Integrated Forest Ecosystem Research (IFER)

Program outcomes 2010-16

THE UNIVERSITY OF MELBOURNE

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Cover: Mountain Ash trees at Powelltown, February 2014 (photograph courtesy Sabine Kasel).

Contents

Executive summary

This report provides information on the Integrated Forest Ecosystem Research (IFER) agreement between the Department of Environment, Land, Water and Planning (DELWP) and the University of Melbourne (UM). The agreement reflects a synergistic relationship, in which targeted research on the effects of fire regimes in forests, undertaken by UM, better informs policy and management within DELWP.

Research targets a range of pertinent and overarching core themes at the landscape scale, the scale at which management regimes are applied. The themes include forest biodiversity, carbon, socio-economics, water, hazards, vulnerability and health. These are brought together in a final integrative approach.

The research from 2010 to 2016 has helped to shape a range of DELWP polices and management practises. DELWP is now better informed about the design of planned burning regimes to benefit biodiversity and minimise carbon loss; it has improved the predictability of bushfire behaviour, so that suppression is better targeted to minimise environmental, and social and economic damage; and the development of risk assessment tools has enabled better prediction of post-fire water hazards, like contamination, debris flows and flooding.

A summary of all the Integrated Forest Ecosystem Research from 2010-16 and its applications to DELWP policy and management practices within each core theme, is given in the following Table 1.

Figure 1: Researchers collecting data at a planned burn (photograph courtesy Patrick Lane)

Table 1: Summary of IFER Projects from 2010 to 2016

Core Theme	Project Description	Results and scientific achievements	Applying the research	Opportunities, extra benefits and collaboration
Landscape biodiversity	Research examined the effects of landscape scale planned mosaic burning on biodiversity.	The background report *'Fire and adaptive management*' provides support for the research program. Research has provided a framework for understanding the effects of fire on mammal and bird biodiversity. Integration with the *Otways Ranges Hawkeye monitoring project* provides a framework for long term biodiversity monitoring in the Great Otway National Park.	There are two main management outcomes: Managers can use the results to make decisions on the frequency and severity of planned burns; Managers can explore planned burning scenarios that foster biodiversity at landscape scales.	Project was incorporated into a DELWP funded multi-disciplinary *Landscape Mosaic Burning Program* with a consortium of Universities, providing an understanding of planned burning across Victoria. Under Bushfire CRC management and DELWP funding, the consortium examined gaps in our knowledge in '*Managing Scale and Uncertainty in Fire Management Planning*' and '*Foothills Fire and Biota Project*'.
Landscape carbon	Research measured the quantity of carbon stored in Victoria's forests, how it is affected by bushfire, other natural phenomena, and management.	Planned burning involves a carbon cost. Carbon costs of severe bushfire could be much greater, particularly if established trees are killed by bushfire. Broad-scale patterns in Victoria's carbon stores were shaped more by inherent drivers like climate and topography than management practices. Confirmed estimates of forest carbon published in '*Victorian State of Forests Report*' were robust, supporting *DELWP's Victorian Fire Monitoring Program (VFMP*). Establishment of the Victorian Forest Carbon Modelling Framework for examining risks and opportunities in forest carbon management.	The research provides: A strong basis for making informed decisions about planned burning regimes in dry sclerophyll forest: ten yearly burning (*cf.* 3) and burning in spring rather than autumn minimises carbon loss and maintains a future capacity to fix carbon. A basis for assessing the relative carbon costs of planned burning regimes and bushfires. A review-based method and algorithms to convert *VFMP* data to reportable carbon pools. Evidence that informed policy discussions on carbon accounting between Victorian and Commonwealth governments in *Kyoto Protocol* negotiations (including how the Commonwealth considers fire management in native forest). Enhanced capacity to model the relative effects of natural and management drivers on forest carbon at landscape scales.	Contributed to a broader project led by CSIRO, lauded by the carbon offset industry that responds directly to policy priorities set out by the Victorian Government in its *Environmental partnerships* document. Improved research novelty and capacity through external funding (Department of the Environment Biodiversity Fund, ARC Linkage Grant). Supplementary projects (e.g. Soil Carbon under Biodiverse Woody Vegetation) have allowed DELWP to integrate soil carbon benefits with above ground biomass helping farmers benefit from Commonwealth's *Carbon Farming Initiative.*
Landscape Integration – social and economics	Research examined ways to reduce the human costs of bushfire through better forest management and predicting fire behaviour.	Development of the model PHOENIX RapidFire. Improved methods for representing the landscape properties that affect fire, including fuel dynamics and moisture. The development of methods for assessing the performance of fire prediction models. The development of methods for assessing risk using ensembles of fire simulations. New methods for tracking fires, including using radar and emergency phone calls, and predicting vehicular travel.	DELWP uses PHOENIX RapidFire to predict the movement of fires, issue warnings and set priorities for fire suppression. DELWP risk landscape teams use PHOENIX RapidFire to assess fire risk and options for planned burning to prevent damage to life and property. This is done to prioritise management activities as part of a risk based framework. PHOENIX RapidFire is key to applying *Code of Fire Management Practice* and in addressing recommendations of the 2009 Bushfires Royal Commission. Outcomes of research have been integrated into training programs for DELWP staff.	Collaborative relationships across Australia have led to new research on fuel input data, fuel moisture estimation across the landscape, the use of weather radar data for monitoring fire spread, smoke plumes and fire convection column development. Collaborations have brought greater credibility to PHOENIX RapidFire, enabled it to be tested in a wider range of environments, and confirmed the robustness of its design. Outside Victoria, PHOENIX RapidFire is now used operationally in Tasmania, South Australia, Queensland and New South Wales.
Landscape vulnerability and health	Research examined the factors influencing the vulnerability and resilience of significant tree species and ecosystems at the landscape scale.	Parameterisation of the landscape simulation model, LANDIS-II, allows exploration of the role of management, fire and climate on species and ecosystem distributions, both in time and space. Establishment of a network of more than 285 plots, across a topographic and fire history gradient has created a foundation for testing and validating the growth stage model developed by DELWP.	Development and application of tools to explore the vulnerability and resilience of forest tree species and ecosystems to climate, management and fire over time. Inform policies for forest management and planned burning, climate change adaptation, and the validity of growth stage modelling within DELWP. Policy implications for decision makers under the *Victorian Climate Change Act 2010*, which requires the preparation of a '*Climate Change Adaptation Plan'.* Relates directly to the S*ustainability Charter 2007*, providing information to managers on forest health and productivity, in accordance with the *Sustainable Forests (Timber) Act 2004*. Influences planning through *Bushfire Risk Management Planning Reform* process.	Collaborating with the Royal Botanic Gardens, CSIRO and ARI has improved the modelling of species' responses to environmental variation, and the ability to address management questions. The research has led to a successful ARC Linkage proposal, which aims to develop socially relevant indicators for testing alternative scenarios of sustainable forest management in the Central Highlands area. The research capitalised on modelling tools and datasets (Asia-Pacific Forest Network for Sustainable Forest Management and Rehabilitation grant) to test adaptation strategies that reduce the impacts of climate change on the Central Highlands forests.

Table 1 cont.: Summary of IFER Projects from 2010 to 2016

Core Theme	Project Description	Results and scientific achievements	Applying the research	Opportunities, extra benefits and collaboration
Landscape water	Research examined fundamental gaps in our knowledge of the impacts of fire on water yield and quality.	Ability to model water yield after fires of different intensities. Greater understanding of the water-use dynamics of Ash and mixed-species stands under variable climate. Better understanding of scaling issues, spatial variability of evapotranspiration and use of remote sensing. Discovery of crucial role of post-fire debris flows in water supply contamination in south-east Australian forests. Discovery of large runoff scaling effects in burnt forests, and understanding of the processes driving the effects. Improved capacity to predict runoff and erosion after fire.	New research has been quickly integrated into policy and planning e.g.: Development of risk assessment tools for post-fire hydrologic hazards (e.g. water contamination, debris flows, flash flooding) used routinely by DELWP's Bushfire Rapid Response Assessment Teams (BRRAT's); Evaluation of risks of water supply contamination under different fire management scenarios, and results applied in the development of the '*Strategic Bushfire Management Plan: East Central Bushfire Risk Landscape*' and in other bushfire risk landscapes; Application of research to model the effects of 2009 Black Saturday bushfires on long term water yield and evaluate alternative fire management scenarios as part of DELWP's *Bushfire Risk Landscape* planning process using the HydroFire model.	Collaboration with a range of organisations has: Improved modelling of post-fire water quality, and helped to integrate PHOENIX RapidFire into hydrologic risk models; Improved modelling of evapotranspiration and water yield under undisturbed and disturbed conditions, and to better understand the effect of bushfire on tree mortality, water use and catchment water yield; Led to completion of a pilot study in the Otway region, a forerunner to the Strategic Bushfire Risk Landscapes approach DELWP follows across Victoria; Partner funding for two ARC Linkage grants that have and will contribute significantly to the Core project aims.
Landscape Socio-economics	Research examines community values in relation to forests and fire.	Insights to diverse values of the Victorian public in relation to public land, forests, and fire prone landscapes. Conceptual frameworks developed to facilitate the incorporation of values in strategic planning. Identification of socially relevant indicators of sustainable forest management. Integration of social and ecological sciences to model the outcomes of socially relevant indicators using a range of management scenarios.	Potential for policy and decision making frameworks to be better aligned with values of the Victorian public. Potential for State of the Forest reporting to present outcomes in ways that have greater meaning to the Victorian public.	The research was funded from 2012 and entirely through supplementary projects and through an Australian Research Council Linkage grant, but contributes to core goals and themes of the IFER program.
Landscape integration	Developed ways of integrating core themes in decisions about bushfire response and forest management.	Discussions between DELWP and Melbourne University have created: A shared understanding of the influence that research evidence can have on policy; A better understanding and appreciation of their respective operating contexts, objectives and operating environments; A strong common vision and ambition to conduct world-class quality research.	The substantive landscape integration research will continue in future phases of the IFER program. Groundwork in policy, sharing goals and building relationships has improved the results of the IFER 2010–16 research.	

Introduction

The purpose of the IFER agreement

In 2010 the University of Melbourne (UM) and the Victorian Department of Environment, Land, Water and Planning (DELWP) made an innovative agreement to secure research services to improve public land management in Victoria. The resulting Integrated Forest Ecosystem Research (IFER) agreement is a three-year contract, with an option for rolling annual extensions, to undertake research on six core themes:

- Landscape biodiversity
- Landscape carbon
- Landscape integration
- Landscape socioeconomic
- Landscape vulnerability
- Landscape water

Having a consistent three-year forward program has enabled DELWP to benefit from longer-term research that it can apply in its policy making and operations. The program's certainty of funding and government support have enabled UM to develop robust research projects, recruit and retain permanent quality research staff, and encourage and support more postgraduate students, who in turn deliver further benefits to DELWP.

Supplementary projects

IFER also provides for further research, additional to the six core landscape theme projects. These supplementary projects can take advantage of, and build upon, the existing program, without the need to negotiate separate research contracts each time. A supplementary project can be initiated by either DELWP (or its statutory bodies) or UM, must be consistent with the objectives of one of the core landscape themes, and must have its own funding, separate from the core program.

Building on earlier research collaboration

Before 2010, DELWP and UM (through its Department of Forest and Ecosystem Science) had a long-established research collaboration. Recognising the value of this relationship and the need to retain and develop specialised research capacity, the institutions began negotiating a new agreement. The IFER agreement in its final form came into effect on 1 July 2012.

Content of the agreement

As well as establishing the core themes and providing for supplementary projects, the IFER agreement sets up a strong governance framework. This includes:

Structuring the research program to address strategic DELWP policy questions (listed for each core theme in later sections of this report), and the capacity to review these periodically to ensure continuing relevance to DELWP's program;

Active participation by UM and DELWP policy leads in developing research themes and projects;

Flexible delivery at the project level to foster innovation and efficiency;

Collaborative governance that enables information sharing, problem solving and resource management, through a Management Committee, Delivery Team and Development Team.

The Management Committee directs and supervises the program, including monitoring progress and outcomes, and is made up of senior executives from UM and DELWP.

The Delivery Team develops, manages and delivers the program. It also integrates research between disciplines at a landscape scale for public land management. It is made up of the UM and DELWP policy leads for each core theme, as well as numerous theme experts from both organisations.

The Development Team provided program governance, process coordination and quality assurance. Its work ended after it had established the delivery protocols. It comprised senior managers and executives from UM and DELWP.

The secretariat for the program is provided by UM with support from staff in DELWP.

After the agreement was signed, a Governance guide and Supplementary project planning guidelines were established. These help participants work more effectively, by setting out each party's roles, functions, and operating parameters.

Building relationships

This report highlights the research achievements of the first six years of the IFER program. It describes what the IFER team learnt, and how

this is influencing improvements in the ongoing and future program.

Structure of this report

> A collaborative approach will be fundamental to strategic, visionary and integrated program design and delivery' (IFER charter).

For each of the six core themes, the research leader from UM, in consultation with the senior policy lead from DELWP, has reported on the following:

- Project description;
- Results and scientific achievements;
- Applying the research;
- Opportunities, extra benefits and collaboration.

Project description

This sets out the project's aims and whether these were achieved, what was learnt, and how the results have shaped plans for the future. It discusses successful adaptation, modifications and results from the original project plan, and comments on where the project may go in the future.

It describes the core landscape theme project and refers to relevant supplementary projects.

Results and scientific achievements

Here we describe the most critical aspect of the program over three years: the scientific results of each core project, and their potential to inform better management decisions, policy and operations.

Applying the research

Applying the results of research to the way land is managed is an important benefit of the program. Here we discuss how DELWP has or could use the research to improve land management. We have included comments from the UM senior research leader and the DELWP senior policy lead:

How are managers using or applying this research when making decisions?

Has this research influenced DELWP policy, operations or decision making?

Opportunities, extra benefits and collaboration

Using the core program to attract additional resources or funding, or to exploit opportunities for further work, demonstrates efficiency. For each core theme we discuss such opportunities and whether these increased the project's scientific or policy benefits.

We also describe the supplementary projects for each core theme, as well as associated student projects – including what attracted the students, what they studied and how their work complemented the core project.

We discuss collaboration with institutions or individuals outside the Department of Ecosystem and Forest Science, including with other parts of UM, how effective the collaboration was, and what we gained or learnt from it.

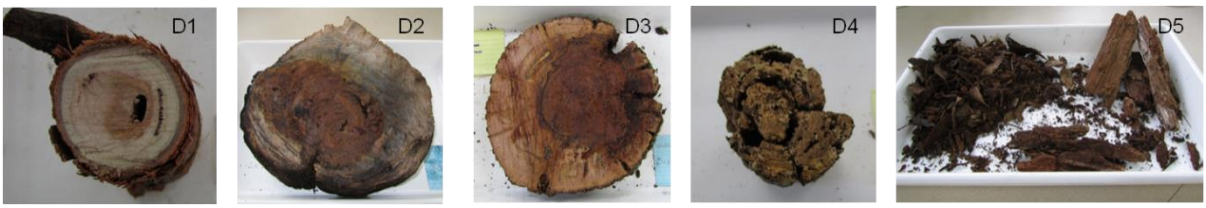

Figure 2: Classes of coarse woody debris, sampled in the fire effects study areas (photograph courtesy Cristina Aponte). These range from least decayed (D1) to most decayed (D5). The team found that, after repeated planned burns, biomass, carbon and nitrogen stocks in substantially decayed (D3 to D5) debris decreased significantly, but stocks in the least decayed debris (D1, D2) did not.

Landscape biodiversity

‘Biodiversity’ means the variety of species of plants, animals and microorganisms, their genes, and the ecosystems they comprise, in a particular area. Fires and climate change can impact biodiversity, and thus the ecological health of an area. Research for this theme examined how natural phenomena and land management practices are affecting biodiversity in Victorian forests. DELWP managers will use the information gathered when deciding on the frequency, severity and patchiness of planned burns, to help create and maintain habitat.

‘

University of Melbourne research leader: Associate Professor Alan York

Research team: Dr Julian Di Stefano, Dr Holly Sitters, Dr Matt Swan, Dr Janet Cohn, Dr Fiona Christie, Ms Amanda Ashton, Mr Julio Najera-Umana

Department of Environment, Land, Water and Planning senior policy lead: Dr Gordon Friend, Imogen Fraser

Table 1: IFER landscape biodiversity policies and policy implementation questions 2010–16

Policy	Policy implementation questions
Sustaining healthy and productive forests on public land in Victoria in accordance with the objectives of sustainable forest management (Sustainability Charter 2007). Securing the health of Victoria’s biodiversity in the face of a changing climate (Biodiversity Strategy 1997). To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products (Code of Practice for Fire Management on Public Land 2012). Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the Victorian Bushfires Royal Commission (VBRC) recommendations – in particular through planned burning of five percent of public land per annum.	Is vegetation condition a good indicator for biodiversity health? What is the relationship between abundance/distribution of plants and animals and ecosystem resilience? How can we minimise the impact of fire on biodiversity?

Project description

Planning for this core theme began in late 2008 after DELWP released Living with fire: Victoria's bushfire strategy, which introduced a landscape-scale mosaic burning program.

DELWP commissioned a review (Stefano & York 2012) to set the scope for a landscape-scale research investigation (this project) into how planned fire could be best applied to create spatially heterogeneous environments and maximise biodiversity.

In 2009–10, DELWP provided funding from its Landscape Mosaic Burning Program to start the research project. This was later increased to employ a postdoctoral fellow for three years and provide top-up scholarships for postgraduate students. The DELWP HawkEye program and Parks Victoria provided supplementary support.

After consulting widely and examining various possible research locations, the Otway Ranges was chosen as a landscape that best met the selection criteria. Planning and site selection began in early 2010. The project was then incorporated into the 2010–13 and 2013-6 IFER core research programs.

Research has been undertaken primarily as PhD, MSc and Honours student projects, supervised by staff of the School of Ecosystem and Forest Sciences at UM.

Phase 1: In 2010, 36 'land mosaics' were established, each of 100 hectares (comprising 182 sites). In 2010–11 their vegetation, birds and mammals were surveyed.

Phase 2: In 2012 and 2013 the team worked with DELWP at experimental burns on an operational scale in the Henderson's Creek and Breakfast Creek catchments. This enabled the team to monitor selected fauna before and after these burns. The interaction between fire and invasive species (foxes and cats) and subsequent impacts on biodiversity was also investigated.

The group's focus in 2013-6 was twofold: Firstly, the successful completion of six PhD, two MSC and four BSc (Hons) projects; Secondly, communication and engagement. Eleven peer-reviewed journal articles are now published with others in preparation. Stakeholder workshops were held in Lorne and Forrest, a new group website was launched and research summary material produced and distributed (see (www.fireecologyandbiodiversity.com).

The core project has produced significant results in its own right, and has substantially laid the groundwork for collaborative projects through the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) (Foothills Biota) and two IFER supplementary projects (Fire in Wet Forests and Resilience Metrics Sensitity Analysis).

The extensive dataset generated will be used after planned burns in the Otway Ranges when sites are revisited in 2016–19 (Phase 3) to test and refine the models developed in Phases 1 and 2. This will be undertaken in conjunction with the Barwon Otway Bushfire Risk Landscape team's monitoring work (as specified in their MER Plan).

Results and scientific achievements

The project resulted in:

Publication of a Fire and Adaptive Management report, which provides background science to support the biodiversity component of the DELWP Landscape Mosaic Burning Program;

Integration of a number of research projects with two large planned burns in the Otway Ranges. This enabled the test of ecological theories in a rigorous experimental framework and provided feedback to DELWP on the short-term and medium-term effects of its burning activities;

Integration of the landscape biodiversity project with the Otway Ranges HawkEye monitoring project. This integration will give DELWP a long-term biodiversity monitoring network in the Otways;

Publication of an age–class distribution paper, which enables DELWP to evaluate the results of various planned burns at landscape scales;

Publication of 11 journal articles which test aspects of the heterogeneity-biodiversity hypothesis; making a substantial contribution to the science that underpins DELWP's fire management.

Applying the research

Two research areas in the landscape biodiversity theme can support evidence-based management in DELWP.

Firstly, investigations into the effects of fire-induced heterogeneity on biodiversity have enabled us to model the relationships between species and their habitat components. Managers

'… a better understanding of the relationship between post-fire growth stages and habitat elements has led to algorithms that allow managers to explore planned burning scenarios at landscape scales that foster biodiversity.'

can use this information when deciding on the frequency and severity of planned burns, to help create and maintain habitat at patch scales.

Secondly, a better understanding of the relationship between post-fire growth stages and habitat elements has led to algorithms that allow managers to explore planned burning scenarios at landscape scales that foster biodiversity.

These two themes provide a framework for understanding the effects of fire on biodiversity. This can be integrated into the Strategic Bushfire Management Planning Framework, to enable scenario modelling to better understand trade-offs.

Figure 3: Bushfire and Biodiversity Masters students checking animal traps during fieldwork (photograph courtesy Alan York).

Opportunities, extra benefits and collaboration

The original 2010–13 and 2013-16 project plans were augmented with additional funding from DELWP, which allowed UM to employ a postdoctoral fellow for three years and providing top-up scholarships for six postgraduate students. This led to better (dedicated) project management and attracted four high-calibre research students. Core research has been mostly undertaken by these students, with guidance from senior research staff. This is an extremely cost-effective means of doing field-based research.

In 2010–13 Parks Victoria, through the Research Partners Panel Agreement with UM, funded operational support for the four PhD students.

In 2012–15 DELWP HawkEye funded a supplementary project which gave operational support to two new PhD projects. In addition, HawkEye provided significant in-kind support, mostly for collecting data and buying equipment.

The Collaborative Research Network gave Federal Government funding, through Federation University, to support a postdoctoral fellow, a PhD and a Master's student. This added value to the core project by enabling us to include vascular plant components in our research.

Our PhD students have attracted an additional $79,000 in funding over 2010–16, from the Holsworth Wildlife Research Endowment and Birdlife Australia.

In 2010 this project was incorporated into a large DELWP-funded multi-disciplinary Landscape Mosaic Burning Program, which involved Melbourne, Deakin and La Trobe Universities and the Arthur Rylah Institute. Although the project was undertaken as part of the 2010–13 and 2013-16 IFER programs, under the Landscape Biodiversity theme, information was shared between DELWP and the Landscape Mosaic Burn research partners. This improved understanding of the effects of planned burning across the state.

Figure 4: Eastern Spinebill (photograph courtesy Amanda Ashton).

In 2012 the Victorian Fire and Biodiversity Consortium, which is made up of the research partners outlined previously, successfully bid for $810,000 to undertake two new research projects sponsored by DELWP and managed by the BNHCRC: Managing Scale and Uncertainty in Fire Management Planning, and Growth Stage and Habitat Analysis. These were consolidated into the Foothills Fire and Biota project, and built

on extensive databases accumulated during 2010–13 and earlier.

Knowledge gained from this collaboration was used in designing research in the Fire in Wet Forests Supplementary project (2013–16), and formed the basis of a successful Australian Research Council Linkage proposal commencing in late 2016.

Table 2: Landscape biodiversity – additional funding 2010–16

Source	$
DELWP	1,432,914
Collaborative Research Network	180,000
DELWP HawkEye	165,000
Parks Victoria	60,000
PhD endowments	79,000
Total	**1,916,914**

Landscape carbon

The release of greenhouse gases, particularly carbon dioxide, into the Earth's atmosphere is causing climate change. Climate change can be slowed to some extent by 'storing' carbon in forests. Forests are in this sense 'carbon assets' that serve a valuable environmental purpose.

This research project aimed to measure the quantity of carbon stored in Victoria's forests; how these stores are affected by bushfire and other natural phenomena, and by forest management practices. We can apply this knowledge in managing our forests – such as when scheduling fuel-reduction burns – to preserve and even increase carbon stores.

University of Melbourne research leader: Dr Lauren Bennett

Research team: Dr Cristina Aponte, Mr Julio Najera

Department of Environment, Water, Land and Planning senior policy leads:
Andrew Haywood, Andrew Mellor, Courtney Johnson, Peter Chronopolous, Gordan Ivancic, and John Houlihan

Table 3: IFER landscape carbon – policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Delivering Community Benefits from the management of public forests. • Sustaining healthy and productive forests on public land in Victoria in accordance with the objectives of sustainable forest management (Sustainability Charter 2007). • Maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products (Code of Practice for Fire Management on Public Land 2012) • Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the 2009 Victorian Bushfires Royal Commission (VBRC) recommendations – in particular through planned burning of five per cent of public land per annum. • Climate change mitigation and adaptation, including the development of national, global and	• How can we best monitor, report and predict forest carbon assets through time at the landscape scale? • What are the inherent and operational drivers that change forest carbon assets, including fire regime and climate?

local carbon markets (Commonwealth Carbon Farming Initiative; Victorian Climate Change Act 2010).

Project description

The landscape carbon theme was established in 2010 to assess the size of Victoria's public forest carbon assets, and to determine the optimal way to maintain and enhance carbon stores while managing for other values and objectives, such as reducing the impact of large and damaging bushfires. The following research tasks were designed to achieve these goals:

- Establish field sites and measure carbon across a broad range of forest types and fire conditions to develop the most comprehensive dataset of carbon stores for Victoria's forests;
- Develop relationships between forest carbon stores, and inherent and operational drivers of carbon store change, particularly fire and climate;
- Apply the data and relationships within a newly developed carbon modelling framework for examining landscape-scale effects of management scenarios on carbon as an asset.

Our landscape carbon research met and exceeded many project milestones. For example, the supplementary project, Wombat Forest Fire Effects Study Areas, included a carbon component that developed and tested field measurement protocols and laboratory methods for measuring forest carbon stores, and interpreted the effects of planned burning regimes on those stores.

This project reinforced the importance of long-term research sites for improving the robustness of research findings. Its strengths included access to long-term climate and tree-growth data, and a replicated experimental design that included multiple repeat burns.

This project influenced subsequent work in several ways, by identifying:

- The need for a stronger conceptual framework for understanding the many complex, interactive relationships between fire intensity, fire severity, climate, geography and forest carbon stores;
- Those forest carbon pools most responsive to fire effects (large trees, coarse woody debris, soil) and therefore worthy of further study;
- Gaps in knowledge about the effects of fire on carbon stores, notably:
  - Carbon losses beyond the immediate post-fire period ('legacy' effects);
  - Changes in soil carbon composition;
  - The magnitude of planned burning versus bushfire effects;
  - The interactions between these effects and climate.

Figure 5: Measuring char depth in a piece of coarse woody debris from a forest ecosystem study area (photograph courtesy Cristina Aponte). Such measurements help to assess changes in pyrogenic carbon stocks due to repeated planned burns.

Involvement in the Victorian Forests Monitoring Program (VFMP) estimation of forest carbon stores generated much-needed carbon data for a range of forest conditions. Our eventual findings required modification due to measurement of many fewer plots than originally anticipated and unforeseen delays in accessing the data.

In addition, analysis of data from 300 plots revealed problems in our original thinking – notably, that broad-scale data, and associated coarse fire data, will not be sensitive enough to distinguish between the effects of inherent (e.g. climate, topography) and operational (e.g. planned burning) factors on forest carbon stores. This shaped our subsequent research by confirming the need for multiple lines of evidence, especially broad-scale VFMP-type data, to improve prediction of broad-scale patterns (relevant to calibrating landscape-level models),

combined with more intensive measures at finer temporal and spatial resolutions to improve our power to discern the respective effects of operational and inherent factors.

'… broad-scale data, and associated coarse fire data, will not be sensitive enough to distinguish between the effects of inherent (e.g. climate, topography) and operational (e.g. planned burning) factors on forest carbon stores. This shaped our subsequent research by confirming the need for multiple lines of evidence …'

We addressed many of these challenges in our second three-year research cycle (2013–2016) by:

- Filling gaps in our carbon data by sampling under-represented forest types (e.g. rainforest), growth stages (e.g. old-growth), and fire conditions (e.g. different combinations of bushfire severity and planned burns);
- Establishing a forest carbon database including over 500 field plots with carbon stores estimated using standardised methods;
- Using intensive measures of selected sites to improve our understanding of when forest trees grow and when they might be most vulnerable to changes in climate and fire regimes.

Developing the conceptual framework to establish our Victorian Forest Carbon Modelling Framework for assessing future risks and opportunities in carbon management.

Figure 6: Researcher sampling soil for carbon assessments (photograph courtesy Julio Najera).

Results and scientific achievements

By 2016, the landscape carbon theme had delivered results consistent with the proposed three to ten-year:

- Quantifying the risks that repeated planned burning poses to forest carbon stores – sampling and analysis of carbon pools in the Wombat Forest fire effects study area clearly showed that planned burning regimes will involve a carbon cost, although the total cost has a high degree of uncertainty;
- Information useful for adaptive forest management – our analysis of the forest carbon store estimates published in the *State of the Forests 2013* report found that these data were robust, thus supporting carbon methods in DELWP's VFMP. It also showed that broad spatial patterns in live carbon stores are shaped more by inherent factors (e.g. climate, topography) than by operational factors;
- Other information useful for adaptive forest management – quantified carbon store changes associated with occasional severe bushfires relative to more frequent planned burns provides DELWP with a stronger basis for

weighing up the relative carbon costs of fire management decisions.

Applying the research

The Wombat forest Fire Effects Study FESA carbon research (Core augmented by Supplementary funding) provides a strong basis for making informed decisions about planned burning regimes in dry sclerophyll forest. In particular, ten-yearly rather than three-yearly burning offers better potential to minimise carbon loss and maintain future capacity to fix carbon. In addition, the carbon cost of frequent burning can now be more accurately estimated. We also found that planned burning in moist (Spring) conditions will lead to lower overall carbon losses than burning in dry (Autumn) conditions.

In subsequent collaborative research with Arthur Rylah Institute (funded by the Federal government's *Biodiversity Fund*), we established that the greatest potential for planned burns to minimise the carbon costs of bushfires lies in reducing the extent of severe bushfires. In particular, practices that help minimise large tree death and soil erosion after bushfire will help retain carbon stores and potential for recovery.

The project's involvement in the VFMP estimation of forest carbon stores included provision of review-based methods and algorithms to convert VFMP field measurements to reportable carbon pools. We also helped revise standard operating procedures and identify control plots for interpreting VFMP post-fire recovery plots. This work improved quality control over the VFMP data and streamlined field and laboratory methods. In addition, analysis of VFMP carbon data trends provided advice on refinements to the current measurement approaches, and support for continuing to establish new plots.

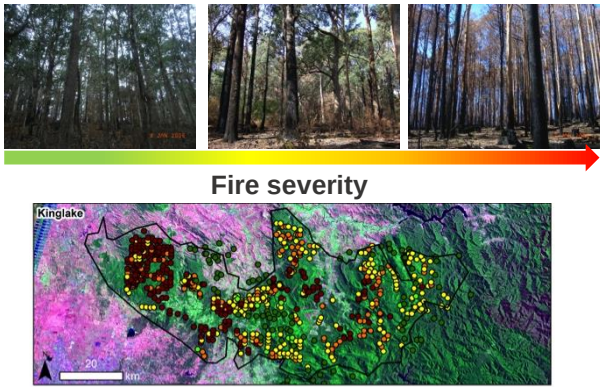

Figure 7: Fire severity mapping from space (image courtesy Cristina Aponte).

Mapping fire severity using high quality remotely sensed data is vital to understanding bushfire effects on forest carbon assets at broad scales.

The landscape carbon research has directly informed policy discussions between the Victorian and Commonwealth Governments on the implications of full carbon accounting in Kyoto Protocol negotiations. The research generated additional evidence for discussions and allowed the Victorian Government to influence how the Commonwealth models fire management in native forest. The information is also valuable in assessing the impacts and benefits of planned burning on carbon sequestration in mixed-species forest.

Supplementary projects, such as the Soil Carbon under Biodiverse Woody Revegetation project, have allowed DELWP to integrate soil carbon benefits, in addition to above-ground biomass, in helping Victorian farmers get the greatest benefit from the Commonwealth's Carbon Farming Initiative. The work in IFER, which contributes to a broader project led by CSIRO, has been lauded by the carbon-offset industry, and responds directly to policy priorities set out by the Victorian Government in its *Environmental partnerships* document.

'the greatest potential for planned burns to minimise the carbon costs of bushfires lies in reducing the extent of severe bushfires.'

Opportunities, extra benefits and collaboration

Since its establishment in 2010, the landscape carbon theme has capitalised on several opportunities to improve research novelty and capacity, and provide a strong base for further research. Successful external funding applications (see Table 4) include:

- Managing Fire to Protect Biodiversity, Carbon and Assets, and Build Resilient Landscapes, DAFF Biodiversity Fund (collaboration led by ARI: $850,000, July 2012 – June 2017);
- Incorporating Contested Social Values into Native Forest Management, Australian Research Council (ARC) Linkage Projects Scheme ($205,000, July 2012 – June 2015);
- Three equipment grants:
- Rowden White Foundation ($60,000);
- Melbourne School of Land and Environment (MSLE) ACG Development Grant ($20,000);
- MSLE Equipment Grant ($50,000).

- The landscape carbon project also led four IFER Supplementary projects:
- Fire Effects Study Areas Carbon (2011–13);
- Soil Carbon Under Biodiverse Woody Revegetation (2010–13);
- Public Benefits from Soil Management (2010–13);
- Victorian Forests Management Program – analysis of soil and litter samples (2012–13).

Table 4: Landscape carbon – additional funding 2010–16

Source	$
DAFF Biodiversity Fund	850,000
Australian Research Council Linkage grant	205,000
Equipment grants	130,000
Total	**1,185,000**

Several PhD students were involved in research that aligned with the landscape carbon theme. They were attracted by the forest-based research and by a large integrated research program. Their work adds considerably to the novelty and diversity of the core research:

Melissa Fedrigo (2012–15, complete): Characterising and modelling the structure and extent of south-eastern Australian temperate forests for improved estimation of carbon stocks (integrated project with vulnerability theme);

Anne Griebel (2012–16, submitted): Seasonal growth dynamics of a broadleaf evergreen forest;

Merryn Smith (2013–17): Non-structural carbohydrate allocation and dynamics in eucalypt trees (integrated project with vulnerability theme);

Thomas Fairman (2013–17): Too Much, Too Soon? The impact of repeat fire on temperate eucalypt forest communities (integrated project with vulnerability theme);

Hari Shrestha (2011–15, complete): Long-term effects of repeated low-intensity fire on litter and soil carbon and nitrogen in a mixed eucalypt forest in south-eastern Australia.

As well as encouraging close collaboration with DELWP personnel, the additional grants and supplementary projects fostered a variety of broader collaborations on landscape carbon. Principal collaborators, who brought substantial expertise, novel equipment and field knowledge to the project, included:

Kathryn Williams and Rebecca Ford (UM Department of Resource Management and Geography): Social sciences;

Darius Culvenor (Environmental Sensing Systems) and colleagues at CSIRO: LiDAR technology;

Malory Weston and David Heislers (Kilter Pty Ltd): case study landscapes and associated metadata;

Kerryn Paul, Stephen Roxburgh, Jacqui England and CSIRO colleagues: carbon protocols and shared carbon data;

Josephine MacHunter, Matthew Bruce, Michele Kohout, Richard Loyn and ARI colleagues: integrated carbon-biodiversity methods and establishment of collaborative sites;

Mihai Tanase (University of Alcala de Henares, Spain) and colleagues: spatial data analysis (GIS and remote sensing), particularly analysis of bushfire severity;

Various colleagues in the OzFlux network and the AusCover TERN: flux data and protocols.

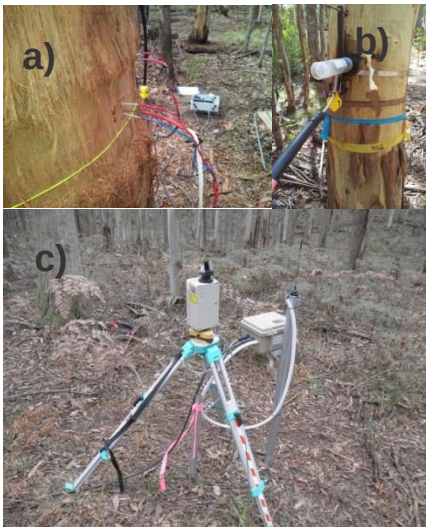

Figure 8: Equipment used in a PhD project to investigate changes in forest carbon stocks: a) autodendrometer; b) sap flow meter; c) ground-based LiDAR sensor (photograph courtesy Anne Griebel).

Landscape hazards

This project formerly sat in the program as “Landscape socio-economics”. It has subsequently been split out into “Landscape hazards” and “Landscape socio-economics”, with the latter explicitly addressing policy and land management interaction with communities (see next section). The “hazards” research looked at ways to reduce the human costs of bushfire through better forest management and predicting how fires behave. By measuring factors such as fuel moisture and wind, using weather radar data for monitoring fire spread, and mapping assets such as houses, this project has developed methods to respond to bushfires and manage planned burns in ways that reduce the risk of harm to people, their property, essential services and the environment.

DELWP is using the bushfire simulator developed when setting priorities for bushfire suppression, identifying communities at risk and issuing warning messages. Power companies and water distributors are applying our research, such as when investing in improving the safety of power lines. These methods have also been emulated in New South Wales, Queensland, Tasmania and South Australia.

University of Melbourne research leader: Associate Professor Kevin Tolhurst

Research team: Mr Derek Chong, Mr Brett Cirulis, Dr Jane Cawson, Dr Thomas Duff, Dr Trent Penman, Mr Sean Walsh

Department of Environment, Land, Water and Planning senior policy leads: Gordon Friend, Liam Fogarty

Table 5: IFER landscape hazards– policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Adaptive management of the forested landscape on public land in Victoria in accordance with the principles of sustainable forest management as described in the Sustainability Charter. • Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the 2009 Victorian Bushfires Royal Commission (VBRC) recommendations – in particular through planned burning of five per cent of public land per annum. • Code of Practice for Fire Management on Public Land (2012) which states the two primary objectives for bushfire management on public land: -To minimise the impact of major bushfires on human life, communities, essential services and	• What are the impacts of fire (natural and managed), climate variability/change and forest management regimes on social, economic and environmental values, from Victoria’s forests now and into the future? • What fire and land management regimes could be used to support preferred bushfire management outcomes – natural (carbon, water, biodiversity) and social (public safety) and economic (recreation, tourism, horticulture, agriculture, timber, public)? • How does fuel and fire (planned and unplanned) behave in our highest hazard and risk environments, (such as the Otway Range, Ballarat Macedon area and the Yarra and Dandenong

community infrastructure, industries, the economy and the environment. -To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products.	Ranges), and how can we more effectively reduce bushfire related risk to communities and other priority values? • How do fire severity, fire patchiness, pattern, size and connectivity influence bushfire hazard and damage potential as well as resilience, the provision of services such as biodiversity, carbon, water and forest products? • What are the impacts of planned fire in the long term versus the short-term?

Project description

This research theme, built on DELWP's investment in critical research into bushfire risk, has enabled a whole new way of undertaking fire management. This Victorian approach has been emulated in other States (NSW, QLD, TAS, and SA) indicating the acceptance of the approach as being accepted as best practice.

An essential part of this work was the development of the fire simulator PHOENIX RapidFire (PHOENIX), which integrates many inputs and processes, making it possible to identify a number of data collection and research priorities. More accurate measurement of fine variations in fuel moisture across the landscape, and measuring vertical wind profiles in vegetation with differing structures, are two examples of research needs identified by PHOENIX. Work has also been undertaken on better ways to map values and assets (such as houses) across the landscape, so that bushfire impacts can be better estimated. The team also started fuel mapping and re-accumulation modelling, to improve the accuracy of bushfire simulations, whether in PHOENIX or any other fire simulator. Further work looked into better representing the landscape dynamics in flammability and also explored the key drivers of fire behaviour so that it can be better modelled. Additionally new methods of gaining intelligence about bushfires as the burn were investigated, including using weather radar and emergency calls.

Other businesses, such as power distribution companies and Melbourne Water, are also taking advantage of this research. Electricity distributors and Energy Safe Victoria have used spatial analysis to allocate the $700 million being invested in reducing the damage caused by bushfires ignited by power lines.

Results and scientific achievements

We have shown that it is possible to quantify bushfire risk in an objective and scientifically defendable manner, using expertise and resources currently available.

By developing fire shape metrics and using ensemble modelling the project has shown that bushfire risk assessments can be ascribed levels of uncertainty, based on defendable statistical and simulation methods. The project has demonstrated that the bushfire simulation process can be applied to fire suppression. This offers the possibility of modelling fire suppression effectiveness and options using a portion of existing data and computing capacity.

Applying the research

As a result of this research, DELWP is now using PHOENIX RapidFire to predict the hourly extent of every fire reported, for a six hour forecast period. This is done at the State Control Centre and in the regions, for setting priorities for bushfire suppression, identifying communities at risk and issuing warning messages.

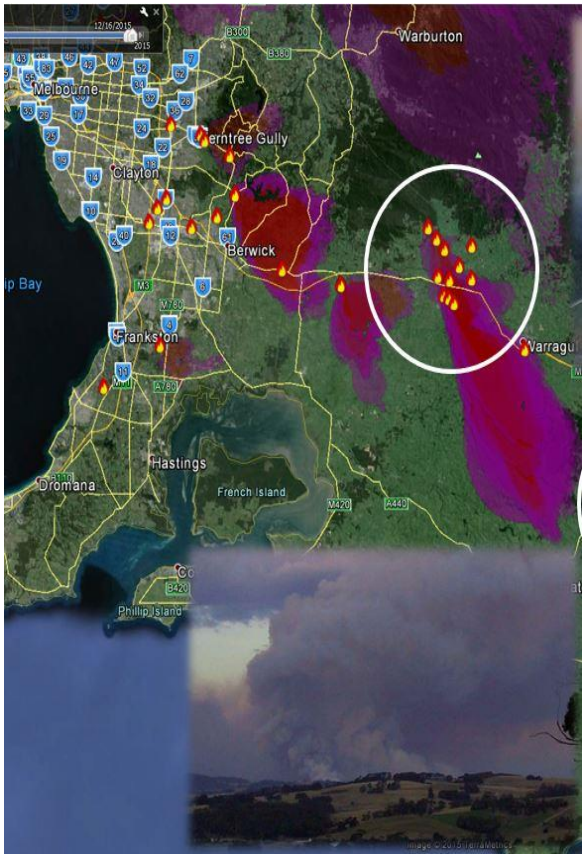

Figure 9: Ensemble forecasting of bushfires across Victoria using PHOENIX RapidFire (photograph courtesy Derek Chong).

Seven DELWP bushfire risk landscape teams have been established across Victoria. They are all using PHOENIX RapidFire to assess bushfire risk in the absence of fire, and various options for planned burning. This work focuses primarily on preventing the loss of human lives and houses, but other values are being considered. The Future Fire Program pilot study in the Otway Ranges showed how people and a range of values (infrastructure, environmental, economic and social) could be included in the risk landscape assessment. This work is developing.

In conjunction with the Office of the Fire Services Commissioner, the team undertook a pilot study to assess and reduce the level of bushfire risk in the Dandenong Ranges. PHOENIX RapidFire has been crucial in providing images and analysis for public discussion and bushfire planning.

PHOENIX RapidFire is an essential tool in applying the Code of fire management practice and in addressing several recommendations of the 2009 Bushfires Royal Commission.

Figure 10: Melbourne University and DELWP staff working together to take fuel moisture measurements during a planned burn (photograph courtesy Brett Cirulis).

Opportunities, extra benefits and collaboration

Three PhD students have been working on IFER related projects:

- Kangmin Moon (2012-2016): Characterising forest wind profiles for utilisation in fire spread models;
- Lisa Cheong (2012-2016): Visualisation of uncertainty for decision making in bushfire and disaster management;
- Geofe Cadiz (2015-2018): Landscape dynamics of a flammable understorey species.

Work in this program has led to new research on fuel input data, fuel moisture estimation across the landscape, the use of weather radar data for monitoring fire spread, and plume development. Collaborators include:

- Bushfire CRC
- Bushfire and Natural Hazards CRC
- Geoscience Australia
- Bureau of Meteorology
- CSIRO
- Rural Fire Service, New South Wales
- Sydney Water
- Combined New South Wales power distribution businesses
- Tasmania Fire Service
- Tasmanian National Parks and Wildlife

- Department of Environment and Heritage, South Australia
- Combined Victorian power distribution businesses
- Melbourne Water
- US Department of Agriculture
- University of Berkeley
- University of Wollongong
- University of Tasmania.

These collaborations have brought greater credibility to PHOENIX RapidFire, enabled it to be tested in a wider range of environments, and confirmed the robustness of its design.

Table 6: Landscape socioeconomics – additional funding 2010–16

Source	$
Australian Research Council Linkage grant	770,845
IBM	741,577
IFER supplements	1,520,500
Bushfire CRC	569,700
Fire Services Commissioner	300,000
CSIRO	110,000
Total	**4,012,622**

Landscape socio-economics

The knowledge, values and activities of the public and stakeholder groups play a critical role in the effective management of public land. Recent policy changes, such as the Safer Together program, draw increasing attention to the need for government to work with communities to address environmental challenges.

Since 2012, DELWP has supported a number of supplementary projects exploring values of forests, public land and fire-prone landscapes that are important to the Victorian public. A series of small projects are providing insights to how members of the public prioritise a range of important outcomes of management, and how this knowledge can be incorporated in agency decision making.

University of Melbourne research leader: Associate Professor Kathryn Williams

Research team: Dr Rebecca Ford, Dr Nerida Anderson, Dr Andrea Rawluk, Dr Lauren Bennett, Dr Craig Nitschke, Dr Dave Kendal

Department of Environment, Land, Water & Planning senior policy leads: Ian Campbell-Fraser, Laura Little

Table 7: IFER landscape integration – policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Delivering Community Benefits from the management of public forests. • Sustaining healthy and productive forests on public land in Victoria in accordance with the objectives of sustainable forest management (*Sustainability Charter 2007*). • To minimise the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment. (*Code of Practice for Fire Management on Public Land 2012*). • Delivering on the government objectives for the management of forest on public land relevant, natural resource management, commercial, recreational and social objectives described in the relevant Government endorsed strategies and plans (e.g. Victoria's *Timber Industry Action Plan 2012*). • Contribute to regional economic sustainability and development.	• How can we best assess, monitor and report the value the broader community places on different outcomes of risk management? • How can community values be incorporated into risk management decision-making?

Achievements

Landscape socio-economic research has been conducted across three projects addressing three distinct contexts of relevance to the IFER program: public land management, sustainable forest management, and strategic bushfire risk management. Across these projects, researchers have utilised a combination of interviews, workshops and surveys to provide insights to the many different ways that landscape and community are important to members of the Victorian public. This knowledge can help decision makers – both professional and community – to consider how policy and management can better reflect the diverse expectations of the Victorian public.

Each of these studies is underpinned by conceptual frameworks developed to facilitate the incorporation of values in strategic planning. These frameworks bring together robust academic knowledge from psychology and sociology together with an understanding of policy and planning processes utilised in government and other agencies. This integration across academic and professional knowledge facilitates the practical use of new knowledge by professionals.

The project 'Community values for public land' placed particular emphasis on providing tools that agencies can use to better understand the values of stakeholders and residents. This has resulted in a questionnaire, the 'Valued Attributes of Landscape Scale'. Originally developed to measure different general characteristics of public land that are important to people, this tool has now been adapted and used to understand diverse public values across a wide range of landscape contexts.

The project 'Incorporating contested social values into native forest management' has given particular attention to improving indicators of sustainable forest management (SFM). International criteria and indicators for SFM have been developed by scientists and stakeholders to provide consistent approaches to reporting on forest management. This project explored how well existing indicators fit with the values and concerns of the Victorian public, and identified a range of other indicators that might help make SFM reporting more relevant to communities. This research led to an extended list of socially relevant indicators for SFM.

Another important contribution of this project was integration of social and ecological sciences to better understand the links between social values and ecological processes of forest. Researchers worked with forest planners to develop a range of forest management scenarios that reflect different policy concerns for the Victorian government. They then used ecological knowledge to model the outcomes of these scenarios against socially relevant indicators. This enabled new insights to the ways that social expectations might influence forest ecosystems over time, and how members of the public respond to these potential future forests.

The project 'Assessing and incorporating social, economic, ecological and community safety values of forests in bushfire risk decision-making' is particularly considering how an understanding of social values can be incorporated into planning decisions. Researchers are developing and testing guidelines and a range of strategies that will help decision makers to understand what the Victorian public want protected through fire risk management, and plan for fire management in ways that reflect these values.

Applying the research

Benefits of this new research program can be seen in a number of areas. Conceptual frameworks have provided a platform for multi-agency conversations about sustainable forest management, and strategic risk-based fire planning. The frameworks have also enabled robust measurement of public values in ways that can inform DELWP planning objectives. The research has provided new lists of socially relevant indicators for SFM that can inform State of the Forest reporting. The program has also led to a successful Australian Research Council Linkage Project application, leveraging federal funding through DELWP contributions.

In the future, outcomes from this research program will extend the capacity and confidence of DELWP staff to consider social values in their policy and planning and to work more effectively with communities in these planning processes. Ultimately this creates the potential for better alignment between landscape management and the values of the Victorian public.

Landscape vulnerability and health

This research examined the vulnerability of particular plants and ecosystems to bushfire, planned burning, tree harvesting and climate change. The project developed a method to examine effects of these phenomena on forest water, carbon, biodiversity and timber. We explored the mortality and survival responses of particular tree species to fire and drought.

This work is already helping to shape forest, fire and climate change policy in many parts of DELWP.

University of Melbourne research leader: Dr Craig Nitschke

Research team: Dr Sabine Kasel, Mr Ben Smith

Department of Environment, Land, Water and Planning senior policy lead: Dr Gordon Friend

Table 8: IFER landscape vulnerability – policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Adaptive management of the forested landscape on public land in Victoria in accordance with the principles of sustainable forest management as described in the Sustainability Charter. • Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the 2009 Victorian Bushfires Royal Commission (VBRC). Recommendations – in particular through planned burning of five per cent of public land per annum. • Promoting the resilience of Victoria's ecosystems and improving their management (*Victorian Climate Change Act 2010*; Policy objective 6f). • To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products (*Code of Practice for Fire Management on Public Land 2012*). • Climate change mitigation and adaptation, including the development of national, global and local carbon markets (*Commonwealth Carbon Farming Initiative; Victorian Climate Change Act 2010*).	• What are the impacts of fire (natural and managed), climate variability/change and forest management regimes on the vulnerability and resilience of Victoria's public forests now and into the future? • How can we improve our understanding of landscape level resilience and productivity given current scientific methods? • What is the relative importance of soil versus other resilience measures? • What are the relationships between various resilience 'states' and the delivery of other ecosystem services such as water, timber and carbon?

Project description

The landscape vulnerability theme investigated:

- Factors influencing regeneration success or failure for significant tree species;
- Mechanisms of plant survival and mortality of significant tree species;
- Climatic and photoperiodic effects on flowering phenology of eucalypts;
- Environmental effects on germination and growth phenology of eucalypts;
- The use of empirical data in model calibration and validation, and to predict significant tree species' response – at the landscape scale – to climate change, bushfire, planned burning and harvesting.

All of these objectives were achieved to varying extents. The final objective was partially achieved, through the calibration, validation and application of models to assess tree species' responses to climate change. Testing of bushfire, planned burning and harvesting at the landscape scale was conducted on a 100,000 hectare case study area, but needs further testing and application in the broader Central Highlands forest management area.

Problems with data quality for model parameterisation slowed model development. The logistical and stochastic nature of the regeneration transects and common garden experiments led to the need to repeat experiments to ensure scientific rigour, or in some cases it delayed data collection and analysis. This delayed some results but taught us some important lessons on conducting a large, field-based experiment involving developing a model in a dynamic environment on a three-year timeline.

In 2013–16 we further developed robust models through continual model calibration based on field experiments and validation. We also collected new data and developed models on forest composition and structure, to investigate the effects of fire, climate and land management on vegetation communities. In addition to assessment of forest structure and plant diversity, these studies have included assessment of the soil seedbanks and the use of dendroecology and radio carbon dating to determine the age of forest understories.

We have also begun to use remote sensing (LiDAR) to improve our characterisation of forest structure and linking these analyses to species distribution models. This includes the mapping of cool temperate rainforest using LiDAR and estimating biomass across wet eucalypt and rainforest communities. Our project is increasingly investigating the impacts of repeat bushfires on plant communities, in particular for snow gum woodlands and mixed species eucalypt forests.

Once the team has finalised robust models, they will apply field data and models to test the veracity of the growth stages management model and geometric mean abundance of species as a potential measurement of ecosystem resilience. This work will continue to provide information to DELWP managers implementing the Victorian Climate Change Act 2010, the Sustainable Forests (Timber) Act 2004 and the Biodiversity Strategy 1997.

Results and scientific achievements

A key scientific achievement was publishing the TACA-GEM regeneration model in the peer-reviewed journal *Global Change Biology* as well as published models of the impact of climate on eucalypt germination, growth and flowering. Publishing these models provides a foundation for assessing the vulnerability of recruitment potential for key flora species in Victoria. Now that the regeneration model has been published, the team can explore the roles of management, fire and climate in species regeneration – and thus species' ability to produce sustainable populations – in a scientifically rigorous manner.

Parameterisation of the landscape simulation model, LANDIS-II, was a key achievement. This now allows the team to explore the role of management, fire and climate on species and ecosystem distributions, both in time and space. It also allows the effects of management, fire and climate on forest values (water, carbon, and biodiversity, timber) to be explored.

Establishment of a network of more than 285 plots, from which the team collected data on soil, stand structure, species diversity and abundance, and microclimates, all across a topographic and fire history gradient. This network of plots now creates a foundation for testing and validating the growth stage model developed by DELWP.

Establishing two common garden experiments (at the Burnley and Dookie campuses of MU) was another achievement. Trees in the common garden allowed the team to explore mortality and

survival responses of trees to drought. Preliminary results are being linked to the TACA-GEM model to improve the modelling of drought's effect on regeneration and establishment. In November 2015 the team completed a full biomass harvest of the Burnley arboretum with also sampling for non-structural carbohydrates from all organs. This work is being progressed by a PhD student and will provide valuable insight into the carbon resource allocation strategies and in turn how this relates to regeneration strategies and response to drought.

Figure 11: Vegetation survey of grassy dry forest at Mount Torbreck, Eildon, October 2013 (photograph courtesy Sabine Kasel).

Applying the research

Research over the last six years has focused on developing tools to explore the vulnerability and resilience of forest ecosystems to climate, management and fire. As a result the project has established methodologies and a network of research sites and infrastructure that will help us conduct future research that improves our understanding of forest ecology and forest management.

'Research … is helping DELWP understand the implications of climate change for the distribution of major forest species. Critically, considering multiple causes of disturbance together with various measures of forest value, brings a new and practically applicable way of understanding risk for these valuable forests.'

The project has applied these tools when testing the implications of climate change on recruitment for key *Eucalyptus* species. They have also helped build a strong evidence base to inform policies for forest management and planned burning, adaptation to climate change, and the validity of the growth stage management model.

This work has policy implications for decision makers under the *Victorian Climate Change Act 2010*, which specifically states that decision makers must have regard to climate change and that the Minister must prepare a Climate Change Adaptation Plan that includes an outline and risk assessment of the potential impacts of climate change on various regions of Victoria and the government's state-wide priorities and strategic responses for adaptation to climate change.

This work also relates directly to the *Sustainability Charter 2007*, as it provides information to managers on forest health and productivity, in accordance with the *Sustainable Forests (Timber) Act 2004*.

Research under the landscape vulnerability and health theme is helping DELWP understand the implications of climate change for the distribution of major forest species. Critically, considering multiple causes of disturbance together with various measures of forest value brings a new and practically applicable way to understand risk for these valuable forests. The current work is helping to shape forest, fire and climate change policy in many parts of DELWP, and is directly influencing planning processes through programs such as the Bushfire Risk Management Planning reform process.

The research is essential to understanding the implications of bushfire risk and how risk may change over time. The combined findings of this research are already being assessed and will improve the way we plan for bushfire risk over the coming decades.

Opportunities, extra benefits and collaboration

The project has used the new modelling tools and their associated datasets in a successful ARC Linkage proposal. The project, 'Defining the intangible: incorporating contested social values into native forest management', aims to develop socially relevant indicators for testing alternative scenarios of sustainable forest management in the Central Highlands forest management area. Work is under way and will improve science and policy by incorporating the response of social values to management, climate and fire.

This project also capitalised on the modelling tools and datasets in an Asia-Pacific Forest Network for Sustainable Forest Management and Rehabilitation grant to fund a PhD top-up scholarship project: 'Adaptation of Asia-Pacific forests to climate change'. This tested adaptation

strategies that reduce the impacts of climate change on the Central Highlands forests.

The project also built on Melissa Fedrigo's PhD work to obtain an Australian Institute of Nuclear Science and Engineering grant for carbon-dating tree ferns to estimate age and growth rates.

The project has used the new modelling tools and their associated datasets in a successful ARC Linkage proposal. The project, 'Reversing the loss of Leadbeater's Possum habitat: An integrated stand- and landscape-scale approach to accelerating habitat development', aims to develop knowledge and models for testing alternative silvicultural approaches for conserving Leadbeater's Possum. Work is under way and will improve science and policy by improving tools for mapping and modelling habitat for this threatened species.

Table 9: Landscape vulnerability – additional funding 2010–16

Source	$
Australian Research Council Linkage grant (social values)	205,000
Australian Research Council Linkage grant (Leadbeater's Possum)	415,000
Asia-Pacific Forest Network	25,000
Australian Institute of Nuclear Science and Engineering	18,480
Total	**663,480**

The project began with no student or PhD projects but between 2010 and 2016 the team built a research group that included seven Honours and PhD students working on projects that complement the core:

- Megan Hirst (2010): The role of germination ecophysiology in increasing the vulnerability of Victorian *Eucalyptus* species to climate variability and change (Honours);
- Deepa Shree Rawal (2012-2014): Phenology, ontogeny and genetic variation: Phenological responses of select *Eucalyptus* species to environmental variability (PhD);
- Melissa Fedrigo (2012-2014): Characterising and modelling the structure and extent of cool temperate rainforests for improved estimation of carbon stocks (integrated project with carbon theme, PhD);
- Helen Vickers (2012-2016): The influence of climate variability and fire regimes on shrub communities (PhD);
- Linda Parker (2012-2016): The autecology of *Astelia australiana*: the role of light, fire and climate variability (PhD);
- Gregor Sanders (2011-2016): Trees and drought: physiological adaptation and survival of eucalypts across climate gradients (PhD);
- Matthew Chick (2012-2016): Impact of changes in fire regimes and climate on heathland community ecology (integrated project with biodiversity theme, PhD), and Master's research project: Temperate rainforest regeneration and climate variability;
- Merryn Smith (2013-2016): Effects of fire severity on tree growth and carbon allocations in temperate forests (integrated project with carbon theme, PhD);
- Ru Withana (2015-2018) Changes in eucalypt-mycorrhizal associations under changing climate (integrated project with carbon theme, PhD);
- Stephen Stewart (2014-2017) High resolution mapping of climate variables in Victoria: implications for species distribution modelling under climate change (PhD);
- Ruizhui Jiang (2015-2018) Mapping forest structure using remote sensing: implications for the conservation of Leadbeater's Possum (PhD);
- Tom Fairman (2014-2017) Too Much, Too Soon? The impact of repeat fire on temperate eucalypt forest communities (integrated project with carbon theme, PhD).

Each PhD project has contributed to achieving the goals set out in the 2010–16 project plans, specifically:

- Investigating factors that affect regeneration success or failure for significant tree species. This involved establishing plots across edaphic

and climatic gradients (Deepa Rawal, Gregor Sanders, Megan Hirst, Melissa Fedrigo, Helen Vickers, Linda Parker, Matthew Chick);

- Investigating mechanisms of plant survival and mortality of significant tree species. This involved a common garden experiment (Gregor Sanders, Deepa Rawal);
- Climatic effects on germination, growth and flowering phenology of eucalypts (Deepa Rawal);
- Using empirical data for model calibration, validation and prediction of significant tree species' responses to climate change, bushfire, planned burning and harvesting at the landscape scale (Deepa Rawal, Gregor Sanders, Megan Hirst);

We will continue our collaboration with the Royal Botanical Gardens, Parks Victoria and VicForests. The collaboration with VicForests will be critical for undertaking the response of flora to logging and will involve Chela Powell and Liz Pryde from VicForests which we have been working with on an ARC Linkage project investigating the potential for creating habitat for Leadbeater's possum through alternative forest management practices. This collaboration will also include working with A/Prof Patrick Baker's research group at the University of Melbourne;

We will continue to work with Teresa Lebel and Tom May from the Royal Botanical Gardens and Eleanora Egidi from La Trobe University on a PhD project studying the effect of climate on the distribution of mycorrhizae and their relationship with eucalypts;

We will also continue to work with Marie Keatley from Parks Victoria on a project investigating flowering and growth phenology in box-ironbark forests.

Figure 12: Researcher with an old-growth Mountain Ash, Snobs Creek Road, Eildon, October 2013 (photograph courtesy Sabine Kasel).

Figure 13: Searching for old growth Mountain Ash sites, Big Creek Road, Powelltown, February 2014 (photograph courtesy Sabine Kasel).

Landscape water

Forests are the main source of drinking water for Victoria's cities and regional towns. A dependable supply of high-quality water is critical to the population's physical health and the state's economic wellbeing. Planned and unplanned fire can substantially alter both the quantity and quality of water from forested catchments.

DELWP now regularly uses this project' findings when assessing the risks of post-fire hazards such as water contamination, debris flows and flash flooding. DELWP's Fire and Emergency Management Division applied our research to evaluate risks of water supply contamination under different fire management scenarios. Better understanding of tree mortality and water use as a function of fire severity has improved DELWP's capacity to predict the effects of bushfires (such as the catastrophic 2009 Black Saturday fire) on long-term water yield.

All this work directly supports better water resource planning.

University of Melbourne research leader: Associate Professor Patrick Lane

Research Team: Dr Gary Sheridan, Mr Phillip Noske

Department of Environment, Land, Water and Planning senior policy lead: Will Guthrie, Geoff Steendam

Table 10: IFER landscape water – policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Fuel Reduction burning of five per cent (385 000 ha) of public land per annum. • To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products (*Code of Practice for Bushfire Management on Public Land*). • Reduce major bushfire risk to people, community and environmental assets, essential and ecosystem services through understanding community values and knowledge and incorporating these values into a risk based approach. • Maintain or enhance water quality, water quantity and river health (Action for Code Principle 4 of *Code of Practice for Timber Production 2007).* • Assessment of and accounting for water *(Water Act 1989, Section 3*).	• What are the impacts of fire (natural and managed), climate variability/change and forest management regimes on water quantity and quality from Victoria's public forested catchments now and into the future? • How can we better understand and model the integrated impacts of fire (planned and unplanned) and climate variability/change on water quantity and quality? • What are the relationships between various resilience "states" and water quality and quantity?

Project description

DELWP's land, water and fire managers take into account the effects of fire on water values when making planning and policy decisions. However, there are still fundamental gaps in our knowledge of the hydrologic impacts of fire. These gaps prevent us from making the best decisions for managing fire on public land.

The aim of the landscape water theme was to start to fill these knowledge gaps and provide for more informed land-management decision making. UM researchers and the DELWP project lead developed research objectives to answer the policy implementation questions (see above) based on consultation.

Fire affects water yield and quality through very different processes, so at the highest level the research objectives are related to these two values.

Water yield research

When this project began the team realised there were large gaps in our fundamental knowledge of system responses to fire, including knowledge of the water yield response of mixed-species forests. Further, existing models did not take into account new understandings of the combined effects of fire and climate change.

The project has significantly advanced our knowledge of the fundamental biophysical and physical processes in burnt forests, and conceptual understanding of system responses. Examples are described below. On evapotranspiration and water yield the fundamental work on mixed-species forests has been highly successful, as has our work on the importance of soil moisture storage on post-fire yield responses. Subsequent activities have focussed on improving our understanding of forest water balance as a function of landscape position and climate/energy budgets. This has revealed patterns of eco-hydrologic functioning at the hillslope scale that are crucial to predicting responses to disturbance and climate variability.

Water quality research

An initial review identified that while there was a substantial body of international literature (and several Australian publications) on fire, erosion and water quality, there had been no attempt to systematically synthesise this knowledge. As a result, the project team published two review papers on fire and water in international journals, one on planned fire and one on bushfire. These papers established baseline knowledge and helped refine main gaps in research knowledge.

The ability to accurately predict changes to water quality caused by fire was hampered by a lack of appropriate models. That is, there were no models that included the correct processes and that could be applied at a range of scales and resolutions for different purposes – for policy development, to assist planning, and at the operational scale. This was a constraint because models give us an understanding of the system under investigation, and a capacity to predict how changes to the inputs to that system (such as climate and fire) may cause changes to the outputs from that system (such as water quality).

Existing models were also limited by a lack of understanding of the dominant system properties and processes that affect water quality after fire. Such understanding would allow us to construct, and correctly parameterise, robust models.

In response to these limitations, the team developed several models and undertook extensive field and laboratory experiments to calibrate them. Three models are now being used by DELWP in policy, management and planning.

Although the Landscape Water Project achieved more than 90 per cent of its aims, it also produced a significant body of closely related research that was not originally envisaged. One reason for the latter was the need to take advantage of new ideas, particularly from PhD students, and of the unexpected turns that any research program can take. More than 50 peer-reviewed publications were either published or accepted over the six-year life of the project, and a further five were submitted. This output was facilitated by the combination of the project's antecedence and the additional activities.

Looking ahead, there are still challenges in understanding fundamental process responses to fire and climate variability – and the interaction between the two factors is probably crucial. Identifying system attributes that will be affected and spatial data sets that describe these attributes is important in modelling the systems.

Results and scientific achievements

Our water yield research achieved the following:

- The first process understanding of post-fire evapotranspiration dynamics in mixed-species forests. This significantly improved our

understanding of ecosystem functioning under varying fire intensities and our ability to model post-fire water yield;

- Greater understanding of the water-use dynamics of Ash and mixed-species stands under variable climate. We demonstrated lagged recovery of stream flow in response to drought;
- Better understanding of scaling issues, spatial variability of evapotranspiration, and the use of LiDAR (a combination of light and radar) in remote sensing of evapotranspiration.

Figure 14: Post-fire runoff and erosion study in north-east Victoria (photograph courtesy Gary Sheridan).

The water quality research achieved:

- A synthesis of Australian and international literature, culminating in two review papers in high-ranking international journals on the water quality effects of fire in relation to water supplies, and the effects of planned burning on runoff and erosion;
- Discovery of the crucial role of post-fire debris flows in water supply contamination in south-east Australian forests, published in a leading international journal;
- Development of a new model for predicting the effects of fire on water yield and quality. The new model, called HydroFire, was structured to enable different users within DEPWP to easily implement the model in different contexts, including for statewide strategic planning, planning at the Bushfire Risk Landscape level, and for post fire risk assessment. The uptake of the model by DELWP has been strong, and it is currently used operationally at all these levels.

Applying the research

This research has directly and quantifiably affected the management and planning of forested public land. Close collaboration between UM researchers and DELWP staff has ensured that new research has been quickly integrated into policy and planning, as illustrated by the following examples:

Bushfire rapid response assessment teams (BRRATs)

The research findings were used to develop risk assessment tools for post-fire hydrologic hazards such as water contamination, debris flows, and flash flooding. These algorithms and computer models are now used routinely by DELWP's BRRATs doing post-fire risk assessments throughout Victoria. This collaboration between DELWP staff and UM researchers will continue, ensuring new IFER research is quickly incorporated into DELWP's risk assessment methodologies.

Strategic bushfire risk assessment tools

DELWP's Fire and Emergency Management Division used this research to evaluate risks of water supply contamination under different fire management scenarios. The results of these risk assessments are being applied in the development of the East Central Strategic Bushfire Management Plan. The Forest and Water Group is continuing to help DELWP develop, test and adapt these water-related risk assessment tools for other bushfire risk landscapes in Victoria.

Post-fire water yield modelling

Our significantly improved understanding of tree mortality and evapotranspiration dynamics as a function of fire severity means we can parameterise models with far more certainty than in the past. The project applied this improved understanding to modelling the effects of the 2009 Black Saturday bushfires on long-term water yield, and to evaluating alternative fire management scenarios as part of DELWP's Bushfire Risk Landscape planning process. This work directly supports better water resource planning, required under the Water Act.

Figure 15: PhD student Rachael Nolan measuring transpiration in Maroondah catchment (photograph courtesy Patrick Lane).

Opportunities, extra benefits and collaboration

We entered into several important collaborations to obtain additional funding and resources:

- Melbourne Water – a five-year project provided PhD scholarships, postdoctoral positions and operating funding for crucial field-based process experiments for mixed-species fire-evapotranspiration and water yield response, and for debris flow occurrence and water contamination process experiments. This collaboration also significantly improved our ability to model post-fire water quality, and helped us integrate the PHOENIX fire model into hydrologic risk models;
- Australian Research Council – an ARC Linkage grant with Melbourne Water enabled us to build on an ability to model evapotranspiration and water yield under undisturbed and disturbed conditions, and to better understand the effect of bushfire on tree mortality, water use and catchment water yield;
- Forestry Cooperative Research Centre – provided PhD scholarships, funding for a postdoctoral position and operating funds to investigate post-fire (planned and unplanned) water quality and water yield effects;
- Bushfire Cooperative Research Centre – provided a PhD scholarship and research fellow funding to research water quality and erosion following the 2009 Black Saturday fires;
- Natural Disaster Resilience Grants Scheme – provided funding for a Research Fellow and research assistant to develop better landscape water balance models for the prediction and modelling of fuel moisture, improving our capacity to predict and model planned and unplanned fire;
- Australian Research Council – a three-year ARC Linkage grant with Melbourne Water, DELWP's Bushfire RRAT's and East Gippsland Water, beginning in early 2106, is funding a post-doc and PhD position, developing statewide post-fire risk assessment tools for flash-flooding, debris flows and water quality;
- Bushfire and Natural Hazards CRC – provided funding for a research fellow to test the performance of an Automated Fuel Moisture Monitoring network for Victoria.

Additionally, the team completed three years of collaborative research as part of the DELWP Future Fire Project. This was a pilot study in the Otway region and a forerunner of the strategic bushfire risk landscapes approach that DELWP now follows across Victoria.

Other significant scientific collaborators included the University of Washington, Swansea University in the UK, US Geological Survey, CSIRO Ecosystem Sciences, CSIRO Land and Water, UM Department of Mathematics and Statistics, and the University of Newcastle. These collaborations brought greater expertise to the landscape water research theme.

PhD and postdoctoral researchers included:

- Petter Nyman (2009-2014): Post-fire debris flows in southeast Australia: initiation, magnitude and landscape controls;
- Rachael Nolan (2009-2013): Effects of bushfire on forest structure and plant functioning in re-sprouting forests: implications for catchment water balance;
- Sandra Hawthorne (2008-2011): Long-term impact of thinning on water yield;
- Craig Mason (2010-2016): A probabilistic sediment load model for fire-prone landscapes in southeast Australia;
- Jane Cawson (2008-2012): Effects of prescribed burning on surface runoff and erosion;

- Assaf Inbar (2013-) The coevolution of forests, fire regimes and soils in south east Australia;
- Daniel Metzen (2013-) Eco-hydrological implications of energy and water-availability patterns in complex terrain;
- Leila P. Kasmaei (2013-) Scale dependency of post-fire surface runoff and erosion;
- Postdoctoral research fellows: Hugh Smith, Patrick Mitchell, Richard Benyon, Christoph Langhans, Petter Nyman and Dominick Jaskierniak.

The PhD students and postdoctoral research fellows were funded by a mix of grants including IFER scholarships or top-ups and operating budgets, and from non-DELWP funders. However, in every case they both contributed to, and benefited from, the core project. These students produced high-quality research directly relevant to the core landscape water project, and their work contributed to reaching several milestones.

Table 11: Landscape water – additional funding 2010–16

Source	$
Melbourne Water	1,200,000
Australian Research Council Linkage grant	1,132,035
Department of Sustainability and Environment Future Fire Management Project	390,000
Bushfire CRC	330,000
Forestry CRC	300,000
National Disaster Resilience Grants Scheme (NDRGS)	180,000
Bushfire and Natural Hazards CRC	200,000
Total	**3,732,035**

Figure 16: A fire effects study area in the Wombat State Forest (photograph courtesy Cristina Aponte).

Landscape integration

This project involved developing ways to make sure that all of the core themes are taken into account by individuals and organisations making decisions about bushfire response and forest management. Both biophysical and socioeconomic factors need to be combined in the one framework. The majority of this work will be done in 2013–16.

University of Melbourne research leader: Associate Professor Stefan Arndt/Associate Professor Patrick Lane

Department of Environment, Land, Water and Planning senior policy lead: Liam Fogarty

Table 12: IFER landscape integration – policies and policy implementation questions 2010–16

Policy	Policy implementation questions
• Adaptive management of the forested landscape on public land in Victoria in accordance with the objectives of sustainable forest management as described in the Sustainability Charter. • Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the Victorian Bushfire Royal Commission (VBRC) recommendations – in particular through planned burning of five per cent of public land per annum. • Climate change mitigation and adaptation, including the development of national, global and local carbon markets (Commonwealth Carbon Farming Initiative; Victorian Climate Change Act 2010). – Relevant commercial (e.g. Victoria's 2009 timber industry strategy), recreational (e.g. sustainable recreation in parks) and social (e.g. Metropolitan parks strategy) strategies of government.	• What are the interactions, including, tipping points and trade-offs between forest values - natural (carbon, water, biodiversity) and socioeconomic (recreation, commercial, heritage, amenity)? • What are the impacts of fire (natural and managed), climate variability/change and forest management regimes on the interactions mentioned above now and into the future?

Achievements

Following the Bushfires Royal Commission 2009 DELWP established a Bushfire Management Reform Project with an Expert Reference Group (ERG) of senior academics and government staff of international standing. This group, in their final report stated "(program success and improvements)…are based on sound evidence and is the culmination of several decades of work that draws on scientific research and best available knowledge to understand bushfire risk. This has resulted in a program that sets a new standard in bushfire risk management both nationally and internationally" (ERG (2014), p.7). IFER is a significant component of this scientific research and major contributor to bushfire risk knowledge to which the ERG alludes.

Broader than bushfire risk, IFER core projects are also a substantial contributor to the knowledge base DELWP uses to enable and support decision making across a wider range of contexts. From the ability to simulate fire impacts, development of ecosystem resilience indicators, understanding the impact of fire regimes on water quality, to the future of work with carbon stores.

Recognising the need to integrate understanding of the core theme research so it can be *effectively utilised* when people are making decisions about management DELWP staff and researchers have worked together in co-generation of knowledge, through adaptation of the projects and the program to meet emerging government obligations, and in delivering outputs that enable understanding in preference to the delivery of information.

Applying the research

This task of integration has been a complex and difficult one. Combining biophysical models with socioeconomic analysis in the one framework has been a significant topic in complex ongoing conversations between researchers and DELWP. These conversations have helped the collaborators to understand how decisions are made in any space and time, and how they could be made in a more integrated way. In doing this, relationships were built, ideas shared and discussed, and ways of thinking were adapted. The result is a robust basis on which project plans for 2013–16 were developed that explicitly spoke of and included integration. This has been followed by a move towards an even stronger 2016-19 IFER program where integration of the IFER core themes into a framework that can operate across a local, regional and state wide context is being developed.

From this IFER work a framework that will enable complex decisions that incorporate community values and contributions, state significant resources and biophysical attributes, and the full suite of land management agencies to be accounted for in decision making. The costs and benefits of management decision making and actions will be transparent.

Learning and adaptation

In addition to the specific research findings highlighted in this report, we made the following general observations and recommendations. It will be important to apply these, both in future research projects and in the management of Victoria's forests.

Both researchers and forest managers must:

- Learn from the program and projects;
- Share what they have learnt;
- Apply this knowledge to future IFER research.

What was learnt in the 2010–13 cycle has strengthened planning for 2013–16, by developing stronger relationships, building common understanding and a clearer picture of what projects should look like, and shaping a vision for an integrated research framework. Three significant issues were identified, which were taken into account when planning the next round of research:

1. Fieldwork and data

Research projects that involve planned burns are difficult to coordinate, particularly because of uncertainty on the best timing for a burn. This created difficulties for several research projects subject to narrow timeframes. Although addressed by meeting regularly with regional participants and managers, adopting a collaborative approach to the research in future will help better understand the lead times and communication needed for planning burns and accessing burn areas.

Sharing data between PhD student projects and broader DELWP projects can be complex and contractually difficult. This was solved this by developing a protocol within the IFER agreement that enabled DELWP to use research data for reporting and planning purposes, without pre-empting the opportunity for students to publish their work in the academic literature.

Conversely, delays in obtaining DELWP data held up aspects of the research work. Processes were developed to shorten such delays, but they enjoyed limited success. In the future this can be avoided by not constructing milestones based on data sourced from outside the UM's Department of Ecosystem and Forest Science. The program also needs a more flexible approach and better process for accessing data. This should include new tools such as the Victorian Government's web-based open data platform.

The field-intensive nature of the research requires many people and resources, which brought some unexpected costs. Resolving these situations as they arose has taught us how to scope projects and their budgets better, identify and seek additional funding, and involve more high-quality postgraduate students in the research program.

Occasionally there were delays in accessing custom-made equipment owned by third parties. We will resolve this in the future by waiting for resolution of delays, shifting the project milestones, or avoiding constructing milestones based on third-party equipment.

2. Models and tools

Training in applying modelling tools to ensure that they produce good-quality analyses is imperative. For instance, PHOENIX can be inadvertently used as a 'black box', which could lead to incorrect decisions that have possibly catastrophic consequences. Although PHOENIX gives a useful representation of fire behaviour, it needs to be used in an ensemble environment so that users understand the uncertainty created by inputs and model characteristics. Also, it is important that the version and distribution of PHOENIX be tightly controlled to ensure consistency of research outputs and management of risk to DELWP.

Planning for PHOENIX's development and maintenance is crucial as well as backup support and ongoing checking and validation.

3. Servicing the agreement

To get the best value from the IFER program, a workable balance between research and service components is required. This could be done by encouraging innovative research that fosters initiative and a sense of ownership and by open discussion between UM and DELWP colleagues about their respective expectations and research requirements.

The experience of many Core projects has been that much of the transfer and application of new research took place through supplementary projects. A primary intent of supplementary projects is to bring additional resources to the core project. But the more focused, applied and interactive nature of the supplementary projects proved to be very effective for using and transferring some of the more fundamental research. We could consider recognising more formally the role of supplementary projects in transferring knowledge.

Many large projects used modelling, including developing and calibrating models, to provide rigorous and robust analyses that can be used to answer climate and management questions. These data- and labour-intensive exercises place further pressure on already limited time and labour. In order to balance the need for scientific rigour and practical policy solutions with finite funding, greater authority and knowledge at the project scoping phase is needed.

Directions 2013–16

In 2013 the entire IFER team worked to apply the experiences and lessons learnt over the previous three years, and changes in operations and policies, to plan the next three years of the core program. The team developed fresh core project plans that are responsive, robust and relevant. The revised policy implementation questions, and management objectives and policies for 2013–16, are set out in Tables 13 and 14 below.

Table 13: IFER implementation questions 2013–16

Implementation questions	
Landscape biodiversity	How can we maintain the biodiversity of Victoria's public forests? – Is vegetation condition a good indicator for biodiversity health? – What is the relationship between abundance/distribution of plants and animals with resilience? – How can we minimise the impact of fire on biodiversity?
Landscape carbon	How can we maintain the carbon of Victoria's public forests? – How can we best monitor, report and predict forest carbon assets through time at the landscape scale? – What are the inherent and operational drivers that change forest carbon assets, including fire regime and climate?
Landscape socio economic	How can we improve community value of Victoria's public forests? – How can we best asses, monitor and report community value? – How can community values be incorporated into risk management decision making?
Landscape vulnerability	How can we maintain resilience and productivity of Victoria's public forests? – How can we improve our understanding of landscape level resilience and productive given current scientific methods? – What is the relative importance of soil versus other resilience measures? – What are the relationships between various resilience 'states' and the delivery of other ecosystem services such as water, timber and carbon?
Landscape water	How can we maintain the water quality and quantity of our catchments? – How can we minimise the impact of fire on water quality and quantity? – What are the relationships between various resilience 'states' and

	water quality and quantity?
Landscape integration	How can we improve the science to policy interface? – How do our value systems affect it? How do we balance and trade off different objectives/values to maximise community benefit? – What are the interactions, including, tipping points and trade-offs between forest values - natural (carbon, water, biodiversity) and socioeconomic (recreation, commercial, heritage, amenity)? – How can community values be incorporated into risk management decision making? – How can we more effectively reduce bushfire risk to communities and other values? – How does fuel and fire (planned and unplanned) behave in our highest hazard and risk environments (such as the Otway Range, Ballarat Macedon area and the Yarra and Dandenong Ranges), and how can we more effectively reduce bushfire related risk to communities and other priority values? – How do fire severity, fire patchiness, pattern, size and connectivity influence bushfire hazard and damage potential as well as resilience, the provision of services such as biodiversity, carbon, water and forest products? – What are the impacts of planned fire in the long term versus the short-term?

Table 14: IFER management objectives and policies 2013–16

DELWP's management objectives for the public land estate	Some major external influences on the management of public land
The community benefits from effective management of Victoria's public and private land assets. Reduced impact of major bushfires and other extreme events on people, infrastructure and the environment. Effective environmental policy, investment and regulation. Maintenance or enhancement of water quantity and water quality.	The biophysical impacts of a changing climate in Victoria (e.g. water variability, increased fire threat, new pest and disease threats) Significant population growth, and the resultant: – Urban expansion, increased urban forest interface and infrastructure development, and – Increased use of public land. Bushfire and emergency management reform, and increased planned burning The impacts of carbon markets and the carbon tax Changes in the way the community values and uses public land Innovations in spatial and information technologies, and social

	media trends and technologies
Policy	**Some major external influences on the management of public land**
Public land management	Delivering community benefits from the management of public forests. Sustaining healthy and productive forests on public land in Victoria in accordance with the objectives of sustainable forest management (*Sustainability Charter 2007*). Delivering on the government objectives for the management of forest on public land relevant, natural resource management, commercial, recreational and social objectives described in the relevant Government endorsed strategies and plans (e.g. Victoria's *Timber Industry Action Plan 2012*). Contributing to the regional economic sustainability and development.
Biodiversity management	Securing the health of Victoria's biodiversity in the face of a changing climate (*Biodiversity Strategy 1997*).
Fire management	*Code of practice for fire management on public land (2012)* which states the two primary objectives for bushfire management on public land: To minimise the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment. To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products. Reduce the risk of severe bushfires to people, their assets, essential services and ecosystem services through implementation of the Victorian Bushfire Royal Commission (VBRC) recommendations – in particular through planned burning of five per cent of public land per annum.
Climate change adaptation	Climate change mitigation and adaptation, including the development of national, global and local carbon markets (*Commonwealth Carbon Farming Initiative*; *Victorian Climate Change Act 2010*). Promoting the resilience of Victoria's ecosystems and improving their management (*Victorian Climate Change Act 2010*; *Policy objective 6f*).
Water management	Maintain or enhance water quality, quantity and river health. Assessment of and accounting for water *(Water Act 1989, Section 3*).

Selected publications

The Integrated Forest Ecosystem Research program 2010–16 resulted in a substantial number of articles being published in high-quality, peer-reviewed journals, both in Australia and overseas. It also produced government reports and guidelines, technical reports and conference papers. Selected titles are listed here.

Landscape biodiversity

Berry LE, Sitters H (2015) Case study: the ecology of mixed-severity fire in Mountain Ash forests. In "The Ecological Importance of Mixed-Severity Fires: Nature's Phoenix". (Eds. DellaSala, D. and Hanson, C.) Pp. 210-222. Elsevier.

Brown J, York A, Christie F, McCarthy M (2016) Effects of fire on pollinators and pollination. *Journal of Applied Ecology.*

Brown J, York A, Christie F (2016) Fire effects on pollination in a sexually-deceptive orchid. *International Journal of Wildland Fire.*

Chick M, Cohn J, Nitschke C, York A (2016) Lack of soil seedbank change with time since fire: Relevance to seed supply after prescribed burns. *International Journal of Wildland Fire.*

Cohn JS, Di Stefano J, Christie FJ, Cheers G, York A (2015) How do heterogeneity in vegetation types and post-fire age-classes contribute to plant diversity at the landscape scale? *Forest Ecology and Management* 346: 22-30.

Di Stefano J, McCarthy MA, York A, Duff TJ, Slingo J, Christie FJ (2013) Defining age class distributions for multispecies conservation in fire-prone landscapes. *Biological Conservation 166*, 111–117.

Di Stefano J, York A (2012) Relationships between disturbance regimes and biodiversity: background, issues and approaches for monitoring. Fire and Adaptive Management Report No. 91. Victorian Government Department of Sustainability and Environment, Melbourne.

Di Stefano J, Ashton A, York A (2014) Diet of the silky mouse (*Pseudomys apodemoides*) and the heath rat (*P. shortridgei*) in a post-fire environment. *International Journal of Wildland Fire* 23: 746-753.

Di Stefano J, Coulson G, Swan M, Greenfield A (2011) Heterogeneity of food and shelter resources influences home range size in the swamp wallaby (*Wallabia bicolor*). *Ecography* 34: 469-479.

Di Stefano J, Owen L, Morris R, Duff T, York A (2011) Fire, landscape change and models of small mammal habitat suitability at multiple spatial scales. *Austral Ecology* 36: 638-649.

Di Stefano J, Swan M, Greenfield A, Coulson G (2010) Effect of habitat type, sex and time of day on space use by the swamp wallaby (Wallabia bicolor). In: Macropods: the Biology of Kangaroos, Wallabies & Rat-kangaroos. (Eds. G. Coulson and M.D.B. Eldridge.) Pp. 187-196. CSIRO, Melbourne.

Di Stefano J, York A, McCarthy M, Duff T, Christie FJ, Slingo J (2013) Defining vegetation age class distributions for multispecies conservation in fire prone landscapes. *Biological Conservation* 166: 111-117.

Duff TJ, Bell TL, York A (2013) Managing multiple species or communities? Considering variation in plant species abundances in response to fire interval, frequency and time since fire in a heathy Eucalyptus woodland. *Forest Ecology and Management* 289: 393-403.

Duff TJ, Bell TL, York A (2013) Predicting continuous variation in forest fuel load using biophysical models: a case study in south eastern Australia. *International Journal of Wildland Fire* 22: 318-332.

Duff TJ, Bell TL, York A (2011) Patterns of plant abundances in natural systems: is there value in modeling both species abundance and distribution? *Australian Journal of Botany* 59: 719-733.

Duff TJ, Bell TL, York A (2014) Recognising fuzzy vegetation pattern: the spatial prediction of floristically defined fuzzy communities using species distribution modelling methods. *Journal of Vegetation Science* 25: 323-337.

Fordyce A, Hradsky BA, Ritchie E, Di Stefano J (2016) Fire affects microhabitat selection, movement patterns and body condition of an Australian rodent (*Rattus fuscipes*). *Journal of Mammalogy* 97(1): 102-111.

Garnick S, Di Stefano J, Elgar MA, Coulson G (2016) Ecological specialisation in habitat selection within a macropodid herbivore guild. *Oecologia* 180(3): 823-832.

Haslem A, Leonard SWJ, Bruce M, Christie F, Holland GJ, Kelly LT, Mac Hunter J, Bennett AF, Clarke MF, York A (in press) Do multiple fires interact to affect vegetation structure in temperate eucalypt forests? *Ecological Applications*.

Hradsky BA, Loschiavo J, Hradsky M, Di Stefano J (2015) Shrub expansion alters forest structure but has little impact on native mammal occurrence. *Austral Ecology* 40: 611-624.

Hradsky BA (2014) More than just presence-absence: camera traps reveal fine scale resource partitioning by the ubiquitous swamp wallaby (*Wallabia bicolor*). In "Camera Trapping: Wildlife Management and Research". (Eds. P.D. Meek, P.J.S. Fleming, A.G. Ballard, S.C. Banks, A.W. Claridge, J.G. Sanderson and D.E. Swann). CSIRO, Melbourne.

McMullan-Fisher SJM, May TW, Robinson RM, Bell TL, Lebel T, Catcheside P, York A (2011) Fungi and fire in Australian ecosystems: a review of current knowledge, management implications and future directions. *Australian Journal of Botany* 59: 70-90.

Miehs A, York A, Tolhurst K, Di Stefano J, Bell T (2010) Sampling downed coarse woody debris in fire-prone eucalypt woodlands. *Forest Ecology and Management* 259: 440-445.

New TR, Yen AL, Sands DPA, Greenslade P, Neville PJ, York A, Collett NJ (2010) Planned fires and invertebrate conservation in south east Australia. *Journal of Insect Conservation* 14: 567-574.

Penman TD, York A (2010) Climate and recent fire history affect fuel loads in Eucalyptus forests: Implications for fire management in a changing climate. *Forest Ecology and Management* 260(10): 1791-1797.

Penman TD, Christie FJ, Andersen AN, Bradstock RA, Cary CJ, Henderson MK, Price O, Tran C, Wardle GM, Williams RJ, York A (2011) Prescribed burning: how can it work to conserve the things we value? *International Journal of Wildland Fire* 20: 721-733.

Sitters H, Christie F, Di Stefano J, Swan M, Collins P, York A (2014) Associations between occupancy and habitat structure can predict avian responses to disturbance: implications for conservation management. *Forest Ecology and Management* 331: 227-236.

Sitters H, Christie FJ, Di Stefano J, Swan M, Penman T, Collins P, York A (2014) Avian responses to the diversity and configuration of fire age classes and vegetation types across a rainfall gradient. *Forest Ecology and Management* 318: 13-20.

Sitters H, Di Stefano J, Christie F, Swan M, York A (2016) Bird functional diversity decreases with time since disturbance: does patchy prescribed fire enhance ecosystem function? *Ecological Applications* 26(1): 115-127.

Sitters H, Di Stefano J, Christie FJ, Sunnucks P, York A (2015) Bird diversity increases after patchy prescribed fire: implications from a before-after control-impact study. *International Journal of Wildland Fire* 24(5): 690-701.

Swan M, Christie F, Sitters H, York A, Di Stefano J (2015) Predicting faunal fire responses in heterogeneous landscapes: the role of habitat structure. *Ecological Applications* 25(8): 2293-2305.

Swan M, Di Stefano J, Christie F (2014) Comparing the effectiveness of two types of motion-camera for surveying ground-dwelling mammals. In "Camera Trapping: Wildlife Management and Research". (Eds. P.D.

Meek, P.J.S. Fleming, A.G. Ballard, S.C. Banks, A.W. Claridge, J.G. Sanderson and D.E. Swann.) CSIRO, Melbourne.

Swan M, Di Stefano J, Christie, FJ, Steel E, York A (2014) Detecting mammals in heterogeneous landscapes: Implications for biodiversity monitoring and management. *Biodiversity and Conservation* 23: 343-355.

Swan M, Gallindez-Silva C, Christie FJ, York A, Di Stefano J (2016) Contrasting responses of small mammals to fire and topographic refugia. *Austral Ecology 41*, 443-451.

York A (2012) Invertebrates and fire – Challenges and opportunities for conserving biodiversity. *Proceedings of the Royal Society of Victoria* 124 (1): 47-55.

York A (2014) Changing fire regimes: The response of litter-dwelling invertebrates to altered seasonality and frequency of fire. In "Advances in Forest Fire Research" (Ed. D.X. Viegas.) Pp. 519-526. University of Coimbra, Portugal.

York A, Bell TL, Weston C (2012) Fire regimes and soil-based ecological processes: implications for biodiversity. In “Flammable Australia: Fire Regime, Biodiversity and Ecosystems in a Changing World”. (Eds. R.A. Bradstock, R.J. Williams & A.M. Gill.) Pp. 127-148. CSIRO Publishing, Collingwood, Victoria.

York A, Friend G (in press) Towards an ecologically sustainable fire management strategy. *Victorian Naturalist*

Landscape carbon

Aponte C, De Groot W, Wotton M (in press) Forest fires and climate change: causes, consequences and management options. *International Journal of Wildland Fire*

Aponte C, Tolhurst KG, Bennett LT (2014) Repeated prescribed fires decrease stocks and change attributes of coarse woody debris in a temperate eucalypt forest. *Ecological Applications 24*, 976-989.

Bennett LT, Aponte C, Baker TG, Tolhurst KG (2014). Evaluating long-term effects of prescribed fire regimes on carbon stocks in a temperate eucalypt forest. *Forest Ecology and Management 328*, 219-228.

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Figure 17: Agile Antechinus (photograph courtesy Fiona Christie).

Program contributors

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Table 15: The many individuals who collaborated to make IFER 2010–16 a success

University of Melbourne
Professor Liz Sonnenberg, Professor Rick Roush, Professor Gerd Bossinger, Associate Professor Alan York, Dr Julian Di Stefano, Dr Fiona Christie, Dr Janet Cohn, Dr Lauren Bennett, Dr Cristina Aponte, Dr Tom Baker, Associate Professor Kevin Tolhurst, Dr Tom Duff, Markus Loewe, Dr Craig Nitschke, Dr Sabine Kasel, Associate Professor Patrick Lane, Dr Gary Sheridan, Associate Professor Stefan Arndt, Lisa Rodier, Alison Cowan, Claire Blake, Kathy Lynch, Dr Ruth Beilin, Juio Najera, Benjamin Smith.
Department of Environment, Land, Water and Planning (previously the Department of Environment and Primary Industries; prior to that, the Department of Sustainability and Environment)
Lee Miezis, Peter Beaumont, Duncan Pendreigh, Dr Peter Appleford, Andrew Haywood, Liam Fogarty, Peter Chronopolous, Courtney Johnston, Gordan Ivancic, John Houlihan, Liam Fogarty, Dr Gordon Friend, Gary Howell, Geoff Steendham, Jaymie Norris, Beth Roberts, Anjali Pal, Andrew Wilson, Elizabeth Ashman, Amanda Curlewis, Andrew Mellor, Imogen Fraser, Barry Denham.
Arthur Rylah Institute
Tim O'Brien, Dr Kim Lowe, Dr Josephine McHunter, Dr Matthew Bruce, Dr Michele Kohout.

This table includes participants over the full six-year program, but some are no longer involved. We apologise to any person we have inadvertently omitted.

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