Graham, V., Auld, T., Beaumont, L., Bell, L., Dunford, S., Gallagher, R., Hancock, N., Leishman, M. R., Mitchell, P., Staas, L., & Hughes, L. (2021). Embedding biodiversity research into climate adaptation policy and practice. *Global Change Biology*, 27(19), 4935– 4945.

https://doi.org/10.1111/gcb.15770

Title: Embedding biodiversity research into climate adaptation policy and practice

Running title: Embedding research into policy and practice

List of Authors: Victoria Graham[1,2], Tony Auld[3], Linda Beaumont[1], Linda Bell[3], Suzanne Dunford[3,4], Rachael Gallagher[1], Nola Hancock[1], Michelle R. Leishman[1], Polly Mitchell[3], Leigh Staas[1] and Lesley Hughes[1]

Institutional Affiliations:

[1] Department of Biological Sciences, Macquarie University, Sydney, Australia

[2] Department of Earth and Environmental Sciences, Macquarie University, Sydney, Australia

[3] New South Wales Office of Environment and Heritage, Sydney, Australia

[4] Waverley Council, Sydney, Australia

Contact Information: victoria.graham@mq.edu.au; +61 414 074 823

Keywords: engagement, research-implementation space, knowledge transfer, roadmap, communication, biodiversity, climate change, adaptation

Highlights:

- We present an engagement approach for embedding biodiversity research outputs into policy development and describe its implementation.
- The co-design of projects in an iterative and collaborative process, and ongoing engagement between policy-makers, practitioners and researchers, was effective at achieving research translation and uptake.

- We found that capacity building after project completion was essential for research uptake. This action takes considerable time and effort from key individual stakeholders who act as champions of the research.

1 Abstract

Addressing climate change risks requires collaboration and engagement across all sectors of society. In particular, effective partnerships are needed between research scientists producing new knowledge, policy-makers, and practitioners who apply conservation actions on the ground. We describe the implementation of a model for increasing the application and useability of biodiversity research in climate adaptation policy and practice. The focus of the program was to increase the ability of a state government agency and natural resource practitioners in Australia to manage and protect biodiversity in a changing climate. The model comprised a five stage process for enhancing impact (i) initiation of research projects that addressed priority conservation policy and management issues; (ii) co-design of the research using a collaborative approach involving multiple stakeholders; (iii) implementation of the research and design of decision tools and web-based resources; (iv) collaborative dissemination of the tools and resources via government and community working groups; and (v) evaluation of research impact. We report on the model development and implementation, and critically reflect on the model's impact. We share the lessons learnt from the challenges of operating within a stakeholder group with diverse objectives and criteria of success, and provide a template for creating an environmental research program with real world impact.

2 Introduction

The growing realisation that anthropogenic climate change presents an existential and accelerating threat to life on Earth has spawned an extraordinary volume of research effort. Further, the need for significant and pro-active adaptive management of species and ecosystems to mitigate this risk has been recognized for well over three decades (Peters & Darling, 1985). But for all this effort and recognition, examples of research being implemented in the conservation and natural resource management space, in the face of the rapidly changing climate, remain scarce (Hughes, 2018; Hoeppner & Hughes, 2019).

The gulf between research and effective implementation in relation to environmental threats from climate change is symptomatic of that between conservation research and practice more broadly (Salafsky *et al.*, 2002; Van Kerkhoff & Lebel, 2006; Knight *et al.*, 2008; Farwig *et al.*, 2017). The exchange of knowledge between researchers and the management bodies that develop and apply policies and practices should ideally be a two-way process, with research informing management actions (i.e. through evidence-based policy) and management and societal needs informing the direction of research (i.e. policy-relevant science; Cook *et al.*, 2013). But criticisms have been levelled at both the researcher and policy-maker/practitioner sides – described as "researcher complacency" and "evidence complacency" respectively (O'Connell & White, 2017; Sutherland & Wordley, 2017).

On the researcher side, Knight et al. (2008), for example, reviewed the literature on conservation assessments (defined as any spatially explicit, repeatable approach that identified priority areas for nature conservation) published in peer-reviewed journals and found that two thirds did not deliver conservation actions, primarily because the researchers did not plan for implementation. The authors concluded that relying on a "trickle down" effect from research publications is essentially failing those species and ecosystems the research aims to conserve, a sentiment echoed by Laurance et al. (2012) and others. Researchers may fail to comprehend the full suite of factors that are considered in guiding policy decisions, which typically include political, social, economic and personal influences or fail to address a political or operational priority (Arndt *et al.*, 2020).

Similarly, several authors have noted that policy-makers and practitioners frequently develop their own experience-based, rather than evidence-based, practices and techniques (e.g. Prendergast *et al.*, 1999; Redford & Taber, 2000; Pullin *et al.*, 2004; Hulme, 2014; Sutherland & Wordley, 2017). Policy-makers and practitioners may lack the understanding of the appropriate use, limitations and complexities of drawing conclusions from scientific information (Sutherland & Wordley, 2017). Further, in some cases, lack of access to the relevant literature or experts means that useful knowledge simply fails to come to the attention of practitioners (Sutherland & Wordley, 2017; Taylor *et al.*, 2017; Alston, 2019), although the trend toward open-access availability and free data repositories has increased accessibility (e.g. Conservation Evidence; www.conservationevidence.com). Inaccessibility issues may also arise from differences in language traditionally used by researchers and practitioners (Sutherland & Wordley, 2017).

Other impediments to creating a collaborative research-implementation program include the lack of alignment of reward systems between academic researchers, policy-makers and practitioners, and funding constraints that limit the scale in time and space of effective collaborations (e.g. Cook et al., 2013; Farwig et al., 2017). Even when these factors are not at play, lack of political will can stymie the application of research into operations if there is insufficient support from the top level of decision-makers across both the political and administrative spheres (Lemos & Morehouse, 2005). The need to establish stronger research-implementation spaces clearly requires far closer engagement between researchers, policy-makers and practitioners to generate the questions, co-design processes to gather evidence, and facilitate knowledge exchange and translation to effective outcomes in an iterative way (Knight et al., 2008; Dilling & Lemos, 2011; Laurance et al., 2012; O'Connell & White, 2017; Toomey *et al.*, 2017).

In this paper we describe the creation and implementation of a partnership between a state government environment agency in Australia, natural resource practitioners, and academic researchers, aimed at increasing the collective capacity to protect and manage biodiversity in a changing climate. The challenges of protecting Australia's unique biodiversity in the face of multiple threats, including climate change, are considerable. Environmental degradation and species decline have been rapid since European settlement 230 years ago. Between 1996 and 2008, Australia was among the top seven countries responsible for 60% of global biodiversity loss and is the only developed nation to be included in the 11 worst deforestation hotspots in the World Wildlife Fund's 2018 Living Planet report (WWF 2018). Populations of some Australian vertebrates plummeted by up to 97% between 1970 and 2016, compared to the average global decline of 68% (WWF, 2020). The International Union for the Conservation of Nature (IUCN) ranks Australia fourth in the world for species extinctions, and first for loss of mammals (Ward *et al.*, 2019). The most recent Australian State of the Environment report describes an ongoing trajectory of species loss and notes that the well-recognised pressures facing the Australian environment, including land clearing and habitat fragmentation, invasive species, pollution, and overharvesting, are now exacerbated by climate change (Cresswell & Murphy, 2016). In 2016, an endemic Australian rodent, the Bramble Cay melomys (*Melomys rubicola*), was documented as the first mammalian extinction attributed to climate change (Gynther *et al.* 2016).

In New South Wales (NSW), Australia's most populous state, only 15% of native vegetation is considered to be in a state similar to pre-European settlement (EPA, 2018). Protected areas cover 9.5% of the state with many bioregions and vegetation types remaining under-represented. Extreme climatic events can cause widespread, immediate disruption to ecosystems, as seen in the 2019-2020 Australian bushfire season that resulted in the burning of ~97,000 km^2 of Australia's southern and eastern vegetation, including a large area of protected habitat (Ward *et al.*, 2020). More than 1000 species and 100 ecological communities are listed as threatened under the NSW Biodiversity Conservation Act 2016, with nearly 80 species listed as presumed extinct. Nearly 50 Key Threatening Processes (KTPs), including anthropogenic climate change, are also listed. The most recent State of the Environment report for Australia acknowledges that a lack of long-term data and information is a major impediment to the conservation of biodiversity in Australia (Cresswell & Murphy, 2016). The report recommends that establishing strong, workable relationships between individuals in research, policy, and those undertaking actions on the ground (natural resource managers / practitioners) is critical to improved conservation outcomes.

We present an approach for engagement by focusing on the Biodiversity Node of the NSW Adaptation Research Hub, a state government initiative that operated from 2013 to 2018. We share an example of a successful research-implementation partnership that embedded biodiversity research into climate adaptation policy and on-ground natural resource management. We report on the collaborative approach developed for the program, and provide examples of successes, challenges and lessons learnt. We draw from the different perspectives of policy-makers, research scientists and conservation practitioners to evaluate the initial progress towards achieving intended impacts.

3 Engagement approach for embedding research into policy and practice

To achieve the objectives of the Biodiversity Node (Box 1), we developed a five-stage model, comprising (i) initiation of research projects that addressed priority conservation policy and management issues; (ii) co-design of the research involving multiple stakeholders; (iii) implementation of the research and design of decision tools and web-based resources; (iv) collaborative dissemination of the tools and resources via government and community working groups; and (v) evaluation of the research impact (Figure 1). The approach was not linear but highly iterative, reflecting the evolution of research agendas and partnerships that commence before the project start date based on pre-existing relationships and networks, and the evolution into new themes in light of emerging information or challenges. Varied stakeholders were involved in each stage.

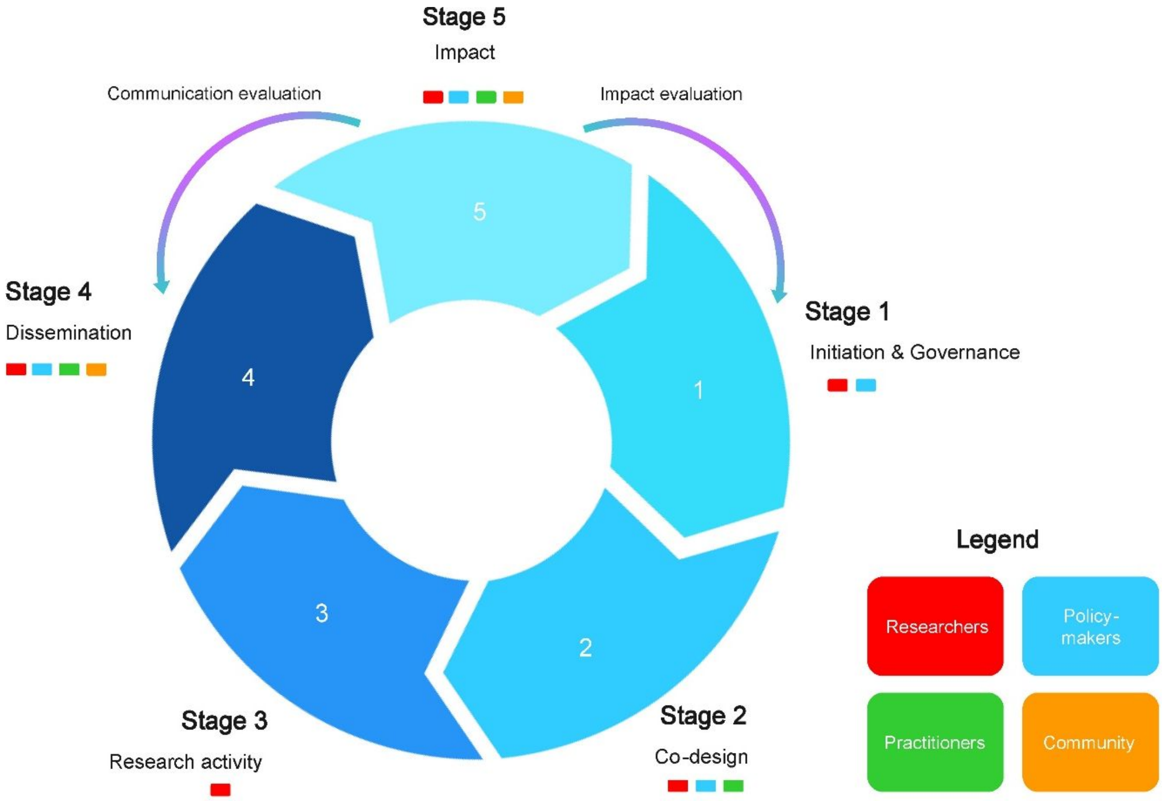

Figure 1. An illustration of the process for initiating, co-designing, delivering, and disseminating the Biodiversity Node research program as well as evaluating its impact. Varied stakeholders were involved during each stage. The engagement process was iterative with different stages revisited throughout the life of the program. Evaluation to date has focused more heavily on dissemination, as it will take longer to comprehensively evaluate the applied conservation impact. The results of the impact evaluation will ideally be used to inform future research agendas resulting in improvements to the model.

3.1 Stage 1: Initiation and Governance

The initiation of the NSW Adaptation Research Hub program and the Biodiversity Node's objectives and outcomes are described in Box 1. The program partners were selected via a competitive tender process based on research capability and partnership capacity. The Biodiversity Node's governance model included a cross-disciplinary Steering Committee that met twice yearly to review new project proposals, progress reports, amendments to allocations or schedules, level of engagement with government and other stakeholders, dissemination of project outputs, and the communications plan. The Steering Committee comprised representatives from the partner research institutions and three levels of government: state government, an independent federal government agency, and a local council. Individuals from within the state government were a diverse group including scientists, a manager of a threatened species management portfolio, national park managers, and representatives from the climate change adaptation team. Multi-agency workshops were held to identify and share the research priorities of practitioners and policy-makers. The Steering Committee elicited ideas for projects from researchers, and from decision-makers based on needs, and then discussed areas of overlap and their relation to the overall strategic objectives of the government agency. Individuals and organisations operating in the relevant research space were invited to propose ideas.

Box 1. The objectives and outcomes of the New South Wales Adaptation Research Hub's Biodiversity Node

In 2013, the NSW Government created the NSW Adaptation Research Hub to facilitate collaboration between the Office of Environment and Heritage (OEH) in the Department of Premier and Cabinet, and experts in climate change adaptation science in research institutions, aiming to leverage collective, multidisciplinary, science capacity. An initial three research 'nodes' (Biodiversity, Coastal Processes and Responses, and Adaptive Communities) were established with a fourth node, Human Health and Social Impacts, added in 2017.

We focus here on the Biodiversity Node, which aimed to increase the capacity of natural resource managers to incorporate climate change considerations into on-ground action (see below). Led by Macquarie University in Sydney, NSW, the Biodiversity Node was a partnership between OEH, the primary agency with responsibility for climate change adaptation and biodiversity conservation and management, and local governments, land managers, and multiple research institutions including Taronga Conservation Society, Royal Botanical Gardens and Domain Trust, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). 19 research projects were supported over the five-year program, involving over 60 collaborators from 17 institutions. Over five years, approximately AUD $2 million was invested by OEH and a similar sum leveraged in cash and in-kind from partner institutions.

The Biodiversity Node set six program objectives at conception, which were achieved in the program outcomes. The program objectives and outcomes achieved are detailed below:

Program Objectives	Achieved Outcomes (example)
• To increase knowledge of the capacity of species to adapt to current and future climates, and the response of landscapes to change	• Increased understanding of the resilience, vulnerability and adaptive capacity of species to respond to climatic variability and extreme events, and the impact on ecosystems (e.g. various webtools and publications)
• To identify current and future landscape refugia for species in a changing climate	• Increased capacity to identify and protect 'refugial' environments for biodiversity conservation and an enhanced understanding of the role of landscape connectivity (e.g. development of the ClimateRefugia webtool and implementation in threatened species management)
• To support governments and communities to make integrated decisions to optimise outcomes for landholders and biodiversity conservation	• Improved capacity for implementing integrated decision-making to ensure biodiversity protection (e.g. delivery of a compilation of flora translocations that informed the development of the NSW Government's Translocation Operational Policy)
• To improve understanding of potential multiple threats to species	• Enhanced understanding of the risks posed by exotic species, pathogens

3.2 Stages 2 and 3: Co-design and research activity

Collaboration during project design is ideally a two-way process between researchers and end-users to strike a balance between scientific objectivity and generating information of scientific interest and driven by decision-maker and practitioner needs (Dilling & Lemos, 2011). In this program, the co-creation of knowledge was a crucial aspect of the co-design. Knowledge, as defined by Roux et al. (2006), is a mix of experiences, values, contextual information, and intuition that provides a framework for evaluating new experiences or information, and a significant component of knowledge exists in tacit form (Polanyi 1983; Davenport and Prusak 1997; Roux et al. 2006).

During the co-design stage, personnel and groups with relevant expertise and additional funding streams were involved in refining project proposals and multi-stakeholder workshops were held to provide opportunities to discuss ideas and explore potential logistical challenges. A subset of the research ideas were developed into full proposals. Many of the project teams included early career researchers and several projects had a strong cross-disciplinary focus. For example, one project integrated cultural knowledge from Traditional Owners (Indigenous Bandjalang Elders from the north coast of NSW) and Indigenous park rangers, with western scientific approaches to guide adaptation planning within the Minyumai Indigenous Protected Area. All project teams had at least one end-user representative to ensure operational relevance and maximise transfer of skills and knowledge. For example, in a project aimed at identifying climate refugia in the NSW landscape, research scientists and the leadership team of a threatened species management program developed the focal species list collaboratively.

Figure 2. Examples of stakeholders within a research-implementation space include policy-makers, practitioners, researchers, and the broader community. Some stakeholders represented multiple categories. In the Biodiversity Node program, for example, many of the stakeholders had experience working in government, academic institutions and practitioner-based organisations.

3.3 Stage 4: Dissemination

We adopted a broad definition of research uptake that included the use of findings by other researchers (replication in novel contexts) and subsequent projects that extended the findings. Dissemination products (Figure 3) were co-developed by the researchers, government knowledge brokers and practitioners. Knowledge brokers were critical to the dissemination stage. There was no single knowledge broker appointed for this program, rather the role was shared by many individuals.

Figure 3. The diversity of outputs from the Biodiversity Node projects and examples of the investment made in packaging the information to suit diverse end-users. The graphics displayed here were designed to aid our communications by capturing the range of research undertaken in the partnership. Engagement of people designing and implementing the research occurred in the dissemination stage to support uptake. Dissemination was undertaken by policy-makers, practitioners, community members and researchers to infiltrate diverse networks and capture different perspective of how the output can be used for various purposes. For example, dissemination was enhanced by engagement between individuals who were leading the research and those who were implementing, or advocating, the research to understand and guide the messaging of each communication product.

3.3.1 Traditional academic outputs: publications, reports and conference presentations

Given that peer-reviewed research papers, externally reviewed reports and conference presentations are key performance indicators for evaluating research impact for academic researchers, these products were an important component of the collective output from the Biodiversity Node.

3.3.2 Decision support tools: websites, webtools and technical/policy guidelines

Many of the research projects produced web-based tools, databases and policy guidelines. For example, the Biodiversity Node's site-selector tool was developed in collaboration with government staff for the *Saving our Species* program, the primary threatened species management program in NSW. This tool enables portfolio managers to focus investment on managing existing sites and selecting new sites for protection where future climate conditions are suitable for the targeted threatened species. Training workshops and video instructions were provided to users to support the tool's application (see Supporting Information for weblink).

Other Biodiversity Node outputs included guidance for best practice translocations and assisted colonisations in changing climates to inform updates to the NSW Translocation Operational Policy (Case Study Box 1, and see Impact section below). Links to webtools, videos, Information Sheets, publications and other resources are available on the Biodiversity Node website (mq.edu.au/about/biodiversity-node).

3.3.3 General information: case studies, videos, datasets and information sheets

All projects resulted in the production of information sheets that were distributed at conferences, networking events and online. For half of the projects, extended case studies and videos were produced to provide explicit guidance to end-users on their application. For example, a video case study was produced for the WeedFutures webtool (www.weedfutures.net) in collaboration with a weed ecologist in the NSW Department of Primary Industries (DPI). This tool has become a critical part of standard weed assessment practice within the NSW DPI and the Victorian Department of Environment, Land, Water and Planning, and these agencies have subsequently championed the tool more widely to local land management groups.

3.3.4 Capacity building and awareness raising: workshops, masterclasses, seminars and the roadshow

We define capacity building as the process of equipping individuals, communities and institutions with the knowledge and skills to apply climate adaptation tools (Alpízar *et al.*, 2019). Capacity building and awareness-raising activities included masterclasses, workshops, seminars, and media interviews (2013-18). NSW Government staff facilitated the discussion and the process of information sharing by brokering the relevance of the research into current programs, practice and policy. Invitee lists targeted specific individuals who had input into the research to act as advocates for spreading awareness within their networks. Copies of slides and presentation materials were freely supplied to groups interested in delivering further training. For example, workshops on how to consider climate change in revegetation plantings using the "Climate-ready revegetation guide" were delivered to local councils, Landcare groups, and natural resource practitioners (2016-2018). Interested Landcare members were provided with booklets and support to deliver their own workshops, via a 'train the trainer' approach. This engagement process initiated the development of several 'climate-ready' revegetation demonstration trials throughout NSW, starting with the Yass Area Network Landcare Group in 2019 (see Case Study Box 2).

At the completion of the Biodiversity Node's projects in 2018, a state-wide roadshow was delivered in seven urban and regional locations. The roadshow covered outputs from the whole research program and contained a demonstration of the decision support tools. The events were promoted through government and practitioner networks, community groups and research institutions. Feedback from over 100 attendees indicated the roadshow was successful in enhancing awareness of climate adaptation tools and building capacity in their application. Feedback was captured from surveys at the end of each event. In addition, a formal program-wide audit was conducted at the completion of the program, solicited by the NSW Government.

Case Study Box 1. Assisted colonisation as a climate change tool: embedding research into policy

A large number of species will require active conservation interventions such as translocation/assisted colonisation to avoid extinction in coming decades because many species will be unable to disperse or adapt adequately to prevent population losses (Hoegh-Guldberg *et al.*, 2008; Chen *et al.*, 2011; Hällfors *et al.*, 2014). While approximately 1000 translocations of plant species to avoid threats other than climate change have been carried out in Australia to date (Silcock *et al.*, 2019), this type of intervention has been rarely employed, in Australia or elsewhere, as a climate adaptation strategy.

A Biodiversity Node project aimed to (1) synthesise literature on the current state of assisted colonisation globally (Gallagher *et al.*, 2014), (2) survey practitioners about their conceptual understanding and acceptance of the practice (Hancock & Gallagher, 2014), and (3) run masterclasses to communicate the current state of research among practitioners and policy-makers.

Key outcomes from this project included a compilation of all Australian flora translocations as at 2014, and collation of global case studies of best practice. This work then informed the development of the NSW government's Translocation Operational Policy (environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/translocation-operational-policy-190552.pdf). Since the release of this policy, more than 150 listed threatened species in NSW have had translocation identified as an important potential management action, including several for which this strategy is needed to reduce climate risk (Butt *et al.*, 2020). Planning is underway for translocations for a range of species (e.g. Nielsen Park She-oak; *Allocasuarina portuensis*) but to our knowledge no species have been moved yet outside their main range.

Case Study Box 2. Climate-ready revegetation trial: enhancing research uptake in translating research into practice

The *Climate-ready revegetation: A guide for natural resource managers* (the Guide), published in 2016, provides step-by-step guidance on the use of publicly available online tools for practitioners to incorporate the inherent uncertainties associated with climate change into revegetation activities. The Guide includes advice on finding and using climate change projections and how to consider the suitability of species and provenances at local planting sites (Hancock *et al.*, 2018). Hard copy booklets, an interactive web page, and a downloadable pdf version were produced to cater for a diverse target audience.

Whilst the aim of the Guide is to provide the tools and information to plan local revegetation activities, the subject and some of the tools are nevertheless complex. Through the Biodiversity Node, a series of 'hands on' workshops and seminars were conducted across New South Wales and the Australian Capital Territory to build the capacity of practitioners to apply the tools within their local areas. The early workshops essentially provided "train the trainer" opportunities, eventually leading to broader dissemination, especially amongst local governments and Landcare groups which are community-based organisations dedicated to managing and protecting natural resources and creating more productive and sustainable agriculture and resilient communities.

The positive feedback received from workshop attendees led the NSW Office of Environment and Heritage to establish a partnership with the Yass Area Network Landcare group, to undertake a case study. A field trial began in 2019 using species and seed sources selected for their likely persistence under future climatic conditions at the site. Early lessons from this case study have enabled other Landcare groups to trial alternative provenance strategies for improving resilience of revegetation programs to the changing climate.

Three main lessons are apparent. First, translating complex science into readily understood language is difficult, but not impossible. Early reviews of the Guide by practitioners indicated the need for better visual information which was tackled with the inclusion of a flow diagram and additional visual aids. Second, an additional step was required to move from research to 'on the ground' impact. This required NSW Government staff to analyse and provide climate change projections for the revegetation site and develop the provenance strategy for the community groups. This step needed considerable iterative communication from Government experts and scientists to practitioners over a significant period. Third, the approach of practitioners towards on ground trials at times differed substantially from that of scientists, for whom factors such as balanced designs and statistical rigour are core, requiring flexibility and compromise.

Notwithstanding the challenges, the collaborative partnerships that have been forged between government, researchers and local restoration practitioners has resulted in a shift in thinking about the relevance of previously held paradigms such as local seed sourcing practices. In the words of practitioners, *the partnership has enabled the generation of a thought process for people wondering what they can do regarding climate change*. The Guide and its dissemination activities have facilitated positive, forward-looking environmental action informed by science that is now triggering activities beyond NSW such as the development of Climate Future Plots in Victoria (Jellinek & Bailey, 2020) and Bush Heritage Australia's climate-ready revegetation at Nardoo Hills, central Victoria (unpublished).

3.4 Stage 5: Impact

Here we summarise how we have evaluated the impact of the Biodiversity Node research three years after the program's completion. We adopted a broad definition of research impact that included both tangible and less tangible outcomes (Morton, 2015, Louder *et al.*, 2021). Our impact metrics were focused on producing usable science, and also ensuring decision-makers and practitioners were supported to assist application (Mach *et al.*, 2020). Many of the immediate impacts have been around awareness raising, capacity building and advancing research agendas and partnerships, but changes in policy and practice will be ongoing as the individuals involved continue to engage others in the work and apply the outcomes in management and policy decisions. The Supporting Information provides a list of the 19 Biodiversity Node research projects and an example of a key impact for each project.

We classified the Biodiversity Node impacts into the following categories:

(1) Advancing research agendas and partnerships: includes the creation or extension of research agendas, partnerships, knowledge networks, relationships, groups or databases, citations of research papers, and ongoing engagement between researchers, policy-makers, practitioners and the community. These activities all have the potential to magnify the tangible future impact after the life of the project. For example, the Biodiversity Node comprised over 60 individual researchers from 16 institutions and several of the partnerships developed during the program have led to additional research projects.

(2) Capacity building and awareness raising: includes increased awareness, knowledge and understanding, changes in attitudes and perceptions, and the transfer of skills and knowledge that increases ability to implement change. This was a two-way process. Government staff built capacity in researchers to understand the operational needs for research to be applied.

Conversely, researchers briefed end-users on the appropriate use of the information as well as the limitations. For example, the desired impact of one of the Biodiversity Node projects was to improve the management of invasive hawkweeds in alpine vegetation communities via development of early detection techniques using remote sensing. The pathway to impact of such a project can be measured by an increased awareness and capacity of natural resource managers for incorporating remote sensing information into their routine operating activities, before a quantitative reduction in hawkweed distribution is evident.

(3) Input into policy: includes revisions to policy guidelines, programs and operational policy as a result of new information discovery. These impacts can be measured by the release of new or updated policy documents, such as the guidelines on best practice translocations and assisted colonisations under climate-change (see Case Study 1). This work led to the researchers being invited to provide input into a review of the guidelines, culminating in an updated Translocation Operational Policy to direct the planning, assessment and implementation of translocations under the *Biodiversity Conservation Act 2016*. This updated policy was implemented in November 2019.

(4) Changes in practice: the most tangible type of impact, where increased awareness, understanding and capacity leads to changes in on-ground practice. An example is the Climate Ready Revegetation project, where workshops on how to incorporate climate change into revegetation planning covered topics such as assessing the sustainability of species to plant in specific locations and selecting seeds with appropriate provenances. Participation in these workshops has led several Landcare groups to further apply the climate ready revegetation guidelines into trials of seed sources selected for their likely persistence under climate change (see Case Study 2).

4 Discussion

This paper presents a five-stage approach for embedding research into policy and practice. This engagement model, applied to the Biodiversity Node program, provides a template for creating research partnerships that support practitioners and influence decision-makers. By focusing on active and consistent engagement between stakeholders at all phases of the program, the ability of a state government in Australia and other natural resource practitioners to manage and protect biodiversity under a changing climate was facilitated. Below, we critically reflect on some of the key successes and challenges we encountered when implementing the approach in the Biodiversity Node program, and share the lessons learnt, from both the researchers and policy-makers perspective, on how to create effective research-implementation spaces.

4.1 Enhancing uptake of policy-relevant science

Policy-makers and practitioners are more likely to use research that is considered credible and salient (relevant to needs), and salience is more likely to result from a collaborative approach to knowledge creation from the outset (Cash *et al.*, 2003; Choi *et al.*, 2016; Arndt et al., 2020). Adopting a collaborative approach where scientists, policy-makers and practitioners co-designed and co-managed research projects, and jointly disseminated the research outcomes, was critical for identifying the multiple knowledge needs of a diverse audience, which in turn led to research uptake. Significant effort went into translating the knowledge into digestible formats for different end-users (highlighted in Figure 3), which required expertise and an understanding of the various pathways to achieve behavioural change. For example, one way we addressed the program objective of supporting government agencies to make integrated decisions with optimal outcomes was the extensive training and advocacy that knowledge brokers provided to end-users in the decision support tools during the statewide engagement roadshow.

However, working with a large stakeholder group with varied opinions and ideas also brought some challenges in resolving different agendas and desired outcomes. In many cases, researchers prioritise established benchmarks of academic success such as publications or grants, over impact and translation of research into application (Cvitanovic et al., 2015; Farwig et al., 2017). Through experience, we found the best way to resolve divergence in desired outcomes was to approach the projects with an attitude of being willing to work towards a shared overarching impact, and then working backwards to design multiple pathways to achieve the impact through different channels, rather than holding an agenda-specific outcome at conception. For example, the desired impact of the hawkweed project discussed above was to improve the management of invasive hawkweeds via development of early detection techniques using remote sensing. A channel to achieving this impact was through increased awareness and capacity of natural resource managers to apply remote sensing approaches to monitoring activities.

An open dialogue was critical for communicating end-user information priorities to researchers, which again takes time and requires an ability to pinpoint the knowledge needs of new policies (Young *et al.*, 2014). Embedding researchers into government agencies, and vice-versa, was one method we applied to foster transparent two-way dialogue, and to create trust and willingness to share information (Roux et al. 2019, Cvitanovic *et al.*, 2015). This occurred informally whereby individuals chose to spend time working in an office space with their collaborators for a day or up to several weeks.

4.2 Embedding evidence-based thinking into policy

Policy-makers and industry partners require science outputs to be readily implemented and to lead to tangible outcomes on investment (Cash et al., 2003; Dilling & Lemos, 2011; Young et al., 2014), but there is little scrutiny of evidence-based policy implementation. We found that a key factor in projects with demonstrated policy impacts was that engagement between researchers, policy-makers and managers was ongoing i.e. extended beyond the life of the immediate data collection and publication. Some of these relationships were pre-existing and others were forged through the partnership, such as when new personnel were appointed. A second key factor was the use of consistent future climate projections across projects. We utilised the outputs of the NSW Government NARCliM (NSW/Australian Capital Territory Regional Climate Modelling) project, a comprehensive set of climate projections for south-east Australia, based on consideration of model skill and independence across a broad ensemble of global and regional climate models (Evans *et al.*, 2014).

4.3 Conflicting measures of success: scientific merit versus usability

Interactions with policy-makers and planners consume time that may otherwise be spent pursuing more established benchmarks of academic success, such as publications and grant funding (Cvitanovic *et al.*, 2015). Despite the existing barriers for academics to engage outside university environments, the emerging importance of 'research impact' in assessment of competitive grant applications and academic promotion guidelines is changing traditional benchmarks of success. For example, a national benefit statement has been introduced by the Australian Research Council in major competitive grant applications, where researchers must reflect upon the broader significance of their proposed work. Similarly, the Australian Government's Excellence in Research in Australia (ERA) now includes an assessment of research impact beyond standard research metrics such as citations. This shift in approach to assessing academic achievement has the potential to gradually alter performance metrics away from traditional quantitative measures such as journal impact factors and h-indices (Louder et al., 2021). In our experience, developing a broad set of key impact indicators holds the research accountable to both traditional scientific quality control methods (peer review of scientific papers) and social accountability (Lemos & Morehouse, 2005). Overall, we found that the approach to co-design in the Biodiversity Node projects lent itself to an easier demonstration of real world impact, far more readily and over a shorter term, than traditional curiosity-driven research design.

4.4 Managing long-term partnerships

There are many barriers to maintaining long-term and productive partnerships between research institutions and the government agencies who control the levers for operational action (Arndt et al., 2020). These include political cycles with commensurate shifts on policy positions, frequent restructuring of government departments, short-term funding cycles for project-based research, and lack of funding for the upkeep and revision of existing work such as databases/websites that can rapidly become out-of-date and lose relevance. Over the life of the Biodiversity Node program we found that frank discussions at regular meetings of the joint Steering Committee were essential to manage expectations and have a shared understanding of the challenges.

5 Conclusion

We have presented a model for increasing the application and usability of biodiversity research into climate adaptation policy and practice and believe our experiences can help shape more collaborative partnerships that have lasting impact (Cvitanovic & Hobday, 2018). Most critically, we found that a combination of research co-creation, continued iterative research integration with practitioners, and ongoing relationships between government staff and academic researchers increased both short-term operational outcomes, and will underpin long-term impact. While these principles of engagement were aimed at addressing complex, wicked challenges such as climate change adaptation, there should be application to any applied discipline.

6 References

Alpízar, F., Bernedo Del Carpio, M., Ferraro, P. J., & Meiselman, B. S. (2019). The impacts of a capacity-building workshop in a randomized adaptation project. *Nature Climate Change, 9*(8), 587-591. doi:10.1038/s41558-019-0536-3

Alston, J. M. (2019). Open access principles and practices benefit conservation. *Conservation Letters, n/a*(n/a), e12672. doi:10.1111/conl.12672

Arndt, E., Burgman, M., Schneider, K., & Robinson, A. (2020). Working with government – innovative approaches to evidence-based policy-making. In J. A. Vickery, N. Ockendon, N. Pettorelli, P. N. M. Brotherton, W. J. Sutherland, & Z. G. Davies (Eds.), *Conservation Research, Policy and Practice* (pp. 216-229). Cambridge: Cambridge University Press.

Butt, N., Chauvenet, A. L. M., Adams, V. M., Beger, M., Gallagher, R. V., Shanahan, D. F., . . . Possingham, H. P. (2020). Importance of species translocations under rapid climate change. *Conservation Biology, n/a*(n/a). doi:10.1111/cobi.13643

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., . . . Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences, 100*(14), 8086-8091.

Chen, I.-C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid Range Shifts of Species Associated with High Levels of Climate Warming. *Science, 333*(6045), 1024-1026. doi:10.1126/science.1206432

Choi, B. C. K., Li, L., Lu, Y., Zhang, L. R., Zhu, Y., Pak, A. W. P., . . . Little, J. (2016). Bridging the gap between science and policy: an international survey of scientists and policy makers in China and Canada. *Implementation Science, 11*(1), 16. doi:10.1186/s13012-016-0377-7

Cook, C. N., Mascia, M. B., Schwarts, M. W., Possingham, H. P., & Fuller, R. A. (2013). Achieving Conservation Science that Bridges the Knowledge–Action Boundary. *Conservation Biology, 27*(4), 669-678. doi:10.1111/cobi.12050

Cresswell, I. D., & Murphy, H. T. (2016). *Australia state of the environment 2016: Biodiversity*. Retrieved from Canberra: https://soe.environment.gov.au/theme/biodiversity,

Cvitanovic, C., & Hobday, A. J. (2018). Building optimism at the environmental science-policy-practice interface through the study of bright spots. *Nature Communication*s, 9(1), 3466. doi:10.1038/s41467-018-05977-w

Cvitanovic, C., Hobday, A. J., van Kerkhoff, L., Wilson, S. K., Dobbs, K., & Marshall, N. (2015). Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: a review of knowledge and research needs. *Ocean & Coastal Management, 112*, 25-35.

Cvitanovic, C., Hobday, A. J., van Kerkhoff, L., Wilson, S. K., Dobbs, K., & Marshall, N. (2015). Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: a review of knowledge and research needs. *Ocean & Coastal Management*, 112, 25-35.

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change, 21*(2), 680-689. doi:https://doi.org/10.1016/j.gloenvcha.2010.11.006

EPA. (2018). *NSW State of the Environment 2018* Retrieved from Sydney, Australia: https://www.soe.epa.nsw.gov.au/

Evans, J. P., Ji, F., Lee, C., Smith, P., Argüeso, D., & Fita, L. (2014). Design of a regional climate modelling projection ensemble experiment - NARCliM. *Geosci. Model Dev., 7*(2), 621-629. doi:10.5194/gmd-7-621-2014

Farwig, N., Ammer, C., Annighöfer, P., Baur, B., Behringer, D., Diekötter, T., . . . Ziegenhagen, B. (2017). Bridging science and practice in conservation: Deficits and challenges from a research perspective. *Basic and Applied Ecology, 24*, 1-8. doi:https://doi.org/10.1016/j.baae.2017.08.007

Gallagher, R. V., Hancock, N., Makinson, R. O., & Hogbin, T. (2015). *Assisted Colonisation as a Climate Change Adaptation Tool*. *Austral Ecology, 40*(1), 12-20.

Hällfors, M. H., Vaara, E. M., Hyvärinen, M., Oksanen, M., Schulman, L. E., Siipi, H., & Lehvävirta, S. (2014). Coming to Terms with the Concept of Moving Species Threatened by Climate Change – A Systematic Review of the Terminology and Definitions. *PLoS One, 9*(7), e102979. doi:10.1371/journal.pone.0102979

Hancock, N., & Gallagher, R. (2014). How ready are we to move species threatened from climate change? Insights into the assisted colonization debate from Australia. *Austral Ecology, 39*(7), 830-838. doi:10.1111/aec.12151

Hancock, N., Harris, R., Broadhurst, L., & Hughes, L. (2018). *Climate-ready revegetation. A guide for natural resource managers. Version 2.* . Retrieved from Macquarie University, Sydney.: https://www.mq.edu.au/__data/assets/pdf_file/0006/807666/Climate-Reveg-Guide-v2-2018.pdf

Hoegh-Guldberg, O., Hughes, L., McIntyre, S., Lindenmayer, D. B., Parmesan, C., Possingham, H. P., & Thomas, C. D. (2008). Assisted Colonization and Rapid Climate Change. *Science, 321*(5887), 345-346. doi:10.1126/science.1157897

Hoeppner, J. M., & Hughes, L. (2019). Climate readiness of recovery plans for threatened Australian species. *Conservation Biology, 33*(3), 534-542. doi:10.1111/cobi.13270

Hughes, L. (2018). Reflections on a seminal paper in conservation biology: the legacy of Peters and Darling (1985). *Pacific Conservation Biology, 24*(3), 267-270. doi:https://doi.org/10.1071/PC18004

Hulme, P. E. (2014). Bridging the knowing–doing gap: know-who, know-what, know-why, know-how and know-when. *Journal of Applied Ecology, 51*(5), 1131-1136. doi:10.1111/1365-2664.12321

Jellinek, S., & Bailey, T. (2020). *Establishing Victoria's Ecological Infrastructure: A Guide to Creating Climate Future Plots*.

Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., & Campbell, B. M. (2008). Knowing But Not Doing: Selecting Priority Conservation Areas and the Research–Implementation Gap. *Conservation Biology, 22*(3), 610-617. doi:10.1111/j.1523-1739.2008.00914.x

Laurance, W. F., Koster, H., Grooten, M., Anderson, A. B., Zuidema, P. A., Zwick, S., . . . Anten, N. P. R. (2012). Making conservation research more relevant for conservation practitioners. *Biological Conservation, 153*, 164-168. doi:http://dx.doi.org/10.1016/j.biocon.2012.05.012

Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global Environmental Change, 15*(1), 57-68. doi:https://doi.org/10.1016/j.gloenvcha.2004.09.004

Louder, E., Wyborn, C., Cvitanovic, C., & Bednarek, A. T. (2021). A synthesis of the frameworks available to guide evaluations of research impact at the interface of environmental science, policy and practice. *Environmental Science & Policy*, 116, 258-265. doi:https://doi.org/10.1016/j.envsci.2020.12.006

Mach, K. J., Lemos, M. C., Meadow, A. M., Wyborn, C., Klenk, N., Arnott, J. C., . . . Wong-Parodi, G. (2020). Actionable knowledge and the art of engagement. *Current Opinion in Environmental Sustainability*, 42, 30-37. doi:https://doi.org/10.1016/j.cosust.2020.01.002

Morton, S. (2015). Progressing research impact assessment: A ‘contributions’ approach. *Research Evaluation, 24*(4), 405–419. doi:https://doi.org/10.1093/reseval/rvv016

O’Connell, M., & White, R. (2017). Academics can also be culprits of evidence complacency. *Nature Ecology & Evolution, 1*(11), 1589-1589. doi:10.1038/s41559-017-0346-9

Peters, R. L., & Darling, J., D. S. . (1985). The Greenhouse Effect and Nature Reserves. *Bioscience, 35*(11), 707-717. doi:10.2307/1310052

Prendergast, J. R., Quinn, R. M., & Lawton, J. H. (1999). The Gaps between Theory and Practice in Selecting Nature Reserves. *Conservation Biology, 13*(3), 484-492. doi:10.1046/j.1523-1739.1999.97428.x

Pullin, A. S., Knight, T. M., Stone, D. A., & Charman, K. (2004). Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation, 119*(2), 245-252. doi:https://doi.org/10.1016/j.biocon.2003.11.007

Redford, K. H., & Taber, A. T. (2000). Writing the Wrongs: Developing a Safe-Fail Culture in Conservation. *Conservation Biology, 14*(6), 1567-1568. doi:10.1111/j.1523-1739.2000.01461.x

Salafsky, N., Margoluis, R., Redford, K. H., & Robinson, J. G. (2002). Improving the practice of conservation: a conceptual framework and research agenda for conservation science. *Conservation Biology, 16*(6), 1469-1479.

Silcock, J. L., Simmons, C. L., Monks, L., Dillon, R., Reiter, N., Jusaitis, M., . . . Coates, D. J. (2019). Threatened plant translocation in Australia: A review. *Biological Conservation, 236*, 211-222. doi:https://doi.org/10.1016/j.biocon.2019.05.002

Sutherland, W. J., & Wordley, C. F. R. (2017). Evidence complacency hampers conservation. *Nature Ecology & Evolution, 1*(9), 1215-1216. doi:10.1038/s41559-017-0244-1

Taylor, H., Dussex, N., & van Heezik, Y. (2017). Bridging the conservation genetics gap by identifying barriers to implementation for conservation practitioners. *Global Ecology and Conservation, 10*, 231-242. doi:https://doi.org/10.1016/j.gecco.2017.04.001

Toomey, A. H., Knight, A. T., & Barlow, J. (2017). Navigating the Space between Research and Implementation in Conservation. *Conservation Letters, 10*(5), 619-625. doi:https://doi.org/10.1111/conl.12315

Van Kerkhoff, L., & Lebel, L. (2006). Linking knowledge and action for sustainable development. *Annu. Rev. Environ. Resour., 31*, 445-477.

Ward, M. S., Simmonds, J. S., Reside, A. E., Watson, J. E. M., Rhodes, J. R., Possingham, H. P., . . . Taylor, M. (2019). Lots of loss with little scrutiny: The attrition of habitat critical for threatened species in Australia. *Conservation Science and Practice, 1*(11), e117. doi:10.1111/csp2.117

Ward, M., Tulloch, A. I. T., Radford, J. Q., Williams, B. A., Reside, A. E., Macdonald, S. L., . . . Watson, J. E. M. (2020). Impact of 2019–2020 mega-fires on Australian fauna habitat. *Nature Ecology & Evolution*, 4(10), 1321-1326. doi:10.1038/s41559-020-1251-1

WWF. (2020). *Living Planet Report 2020 - Bending the curve of biodiversity loss*. Retrieved from Gland, Switzerland: https://www.zsl.org/sites/default/files/LPR%202020%20Full%20report.pdf

Young, J. C., Waylen, K. A., Sarkki, S., Albon, S., Bainbridge, I., Balian, E., . . . Margerison, C. (2014). Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. *Biodiversity and Conservation, 23*(2), 387-404.

Examples of stakeholders within a research-implementation space include policy-makers, practitioners, researchers, and the broader community. Some stakeholders represented multiple categories. In the Biodiversity Node program, for example, many of the stakeholders had experience working in government, academic institutions and practitioner-based organisations.