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SCIENTIFIC DIVERSITY, SCIENTIFIC UNCERTAINTY AND RISK MITIGATION POLICY & PLANNING

Final Report

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Cover: Mick Bourke, a Dja Dja Wurrung man and district planner at Forest Fire Management Victoria, practicing djandak wi (healthy fire). Photo: Timothy Neale.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	**3**
EXECUTIVE SUMMARY	**4**
END-USER STATEMENT	**7**
INTRODUCTION	**8**
BACKGROUND	**9**
1. Scientific facts	9
2. Risk frames	12
RESEARCH APPROACH	**14**
LITERATURE REVIEWS	**15**
1. Scenario exercise methods	15
2. Scientific diversity and uncertainty	16
CASE STUDIES	**18**
1. Method	18
2. Case study snapshots	19
SYNTHESIS	**21**
1. Practitioner experiences	21
2. Consequences for practice	22
GUIDELINES	**24**
UTILISATION ACTIVITIES AND OUTPUTS	**26**
1. Applied research approach	26
2. Flyer and guidelines	26
3. Utilisation workshop and communication tools	26
4. Industry presentations and seminars	27
WHERE TO FROM HERE	**28**
PUBLICATIONS LIST	**29**
Journal articles	29
Conference proceedings and other publications	29
Posters	30
Reports	30
Presentations	31
BNHCRC Blog Posts	33
TEAM MEMBERS	**34**
PROJECT LEADER	34
PROJECT TEAM	34
END USERS	34
REFERENCES	**35**

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All errors and omissions remain our own responsibility.

EXECUTIVE SUMMARY

This is the Final Report of the 'RMPP project' (Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning project), which addressed the use and utility of science and other forms of knowledge by natural hazard practitioners, and the pragmatic meaning these hold for their risk mitigation work.

Natural hazard managers often expect, and are expected, to achieve outcomes by using scientific facts and rational problem-solving to increase certainty of decisions in the face of hazardous events (Funtowitcz and Ravetz, 2003). At the same time, the uncertainties of natural hazards means that this sector has always set different terms to the this 'pipeline' approach to the use science (also called the 'linear model of scientific expertise').

The ability of policymakers and practitioners to explain and justify risk mitigation and its evidence is compromised without greater insight into how science and other forms of knowledge are used in emergency management policy and practice. The sector does not receive the full range of information it requires, and continues to be vulnerable to the perpetuation of 'myths' about science, its use and its usefulness.

Instead of relying on facts to generate better policy and practices, as invaluable as they are, we ask:

- what are 'facts',
- how do facts, values and action interrelate, and
- what are the implications of these insights to allow practitioners to make better decisions?

Two literature reviews were conducted, the first examined the use of scenario methods for environmental risk, and the second identified the types of scientific uncertainties in flood and bushfire science.

These uncertainties were then organised into three categories:

- ***historicist***, reliance on historical data, due to assumed determining relationship between the past, the present and the future
- ***instrumental***, uncertainty arising out of limitations of a given apparatus, heuristic or theory, and
- ***interventionist***, are those uncertainties in the predictive calculations about the effect of mitigation interventions (e.g. flood levy banks).

Three case studies were conducted, each located in an important risk landscapes in which scientific knowledge was being used to change policy and/or practice and address a complex emergency management problem:

- Wildfire risk and prescribed burning, in the Barwon-Otway region, Victoria;
- Wildfire risk and an invasive fire-weed, in the Greater Darwin area, Northern Territory; and,
- Flood risk and mitigation planning in the Hawkesbury-Nepean Valley, New South Wales.

Across all three case studies, common insights were summarised as:

- ***Science is critical, but it is not everything***, as it cannot answer many big questions.
- ***Complexity is irreducible***, as risk mitigation is full of subjective 'non-rational' factors, that cannot be reduced to a prediction or model.
- ***Experience is vital, although it is viewed as less authoritative*** than evidence.
- ***Making things 'count' is important***, and in this science was judged as more authoritative than other evidenced-based expertise.
- ***There is confusion about what is a fact.*** Practitioners regularly expressed opposing positions about certainty, and misunderstandings commonly proliferated around what is meant by the 'facts'.
- ***Science has a social life***. When evaluating complex science, practitioners draw on relationships of trust with individuals, who were not necessarily scientists.
- ***Practitioners are not automatons***, but seek out different strategies to address the problematics of their current work context, in relation to their own perceptions and priorities.
- ***Success is often neither attainable nor evident***. Mitigation decisions relating to smaller emergency events may go unnoticed precisely because mitigation was effective, however the large events where mitigation is partially effective is where their actions will be scrutinized and blame will be sought.
- ***Decision-making is embodied***. Practitioners are under considerable stress as a result of the complexity they face, their personal concern for the people present in a risk landscape during a hazard event, and their limited capacity to mitigate risk.

Influential assumptions about the use and utility of science were found to have the following substantial consequences for practice:

- less efficient use of research-practice risk mitigation monies,
- more stressful work conditions for risk mitigation practitioners, and
- less effective risk mitigation policies and practices for all.

As natural hazard risk mitigation is inherently complex, knowledge diversity is needed for practitioners to better understand where the various contributions of science lie, where the contribution of other knowledge lies, and the differing value and utility these have to the matter of concern.

With this, they have the potential to consider a broader scope of options, make better risk mitigation decisions and more effectively defend them.

In support, we offer natural hazard risk mitigation practitioners a set of guidelines focussed on moving from finding **the** risk mitigation solution, to a more pragmatic approach that embraces risk complexity and uncertainty.

Through our research and case studies, we see parts of the emergency management sector is already pioneering this work, and in doing so, is providing leadership for the broader public sector grappling with related issues of climate change and sustainability.

END-USER STATEMENT

Ed Pikusa, *Department for Environment and Water, SA*

As emergency management practitioners, we are all focused on making the best possible decisions with the best available evidence to reduce risks to the community as much as we can. Many of the settings in which we do this contain significant complexities and uncertainty.

The value of scientific 'facts' and evidence is often used as the basis of decision making, but in complex settings, the value of such evidence is often less than we think.

It is easy to take science on face value when making a decision. The research in this project suggests this often creates additional problems by ignoring uncertainties. For example, extra uncertainties occur when decision-makers minimise the non-scientific expertise of other practitioners, arbitrarily select the 'facts' that are used, and assume that the science is correct, accurate and totally applicable to the risk environment.

This project has used research and case studies to illustrate the value of scientific evidence, focusing on three particularly complex and important emergency management problems across fire and flood in Australia. Indeed, the flood case study meets the criteria for a 'wicked' problem.

The project shines a light on the uncertainties of scientific information, and gives practitioners a language to recognise and understand how 'facts' and 'science' may not be as absolute and certain as we think.

Better decisions in complex and uncertain settings can be made by taking a different perspective, embracing uncertain scientific evidence as part of a broader understanding of the risk environment, and making better decisions while being comfortable with the uncertainty.

This is a project that presents its understanding of myths around scientific evidence, and provides practitioners with guidelines to make better decisions.

The opportunity and challenge this project presents is as much cultural as it is scientific. Practitioners need to recognise that it may be uncomfortable to discount science on face value, and invest time in embracing evidence within an uncertain and more complex environment.

This project has shown through three case studies how this can be done, and I welcome more practitioners to do the same.

INTRODUCTION

This is the Final Report of the 'RMPP project' (Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning project), which addressed the use and utility of science and other forms of knowledge by natural hazard practitioners, and the pragmatic meaning this holds for their risk mitigation work. The project was part of the Governance and Institutional Knowledge cluster of the BNHCRC, and was a collaboration between the Institute for Culture and Society, Western Sydney University and the Fenner School of Environment and Society, The Australian National University.

New public policy positions for bushfire and flood risk planning, preparedness, response and recovery rely on best practice scientific evidence; however, scientific evidence does not always meet the knowledge needs of risk mitigation practitioners. Further, risk mitigation practitioners work in very uncertain contexts. Natural hazard events are, by definition, powerful spatio-temporal events, that generate a chaotic complexity of unique uncertainties, affecting entire landscapes and all lives within those landscapes.

Without greater insight into how science and other forms of knowledge are used in sector policy and practice, the ability of policymakers and practitioners to explain risk mitigation and translate its basis is compromised. The sector does not receive the full range of information it requires, and it continues to be vulnerable to the perpetuation of received ideas and 'myths' about science, its use and its utility. In this project we asked:

> *Given that uncertainty is an inherent part of scientific practice and method, and risk mitigation is also inherently uncertain, how do risk mitigation practitioners manage these uncertainties in their decision-making?*

Through case study research directly with practitioners, our research moves beyond the simplistic assumption that science can be directly translated into policy and practice. We documented and analysed how risk practitioners express and manage the different uncertainties they face with both knowledge and natural hazards, including the cycles of inquiry and blame that follow large and catastrophic natural hazard events. Through this, our research has provided an improved understanding of knowledge pathways and an improved basis for articulating and defending science-based decision-making in natural hazard risk mitigation. Further, our findings show how the 'knowledge work' of qualitative research is not esoteric, but *essential* to risk mitigation.

BACKGROUND

Instead of simply relying on facts to generate better policy and practice outcomes, as invaluable as they are, we join with those who ask what are 'facts', and how do facts, values and action interrelate (Beck, 2010; Durant, 2016; Kerkhoff and Lebel, 2006). This requires paying particular attention to reflexivity, which examines the foundations of *how* we think about something, rather than the more commonplace reflection, which examines *what* we think about something.

In this section we introduce some conceptual matters concerning scientific facts, subjectivity, decision making, risk and risk mitigation. We track how facts/objectivity and values/subjectivity are differently and similarly constituted; including how they inform and form each other. This enables a greater understanding of how practitioners use different sources of knowledge, including research expertise, intuition, and professional, experiential, and local knowledge.

We have defined 'science' as the legacy term that people are most familiar with – that is, the research and methods of the natural and physical sciences, as well as the institutions, practices and values that are created alongside. For example, maths, physics, chemistry, biology, hydrology, meteorology, climate science, agent modelling, and fire science.

1. SCIENTIFIC FACTS

Science is unique in its specific practices that are designed to be replicated by anyone to produce the same findings. Through the iconic scientific method of experimentation and observation, science creates 'falsifiable facts' or 'scientific facts' – facts that are known to be true until they are proved otherwise. Scientific unity is found and undone through processes of scientific consensus and dissensus (Pickering 2008). Scientific studies are constantly evolving through highly specialised, fragmented, and diverse disciplinary approaches.

The scientific method is designed to remove subjective human perspectives; however, it will always include the values of the people who undertake and fund it. Scientists, administrators, governments and others make decisions about which questions to pursue, which arguments to make more forcefully, what standards of proof are needed, which uncertainties to rule in or out of the scope, and so on (Table 1).

1.1 The use and utility of science

In liberal democracies (and elsewhere), the extraordinary strengths of science have become glossed as 'objective facts' that are useful for decision making. This is the reductionist or instrumental approach to science and its use, which assumes that:

- science generates objective facts, that are value free and independent of politics; and,
- these facts can be directly used for better policy and practice decision making.

This arrangement dovetails with the accountability and transparency values of democracy; for example, in the oft repeated phrase 'evidenced-based policy and practice' (Durant 2010).

However, such reductionist approaches to science are routinely confounded by the complexity of reality, as is well known by both the scientists and decision makers (Morss et al. 2005). The science-action pipeline is no such thing. It is neither unidirectional nor rational, science and policy are not separate domains, and, facts and values themselves are not separate.

Yet, the promise of linearity and certainty persists. Natural hazard managers often expect, and are expected, to achieve outcomes by using scientific facts as a rational problem-solving tool to make more certain decisions in the face of hazardous events (Funtowicz and Ravetz, 2003). At the same time, the overwhelming uncertainties of natural hazards means that this sector has always set different terms to the assumptions of the science-action pipeline.

The problems of this context play out in the public sphere of political, media, and quasi-judicial inquiries that follow large natural hazard events, where the focus is on apportioning blame for 'what went wrong' (Eburn and Dovers, 2015: 501; Shrum, 2014).

1.2 Post-truth politics

Recent contestations over 'facts' have brought the relationship between science and democracy into the centre of public debate. The rise of populism has placed 'truth' in the hands of elite populists, with experts to be distrusted. Scientists have staged protests to defend the value of their methods and results.

This questioning of scientific expertise has occurred around:

- high-profile debates in which science has been cast as unreliable, controversial, and dangerous (e.g. climate change, nuclear power, genetically-modified organisms, fracking, and invasive species); and,
- the selective use of scientific facts by governments to support political agendas and shutdown public debate (Whatmore 2009).

1.3 Locating facts through degrees of certainty

Instead of requiring science to be objective if it is to be scientific, it is better to consider different degrees of certainty and uncertainty. For example, there is strong scientific agreement about the existence of anthropogenic climate change, more contested scientific debate about its specific causes and effects, and exploratory 'blue sky' science about possible ameliorating technologies.

With a nuanced approach, science is no longer vulnerable to charges of not being objective. This is not to neglect what is unique about science, and thus where its traction lies; but allows a better understanding of its contribution, including in relation to other sources of knowledge.

1.4 Knowledge plurality

Through understanding how knowledge is formed, practiced, and re-formed as 'justifiable belief', different sets of knowledge can be identified:

> Scientific knowledge, for example, must be justifiable according to the standards set by adherence to accepted scientific practice and peer review. Local knowledge must be justifiable according to claims of connection with a particular place. Practical knowledge is justifiable on the basis of experience in practice, and political knowledge must be justifiable according to experience within the political process. (van Kerkhoff and Lebel, 2006: 447).

Decision-makers are still required to evaluate the different knowledge sources they have access to, but with a greater awareness of knowledge practices and plurality. This helps address the unrealistic deference to science as *the* knowledge expertise of choice.

1.5 Valuing values

Whilst values are ever present in natural hazard risk mitigation, the importance of science has meant that expertise in subjectivity is relatively under-explored, under-represented and downplayed (Sword-Daniels et al., 2015: 292). This has resulted in a knowledge deficit for practitioners.

In addition, science has become so influential that:

- questions about values are being expected to be answered through the debate of facts; rather than also considering expert scholarship on values (Durant, 2016: 21); and,

- the kinds of answers that science can provide, are forming the type of questions that are being asked in the first place.

For example, the predictive sciences are given the authority to determine the climate change problem and our responses to it, when these are value questions about how we want to live and why (Rigg and Mason, 2018).

To persist with governance approaches that only focus on the facts, is not to exclude values, but to suppress some values for others:

> with those whose values are left out rejecting the other side's 'truth' as merely politics by another name. (Jasanoff and Simmet, 2017: 763)

2. RISK FRAMES

Risk and risk mitigation may seem to be self-evident terms; however, they are complex, and viewed differently from different viewpoints. Exploring and accepting this complexity, generates opportunities to clarify misunderstandings, identify uncertainties, and establish broader grounds for learning and action.

2.1 Risk is not the hazard

Risk is often equated with the hazard, but it is explicitly defined by the natural hazard sector as the interaction of hazards, communities and the environment (COAG, 2011: 22). Risk mitigation requires attending to how these are differentially imbricated, before, during and after hazard events.

2.2 Risk is a combination of social and natural

The significance of the natural hazard sector's focus on risk, rather than the hazard, is that it is responsive to and embraces our co-located natural and social worlds. Natural forces are pre-dominant in natural hazard events; however, these events are also always social phenomena in how we experience and understand them, as well as how our decisions mitigate and/or amplify them. For example, wildfires are often considered preventable in social, political and regulatory spheres (Sherry et al., 2019), whilst floods are considered as unpreventable and thus are more pro-actively planned for (Mercer et al., 2011).

This is a very different viewpoint to that which places nature as the background for human activity, and over which humans dominate. The clash of viewpoints is evident when the natural hazard sector is required to explain that risk mitigation is not 'stopping the hazard'. That would be called risk elimination.

2.3 Risk values are not self-evident

The precursor to undertaking risk mitigation is deciding what are the priorities to protect. Traditionally, risk values are listed as – the primacy of life, built assets, and the environment. However, these are not self-evident. Further, there is a paucity of research into what is even considered at risk. For example, after the primacy of human life, is it property (and is that insured/uninsured, commercial/residential, and/or holiday/work property?), community assets (halls/clubs, infrastructure, water/soil health, and/or aesthetic/recreational places?), Aboriginal peoples' values (cultural-historic heritage sites, intergenerational practices, and/or Country in general?), environmental values (ecological communities and/or carbon emissions?), and so on.

2.3 Risk mitigation is bound up in values

Risk mitigation practices themselves require value decisions. For example, risk mitigation practice prioritises activities that are quantifiable, such as prescribed burning, and building levees and dams. (Sword-Daniels et al., 2015; Sherry et al., 2019). This relates to how reductionist approaches to science and its use informs what is viewed by society and political leaders as evidenced based policy and practice.

Recently, the natural hazard sector has begun using the language of 'resilience' and 'vulnerability', explicitly linking risk mitigation within the 'public good' goal of sustainability (COAG 2011; AGD 2017). This includes adopting participatory governance methods to engage with societal values (Edwards and Osuchowski, 2018).

RESEARCH APPROACH

This project used qualitative social science and humanities methods to investigate and analyse how diverse knowledges are ordered and judged as salient, credible and authoritative, and the consequences for risk mitigation practice. We drew on critical theory, narrative analysis, literature reviews and fieldwork to support our interpretation and argument.

We had three key tasks:

1. Investigate the diversity and uncertainty of bushfire and flood science, and its contribution to risk mitigation policy and planning;
2. Explore how diverse individuals use and understand scientific evidence and other knowledges in their bushfire and flood risk mitigation roles; and,
3. Analyse how this interaction produces particular kinds of opportunities and challenges in the policy, practice, law and governance of bushfire and flood risk mitigation.

Three case studies were identified in consultation with our end user group, each located in an important risk landscapes, in which scientific knowledge was being used to change policy and/or practice:

- Wildfire risk and prescribed burning, in the Barwon-Otway region, Victoria;
- Wildfire risk and an invasive fire-weed, in the Greater Darwin area, Northern Territory; and,
- Flood risk and mitigation planning in the Hawkesbury-Nepean Valley, New South Wales.

Conducting empirical research directly with practitioners was prioritised, because it enabled tracking their use of science over time and within the communities and landscapes where they work. This has facilitated greater insight into practitioner meanings about certainty, linearity, and science. The case study methods are detailed further in the case study section.

Our key milestones were set around our core research activities – a review of scenario exercises, a literature review, the case studies, and this synthesis report.

LITERATURE REVIEWS

1. SCENARIO EXERCISE METHODS

Scenario exercises were proposed in the project plan, as part of the case studies. To investigate this possibility, we conducted research into: what scenario exercise are, why they are used, and, how they can be used to achieve the aims of the RMPP project.

Approximately 250 sources on scenario exercises, methodology, analysis, and design were reviewed. The key findings of the review were:

- Two dominant approaches to scenario exercises exist. In one, scenario exercises involve the generation of predictive models of possible future events through combined quantitative analyses. In the other, scenario exercises involve participants of various kinds responding to possible future events in order to pay attention to how knowledge of such futures is produced.
- There are many methodological lessons to be drawn from the existing use of scenario exercises.
- While they can bring together diverse expert knowledges to better understand complex systems, the focus is often on the product and not the process.

This work informed our approach to the scenario exercises in the case study fieldwork. These took the second approach, and can also be described as a facilitated group discussion about future scenarios.

2. SCIENTIFIC DIVERSITY AND UNCERTAINTY

We published a literature review and journal article which surveyed the key scientific uncertainties encountered, managed and utilised by practitioners involved in bushfire and flood risk mitigation practices in Australia. Scientific uncertainties are those 'known unknowns' and 'unknown unknowns' that emerge from the development and utilisation of scientific knowledge.

Central finding:

- Bushfire and flood risk mitigation sciences have specific uncertainties, but they also share some common practices and common uncertainties. For example, imperfect historical data, fluid entities (climate, weather, flora, fauna and human populations), and widespread practical issues, such as the 'data and computational friction' generated by modelling and the unavoidably fragmented work of data collection and storage.

We organised these uncertainties into three categories:

- *Historicist uncertainties* are those uncertainties which emerge from the reliance of scientific knowledge on archives of historical data;
- *Instrumental uncertainties* are those uncertainties which emerge from the limitations of a given apparatus, heuristic or theory; and,
- *Interventionist uncertainties* are those uncertainties in the predictive calculations about the effect of mitigation interventions

Table 1 summarises our findings across these three categories for both wildfire and flood risk.

These categories are a teaching and organizational device for practitioners and scholars to interpret the science knowledge they are working with.

Uncertainty type	Key forms	Elaboration
Historicist – uncertainty arising out of reliance on historical data, due to assumed determining relationship between the past, the present and the future	a) Gaps and inconsistencies in historical datasets on relevant environmental variables	Gaps can arise out of: innovations in measuring apparatuses; variations in data metrics; variations in the geographical spread of measuring apparatuses; unreliable measurements; commercially sensitive data collections; fragmented storage; and, funding constraints.
	b) Relative rarity, uniqueness and force of a given hazard event	Lack of historical exemplars is a barrier to validation and prediction. Measuring apparatuses can be destroyed during hazard event. Relative randomness of bushfire ignition points, and fire behaviour unique to fire-terrain and fire-atmosphere interactions.
	c) Assumption that natural systems fluctuate within an envelope of variability known as 'stationarity'	Climate change requires recognition of both temporal and spatial variability into the future, the parameters of which are uncertain.
Instrumental – uncertainty arising out of limitations of a given apparatus, heuristic or theory[1]	a) Difficulty of capturing hazard behaviours in simulators, largely due to uncertainties surrounding behavioural algorithms	E.g.: the complexity of feedback mechanisms between fire and atmosphere. Difficulties with behavioural algorithms include historicist uncertainties, such as data limits. Data synthesis strains against computational resources and reporting requirements.
	b) Limits to modelling of at-risk assets and values	Spatially static entities (e.g. property, infrastructure) can be incorporated into topographical modelling; but spatially dynamic entities (e.g. human life, flora and fauna) are either excluded or rendered through static proxies.
	c) Contested methodological standards	E.g. McArthur FFDI. Standards do not include all available data but remain in use because of resource limitations, institutional preferences and literacies. These also iteratively influence the framing of scientific methods and projects.
Interventionist – uncertainty inherent in the predictive calculations about the effect of mitigation interventions	a) Quantifying intervention additionality	Mitigation benefits have their own historicist and instrumental uncertainties. Selection of benefit metrics influenced by non-scientific aspects such as policy priorities, social values, and political context.
	b) Reflexivity, with respect to parameters and primary, secondary and emergent consequences of interventions	Uncertain effects of interventions on at-risk values, e.g.: 'safe development paradox'; the ecological effects of prescribed burning. Uncertainty surrounding implementation of interventions. These unintended consequences should be considered calculable and non-calculable uncertainties.

TABLE 1: UNCERTAINTY CATEGORIES FOR SCIENTIFIC KNOWLEDGE USED IN BUSHFIRE AND FLOOD RISK MITIGATION

[1] Note that bushfire risk is typically figured on likelihood of conducive conditions not on likelihood of occurrence. Flood risk is usually calculated in two ways: the likelihood of occurrence of rain-driven flood events; and, the spatial modelling of flood behaviour.

CASE STUDIES

Three case studies were conducted with wildfire and flood risk practitioners in Australia (Tables 2 and 3).

1. METHOD

Our fieldwork methods centred on spending time with people and places, with specific methods including landscape immersion, participant observation, document analysis, repeat semi-structured interviews, and a facilitated group discussion at each location. Methods were adapted as the project developed and in response to specific case study priorities.

We defined practitioners broadly as the people who are professionally engaged in the various processes involved in developing and implementing risk mitigation strategies, whether executives, field officers, planners, modellers, or public officials in research positions. In both the Barwon-Otway and Greater Darwin area case studies, one or two university researchers were also interviewed on the basis of their close professional engagement with the practitioners.

Case study	Individuals interviewed	Workshop group	Fieldwork host organisation
Barwon-Otway Region, Victoria	21	12	Department of Environment, Land, Water and Planning
Greater Darwin Area, Northern Territory	27	14	Bushfires NT
Hawkesbury-Nepean Valley, New South Wales	22	17	Hawkesbury-Nepean Flood Management Taskforce

TABLE 2: CASE STUDY PARTICIPANTS

Case study	Natural Hazard	Risk Landscape	Development context	Visual risk cues in the landscape
Barwon-Otway Region, Victoria	Eucalypt forest, shrub and woodlands wildfire	Coastal temperate, rural & coastal towns. Very limited exit routes.	Gentrification of coastal areas, rural decline, summer tourism	Moderate – regular local bushfire events, large events rare. Nil for tourists.
Greater Darwin Area, Northern Territory	Gamba grass fuelled wildfire	Peri-urban & rural tropical savannah	Frontier expansion	Low – new out of town Gamba grass growth, plus familiarity with cool dry season fires.
Hawkesbury-Nepean Valley, New South Wales	Low frequency high impact flood	Sandstone valleys, floodplains for multiple rivers, rural, peri-urban and urban edge. Very limited exit routes from many areas	Intense residential housing pressure for Sydney	Low – confusing and often difficult to see. The last two serious floods were 1961 (15 metres above sea level) and 1867 (19 metres)

TABLE 3: CASE STUDY RISK LANDSCAPES

2. CASE STUDY SNAPSHOTS

2.1 The Australian case studies

Each case study was located in an important risk landscapes, in which scientific knowledge was being used to change policy and/or practice:

- The Barwon-Otway region is a rugged forested coastal and rural area in southwest Victoria where peak bushfire risk periods coincide with peak summer holiday seasons, and evacuation routes are choked with tourist buses. This region was selected because practitioners were piloting the use of a two-dimensional computational model (PHOENIX RapidFire, or 'PHOENIX') to simulate fire risk and identify prescribed burning management priorities. To address limitations with the bio-physical model, practitioners developed quantitative datasets of qualitative values, such as 'sense of place' and 'community resilience'. Also, two years of community meetings were held to learn more about local priorities, and build and strengthen relationships around risk responsibilities. Described as a 'more scientific' strategic approach to wildfire risk, the pilot helped inform the state-wide debates on quantitative prescribed burning targets.

- In the Greater Darwin area, huge climactic flux between wet and dry seasons supports vigorous grass growth and curing. This case study was selected because wildfire risk is dramatically changing with the spread of Gamba grass (*Andropogon gayanus*). This invasive weed fuels high intensity fires that destroy savannah habitat, allowing for further invasion in a self-perpetuating 'grass-fire cycle' that has the potential to spread across Australia's northern savanaah (Setterfield et al., 2010). Scientific research has provided a degree of certainty about these threats, and helped create policy change in 2008; however, it is widely understood that subsequent action has been insufficient. Knowing this, practitioners expressed feelings of futility and despair about their work and the unrealised promise of impactful scientific results.

- On the flood plains of the Hawkesbury-Nepean Valley in Western Sydney, political leaders must make development decisions for a largely risk-unaware populace. These floodplains are prone to very low-probability but very high-impact floods. Following the Brisbane and New South Wales floods (2011 and 2013), the Hawkesbury-Nepean Valley Flood Management Taskforce was established to advise the state government. During our fieldwork, the Taskforce's work included flood modelling, scenario building, social network analysis, spatial and transportation route mapping and evacuation modelling, combined with field research and consultation. The Taskforce consciously engaged with uncertainty rather than avoiding or minimising it.

2.1 The Canadian case study

An additional international case study was added to the project in response to Canadian interest in the methodology. Led by Professor Tara McGee, and assisted by postdoctoral researcher Dr Jenny Sherry, this research examined how wildfire managers used scientific and other forms of knowledge to generate a new wildfire risk management plan for the Lac La Biche Forest Area. The Canadian costs of the research were funded by the Government of Alberta Wildfire Science and Technology Program with a CAD $20,000 grant. The costs of Dr Neale's travel were covered by the RMPP project.

Due to time limitations, the results of the Canadian case study were not included in the comparative analysis of the Australian case studies; however, they did provide additional insights for the broader synthesis discussion and implications, and are part of ongoing collaborative research relationships.

SYNTHESIS

The synthesis brings together the results of the three Australian case studies of practitioner experiences with reductionist/instrumental approaches to science and its use.

1. PRACTITIONER EXPERIENCES

Across these diverse case studies, clear commonalities can be drawn:

- *Science is critical, but it is not everything*
  All the practitioners placed a high value on the use of science; however, the idea that 'more science' is needed was not a priority in any case study. Science does not resolve the big questions the practitioners had about what society values.

- *Complexity is irreducible*
  The practitioners were keenly aware that risk mitigation is full of cultural values and other subjective 'non-rational' factors, that cannot be reduced to prediction or modelling.

- *Experience is vital, although seen as less authoritative*
  The practitioners valued their intuition and experiential, local and professional knowledge with the risk landscape and communities, and other hazard events. Yet many practitioners often apologised for, disparaged or marginalised this knowledge, for not carrying the authority of knowledge arising out of formalised methodologies.

- *Making things 'count' is important*
  Science was judged as more authoritative than other evidenced-based expertise. Practitioners spoke about how some people living within risk landscapes highly value science for its assumed capacity to produce 'hard data' to be used in practice and policy, in a way that, as some practitioners expressed, was not similarly understood as possible with data from qualitative research.

- *There is confusion about what is a fact*
  The practitioners' own assumptions about using science to secure objectivity and certainty were either internalised, acknowledged as an externally required goal, or both. Practitioners regularly expressed opposing positions about certainty, and it was common for misunderstandings to proliferate around what is meant by the 'facts' within the sector.

- *Science has a social life*
  Practitioners were in a unique position to influence outcomes through how they selected, interpreted, used, modified and presented science. When evaluating complex science, practitioners often drew on relationships of trust with individuals, who were not necessarily scientists.

- *Practitioners are not automatons*
  Practitioners seek out different strategies to address the problematics of their current work context within their capacity, time, logistical and material constraints, and in relation to their own perceptions and priorities of natural hazards, risk, and risk mitigation.

- *Success is often neither attainable nor evident*
  Practitioners are focused on anticipating large and catastrophic natural hazard events, although saw their mitigation work as most effective with respect to moderate natural hazard events. Yet, their decisions in relation to smaller events may go unnoticed precisely because this work might have been effective, whilst it is the large events where their actions will be scrutinized (Eburn and Dovers 2015).

- *Decision making is embodied*
  Many practitioners spoke about the anticipatory stress they experienced because of their role, and how it can keep them awake at night. They connected the full spectrum of complexity they faced, with their personal concern for the people present in a risk landscape during a hazard event, and their limited capacity to mitigate risk.

The most striking difference amongst the three case studies was the perception of risk between southern Australia, and that of the Greater Darwin Area. The monsoonal savannah was not yet seen as a catastrophic fire risk landscape by those that matter – political leaders and influential electorates.

2. CONSEQUENCES FOR PRACTICE

Influential assumptions about the linear 'pipeline' use and utility of scientific expertise have substantial consequences for practice:

- less efficient use of research-practice risk mitigation monies,
- more stressful work conditions for risk mitigation practitioners, and
- less effective risk mitigation policies and practices for all.

Across all case studies, differently placed practitioners worked to address these problematics within their capacity, time, logistical and material constraints. In this, they demonstrated how it is possible to avoid being bound by reductionist approaches. Our research shows that this sector is providing leadership on engaging with natural and social complexity through seeking out knowledge plurality and reflexivity, and avoid ideological retreat and polarisation. Their initiatives have generated possible alternative starting points to reconsider the purpose, consequences and limits of mitigation. This is critical in this time of global environmental crises, which are amplifying natural hazard risk, and undermining planetary life systems.

GUIDELINES

As natural hazard risk mitigation is inherently complex, knowledge plurality is needed for practitioners to better understand where the contribution of science lies, where the contribution of other knowledge lies, and the differing value and utility these have to the matter of concern. With this, they can better make and defend their risk mitigation decisions. In support, we offer natural hazard risk mitigation practitioners these guidelines, noting that we are reflecting back many of their insights shared with us.

These guidelines are centred on moving from finding the risk mitigation solution, to the pragmatics of embracing risk complexity and uncertainty. We see this sector is already doing this work, and in doing so, is providing leadership for the broader public sector which is grappling with related issues of climate change and sustainability.

1. Complexity is irreducible

It is important to keep engaging consciously and visibly with complexity and uncertainty rather than seeking to reduce or eliminate it. For example, continuing to emphasize that: a consequential nature necessarily limits the expectations of risk mitigation possibilities; subjective and other 'irrational' matters are present throughout natural hazard events and their risk mitigation; and, that knowledge is always partial and plural.

2. Reflexivity and the possible

It is important to keep developing understandings that practitioners are not external to the risk mitigation problem but part of it, and thus reflective and reflexive approaches are needed to unpack the understandings of individuals and institutions. For example, processes such as reframing, domain mapping and group discussions, allow participants to understand different perspectives and review their own assumptions in light of other knowledge. This helps generate possible alternative starting points to reconsider the purpose, consequences and limits of risk mitigation.

3. Problems and solutions as complex and plural

It is important to continue with the general understanding that all solutions are partial and provisional, that the problem definition itself depends on the knowledge and values held by people, and that any resolution is likely to result in further issues emerging (e.g. Clarke and Ashhurst, 2018).

4. Knowledge plurality is integral to decision making

It is important to continue to state that diverse knowledge sources are necessarily for risk mitigation, as this is responsive to the social and environmental complexity that constitutes the risk. As part this, it is appropriate to identify and evaluate different knowledge sets, including against their own standards of justification.

5. Secure complexity within the expertise base

It is important to continue engaging with expertise that understands facts and values together. For example, through: qualitative, interdisciplinary and transdisciplinary research projects and partnerships; the recruitment of individuals with relevant expertise; and, using methods that support knowledge co-creation and sharing. This includes understanding that participatory approaches only go so far. Exchanging viewpoints about the 'facts', is not the same as securing expertise in subjectivity (Durant 2016).

6. Complexity has navigational tools

It is important to keep finding and using tools to navigate complexity, without simplifying it. For example, creating temporary boundaries around an area of work to limit uncertainty for that in the short-term, while knowing and accepting that uncertainty remains pre-dominant throughout.

7. Support experimentation and iterative learning

Keep encouraging a dynamic learning context, in which experimentation is allowed, and failure appreciated as part of the learning process.

UTILISATION ACTIVITIES AND OUTPUTS

In addition to regularly meeting with our end users, and providing updates through a quarterly newsletter, which was then published in part on the BNHCRC website, we undertook the following utilisation activities and outputs.

1. APPLIED RESEARCH APPROACH

Our research approach involved the end users directly as we did the research. For example, the workshops held in the case study locations were also an opportunity for practitioner reflection, networking, and learning.

2. FLYER AND GUIDELINES

A guideline and flyer have been prepared, summarising the findings of the research in brief, with specific guidelines for practitioners. The draft guidelines are reproduced within this report.

3. UTILISATION WORKSHOP AND COMMUNICATION TOOLS

The workshop 'Making Science Social: Making sense of risk & uncertainty' was convened by Jessica Weir, Elizabeth Clarke, Timothy Neale and Craig Ashhurst, and facilitated by Liz and Craig (Sydney, 7 September 2017). Twenty people attended, including participants from each of the three case study areas (Barwon-Otway, Hawkesbury-Nepean Valley and Greater Darwin area), as well as key end users.

The workshop introduced participants to techniques and tools to help bring scientific and societal knowledge together, in order to tackle complexity and uncertainty in risk mitigation. Workshop participants were provided with summary research results from across the three case studies, and a "Risk Thinking Toolbox" was presented, which included the following four items:

1. A tool for navigating between science and practice: "The thinking wave"
2. A Brainstorming tool: concept mapping
3. A sensemaking tool: the wicked problems framework
4. A tool for surfacing tacit knowledge: a systems iceberg

All of the tools are designed to enable stakeholders with different expertise and backgrounds to share knowledge and synthesize a diversity of risk mitigation expertise, viewpoints and experience. The tools were chosen to meet the needs identified by the research results. We note that the tools shared at the workshop were not a result of the RMPP project, but were developed previously by Craig Ashhurst and Liz Clarke.

4. INDUSTRY PRESENTATIONS AND SEMINARS

In brief we have presented at five Research Advisory Forums (2014-2018), given five AFAC conference presentations (2015-2017), and presented at the BNHCRC Showcase 2017. In addition, we have presented to: Forest Fuels Management Workshop (Hinton, Canada, 2014); Information Share, NSW Rural Fire Services, (Sydney, 2015); DWELP (Melbourne, 2016); Wildfire Management Branch, (Edmonton, Canada, 2016); AFACs Predictive Services Group, 2017; and, Bushfires NT and others (Darwin, 2018). The industry presentations and seminars are fully listed in the publications list.

WHERE TO FROM HERE

We continue to present at industry events, and engage with our case study partners, as well as publish and conduct ongoing research about the role of science in natural hazard risk mitigation, as well as sustainability and climate change more generally. This includes:

- Timothy Neale is researching wildfire risk in the Northern Territory and Victoria as part of his ARC DECRA project *Pyrosecurity: understanding and managing bushfires in a changing climate*.
- The RMPP project has been succeeded by the 'Hazards, Culture and Indigenous Communities' BNHCRC project. This project analyses the engagement between the natural hazard sector and Indigenous communities across southern Australia. This brings the particular insights and priorities of Australia's First Nations peoples to natural hazard risk mitigation.

PUBLICATIONS LIST

JOURNAL ARTICLES

- Neale T and Weir JK. 2015, Navigating scientific uncertainty in wildfire and flood risk mitigation: a qualitative review. *International Journal of Disaster Risk Reduction* 13: 255–265.
- Wodak J and Neale T. 2015, A critical review of the application of environmental scenario exercises. *Futures* 73: 176-186.
- Neale T, Weir JK and McGee TK. 2016, Knowing Wildfire Risk: scientific interactions with risk mitigation policy and practice in Victoria, Australia. *Geoforum* 72: 16-25.
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- Neale, T, 2019, A sea of Gamba: making environmental harm illegible in northern Australia, *Science as Culture,* 1-24.
- Sherry J, Neale T, McGee TK, and M Sharpe. (2019) Rethinking the maps: A case study of knowledge incorporation in Canadian wildfire risk management and planning. Journal of Environmental Management 234: 494-502.

CONFERENCE PROCEEDINGS AND OTHER PUBLICATIONS

- Weir, JK, Neale, T and L Clarke ‘Science is critical, but it is not everything: Our Findings’, AFAC 2017 conference proceedings paper.
- Dovers, S, ‘Emergency Management and Policy: Research Impact and Utilization’, AFAC 2017 conference proceedings paper.
- Clarke, L, Weir, JK, Neale, T Cinque, and M Abood ‘Making sense of Hawkesbury-Nepean flood risk: Bringing science and society together’, AFAC 2017 conference proceedings paper.

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- Neale, T and JK Weir 2016, The social life of science in natural hazards policy and planning: opportunities and challenges, AFAC poster, Brisbane, Qld.
- Weir, JK, Neale, T and L Clarke, 'Scientific Knowledge QandA', poster, BNHCRC Showcase 2017: Research Driving Change and AFAC 2017.

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- Neale, T. 2015, Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning, *Information Share,* NSW Rural Fire Services, Homebush.
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- Neale, T. 2015, Practising Calculability: wildfire, risk mitigation, and simulation modelling in southwest Victoria,' *Institute for Culture and Society Seminar Series*, Western Sydney University, Parramatta, NSW.
- Neale, T. 2015, Inexistent Fires: imagining risk, knowledges and uncertainties in southwestern Victoria, *Institute of Australian Geographers Conference*, Canberra, ACT.
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- Neale T. 2016, Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning: Project Update. *Research Advisory Forum.* Hobart, TAS.
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- Weir, JK, Neale, T and L Clarke 2017, What to do with uncertain science, BNHCRC RAF Perth, April 2017.
- Weir, JK, 'Influencing the policy and practice of disaster resilience', panel, BNHCRC Showcase 2017: Research Driving Change, BNHCRC, Adelaide, 4 July 2017.
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- Weir, JK, Neale, T and L Clarke 'Science is critical, but it is not everything: Our Findings', AFAC conference, Sydney, 4 September 2017.
- Dovers, S, 'Emergency Management and Policy: Research Impact and Utilization', AFAC conference, Sydney, 5 September 2017
- Clarke, L, Cinque, P, Abood, M, Weir, JK and T Neale 'Making sense of Hawkesbury-Nepean flood risk: Bringing science and society together', AFAC conference, Sydney, 6 September 2017.
- Weir, JK, Neale, T and E Clarke, 'Gamba Grass: Science, Research, Action', presentation to North Australia Forum, The Australian National University, Canberra, 17 November 2017.
- Weir, JK 2018. Utilisation panel, Research Advisory Forum presentation, Bushfires and Natural Hazard CRC, Sydney, 13 April 2018.
- Weir, JK, Neale, T and L Clarke, 'Responsibility, Criticism, Evidence: Making and Defending Your Risk Mitigation Decisions', Berrimah Fire Station, 23 May 2018.
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- Neale, T 2016, *The social life of science in policy and planning*, 12 April, BNHCRC, <http://www.bnhcrc.com.au/news/blogpost/timothy-neale/2016/social-life-science-policy-and-planning>.

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