

A review of NSW Office of Environment and Heritage investment in bushfire research

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Executive summary and key findings

This review examines the efficacy, appropriateness and outputs of the NSW Office of Environment and Heritage (OEH) investment model for undertaking bushfire research, in particular, the returns on investment in the Centre for Environmental Risk Management of Bushfires (CERMB) at the University of Wollongong.

The review was conducted by Dr Richard J (Dick) Williams, an ecologist from CSIRO with extensive experience in fire ecology and management, and in evaluating research quality and relevance. The review's primary objective was the extent to which this research portfolio generated knowledge to underpin primary management objectives and research priorities for NSW National Parks *'Living with Fire'* strategy (2012).

Key findings

1. The OEH co-investment model funding a mix of internal and external research is highly effective and efficient for supporting research that addresses the policy and research priorities for fire management in NSW, as documented in *'Living with Fire'* (2012).
2. Research partnerships supported by OEH, particularly the Centre for Environmental Risk Management of Bushfires, are first class and consistent with national best-practice.
3. CERMB is the only individual fire research group within Australia with the capacity and track record to undertake the research required to support OEH's objectives under *'Living with Fire'*.
4. The relationship between OEH and the University of Wollongong that underpins CERMB must be maintained and enhanced. Dissolving or weakening this relationship would not be cost-effective, and would be counterproductive to all parties involved.
5. Fire research conducted within OEH and by CERMB is outstanding. Collaborations involving some 200 researchers have produced more than 180 peer-reviewed research publications since 2006, resulting in major discoveries concerning the management of bushfire risks to people and ecosystems. Both OEH and CERMB have excellent track records in leveraging external research funds; every \$1 invested by OEH in CERMB generates a further \$3.16.
6. The platform for adoption of research findings by management agencies is robust, as the research portfolio explicitly addresses policy and management imperatives. There are no apparent barriers to effective uptake and application of the research. Key discoveries resulting from OEH and CERMB research address all seven research priorities in *'Living with Fire'*.
7. The OEH co-investment model compares favourably when benchmarked against a similar model in Victoria, where fire management objectives and research requirements are comparable to those of NSW.
8. Governance of knowledge transfer requires improvement and additional investment in both the strategic guidelines and specialised personnel.
9. Failure to support fire research under the current co-investment model will carry a high risk that OEH and partner agencies will not be able to meet their fire management objectives in NSW, with a consequential increase in the risk of adverse outcomes of bushfires to the people and the environment of NSW.
10. The current co-investment model offers excellent prospects for supporting future fire research in NSW. The highest research priority is to quantify the relative cost–benefit of various risk-mitigation options.

Recommendation

I recommend that OEH continue to support fire research under the current co-investment model and with the current research partners for the next five years at least.

1. Introduction, background and scope of review

Purpose and scope of review

This review examines and reports on the efficacy, appropriateness and outputs of the NSW Office of Environment and Heritage (OEH) investment model for undertaking bushfire research. In particular, the review examined the returns on one of its major investments, the Centre for Environmental Risk Management of Bushfires (CERMB) at the University of Wollongong.

The review has been conducted by Dr Richard J (Dick) Williams, a fire ecologist from CSIRO with extensive experience in fire ecology and management and in evaluating research quality and relevance. The primary term of reference for this review was the extent to which the OEH research portfolio generated knowledge to underpin primary management objectives and the research priorities of NSW National Parks *'Living with Fire'* strategy (2012).

Background to review

OEH has statutory fire management responsibilities in NSW. Within OEH, the NSW National Parks and Wildlife Service (NPWS) is one of four recognised fire authorities in NSW under the *Rural Fires Act 1997*. NPWS is committed to managing fire and associated risks to people, communities and biodiversity, in partnership with other NSW agencies.

The basis for managing fire in national parks is the 2012 document *Living with Fire in NSW National Parks: a strategy for managing bushfires in national parks and reserves 2012–2021 ('Living with Fire')*. The mission of NPWS with respect to fire management is:

*'to protect life, property and community assets from the adverse impacts of fire' and
'to manage fire regimes in reserves to maintain and enhance biodiversity' ('Living with Fire', p. 1)*

High-quality scientific research is fundamental to the ability of OEH to meet these twin objectives. The OEH fire research model to support this research is a co-investment model. It supports a mix of research conducted internally, largely by the OEH fire researchers within the Ecological Processes Team (Ecosystem Management Science, Science Division), and research conducted in collaboration with external research partners, and part-funded by OEH. The largest of these ventures is with the Centre for Environmental Risk Management of Bushfires (CERMB) at the University of Wollongong (UOW). OEH has invested ca. \$3M in CERMB over the past 10 years.

Review structure and process

The review is a 'narrative review', based on evaluation of the evidence that is pertinent to the key questions. There are six parts to the Review Report: (1) details of the background to, and need for, the review, and methodological approach; (2) review of internal OEH research; (3) review of external collaboration with CERMB; (4) assessment of outcomes and adoption of the research; (5) benchmarking the OEH investment model against models used in other states and territories, and (6) conclusions and recommendations for future investment.

I have based my review and conclusions on a number of primary criteria:

- the extent to which the research portfolio is germane to the primary management objectives and research priorities of *'Living with Fire'*;
- the quality and quantity of the research outputs, using criteria similar to those used internationally to judge research quality;
- the extent to which research products meet strategic management and research priorities; the extent to which research is adopted, and

- whether the research investment model is effective, and how it compares with models, management priorities and research needs in other states, particularly Victoria.

Primary sources of information were publicly available strategic policy documents such as *'Living with Fire'*, policy documents from other states (e.g. Victoria's *'Code of Practice for Bushfire Management on Public Land'*, 2012), and internal documentation of the respective research portfolios provided by OEH and CERMB. Secondary sources of information included discussions with appropriate personnel within OEH, UOW, the NSW Rural Fire Service, and agencies in other states.

Summary of report structure and contents

The report is in six sections. The Section topics, and the major headings and subheadings, are indicated below. This shows the breadth and depth of the topics addressed in the course of my review.

Section 1. Introduction, background and scope of review

Purpose of and scope of review

Background: the importance of the document *'Living with Fire'*

Review structure and process: approach and sources of information

Section 2. Review of internal OEH portfolio of fire research

Fire ecology and management: the landscape ecological context

NSW OEH internal research portfolio

- Team
- Funding – sources and amounts
- Ecosystem coverage
- Research projects
- Research outputs

Hallmarks of OEH internal fire research

Conclusion

Section 3. Review of research portfolio of Centre for Environmental Risk Management of Bushfires

Summary

Introduction

Establishment of the Centre

Centre personnel

- Research staff
- Post graduate research students
- Centre Director

Centre business model

- Funding amounts and sources, 2005–2016
- Leverage

Centre research portfolio

- Biogeographic and ecosystem coverage
- Research themes and projects
 - o Projects that define and quantify risk and landscape scales
 - o Projects for managing fire and natural values

Research outputs

- Peer-reviewed publications
- Research products

Hallmarks of CERMB research

Conclusion

Section 4. Adoption and outcomes of OEH-supported fire research for policy and practice

Summary

Background

The strategic context: priorities for management and research as outlined in *'Living with Fire'*

Discoveries resulting from the OEH portfolio of research in relation to *'Living with Fire'*

- Internal OEH fire research
- CERMB research

Discoveries in relation to strategic objectives and priorities in other states and territories

Adoption of OEH and CERMB research findings in fire risk management

- Adoption in NSW
- Other states and territories
- Demand for CERMB personnel and skills

Communication of research findings

Hallmarks of the adoption and outcomes context for OEH-supported fire research

Conclusions

Section 5. Benchmarking the OEH research co-investment model

Summary

Benchmarking context

The Victorian co-investment model

- Victorian landscapes, fire regimes and risks from bushfires
- Fire management objectives and knowledge needs in Victoria
- Fire research co-investment in Victoria
- Fire management objectives and knowledge needs in other states
- Research themes and projects

- Research communication and evaluation

Corroborative evidence for efficacy of co-investment model

Capacity analysis of potential providers of research

Knowledge transfer among partners in the OEH venture

Conclusions

Section 6. Conclusions, key findings and recommendations

Summary

Review scope

Key findings

Recommendations

- The OEH co-investment model
- Future research priorities

2. Review of internal OEH portfolio of fire research

Summary

OEH has a small, internal fire research team of two to three full-time equivalent (FTE) staff per year working on fire ecology and management. Despite its size, it has been very productive. Its focus is on the highly relevant area of the responses of native biota to variation in fire regime components. The research has covered a broad range of NSW ecosystems. The group has published some 50 peer-reviewed papers in the past 10 years, and has an excellent track record in attracting external funds, principally through the highly competitive Australian Research Council (ARC) Linkage Scheme. Internal OEH fire research, in conjunction with formal ecosystem risk analyses undertaken in partnership with the University of New South Wales, has greatly increased our understanding of ecosystem risk management.

Fire ecology and management: the landscape ecological context

Managing natural ecosystems, and thus deciding where, when and if to intervene, requires knowledge of variation in ecosystem state and ecosystem function. Ecosystem state includes structure (plant cover, height, nature of understorey) and composition (species diversity; mix of different life forms, such as trees, shrubs and grasses). Ecosystem function can be regulated by 'bottom-up' processes (e.g. via variation in annual rainfall and soil nutrients), and by 'top-down' processes, such as herbivory and fire. This is true regardless of land tenure.

Both ecosystem state and function can vary in space and time. Hence the veracity, relevance and quality of OEH fire research needed to support management of fire regimes—core business for OEH—must be in the context of the range of spatial and temporal variability in ecosystem drivers.

The OEH research portfolio is reviewed in this context. This component of the review is in the following two sections; the OEH internal fire and ecosystem management research portfolio, and the major recipient of OEH funds directed towards external research providers, CERMB. My assessments are based on detailed summaries of research activities provided by Dr Tony Auld for the former, and Professor Ross Bradstock for the latter. In the course of reviewing this research model and portfolio, I examine the approach, focus, quality and efficacy of the model, as a basis for commenting on the return on OEH's investment.

NSW OEH internal research portfolio

I examine the team, funding base, projects undertaken and research fields addressed, outputs, key findings.

Team

Principal staff who contribute to work on fire are listed below. All are part of the Ecological Processes team in Ecosystem Management Science, Science Division, OEH:

Dr Tony Auld,

Prof. David Keith (to 2012)

Dr Liz Tasker

Mr Andrew Denham

Mr Mark Tozer

Mr Berin McKenzie

Dr Dan Lunney (to 2014)

This is the equivalent of about two to three FTEs per year working on fire ecology and management. This is a relatively small team.

Funding: sources and amounts

Funding comes from two streams. Firstly, there is direct internal OEH sources, which supports staff salaries and a small proportion of operating costs. Secondly, there is substantial external funding, via peer-reviewed funding sources, such as the Australian Research Council (ARC), NSW Environment Trust, and the National Environmental Science Program. This has generated ca. \$3.25M in funding for research since 2002.

Especially noteworthy is ARC funding through the Linkage Grants program. This has been leveraged with a relatively modest outlay of OEH resources, both cash and in-kind. ARC Linkage grant funding has:

- been continuous since 2002
- provided \$2.85M from the ARC (in addition to the cash and in-kind resources from OEH)
- supported 9 projects at an average of \$316K per project.

Most projects have been funded for four years, with at least two projects in any one year over most of this period. All projects have produced several peer-reviewed scientific articles. This is outstanding. It indicates the ability to sell the ideas (1) within OEH to gain the necessary cash and in-kind support to leverage further funding, (2) to outstanding, collaborating research groups within universities, and (3) to the ARC itself, where success rates for Linkage Grants is typically between 30 and 40 per cent.

This approach has attracted high quality researchers from a range of universities to focus research efforts on OEH priorities for fire management.

This research has also provided a very important collateral benefit for OEH staff; mentoring, training, and integrating the scientific process with the complex task of biodiversity and land management, the core business of OEH.

Ecosystem coverage

The research projects have been undertaken over a range of NSW ecosystems. Not all NSW ecosystems or NPWS reserve estate are covered by this research. This is understandable, given the extent of the conservation reserve network in NSW, and the small number of research staff in OEH. Nevertheless the projects and the biogeographic coverage are appropriate, and encompass a number of bioregions, including: the Warrumbungles; Southern Tablelands; South-east Highlands and Australian Alps Bioregions; north-eastern NSW; mallee; semi-arid western NSW; Blue Mountains World Heritage Area, and Sydney Basin.

Ecosystems that have been studied include the grassy woodland communities of Karst lithology; temperate heathlands; grassy woodlands, in both sub-humid and semi-arid regions of NSW; wet and dry sclerophyll eucalypt forests. Particularly noteworthy is the work on the 'problem of grass' in temperate ecosystems (grassy balds; sub-humid and semi-arid woodlands; mountain karst systems). The fire ecology and management of forests and woodlands is relatively understudied compared with their shrub/sclerophyll-dominated cousins.

Research projects

Projects undertaken by OEH cover a wide range of topics integral to effective and efficient landscape fire management. These include documentation of fire regime components, fuel dynamics, and a range of topics central to managing fire to protect biodiversity assets (fire intervals; plant regeneration; ecosystem state and transitions; climate change-fire interactions). This unquestionably adds to our understanding of vegetation change in relation to ecological processes, and provides a strong evidence base for management decisions.

Documenting fire regime components

This GIS-based research involves preparing fire severity maps from remote sensed imagery, and combining these with existing datasets to better document the fire regimes of a range of reserves. This is fundamental

research for fire management and is applied in every fire-management jurisdiction in Australia with which I am familiar.

Fire interval thresholds

This is a classic fundamental area of fire ecology. Understanding variation in inter-fire interval is classically applied to the conservation management of obligate seeder plants, by examining critical life-history processes (time to first flowering etc.) and the replenishment of seed banks in face of frequent fires. This research has had a classical focus in fire-prone temperate sclerophyllous ecosystems, which has a high proportion of obligate seeder plants. Understanding intervals, however, is also fundamental to the problem of managing fire in semi-arid systems such as the mallee, where, for example, how to preserve patches of long-unburnt mallee is a pressing ecosystem management problem. This work is captured in the NSW fire response database (managed by NPWS and Science in OEH) and used to underpin fire frequency thresholds for threatened species, populations and ecological communities and vegetation formations in the *Bush Fire Environmental Assessment Code for New South Wales* (NSW Rural Fire Service 2006).

Seed and seed banks

This is a vital area of fire research, applicable to both common and threatened species. This research will further understanding of the capacity of species to cope *in situ* with predicted climate change, including climate change effects on fire regimes and fire management, particularly the frequency and seasonality of prescribed burning.

The climate change applications of this research are very important. Climate change (including impacts on temperature and moisture) will interact with fire regimes to affect biodiversity. The potential pathways are complex; nevertheless, one highly plausible scenario across much of temperate NSW is 'interval squeeze' (Enright et al. 2015). Under this scenario, intervals between fires become shorter (essentially due to warming), but longer periods between fires may be needed for species to achieve critical life stages (due to drying). As a consequence it will take longer for plants to flower, set seeds and replenish seed banks.

The work in the long-unburnt mallee is particularly noteworthy. Long unburnt mallee is of high conservation significance, but is under threat from frequent fire (both planned and unplanned). It is an excellent example of the use of planned and unplanned fires to design experiments that examine recruitment in relation to variation in inter-fire intervals. The work complements cutting edge work on fire ecology in the mallee being undertaken in Victoria by Professors Michael Clarke and Andrew Bennett at La Trobe University and the Arthur Rylah Institute in Victoria. The work is also applicable to other semi-arid systems in Australia where long-unburnt parts of the landscape persist, and have high conservation significance, such as the Great Western Woodlands in south-west Western Australia (Gosper et al., 2013).

Fire severity

The ecological effects of variation in fire severity on ecosystem function is a very difficult area of research. For obvious reasons, it does not fit easily into the experimental paradigm. Research in this area at the landscape scales relevant to management generally has to make use of fire events, although some components such as the impact of temperatures experienced during fires on seed germination are more amenable to experimental and laboratory study.

Large and severe fires of themselves are not necessarily an automatic problem (Williams and Bradstock 2008), but are seen as such in some fire research and management circles and the media; terminology such as 'ecological disaster'; 'forests destroyed' etc are used regularly in media accounts of large fires. It is therefore very important that the issue is tackled, and in an objective scientific framework that includes the consideration of fire regimes and species life histories and responses to fire. Obviously this cannot be done everywhere, but it is highly commendable that it is addressed in the first place. It is also highly complementary to UOW/CERMB work on quantifying fire severity (see Section 3).

Moreover, the problem of structural change over time as a consequence of severe fire events, is extremely important for furthering our understanding of the internal drivers of fire regimes (fuels in relation to ecosystem structure); habitat for rare/threatened plants/animals; carbon dynamics; understanding historical drivers of vegetation change (aboriginal burning; competition); interpreting the historical record, and predicting the outcomes of various management options (e.g. changing the frequency of prescribed burning).

Threatened Species and Ecological Communities

This research includes classical investigations of the fire ecology of threatened species, such as *Grevillea caleyi* and *Wollemia nobilis*, and threatened ecological communities, such as *Acacia loderi* shrub land, with direct relevance to the conservation management of these.

Research on the 'grassy balds' plant communities of NE NSW is particularly noteworthy, as it focuses on a curious, rare ecosystem. The research model is highly relevant to wider ecosystem management, and is highly complementary to research in this field by Dr Rod Fensham and colleagues at the Queensland Herbarium/University of Queensland.

That these systems are critical habitat for the Eastern Bristlebird (*Dasyornis brachypterus*) is reason enough to invest in further understanding the fire ecology of grassy balds. There is also a fundamental ecological question regarding the origin of grassy balds; Aboriginal burning is strongly implicated in the origin and maintenance of these systems. Therefore this is a first class ecosystem within which to undertake research directed at understanding the biodiversity and conservation outcomes of Aboriginal cultural burning.

Funding for this field of research has been secured through the NSW Environment Trust, and the prospect for further funding through this and other sources is good. The research also represents an excellent collaboration with the Regional Operations Group of OEH, local NPWS rangers, Queensland Department of Natural Resources and Mines (DNRM), and the University of Queensland. This field of research has exceptional potential for ongoing collaborations between researchers, on-ground NPWS staff and Aboriginal people.

Climate change, fire regimes and biodiversity interactions

This is a rich field of research both nationally and internationally. The research has been actively supported by the NSW Environment Trust. It is a complex field, where changes in climate and fire regimes may act together to amplify potential problems (or indeed benefits), or antagonistically to mute potential effects. Knowledge of climate-fire-biota interactions is vital to understanding how and why to manage the conservation estate in the face of climate change.

There have been numerous studies on potential climate change effects on species using species distribution models (SDMs). Climate change-fire interactions, however, will affect ecosystems through the filter of biological interactions. These include phenological processes governing seed production, demographic processes affecting recruitment and mortality, and biotic interactions (e.g. competition or facilitation between species or life-forms).

Thus, the OEH focus has been to explicitly incorporate detailed demography into climate envelope SDM work to examine scenarios. There are numerous potential adverse effects on recruitment success, especially for obligate seeders, if fire frequency increases under climate change, fire seasonality changes, or possibly variation in fire severity changes. This has important implications for projected widening of the fire season under climate change, and for any increase in the use of prescribed fire for hazard reduction purposes. Obligate seeders are only one part of the ecosystem, so studies have examined a range of species with different life history strategies to see how different groups are likely to respond to changing climate and fire regimes.

Competitive interactions

Understanding competitive interactions between the species/life-forms of the overstorey and the understorey (e.g. the state-transition work in heathlands) is research that is also highly relevant to formulation of management strategies that deal with climate change-fire regime interactions, in particular the proposition that there should be 'more' prescribed burning in parks to reduce risks to both environmental and property assets.

This research fills an important knowledge gap, and also provides an additional experimental, methodological approach to understanding the complexity of climate change impacts on fire regimes and ecosystems.

Fire regimes and fauna

There have been several projects on fire and fauna, generally single-species studies. These include studies of koalas and bats, undertaken by Dr Dan Lunney in the Conservation Science team of Ecosystem Management Science at OEH, and frogs, involving Prof. David Keith and collaborators. Importantly, these studies have focussed on the effects of variation in fire regime on critical components of faunal habitat, e.g. tree hollows.

Fire regimes and soils

Various OEH/NPWS teams have undertaken research on fire regimes and soils. A summary of this work was provided by Dr Mitchell Tulau of OEH. The work has resulted in two substantial reports, published by OEH/NPWS, and papers at various national and international conferences, including the International Geoscience and Remote Sensing Symposium; Soil Science Australia National Soil Science Conference; International Congress on Modelling and Simulation, and International Symposium on Digital Earth. Peer-reviewed scientific journal papers are being prepared.

One OEH report, the *'Fire and Soils'* review (Tulau 2016), was commissioned to address potential impacts of fire on soils, so that this knowledge could be incorporated into the NPWS Enhanced Burning Management Plan (EBMP). This work also plans to assess whether existing standards for planning and conducting prescribed burns adequately account for soil erosion impacts.

Work on soils and fire also commenced following the Wambelong fire in the Warrumbungles in January 2013, and investigated the impacts of the fire and subsequent rainfall event on soil erosion, sedimentation and stream condition, and soil organic carbon (SOC) in the Park. The research will help clarify the potential impacts of fire on soils, and to guide post-fire recovery and remedial actions in the National Park and in NSW national parks more generally. This project is continuing, in collaboration with Xihua Yang at OEH.

Additional (non-fire) projects

Of particular note is recent work applying the IUCN Red Listing methodology to ecosystem risk assessment. This is a test of a 'new global standard' for setting priorities for conservation management. Assessments have been made for a number of ecosystems in NSW, including Cumberland Plains woodlands, cloud forest on Lord Howe Island, alpine snow patch herb fields, wetlands of the Murray-Darling Basin, and River red gum/black box/coolibah woodlands and forests of flood plains of in eastern Australia.

This work was awarded the Australian Museum Eureka Prize in the field of Scientific Research and Innovation for Environmental Research in 2015. The team was led by Professor David Keith (NPWS/UNSW) with major contributions from Drs Tony Auld and Mark Tozer. This project indicates unequivocally that the investment in supporting Professor Keith at UNSW is providing excellent returns in terms of biodiversity and conservation research that is relevant, of the highest quality and applicable ecosystem management globally.

Research outputs

The outputs from the internal OEH research are substantial. They include:

- Publications: 53 papers published between 2005 and 2015
- Fire response databases for threatened species

- Threatened Species Hazard Reduction List for the NSW *Bush Fire Environmental Assessment Code*
- Decision frameworks for where and when to burn
- Plant demographic models including high profile threatened species.

These outputs are all essential tools for effective and efficient landscape fire management.

Hallmarks of OEH internal research

1. Topical, relevant and appropriate research themes and projects across a range of biomes
2. Team well-led by Dr Tony Auld, who is an Senior Principal Research Scientist (equivalent to Professorial status at a university)
3. Excellent record of peer reviewed research publication
4. Excellent record collaboration with staff within OEH, research groups in universities and other fire management agencies
5. Outstanding rates of success at securing external funding for fire research, especially through the Australian Research Council
6. Research focus and outputs that highly complements research into fire ecology and management undertaken in other agencies, particularly CERMB
7. Forward-looking research, e.g. working on poorly known groups and climate change.

Conclusion

The internal OEH research team (Ecological Processes group in Ecosystem Management Science Branch) that works on fire ecology is a small group, with high relevance and a substantial output. The group produces quality peer reviewed scientific publications. It has an excellent track record in attracting external funding, especially through ARC Linkage Grants. The research complements research in other agencies, particularly the Centre for Environmental Risk Management of Bushfires (CERMB) at the University of Wollongong.

The research addresses issues of international significance (e.g. managing minimum fire intervals) which have profound practical applications in fire management in virtually all fire-prone biomes across Australia; the temperate ecosystems of SE and SW Australia, arid zone ecosystems of central Australia, and the tropical savannas of northern Australia. Internal OEH fire research, in conjunction with formal ecosystem risk analyses undertaken in partnership with the University of New South Wales, has greatly increased our understanding of ecosystem risk management.

3. Review of the research portfolio of the Centre for Environmental Risk Management of Bushfires

Summary

The Centre for Environmental Risk Management of Bushfires at the University of Wollongong produces world-class research on the ecology and management of fire regimes, and the risks posed by bushfires to people, property and the environment. Its research explicitly addresses the policy imperatives and research priorities of the NPWS *'Living with Fire'* Strategy. It is ably led by Professor Ross Bradstock and has produced ca. 150 peer reviewed scientific publications in 10 years. It has made major discoveries concerning management of the risks bushfires present to people and ecosystems. Its financial performance is exemplary; each OEH dollar invested in CERMB generates a further \$3.16 of external funding for further collaborative research. CERMB is the only research group in Australia that is explicitly dedicated to undertaking research that quantifies risks from bushfires to people and the environment, at landscape scales, and quantifies the sensitivity of risk to various fire management options. It is the major agency for knowledge generation to underpin OEH's fire management responsibilities.

Introduction

As for the review of internal OEH fire research (Section 2), here I examine the research portfolio of CERMB. I discuss the team, with special reference to the Director, Professor Bradstock, its funding base, the research themes addressed and projects undertaken, and research outputs including the publication record and fire management products ensuing from the research portfolio. Section 4 of the review will analyse the major discoveries that CERMB and collaborators have made, and how these discoveries align with the priorities of the *'Living with Fire'* Strategy.

Establishment of the Centre

The idea for the Centre was conceived by the University of Wollongong in 2005, and developed in partnership with NSW National Parks and Wildlife Service (NPWS). Professor Rob Whelan, then Vice Chancellor Research at UOW and a Member of the Council of Australian Governments (COAG) Expert Committee, which examined the widespread fires of 2003, originally conceived of the Centre. Professors Whelan and Bradstock (then an employee of NPWS) jointly developed a detailed proposal, which was taken to NPWS in 2005 for consideration and negotiation. The proposal was approved by the Science Directorate, supported by NPWS, and taken directly to the then Minister, who approved the establishment of the Centre in early 2006.

Centre personnel

Research Staff

Over the last 10 years, the Centre's research team has consisted of 22 UOW staff:

Prof. Ross Bradstock, 2006-present (Director)

Mr Michael Bedward, Senior Research Assistant, 2013 to 2015

Mr Rittick Borah, Research Assistant, 2008 to 2012

Dr Gabriele Caccamo, Associate Research Fellow, 2011 to 2013

Dr Luke Collins, Associate Research Fellow, 2011 to 2013

Dr Christine Eriksen, Research Fellow, 2013 to 2014

Mr Brad Cook, Research Assistant, 2008 to 2009

Dr Rebecca Gibson, Research Assistant 2013

Dr Chris Gordon, Associate Research Fellow, 2014 to 2015
Ms Bronwyn Horsey, Research Assistant, 2011 to 2015
Dr Meaghan Jenkins, Research Fellow, 2014 to 2015
Mr Simon Metcalfe, Research Assistant, 2012 to 2013
Dr Rachael Nolan, Associate Research Fellow, 2013
Dr Mark Ooi, Research Fellow, 2014 to 2015
Ms Sandra Penman, Research Assistant, 2008 to 2014
Dr Trent Penman, Senior Research Fellow, 2011 to 2014
Dr Owen Price, Senior Research Fellow, 2007 to 2015
Mr Michael Storey, Research Assistant 2013 to 2014
Dr Paul Thomas, Research Assistant & Research Fellow, 2011 to 2012
Dr Penny Watson, Research Fellow, 2008 to 2012
Ms Carrie Wilkinson, Research Assistant 2014
Dr Phil Zylstra, Research Fellow, 2012 to 2015

This is a medium-sized research team. For the first five years of its operation (2006–2010) there were between one and five FTEs per year working in the Centre. This more than doubled in the next five year period (2011–2015) to between eight and 14 FTEs per year. A further three appointments are pending, each for a duration of three to five years. Dr Owen Price has been re-appointed until 2020.

Approximately two-thirds of the staff are Research Fellows/Scientists and one-third Technical/Research Assistants. All staff have authored or co-authored at least one peer-reviewed scientific journal publication. All senior staff (Bradstock, Penman, Price) have been promoted at least one level since being appointed.

This increase in staff numbers since 2006 reflects the success of the Centre in attracting external funds and undertaking and publishing high-quality research, which in turn enables the centre to attract more funding (see below).

Post-graduate research students

A vital role of any university research department or centre is the training and supervision of post-graduate students. Since 2006, there have been 13 successful PhD completions, of which six have been through the University of Wollongong and seven through other universities. CERMB staff are currently supervising 12 PhD students, all through the University of Wollongong. The bulk of supervisory duties have been shared between Prof. Bradstock (18), Dr Price (2) and Dr Penman (3). Only one student in 10 years has not completed their study. All completed PhD students have published some or all of their thesis work in peer-reviewed scientific journals. Funding to support these PhD projects has come from a variety of competitive granting bodies, including the Australian Research Council, the Bushfire and Natural Hazards CRC and the NSW Environment Trust.

All PhD projects focussed on some practical aspect of fire management.

Undertaking such research with PhD students is highly cost-effective. The Centre effectively receives a full-time researcher for less than half the cost of a salaried research fellow. That the projects are at the vanguard of fire ecology and management, and that the completion rate is very high, indicate that the students recruited into the Centre's program are of the highest calibre.

The breadth and quality of the PhD projects, the degree of engagement of the students with the Centre staff, and the degree of collaboration of Centre staff with colleagues at other universities, are all indicators of the Centre's exceptional performance in this critical task of training young researchers.

Centre Director

Professor Ross Bradstock has directed the Centre since its inception. Prof. Bradstock played a pivotal role in establishing the Centre, as indicated above. The on-going success of CERMB is due in very large part to the diligence and vision of Prof. Bradstock. He has negotiated and set the strategic directions of the Centre, sought and secured the necessary funding to support the Centre's work, managed its staff, trained PhD students, and maintained a first-class publication record of his own.

Since its inception, Prof. Bradstock has worked effectively to ensure the Centre maintains its base funding from OEH and RFS, and, most importantly, secured substantial additional funds from external sources (see below). This has required detailed, hard negotiations with directors of state government agencies, other senior team leaders within OEH and RFS, various senior academic managers at UOW, and senior collaborating researchers at UOW, CSIRO and other universities. All this has been done without administrative assistance.

Prof. Bradstock came to the University of Wollongong from NSW NPWS where he had established himself as one of the world's leading fire ecologists. His reputation in the field of fire ecology and management has continued to grow, and his achievements and contributions are recognised internationally. He has published more than 120 peer-reviewed journal papers and book chapters, four books on fire ecology and two on biodiversity conservation and management. He has also written more than twenty major scientific reports and policy documents. His published works have been cited ca. 7500 times, and he has an H Index of 47 (Google Scholar, 27/1/2016). He is the senior editor of the seminal book on fire ecology in Australia: *'Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world'* (2012).

The majority of Prof. Bradstock's peer-reviewed publications (ca. 100) have been published since the establishment of CERMB. This equates to approximately 10 publications per year, an outstanding achievement. Of the 120 CERMB papers published or submitted to peer-reviewed journals since 2006, Prof. Bradstock is the author or co-author of 100. This personal output reflects his substantial personal contribution to the research work of CERMB; it is not an artefact of the practice of some directors of research centres and departments being named as authors on publications simply by virtue of their position.

Prof. Bradstock is a noted research collaborator. He is an invited member of 16 national and international research working groups (past and present) on vegetation-climate-fire interactions. He won the University of Wollongong Vice Chancellor's Award for Excellence in Research Partnerships (2012). He served on the panel of Expert Advisors to the Royal Commission into the Victorian Black Saturday Bushfires of 2009.

Prof. Bradstock has expertly mentored the staff of CERMB. He has recruited wisely, and the CERMB research staff all have excellent publication records. Senior Research Fellow Dr Owen Price is an internationally recognised ecological modeller, with particular expertise in quantifying fire regime components. Several younger Research Fellows have left CERMB to take up academic appointments; Dr Mark Ooi at University of Wollongong and University of New South Wales, and Dr Trent Penman at University of Melbourne. This indicates that the training and mentoring that younger researchers receive at CERMB equips them extremely well for the highly competitive job market in academia.

In summary, Prof. Bradstock has made an outstanding contribution to the field of fire ecology and management. He has enhanced the research standing of the University of Wollongong and its reputation for producing knowledge that improves public policy in disciplines that are valued by society. He has overseen the generation of a large and complex knowledge base that is needed to underpin OEH's fire management needs in NSW's conservation estate, neighbouring lands, and in the urban-rural interface.

Centre business model

The Centre business model has performed exceptionally well over the past decade. The base OEH funding has been used to leverage additional funds, which are in turn reinvested in further research that addresses the policy and management imperatives of *'Living with Fire'*.

Funding amounts and sources 2006-2015

CERMB funding has come from three streams: direct cash contribution from OEH; similar direct cash contributions from the NSW Rural Fire Service (RFS), and from various external research funding providers, generally via research contracts or a competitive bidding process.

Funding from NSW OEH for the establishment and maintenance of CERMB for the period 2006–2015 (i.e. two rounds of five-year funding) was ca. \$2.97M. This was augmented by a further \$4.15M from the NSW Rural Fire Service, for a total \$7.10M over this 10-year period. [Note that funding from RFS was contingent on funding from OEH].

Additional funding of \$4.25M was secured from contracted research via competitive bidding from a variety of sources, such as the NSW Rural Fire Service, the Bushfire and Natural Hazards CRC, the National Disaster Resilience Program and the Victorian Department of Environment and Primary Industry.

Further funding of \$3.3M was secured from various research funding sources through competitive bidding. Sources included the Australian Research Council, the New South Wales Government, and the New South Wales Environment Trust. Approximately 30 per cent of this was administered by the University of Wollongong/CERMB, hence CERMB's share of this is ca. \$1M.

Leverage

The extent to which OEH funding has been used to leverage additional funding can be calculated from these figures. The total funding for the period 2006–2015 was \$12.34M. OEH's investment over this time was \$2.97M, with a further \$9.38M generated from other sources. In leverage terms, then, for every dollar invested in CERMB by OEH, CERMB has generated an additional \$3.16. This is an excellent return on investment.

Centre research portfolio

The biogeographic and technical range of the projects undertaken by CERMB is extensive. All are germane to OEH's core fire management responsibilities – managing fire regimes such that risks to both life and property and natural values are mitigated in the most cost-effective manner. The research portfolio of CERMB explicitly addresses the policy imperatives and research priorities of *'Living with Fire'*. Moreover, CERMB is the only research group in Australia that is explicitly dedicated to undertaking research that is explicitly focussed on quantifying such risks, at landscape scales, and quantifying the sensitivity of risk to various fire management options.

Biogeographic and Ecosystem coverage

Research projects have been undertaken over a range of Australian ecosystems, from the temperate south to the tropical north, and from the high rainfall mountains of the south-east to the arid and semi-arid interior. This wide biogeographic activity stems partly from the demand of clients, and the Centre responding to such opportunities, as well as from the fact that the Centre is naturally very outward looking in its view. Staff have also been recruited from across Australia, so they bring to the Centre a breadth of ecological experience and knowledge. Major biomes and regions that have been the subject of Centre research include:

- Sydney Basin, particularly the Blue Mountains World Heritage Area, encompassing the largest population centre in Australia
- SW Tasmania

- Savannas of Australia's northern wet-dry tropics
- Forests, heathlands and grasslands of the Australian Alps Bioregion
- Forests of the Victorian Central Highlands
- Woodlands and shrub lands of the mallee of SE Australia
- Woodlands, shrub lands and hummock grasslands of arid inland Australia

The Centre has also been engaged in the study of ecosystems in other countries. These include:

- Californian shrub lands
- South African savannas

Particular ecosystems that have been studied include temperate open eucalypt forests (both 'wet sclerophyll' and 'dry sclerophyll' forests); temperate heathlands; sub-humid and semi-arid open grassy woodland communities; alpine heathlands and grasslands; arid spinifex (Hummock) grasslands; arid shrublands.

A very important product of this Australia-wide ecosystem coverage, and the involvement of CERMB staff in collaborative, national fire ecology workshops funded through bodies such as the Australian Centre for Ecological Analysis and Synthesis (ACEAS), is the delineation of Australian fire regimes. The 20 'fire regime niches' of Murphy et al. (*Journal of Biogeography*, 2013) and the primary climate and landscape determinants of such continental scale variation in fire regimes – the 'four-switch model' described by Bradstock (*Global Ecology and Biogeography*, 2010) are both major conceptual advances in the understanding of Australian fire regimes, their drivers, and thus biogeographic variation in their sensitivity to management.

Research themes and projects

The thematic and technical spread of CERMB projects is considerable. Projects fall broadly into two categories: (1) those pertinent to the quantifying risks to assets (both man-made and natural) and (2) those directed at evaluating options for managing fire regimes to enhance natural values in the landscape. All are relevant to the research priorities listed in *'Living with Fire'*.

There are several dozen subject/theme areas, as listed below. Multiple peer-reviewed papers have been published on each project area. All are current 'hot topics' in fire ecology and management globally. Major discoveries have ensued through this work, all with significant practical application. These include:

- The relative influences of fuel treatment and weather as determinants of area burnt
- The relative cost-effectiveness of various fire management options
- How fire regimes may respond to climate change
- Fire regimes and carbon dynamics
- The biogeography of fire regimes at continental scales

CERMB research intentionally and effectively complements fire research conducted by researchers within the OWH Ecological Processes team.

Projects that define and quantify risk at landscape scales

Risk metrics

Documenting fire regime components: interval, spatial extent, severity

Fuel dynamics: mass, moisture and connectivity

Fire spread modelling

Quantifying prescribed burning efficacy
Fire suppression effectiveness
Fire ignition causes, patterns and probabilities of occurrence
Climate change and fire regimes

Projects for managing fire and natural values

Grazing impacts on fire regime
Biogeography of fire regimes
Long-term fire-vegetation dynamics
Greenhouse gas emissions from bushfires
Fire management for carbon benefits
Seed ecology
Fire as an evolutionary force
Fire management at the urban-interface
Quantifying fire intervals
Quantifying fire severity
Quantifying fire heterogeneity
Fire regimes, fauna and habitats
Ecophysiology of post-fire regeneration
Fire regimes and catchment processes

Research outputs

CERMB research program outputs include (1) scientific publications (an essential component of any research organisation) and (2) specific products designed for use by fire management agencies. Over the past 10 years, CERMB has had an outstanding track record in providing the scientific and management communities with both.

Peer-reviewed publications

CERMB's publication record is outstanding. The Centre has published 153 scientific, peer-reviewed papers, book chapters or reports since 2006, with a further 11 being reviewed. The vast majority of these publications have been in peer-reviewed scientific journals, including *Nature*, *Proceedings of the National Academy of Sciences*, *Frontiers in Ecology* and the *Environment*, *Global Change Biology*, *International Journal of Wildland Fire*. Centre publications have involved collaboration with more than 200 co-authors from Australia, North America, South Africa and Europe.

Research products

The Centre has provided fire management agencies with numerous products of its research, all of which enhance the capacity of the agencies to manage fire in the landscape. These products are being operationalised by agencies, and refined in the process of being applied to real world fire management problems. Important examples include:

- Fuel accumulation models (used by RFS and NPWS)
- Remotely sensed maps and models of fuel moisture (used by RFS; Victorian DELWP)

- Evaluation of fire spread models (e.g. and especially the ‘Phoenix’ model)

The CERMB research effort has led to a number of major discoveries about Australian fire regimes, their determinants, and their sensitivity to management. The significance and practical application of these discoveries are discussed in further detail in Section 4.

Hallmarks of CERMB research

1. Research themes that are closely aligned to the research priorities of ‘*Living with Fire*’
2. The only research group in Australia that is specifically focused on the management of bushfire risk to both people and the environment, in complex landscapes and at landscape scales
3. Outstanding research teams, well-led by Prof. Ross Bradstock
4. Outstanding success rate using OEH base-funding to leverage additional funding from research funding providers
5. Outstanding record of collaboration with staff within OEH, research groups in other universities, and fire management agencies in NSW and elsewhere in Australia
6. Outstanding record of research publication
7. Forward-looking research that is at the cutting edge of fire research, both nationally and globally
8. Research projects undertaken in a number of Australian biomes
9. Research outputs that are practically oriented, highly relevant to applied problems in fire management across Australia, and are used by agencies.

Conclusion

CERMB is a very high-performing, medium-sized research group. Its research portfolio is strategic in outlook, wide-ranging, technically advanced and, above all, highly relevant to the needs of NSW’s key fire and land management agencies, OEH and RFS. The team is internationally-recognised, and well-led by the Director, Professor Ross Bradstock.

The research addresses issues of international significance which have profound practical applications in fire management in virtually all fire-prone biomes across Australia. The group produces quality scientific publications. It has an excellent track record in attracting external funding, over and above the core funding provided by OEH. The ability of CERMB to leverage external funds is exceptional – for every dollar provided by OEH since 2006, CERMB has been able to generate an additional \$3.16.

CERMB is the only research group in Australia that is specifically examining how risks from bushfires, to both man-made and natural features in the landscape, may be mitigated in the most cost-effective way. The research intentionally and effectively complements research in other agencies, particularly the internal research conducted by researchers within the OEH Ecological Processes team. The knowledge needed to underpin fire management in the NSW landscape, both within the National Parks’ reserve system and in those lands bordering the estate, is both broad and complex; its generation requires precisely the type of cross-disciplinary research capacity provided by CERMB. It also requires the economies of scale that comes from having a dedicated research group. It is highly unlikely that such a broad, policy-relevant and technically challenging research portfolio could be sustained cost-effectively purely from investment in internal OEH research. This issue is discussed in more detail in Section 5, on benchmarking.

4. Adoption and outcomes of OEH-supported fire research for policy and practice

Summary

This section of the Review evaluates the internal OEH and CERMB research findings against four key criteria for effective adoption, namely that:

1. the research aligns with strategic management priorities;
2. there is demand from management agencies for the products and capacity of the research teams;
3. research findings are effectively communicated, and
4. there is evidence for adoption of research findings by management agencies.

The portfolio of research has resulted in a number of fundamental discoveries concerning fire regimes and their management. These discoveries are highly relevant to the key policy objectives and research priorities for fire management as outlined in *Living with Fire*. The research findings are also highly relevant to fire management objectives and research priorities in other jurisdictions in Australia, particularly Victoria.

Most research projects undertaken by CERMB have been instigated by managing agencies. A number of key research findings are being adopted by partner agencies and applied in fire management protocols both in NSW and in Victoria. A major partner in CERMB, NSW Rural Fire Service, has committed funding for the next five years, indicating it has adopted the OEH co-investment model and CERMB as its preferred research provider. There is no fundamental barrier to the adoption of the outputs of the OEH portfolio of research, but there is a clear need to develop dedicated, well-resourced fire knowledge exchange expertise.

Background

Evaluating the adoption of research findings such that outcomes ensue is an important component of assessing the value of knowledge that results from research. However, turning research findings into outcomes is complex, and depends on many factors. These include the relevance of the research portfolio to strategic needs, the quality of the research, the nature of the research partnerships, the utility of research products, modes of knowledge transfer, practices for application of research findings and products, and on-going review and assessment of these components of the knowledge supply and demand chain.

Here, I focus on four critical criteria against which adoption and application of the outputs from the OEH portfolio of fire research may be judged: (1) the relevance of the research to the strategic fire management objectives as codified in *Living with Fire* and other strategic documents, (2) whether the research findings can be applied to fire management objectives and priorities of *Living With Fire*, (3) evidence of adoption and application of research products and demand for research services, and (4) the communication of research needs and research findings.

The strategic context: priorities for fire research and management as outlined in *Living with Fire*

Fire management in NSW has the policy objectives of managing fire regimes such that the risks to people, property and the natural environment are mitigated. Research is crucial to generating the knowledge required for OEH (and its agency partners) to achieve these strategic, but complex, fire management objectives. The OEH Knowledge Strategy in *Living with Fire* explicitly aligns science and research with management, policy and legislative objectives. Accordingly, the Bushfire Research Statement (p. 23, *Living with Fire*) identifies the following seven priority areas for research:

1. Fuel characteristics and accumulation rates for different vegetation formations and age classes

2. Impacts of bushfire regimes on natural heritage values
3. Effects of bushfire regimes on ecosystem processes and natural resources
4. Effects of climate change on bushfire regimes and biodiversity
5. Impacts of bushfire regimes on Aboriginal and historic heritage values
6. Bushfire risk assessment and fire behaviour modelling
7. Bushfire suppression effectiveness

OEH-supported fire research, through both its internal research program (Section 2) and the research conducted in partnership with CERMB (Section 3), has been targeted explicitly towards six of the seven research priorities. The only area of research not explicitly targeted by this research portfolio is Priority 5, *'Impacts of bushfire regimes on Aboriginal and historic heritage values'*. However, because the OEH-funded fire research has been of the highest quality, it has resulted in a number of ground-breaking discoveries that are applicable to each of these seven priority areas. Below I summarise the major discoveries and their application.

Discoveries resulting from the OEH portfolio of research in relation to *'Living with Fire'*

Discoveries are integral to the advancement of the scientific process and our understanding of the way the world works. The OEH research portfolio has resulted in a number of major discoveries that have in some cases reinforced, and in other cases challenged, our understanding of fire regimes and their management. I review these discoveries and their relevance to *'Living with Fire'* below.

Discoveries from internal OEH fire research

Internal OEH research has resulted in major discoveries that are pertinent to research Priorities 2, 4 and 6.

2. Impacts of bushfire regimes on biodiversity values

There is variation in the sensitivity of species to different components of the fire regime. The use of a range of plant functional trait groupings in combination with new proposed seed dormancy syndromes is a tool to help explain some of this variation.

Extensive severe wildfires, such as the 2013 Warrumbungles fire, have a major legacy effect. Full recovery and re-establishment of the full suite and structure of biodiversity pre-fire will depend on an initial post fire window that is fire-free for several decades.

Successful threatened species and ecological community management in fire-prone habitats can be achieved through a detailed understanding of how fire impacts on the life cycles of component species.

Individual species responses to fire have been incorporated into planning tools such as the NSW Fire Response database and RFS bush fire codes

4. Effects of climate change on bushfire regimes and biodiversity

Climatic warming will impact on many species' capacity to cope with recurring fires, primarily through changes to their capacity to bet hedge or buffer against fire impacts via persistent seed banks.

6. Bushfire risk assessment and fire behaviour modelling

Long term research sites with known fire history have been established and supported by Commonwealth-funded Long Term Ecological Research Network (LTERN).

Remote sensing and field validation offer opportunities to model estimated fire severity with at least some degree of confidence about likely biodiversity impacts.

Discoveries resulting from CERMB research

OEH-supported research through CERMB has resulted in major discoveries pertinent to all seven research priorities.

1. Quantifying fuel characteristics and accumulation rates for different vegetation formations and age classes

Fuel models for major vegetation classes in NSW derived and implemented into risk management planning.

Visual fuel assessment methods were assessed and ranked.

Comprehensive modelling of surface fuel variation as a function of biophysical variation provides a systematic basis for operational fire spread prediction, risk analysis and climate change projections.

Risk of property loss shown to be cost effectively mitigated by 'in depth' fuel treatment at the interface, though the degree of mitigation is only partial (i.e. residual risk remains high). This provides the cornerstone for a risk based approach to fire management given the primacy of human protection is fire management.

2. Impacts of bushfire regimes on biodiversity values

Fires have an important role in the creation of key animal habitat resources such as hollows in trees and logs but the ability to exploit such resources is dependent on effects of other aspects of the fire regime on animals.

The heterogeneity in fire regimes required for persistence of key elements of biodiversity is largely 'hard wired' into landscapes via geomorphic variation. Management can reinforce and enhance such inherent patterns of variation to a limited degree.

Climatic gradients have an overriding role in organising patterns of plant persistence and resilience based on responses of functional traits, types and patterns of community diversity and species abundances. In turn this affects gradients of flammability and fire regimes

3. Effects of bushfire regimes on ecosystem processes and natural resources

Smoke emissions can be pinpointed and estimated via remote sensing. This provides a basis for assessing the impacts of both planned and unplanned fires on air quality and human health.

The prospect of effective mitigation of emissions and enhancement of carbon sequestration in forests via fuel treatment is nil or negligible. Thus prospects for raising revenue for fire management via offsets and carbon markets are negligible.

Trade-offs between fire regime components (i.e. intensity versus frequency) resulting from fire management have been quantified. These trade-offs define the scope for intervention for to mitigate risk to environmental values (e.g. biodiversity, carbon, catchments etc.) using multi-criteria decision analysis methods. This will ultimately provide the template for future risk planning.

4. Effects of climate change on bushfire regimes and biodiversity

Fire regime trajectories in the future are likely to be divergent and non-linear as function of variations in ecosystem productivity and composition and resultant responses to climatic change, plant growth and human activity.

Elevated CO₂ may have either nil or negative effects on flammability and mass of key fuel elements in local ecosystems.

5. Impacts of bushfire regimes on Aboriginal and historic heritage values

Although not addressed explicitly by OEH–CERMB research, in principle this is little different to Priority 2. Heritage sites are particular high-value conservation assets at specific locations (usually small) that are at risk from some inappropriate fire regime component. They are analogous to small patches of rainforest patches, or rare fauna habitats. Manipulation of fire regime components to mitigate risk to these assets will be based on the same principles as managing other small, vulnerable, high value assets in the landscape.

6. Bushfire risk assessment and fire behaviour modelling

The capacity to control or alter fire regimes via fuel management has been quantified and, as a result, demonstrated to be highly constrained.

Potential for large fires in forest ecosystems can be monitored and predicted in close to real time as a function of remotely sensed estimates of dryness of both live and dead fuels. Large fires have been demonstrated to emerge on the basis of connectivity of dryness. This provides the basis for operational resource allocation and preparedness at regional scales.

Plant traits affect aspects of fire behaviour (e.g. flame length) in ways that cannot be predicted using conventional measures of fuel (e.g. litter load, visual rankings).

7. Bushfire suppression effectiveness

Probabilistic models of both human and lightning ignitions derived for the Sydney region and greater south-eastern Australia provide prediction capacity based on key biophysical determinants (e.g. fire weather, fuel age, distance to development etc.).

All seven 'Living with Fire' research priorities are directly or indirectly addressed by the portfolio of research outputs. The mitigation of risk from bushfires to both man-made and natural values, is the primary objective of management of fire in the landscape in NSW. It is clear that each of these major discoveries clarify the risk profile of man-made and natural assets in the landscape. In some cases, the discoveries indicate the degree of risk mitigation that may ensue from a given management input. This is a major outcome of the research portfolio, because it gives fire risk management a robust and quantitative foundation that is subject to further scrutiny and refinement. The OEH research investment has unquestionably enhanced understanding of bushfire risk in NSW and, crucially, fire risk-management capacity of OEH and its partner agencies.

The only research priority without a direct link to research activity is Priority 5: '*The impacts of bushfire regimes on Aboriginal and historic heritage values*'. The suite of discoveries ensuing from OEH research can, however, be applied in this field of research and management. How this research priority can be further addressed, with appropriate and adequate research, is addressed in Section 6 (*Conclusions and Recommendations*).

Discoveries resulting from the OEH portfolio of research in relation to strategic research and management priorities in other states and territories

The OEH portfolio of fire research has relevance and applicability to the desired outcomes as expressed in policy and management priorities in other states and territories. I illustrate one clear example from Victoria.

The Victorian *Code of Practice for Bushfire Management on Public Land* (2012) sets the primary policy and management objectives for fire management in Victoria: '*To minimise the impact of major bushfire on human life etc. ... and the environment. Human life will be afforded priority over all other considerations.*'

A companion document to the Victorian Code of Practice, the *Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land*, evaluates outcomes with reference to a hierarchy of defined short-term to longer-term outcomes. This is illustrated in Figure 8 of the Framework (DEWLP 2015, pp. 18–19). Discoveries ensuing from the OEH portfolio of research as applied to the seven research priorities of 'Living with Fire' are directly applicable to these defined outcomes. For example, with respect to the CERMB discoveries:

Long-term outcomes: '*A measurable reduction in loss of life and community disruption (critical and community infrastructure and services)*'. Applicable Outputs: Discovery1: property loss shown to be cost effectively mitigated by 'in depth' fuel treatment; Discovery 7: ignition models.

Intermediate outcomes: *'A reduction in frequency, size and severity of bushfires'*. Discovery 6: Potential for large fires in forest ecosystems can be monitored and predicted in close to real time; Discovery 3: The prospect of effective mitigation of emissions and enhancement of carbon sequestration in forests via fuel treatment is nil or negligible.

Short term outcomes: *'A reduction of fuel in the appropriate place and appropriate levels in the landscape'*. Discovery 1. Fuel models for major vegetation classes in NSW derived; Comprehensive modelling of surface fuel variation provides a systematic basis for operational fire spread prediction.

Adoption of OEH and CERMB research findings in fire risk management

Adoption in NSW

This is a review of the adequacy of the research co-investment model to create knowledge needed to underpin fire management. It is not a review of fire management practices, nor is it a review of the mechanisms by which research findings are adopted. Nevertheless, numerous research outputs from internal OEH research and CERMB research have been adopted in fire management policies and practices in NSW. A few examples include:

OEH research findings

- Species responses to fire have been incorporated into planning tools such as the NSW Fire Response database and the NSW RFS bush fire codes
- Long term monitoring sites have been established thru the Long Term Ecological Research Network (LTERN), funded through the Commonwealth Government

CERMB research findings

- Fuel accumulation models incorporated into risk planning; NPWS and RFS
- Fuel mass and moisture models incorporated into operational fire spread prediction
- Predictive monitoring of large fires in real time; evaluation of fire spread models (e.g. 'Phoenix')
- Predictive understanding of ignition modes and suppression effectiveness
- Property loss as a function of fuel treatment quantified
- Quantification of trade-offs enhances decision making

Other CERMB findings are very important for setting and communicating the biogeographic and landscape context for fire management

- Fire regimes and landscape flammability are hard-wired by geomorphic variation
- The capacity to control/alter fire regimes via fuel management is constrained
- Future fire regimes are likely to have non-linear trajectories

It is particularly noteworthy that the NSW Rural Fire Service has adopted many of the OEH research findings into fire management. Importantly, the RFS has already committed funding to CERMB for the next five years, indicating that it not only adopts and applies research findings, but it also has adopted CERMB as a preferred and trusted research provider. Indeed most research projects undertaken by CERMB have been instigated by managing agencies, indicating both demand for, and trust in, CERMB's awareness of agency needs, ability to partner effectively, and capacity to both undertake research and deliver findings and products.

It is important to appreciate that research takes time to bear fruit. In my opinion, the OEH portfolio of research findings is now on the cusp of much wider adoption and application, both in NSW and other jurisdictions in Australia.

Other states and territories

Other states such as WA, SA and the NT all have similar concerns articulated in their various codes of practice for fire management. In conservation reserves and other public land the twin policy imperatives are the mitigation of risk to life and property and biodiversity. As a result, the portfolio of research findings ensuing from the OEH co-investment model are relevant to these other jurisdictions achieving their desired outcomes.

Demand for CERMB personnel and skills

There is demand for specific CERMB personnel in inquiries and workshops: Prof. Ross Bradstock was an expert panellist for the Victorian Royal Commission into the 2003 fires. Dr Penny Watson was a member of National Bushfire Fuels Classification Workshop, April 2011, which resulted in, inter alia, *'Bushfire Fuel Classification'* (Hollis et al. 2015). This publication is a contribution to Sub-project 5 of the National Burning Project.

Communication of research findings

Successful adoption of research findings depends on successful communication of research needs and findings between partners. CERMB has a very active program of communicating research to management agencies. The Director, Professor Ross Bradstock undertakes most presentations of CERMB research results to agencies. Prof. Bradstock averages ca. five formal presentations to agencies per annum, at events such as the Rural Fire Service annual information exchange meeting. He also spends five to ten days per year at meetings with various agencies to discuss research results and directions. With preparation and follow up, this amounts to about 10% of his time. This is in addition to communicating research findings at science meetings.

Within OEH there is a Fire Science Interpretation Officer. Until recently this was Dr Belinda Kenny. Dr Kenny worked closely with OEH regional fire management staff, OEH research staff and researchers and communication specialists in the NSW RFS, and the Bushfire and Natural Hazards CRC.

There are no substantial barriers to research needs and findings being communicated between partners in the OEH fire research program, and research products being adopted and applied. However, there is a pressing need for a full time, dedicated knowledge brokering project officer to better facilitate communication of research findings among researchers and managers. I discuss this critical issue in the next section of the report on Benchmarking.

OEH and NPWS websites could also be designed such that researchers and managers have access to a portal dedicated to knowledge exchange. Numerous excellent analogues, both with respect to fire research, and other environmental research that underpins public land management. Examples include the eSPADE and eDIRT websites (www.environment.nsw.gov.au/eSpade2Webapp; www.edirt.environment.nsw.gov.au) in NSW and the North Australian Fire Information (NAFI) website (www.firenorth.org.au).

Hallmarks of the adoption and outcomes context for OEH-supported fire research

1. The combined OEH and CERMB research portfolio is unquestionably aligned to *'Living with Fire'* imperatives and research priorities
2. Major discoveries ensuing from the last 10 years of research are directly or indirectly applicable to each of the seven *'Living with Fire'* research priorities
3. Major OEH–CERMB discoveries are applicable to the objectives and desired outcomes for fire management in other states, particularly Victoria
4. There is agency demand for the research capacity and products of both internal OEH research, and research undertaken by CERMB
5. Critical OEH–CERMB research findings have been adopted and applied in fire management in NSW

6. The research portfolio is on the cusp of far more widespread adoption by fire management agencies nationally.

Conclusions

The OEH-supported research portfolio is unquestionably aligned to Living with Fire imperatives and research priorities. As a consequence, knowledge is generated that can and does underpin management objectives that are explicit, and capable of being rigorously tested. Thus the OEH research strategy — a mix of internally and externally funded research aligned to policy and management objectives — provides a firm foundation for adoption of research findings. There is a clear need for a dedicated, well-resourced fire knowledge exchange specialist, and a web portal dedicated to knowledge exchange. The research portfolio and its adoption framework contributes substantially to quantification of bushfire risk and its management, and the ability to mitigate risk.

5. Benchmarking the OEH research co-investment model

Summary

The current OEH co-investment model, which supports internal and external fire research, is the best model for generating the knowledge requirements to underpin OEH's fire management priorities under *'Living with Fire'*. The Centre for Environmental Risk Management of Bushfires (CERMB) is OEH's most effective and appropriate external provider of fire research. No other fire research group in Australia can match CERMB's capacity to deliver the research outputs that inform OEH's fire management.

Co-investment models for fire research are used in other states because they work, are cost-effective and generate multiple benefits for all parties. Victoria, through the Department of Environment, Land, Water and Planning (DELWP), invests some \$5M per annum in its research partnerships, an order of magnitude more than OEH. Clear benefits to all parties ensue under the Victorian model. The knowledge transfer strategy within OEH is below the standard operating in DELWP; it requires substantial improvement and additional investment.

Benchmarking context

This section of the review is concerned with benchmarking the NSW OEH fire research investment strategy and model against practices in other states. The primary comparison is with the principles and practices employed in Victoria. This is because, for fire management, NSW and Victoria have many factors in common, including:

- fire-prone landscapes
- protecting communities living in or near fire-prone areas
- managing fire to reduce risk to the environment
- policy frameworks and codification of management priorities
- research and knowledge needs to underpin fire management.

Moreover, the strategy and investment model that underpins the current Victorian approach, which has been developed over decades, has been scrutinised and refined recently by a Royal Commission. This scrutiny has shown that the investment model is robust and effective, both conceptually and practically.

Thus, it is germane to this review to benchmark the objectives and knowledge needs for OEH, based on *'Living with Fire'*, against the appropriate codes of practice, products and partnerships of research as codified and applied in Victoria. I acknowledge that other states have comparable knowledge requirements but, for the reasons given above, comparing the OEH model with the Victorian model is the most relevant.

The Victorian co-investment model

Victorian landscapes, fire regimes and risks from bushfires

Victorian landscapes, fire regimes and risk profiles to people, infrastructure and the environment are all highly analogous to those of NSW.

Victorian landscapes, like those of NSW, are diverse. Victoria's ecosystems range from tall wet forests to alpine grasslands and desert shrub lands. Fuel dynamics in these systems are similar to those in their NSW counterparts. The fire regimes of Victoria are determined by the passage of cold fronts which bring occasional periods of extreme fire weather during summer. The vast majority of the area burnt by bushfires is burnt during a few days or weeks over summer when ignition coincides with extreme fire weather, often in drought years. The capacity to manage fire regimes in the face of these fundamental bioclimatic drivers is limited.

Urban, peri-urban and rural communities are at risk from direct fire effects during bushfires, and from indirect effects such as smoke.

The two fire management priorities on public land in Victoria are the protection of life and property, and the protection of natural values. To manage fire on public land in the face of these complex biogeographic and policy drivers, Victoria has adopted a risk-based approach. Risk assessment is based on considering both the likelihood and consequence of major bushfires, and of management actions designed to mitigate bushfire risk (e.g. prescribed fuel-reduction burning). Central to this risk-based approach to fire management is the development of models predicting and projecting expected outcomes of fire management. These models are based explicitly on 'research and expert knowledge' (p 4; Fig. 3; DEWLP 2015).

Fire management objectives and knowledge needs in Victoria

The primary document underpinning fire management on public land in Victoria is the *Code of Practice for Bushfire Management on Public Land* (Department of Sustainability and Environment, 2012).

The Code of Practice states two clear, explicit objectives for the management of bushfires on Victoria's public land. These are:

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

These twin objectives underpin several other strategic documents detailing fire management principles and practices on public land in Victoria, namely:

- DEPI (2013) *Bushfire Science Strategy 2013–2017*
- DELWP (2015) *Monitoring, Evaluation and Reporting Framework for Bushfire Management on Public Land*
- DEPI (2015) *Reducing Victoria's Bushfire Risk on Public Land. Fuel Management Report 2013–2014.*

Research is integral to achieving Victoria's fire management objectives. Scientific research is used to guide management strategies, monitoring, decisions and actions, as stated in the Victorian Code of Practice and other supporting documents.

Victoria's policy settings and knowledge needs, and commitment to knowledge enhancement through research, is highly applicable to the NSW situation. The two primary objectives in Victoria—managing fire regimes to protect life and property, and to protect natural values—are also central to fire management on NSW public lands. This is codified in NSW in *Living with Fire* as 'to protect life, property and community assets from the adverse impacts of fire' and 'to manage fire regimes in reserves to maintain and enhance biodiversity' (*Living with Fire*, p. 1).

Victoria's commitment to research also aligns very well with the NSW NPWS's mission for bushfire research, as laid out in *Living with Fire*: 'to work collaboratively with research partners to acquire, apply and communicate knowledge relating to the protection of life and property and the conservation of significant natural and cultural heritage values'.

Fire management objectives and knowledge needs in other states

Other states have similar approaches to codifying the approaches to fire management in conservation reserves and other public lands.

In Western Australia, it is the Department of Environment and Conservation *Code of Practice for Fire Management* (2008). The WA Code states that the priority objectives in fire management are to ensure that:

- environmental values, including the state's biota, are protected from the deleterious effects of wildfire and inappropriate fire regimes;
- human life, property, and assets are protected from the deleterious consequences of wildfire;
- water catchment, air shed and landscape values are protected; and
- archaeological, historical, and other cultural sites are protected.

South Australia also has a Code of Practice for fire management. *The Code of Practice for Fire Management on Public Land in South Australia 2012–2016* (Department of Environment, Water and Natural Resources 2012) is explicitly risk-based (p. 3), where the latest research is incorporated into operational practice (p. 5).

These fire management principles, as detailed in various codes of practice and other strategic policy documents, are consistent with the *National Bushfire Mitigation and Management Principles*, as laid out in the 2004 Council of Australian Governments (COAG) Report into the 2003 Bushfires in Victoria and NSW (Ellis et al 2004). Furthermore, these risk management principles are all compliant with International Organization for Standardization (ISO) standards.

Thus, at the most fundamental level of fire management, the policy settings and requirements for knowledge to underpin effective risk management of fire in NSW are virtually the same as those documented in various codes of practice in other southern Australian states, particularly Victoria. The standards set by the NSW Government for managing fire risk in the landscape are therefore benchmarked against the high standards as codified by Australia's state and federal governments. Moreover, all states acknowledge the importance of research to generate the knowledge required to mitigate the risks posed by bushfires to people and the environment.

Fire research co-investment in Victoria

Victoria, through the Victorian Department of Environment, Land, Water and Planning (DELWP) invests in research to underpin fire management in Victoria via a mix of internal research within DELWP, and by directly funding research teams in partnership with research agencies such as universities. This, like the OEH model, is a co-investment model.

Below I summarise the key features of this co-investment model. This summary is based on detailed discussions with Mr Liam Fogarty, Director Knowledge and Engagement, Fire and Emergency Management Division, Department of Environment, Land, Water and Planning, and Ms Elizabeth Ashman, Senior Project Officer, Monitoring, Evaluation and Research Unit, Fire and Emergency Management Division, Department of Environment, Land, Water and Planning.

DELWP has responsibility for fire management on public land in Victoria, including the National Park estate, and its fire management responsibilities are analogous to those of NSW OEH. The Victorian Country Fire Authority (CFA) also has responsibility for fire management on private and public land, and is analogous to the NSW Rural Fire Service.

DELWP has been investing in fire research to support fire management in Victoria for many decades. The business of fire management in Victoria, as in all states, is both broad and complex. DELWP explicitly acknowledges that generation of the knowledge needed to manage fire regimes for mitigating risks to both people and the environment is beyond the capacity of internal DELWP staff. Therefore, to develop the research capacity to generate this knowledge, investment has been directed to support research that includes both internal DELWP research, and research undertaken in partnership with DELWP, by external research agencies. This investment model is thus a co-investment model, and is analogous to the co-investment model of NSW OEH.

The externally-funded research is undertaken on a contract basis. Currently DELWP has two main fire research contracts, one with the University of Melbourne (UOM) School of Ecosystem and Forest Sciences, and the other with the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC). Both are long-term investments. DELWP has funded research at the UOM since the 1990s, and has been a partner in BNHCRC and its predecessor since 2004. To facilitate knowledge exchange, DELWP staff, and UOM and CRC researchers have been, and continue to be, co-located, and specialised cross-agency project officers manage research administration and communication.

DELWP invests a total of approximately \$5M per annum across the external program (i.e. both the UOM and the BNHCRC). This is an order of magnitude higher than the investment of OEH in both its internal and externally-supported fire research portfolio. This funding is directed at the management of fire regimes, biodiversity, catchments and forest products in the case of the UOM research, and across some 26 different fire management projects within the CRC.

DELWP funds are used to leverage additional funding from various external sources, and research expertise from other research agencies. Given that the funding is across a range of agencies and project areas, a direct comparison with the CERMB leverage figure (\$1 from OEH generating a further \$3.16) is difficult, potentially misleading and so has not been attempted. Nevertheless, there is a clear expectation among parties that direct DELWP funding is used as leverage to generate additional research funding. A major benefit to the research community of this funding model is that long-term research may be supported well beyond the rolling annual-triennial funding cycle.

Research themes and projects

Fire research themes and projects cover a range of biophysical and social-economic research. Research themes and projects are explicitly framed to address policy objectives, management needs and research priorities (See next Section on Adoption). There are dozens of individual research projects, which address major fire management themes, such as:

- fuel dynamics
- fire behaviour
- fire spread modelling
- prescribed burning efficacy
- smoke and human health
- fire regimes and biodiversity
- fire regimes carbon dynamics
- long-term experiments (e.g. Wombat State Forest)
- community safety and awareness
- research evaluation.

A major benefit to DELWP of such a co-investment model—arguably the major benefit—is the synergy that results when managers and researchers collaborate. In framing research questions, the policy imperatives of fire management drive the research agenda. In generating and applying knowledge, research imperatives (especially rigorous methodological design and peer-review publication of results) ensure quality control of outputs. As a result, research priorities, methods and practical application can be evaluated and modified accordingly.

Research communication and evaluation

Communication and evaluation of research is via a combination of formal and informal reviews, presentations and web-based platforms. Communication channels between parties are open enough to allow knowledge between partners to be shared at all stages of the research and development cycle. A clear lesson from the DELWP experience is that effective evaluation and communication of research outcomes requires the specialist skills of project officers dedicated to managing research project administration (budgets; milestone reporting etc.) and communication. Under the DELWP agreement with University of Melbourne, dedicated support staff from DELWP are co-located with UOM staff. The DELWP–UOM relationship also benefits from access to the substantial BFNHCRC communication network, in particular the ‘Knowledge Broker’, Lesley Wright. Substantial benefits flow to DELWP as a result of these inter- and intra-project relationships, but resources are needed to support such project operation and knowledge transfer; in the DELWP–UOM–BNHCRC case it is approximately two FTEs.

The DELWP co-investment model of fire research is highly relevant to OEH. It is a co-investment research model, and well resourced. It has a long history of successful operation. Its structure allows robust and effective exchange of knowledge between managers and researchers.

Many benefits ensue from the DELWP–UOM–BNHCRC from co-investment model: research projects explicitly address policy and management priorities; research rigour is brought to bear on management needs; DELWP funds can be used to leverage additional funds and expertise; awareness among parties of the work needs and priorities of other partners is enhanced; there is a platform to deal with the complexity of inter-agency communication.

In my opinion, a co-investment research model of the type employed by DELWP and its research partners is the most effective and efficient way to generate the breadth and depth of knowledge needed to underpin fire management of fire on public land.

Corroborative evidence from other jurisdictions in favour of a co-investment research model

Victoria has a number of other co-investment research partnerships. The Arthur Rylah Institute, a research institute within DELWP, has joint appointments between DELWP and universities. Parks Victoria, which is responsible for managing Victoria’s National Park estate, has a co-investment scheme for supporting the research needs to underpin Park Management.

The Western Australian Biodiversity Science Institute is a new initiative of the Government of Western Australia, through a number of departments with land management responsibilities (e.g. Department of Parks and Wildlife; Environmental Protection Authority), three universities (University of Western Australia; Curtin University; Murdoch University) and industry (e.g. BHP Billiton). Protecting the state’s biodiversity, naturally, is a priority area of research for the Institute. Fire research and management, in the temperate ecosystems of the south, the arid interior, and the tropical north of the state is a major focus of research.

In the Northern Territory, Bushfires NT directly supports the savanna fire research group led by Professor Jeremy Russell-Smith at Charles Darwin University. Base funding is used to leverage additional funds, which supports a research group (remote sensing specialists; ecologists) of between three and four FTEs. This relationship is of 20 years’ standing, and has been enhanced via past support from the Tropical Savanna Management and Bushfire CRCs (1996–2007), and current support from the Bushfire and Natural Hazards CRC. This research group has produced numerous peer-reviewed books, book chapters, journal articles and technical reports, and, most notably, the North Australia Fire Information (NAFI) website (firenorth.org.au).

Co-investment models of the type described above are all examples of strategic partnerships, where managing agencies, research institutions and industry are brought together to co-invest in the research that is needed to solve complex environmental management problems in the most cost-effective and robust way.

These co-investment models bring clear benefits to all parties, and to the environment, because research is guided by policy and management imperatives, and the policy outworking is enhanced by research rigour.

Capacity analysis of potential research providers to OEHL

Other fire research groups in Australia are undertaking research relevant to fire ecology and management in national parks and other public land. Their capacity (relative to CERMB) to undertake and deliver research relevant to the suite of priorities listed in *'Living with Fire'* is summarised below.

There is a brief resume of CERMB's focus, track record, capacity and links, based on evidence presented in Section 3. This is followed by a brief summary of capacity and focus of other groups based on publicly available documents, and my specialised knowledge of fire research groups across Australia. My basic terms of reference are: general research focus; current capacity across research disciplines necessary to address *'Living with Fire'* priorities; explicit research into risk analysis; links to NSW fire management agencies (where known); approximate number of full-time equivalent staff (FTEs) involved in fire research.

Centre for Environmental Risk Management of Bushfires

CERMB currently conducts research that is directly aligned to, or applicable to, all seven of the research priorities in *'Living with Fire'*. It has strong research capacity in all of the major areas of expertise needed to conduct this research: spatial science; computer simulation modelling; plant community ecology; statistical analysis; quantification of risk. It has an outstanding track record of publishing research and using base OEHL funding to leverage additional funds for research into fire ecology and management. It has strong and long-standing links to the major fire research and management agencies in NSW and elsewhere in Australia: NSW OEHL and predecessors; NSW Rural Fire Service; NSW Environment Trust; Victorian Department of Environment, Land, Water and Planning; Commonwealth Department of the Environment; CSIRO; Bushfire and Natural Hazards CRC. The Centre has employed between eight and 14 FTEs over past five years.

Other fire research groups from Commonwealth and state jurisdictions are reviewed briefly below.

Commonwealth and cross-jurisdiction agencies

Bushfire and Natural Hazards CRC

The BNHCRC (www.bnhcrc.com.au) is Australia's major cross-jurisdictional research and development provider in fire management. Its predecessor, the Bushfire CRC, was focussed entirely on bushfire science and management. The research charter of the new CRC has been widened to incorporate research into other natural disasters. The CRC has enabled cross-jurisdictional teams to undertake research on biophysical science and social science aspects of fire management. For some critical research needs directed at fire risk management (e.g. fuel dynamics; fire and urban-rural interface; fire management guidelines) the CRC has a long history of explicitly engaging the services of CERMB to undertake the research to meet these needs. The BNHCRC does not have a strong track record in fire-biodiversity research.

CSIRO; Bushfire Research Group, CSIRO Land and Water, Canberra

(www.csiro.au/en/Research/Environment/Extreme-Events/Bushfire). The focus of this research group has long been fire behaviour, fire weather, and fuel dynamics. There is a small group researching fire and biodiversity, and potential adaptation pathways to climate change. The CSIRO Tropical Ecosystems Research Centre, Darwin (www.csiro.au/en/Locations/NT/Darwin) has a very strong track record in research into savanna fire regimes, and their ecology and management. The group has a strong research capacity in landscape ecology, savanna fire regimes and biodiversity, carbon dynamics; ecological modelling; and Aboriginal fire management. It has long-established and effective links to Commonwealth/state/territory agencies and university research groups, particularly CERMB. Indeed CERMB has been a major research partner for three major studies into fire, climate change and biodiversity undertaken by the then CSIRO Climate Adaptation Flagship. CSIROs total capacity in fire research is of the order of six to ten FTEs, but its future is unknown given the substantial cuts to CSIRO proposed in February 2016.

State-based research groups (departmental and universities)

New South Wales

Centre for Carbon Water and Food, at the University of Sydney
(sydney.edu.au/agriculture/research/ccwf/whatwedo.shtml)

The Forests and Fire program (Leader Dr Tina Bell) has a research focus on the biogeochemistry of fire regimes, effects of smoke, and post fire forest regeneration. The Centre Director, Professor Mark Adams, served on the panel of Expert Advisors to the Royal Commission into the Victorian Black Saturday Bushfires of 2009. It has limited research capacity in the fields of fire and biodiversity, and bushfire risk management. It has no major links to NSW OEH or NSW RFS. The number of FTEs engaged in fire research is unknown.

Centre for Ecosystem Science, University of New South Wales (www.ecosystem.unsw.edu.au/)

The Centre has capacity in fire research through Professor David Keith's group. Prof. Keith's appointment is a joint UNSW–OEH appointment. This research centre has a strong focus on conservation risk management, particularly fire and biodiversity, through projects such as 'Managing fire regimes with thresholds to save threatened flora and fauna'. It has a small research capacity in fire regime science. It has very strong links to OEH. FTEs engaged in fire research are unknown, but are substantially less than CERMB.

Victoria

The DELWP–University of Melbourne co-investment research program (www.delwp.vic.gov.au/fire) has been described in detail in previous sections of this report. It is a similar co-investment model to that of NSW OEH–University of Wollongong. The policy and management imperatives that drive its research agenda are very similar to those of NSW. It has a strong research capacity in fire and effects on life/property, fire regimes biodiversity, and risk management. It also has a very strong and dedicated program that evaluates its fire management strategy. It is a strong investor in CERMB, to whom it looks to provide critical components of its research needs. It has strong links to the BNHCRC. Its research budget is ca. \$5M per annum, and it has ca. 20 FTEs engaged in fire research.

Professor Mike Clarke's Group at La Trobe University (www.latrobe.edu.au/she/staff/profile?uname=mfclarke) is an active and collaborative research group. However, its fire focus is on one biome, the mallee, where the group has examined historical fire regimes and fire and mallee biodiversity. The group has little or no capacity in risk analysis. It has strong links to Victorian, NSW and SA agencies. The number of FTEs is in the order of three to five.

Tasmania

Professor David Bowman heads an active fire research group at the University of Tasmania (www.utas.edu.au/profiles/staff/plant-science/David-Bowman). Research focuses on forest ecosystems dynamics, especially in relation to global change, and Aboriginal fire management. It is a highly productive and nationally significant group, but has little or no capacity in fire behaviour, or risk analysis. It has very strong links to management and policy through the Landscapes and Policy Research Hub, National Environmental Research Program. It employs four to six FTEs.

Western Australia

The fire ecology and management group of the Department of Parks and Wildlife is an active fire research and management group (www.dpaw.wa.gov.au/management/fire). It has research capacity in managing risk to people, property and the natural environment, both in temperate forest fires and savanna fires.

The Terrestrial Ecology group at Murdoch University (www.murdoch.edu.au) has expertise in fire and Mediterranean ecosystems, fire and biodiversity and fire modelling. There is a fire research program within the newly established WA Biodiversity Research Institute, which has strong WA agency–university links. Total fire research FTEs are not known.

Australian Capital Territory

There is a small but very productive fire research group within the Fenner School at Australian National University (fennerschool.anu.edu.au; Bushfires and Emergencies). This group researches fire ecology, management and policy. There is limited research capacity in the ACT Rural Fire Service (esa.act.gov.au/actrfs/). There are two to three FTEs in total.

Northern Territory

The primary fire research capacity in the NT is through CSIRO (see above), the Darwin Centre for Bushfire Research at Charles Darwin University (riel.cdu.edu.au/node/2643) and Bushfires NT (www.lrm.nt.gov.au/bushfires). The research focus is tropical savanna fire management and fire in the arid ecosystems. There are clear strengths in spatial science, fire and biodiversity, greenhouse gas abatement, and Aboriginal livelihoods. There is little or no capacity in risk analysis; indeed the fire risk profile in terms of both life and the environment is very different to that of NSW. Dr Owen Price worked extensively in the NT prior to joining CERMB, and he has maintained his NT links. Fire research in the NT has strong links to NT government agencies, the pastoral industry, Aboriginal Land Councils and remote Aboriginal communities. The total number of FTEs is ca.10.

Queensland and South Australia

Both states have very limited fire research capacity linked to agency needs.

Conclusion

CERMB is the only one of the above research groups with both the capacity and proven track record to undertake and provide the research needed to underpin the fire management objectives of *'Living with Fire'*.

While there are obvious areas of excellence in each of these other groups, they are deficient (compared to CERMB) in at least one of the following areas: critical mass, breadth and depth of research capacity; links to NSW fire management agencies; research focus that is relevant to the management of bushfire risk to both the built and natural environments, now and in the future.

Contracting any of these other groups to conduct the breadth of research needed to underpin *'Living with Fire'* would not be cost-effective. Their ability to leverage additional external funding is unknown. There would be substantial transaction costs, potential delays in establishing research credentials, and potential delays in the adoption of research results. The comparative advantage offered by the current OEH–CERMB co-investment research model would clearly be lost.

Finally, there are issues of ownership of intellectual property involved in the current co-investment model. The current arrangements were largely instigated by UOW and, as mandated in Agreements between UOW and OEH, intellectual property, including the specified research program and resourcing arrangements, are jointly owned. Thus the current arrangements, including specified research directions cannot simply be offered to other parties, without potential transgression of these ownership rights. Given the evident success of the current co-investment arrangements, the most prudent and productive option for the future is to continue and enhance these arrangements.

Knowledge transfer and its governance under the OEH co-investment model

Communication of research findings in relation to adoption of research findings was discussed in Section 4 of this report. Here I address the issue in relation to benchmarking the OEH fire research co-investment model.

There is a position within OEH that is dedicated to managing knowledge transfer between the various research and management agencies co-operating under the OEH co-investment model. Other fire management agencies (e.g. NSW RFS; Victorian DELWP) have a similar position or positions. A position such as this is vital to the timely and effective communication of research findings and their applicability within and between partner agencies under any research co-investment model.

The role within OEH was, until recently, undertaken by the Fire Science Interpretation Officer, Dr Belinda Kenny, with whom I have discussed knowledge transfer. Dr Kenny has a PhD in fire ecology, and has worked in both research and management agencies. She has been on secondment to the NSW Rural Fire Service for the past year and, as I understand, the position of Fire Science Interpretation Officer within OEH remained vacant for most of that time. In fulfilling this role, Dr Kenny worked closely with OEH regional fire management staff, OEH research staff such as Drs Liz Tasker and Hamish Clarke, UOW and CERMB staff, and researchers and communication specialists in the NSW RFS, and the Bushfire and Natural Hazards CRC. Dr Kenny did not, however, work full-time in this role, and was diverted into other positions at various times during her tenure.

Communication tasks and products were guided by the seven research priorities in *'Living with Fire'*. Communication events included short-format events such as research seminars, and longer format events such as all-day symposia. These were particularly important fora at which CERMB researchers could present their findings, and agency staff could articulate their knowledge needs. Products included research notes, regular email updates, and publicising of research seminars within OEH and other agencies such as NSW RFS.

However, as I understand, there is no formal, documented strategic communication plan to guide the communication of research results. As such, there were no strategic assessments of: priorities for communication; potential audiences for communication campaigns; end-user awareness of research capacity and focus; mechanisms for communicating research findings; evaluation of communication effectiveness. This is not a failing of individual communications research or on-ground management personnel - it is a shortcoming of OEH at an organisational level to develop an appropriate model and resource base for the governance of knowledge transfer between the partners engaged in fire research and management.

Knowledge transfer in natural resource management requires highly skilled and well-resourced staff. This aspect of the OEH co-investment model is, in my opinion, below the standards that are evident in other fire research co-investment partnerships in Australia. As such it requires urgent and dedicated investment to bring it to an acceptable standard. There are numerous effective models of knowledge transfer to guide OEH in this regard. Notable examples are the BNH CRC and the Victorian DELWP-University of Melbourne models.

At least one FTE is required to undertake this important task. It is a highly specialised position. This role requires detailed knowledge of the research field (fire ecology and management) and skills in the complex business of science communication, and awareness of the needs. In addition a strategic communication plan is required to guide knowledge transfer. The Key Performance Indicator (KPI) section of *'Living with Fire'* (p. 31) indicates that measures relating to research and knowledge dissemination, with appropriate KPIs, are 'to be developed'. This needs to be done as a matter of urgency. Explicit resources are needed to support this vital component of OEH's fire research and management portfolio. However, new resources are required to support this role. It is imperative that resources are not taken from existing research capacity to underwrite knowledge transfer.

Conclusions

1. The current OEH co-investment model, which supports internal and external fire research, is delivering excellence in research in a cost-effective way. There is no better model for generating OEH's knowledge requirements to underpin the fire management priorities of *'Living with Fire'*.
2. The Centre for Environmental Risk Management of Bushfires at the University of Wollongong is the only specialist fire research group in Australia that can undertake and deliver to OEH the research needed to underpin its fire management responsibilities. It is clearly OEH's most effective and appropriate external provider of fire research.
3. The OEH-UOW co-investment venture is not unprecedented. Similar co-investment models are widely used in other states because they work, are cost-effective and generate multiple benefits for all parties.

4. Victoria is the most appropriate state against which to benchmark the NSW OEH co-investment model, because of similarities in fire regimes, fire management imperatives, and research investment strategies.
5. Victoria, through the Department of Environment, Land, Water and Planning (DELWP), has a co-investment model that supports a mix of internally-supported fire research and externally funded research via joint ventures with research agencies. DELWP invests some \$5M per annum under this co-investment model, and order of magnitude more than OEH.
6. The Victorian co-investment model ensures that research is directed towards mitigating bushfire risk to both life/property, and the natural environment. It also ensures that policy imperatives drive the research agenda, and research imperatives (especially the peer-review system) ensure quality control of research outputs.
7. OEH is very well placed to derive future benefits from its current co-investment model and investment partners.
8. Knowledge transfer under the model requires substantial improvement and re-investment.

6. Conclusions and recommendations

Summary

The OEH co-investment model for undertaking applied fire research germane to OEH's needs is a highly successful and productive co-investment model. OEH should continue to support the fire research partnerships, particularly the Centre for Environmental Risk management of Bushfires (CERMB) at the University of Wollongong under the current co-investment model for at least the next five years. Funding should be increased to allow emerging fire management frontiers to be researched; current OEH research partners, particularly CERMB, have the capacity to undertake such research. Failure to support fire research under the current co-investment model will carry a high risk that OEH and other fire management agencies will not be able to meet their fire management objectives in NSW. This will carry a consequent increase in the risk of adverse outcomes of bushfires to the people and the environment of NSW.

Review scope

This review has examined the fire research co-investment model employed by OEH to generate the knowledge needed to underpin its fire management. It has examined the efficacy and appropriateness of the model against a number of criteria:

- the capacity to deliver research findings that are aligned with the research priorities documented in *'Living with Fire'*;
- the quantity and quality of the research partnerships, individual research teams, and associated research outputs (using national criteria to evaluate research efficacy and excellence);
- the platform for adoption of research findings by fire management agencies, with in NSW and in other states and territories; and
- the standard of the OEH co-investment model when benchmarked against similar models used in other states and territories.

Against all of the above criteria, the OEH co-investment model is successful, efficient and effective, and operates, with few exceptions, according to best practice principles that guide applied fire research elsewhere in Australia.

Key findings

Based on the terms of reference for the review, and the evidence provided to me, I have made 10 key findings. These are:

1. The OEH co-investment model, which funds a mix of internal and external fire research, is a highly effective and efficient model for supporting research that addresses the policy and research priorities for fire management in NSW, as documented in "Living with Fire".
2. The research partnerships supported by OEH, particularly The Centre for Environmental Risk Management of Bushfires, are first class, and consistent with best-practice nationally.
3. CERMB is the only individual fire research group within Australia with the capacity and track record to undertake the research required to support OEH's objectives under Living with Fire.
4. The relationship between OEH and the University of Wollongong that underpins CERMB must therefore be maintained and enhanced. Dissolving or weakening this relationship would not be cost-effective, and would be counterproductive to all parties involved.
5. The fire research conducted within OEH and by CERMB is outstanding. Collaborations involving some 200 researchers have resulted in more than 180 peer-reviewed research publications since 2006. Major discoveries concerning the management of bushfire risks to people and ecosystems

have ensued. Both OEH and CERMB have excellent track records in leveraging external research funds; every 1\$ invested by OEH in CERMB generates a further \$3.16.

6. The platform for adoption of research findings by management agencies is robust, because the research portfolio explicitly addresses policy and management imperatives. There are no apparent barriers to effective uptake and application of the research. Key discoveries resulting from OEH and CERMB research address all of the seven research priorities in Living with Fire.
7. The OEH co-investment model compares favourably when benchmarked against a similar model in Victoria, where fire management objectives and research requirements are similar to those of NSW.
8. The governance of knowledge transfer requires improvement, and additional investment in both the strategic guidelines and specialised personnel.
9. Failure to support fire research under the current co-investment model will carry a high risk that OEH and other fire management agencies such as the NSW Rural Fire Service will not be able to meet their fire management objectives in NSW. This will carry a consequent increase in the risk of adverse outcomes of bushfires to the people and the environment of NSW.
10. There are excellent prospects for supporting future fire research in NSW under the current co-investment model. The highest research priority is quantifying the relative costs and benefits of various fire risk-mitigation options.

Recommendations

I make the following recommendations concerning both the co-investment funding model (and associated partnerships) and future research directions and priorities.

The OEH co-investment model

1. OEH should continue to support fire research under the current co-investment model for at least the next five years
2. Financial support must be provided at least at current levels for internal OEH fire research, conducted within OEH by the Ecological Processes Team (Ecosystem Management Science, Science Division), and the fire research conducted by The Centre for Environmental Risk management of Bushfires (CERMB) at the University of Wollongong
3. Additional financial support should also be provided, both internally to OEH and to CERMB, to support expansion of the research capacity in emerging priority areas, and to enhance knowledge transfer within and between partners in the research venture.

Future research priorities

There are excellent prospects for supporting future fire research in NSW under the current co-investment model. The prospective future research areas can be grouped into three areas of priority. These are, in decreasing order of priority:

Priority 1: Benefits and costs of fire management options

Priority 2: Climate change impacts on fire regimes and biodiversity

Priority 3: Fire management for specific ecosystems and heritage values

Priority 1 research: Benefit-costs analyses

There is a pressing need for quantitative analysis of the relative costs and benefits of various fire risk-mitigation options in landscape-scale fire management. In the last five years, OEH has invested some \$200M in fire management. Thus it is critical to determine the returns the state government receives on its management investment, particularly the risk mitigation component of management. The scope is very wide,

and would include prescribed burning; suppression; planning; and account for associated health and environmental impacts of management.

Priority 2 research: Climate change impacts on fire regimes and biodiversity

These themes are interrelated, and have been the subject of much research over the past decade. Recent reports to the Commonwealth Government by Dunlop and Brown (2008) on the impacts of climate change on the National Reserve System, and by Williams et al. (2009; 2011) on climate change-fire regimes-biodiversity interactions illustrate the complexity of the field, the risks to both the built and natural environments, and thus the need for strategic research to address uncertainties.

The OEH fire team, and CERMB, have already developed a substantial body of research on the effects of climate change on fire regimes (fire weather; fuels; fire behaviour; sensitivity of particular biomes in SE Australia to change). This could easily be expanded to encompass additional biomes in NSW and elsewhere in Australia.

The OEH fire team, and CERMB, have also contributed substantially to our national understanding of fire management for biodiversity conservation. There is thus a ready-made platform to undertake further research into managing the risks to biodiversity of bushfires and their management. The cost-benefit framework for risk analysis would be an important component of this research.

Given the existing track record of OEH, CERMB, and their various research partners, the OEH co-investment model is currently very well-positioned to support further research in these two priority areas of fire management for people and the environment.

Priority 3 research: Fire management for specific ecosystems and heritage values

This third tier of research is not currently well-supported or well-developed, and will require some initial investment in strategic planning and scoping of potential projects. There are two broad areas for research: the fire ecology of poorly known species and groups, and the role of Aboriginal burning practices in land management.

The effects of variation in fire regime on poorly known ecosystems and species

Ecosystems include the arid shrub lands of Western NSW, but there are numerous others. Species with poorly-known fire responses include those with a physiological component to their seed dormancy. Such species make up around half of the regional fire-prone shrub flora and their seed ecology and response to variation in fire regimes is very poorly understood. Fire regimes and individual fauna species will always require research.

The use of Aboriginal fire knowledge and practices for park management

This is an emerging area of research and knowledge transfer worldwide. Many parks and reserves have some form of joint management program. The need for research aimed at understanding cultural burning practices by Aboriginal people is identified in *'Living with Fire'* (p 22).

There are a number of successful models of co-investment research partnerships involving research and management agencies, and Aboriginal people. A well-developed one is the north Australian savanna burning program, which uses low intensity burning to reduce the impact of high intensity fires, and thereby reduce greenhouse gas emissions. The lessons from programs such as these are that it takes many years to develop the necessary relationships, and cultural burning activities must be tied to environmental outcomes.

For these and other reasons, projects in this area will require considerable scoping of the strategic and tactical components. Understanding how to use traditional fire practices to protect specific Aboriginal heritage sites is one area of potential research. One potential ecosystem to develop joint agency-Aboriginal research and management partnerships is the 'grassy balds' grasslands of northern NSW.

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