance used to calculate % change from baseline. It can be a single year or a range of years.	1980,1980(default) Any single year, or range of years after 1979 contained in the fire sequence For a single year chose the same value for start and end
Use default or custom species list	The default is to calculate species responses for all species that have relative abundance data, and to plot relative abundances Rasters for all the species that have RA calculated (as an option). Reducing either of these lists to the species of interest in the region only will significantly reduce calculation times and make outputs easier to handle.	Default: Standard species list (all species that have RA data available are calculated whether or not they occur in the region of interest). Alternative values: Uploaded manually edited draft species list produced using the “create draft species” list utility in the app
Use default or custom relative abundance	Where sufficient field data is available the expert opinion data may be replaced with models based on this field data. In other cases, there may be regional variations in responses that are not addressed in the statewide data. Further the current FFO data only addresses treatable EFGs. Ideally as the available curated response data improves the default dataset would be updated to these values	Default relative abundance uses statewide expert opinion data of relative abundance for each growth stage and EFG and firetype available (previously known as the FFO dataset). Custom uses a user uploaded and created dataset of relative abundance (range 0-1), for each species and EFG growth stage. This must be formatted in exactly the same format as the default .csv file
Make relative abundance rasters	Whether to output individual Species x Season relative abundance rasters. These provide the spatial view of changes in abundance for each taxon through the fire sequence, however they increase the computation time.	No (default for more rapid computation) Yes (if spatial output is desired). Note if yes is chosen the default is to do this for each species for each year from the first year for analysis- This can result in a very large number of files being created and require increased download and storage space.
Make TFI status/BBTFI rasters	Whether to output individual season TFI status rasters. Has slight increase in computation time. And data storage/ download requirements	No (default) Yes

Outputs

Preparatory ARGIS tool – separate process on windows PC

Shapefile (four component files .shp,.dbf, .shx, .prj) in Vicgrid94 projection. Required as precursor to all subsequent spatial RA and TFI related calculations in the module.

Outputs created by the module

All outputs created by the module are saved in ./Results/YMMMDDHHMM/ directory or subdirectories thereof.

Fire scenario analysis.

The initial fire scenario analysis replaces the previous corporate “FireHAT” processing. It creates a shapefile that contains on polygon for each unique spatial sequence of fire events. The file (actually four files .shp,.shx,.prj.and .dbf. Collectively these are referred to as the “FH analysis”. An R data file is also saved this contains the same data, plus metadata about the analysis and a raster with the polygon ID values (to allow linking of the FH analysis vector data to further analysis in a raster environment.

The file names and locations:

./FH_analysis_<name_of_input_rawFH file>.shp

./FH_analysis_<name_of_input_rawFH file><Raster Resolution>.Rdata

The polygon attributes (in the shapefile dbf and the SimpleFeatures Dataframe stored in .rdata file are:

Field Name(s)	Description of values contained	Example/ or possible values
SEAS01 ... SEASxx	The date of sequential fire seasons for fires in the area of the polygon, SEAS01 gives the date of the first (oldest recorded) fire at each location. SEASON02 the next fire for SEASxx, xx= greatest number of sequential fires occurring in the study area.	Four-digit integer fire SEASON eg 1980 or 2055. 0= No fire NA= No fire R Sf_DataFrame
FireType01 ... FiretypeXX	The Fire type corresponding to the SEAS01 ... SEASON xx value	Single digit integer 1=Burn 2=Bushfire 3=Other 4=Unknown 0=NULL NA=NULL in R Sf_DataFrame
INT01 ... INTyy where yy=xx-1	The inter-fire interval between sequential fires at a location. INT01 is the interval (in years) SEAS02-SEAS01	Integer value >=1 0= No interval NA=No interval in R Sf_DataFrame
YSFXXXX ... (one field for each) year including and after the First season for analysis output	The number of years (fire seasons) since the last fire at the location prior to season date XXXX	
ID	1 based index unique id for each polygon Present in shapefile and R SFDF	1: number of polygons
FID	Zero based index unique ID for each feature in shapefile, not present in SFDF	0:(number of polygons-1)

An Rdata file named “FH_analysis_”<name_of_input_rawFH file>.Rdata stored in the same directory contains two R objects, each of these is a list containing further objects.

R - Object	Objects listed within it	Details
FHanalysis	TimeSpan	Time span of fire seasons contained in the input fire scenario Min (SEASON):max(SEASON)
	YSFNames	Names of the YSF fields in the FHanalysis
	LBYNames	Names of the YSF fields in the FHanalysis
	LFTNames	Names of the YSF fields in the FHanalysis
	FireScenario	The input fire scenario shapefile analysed
	RasterRes	The raster resolution output from the analysis(75 or 225)
	ClipPolygonFile	The polygon used to clip the analysis extent if one of the standard options is used then this will be "LF_REGIONS.shp", if an Ad hoc polygon was selected it will be the name of the ad hoc polygons shapefile.
	Region_No	Integer value corresponding to the Region selected for the clipping polygon (see Inputs: Region for analysis)
	PUBLIC_ONLY	Whether the analysis was restricted to public land only (“Yes” or No”)
	name	The name of the output FHanalysis. Rdata file
	FH_IDr	R raster object with the extent of the clip polygon. Cell values are the values of the FHanalysis polygon ID values (Note not the FID values from the shapefile)
	OutDF	The R Simple Features Dataframe containing the results of the vector FHanalysis.
	CropRasters	Raster
Extent		Extent object for Raster above
clipIDX		Index values for all cells within the clip polygon from ./InputGeneralRasters/IndexVals225.tif or ./InputGeneralRasters/IndexVals75.tif Corresponding to RasterRes, Used for fast extraction of HDM values etc from corresponding rasters and arrays
IDX		Indices of cells of ./InputGeneralRasters/IndexVals225.tif or ./InputGeneralRasters/IndexVals75.tif Corresponding to RasterRes, For each cell of cropRasters\$Raster
EFG		Cell wise EFG_NO values for cells in the rectangular extent of cropRasters\$Raster
RGN		Cell wise Region_No values for cells in the rectangular extent of cropRasters\$Raster
HDM_RASTER_PATH		The path to the HDM raster files corresponding to the RasterRes

TFI status and Burned below TFI

An .Rdata file containing the results and intermediate steps of the analysis is saved : with the name ./“FH_analysis_”<name_of_input_rawFH file>_TFI.Rdata

Tabular outputs

./UnderTFIbyEFGandSEASONwide.csv

Summary of the area of each EFG under TFI in each SEASON

Column	Value
EFG	EFG number
TFI_STATUS	-99 = no TFI Status (either no EFG, no fire history or not included in analysis) 0 = within TFI 1 = below minimum TFI 2 = above maximum TFI
SEASONS (4-digit year)	SEASONS from the first season selected for analysis outputs to the maximum season value in the fire scenario Cell value: Area in hectares

./TimesBBTFI_Summary.csv

Cross-tabulated summary of the areas burnt below TFI by EFG

Column	Value
EFG	EFG number
1-x	Number of times burned below TFI (these are exclusive not additive, ie an area burned 6 times below TFI will not also be included in the areas burned 1-5 times below TFI, so the sum of the row gives the total area burned below TFI Cell value: Area in hectares

./BBTFI_EFG_Area_SEASON.csv

The long- format version of TimesBBTFI_Summary.csv. Can be formatted for reporting as required

Column	Value
EFG	EFG number
SEASON	SEASON (4 Digits) in which Fire causing to be BBTFI occurred
Times_BBTFI	Resulting number of times burned below TFI
ha	Area in hectares

R .Rdata file

An .Rdata file containing the results and intermediate steps of the analysis is saved for potential further analysis with the name:

./"FH_analysis_"<name_of_input_rawFH file>_TFI.Rdata.

It contains R matrix versions of the .csv files above, plus matrices of the cell values of the TFI raster outputs (myTFI\$Under_TFI_BY_CELL), and the BBTFI dates by in order (myBBTFI\$BBTFI_COMB).

Raster outputs

./TFI_Rasters/FirstBBTFI.tif

Raster cell values for all cells that have at least one inter-fire interval below TFI, the value is the 4-digit SEASON in which the area was first burnt below TFI. All other cells No Value (NA)

./TFI_Rasters/TimesBBTFI.tif

TimesBBTFI cell values for all cells that have at least one inter-fire interval below TFI, the value is the frequency that the cell has been first burnt below TFI. All other cells 0.

./TFI_Rasters/TFI_STATUS_<SEASON>.tif

Optional output, only output if "Make TFIstatus/BBTFI maps for each year" IS "Yes". Multiple Rasters (one for each four digit fire SEASON from the first season chosen for analysis). Cell values -99 = no TFI Status (either no EFG, no fire history or not included in analysis), 0 = within TFI, 1 = below minimum TFI, 2 = above maximum TFI.

./TFI_Rasters/TFI_STATUS_LUT.csv

A lookup table giving the TFI status values and names is.

Spatial Relative Abundance of Fauna.

Tabular Outputs.

`./SpYearSummSpreadbyYear.csv`

Summary of the proportionate species relative abundance for each season after the current year in the dataset, compared to the baseline years set.

Field	Value
1:8	Details are the same as <code>./ReferenceTables/DraftTaxonListStatewidev2.csv</code> .
XXXX-YYYY(4 digit SEASON)	Sum of calculated relative abundance x100 (to convert decimal to integer) for that species.

`./SpYearSumm.csv`

Wide format of above data. `./SpYearSummSpreadbyYear.csv` provided for further analysis if required

`./SppSummChangeRelativetoBaseline.csv`

Comparison of the calculated summed relative abundance in each season to benchmark and threshold value. Used to determine number of species, and which species decline to below a threshold level in reporting.

Field	Value
1:8	Details are the same as <code>./ReferenceTables/DraftTaxonListStatewidev2.csv</code> .
XXXX-YYYY(4 digit SEASON)	Proportion of benchmark value in that season
NoLessthanThreshold	Number of times (in the seasons in preceding columns, that the summed relative abundance was below the threshold).
LastLessThanThreshold	TRUE/FALSE. Whether the species relative abundance was below the threshold in the final year of the scenario.

`./SppConsideredInAnalysis.csv`

Table including only those species that were considered in the analysis – ie those selected for inclusion in the input species list, that had HDMS intersecting with the analysis area. Details are the same as `./ReferenceTables/DraftTaxonListStatewidev2.csv`.

Graphical output.

`./SpYearSummGraph.html`

Graph viewable in web browser showing change in relative abundance for all species considered in the analysis against fire season. The graph has a “hover over” ability to get details of the species id for each line. This graph is run primarily as a check, it is only useful as a final product in cases where relatively few species are considered in the analysis. It is the graphical display of `./SpYearSummSpreadbyYear.csv`

Raster outputs

Optional output is output of species rasters is “Yes” in UI. (Potentially many thousand rasters. One raster will be produced for each Species selected in MakeRasters field of input species table, and for each year selected in the UI. The cell value is the relative abundance x100.

Filenames are:

`./RA_Rasters/Sp_XXXXX_YR_YYYY.tif`

Where XXXXX is the VBA TAXON_ID and YYYY is the SEASON.

Files for aspatial GSO calculator chosen in inputs

The process for running the GSO calculator from R studio was documented previously. A revised version of this file describing the process for running GSO from the shiny app is included in Stage five of workflow above (page 11).

R and Rmarkdown files.

./GSO/GSOAnalysisCodeShiny.R
./GSO/GSOAnalysisOutput.Rmd

Lookup and settings files (excel and CSV files)

./GSO/VBA_FAUNA.xlsx

Common names and codes for fauna (Ideally this file would be replaced with the similar .\ReferenceTables\DraftTaxonListStatewidev2.csv used in the spatial relative abundance part of the module, Reconciliation of fieldnames in the GSO will be required before this can occur).

./GSO/Reference data.xlsx

sheet='Ordinal expert data'

Expert opinion data for Fauna relative abundance, each EFG simplified Growth stage has a column, each data point has a row species. (Ideally this file would be replaced with the similar .\ReferenceTables\DraftTaxonListStatewidev2.csv used in the spatial relative abundance part of the module, Reconciliation of fieldnames in the GSO will be required before this can occur).

sheet='GS lookup'

data to calculate growth stage category given the EFG and TSF . (Ideally this file would be replaced with the similar .\ReferenceTables\EFG_TSF_4GScorrectedAllEFGto400yrs.csv used in the spatial relative abundance part of the module. Reconciliation of fieldnames in the GSO will be required before this can occur).

./GSO/TBL_VegetationGrowthStages.xlsx

Source of lookup for EFG full names. (Ideally this file would be replaced with the similar .\ReferenceTables\EFG_EVD_TFI.csv.csv used in the spatial relative abundance part of the module. Reconciliation of fieldnames in the GSO will be required before this can occur).

./GSO/ExpertEstimate.xlsx

Expert opinion data as an amount of birds, used in recalibration of expert opinion data for use in conjunction with observation data.

List of HDM Raster Files.

List of HDM Raster Files

Agile_Antechinus_Spp11028_Thresholded_Binary.tif
Alpine_Bog_Skink_Spp12992_Thresholded_Binary.tif
Alpine_She_oak_Skink_Spp12987_Thresholded_Binary.tif
Alpine_Tree_Frog_Spp63907_Thresholded_Binary.tif
Alpine_Water_Skink_Spp12550_Thresholded_Binary.tif
Apostlebird_Spp10675_Thresholded_Binary.tif
Australasian_Bittern_Spp10197_Thresholded_Binary.tif
Australasian_Grebe_Spp10061_Thresholded_Binary.tif
Australasian_Pipit_Spp10647_Thresholded_Binary.tif
Australasian_Shoveler_Spp10212_Thresholded_Binary.tif
Australian_Bustard_Spp10176_Thresholded_Binary.tif
Australian_Hobby_Spp10235_Thresholded_Binary.tif
Australian_King_Parrot_Spp10281_Thresholded_Binary.tif
Australian_Magpie_Spp10705_Thresholded_Binary.tif
Australian_Owlet_nightjar_Spp10317_Thresholded_Binary.tif
Australian_Painted_Snipe_Spp10170_Thresholded_Binary.tif
Australian_Pelican_Spp10106_Thresholded_Binary.tif
Australian_Pratincole_Spp10173_Thresholded_Binary.tif

List of HDM Raster Files

Australian_Raven_Spp10930_Thresholded_Binary.tif
Australian_Shelduck_Spp10207_Thresholded_Binary.tif
Australian_Spotted_Crake_Spp10049_Thresholded_Binary.tif
Australian_White_Ibis_Spp10179_Thresholded_Binary.tif
Australian_Wood_Duck_Spp10202_Thresholded_Binary.tif
Azure_Kingfisher_Spp10319_Thresholded_Binary.tif
Baillons_Crake_Spp10050_Thresholded_Binary.tif
Banded_Lapwing_Spp10135_Thresholded_Binary.tif
Banded_Stilt_Spp10147_Thresholded_Binary.tif
Bandy_Bandy_Spp12734_Thresholded_Binary.tif
Bar_shouldered_Dove_Spp10032_Thresholded_Binary.tif
Bar_tailed_Godwit_Spp10153_Thresholded_Binary.tif
Bardick_Spp12667_Thresholded_Binary.tif
Barking_Marsh_Frog_Spp13059_Thresholded_Binary.tif
Barking_Owl_Spp10246_Thresholded_Binary.tif
Bassian_Thrush_Spp10779_Thresholded_Binary.tif
Baw_Baw_Frog_Spp13106_Thresholded_Binary.tif
Beaded_Gecko_Spp12109_Thresholded_Binary.tif
Beaked_Gecko_Spp12137_Thresholded_Binary.tif
Bearded_Dragon_Spp12177_Thresholded_Binary.tif
Beautiful_Firetail_Spp10650_Thresholded_Binary.tif
Bell_Miner_Spp10633_Thresholded_Binary.tif
Black_Bittern_Spp60196_Thresholded_Binary.tif
Black_chinned_Honeyeater_Spp10580_Thresholded_Binary.tif
Black_eared_Cuckoo_Spp10341_Thresholded_Binary.tif
Black_eared_Miner_Spp10967_Thresholded_Binary.tif
Black_faced_Cormorant_Spp10098_Thresholded_Binary.tif
Black_faced_Cuckoo_shrike_Spp10424_Thresholded_Binary.tif
Black_faced_Monarch_Spp10373_Thresholded_Binary.tif
Black_faced_Woodswallow_Spp10546_Thresholded_Binary.tif
Black_Falcon_Spp10238_Thresholded_Binary.tif
Black_fronted_Dotterel_Spp10144_Thresholded_Binary.tif
Black_Honeyeater_Spp10589_Thresholded_Binary.tif
Black_Kite_Spp10229_Thresholded_Binary.tif
Black_Rock_Skink_Spp62938_Thresholded_Binary.tif
Black_shouldered_Kite_Spp10232_Thresholded_Binary.tif
Black_Swan_Spp10203_Thresholded_Binary.tif
Black_tailed_Godwit_Spp528553_Thresholded_Binary.tif
Black_tailed_Native_hen_Spp10055_Thresholded_Binary.tif
Black_Wallaby_Spp11242_Thresholded_Binary.tif
Black_winged_Stilt_Spp528555_Thresholded_Binary.tif
Blotched_Blue_tongued_Lizard_Spp12578_Thresholded_Binary.tif
Blue_billed_Duck_Spp10216_Thresholded_Binary.tif
Blue_Bonnet_Spp10297_Thresholded_Binary.tif
Blue_faced_Honeyeater_Spp10641_Thresholded_Binary.tif
Blue_Mountains_Tree_Frog_Spp13175_Thresholded_Binary.tif
Blue_winged_Parrot_Spp10306_Thresholded_Binary.tif
Booroolong_Tree_Frog_Spp13168_Thresholded_Binary.tif
Bougainvilles_Skink_Spp12475_Thresholded_Binary.tif
Boulengers_Skink_Spp12526_Thresholded_Binary.tif
Broad_toothed_Rat_Spp11438_Thresholded_Binary.tif
Brolga_Spp10177_Thresholded_Binary.tif
Brookss_Striped_Skink_Spp62933_Thresholded_Binary.tif
Brown_Cuckoo_Dove_Spp10029_Thresholded_Binary.tif
Brown_Falcon_Spp10239_Thresholded_Binary.tif

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Brown_headed_Honeyeater_Spp10583_Thresholded_Binary.tif
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Brush_tailed_Rock_wallaby_Spp11215_new_Thresholded_Binary.tif
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Carnabys_Wall_Skink_Spp12326_Thresholded_Binary.tif
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Chestnut_rumped_Heathwren_Spp10498_Thresholded_Binary.tif
Chestnut_rumped_Thornbill_Spp10481_Thresholded_Binary.tif
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Common_Cicadabird_Spp10429_Thresholded_Binary.tif
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Common_Greenshank_Spp10158_Thresholded_Binary.tif
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Crescent_Honeyeater_Spp10630_Thresholded_Binary.tif
Crested_Bellbird_Spp10419_Thresholded_Binary.tif

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Crested_Tern_Spp10115_Thresholded_Binary.tif
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Cunninghams_Skink_Spp12408_Thresholded_Binary.tif
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Sooty_Oystercatcher_Spp10131_Thresholded_Binary.tif
Southern_Barred_Frog_Spp13073_Thresholded_Binary.tif
Southern_Boobook_Spp10242_Thresholded_Binary.tif
Southern_Brown_Bandicoot_Spp61092_Thresholded_Binary.tif
Southern_Brown_Tree_Frog_SOUTHERN_Spp63903_Thresholded_Binary.tif
Southern_Brown_Tree_Frog_Spp13182_Thresholded_Binary.tif
Southern_Bullfrog_(ssp_unknown)_Spp13058_Thresholded_Binary.tif
Southern_Emu_wren_Spp10526_Thresholded_Binary.tif
Southern_Forest_Bat_Spp11378_Thresholded_Binary.tif
Southern_Freetail_Bat_Spp11808_Thresholded_Binary.tif
Southern_Grass_Skink_Spp12994_Thresholded_Binary.tif
Southern_Legless_Lizard_Spp12154_Thresholded_Binary.tif
Southern_Myotis_Spp11357_Thresholded_Binary.tif
Southern_Rainbow_Skink_Spp12318_Thresholded_Binary.tif
Southern_Scrub_robin_Spp10441_Thresholded_Binary.tif
Southern_Smooth_Froglet_Spp13029_Thresholded_Binary.tif
Southern_Spiny_tailed_Gecko_Spp12059_Thresholded_Binary.tif
Southern_Toadlet_Spp13125_Thresholded_Binary.tif
Southern_Water_Skink_Spp62956_Thresholded_Binary.tif
Southern_Whiteface_Spp10466_Thresholded_Binary.tif
Spangled_Drongo_Spp10673_Thresholded_Binary.tif
Speckled_Warbler_Spp10504_Thresholded_Binary.tif

List of HDM Raster Files

Spencers_Skink_Spp12541_Thresholded_Binary.tif
Spiny_cheeked_Honeyeater_Spp10640_Thresholded_Binary.tif
Splendid_Fairy_wren_Spp10532_Thresholded_Binary.tif
Spot_tailed_Quoll_Spp11008_Thresholded_Binary.tif
Spotless_Crake_Spp10051_Thresholded_Binary.tif
Spotted_Bowerbird_Spp10680_Thresholded_Binary.tif
Spotted_Burrowing_Skink_Spp12499_Thresholded_Binary.tif
Spotted_Harrier_Spp10218_Thresholded_Binary.tif
Spotted_Marsh_Frog_(race_unknown)_Spp13063_Thresholded_Binary.tif
Spotted_Marsh_Frog_NCR_Spp63917_Thresholded_Binary.tif
Spotted_Marsh_Frog_SCR_Spp63918_Thresholded_Binary.tif
Spotted_Nightjar_Spp10331_Thresholded_Binary.tif
Spotted_Pardalote_Spp10565_Thresholded_Binary.tif
Spotted_Quail_thrush_Spp10436_Thresholded_Binary.tif
Spotted_Tree_Frog_Spp13195_Thresholded_Binary.tif
Square_tailed_Kite_Spp10230_Thresholded_Binary.tif
Squirrel_Glider_Spp11137_Thresholded_Binary.tif
Sternula_albifrons_sinensis_Spp10117_Thresholded_Binary.tif
Straw_necked_Ibis_Spp10180_Thresholded_Binary.tif
Striated_Fieldwren_Spp10500_Thresholded_Binary.tif
Striated_Grasswren_Spp10513_Thresholded_Binary.tif
Striated_Heron_Spp10193_Thresholded_Binary.tif
Striated_Pardalote_Spp10976_Thresholded_Binary.tif
Striated_Thornbill_Spp10470_Thresholded_Binary.tif
Striped_Honeyeater_Spp10585_Thresholded_Binary.tif
Striped_Legless_Lizard_Spp12159_Thresholded_Binary.tif
Striped_Marsh_Frog_Spp13061_Thresholded_Binary.tif
Striped_Worm_Lizard_Spp12150_Thresholded_Binary.tif
Stubble_Quail_Spp10009_Thresholded_Binary.tif
Stumpy_tailed_Lizard_Spp12583_Thresholded_Binary.tif
Sugar_Glider_Spp11138_Thresholded_Binary.tif
Sulphur_crested_Cockatoo_Spp10269_Thresholded_Binary.tif
Superb_Fairy_wren_Spp10529_Thresholded_Binary.tif
Superb_Lyrebird_Spp10350_Thresholded_Binary.tif
Superb_Parrot_Spp10277_Thresholded_Binary.tif
Swamp_Antechinus_Spp11034_Thresholded_Binary.tif
Swamp_Harrier_Spp10219_Thresholded_Binary.tif
Swamp_Rat_Spp11398_Thresholded_Binary.tif
Swamp_Skink_Spp12407_Thresholded_Binary.tif
Swift_Parrot_Spp10309_Thresholded_Binary.tif
Tawny_crowned_Honeyeater_Spp10593_Thresholded_Binary.tif
Tawny_Frogmouth_Spp10313_Thresholded_Binary.tif
Terek_Sandpiper_Spp10160_Thresholded_Binary.tif
Tessellated_Gecko_Spp12076_Thresholded_Binary.tif
Thick_tailed_Gecko_Spp12138_Thresholded_Binary.tif
Three_toed_Skink_Spp12441_Thresholded_Binary.tif
Tiger_Snake_Spp12681_Thresholded_Binary.tif
Tree_Dragon_Spp12194_Thresholded_Binary.tif
Tree_Dtella_Spp12092_Thresholded_Binary.tif
Tree_Martin_Spp10359_Thresholded_Binary.tif
Tree_Skink_Spp12429_Thresholded_Binary.tif
Turquoise_Parrot_Spp10302_Thresholded_Binary.tif
Tussock_Skink_Spp12993_Thresholded_Binary.tif
Tylers_Toadlet_Spp13931_Thresholded_Binary.tif
Varied_Sittella_Spp10549_Thresholded_Binary.tif

List of HDM Raster Files

Variegated_Fairy_wren_Spp10536_Thresholded_Binary.tif
Verreauxs_Frog_Spp13215_Thresholded_Binary.tif
Verreauxs_Tree_Frog_Spp63906_Thresholded_Binary.tif
Victorian_Smooth_Froglet_Spp13033_Thresholded_Binary.tif
Water_Dragon_Spp18999_Thresholded_Binary.tif
Water_Rat_Spp11415_Thresholded_Binary.tif
Weasel_Skink_Spp12452_Thresholded_Binary.tif
Wedge_tailed_Eagle_Spp10224_Thresholded_Binary.tif
Weebill_Spp10465_Thresholded_Binary.tif
Welcome_Swallow_Spp10357_Thresholded_Binary.tif
West_Australian_Dark_spined_Blind_Snake_Spp12586_Thresholded_Binary.tif
Western_Blue_tongued_Lizard_Spp12579_new_Thresholded_Binary.tif
Western_Brown_Snake_Spp12698_Thresholded_Binary.tif
Western_Gerygone_Spp10463_Thresholded_Binary.tif
Western_Grey_Kangaroo_Spp11263_Thresholded_Binary.tif
Western_Pygmy_possum_Spp11151_Thresholded_Binary.tif
Western_Whipbird_(Mallee)_Spp10422_Thresholded_Binary.tif
Whimbrel_Spp10150_Thresholded_Binary.tif
Whistling_Kite_Spp10228_Thresholded_Binary.tif
White_backed_Swallow_Spp10358_Thresholded_Binary.tif
White_bellied_Cuckoo_shrike_Spp10425_Thresholded_Binary.tif
White_bellied_Sea_Eagle_Spp10226_Thresholded_Binary.tif
White_breasted_Woodswallow_Spp10543_Thresholded_Binary.tif
White_browed_Babbler_Spp10445_Thresholded_Binary.tif
White_browed_Scrubwren_Spp10488_Thresholded_Binary.tif
White_browed_Treecreeper_Spp10561_Thresholded_Binary.tif
White_browed_Woodswallow_Spp10545_Thresholded_Binary.tif
White_eared_Honeyeater_Spp10617_Thresholded_Binary.tif
White_faced_Heron_Spp10188_Thresholded_Binary.tif
White_footed_Dunnart_Spp11069_Thresholded_Binary.tif
White_fronted_Chat_Spp10448_Thresholded_Binary.tif
White_fronted_Honeyeater_Spp10594_Thresholded_Binary.tif
White_headed_Pigeon_Spp10028_Thresholded_Binary.tif
White_lipped_Snake_Spp12665_Thresholded_Binary.tif
White_naped_Honeyeater_Spp10578_Thresholded_Binary.tif
White_necked_Heron_Spp10189_Thresholded_Binary.tif
White_plumed_Honeyeater_Spp10625_Thresholded_Binary.tif
White_stripped_Freetail_Bat_Spp11324_Thresholded_Binary.tif
White_throated_Gerygone_Spp10453_Thresholded_Binary.tif
White_throated_Needletail_Spp10334_Thresholded_Binary.tif
White_throated_Nightjar_Spp10330_Thresholded_Binary.tif
White_throated_Treecreeper_Spp10558_Thresholded_Binary.tif
White_winged_Chough_Spp10693_Thresholded_Binary.tif
White_winged_Fairy_wren_Spp10535_Thresholded_Binary.tif
White_winged_Triller_Spp10430_Thresholded_Binary.tif
Willie_Wagtail_Spp10364_Thresholded_Binary.tif
Wonga_Pigeon_Spp10044_Thresholded_Binary.tif
Wood_Gecko_Spp12077_Thresholded_Binary.tif
Wood_Sandpiper_Spp10154_new_Thresholded_Binary.tif
Woodland_Blind_Snake_Spp12603_Thresholded_Binary.tif
Yellow_bellied_Glider_Spp11136_Thresholded_Binary.tif
Yellow_bellied_Sheathtail_Bat_Spp11321_Thresholded_Binary.tif
Yellow_bellied_Water_Skink_Spp12957_Thresholded_Binary.tif
Yellow_billed_Spoonbill_Spp10182_Thresholded_Binary.tif
Yellow_faced_Honeyeater_Spp10614_Thresholded_Binary.tif

List of HDM Raster Files

Yellow_faced_Whip_Snake_Spp12655_Thresholded_Binary.tif
Yellow_footed_Antechinus_Spp11027_Thresholded_Binary.tif
Yellow_plumed_Honeyeater_Spp10622_Thresholded_Binary.tif
Yellow_rumped_Thornbill_Spp10486_Thresholded_Binary.tif
Yellow_tailed_Black_Cockatoo_Spp10267_Thresholded_Binary.tif
Yellow_Thornbill_Spp10471_Thresholded_Binary.tif
Yellow_throated_Miner_Spp10635_Thresholded_Binary.tif
Yellow_tufted_Honeyeater_Spp10619_Thresholded_Binary.tif
Zebra_Finch_Spp10653_Thresholded_Binary.tif

Appendix E Output 2,3,4: Gap analysis

Supporting documentation for the collated ecological models and threatened species data, including a synthesis of current knowledge, a list of ecosystems for which models have not yet been developed, and outline of threatened species data gaps

Summary

This is the fourth interim report for the project “*Using, updating and integrating ecological models into a decision framework to inform bushfire management planning*”. In this report we review the species, models and data to use in analysis of ecological values in strategic bushfire management planning. We have synthesised the information from legacy monitoring data in the VBMP database to evaluate where there are knowledge gaps in species and ecosystems. Our work shows that while survey coverage of vegetation types is quite comprehensive for flora, there is comparatively little information on birds, mammals, reptiles and frogs, and none on invertebrates. We found that the standard survey methods used were ineffective at detecting rare species except where targeted call playback was used.

We identified several limitations with the data and models including:

- reliance on data elicited through expert judgement
- lack of data for private land and variation in survey methods (rendering data to be currently incompatible for ecological risk analysis)
- problems with using occupancy as a substitute for abundance
- lack of specification or inclusion of uncertainty in data

We provide an overview of guidance materials that we are intending to provide in Output 7 as part supporting material for the consolidated module (Output 6). Lastly, we make recommendations about future work to improve data and models for ecological risk assessment noting that related work (in Output 8) provides more a comprehensive process for dealing with uncertainty for fire management decisions.

Context

Victoria’s Safer Together (2016) provides a framework to managing bushfire risk to minimise the loss of human life, property and ecological values from major bushfires. There has been substantial investment by DELWP in research, monitoring and modelling the impacts of fire on ecological values (DELWP 2015a, 2017). A few examples of this investment includes Pre- and Post-Fire flora monitoring program (Farmilo et al 2017), Science based monitoring, evaluation and reporting (Leonard et al 2018), Refinement of EPBC Assessment process and ecological resilience technical method (MacHunter et al 2018), Interactions between fire, landscape pattern, and biodiversity (IFER Core project), Using Fire to Manage Biodiversity in fragmented Landscapes (Sitters et al. 2019), Spatially explicit solutions for managing fire and biodiversity (UoM & LTU), Managing interactions between fire, invasive predators and invasive herbivores to maximise the persistence of threatened species (UoM & ARI).

The application of data and knowledge for risk assessment of ecological values in fire planning has been constrained by several gaps in the process. For instance:

- the ecological models have not been consolidated, so they are not easily accessible through a single location, or single data manager
- the ecosystems where models are lacking have not been identified and this is required to inform research investment and monitoring prioritisation (although see recent work undertaken as part of the Science based monitoring, evaluation and reporting project (Leonard et al. 2018))
- threatened species data have not been collated at a state-wide scale, and gaps have not been identified. Again, this is required to inform research and monitoring

This report documents our work as part of Output 4 “*Supporting documentation for the collated ecological models and threatened species data, including a synthesis of current knowledge, a list of ecosystems for which models have not*

yet been developed, and outline of threatened species data gaps”. Output 4 builds on work undertaken as part of the collation of ecological models (Output 2) and threatened species data (Output 3).

Overview of methods

This work was undertaken through a series of informal interviews and meetings with taxon experts, the ERP 1 project team and DELWP regional and state-wide planning staff involved in undertaking ecological data management and / or analysis of risk to ecosystem resilience and threatened species. These interviews were conducted to:

- Identify what information is required of the models with the decision context (i.e. clarify the information required to inform the performance measures and decision-making);
- Review the potential suite of ecological models and data within the scope of this project;
- Identify what types of models and data are available that can provide this information;
- Identify the current limitations of these models and data sources,
- Identify guidance to support use of data, models and analysis outputs.

Performance measures for strategic bushfire management planning

As outlined in Output 5 (Conceptual Framework) performance measures are vital to capture the things people care about in the decision-making process. Table 6: Revised fundamental objectives and performance measures (updated from Output 5) provides the fundamental objectives and associated performance measures which are specific, measurable statements that describe what is to be achieved in the context of strategic bushfire management planning. The performance measures in Table 1 provide the basis from which we identified the data and models that could support associated risk analysis strategic bushfire management planning to ensure there is a clear and logical link connecting ecological information to decision-making. Further details about the process used to generate Table 1 is provided in Output 5.

Table 7: Revised fundamental objectives and performance measures (updated from Output 5)

A user can choose as many fundamental objectives as relevant from 1-5, but only one performance measure for each objective can be chosen for trade-off analysis. A report for all objectives and measures will be generated (from the consolidated ecological module). The relevant spatial or temporal scale is not specified in this table but will be defined in the module. ¹Work by Tracey Regan informs the ‘significant impact’ thresholds, which is based on threat status (MacHunter et al. 2018). ²Iconic landscapes or species may or may not be threatened but are particularly valued by stakeholders (e.g. koalas or high profile threatened species). They are socio-ecological objectives that can be calculated using the module. ³At this stage the project team envisages that Ecological Fire Groups (EFGs) and fauna will be available as specified below however work is still underway as to the feasibility of including flora as part of performance measures 9-14 (this includes both conceptual basis of including flora and technical process).

FUNDAMENTAL OBJECTIVES	DIRECTION	PERFORMANCE MEASURES
1. Avoid decline in the persistence of ecosystems	Less is better	1. Cumulative area across EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);
		2. Cumulative area across EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		3. The proportion of minimum TFI species across ecosystems that decline in abundance by $x\%$ ¹ .
2. Avoid decline in the persistence of iconic² landscapes	Less is better	4. For examining the set of iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);
		5. For examining the set of iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		6. For examining one or more individual iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt outside TFI range (choose threshold for number of times burnt);

FUNDAMENTAL OBJECTIVES	DIRECTION	PERFORMANCE MEASURES
		7. For examining one or more individual iconic EFGs in the landscape: Cumulative area across iconic EFGs in landscape burnt below TFI range (choose threshold for number of times burnt);
		8. The proportion of minimum TFI species across ecosystems that decline in abundance by $x\%$ ¹ .
3. Minimise decline in the persistence of all plant and animal species with data³	Less is better	9. Proportion of significantly impacted faunal and flora species (e.g. decline by $x\%$ ¹ in relative abundance, occupancy, extent).
		10. Number of significantly impacted faunal and flora species (e.g. decline by $x\%$ ¹ in relative abundance, occupancy, extent).
		11. Geometric mean abundance of all faunal and flora species
4. Minimise decline in the persistence of threatened species	Less is better	12. Number of significantly impacted threatened species with data ³ (e.g. decline by $x\%$ ¹ in relative abundance, occupancy, extent).
5. Minimise decline in the persistence of iconic² species	Less is better	13. For examining a group of iconic species: Number of significantly impacted iconic species (e.g. declining by more than $x\%$ ¹ in abundance, occupancy, extent over the duration of the strategy).
		14. For examining one or more individual species: % declines in abundance, occupancy, extent over the duration of the strategy.

Review of models and data to inform performance measures

We reviewed models and data using a two-tiered approach. Firstly, we undertook a comprehensive investigation of existing and potential datasets and models that are used in DELWP's ecosystem resilience metrics (TFI, GMA and GSS) and associated performance measures (Table 6). This work consolidated information about the names and locations of datasets, the type of data (expert, field, modelled, threatened species) how the datasets are used in analyses, dataset attributes, metadata and issues (Supplementary material, Table 11).

In the second tier of the review we focused datasets underpinning performance measures relating to the objective "Minimise decline in the persistence of all plant and animal species" (9-14, Table 6). We scanned for datasets regarding species fire responses from the VBMP database, DELWP regional staff, ARI databases and external datasets identified by researchers on the project team from University of Melbourne and La Trobe University (Supplementary material, Table 12). These datasets were examined to determine their compatibility with spatial or aspatial analysis underpinning these performance measures (9-14, Table 6).

Identify species, models and data for performance measures

Which species?

The performance measures developed in collaboration with state-wide and regional risk assessment teams indicate that ideally the risk assessment process should include data on all plant and animal species (not only threatened species) and Ecological Fire Groups (EFGs). Historically the use of key fire response species (KFRS) has been used as a surrogate for other flora species (Noble and Slatyer 1980) or fauna species (MacHunter et al. 2009) but there are many issues and assumptions with this approach (e.g. the habitat needs of non KFRS species not catered for by KFRS). At a minimum including representatives based on traits could be useful but underlying assumptions needs to be made explicit as part of decision-making process.

Which models and data?

The performance measures require a combination of spatial data, aspatial data and management data. The location and purpose of these datasets in relation to each performance measures are provided in Supplementary material: List of supporting documents / datasets (Table 11).

For performances measures 9-14 (Table 6), aspatial analysis permits the use of *raw or mean* values of count data for each growth stage, EFG, species combination. Where spatial analysis is used, only *mean* values (either modelled or via expert judgement) are currently feasible for each growth stage, EFG, species combination. None of the legacy VBMP datasets or the related research datasets had modelled mean values readily available for use in the consolidated ecological module. However, in the longer term modelled data could be used should it become available (but this may require some adjustment to the module code).

Where different species survey or expert elicitation methods are used it is prudent to check for differences in detection in detection probabilities (Guillera-Aroita et al. 2014, Ficetola et al. 2018) or other assumptions (e.g. spatial context of elicitation MacHunter et al. 2015a). If detection varies it can potentially be resolved through calibration to the preferred survey method. Where detection is constant between methods, or assumptions between expert and field data are consistent, then data calibration may not be required. A sensitivity analysis undertaken in a previous ARI research project (MacHunter et al. 2017) by has shown vegetation growth stage optimisation using GMA is sensitive to the choice of calibration method. This work (Moloney, pers comm 2017) indicates the need to provide evidence / rationale to calibration rather than combining data derived from different survey methods and assuming the data are compatible.

Overview of gaps in habitat distribution models, ecosystems and species fire response

Habitat distribution models

Binary Habitat Distribution Models (HDMs) have been generated for a total of 577 vertebrate fauna species comprising 129 FFG listed and 54 EPBC listed fauna species and 448 non-threatened fauna species. The modelling methods to generate the HDMs are described in (Liu et al. 2013) which includes the use of e 18 bioclimatic, terrain and soil radiometric variables. These modelling methods were also used to generate base models for threatened flora which were modified to binary HDMs for Native Vegetation Regulation purposes (approx. 1700 species). These threatened species flora models have been thresholded for native vegetation using different post processing e.g. habitat importance model. Thresholds have not been generated for all non-threatened species models (a further ~3000 models). Currently there is no agreed method for analysing flora species in the context of any performance measure (Table 6). Future methods to include flora need to include evaluation of the flora HDMs models including appropriate post processing.

Ecosystems

In 2016 regional DELWP staff identified 13 ecological communities (EPBC) / EVCs (FFG) that are priority for considering effects of planned burning activities (either planned fire or associated mechanical damage) as part of EPBC assessments. A summary of the status of these communities is provided below (Table 7). Differences in the criteria for threatened communities across EPBC, FFG and regional lists hinders reconciliation of the ecological communities which makes spatial identification unwieldy and therefore present a gap in ecological risk assessment. Currently none of these threatened ecological communities have information that could readily incorporated into the Fire Analysis Module for Ecological values.

Table 8: Threatened ecological communities potentially effected by bushfire or planned burning activities

Type	Description	Reference	EPBC Act	FFG Act
Ecol. Comm	Gippsland Red Gum (Eucalyptus tereticornis subsp. mediana) Grassy Woodland and Associated Native	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=73&status=Critically+Endangered	Critically Endangered	
Ecol. Comm	Silurian Limestone Pomaderris Shrubland of the South East Corner and Australian Alps Bioregions	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=7	Endangered	
Ecol. Comm	White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=43	Critically Endangered	Listed
Ecol. Comm	Buloke Woodlands of the Riverina and Murray-Darling Depression Bioregions	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=3	Endangered	

Type	Description	Reference	EPBC Act	FFG Act
Ecol. Comm	Grey Box (<i>Eucalyptus microcarpa</i>) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=86&status=Endangered	Endangered	
Ecol. Comm	Natural Grasslands of the Murray Valley Plains	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=117	Critically Endangered	
Ecol. Comm	Natural Temperate Grasslands of the Victorian Volcanic Plains	http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=42	Critically Endangered	Listed
EVC	Alluvial Terraces Herb-rich Woodland (Gold0067)			Listed
EVC	Grassy Woodland (Wim_0175)			Listed
EVC	Plains Grassy Wetland (CVU_0125, DunT0125, GleP0125, WaP_0125, Wim_0125)			Listed
EVC	Plains Sedgy Wetland (CVU_0647, DunT0647, GleP0647, VVP_0647, WaP_0647, Wim_0647)			Listed
EVC	Plains Swampy Woodland (VVP_0651)			Listed
EVC	Stony Knoll Shrubland (VVP_0649)			Listed

Our review of state-wide legacy fire monitoring datasets (see Table 8) shows that there is limited flora or fauna species information (field data) in several EFGs some of which are likely to be remedied in proposed future monitoring (Leonard et al. 2018). Finer scale analyses (than at EFG level) was undertaken as part of previous work (MacHunter et al. 2015b) to examine coverage of legacy monitoring in response to topographic position and other environmental gradients such as rainfall.

Gaps in legacy flora and fauna monitoring by EFG excluding aquatic EFGs (#9, 19, 29, 30)

- 4 Heathland (sands)-X. Res. Dominant*
- 5 Heathland (sands)-Little and Big Deserts*
- 6 Heathland (sands)-General*
- 17 Closed-forest
- 20 Alpine Treeless
- 22 Western Plains Woodland
- 23 Basalt Grassland

- 24 Alluvial Plains Grassland
- 25 Dry Woodland (non-eucalypt)
- 31 Chenopod Shrubland

* subset of EFGs proposed for future state-wide monitoring (Leonard et al. 2018) that have no legacy data. See Table 8 for the list of 11 EFGs proposed for future state-wide monitoring.

Flora surveys have the most comprehensive distribution (Table 8) in terms of coverage of EFGs (22 in total). Bird surveys and camera surveys (mammals) have been surveyed in legacy programs across 13 EFGs (Table 8). The least represented groups include reptiles (2 EFGs) and frogs and insects (no EFGs sampled).

Fire response data overview

Regional prioritisation of threatened species likely to be affected by planned fire or associated mechanical disturbance were compiled by regional staff into the Bushfire Risk Landscape Biodiversity Risk Registers to use in operational planning. This statewide values list includes 82 plant species and 45 animal species (listed in Supplementary material: Regional prioritisation of species and communities). Advice from regional staff indicates that there have not been any updates to the values following transition from Bushfire Risk Landscape (BRL) to regional boundaries.

Fire response data - flora

There were 33 threatened flora species detected in legacy monitoring program data although only four of these species were included in the prioritised listed of flora species. In the clear majority of cases only one individual was detected for a species. This level of detection is inadequate to provide information / model impacts about fire on a species population persistence (Ficetola et al. 2018).

Table 10: List of threatened flora species detected in legacy fire monitoring programs in the Victorian Bushfire Monitoring database

Common name	# of detections	EPBC	Vic Advisory list
516 quadrats in Pre-post flora project			
<i>Boronia galbraithiae</i>	1	Vulnerable	Vulnerable
<i>Cassinia ozothamnoides</i>	1		Vulnerable
<i>Cololejeunea minutissima</i>	1		Vulnerable
<i>Cryptostylis erecta</i>	1		Endangered
<i>Eucalyptus litoralis</i>	4		Vulnerable
<i>Grevillea rosmarinifolia</i>	4		Infraspecific taxa
<i>Isolepis congrua</i>	1		Vulnerable
<i>Leiocarpa gatesii</i>	2	Vulnerable	Vulnerable
947 measurement events in Pre-post flora project			
<i>Acacia ausfeldii</i>	2		Vulnerable
<i>Acacia verniciflua (1-nerved variant)</i>	1		Vulnerable
<i>Acacia verniciflua (large bracteole variant)</i>	1		Vulnerable
<i>Allocasuarina luehmannii</i>	3		Endangered
<i>Brachyscome gracilis</i>	1		Infraspecific taxa
<i>Caladenia concolor</i>	1	Vulnerable	Endangered
<i>Cardamine tenuifolia</i>	1		Infraspecific taxa
<i>Chenopodium desertorum</i>	2		Vulnerable
<i>Crowea exalata subsp. revoluta</i>	1		Vulnerable
<i>Dianella tarda</i>	6		Vulnerable
<i>Geranium solanderi s.l.</i>	1		Vulnerable
<i>Glycine latrobeana</i>	1	Vulnerable	Vulnerable
<i>Olearia passerinoides</i>	1		Infraspecific taxa
<i>Phebalium festivum</i>	3		Vulnerable
<i>Polygala japonica</i>	1		Vulnerable
<i>Pomaderris apetala</i>	1		Infraspecific taxa
<i>Pomaderris oraria</i>	1		Infraspecific taxa
<i>Prasophyllum aff. pyriforme (Inglewood)</i>	1		Endangered
<i>Pterostylis chlorogramma</i>	2	Vulnerable	Vulnerable
<i>Pterostylis coccinea</i>	1		Vulnerable
<i>Pultenaea graveolens</i>	2		Vulnerable
<i>Stackhousia aspericocca</i>	2		Infraspecific taxa
<i>Thelymitra benthamiana</i>	1		Vulnerable
<i>Thelymitra pallidiflora</i>	1		Endangered
<i>Thelypteris confluens</i>	1		Endangered

Fire response data - fauna

Of those priority threatened bird species of interest, only nine threatened species were detected in legacy monitoring programs using standard 20 min / 2ha area search surveys (Table 10). Most species had fewer than five individuals detected which is insufficient to provide adequate sensitivity and accuracy to detect changes in population trends that could help inform management. The most commonly detected threatened bird species using standard area search

surveys was Spotted Quail Thrush at 54 sites (Table 10). Targeted threatened surveys using call playback were more successful than standard surveys in the number of individuals detected per survey (Table 10); from 500 surveys there were seven threatened species detected of which six species had more than 45 individuals detected.

For mammals, there were only four threatened species detected through camera surveys and four additional species detected via Elliot trapping (Table 10). Two threatened reptiles were detected via Elliot trapping surveys (Table 10). Note that the number of detections using Elliot trapping was not available when this information was exported from the VBMP database. There were no tailored bats surveys in the legacy fire monitoring program.

Table 11: List of threatened fauna species detected in legacy fire monitoring programs in the Victorian Bushfire Monitoring database

Common name	# of detections	EPBC	Vic Advisory list
703 Standard surveys (10/20 min area 2ha search) across 478 sites			
Chestnut-rumped Heathwren	7		Vulnerable
Eastern Bristlebird	4	Endangered	Endangered
Glossy Black-Cockatoo	1		Vulnerable
Rufous Bristlebird	3		Near threatened
Speckled Warbler	1		Vulnerable
Square-tailed Kite	1		Vulnerable
Spotted Quail-thrush	54		Near threatened
White-browed Treecreeper	1		Vulnerable
White-throated Needletail	10		Vulnerable
500 threatened species surveys (using call playback at 20 points along 5km transect lines) along 25 transects			
Black-eared Miner	42	Endangered	Critically endangered
Crested Bellbird	542		Near threatened
Major Mitchell's Cockatoo	4		Vulnerable
Mallee Emu-wren	65	Endangered	Endangered
Malleefowl	47	Vulnerable	Endangered
Red-lored Whistler	107	Vulnerable	Endangered
Regent Parrot	28	Vulnerable	Vulnerable
643 camera surveys across 233 sites (VBMP t582_SiteNumber)			
Long-footed Potoroo	347	Endangered	Vulnerable
Long-nosed Potoroo	4150	Vulnerable	Near threatened
Smoky Mouse	49	Endangered	Endangered
Southern Brown Bandicoot	2855	Endangered	Near threatened
98 sample points using Elliot traps (t500_SamplePointID)			
Little Pygmy-possum	NULL		Near threatened
Mallee Ningau	NULL		Near threatened
Mitchell's Hopping-mouse	NULL		Near threatened
Western Pygmy-possum	NULL		Near threatened
Western Blue-tongued Lizard	NULL		Near threatened
Yellow-faced Whip Snake	NULL		Near threatened

Current limitations of models and data sources to be used

The main limitations with the models and data used in the performance measures include:

- Use of expert data which was essentially designed for a non-quantitative (largely conceptual mapping) purpose and has been rescaled and averaged to enable inclusion in analysis. Validation of expert data is urgently needed (see Output 8 of this project for further discussion)
- Lack of species fire response data across several EFGs relevant to regional risk assessment, particularly on private land
- Lack of calibration between different survey techniques rendering data incompatible for use in analysis due to violation of model assumptions, i.e. detection may be inconsistent between methods (Guillera-Arroita et al. 2014)
- Limited understanding / evaluation regarding the effects of substituting occupancy as an index of abundance apart from rules of thumb regarding rare species (MacKenzie et al. 2005)
- Currently there is no agreed method for analysing flora species in the context of any performance measure
- Risk tolerance to uncertainty has not been elicited for the performance measures aside from those generated in a related project (MacHunter et al. 2018) regarding significant impact thresholds at the state-wide scale for EPBC matters of significance

- Ownership and use of HDMs including setting binary thresholds for analysis
- Interactions between time since fire and other factors such as climate change, predations and other elements has not been accounted for (see Output 8 of this project for further discussion)
- Fire history is less accurate further back in time e.g. fire severity is often inferred from fire type (planned or bushfire) and only recently contains a more nuanced view based on aerial and on ground mapping)
- Intermittent resourcing of data curation has hampered effective access to data in the VBMP database

Guidance to support ecological analysis underpinning SBMP

The following documents will be included as supporting material for the consolidated module.

1. For spatial GSO and changes in relative abundance
 - “Guide to Geometric Mean of Abundance (GMA) Analyses and Vegetation Growth Stage Structure (GSS) Optimisation (Guide+to+GSS+and+GMA+Analyses+v9+20171220.docx)
 - MacHunter, J., et al. (2009). Towards a process for Integrating Vertebrate Fauna into Fire Management Planning. Heidelberg, Victoria, Arthur Rylah Institute for Environmental Research: 48.
 - Work undertaken as part of the GMA / GSS and FFO database refinement 2015/16
2. For spatial GSO and changes in relative abundance
 - Manual will be produced in line with consolidated module
3. For information relating to vegetation growth stages and TFIs
 - Cheal, D. (2010). Growth stages and tolerable fire intervals for Victoria's native vegetation data sets. East Melbourne, Victoria, Department of Sustainability and Environment.
4. For metadata not already in CSDL
 - EFGs (note that TFIs look up table in CSDL)
 - Flora vital attributes
 - Fauna vital attributes
 - HDMs
5. For the decision-making process
 - Garrard GE, Rumpff L, Runge MC & Converse SJ (2017) Rapid prototyping for decision structuring: an efficient approach to conservation decision analysis. In Bunnefeld N, Nicholson E & Milner-Gulland EJ (Eds) Decision-making in conservation and natural resource management: models for interdisciplinary approaches, Cambridge University Press.
 - MacHunter, J., et al. (2018). Refinement of EPBC Act Assessment Process. Unpublished Client Report for the Forest Fire and Regions Division. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Future work in improving data and models for risk assessment

- Develop an analysis approach and datasets to support flora-based performance measures (e.g. review recent work by Chick 2018)
- Calibrate species response data derived from different survey methods (see Output 8 for further discussion) and encourage consistency of methods for future data collection (reviewing methods from MER scientifically based monitoring project).
- Determine which survey and modelling methods are appropriate for each species including an estimate of detection probabilities to evaluate if species are likely to be detected with proposed method e.g. occupancy as an index of abundance if a species is rare. Table 9 and Table 10 indicate that the state-wide survey methods from MER scientifically based monitoring project (Leonard et al. 2018) are unlikely to provide adequate data for rare species. This suggests that the regional monitoring tier would be more appropriate for rare species providing there is coordination across regional boundaries regarding survey design so that the resulting monitoring data can be used in different regions.
- Annual review of the suitability of the performance measures and associated data to determine if there are critical uncertainties and / or any changes in the decision context in which data is being applied e.g. inclusion of ecological values on private land (see Output 8).
- Review and spatially map the ecological communities across different legislation (EPBC, FFG).

- Develop agreements to access data from university research that have used compatible survey methods (e.g. see Table 12 in Supplementary material: List of supporting documents / datasets)
- Ongoing curation of VBMP database
 - Consolidate research data into VBMP database in a format that is compatible with ERP1 module analysis methods.
 - Aspatial analysis: for each TSF / EFG combination provide: mean values, upper and lower 95% CI's, raw count data and calibration factor if using non-standard survey methods. In future provide distribution of modelled values.
 - Spatial analysis: for each TSF / EFG combination provide: mean values, upper and lower 95% CI's
 - As new data is consolidated in the VBMP database, develop an automated process to report on knowledge gaps (distinct from critical uncertainty – see further discussion in Output 8) at the species level for each EFG, TSF combination that can be aggregated to broader growth stages and taxonomic group. This information will can assist with promoting the value of the database and communicate findings from monitoring to date (Robinson et al. 2018).

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Supplementary material: List of supporting documents / datasets

Table 12: Datasets used in ecosystem resilience

Data Source	Brief description	Comments	Collation of Data	Data type	Performance measure (see Table 1)	Location of data
NV2005_LSIMP.shp NV2005_CONN10.shp	Connectivity - to inform landscape unit for analysis	This is a derived dataset that rates the landscape between existing native vegetation according to its proximity to native vegetation and contribution to landscape connectivity for biodiversity. It indicates potential connectivity for a range of mobile species. Note: that this view of connectivity does NOT include barriers to movement of individual species, or any assessment of the potential recoverability of the landscape. It is created from spatial analysis of native vegetation as described in NV2005_EXTENT	Yes Done	Ecological spatial data	1-14	Previously on CSDL but no longer published there. Copy stored at: J:\Community Ecology\Projects - shared\Fire\2017 BNHCRC Eco Model Consolidation\Output_2_3_4\nv2005_conn10.zip
LMUs	Sub-regional units that form the basis for landscape scale analysis and summaries	Opportunity to compile a state-wide dataset comprising LMUs from across the state. At the moment the module user can load their LMU according to shapefile specifications	Future work	Management spatial data	1-14	Regional
HDM_V5_Thresholded_100percent_Mask	Raster Binary HDMs for Fauna threatened and non-threatened species	Models for 577 fauna taxa at 225 and 75metre raster resolution. Data is used in GMA and relative abundance calculations to identify fauna species in study area. Spatial extent of area considered in assessment of fire effects on species. The HDMs and thresholding methods were developed by Ecological Analysis and Synthesis group at Arthur Rylah Institute.	Complete	Ecological spatial data	8-14	TBA, currently stored as data sources in draft ERP-1 module

Data Source	Brief description	Comments	Collation of Data	Data type	Performance measure (see Table 1)	Location of data
HDM-V5 Flora and Flora Mutispecies models for many non-treated species	Raster Binary HDMS for Flora species	Simple binary thresholded HDMS have not been produced for all these species. For threatened flora, binary HDMS that have been modified for Native Vegetation Regulation purpose with further post processing have been created (approx. 1700 species). Thresholds have not been generated for all non-threatened species models (a further ~3000 models). Currently there is no analysis process for incorporating flora into performance measures, so the models are not incorporated in the ERP1 module.	Future work	Ecological spatial data	3, 8-14	Future work
Future Fauna Occupancy v4.0.0_160321.mdb; TBL_abundance	Expert judgment of fauna abundance data by four growth stages in a selection of EFGs	Data needed for GSO, GMA, individual species spatial relative abundance calculations. Includes fauna species included in the FFO. Extract table and provide metadata version. Longer term store data in the VBMP database.	In progress	Ecological spatial data	9-14	EMDrive:\60-Reference\JointProjects\FireEcology\Statewide\5. Information Management\Future Fauna Occupancy Project\Future Fauna Occupancy Database July 2015
Raw data in Victorian Bushfire Monitoring Program database	Field data collated in the Victorian Bushfire Monitoring Program database	Data needed for GSO, GMA, individual species spatial relative abundance calculations. See worksheet "Tabulation sp resp data" which include data from state-wide legacy fire monitoring Extract from Thu Phan in 2018 lacks key information regarding EFG and Time Since Fire Cross checking against ARI databases underway If data is to be combined in GSO then a process is needed to calibrate different survey methods	In progress to develop a system to export necessary data from VBMP database to ERP1 module	Ecological spatial data	9-14	Victorian Bushfire Monitoring Program database

Data Source	Brief description	Comments	Collation of Data	Data type	Performance measure (see Table 1)	Location of data
Flora Vital attributes and KFRS dataset	Expert and field derived data on plant life history traits	Archived version available. Database with previous updated annual via ARI PP Division agreement. Note that other trait datasets may be of interest e.g. Flora Traits Dataset (Carr, White, Sinclair et al) which is more comprehensive but broader classes than Vital Attributes Dataset. Useful to identify species that may be sensitive to fire intervals. Matt White has used in mapping fire sensitive species across the landscape. Nevil Amos used in proof of concept fire vulnerability of flora mapping.	Future work	Ecological aspatial data	3, 8	J:\Biodiversity Research\Vital Atts\Flora_VA_Data_Dec2017.xlsx
VBA_FAUNA25 VBA_FAUNA100	Species location records from the Victorian Biodiversity Atlas (VBA)	Maybe used in selection of fauna species for GSO but now redundant if HDMs are used. Regional staff may use this data in lieu of expert judgement of species response to provide a view of occupancy.	Corporate data	Ecological spatial data	9-14 (don't envisage providing a process for VBA data in current module)	CDSL (J:\GIS_public\CSDL\FLOFAUNA1.gdb\VBA_FAUNA25 J:\GIS_public\CSDL\FLOFAUNA1.gdb\VBA_FAUNA100)
TBL_EFG_BGS TBL_GS_BGS_L UT TBL_BGS_Names	Tables to identify growth stages and vegetation units (expert derived)	Need to move away from FFO database tables - suggest that the currently derived time since fire. Lookup table becomes the origin for growth stages - allows it to deal with multiple nuances of growth stages (at least down to annual breaks - thresholds that are not integers of year may be problematic. Store consolidated LU table: EFG, TSF, TFI, 4GS, Cheal GS.	Future work to store this consolidate LU table in CSDL or VBMP database	Ecological aspatial data	9-14	EMDrive :\60-Reference\JointProjects\FireEcology\Statewide\5. Information Management\Future Fauna Occupancy Project\Future Fauna Occupancy Database July 2015

Data Source	Brief description	Comments	Collation of Data	Data type	Performance measure (see Table 1)	Location of data
evdefg_rc2.shp	Vegetation classes and their fire related attributes	This is a derived layer summarising base ecological fire categories. There is no metadata file accompanying EVD_EFG RC2v2 however v1 metadata document in same location as v2 file: EVDEFG_RC1 https://emdrive.ffm.vic.gov.au/ServicesPortal/#/cloudDrive/Shared%2520With%2520Me/EM%2520Drive/60-Reference/JointProjects/FireEcology/Statewide/5.%2520Information%2520Management/GIS%2520Data/EVD_EFG_ReadMe_EVDEFG_RC1.doc Recommend layer to be formalised through CSDL.	In progress	Ecological spatial data	1-14	https://emdrive.ffm.vic.gov.au/ServicesPortal/#/cloudDrive/Shared%2520With%2520Me/EM%2520Drive/60-Reference/JointProjects/FireEcology/Statewide/5.%2520Information%2520Management/GIS%2520Data/EVD_EFG
Ecological Fire Group Attributes lookup tables	Look up tables to derive tolerable fire intervals and growth stage (expert derived)	This information is used in TFI performance measures	Corporate data	Ecological spatial data	1, 2, 4-7	J:\GIS_public\CSDL\FIREECO.gdb\EFG_EVD_GROWTH_STAGES J:\GIS_public\CSDL\FIREECO.gdb\EFG_EVD_TFI
FIRE_HISTORY	Fire History - provides the past and current fire history	Used in past, present fire sequences, types (planned or bushfire) and fire intervals. Many issues but best readily available information for Fire history e.g. regional staff may prefer local fire history amendments. Need to develop a path to link ERP 1 module to latest fire history – to discuss with Andrew Blackett	Corporate data	Management spatial data	1-14	CDSL

Data Source	Brief description	Comments	Collation of Data	Data type	Performance measure (see Table 1)	Location of data
FIRE_FUTURES	Regional files showing FOPs and alternative strategies	Input data from regional staff showing future fire history.	Template for use in module	Management spatial data	1-14	Template for use in ERP1 module
FIREFMZ	Fire management zones	Used in summary analyses.	Corporate data	Management spatial data	1-14	CDSL
Burn Units spatial layer	Individual burn units provided by regions	Potentially could be used in summary analyses at burn unit level but not anticipating inclusion in ERP 1 module.	Future work	Management spatial data	1-14	J:\GIS_public\GISDesk\GIS Data\RegionalData.gdb\BLD_DSE_BURNUNITS_DRAFT

Table 13: Summary of survey methods for legacy fire monitoring program and related fire research

Program	Birds	Mammals	Reptiles	Flora
ARI Fire Ecology Retrospective/ Gippsland Hawkeye	20 min / 2 ha area-search	Camera Trapping		Multi quadrat arrangement
Fire Division Landscape Mosaic Burn LMB Project	20 min / 2 ha area-search	Camera Trapping		Frequency along transect
	Uncertain, Mallee Bird technique or 2ha 20 min counts			
Pre and Post Fire				Quadrats, Indicator species
Mallee Hawkeye	Mallee Bird technique (transects and points)	Pitfall	Pitfall	
	Threatened species playback			
Hawkeye Otways	Point Count 1.58ha	Camera Trapping		Non-standard quadrat
		Elliot trapping		
*Mallee Fire and Biodiversity	Mallee Bird technique (transects and points)	Pitfall	Pitfall	Quadrat 10mx50m-perennial species only
*Otway Fire, Landscape Pattern and Biodiversity Study		Camera		Intervals along transect
	Point Count 1.58ha	Elliot trapping		
*Fauna Refuges	Point Count	Camera Trapping	Elliot trapping	Nested Quadrats
		Spotlight survey		
*Fire Effects Study Areas (ARI_FESA)	20 min / 2 ha area-search	Camera trapping		

* data not currently (May 2018) in Victorian Bushfire Monitoring Program database

Supplementary material: Regional prioritisation of species and communities

Table 14: Regional prioritisation of species and associated threat status

Priority group: T. Fauna – terrestrial fauna

Primary	Taxon	Taxon	Common name	Scientific name	EPBC	FFG	VIC
T. fauna	Reptiles	12987	Alpine She-oak Skink	<i>Cyclodomorphus praealtus</i>	Endangered	Listed	Critically
T. fauna	Amphibians	63907	Alpine Tree Frog	<i>Litoria verreauxii alpina</i>	Vulnerable	Listed	Critically
T. fauna	Other Non-	10170	Australian Painted Snipe	<i>Rostratula australis</i>	Endangered	Listed	Critically
T. fauna	Amphibians	13106	Baw Baw Frog	<i>Philoria frosti</i>	Endangered	Listed	Critically
T. fauna	Passerine birds	10967	Black-eared Miner	<i>Manorina melanotis</i>	Endangered	Listed	Critically
T. fauna	Amphibians	13168	Booroolong Tree Frog	<i>Litoria booroolongensis</i>	Endangered	Listed	Critically
T. fauna	Mammals	11215	Brush-tailed Rock-wallaby	<i>Petrogale penicillata</i>	Vulnerable	Listed	Critically
T. fauna	Passerine birds	10524	Australian Reed Warbler	<i>Acrocephalus australis</i>			
T. fauna	Bats	61343	Common Bent-wing Bat (Southern Species)	<i>Miniopterus schreibersii bassanii</i>	Critically	Listed	Critically
T. fauna	Amphibians	13042	Giant Burrowing Frog	<i>Heleioporus australiacus</i>	Vulnerable	Listed	Critically
T. fauna	Invertebrates	15021	Golden Sun Moth	<i>Synemon plana</i>	Critically	Listed	Critically
T. fauna	Bats	61332	South-eastern Long-eared Bat	<i>Nyctophilus corbeni</i>	Vulnerable	Listed	Endangered
T. fauna	Bats	11280	Grey-headed Flying-fox	<i>Pteropus poliocephalus</i>	Vulnerable	Listed	Vulnerable
T. fauna	Amphibians	13207	Growling Grass Frog	<i>Litoria raniformis</i>	Vulnerable	Listed	Endangered
T. fauna	Reptiles	12432	Guthega Skink	<i>Liopholis guthega</i>	Endangered	Listed	Critically
T. fauna	Mammals	11468	Heath Mouse	<i>Pseudomys shortridgei</i>	Endangered	Listed	Near threatened
T. fauna	Other Non-	10168	Latham's Snipe	<i>Gallinago hardwickii</i>			Near threatened
T. fauna	Mammals	11141	Leadbeater's Possum	<i>Gymnobelideus leadbeateri</i>	Critically	Listed	Endangered
T. fauna	Mammals	11179	Long-footed Potoroo	<i>Potorous longipes</i>	Endangered	Listed	Vulnerable
T. fauna	Mammals	11175	Long-nosed Potoroo	<i>Potorous tridactylus trisulcatus</i>	Vulnerable	Listed	Near threatened
T. fauna	Passerine birds	10527	Mallee Emu-wren	<i>Stipiturus mallee</i>	Endangered	Listed	Endangered
T. fauna	Other Non-	10007	Malleefowl	<i>Leipoa ocellata</i>	Vulnerable	Listed	Endangered
T. fauna	Mammals	11156	Mountain Pygmy-possum	<i>Burrhamys parvus</i>	Endangered	Listed	Critically
Aquatic	Fish	4871	Murray Cod	<i>Maccullochella peelii</i>	Vulnerable	Listed	Vulnerable
Aquatic	Fish	4784	Murray Hardyhead	<i>Craterocephalus fluviatilis</i>	Endangered	Listed	Critically
T. fauna	Mammals	11455	New Holland Mouse	<i>Pseudomys novaehollandiae</i>	Vulnerable	Listed	Vulnerable
T. fauna	Other Non-	10305	Orange-bellied Parrot	<i>Neophema chrysogaster</i>	Critically	Listed	Critically
T. fauna	Reptiles	12144	Pink-tailed Worm-Lizard	<i>Aprasia parapulchella</i>	Vulnerable	Listed	Endangered
T. fauna	Other Non-	10020	Plains-wanderer	<i>Pedionomus torquatus</i>	Critically	Listed	Critically
T. fauna	Other Non-	10329	Rainbow Bee-eater	<i>Merops ornatus</i>			
T. fauna	Passerine birds	10402	Red-lored Whistler	<i>Pachycephala rufogularis</i>	Vulnerable	Listed	Endangered
T. fauna	Other Non-	10264	Red-tailed Black-Cockatoo (south-eastern)	<i>Calyptorhynchus banksii graptogyne</i>	Endangered	Listed	Endangered
T. fauna	Passerine birds	10603	Regent Honeyeater	<i>Anthochaera phrygia</i>	Critically	Listed	Critically
T. fauna	Other Non-	10278	Regent Parrot	<i>Polytelis anthopeplus</i>	Vulnerable	Listed	Vulnerable

Primary	Taxon	Taxon	Common name	Scientific name	EPBC	FFG	VIC
T. fauna	Passerine birds	10362	Rufous Fantail	<i>Rhipidura rufifrons</i>			
T. fauna	Passerine birds	10366	Satin Flycatcher	<i>Myiagra cyanoleuca</i>			
T. fauna	Mammals	11458	Smoky Mouse	<i>Pseudomys fumeus</i>	Endangered	Listed	Endangered
T. fauna	Mammals	61092	Southern Brown Bandicoot	<i>Isoodon obesulus obesulus</i>	Endangered	Listed	Near threatened
T. fauna	Mammals	11008	Spot-tailed Quoll	<i>Dasyurus maculatus maculatus</i>	Endangered	Listed	Endangered
T. fauna	Amphibians	13195	Spotted Tree Frog	<i>Litoria spenceri</i>	Endangered	Listed	Critically
T. fauna	Reptiles	12159	Striped Legless Lizard	<i>Delma impar</i>	Vulnerable	Listed	Endangered
T. fauna	Other Non-	10277	Superb Parrot	<i>Polytelis swainsonii</i>	Vulnerable	Listed	Endangered
T. fauna	Other Non-	10309	Swift Parrot	<i>Lathamus discolor</i>	Critically	Listed	Endangered
T. fauna	Passerine birds	10422	Western Whipbird (Mallee)	<i>Psophodes nigrogularis leucogaster</i>	Vulnerable	Listed	Critically
T. fauna	Other Non-	10226	White-bellied Sea-Eagle	<i>Haliaeetus leucogaster</i>		Listed	Vulnerable
Flora	Dicotyledons	503744	Anglesea Grevillea	<i>Grevillea infecunda</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	504555	Aniseed Boronia	<i>Boronia galbraithiae</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	503389	Austral Toad-flax	<i>Thesium australe</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	500588	Bald-tip Beard-orchid	<i>Calochilus richiae</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	504156	Basalt Rustyhood	<i>Pterostylis basaltica</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	503761	Bead Glasswort	<i>Tecticornia flabelliformis</i>	Vulnerable	Listed	Endangered
Flora	Dicotyledons	501535	Ben Major Grevillea	<i>Grevillea floripendula</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	501340	Bogong Eyebright	<i>Euphrasia eichleri</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	500522	Candy Spider-orchid	<i>Caladenia versicolor</i>	Vulnerable	Listed	Endangered
Flora	Dicotyledons	502099	Chariot Wheels	<i>Maireana cheelii</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	503726	Charming Spider-orchid	<i>Caladenia amoena</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	501456	Clover Glycine	<i>Glycine latrobeana</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	503986	Club Spear-grass	<i>Austrostipa nullanulla</i>			Vulnerable
Flora	Monocotyledons	503729	Colourful Spider-orchid	<i>Caladenia colorata</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504716	Colquhoun Grevillea	<i>Grevillea celata</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	504532	Concave Pomaderris	<i>Pomaderris subplicata</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	504347	Crimson Spider-orchid	<i>Caladenia concolor</i>	Vulnerable	Listed	Endangered
Flora	Monocotyledons	500650	Curly Sedge	<i>Carex tasmanica</i>		Listed	Vulnerable
Flora	Dicotyledons	505087	Dergholm Guinea-flower	<i>Hibbertia humifusa subsp. debilis</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	503936	Desert Greenhood	<i>Pterostylis xerophila</i>	Vulnerable	Listed	Endangered
Flora	Dicotyledons	500300	Downy Star-Bush	<i>Asterolasia phebaloides</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	501476	Dwarf Yellow-heads	<i>Trichanthodium baracchianum</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	504486	Elegant Spider-orchid	<i>Caladenia formosa</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	503743	Enfield Grevillea	<i>Grevillea bedggoodiana</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	501909	Erect Peppercross	<i>Lepidium pseudopapillosum</i>	Vulnerable	Listed	Endangered
Flora	Dicotyledons	500352	Fern-leaf Baeckea	<i>Sannantha crenulata</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	503916	Floodplain Rustyhood	<i>Pterostylis cheraphila</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	504567	Fragrant Leek-orchid	<i>Prasophyllum suaveolens</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	500771	French Island Spider-orchid	<i>Caladenia insularis</i>	Vulnerable	Listed	Vulnerable

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Flora	Monocotyledons	502706	Gorae Leek-orchid	<i>Prasophyllum diversiflorum</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504423	Grampians Bitter-pea	<i>Daviesia laevis</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	500431	Grampians Pincushion-lily	<i>Borya mirabilis</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	502532	Grampians Rice-flower	<i>Pimelea pagophila</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	504728	Green-striped Greenhood	<i>Pterostylis chlorogramma</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	500039	Hairy-pod Wattle	<i>Acacia glandulicarpa</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	500032	Jumping-jack Wattle	<i>Acacia enterocarpa</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504534	Langi Ghiran Grevillea	<i>Grevillea montis-cole subsp.</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	502790	Leafy Greenhood	<i>Pterostylis cucullata</i>	Vulnerable	Listed	All infraspecific
Flora	Dicotyledons	503633	Limestone Blue Wattle	<i>Acacia caeruleascens</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	500525	Limestone Spider-orchid	<i>Caladenia calcicola</i>	Vulnerable	Listed	Endangered
Flora	Monocotyledons	503669	Little Pink Spider-orchid	<i>Caladenia rosella</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	502486	Lowan Phebalium	<i>Phebalium lowanense</i>	Vulnerable		Vulnerable
Flora	Monocotyledons	503957	Lowly Greenhood	<i>Pterostylis despectans</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	502709	Maroon Leek-orchid	<i>Prasophyllum frenchii</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	505084	Matted Flax-lily	<i>Dianella amoena</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	504348	Mellblom's Spider-orchid	<i>Caladenia hastata</i>	Endangered	Listed	Endangered
Flora	Monocotyledons	503367	Metallic Sun-orchid	<i>Thelymitra epipactoides</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	503326	Mountain Swainson-pea	<i>Swainsona recta</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	500465	Mueller Daisy	<i>Brachyscome muelleroides</i>	Vulnerable	Listed	Endangered
Flora	Monocotyledons	504343	Ornate Pink-fingers	<i>Caladenia ornata</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	502724	Pomonal Leek-orchid	<i>Prasophyllum subbisectum</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	501338	Purple Eyebright	<i>Euphrasia collina</i>			
Flora	Dicotyledons	503324	Red Swainson-pea	<i>Swainsona plagiotropis</i>	Vulnerable	Listed	Endangered
Flora	Dicotyledons	502257	Ridged Water-milfoil	<i>Myriophyllum porcatum</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	500338	Rigid Spider-orchid	<i>Caladenia tensa</i>	Endangered		Vulnerable
Flora	Monocotyledons	503623	River Swamp Wallaby-grass	<i>Amphibromus fluitans</i>	Vulnerable	Rejected	
Flora	Dicotyledons	503321	Slender Darling-pea	<i>Swainsona murrayana</i>	Vulnerable	Listed	Endangered
Flora	Monocotyledons	501473	Small Golden Moths	<i>Diuris basaltica</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	502729	Snow Pratia	<i>Lobelia gelida</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	501217	Southern Pipewort	<i>Eriocaulon australasicum</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	508115	Southern Shepherd's Purse	<i>Ballantinia (monotypic)</i>			
Flora	Dicotyledons	503894	Spiny Rice-flower	<i>Pimelea spinescens</i>		Listed	All infraspecific
Flora	Monocotyledons	503378	Spiral Sun-orchid	<i>Thelymitra matthewsii</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	503101	Stiff Groundsel	<i>Senecio behrianus</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504558	Strzelecki Gum	<i>Eucalyptus strzeleckii</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	503763	Swamp Everlasting	<i>Xerochrysum palustre</i>	Vulnerable	Listed	Vulnerable
Flora	Monocotyledons	504498	Tawny Spider-orchid	<i>Caladenia fulva</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	501339	Thick Eyebright	<i>Euphrasia crassiuscula</i>			All infraspecific
Flora	Monocotyledons	500547	Thick-lip Spider-orchid	<i>Caladenia tessellata</i>	Vulnerable		Vulnerable

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Flora	Dicotyledons	501090	Trailing Hop-bush	<i>Dodonaea procumbens</i>	Vulnerable		Vulnerable
Flora	Dicotyledons	503991	Turnip Copperburr	<i>Sclerolaena napiformis</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	503928	Wellington Mint-bush	<i>Prostanthera galbraithiae</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	500569	Western Water-starwort	<i>Callitriche cyclocarpa</i>			
Flora	Dicotyledons	503567	Whipstick Westringia	<i>Westringia crassifolia</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504581	White Sunray	<i>Leucochrysum albicans subsp.</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504824	Wimmera Rice-flower	<i>Pimelea spinescens subsp.</i>	Critically	Listed	Endangered
Flora	Monocotyledons	500676	Wimmera Spider-orchid	<i>Caladenia lowanensis</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	501905	Winged Peppercross	<i>Lepidium monoplocoides</i>	Endangered	Listed	Endangered
Flora	Dicotyledons	504358	Wrinkled Cassinia	<i>Cassinia rugata</i>	Vulnerable	Listed	Vulnerable
Flora	Dicotyledons	503317	Yellow Swainson-pea	<i>Swainsona pyrophila</i>	Vulnerable		Vulnerable
Flora	Monocotyledons	504691	Yellow-lip Spider-orchid	<i>Caladenia xanthochila</i>	Endangered	Listed	Endangered

