bnhcrc.com.au

bushfire&natural HAZARDSCRC

THE VALUE OF RESEARCH FROM THE BUSHFIRE AND NATURAL HAZARDS CRC

Final Report, July 2020

John Handmer[1,2], Adriana Keating[1,2] and Ken Strahan[3]

1 The Risk Laboratory

2 International Institute for Applied Systems Research

3 Strahan Research

Version	Release history	Date
1.0	Initial release of document	14/08/2020

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

Publisher:
Bushfire and Natural Hazards CRC

ISBN: 978-0-6482756-7-1

Report No: 601.2020

August 2020

Citation: Handmer J, Keating A & Strahan K (2020) The value of research from the Bushfire and Natural Hazards CRC, Bushfire and Natural Hazards CRC, Melbourne.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

We thank the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) for the opportunity to examine the value of its work. Thanks are also due to those who provided details and comments through interviews for the case studies summarised in this report: BNHCRC researchers, end-users and all those connected with the Tasmanian fire study. We appreciate the insights on our methodology provided by Junko Mochizuki (International Institute for Applied Systems Analysis and World Bank) and Muneta Yokomatsu (Kyoto University and International Institute for Applied Systems).

EXECUTIVE SUMMARY

The Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC – the CRC) retained us to develop a transparent, reproducible estimate of the total value to Australia of its research: to answer the question, what is the return to Australia of its investment in the BNHCRC?

Cooperative Research Centres, like the BNHCRC, represent the main formal vehicle for explicitly enhancing research and industry collaboration in Australia. With government sponsorship, researchers and industry work closely to produce socially and commercially desirable outcomes.

Funders of all research, including that of bushfire and emergency management, increasingly want to ensure that their investments generate value for the emergency management sector and contribute to risk reduction. Research value can take a number of forms, from a readily assessed improvement in performance due to a new widget or process, to increases in capacity and risk management across the emergency sector, and direct and indirect benefits to the whole of society and economy.

The ARC (Australian Research Council) has a broad definition of research impact:

> "Research impact is the contribution that research makes to the economy, society, environment or culture, beyond the contribution to academic research."

The definition suggested by the European Commission is broader still and includes indirect impacts and effects, on for example, innovation culture, capacity building, and increasing the stock of useful knowledge. We use the ARC's definition broadened slightly to encompass the specifics set out in the European definition as they help to capture the CRC's contribution. This is achieved through four pathways to value, set out in the following section.

IDENTIFYING AND ASSESSING VALUE

Conventionally, research value for emergency management related research in Australia has been conceptualised in terms of value for specific fire and emergency service agencies, or in some cases for the whole formal fire and emergency management sector. Yet this research has produced far wider impacts. Following our broad definition of research impact we consider the potential value of BNHCRC research through four distinct pathways to value. They expand the potential value of research and highlight the range of strategic areas that publicly funded research enhances; and indicate the main ways the CRC has value. We have also used a number of CRC projects and a major case study to examine how research has had impact.

The four pathways to, and sources of, value are:

1. *Project level impacts*: mostly direct impacts on agency policy or practice. These include improved agency policy and/or practice; cost savings and effectiveness; and impacts resulting from the combined value to the fire and EM sector of all projects and other work, which includes a "trusted

adviser" role for the CRC. The investment of $120 million by the Federal Government and the BNHCRC end-users and other contributors provides an estimate of the CRC's value to them. To take account of the potential overlap with Pathway 4, this is reduced by 50%.

2. *Training and capacity building*: impacts on the development of the skills, expertise and capacity of people in the emergency management sector. We focus specifically on training which is a key, but nevertheless only one component of capacity building or human capital development. Training can be formal with both user engagement in research projects and researcher engagement with practice. This can also include the proactive creation of active networks and communities of practice (we have not valued networks explicitly – see Appendix). Informal training also occurs, typically between co-workers. The value of training and capacity building is based on the conclusion that training generates productivity improvement of about 7%. On this basis, training of the Australian emergency management workforce produces a productivity improvement against gross wages (Department of Education, Skills and Employment) of $137.8 m/ annum. Based on a sample of 28 of its projects, the BNHCRC is assessed as contributing about one quarter to the workforce's productivity improvement through training and capacity building, valued at $34.5 m per year. (Note that this takes account of career fire and emergency managers only. The volunteer workforce is not included.)

3. *Knowledge generation*: includes production of both formal codified knowledge (published papers, reports, PhDs, etc.), and informal knowledge through, for example, seminars and conferences, and exchanges through networks of practice. PhD value is based on the government investment made giving a value of $175,000 per PhD. For papers, we used estimates of the value of published peer reviewed papers and of conference presentations. For applied research in disaster risk reduction, and in some academic areas like information and communication technologies, conference presentations are highly valued by industry.

4. *Broader social and economic impacts*: for the purposes of our assessment, we focus on the value of avoided loss and damage that can be attributed to BNHCRC research. We used figures from Deloitte Access Economics (Deloitte Access Economics, 2016) to estimate the yearly cost of disasters to Australia in terms of government, and social and economic costs. The value of mortality and morbidity comes from the AusDIS database (Handmer et al., 2018). These values were then increased by 3.5% per annum to account for population and exposure growth and the resultant change in disaster damages. We have assumed that the work of the BNHCRC will reduce future loss and damage from disasters by 0.25%, and estimate the value of Pathway 4 from the stream of benefits from 2017 to 2032.

THE VALUE OF BNHCRC RESEARCH

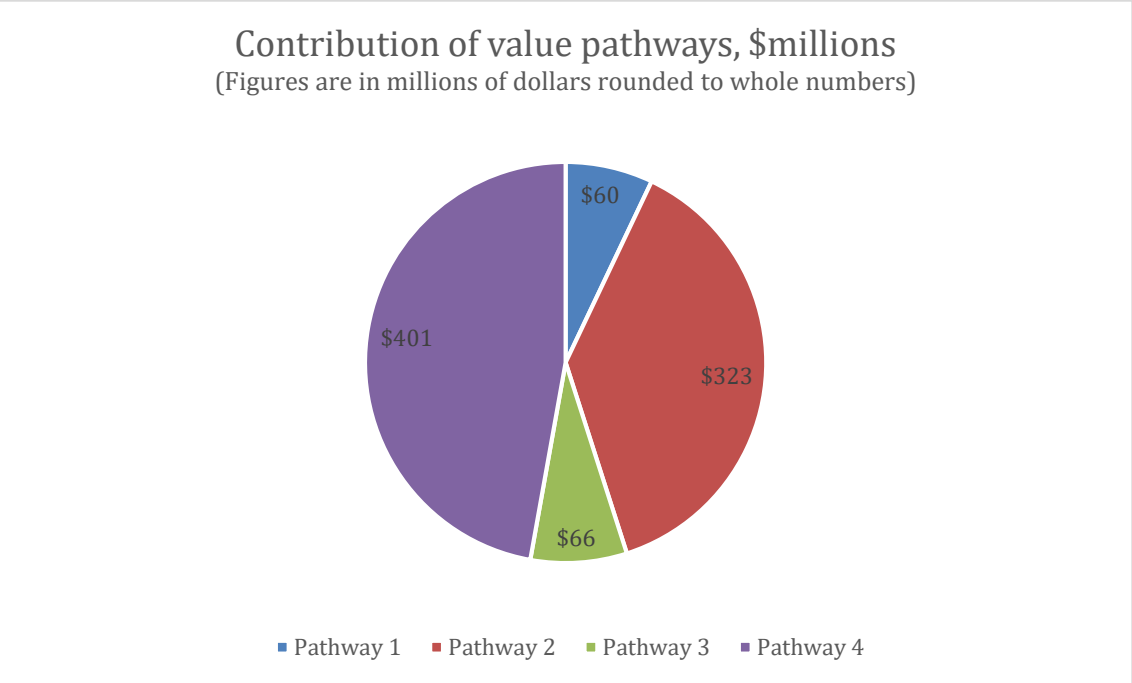
Summing the value of each of the pathways, the total value of BNHCRC research is estimated at $850.1 million (net present value). Net present value (NPV) in 2019 dollars consists of the total benefits over 15 years (to 2032) at a 5 percent discount rate. The sensitivity of the result is discussed under "Assumptions and sensitivity analysis" below. The contribution of each pathway is:

Pathway 1, Direct project impacts - $60m

Pathway 2, Training and capacity building - $323.1m

Pathway 3, Knowledge creation – $65.9m

Pathway 4, Broader socio-economic impacts – $401.1m (@0.25% reduction in losses); $1.6b (@1% reduction in losses).



Results are given here for a 5 percent discount rate over 15 years. Lower discount rates increase the capitalised value, and the value of the CRC, while higher rates lower the value of future benefits thereby lowering the overall value of the CRC.

Value of research benefit cost ratio (OPBR, 2016)

Adding the value of the pathways together gives a total benefit of $850.1 million over a 15-year period. The total cost of the BNHCRC over its life is $120 million. This gives a benefit-cost ratio of approximately 7:1, meaning that for every dollar spent on the BNHCRC there is a $7 return.

Sensitivity analysis

The calculations contain assumptions which, if varied, alter the final results. The most sensitive factor overall being the discount rate. Other changes to inputs have a relatively small impact on the final value of CRC research. Pathway 4 provides a possible exception: results are sensitive to the proportion of disaster

impacts attributed to research outcomes: $401.1 million at 0.25% reduction versus $1.6 billion at 1.0% reduction.

Summary

Based on our valuation of research impacts, the Bushfire and Natural Hazards CRC represents outstanding value for Australia.

INTRODUCTION

THE BRIEF FROM THE BNHCRC

The Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) asked us to work with them to develop a transparent, reproducible estimate of the total value to Australia of its research: in short, to answer the question: what is the return to Australia of its investment in the BNHCRC? This included the development of potentially novel methods for valuing identifiable research outcomes as well as the total value of the BNHCRC. Other elements include case studies showing how value occurs and peer reviewed publications on both the literature review and analysis, and on methodologies.

RESEARCH AND INDUSTRY COLLABORATION IN AUSTRALIA

The main formal vehicle for explicitly enhancing research and industry collaboration in Australia is the national CRC (Cooperative Research Centres) program; of which the Bushfire and Natural Hazards CRC is an example. With government sponsorship, researchers and industry work closely to produce socially and commercially desirable outcomes. However, the CRC program emphasis is on the researchers and industry being focused on business outcomes, with the degree of government involvement depending on the sector. Much effort is arguably needed, as (in 2014) Australia had the second lowest level of research collaboration with industry in the OECD (Innovate and Propser, 2014). However, there are areas of solid collaboration: for example, parts of the medical/health sector where university and private research groups are concentrated or co-located with major teaching hospitals in some metropolitan areas. These concentrations are also characterised by cross appointed staff and facilities. This arrangement can also be found, although to a much more limited extent, within information and communication technologies. It has also been argued that the wine industry has a record of strong interaction between research and industry (Hira & Aylward, 2013).

This idea of the integration of research and industry was conceptualised for the information age by Etzkowitz and Leydesdorff in their 1995 work on a "triple helix" approach involving research, industry and government (Etzkowitz & Leydesdorff, 1995). Researchers and industry work together to ensure the utility of research, industry uses the research to develop new products and processes, and government funds and may set priorities for research, ensures that the regulatory environment is supportive, and that markets are accessible. This integrative collaborative approach is seen as an essential underpinning of today's knowledge economy (Leydesdorff, 2012).

The BNHCRC and its predecessor, the Bushfire CRC, have many of the characteristics of the "triple helix model" with close collaboration between the three main groups (Garret-Jones & Turpin, 2007). In this sector much of the "industry" is also government. The CRC forms collaborative groups between university and government researchers, agency researchers, policy makers and practitioners from diverse agencies, as well as finance and regulatory authorities. This should ensure that the regulatory environment is appropriate and should

result in the research having a high probability of achieving impacts. It also suggests where the Australian natural hazard and disaster risk reduction enterprise could evolve to achieve enhanced impacts. The current evolution of the triple helix approach into the extended quadruple and quintuple models explicitly incorporates civil society, media and the environment (Galvao et al., 2019). This highlights that assessment of the BNHCRC's impact needs to extend beyond direct business outcomes to include broader social and economic impacts (Tortia, 2018), especially as the BNHCRC's emphasis is on open science and public value.

Those funding applied research of the sort undertaken by CRCs often expect a clear line of sight between the research they fund and measurable impacts on the agencies or sectors involved. Others are more interested in increases in knowledge, or in wider social and economic benefits to the nation. It is these wider benefits that underlie the models of industry-government and research discussed above. Those proposing and undertaking research often need to demonstrate that it provides good value or a solid return on the investment in research. This report examines the return for Australia on its investment in the Bushfire & Natural Hazards CRC.

CAPTURING THE FULL VALUE OF RESEARCH

The objective of the work reported here is to estimate values of research for communicating with a number of important audiences: a) finance departments, where economic impacts across society in the form of e.g. benefit-cost ratio, cost effectiveness, or return on investment are important; b) agency funders, who are interested in financial impact for their agencies and focus on the return on their contribution; and c) dedicated research funding organisations that want to understand and promote the value of the research they fund, for Australian society broadly.

Despite its importance the full value of research impact is generally not captured. There are a number of key definitions on research impact and value which underlie what is included in assessments (more detail is found in our literature review (Strahan et al., 2020)). The government department administering the CRC program has an "impact tool" for estimating expected return on investment (Department of Industry, Innovation and Science, 2019), which focuses on direct, tangible, project impacts. The Australian Research Council's (ARC) definition is broader:

> "Research impact is the contribution that research makes to the economy, society, environment or culture, beyond the contribution to academic research." (Australian Research Council, 2019)

This ARC definition is more encompassing than many of the others reviewed for this study (Strahan et al., 2020). Yet the definition suggested by the European Commission is broader still and includes indirect impacts and effects, on for example, innovation culture, capacity building, and the development of new approaches (Georghiou, 2015). This approach expands the potential benefits of research considerably. It includes, among other things, increasing the stock of useful knowledge (through publications, commercialisation, and creation of intellectual property); capacity building (training skilled people); and collaboration in further research projects and creating networks with end-users of the research.

We prefer a definition that includes the ARC's points but is broader in scope by making what is implicit in the ARC definition explicit, as with that used by the European Commission. Therefore, to the ARC definition we add knowledge generation and the capacity to make use of it (absent from the CRC "impact tool" mentioned above), as well as the innovation benefit throughout society and economy, for example through promoting a culture of continuous improvement. This definition or concept of research impact is operationalised through four "pathways to value" representing (detailed in a following section of this report): direct impacts of research on fire and emergency management agencies; human capital development; knowledge generation; and broader social and economic impacts.

Our aim is to develop an approach that does this in a way that, while it might not be definitive, is plausible and transparent. Ideally, there would be more than a single source of estimated value to help ensure the robustness of our results.

THE UNDERLYING CONCEPT OF PUBLIC VALUE

An underlying concept for a major part of our analysis is that of "public value" as defined by the Australian/New Zealand School of Government (Australian/New Zealand School of Government). Public value is the value created by governments by making laws and regulations, providing services and undertaking other activities to improve the wellbeing of the nation. Public value stands in contrast to the value generated by private commercial activity.

Public value aligns with our definition of research impact and emphasises that – in the case of disaster-related research - public value is 'consumed' collectively in a similar manner to "public goods": these can be consumed by anyone without reducing the ability of others to also consume the same good. Emergency management is such a good.

Public value mapping of science outcomes is described by Bozeman and Sarewitz (2011) as a way to consider non-economic and non-scientific measures of the goals of research that are their core values (termed "public values"). It has been proposed as a tool for research and program funding allocation and for measuring the impact of research (Moore, 2013). Bozeman and Sarewitz recognize the limitations of the approach, particularly in measuring innovation and capacity, and value-laden metrics such as quality of life but demonstrate progress towards assessment of goals such as decreased loss of life or cleaner air. Where research impact occurs mainly through public value, the use of market prices is problematic as they are 'weak partial indicators of the social value of research and research outcomes' (p.15) (Bozeman and Sarewitz, 2011).

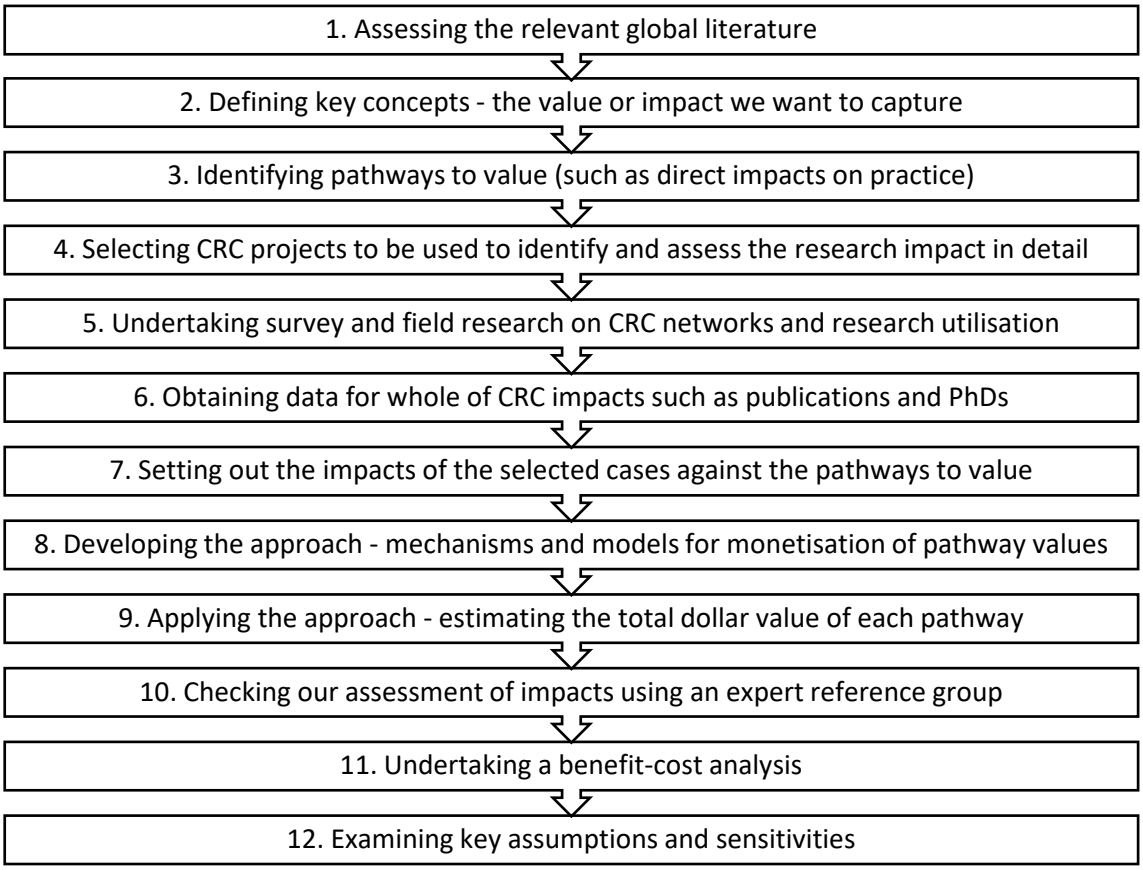
THE PROCESS OF ASSESSING THE VALUE OF RESEARCH

The process of assessing the value of BNHCRC research involves a series of steps to identify the appropriate conceptual approach and potential impacts of research through a global literature review (published as part of this study – see Appendix 1). As a result of this review it became clear that new approaches would need to be developed. The actual impacts of BNHCRC research were identified through detailed study of a sample of CRC projects and case studies of conferences and of a major bushfire. About half of all CRC projects were examined in detail. These were selected to be representative of CRC project clusters, research approach, geography and the involvement of a range end-users and agencies. Examples from the CRC projects are summarised below, along with a summary of the Tasmanian fire case study. The conference case studies of networks and networking are summarised in Appendix 2. The details of PhDs, and number of types of publications were provided for all CRC activities.

Methods for valuing each pathway were developed and applied, as set out below. The results estimate the value of CRC research, which was then used to undertake a benefit cost analysis. The methods and results were subject to sensitivity analysis, set out in the final section of this report. Originally, the project intended to develop a second or alternative approach based on individual project impacts. However, this was not practical without workshops and many detailed interviews. Both of which were made difficult by the fires of 2019/20 and then Covid-19. This "alternative approach" is summarised below.

The process of assessing the value of BNHCRC research can be organised around a number of steps as set out in Figure 1.

Figure 1: Steps in assessing the dollar value of BNHCRC research:



FOUR POTENTIAL PATHWAYS TO CAPTURE THE FULL VALUE OF RESEARCH IMPACT

There is no specific framework for assessing the value of hazards and disaster related research. Drawing on the models reviewed (Strahan et al., 2020), and applying a broad view of public value to - as far as possible - capture the full value of CRC research, we have identified four main pathways from research to value:

Pathway 1: Project level impacts

Mostly direct impacts on agency policy or practice. These include improved agency policy and/or practice; quality of agency service and service delivery; cost savings and effectiveness; improved resource allocation; and impacts resulting from the combined value to the fire and emergency management sector of all projects and other work, which includes a "trusted adviser" role for the CRC (some overlap with other pathways, in particular Pathway 4, has been allowed for);

Pathway 2: Training and capacity building

Impacts on the development of the skills, expertise and capacity of people in or entering the emergency management sector. This pathway can also be broadly conceptualised as "human capital" (Becker, 1964), which encapsulates the idea of investing in the work force of an organisation, and by extension, a sector. It refers to the value of the human side of production, defined in terms of (among other things) education, training, health, communication skills and work experience. This is now generally seen as more valuable than traditional organisational assets and is the subject of a new reporting standard (ISO 30414:2018). It has become desirable to talk of investing in human capital and to seek to value it. Most valuing efforts draw on variations of a return on investment approach. An important and often overlooked aspect of human capita is that it is subject to partial obsolescence (De Grip, 2004), rapid at times due for example, to technological change. One implication of this is the need for continual training and updating.

In our study we focus specifically on training, which is a key part of human capital, but it is important to appreciate that it is only one component. Training includes formal training, user engagement in research projects and researcher engagement with practice, and creation of active networks and communities of practice to facilitate collaboration (to reduce potential overlap with Pathway 3 networks have not been valued explicitly in either pathway). Research into CRC networks is appended to this report;

Pathway 3: Knowledge generation

Includes production of both formal codified knowledge (papers, reports, PhDs, etc.) and of informal knowledge through, for example, seminars and conferences, and exchanges through networks of practice;

Pathway 4: Broader social and economic impacts

Here we focus on the value of avoided loss and damage from disasters as a result of the research of the BNHCRC. The costs are defined broadly as tangible and intangible and include: insured and uninsured private losses, government disaster response and clean-up, infrastructure damage costs, indirect economic impacts (business interruption), social costs (including mortality/morbidity) and environmental costs.

Note that the resulting values are generally conservative, and data and measurement limitations mean that some significant impacts are unable to be included. There may be some overlaps between pathways, some of which have been accounted for, others will likely reduce the total value slightly.

HOW VALUE OCCURS: EXAMPLES USING THE PATHWAYS FROM CRC RESEARCH

Before monetising the BNHCRC's impacts, we provide some examples of how research can have impact on the four pathways. These examples are drawn from the CRC's portfolio of active projects. The Tasmanian fire case is an additional study undertaken by the project jointly with the Zurich Flood Resilience Alliance and others (it will be published in full separately).

PROJECT: INFRASTRUCTURE RESILIENCE

The BNHCRC Infrastructure Resilience project is a collaboration between RMIT University, the University of Melbourne, and the University of Southern Queensland, to look at the impacts of flood, bushfire and earthquake on transport infrastructure. Outputs include a vulnerability index, a floodway asset management platform, floodway design guidance, and bridge closure modelling.

In terms of pathway 1 set out above, direct project impact is high; the end-user Victorian Department of Transport (formally VicRoads) is already incorporating the project's modelling into its asset management system to improve the efficiency and efficacy of asset upgrade and maintenance investments. Capacity impacts on the sector (pathway 2) are also high and a high level of satisfaction is reported by the Victorian Department of Transport. Infrastructure engineering design guidance and codes developed from this research are being adopted at the national level, and disaster risk management considerations are being incorporated into infrastructure decision-making. Capacity building has also occurred for the research sector due to secondments with end-users where researchers have gained invaluable practical insight.

Pathway 3 on knowledge creation is also high: the project has generated 14 journal articles, many in highly ranked journals, nine reports and many presentations for the sector, and six completed PhDs at RMIT alone. Finally, broader socio-economic impact (pathway 4) is expected to be high as the research influences infrastructure design and maintenance decisions which will ultimately lower the impact and cost of disasters.

PROJECT: FIRE SURVEILLANCE

The Fire Surveillance project is a research collaboration between researchers and fire agency end-users to use satellite data to track fires in real time. The project has a clear output, in the form of an algorithm and software to rapidly process satellite data and provide a live feed of information to fire agencies. Key improvements on existing satellite observation technology for fire surveillance are the frequency of observations – every 10 minutes as opposed to every 6 hours – and the fact that observations are provided throughout the night.

The value of this research is realised along all four pathways. Direct project impact is high as the product supports fire monitoring during operations; this is particularly useful for making strategic decisions when resources are stretched. The product also provides up-to-date information to fire models which inform

suppression planning. Upon project completion the algorithm will be run, free of charge, by a public entity, making the real-time data available to all Australian fire agencies.

This project has made significant contributions to Pathways 2 and 3, the capacity of the sector and enhancing the body of knowledge. This has included one masters by research complete, two PhDs complete and several more expected to be complete soon, in addition to multiple journal publications. The project has resulted in an innovation in the satellite data processing code that allows for the very quick processing of data, which is expected to have implications for all highly temporal datasets, big data computing etc. Benefits for Pathway 4 on society and economy, are highly likely to be seen as the products support risk reduction and hence avoidance of disaster costs.

PROJECT: RISK AND WARNING COMMUNICATION DURING NATURAL HAZARDS

The Risk and Warning Communication during Natural Hazards project resulted from the need to understand why people did not more consistently adhere to advice and messaging during the response phase of disaster events. It brought together researchers from the marketing and public relations space, together with psychology and public health. The project examined messaging regarding risk and warnings – such as when and how to evacuate, advice not to drive through flood waters etc. It also generated evidence on how people understand messaging, particularly when they receive contradictory information from different sources.

The project has significant direct impact on agency practice because it influenced the nature of risk and warnings communication by agencies before and during disaster events. Agencies have changed the language used in messaging, as well as developed a more sophisticated use of social media. Agency costs are reduced because there are fewer people in danger, although evacuation costs may increase as more people follow the advice to evacuate.

The engagement between researchers and agencies has resulted in capacity building (pathway two) amongst agencies as well as several PhD projects and post-doctoral fellowships. In regard to pathway three, the project has resulted in journal articles, reports and other informal knowledge creation such as media articles. The impact on society and economy (pathway four) is particularly significant: the contribution of marketing strategies to the public good through this innovative research has the potential to significantly impact several public health and community challenges. The project has been credited with saving lives, as well as promoting asset protection such as animal evacuation.

CASE STUDY: THE ROLE OF RESEARCH IN DISASTER RESPONSE – THE 2019 SOUTHWEST TASMANIA BUSHFIRES

Zurich Insurance Australia and the International Institute for Applied Systems Analysis (IIASA) Austria, in collaboration with The Risk Laboratory, conducted a post-event review of the Southwest Tasmania Bushfires of the summer of 2018/19 (Keating and Handmer, to come). The review utilised the Post-Event Review

(PERC) methodology (Venkateswaran et al., 2015) to identify lessoned learned for disaster resilience. The key findings from the review were:

- Climate change has led to a "new fire regime" in Tasmania: from unprecedented drying and increased dry lightning strikes. This has threatened communities, economy (especially forestry and tourism) and the Tasmanian Wilderness World Heritage Area (TWWHA);
- Prescribed burning reducing risk, could be complemented with other fuel management strategies. There is a need for land-use restrictions in the highest risk areas. Tourism, wine and other industries would benefit from further (climate change) adaptation planning;
- Warnings worked well, although reaching visitors/tourists was a challenge, and warning fatigue was an issue;
- Evacuation planning was excellent. However, the relationships between councils and NGOs needs attention regarding activation, expectations and cost-recovery. The role of spontaneous volunteers also needs attention.

The review review took a special interest in the role of research and science in risk reduction, preparedness, response and recovery for this event. Overall, we found that at the state level, agencies and staff drew heavily on research and science from the BNHCRC and elsewhere, as they need to be across current thinking and are committed to continuous improvement. NGOs presented a more mixed picture, with research and science being seen as important by policymakers in their organisations, who in turn work to ensure that, where relevant, it is incorporated into practice. At the local level, research and science were not drawn on directly, and were seen as not very relevant. Nevertheless, training courses undertaken by people from the local level would almost certainly draw on current research.

As Tasmania begins to feel the impacts of climate change there is already research underway to model impacts at the local level. There is general demand for more climate change-oriented research, particularly that which translates modelling to information actionable by state and local decision-makers. With regard to bushfire risk management and community action, the Tasmania Fire Service is involved in a number of research projects with the BNHCRC and draws on its national findings. Policy-makers mentioned the Australian Institute of Disaster Resilience (AIDR) handbook series as an important source of synthesised research and science. The small size of the state of Tasmania makes national-level resourcing of initiatives more important.

The report's recommendations identify important roles for research to support Tasmania's bushfire resilience. These include supporting a multi-stakeholder, adaptive bushfire risk management plan for the TWWHA; involvement in expanding community engagement in bushfire risk reduction and resilience programs; supporting climate change adaptation for Tasmanian industries such as the tourism, wine and apiary industries; understanding and preventing the impact of bushfire smoke on human health, and; supporting the developing of an updated strategy for emergency volunteers.

INITIAL APPROACHES

Our initial aim was to estimate the value of research in two distinct ways to ensure a more robust result. As mentioned earlier, limited time and the reality of the summer fires followed by the Covid-19 lockdown altered what could be done, and we have used one approach only. The other approach is summarised as a potential alternative approach to valuation.

Our approaches to value are:

1. The approach used – *the total value of each of the four pathways* is estimated. The value of each is derived in a way appropriate for the pathway in question, as set out below;
2. An alternative approach uses *values derived through case studies*. This was to provide a second estimation of value from a completely different source and method, as it draws primarily on expert judgment. The values derived in this way are scaled up through an approach developed for the project where each research impact is rated on a ten-point index. This is described in more detail below under "Alternative approach: impacts by projects". This approach was developed for the project, but circumstances made full implementation difficult. As a result it was not used in the assessment of the value of CRC research.

THE APPROACH USED: ESTIMATING THE TOTAL VALUE OF EACH PATHWAY

Our approach to valuing research identifies a plausible way to estimate a total value for each of our four pathways to value. The approach used for each pathway is summarised below, with details in Table 1.

PATHWAY 1, DIRECT PROJECT VALUE TO AGENCIES: OBSERVED VALUE

Estimating the value of goods not traded in the marketplace – in this case the value of BNHCRC research – is challenging because there is no market-determined price. This is typically the case for "public value". Economists use techniques for estimating these types of values, which fall into the two broad categories of 'revealed preference' and 'stated preference' techniques (OPBR, 2016). However, these techniques have been developed for estimating the value to individuals (which is then aggregated) rather than to public institutions such as emergency management agencies.

Fortunately, the investment by the Federal Government and the BNHCRC end-user agencies into the BNHCRC provides an observable dollar figure of how much it is valued by them. The total investment into the BNHCRC of $120 million represents the minimum return that the investors (primarily the Federal Government and state agencies) expect to receive.

The value for pathway 1 of $120 million is based on the assumption that the motivation for investment in the BNHCRC was improvement in agency efficiency. This assumption is strong for the agency contributions but may be less so for the Federal Government contribution. This is because the Federal Government contribution was justified on the basis of the CRC Impact Tool, which included reduction in disaster losses as part of the benefits it was assumed would come from the BNHCRC. Therefore, we may have some overlap with pathway 4 which is valued separately.

To take account of the potential overlap with Pathway 4, we have taken only half the value of $120m. Sensitivity analysis shows that this has little impact on the cost-benefit ratio.

PATHWAY 2, TRAINING AND CAPACITY: RETURN ON INVESTMENT

Return on investment (ROI) measures the gain or benefit (or loss) from an investment relative to its cost. Investment in training and capacity building is important for maintaining and increasing efficacy and efficiency of operations. As discussed above, this is part of "human capital" which is highly valued and needs regular attention to maintain currency.

The valuation of BNHCRC's impact through the training and capacity building Pathway 2 reflects Bassanini et al.'s (Bassanini et al., 2005) conclusion that training generates productivity improvement of 7% (measured against gross wages). On this basis, training of the Australian emergency management workforce (18,400 EFT) produces a productivity improvement against gross wages ($107,000/EFT/ annum) (Department of Education, Skills and Employment) of $137.8 m/ annum.

Based on the sampling of 28 of its projects, the BNHCRC is assessed as contributing about one quarter to the workforce's productivity improvement through training and capacity building, valued at $34.5 m per year. Here, we used the gross wage bill of the number of full-time equivalent staff by the average gross annual wage. Another approach would add the emergency management volunteer workforce. This is a large number compared with salaried staff, but their involvement is mostly part-time (now estimated at about 240,000 (Productivity Commission, 2020)).

Note that we have not added a value for professional networks. We know from interviews and surveys that these are highly valued by end-users (see Appendix 2). Their inclusion would increase the value of this pathway but is a potential overlap with the informal knowledge aspects of Pathway 3. These informal aspects are not valued due to the absence of data.

PATHWAY 3, KNOWLEDGE GENERATION: OBSERVED VALUE

Similar to Pathway 1, here we observe the value of PhDs based on the investment that is made towards them. The total value of $175,000 per PhD is composed of: $90,000 for a three-year scholarship; and $85,000 which is the government payment to the university concerned when a PhD is awarded. An alternative approach to valuing PhDs would use the return on investment – the same method used in Pathway 2. This could for example, use an increase in salary for individual PhD holders. Issues with this approach include that it varies greatly by field and the state of the economy when the measurement is done, and other factors significant in salary level including gender. Importantly, by focusing on individuals it does not explicitly consider the social value of PhDs.

For papers, we used estimates of the value of a published peer reviewed paper (at $15,000 per paper) and conference presentations (at $10,000 per academic conference paper). There are wide ranging estimates for the cost of producing academic papers and their value, with estimates depending on discipline, institutions and research methods – among other factors. However, they are generally substantially more than the estimates used here. Note that the value for a conference paper is on the basis that for applied research in disaster risk reduction, and in some academic areas like information and communication technologies, conference presentations are highly valued by industry. Their value for the fire and emergency management sector was confirmed in interviews with practitioners and at conference events (see Appendix 2).

As with PhDs, there is some supporting evidence from the perspective of the benefits to individuals from publishing peer reviewed papers. O'Brien et al. argue that knowledge creation through research publication in peer reviewed journals hones the analytical skills and problem-solving rigour of faculty which consequently benefits students, as reflected in graduate renumeration. This benefit is estimated as being up to a 21% supplement on average salary after three years in the job (O'Brien et al., 2020). On this basis production of peer reviewed papers would contribute an additional economic value of $24 360 (AUS 2019) to an MBA graduate after three years. Given that this is only one element of value generated through the production of peer reviewed articles

and excludes informal knowledge creation and dissemination, our estimate of $15,000 per paper is reasonable.

PATHWAY 4, BROADER SOCIO-ECONOMIC VALUE: DAMAGE COSTS AVOIDED METHOD

The damage costs avoided method calculates the economic value of benefits provided by the investment – in this case the outputs of the BNHCRC – that would not exist without the investment in place, and would instead represent an added cost to society.

We used figures from Deloitte Access Economics (2016) to estimate the yearly cost of disasters to Australia in 2013 in terms of a) government costs, and b) social and economic costs. We drew the value of mortality and morbidity in 2013 from the AusDIS database (Handmer et al., 2018). These values were then increased by 3.5% per annum to account for population and exposure growth and the resultant disaster damages. This resulted in a stream of values for the costs of disasters in Australia between 2013 and 2032.

We have assumed that the work of the BNHCRC will reduce future damage costs from disasters by 0.25%[1], and estimate this value based on the stream of values described above. Because costs were incurred from 2013, we take a 20-year stream from 2013 but set the first five years to 0; this is because benefits are assumed to start occurring in 2018 and continue for 15 years. The final figures are in net present value (NPV) using a discount rate of 5%, and adjusted for inflation to bring them from 2013 to 2019 dollars. A discount rate of 5% was chosen rather than a higher value because the current environment is one of historically low interest rates. The sensitivity of the final result to a range of discount rates is tested in the section on "Assumptions and sensitivity" below.

Table 1: Estimating the contribution to value in dollars of each pathway:

Pathway	Concept	Approach	Estimates
1.Direct project impacts	Observed value; return on investment	Total amount spent on projects + agency and researcher in kind expenditure; To avoid potential overlap with Pathway 4, we take 50% of this value.	**$120m/2 = $60m** This is the total cost of the BNHCRC and can be taken as equivalent to a NPV.
2. Training	Return on investment	Percentage of wages of those trained. From the literature, the usual value	7% of gross wages 18,400 FTE (Department of Education, Skills and Employment) x $107,000

[1] 0.25% was chosen because we extended the analysis to include indirect and intangible losses. This expands the cost of disasters in Australia and reduces the relative impact of the BNHCRC's research. In the CRC impact tool (provided by the Department of Industry, Innovation and Science) there are three pathways with values of 0.08%, 0.31% and 1.75%. The weighted average reduction in disaster losses of these pathways is approximately 0.91%, which is substantially higher than the figure used here, yet still designed to be a conservative estimate. Our sensitively analysis (below) shows the value of pathway 4 if disaster loss and damage is reduced by 1% instead of 0.25%. The true value of the BNHCRC's impact on total disaster losses would lie between 0.25 and 1%.

		is 7-10% (Bassanini et al., 2005)	(2019 $AUS). x 0.07 x 0.25 = $34.45 m per year. [The NPV over five years (15 years) is **$323.1** m at 5%.
3.Knowledge creation	Observed value	For PhDs: total amount allocated by government (and universities) for each PhD. For papers: estimate of the value of a published paper and conference presentation.	PhD=scholarship + grant to universities. $175k per PhD 120 PhDs **=$21m** About half are BNHCRC associates, but worth the same to the sector and Australia, and are included on the same basis. Papers/reports: $**44.9m** These figures are assumed to represent the capitalised (future) value of PhDs and publications and are treated as NPVs.
4.Society and economy wide benefits	Disaster damage costs avoided	Uses the NPV of losses from disasters in Australia based on the CRC model, and presents estimates of how much the CRC work will reduce the losses.	If the BNHCRC's work results in a reduction of disaster damage costs by 0.25%, this is estimated to be worth approximately **$401.1 million** (NPV over 15 years at 5% discount rate, 2019 dollars). If the BNHCRC's work results in a reduction of disaster damage costs by 1%, this is estimated to be worth approximately $1.6 billion (NPV over 15 years at 5% discount rate, 2019 dollars).

AN ALTERNATIVE APPROACH: IMPACTS BY PROJECT

This approach is designed to ascribe values for each of the four pathways by individual BNHCRC projects. The approach was developed for, but not used in, this project.

The projects and cases reviewed produce many impacts covering a wide range, from very specific tangible widgets to intangible cultural shifts. There appear to be three major issues:

- Assessing each impact individually would be time and resource hungry and the project did not have the capacity for this. Even if we valued all the individual impacts, by itself this would not allow us to generalise the valuation to other cases;
- It was not clear how many of the impacts can be valued, and there are likely cases that defy valuation in dollar terms;
- In conventional terms, many project impacts are incommensurable, and so cannot be compared directly with each other or added together.\

This all suggests that another approach was needed; one that avoids both the need to value everything and can also deal with the problem of incommensurability. One approach is to use the concept of dimensionality. The use of a non-dimensional metric can enable comparison of incommensurate items by drawing on some inherent attribute of the diverse impacts – in our case the attribute is the value of impacts. A percentage or ratio can be used for this purpose as percentages are non-dimensional. They can be seen as a ratio of items that are comparable, in this case the dollar value of impacts.

Applying this approach, a ratio scale of 1 to 10 was used to attribute value to each identified impact in a sample of about one third of the CRC's projects. Impacts were categorised by the four pathways to value. Each identified impact was given a value in non-dimensional units between 1-10. We had expected that through detailed analysis of a few projects and cases, some of these impacts would be able to be valued in dollars.

Assuming that the ratios, allocated through the non-dimensional approach above, are valid, the nominal dollar values for the impacts with such values were to be used to value all the impacts, using the non-dimensional ratios. This would result in monetized values for all (or most) impacts.

An initial methodological question concerned how value would be distributed across the four pathways – our in-depth case studies and examination of CRC projects provide evidence here. We could for example, have made the assumption that a strong project level effect is worth more than knowledge accumulation.

The initial allocation of the non-dimensional units to identified impacts was done independently by the three members of the project team. This was to be followed by a stakeholder review process. However, the 2019/20 summer fires and then COVID19 pandemic made pursuit of this alternative approach difficult, and as a result it was not fully implemented.

THE DOLLAR VALUE OF BNHCRC RESEARCH

Using our approach, the value of each of the pathways, the total value of BNHCRC research is estimated at $850.1 m. Note that the amount doubles with small changes to assumptions about the contribution to disaster loss avoided by the CRC (Pathway 4 – see under "Assumptions and sensitivity" below).

Net present value (NPV) in 2019 dollars is calculated over fifteen years at a 5 percent discount rate. The sensitivity of the result to the rate is shown under "Assumptions and sensitivity analysis" below. Details of the calculations are found in the section above on "Our approach". The contribution of each pathway is (Figure 2):

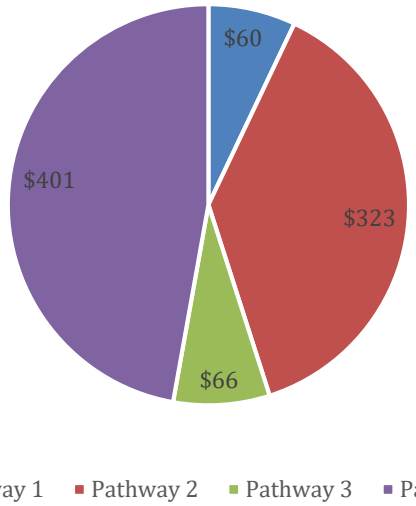
Pathway 1, Direct project impacts - $60m

Pathway 2, Training and capacity building - $323.1m

Pathway 3, Knowledge creation – $65.9m

Pathway 4, Broader socio-economic impacts – $401.1m (@0.25% reduction in losses).; $1.6b (@1% reduction in losses)

Figure 2: Contribution of value pathways, $millions
(Figures are in millions of dollars rounded to whole numbers)



VALUE OF RESEARCH BENEFIT COST RATIO (OPBR, 2016)

Following the case outlined above, we sum the value of the pathways for a total benefit of $850.1 million over a 15-year period. The total cost of the BNHCRC over its life is $120 million. This gives a benefit-cost ratio of approximately 7:1, meaning that for every dollar spent on the BNHCRC there is a $7 return.

Benefit cost when varying pathway 4:

As described above, pathway 4 relates to avoided disaster losses. If the work of the BNHCRC reduces 1% of disaster losses between 2018 and 2032 (instead of 0.25%), then it will be worth a total of $1.6 billion to Australia. Savings are assumed to occur as follows:

- $386 million in government costs (response, clean-up, recovery, infrastructure, etc.)
- $1.17 billion in social and economic costs
- $44 million in the value of mortality and morbidity

Under this scenario for pathway 4 while holding the other pathways the same, the benefit-cost ratio increases to 17:1. The sensitivity of the result to the discount rate used is set out below in "Assumptions and sensitivity analysis".

If a 7% discount rate is used, the benefit cost ratio is 6:1.

ASSUMPTIONS AND SENSITIVITY ANALYSIS

There are important assumptions in this analysis; both in the views of the experts we draw on and the approach used to derive the value of each of the four pathways. When examining impacts, the available data means that we are also limited by our knowledge of the detail and reality of impacts.

First, the most sensitive factor overall influencing the estimate of value is the discount rate. This is frequently the case with any benefit-cost analysis, and is examined below. Second, the details of the calculations contain assumptions which if varied alter the final results. However, the impact of changes on the results are mostly minor compared with changes to the discount rate.

Pathway 1 - To take account of the potential overlap with Pathway 4, we have taken only half the value of $120m. If we reduce the value of pathway 1 by 50% to account for possible overlap between Pathways 1 and 4, the benefit-cost ratio of the BNHCRC only reduces by about 0.5. On this basis we conclude that our findings are robust.

Pathway 2 - training and capacity building - includes only training undertaken by emergency agencies and not training by associated organisations. Also, any additional value through capacity building that does not include training is excluded – for example the value of networking through CRC conferences. The calculation of the value of this pathway is sensitive to the productivity improvement generated by the training, which although derived from an authoritative published source, is one of a number of estimates. Variation of this factor or including capacity building in the calculation of value would see significant changes in the final value generated by this pathway.

For pathway 3 - knowledge creation - the value given to publications and reports is an estimate and could vary significantly. However, the impact on the final value of research would be small as the contribution of publications to the total dollar value of research is small. Informal knowledge creation and dissemination is not included and would increase the value of this pathway. Lack of data precludes its inclusion.

Pathway 4 - results are very sensitive to the estimated proportion of disaster impacts avoided by research outcomes. A range is given in the table below.

Sensitivity analysis for discount rates:

This analysis shows that the discount rate selected can alter the value substantially. Here we have applied a range of discount rates as recommended by the Australian Government. Traditionally, Australia has used relatively high discount rates. Given that interest rates globally are currently not far above zero, there is a strong case for the use of lower rates. This would have the effect of increasing the present value of future benefits.

The table also shows that results are very sensitive to assumptions about how much loss is avoided as a result of CRC work: the value varies by a factor of 4 when the assumed savings are 1% instead of 0.25 %. We have conscientiously chosen the conservative value of 0.25% for this assumption about the proportion of damage reduction that can be attributed to BNHCRC research. The weighted average from the CRC Impact Tool (see above Ftn under "Our approach",

Pathway 4) is 0.91%, and 1% is used to show the potential value of a higher level of damage reduction.

The base estimates for Pathways 1 and 3 include the expected flow of benefits (likely at a high discount rate) and so are not further capitalised.

Discount rate	**3%**	**5%**	**7%**	**10%**
Pathway 1*		60 m		
Pathway 2				
Training	376.8 m	323.1 m	279.3 m	227.6 m
Pathway 3**		65.9 m		
Pathway 4				
Broader benefits for society & economy	514 m @0.25% 2056.6 m @1%	401.1 m @0.25% 1604.4 m @1%	316.5 m @0.25 1266 m @1%	226 m @0.25% 905 m @1%
Total NPV	1017.7 m	850.1 m	721.2 m	579.5 m

Table 2: showing the total value (NPV over 15 years) of BNHCRC research under 3, 5, 7 and 10 percent discount rates. For Pathway 4, the results are also shown assuming that CRC research results in a reduction of loss of 0.25 %, and of 1%. Note that Pathway 1 and 3 are treated differently. This is because the estimates are in effect NPVs and implicitly include future benefits. These amounts do not vary with changed discount rates.

*In Pathway 1, the amount of 60 m is half the potential value. This low amount was selected to ensure no overlap with Pathway 2. Any change would increase the total CRC value by up to 60 m.

**In Pathway 3, the value we use for a PhD is unlikely to vary much. For publications, as the total amount is relatively small at $44.9m, variations would make little difference to the total value of the BNHCRC.

REFERENCES

1 Anderson HE. *Heat transfer and Fire spread*. USDA Forest Service; 1969. Res Pap INT-69.
2 Andy Hira & David Aylward (2013) Australia as a Triple Helix exemplar: built upon a foundation of resource and institutional coordination and strategic consensus, Prometheus, 31:4, 399-417, DOI: 10.1080/08109028.2014.933599
3 Annike I. Totlandsdal, Nina Fudge, Eric G. Sanderson, Leendert van Bree, Bert Brunekreef, Strengthening the science–policy interface: experiences from a European Thematic Network on Air Pollution and Health (AIRNET), *Environmental Science & Policy*, Volume 10, Issue 3, 2007, Pages 260-266, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2007.01.003.
4 Australian/New Zealand School of Government https://www.anzsog.edu.au/resource-library/research/what-is-public-value
5 Australian Research Council, 2019 "Research Impact Principles and Framework" https://www.arc.gov.au/policies-strategies/strategy/research-impact-principles-framework
6 Bassanini, A., et al., IZA Discussion Paper No. 1640: Workplace training in Europe, in Annual Conference of the Fondazione Rodolfo De Benedetti. 2005: Venice, Italy.
7 Becker GS 1964 Human Capital Theories. University of Chicago Press,
8 Bozeman, B. & Sarewitz, D. 2011. Public value mapping and science policy evaluation. *Minerva,* 49, 1-23.
9 Catchpole T, De Mestre N. *Physical models for a spreading line Fire*. Aust For 1986;49(2):102–11.
10 Cekirge HM. *Propagation of Fire fronts in forest*. Comput Math Appl 1978;4:325–32.
11 De Grip A. 2004. Evaluating human capital obsolescence. EC-OECD Seminar on Human Capital and Labour Market Performance, Brussels. https://www.oecd.org/els/emp/34932083.pdf
12 Department of Education, Skills and Employment. Fire and Emergency Workers. Prospects. https://joboutlook.gov.au/Occupation?code=4412
13 Department of Industry, Innovation and Science, 2019 https://www.business.gov.au/-/media/Grants-and-programs/CRC/Cooperative-Research-Centres-Grants-round-21-Impact-Tool-User-Guide-PDF.pdf
14 Deloitte Access Economics (2016) *The economic cost of the social impact of natural disasters*, Deloitte Access Economics, Sydney, http://australianbusinessroundtable.com.au/assets/documents/Report%20-%20Social%20costs/Report%20-%20The%20economic%20cost%20of%20the%20social%20impact%20of%20natural%20disasters.pdf
15 Emmons HW. *Fire in the forest*. Fire Res Abs Rev 1964;5: 163–78.
16 Etzkowitz, Henry; Leydesdorff, Loet (1995-01-01). "The Triple Helix -- University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development". Rochester, NY.
17 Fons WL. *Analysis of Fire spread in light forest fuels.* J Agric Res 1946;72(3):93–121.
18 Frandsen WH. *Fire spread through porous fuels from the conservation of energy*. Combust Flame 1971;16:9–16.
19 Fujii N, Hasegawa J, Phallop L, Sakawa Y. *A nonstationary model of Firespreading*. Appl Math Model 1980;41: 76–180.
20 Galvao, A., Mascarenhas, C., Marques, C., Ferreira, J. and Ratten, V. (2019), "Triple helix and its evolution: a systematic literature review", *Journal of Science and Technology Policy Management*, Vol. 10 No. 3, pp. 812-833. https://doi.org/10.1108/JSTPM-10-2018-0103
21 Garrett-Jones, Samuel E. and Turpin, T.: The Triple Helix and institutional change: reward, risk and response in Australian cooperative research centres 2007. https://ro.uow.edu.au/commpapers/327
22 Georghiou, L. 2015. Value of Research Policy Paper by the Research, Innovation, and Science Policy Experts (RISE). *European Commission (June 2015)*.
23 Grishin AM, Gruzin AD, Zverev VG. *Mathematical modelling of the spreading of high-level forest Fires*. Sov Phys Dokl 1983;28:328–30.
24 Handmer J, Ladds M, Magee L (2018) Updating the costs of disasters in Australia – 1967-2013. *Australian Journal of Emergency Management*. 33(2).
25 Hottel HC, Williams GC, Steward FR. *Modelling of Firespread through a fuel bed.* Tenth Symposium (International) on Combustion, Pittsburgh: The Combustion Institute; 1965. p. 997–1007.
26 INNOVATE AND PROSPER Ensuring Australia's Future Competitiveness through University-Industry Collaboration. (2014) ATN. https://www.atn.edu.au/siteassets/publications/atninnovateprosper.pdf
27 ISO 30414:2018. Human resource management — Guidelines for internal and external human capital reporting. https://www.iso.org/standard/69338.html
28 Job Outlook. Department of Education, Skills and Employment. Fire and emergency Workers. Prospects. https://joboutlook.gov.au/Occupation?code=4412
29 Kasperson, R.E., and Berberian, M. (eds.) (2011) Integrating science and policy: Vulnerability and resilience in global environmental change. London: Earthscan.
30 Keating, A. and Handmer, J. (forthcoming), *The Southwest Tasmania Fires of Summer 2018-2019*, to be available at https://floodresilience.net/perc
31 Konev EV, Sukhinin AI. *The analysis of flame spread through forest fuel*. Combust Flame 1977;28:217–23.
32 Leydesdorff, Loet (2012). "The Knowledge-Based Economy and the Triple Helix Model" (PDF). University of Amsterdam, Amsterdam School of Communications *Research*. arXiv:1201.4553. Bibcode:2012arXiv1201.4553L
33 McArthur AG. *Fire behaviour in eucaliptus forests*. Forest Research Institute, Forest and Timber Bureau of Australia; 1967. Leaflet No. 107.
34 McArthur AG. *Weather and grassland Fire behaviour*. Forest Research Institute, Forest and Timber Bureau of Australia; 1966. Leaflet No. 100.
35 Moore, M. H. 2013. *Recognizing public value*, Harvard University Press.

36 Newson, R., King, L., Rychetnik, L. *et al.* Looking both ways: a review of methods for assessing research impacts on policy and the policy utilisation of research. *Health Res Policy Sys* **16,** 54 (2018). https://doi.org/10.1186/s12961-018-0310-4

37 O'Brien et al (2010) Does business school research add economic value to students? *Academy of Management Learning and Education.* 9 (4).

38 O'Connor, N. 2018. The potential for public value frameworks in Northern Ireland and Ireland *Administration,* 66**,** 33-54.

39 OPBR (2016) *Cost-Benefit Analysis*, Guidance Note, Office of Best Practice Regulation, Department of the Prime Minister and Cabinet, Australian Government, February 2016, https://www.pmc.gov.au/sites/default/files/publications/006-Cost-benefit-analysis.pdf

40 Pagni J, Peterson G. *Flame spread through porous fuels*. Fourteenth Symposium (International) on Combustion, USDA Forest Service, Washington, DC, Pittsburgh: The Combustion Institute; 1973. p. 1099–107.

41 Perry GLW. *Current approaches to modelling the spread of wildland Fire: a review*. Prog Phys Geogr 1998;22(2): 222–45.

42 Report on Government Services 2020. Productivity Commission. https://www.pc.gov.au/research/ongoing/report-on-government-services/2020/emergency-management/emergency-services

43 Rothermel RC. *A mathematical model for predicting Fire spread in wildland fuels*. USDA Forest Service; 1972. Res Pap INT-115.

44 Steward FR. *Fire spread through a fuel bed. Heat transfer in Fires*: *thermophysics, social aspects, economic impact*. Blackshear, PL; 1974.

45 Strahan K, Keating A, and J Handmer (2020) Models and frameworks for assessing the value of disaster research. Progress in Disaster Science. Vol 6 (April). https://www.sciencedirect.com/science/article/pii/S2590061720300314

46 Telisin HP. *Flame radiation as a mechanism of Fire spread in forests*. *Heat transfer in flames*. New York: Wiley; 1974. p. 441–9.

47 Thomas PH. *Some aspects of the growth and spread of Fires in the open*. Forestry 1967;40:139–64.

48 Tortia, Ermanno. (2018). Conclusion. The triple helix, social impacts and beyond. In: Dallago B and Tortia E C (2019) Entrepreneurship and Local Economic Development A Comparative Perspective on Entrepreneurs, Universities and Governments, Publisher: Routledge - Taylor & Francis.

49 Van den Hove, S. (2007) 'A rationale for science-policy interfaces' *Futures*, vol. 39, issue 7, pg. 807-826, https://www.sciencedirect.com/science/article/abs/pii/S0016328706002060

50 Van Wagner CE. *Calculations on forest Fire spread by flame radiation*. Canadian Department of Forestry; 1967. Report No. 1185.

51 Venkateswaran, K, MacClune, K, Keating, A, Szoenyi, M (2015). Learning from disasters to build resilience: a simple guide to conducting a Post Event Review. ISET-International, Zurich Insurance Group, 32 pp, https://floodresilience.net/perc

52 Weber RO. *Modelling Fire spread through fuel beds*. Prog Energy Combust Sci 1991;17:62–82.

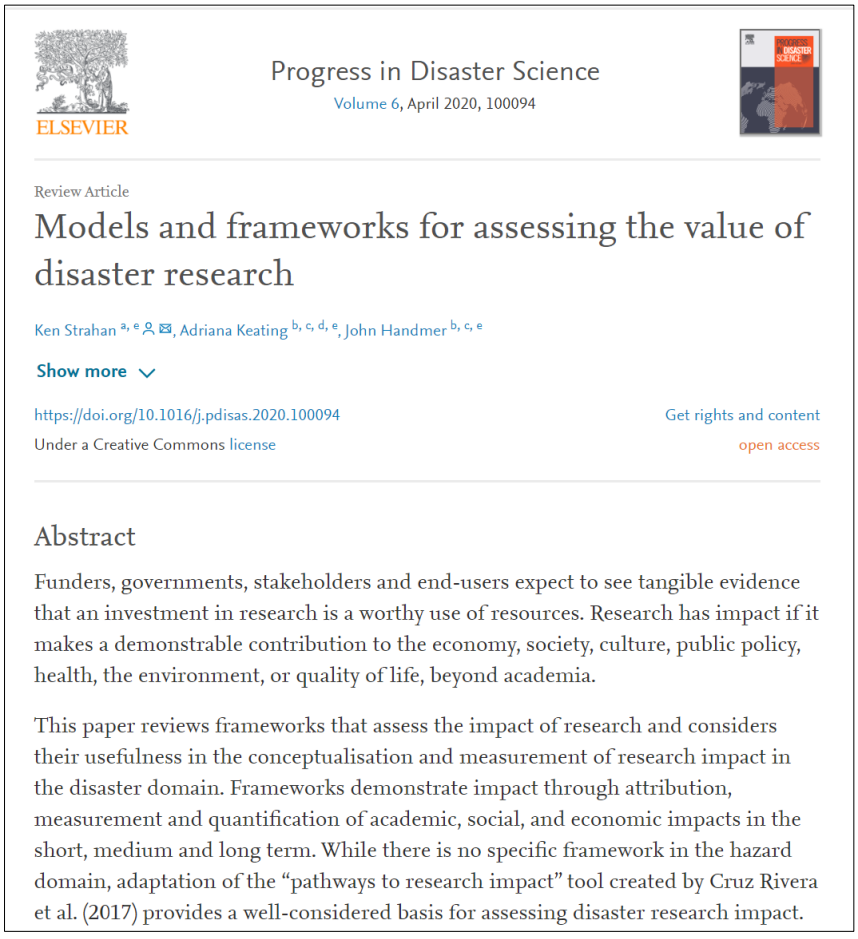
APPENDIX 1: PUBLICATIONS FROM THE PROJECT TO DATE

There are three peer reviewed publications so far.

[1] ENVIRONMENTAL SCAN PAPER: MODELS AND FRAMEWORKS FOR ASSESSING THE VALUE OF DISASTER RESEARCH

Strahan, Keating and Handmer, 2020

Published in *Progress in Disaster Science*



ELSEVIER

Progress in Disaster Science

Volume 6, April 2020, 100094

Review Article

Models and frameworks for assessing the value of disaster research

Ken Strahan [a, e], Adriana Keating [b, c, d, e], John Handmer [b, c, e]

Show more

https://doi.org/10.1016/j.pdisas.2020.100094

Get rights and content

Under a Creative Commons license

open access

Abstract

Funders, governments, stakeholders and end-users expect to see tangible evidence that an investment in research is a worthy use of resources. Research has impact if it makes a demonstrable contribution to the economy, society, culture, public policy, health, the environment, or quality of life, beyond academia.

This paper reviews frameworks that assess the impact of research and considers their usefulness in the conceptualisation and measurement of research impact in the disaster domain. Frameworks demonstrate impact through attribution, measurement and quantification of academic, social, and economic impacts in the short, medium and long term. While there is no specific framework in the hazard domain, adaptation of the "pathways to research impact" tool created by Cruz Rivera et al. (2017) provides a well-considered basis for assessing disaster research impact.

[2] A PRAGMATIC APPROACH TO VALUING RESEARCH ON DISASTER RISK REDUCTION

Handmer, Keating and Strahan, under review

Abstract

A question surrounding much research concerns the return on investment. Funders of research on fire and emergency management increasingly want to ensure that research dollars will generate value for the emergency management sector and contribute to risk reduction. Researchers are often asked to justify their funding requests as well as their expenditure. Research value can take a number of forms from a readily assessed improvement in performance due to a

new widget or process, to increases in capacity and risk management across the emergency sector, and direct and indirect benefits to the whole of society and economy.

This paper sets out an approach developed and used to value the disaster risk management research funded by the Bushfire and Natural Hazards Cooperative Research Centre, a national body. Conventionally, research value for emergency management related research in Australia has been conceptualised in terms of value for specific fire and emergency service agencies, or in some cases for the whole formal fire and emergency management sector. We have broadened the potential value by considering a variety of pathways to value. These were drawn from the relevant literature on the value of public research. They expand the potential value of research and highlight the range of strategic areas that publicly funded research enhances. Cases are provided to illustrate the application of the approach. Initial results indicate that the BNHCRC is good value for the Australian tax-payer with a benefit-cost ratio of about 7.

[3] THE SOUTHWEST TASMANIA FIRES OF SUMMER 2018-2019

Keating and Handmer, 2020

To be available at https://floodresilience.net/perc

For a summary see the case study in the section "How value occurs", above.

APPENDIX 2: BNHCRC VALUE THROUGH NETWORKS – ANHMC AND AFAC CONFERENCES

The value generated by the BNHCRC is both direct and indirect, accruing to end-users, and Australian society and economy (see Strahan, Keating and Handmer, 2020, at Ftn above). The value pathways between individual research projects and improved risk management service provision by agencies are relatively clear, if challenging to monetize. In addition to these direct benefits, the BNHCRC is generating significant value for the emergency management sector by influencing policy via the facilitation of networks between researchers, agencies and policy-makers. This case study looks at the characteristics of this network and the success of two key network events: the ANHMC and AFAC conferences.

INTRODUCTION

The second phase of the BNHCRC is characterised by an even greater emphasis on utilisation, reflecting the insight of the importance of the science-policy interface. Van den Hove (2007) defines the science-policy interface as:

> *[S]ocial processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making.*

The BNHCRC is a key player in the emergency management science-policy interface in Australia. It promotes work at this interface via a variety of means, including but not limited to a focus on direct user engagement in research, RAFs (Research Advisory Forums), its website and blog, and via running and supporting conferences. A key outcome of this investment is the development of a network of researchers and end-users.

Networks are critical for facilitating research impact, particularly in regard to higher-level influence on policy (Newson et al., 2018) We also know that work at the science-policy interface is challenging and resource intensive because it means grappling with the different values, approaches and interests of different actors (Kasperson and Berberian, 2011). Indeed, research on science-policy interface networks shows that these networks do not develop spontaneously (Totlandsdal et al., 2007), which demonstrates the need for an organisation such as the BNHCRC in facilitation. Totlandsdal et al. (also identify the importance of communication, and forums for that communication, for the establishment and success of such networks.

The 12th Australasian Natural Hazards Management Conference (ANHMC), held in Canberra in June 2019, and the Australasian Fire and Emergency Service Authorities Council's (AFAC) conference in Melbourne, August 2019, were key events where the emergency management sector coalesced with the support of the BNHCRC. This case study looks at the characteristics of the network represented at these events, and participant perspectives on the science-policy interface generally and the role of the BNHCRC specifically. We highlight findings on why and how much members of the emergency management sector value the BNHCRC.

CONFERENCE DATA COLLECTION

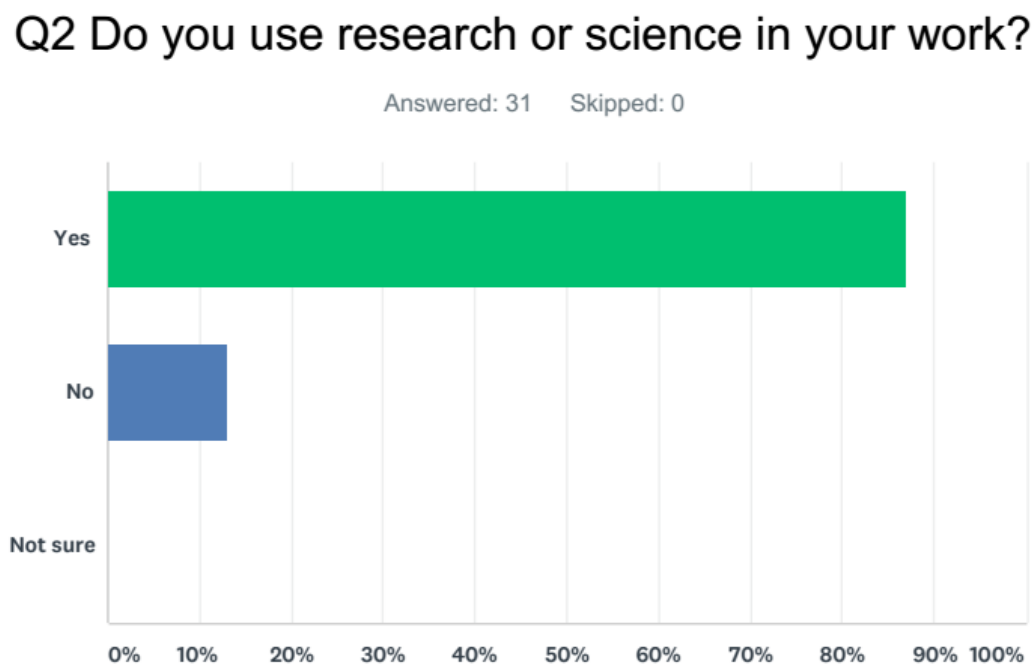
ANHMC 2019 Conference: Pre- and post-conference surveys were distributed electronically before and after the event, and paper copies were available at the event itself. 40 people completed the pre-conference survey, and 47 completed the post-conference survey. Results do not represent a cross-section of conference attendees because they were targeted specifically at non-researcher participants, although approximately 10% of results are from researchers. Pre- and post-conference surveys were not linked at the level of the respondent, some attendees answered only one survey and some both.

AFAC 2019 Conference: At the AFAC Conference RMIT researchers interviewed a random sample of attendees (excluding BNHCRC staff) about the role of research and science generally, and the BHNCRC in particular. Surveys were taken using the SurveyMonkey app on tablets. Respondents were approached in all areas of the conference, including the research sessions and the trade hall. A total of 31 attendees completed the survey.

NETWORK MEMBERSHIP

On the 'policy' side of the science-policy interface, membership of the network is dominated by representatives of fire and emergency services agencies, followed by state and federal government staff.

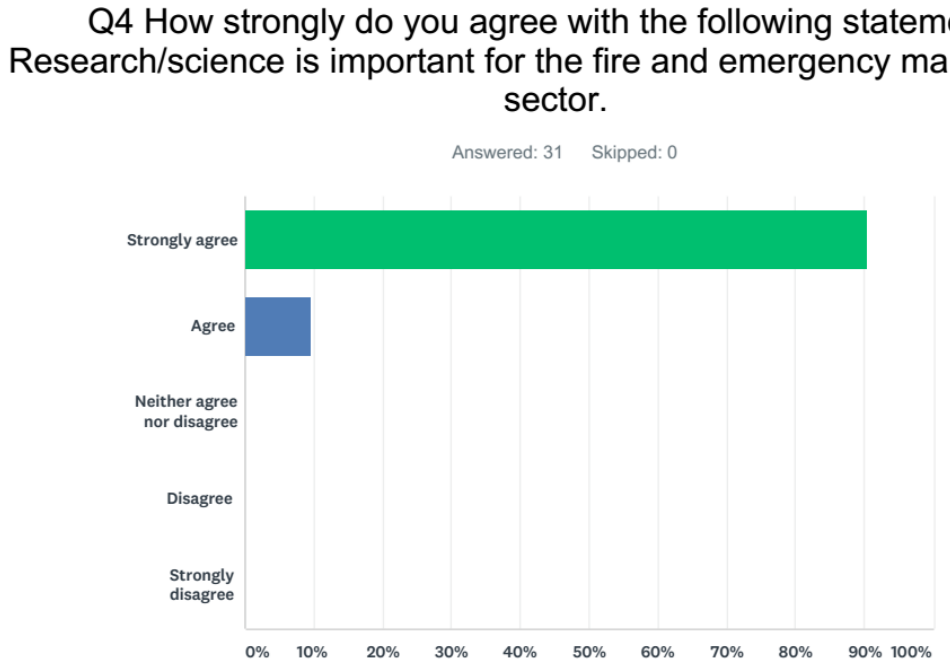
Perceptions of research and science in the network:



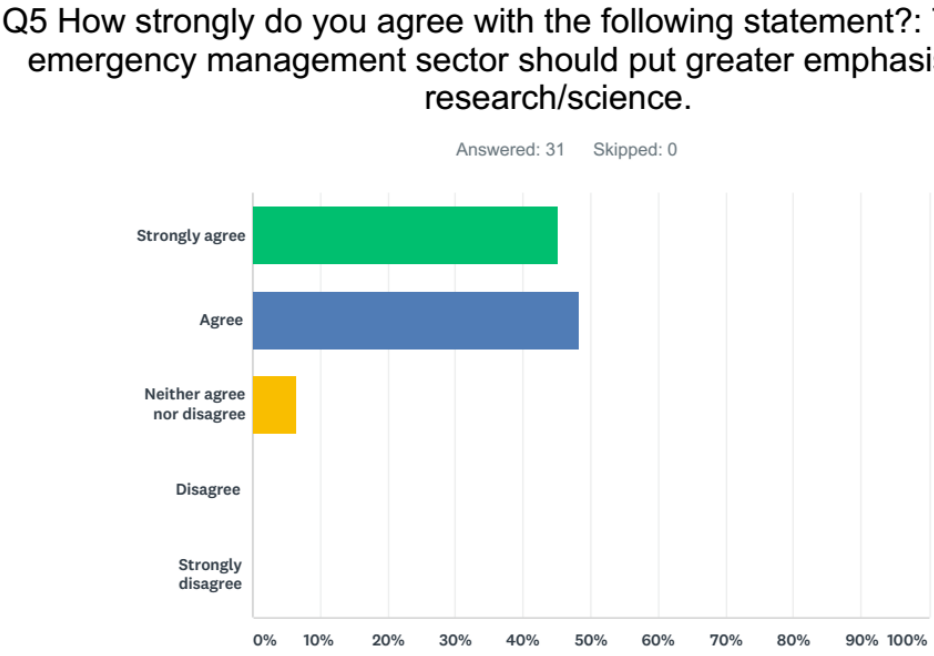
AFAC conference survey

Attitude to research:

Respondents across both conferences had a very positive view of the importance of research to the sector.



AFAC conference survey

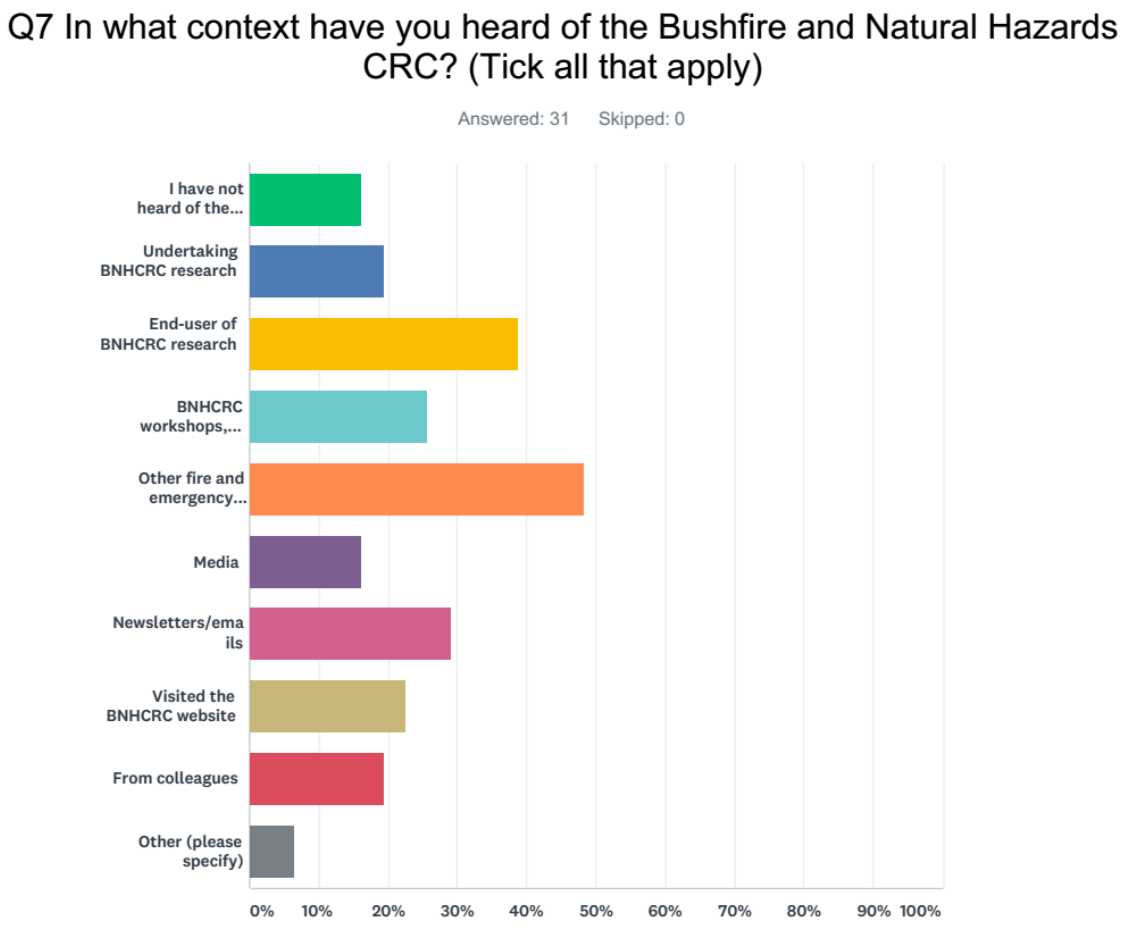


AFAC conference survey

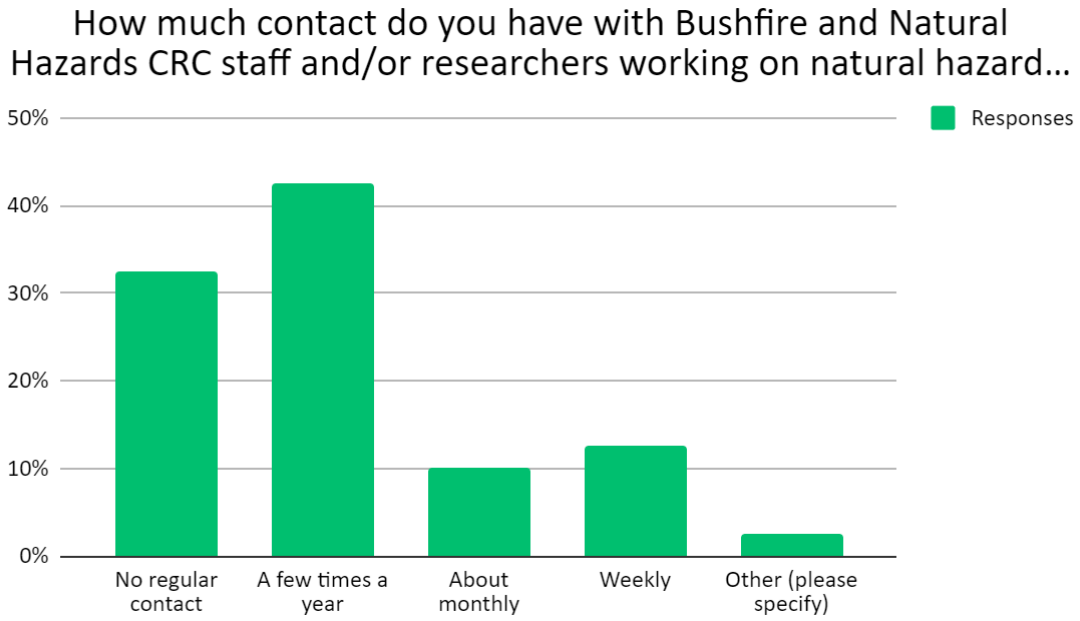
Attitude to the BNHCRC:

The BNHCRC is generally viewed positively and seen as important to the sector. Respondents report good experience with their interactions with the CRC. However, they have limited direct contact with the CRC and are less certain about its impact on the sector.

Prominence of the BNHCRC in the network:



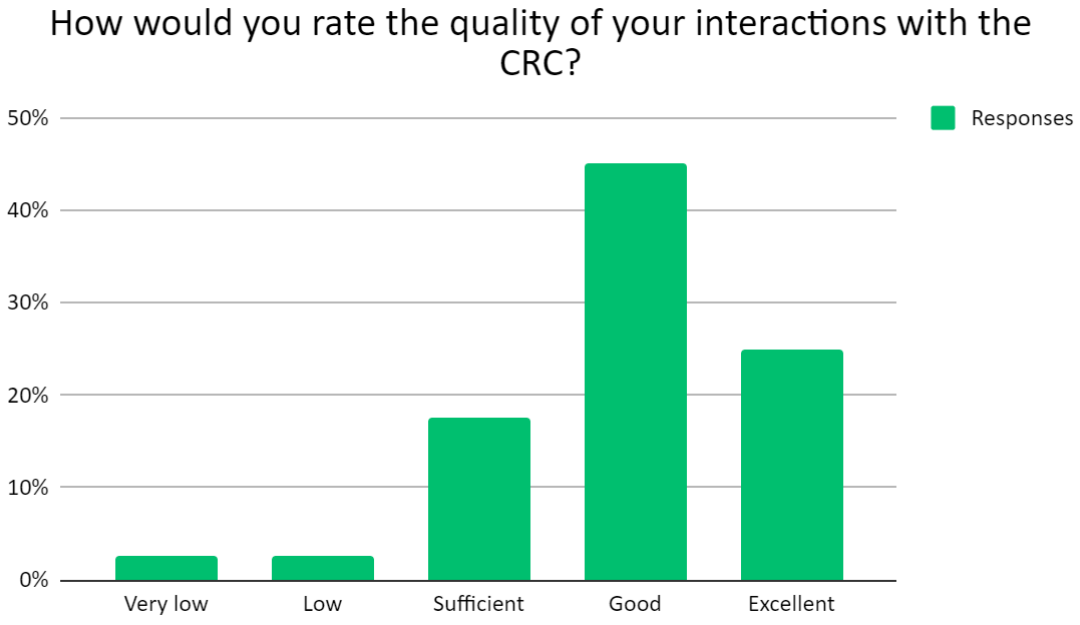
AFAC conference survey



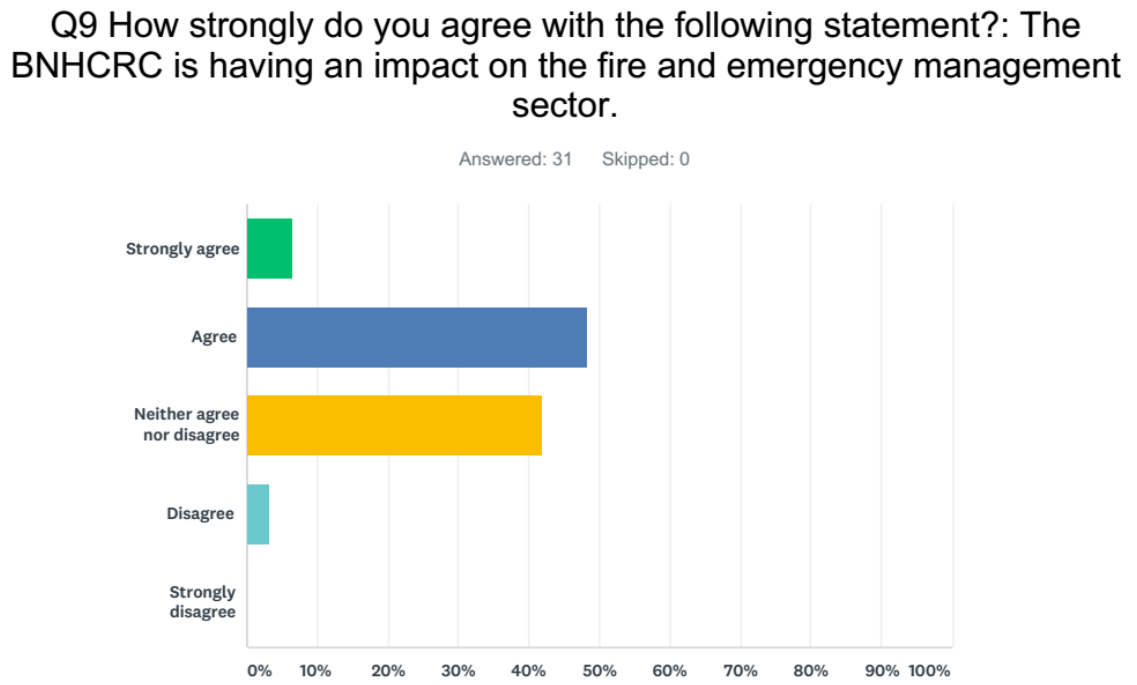
ANHMC pre-conference survey

Perceptions of the BNHCRC within the network:

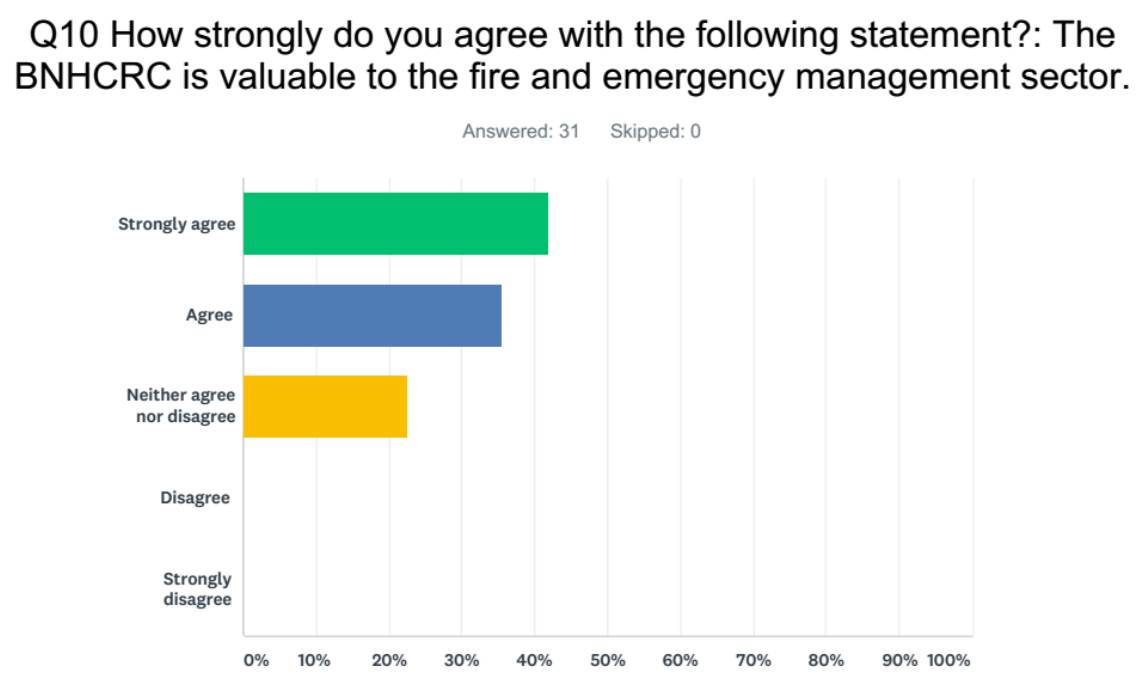
BNHCRC is very well regarded:



ANHMC pre-conference survey



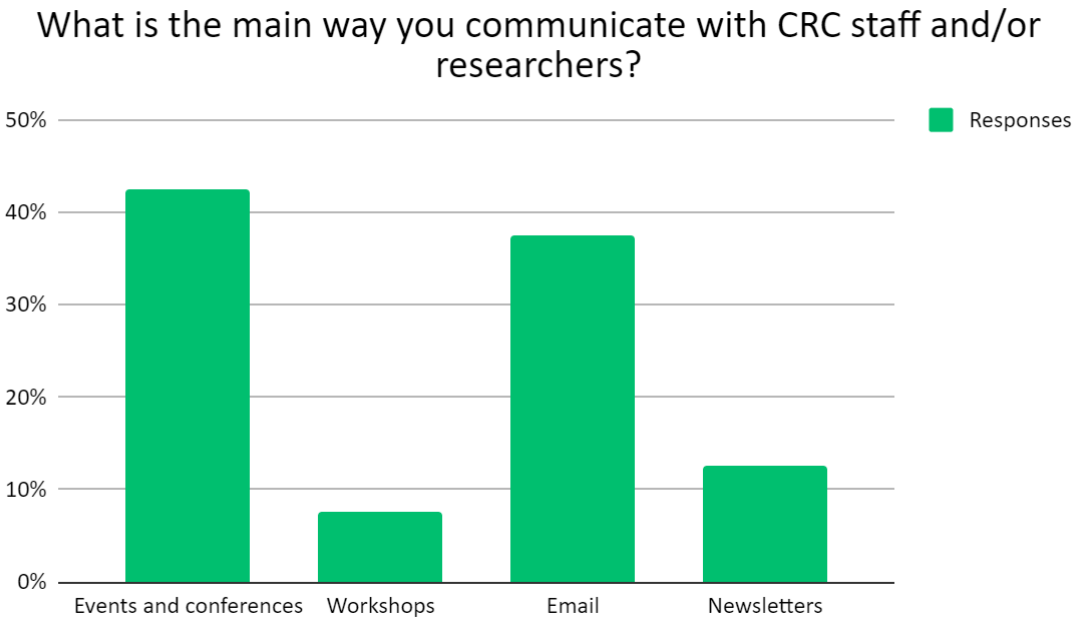
AFAC conference survey



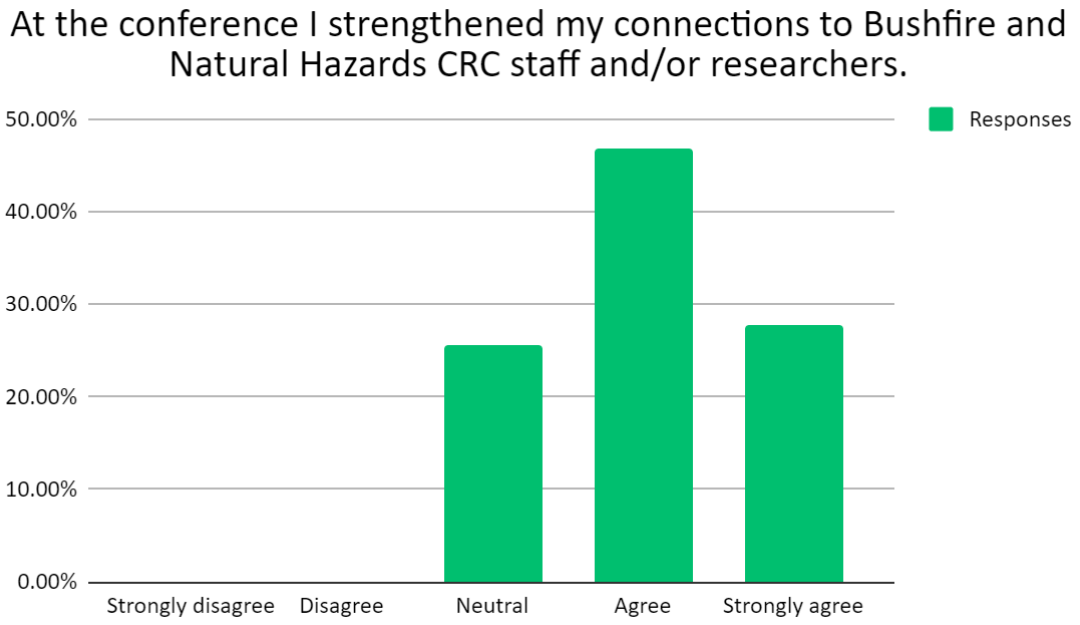
AFAC conference survey

Role of events for network building:

Events and conferences were seen as an important way of communicating with the BNHCRC, and as providing positive experience with the BNHCRC.



ANHMC pre-conference survey



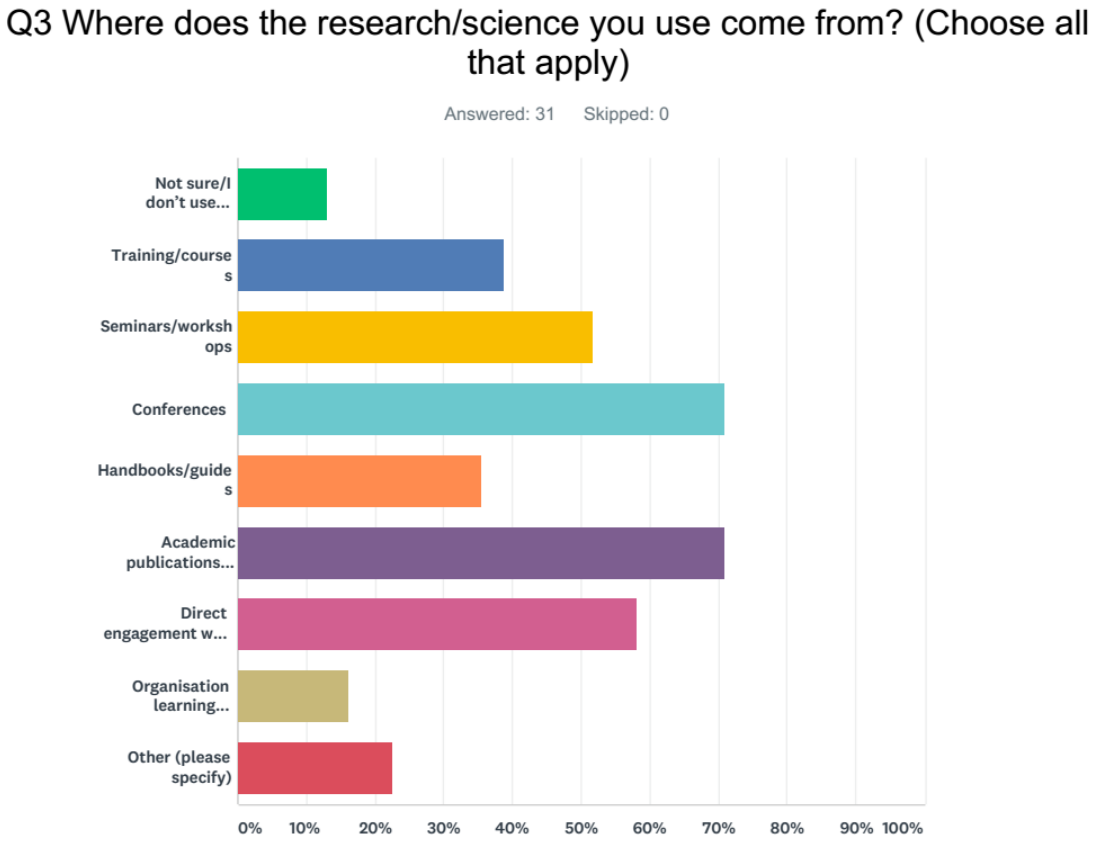
ANHMC post-conference survey

Additional comments from ANHMC post-conference survey:

- Great to meet fresh young minds and people from the various sectors.
- Made a number of new and useful connections
- Would love opportunities to continue this/ strengthen/ be more involved

- Everyone was open and keen to collaborate - the energy was positive and uplifting.
- I put faces to a few names and got to share some great conversations with researchers from a few different disciplines
- All of the BNHCRC staff were extremely supportive and helpful. My networks expanded considerably thanks to introductions by BNHCRC staff. Great spirit of collaboration and sharing, creating a suitable and positive atmosphere for learning and thinking.
- Great to connect with people from other organizations/institutions.
- Good networking!
- Networks and connections were good.
- Thanks to BNHCRC staff for facilitating this.
- Great networking, made new contacts and good to have insurers there

ANHMC pre-conference survey



AFAC conference survey

Knowledge and capacity building at ANHMC:

The post-conference survey asked participants to rate their agreement regarding whether the conference plenaries and sessions provided them with useful insights and assissted in deepening their understanding of disaster risk. This graph provides a summary of the responses.