Science for Social Licence to Arrest an Ecosystem-Transforming Invasion

Norman W.H. Mason (✉ masonn@landcareresearch.co.nz)

Landcare Research New Zealand <https://orcid.org/0000-0002-6445-4285>

Nicholas A. Kirk

Landcare Research New Zealand

Robbie J. Price

Landcare Research New Zealand

Richard Law

Landcare Research New Zealand

Richard Bowman

New Zealand Wilding Conifer Group

Rowan I. Sprague

New Zealand Wilding Conifer Group

Research Article

Keywords: biosecurity, ecosystem services, governance, environmental policy, invasion meltdown, knowledge transfer, science-policy interface, invasive species management

Posted Date: December 30th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1080202/v1>

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Abstract

The primary role for science in addressing complex environmental problems, such as biological invasions, is generally assumed to be as a guide for management decisions. However, science often plays a minor role in decision-making, with practitioners instead relying on professional experience and local knowledge. We explore alternative pathways by which science could help reduce the spread and impacts of invasive species.

Our study centred on attempts to understand the science needs of three local governance bodies responsible for the management of invasive (wilding) conifer species in the southern South Island of New Zealand. We used a combination of workshop discussions, questionnaire responses and visits to field sites to elicit feedback from study participants.

We applied a mixed inductive-deductive thematic analysis approach to derive themes from the feedback received. The three main themes identified were: 1) Impacts of wilding conifers and goals for wilding conifer control; 2) barriers to achieving medium- and long-term goals; and 3) science needed to support wilding conifer control.

Participants identified both instrumental (e.g. reduced water availability for agriculture) and intrinsic (e.g. loss of biodiversity and landscape values) impacts of wilding conifer invasions, with long-term goals focussed on avoiding or reversing these impacts. Barriers to achieving goals were overwhelmingly social, relating either to unwillingness of landowners to participate or poorly designed regulatory frameworks. Consequently, science needs related primarily to gaining social licence to remove wilding conifers from private land and for more appropriate regulations. Participants did not perceive any need for additional scientific information to guide management decisions, relying instead on professional experience and local knowledge.

International experience suggests that invasive species control programmes often face significant external social barriers. Thus, for many biological invasions the primary role for science might be to achieve social licence and regulatory support for the long-term goals of invasive species control programmes and the management interventions required to achieve those goals.

Introduction

The role of science in addressing complex environmental problems, such as chronic biological invasions, is in a state of flux. The classic (yet still popular) model has been for science to guide environmental decision-making in the hope that this will lead to improved outcomes (Cvitanovic et al. 2016; Durant et al. 2019; Enquist et al. 2017; Pullin et al. 2004; Tulloch et al. 2020). Recent years have seen a growing realisation that complexity (*sensu stricto*) and stochasticity often make it difficult to predict outcomes for individual populations or ecosystems from the general principles by which science operates (Fogarty et al. 2016; Shoemaker et al. 2020). Concurrently, there is an increasing emphasis on the value of other knowledge sources, such as professional, local, and traditional experience with individual ecosystems in

environmental decision-making (e.g. Makey and Awatere 2018; Stern et al. 2021; Wheeler and Root-Bernstein 2020).

Both developments present a serious challenge to the primacy of science in guiding environmental decision-making. If science isn't central to decision-making, then what role can it play in coping with complex environmental problems, such as biological invasions? The answer to this question is of fundamental importance to the planning and prioritisation of scientific research.

We explore this question within the context of attempts to understand the science needs of local governance bodies responsible for the management of an ecosystem-transforming woody weed invasion and to develop knowledge transfer tools to service these needs.

Transdisciplinary research: bridging the science–stakeholder divide

Engagement with stakeholder groups can be extremely challenging due to diversity of interests and complex interactions between and within stakeholder groups as well as to power or knowledge imbalances between researchers and stakeholders (Pade-Khene et al. 2013; Talley et al. 2016). Thus it will often be beyond the skills or resources of many researchers to gain a comprehensive understanding of stakeholder science needs in planning research. In a previous study, Mason et al. (2021) proposed a knowledge ecology framework where science- and values-based knowledge systems are linked by a set of high-level “collaborative actions” (e.g. long-term objectives and strategies, Figure 1). They viewed these collaborative actions as important pathways for two-way information flow by which researchers can repeatedly check that the science they are offering is suitable for stakeholder needs (both in terms of content and forms of delivery). Mason et al. (2021) suggested that transdisciplinary research methods would be required in performing collaborative actions, but provided scant detail on what these might look like.

The essential, and conceptually most challenging, aspect of transdisciplinary research is the need to navigate the logical space between knowledge systems (Nicolescu 2010). Individual knowledge systems employ methods of enquiry and modes of communication that have been established and refined over decades, or even centuries. Consequently, navigating the logical space between knowledge systems requires a high level of creativity in developing methods appropriate to the study context (Djenontin and Meadow 2018; Pade-Khene et al. 2013; Reed et al. 2009). Factors to consider include the complexity of the issue in question, the immediate pressures faced by non-research participants, the level of trust between participants, and potential power imbalances due to differences in cultural background, gender, expertise or even personality (e.g. Djenontin and Meadow 2018; Reed et al. 2009). The importance of context on the choice of method also means that detailed contextual background is required to interpret findings of transdisciplinary research (Adler et al. 2018)

A key further consideration in transdisciplinary research is that stakeholders may not wish to devote time and resources toward purely research-focused activities (Pade-Khene et al. 2013). This may require creativity in seeking methods to address research questions while servicing the immediate practical

needs of stakeholders. Further, directly confronting stakeholders with research questions such as “What are your science needs?” may limit the depth or quality of feedback received and creativity may be required in developing less direct paths for eliciting information on stakeholder science requirements (see Burnay et al. 2016; Pacheco et al. 2018 for examples of this in the software design literature).

Wilding conifer invasions in New Zealand as a case study for exploring the role of science in complex environmental problems

Globally, naturalised conifer species (wilding conifers) have demonstrated their ability to rapidly invade large areas of non-forest vegetation (Nuñez et al. 2017). In New Zealand they now occur on ca 10% of the land area (Howell 2016). Although this is at low abundance (<1 tree ha^{-1}) in most areas,, dense forests may form within one or two generations of establishment at a site (Dickie et l. 2011; Mason et al. 2021). Consequently, non-forest ecosystems across much of New Zealand are at risk of transforming into exotic conifer forests in the near future. For these reasons, timely removal of existing invasions may provide huge savings in future control costs while also offering a cost-effective means of averting the ecosystem-transforming impacts of wilding conifers (Edwards et al. 2021; Mason et al. 2021).

In response to the national-scale threat posed by wilding conifers, the National Wilding Conifer Control Programme (National Programme henceforth) was established in 2016. The National Programme established a central information and funding hub linking various community groups and governmental agencies responsible for wilding conifer control. The National Programme coordinates control efforts across the country, allowing the programme and its partners to work across property and land-tenure boundaries. The structure of the National Programme works to include all the stakeholders involved in wilding conifer control; funding is allocated to management units, which are large landscapes divided according to catchments and landforms. The regional councils oversee the spending in their respective regions, and they collaborate with regional and local partners, including community groups, iwi, landowners, and central government agencies. The National Programme received a considerable boost in funding of \$100 million over 4 years as part of the New Zealand government response to the Covid-19 pandemic in 2020 (Edwards et al. 2021). Consequently, the eradication of existing wilding conifer seed sources from massive swathes of vulnerable land is a practicable goal in areas where this funding boost has been directed.

In parallel with the establishment of the National Programme, a consortium of research institutes (based either in New Zealand or overseas) obtained funding for a 5-year scientific research programme covering various issues relating to the spread, ecosystem impacts and control of wilding conifers in New Zealand. In planning the research, generation of spread and impacts predictions through a forecasting model was identified by researchers as an important pathway for delivering research findings to end-users within the National Programme. The expectation was that these predictions would support decision-making by providing an objective basis for prioritisation of control efforts both at the national and regional scales (Mason et al. 2021). To facilitate end-user access, a web-based interface (web tool henceforth) was established. The web tool was intended to support decision-making by allowing end-

users to compare the savings in future control costs and averted ecosystem impacts achieved from competing control scenarios of their own choosing.

Aims and objectives

The primary objective of this study is to identify the main benefits of scientific information to stakeholders in successfully controlling wilding conifer invasions. More generally, this study explores what the benefits of science perceived by stakeholders tasked with addressing complex environmental issues, such as biological invasions, might mean for the planning and communication of scientific research to better serve stakeholder needs.

We conduct our enquiries within the context of workshops seeking feedback on the wilding conifer web tool, ongoing research needs and barriers to achieving short-term goals from three regional governance groups tasked with delivering wilding conifer control programmes in the southern South Island of New Zealand.

Methods

Wilding conifer forecasting web tool

The wilding conifer web tool is available to the public at <https://wildingconifers.landcareresearch.co.nz> (Figure 2). It presents thematic layers representing the effects of removing existing wilding conifer infestations on each of the variables (reduction in future control costs, increases in erosion and averted impacts on biodiversity, water yield, pastoral productivity, and wildfire threat) included in the wilding conifer forecasting model of Mason et al. (2021) for three time periods – from 2020 to either 2027, 2034 or 2041. Seven-year increments were used to match the mean time to first reproduction for the most rapidly maturing species, *Pinus contorta*.

Initial versions of the web tool allowed users to aggregate values for the impacts of wilding conifer removal (expressed as averted control costs or ecosystem impacts in the future) for custom-drawn rectangles or irregular polygons. In response to end-user comments, provisions were made to provide aggregate values for individual catchments and management units.

Data collection

Workshops were organised in Queenstown and Alexandra on, respectively, 21 and 22 April 2021. We used a purposive sampling strategy (Patton 2015) to select workshop participants, aiming to include members of three regional wilding conifer groups – Whakatipu Wilding Conifer Control Group, Mid Dome Wilding Trees Charitable Trust, and Central Otago Wilding Conifer Control Group – operating in the southern South Island of New Zealand (Figure 3), as well as representatives from local, regional and central

government agencies and private consultants supporting the wilding conifer control activities of these groups.

Collectively, these people have detailed knowledge of wilding conifer control activities in their areas of interest. Many also have a long-term connection to areas currently or potentially affected by wilding conifer invasions. Due to existing relationships, we anticipated high levels of trust between the research team and regional wilding conifer group members. Consequently, we devised our engagement processes to suit high levels of participant expertise and trust. Specifically, we were able to design an engagement process requiring comparatively little time for familiarisation between participants and researchers, or to provide participants with background information. This enabled us to focus on rapid elicitation of high-quality feedback from participants.

Invitations were sent via e-mail and through phone calls. Accompanying invitations were:

- The workshop agenda
- An outline of the web tool
- A questionnaire that asked about challenges during the current wilding conifer control season, long-term goals, barriers to achieving these goals, and priority topics for research

Workshops began with a structured discussion on the question “Why should we control wilding conifers?” This was intended as a non-confronting approach to check whether the variables covered in the webtool corresponded to stakeholder priorities for wilding conifer control and as an “ice breaker” to encourage free sharing of knowledge and opinions in subsequent sections of the workshop. Attendees were invited to write down as many reasons for controlling wilding conifers in their area of interest as they wished. Then each attendee was invited to share this with the group. Repeat mentions of topics were tallied. This approach was employed to retain independence of individual viewpoints, and avoid undue influence on discussions by dominant personalities.

Following this discussion, an interactive presentation of the web tool was provided, including key assumptions and limitations in the generation of thematic layers. Attendees were encouraged to raise questions or provide comments during the presentation. Attendees were then encouraged to share any further thoughts on the tool as well as any issues relating to wilding conifer control in their areas of interest. Finally, attendees were invited to complete the questionnaire if they had not done so already.

Indoor discussions were followed by field visits to view wilding conifer invasions and control activities near Queenstown and Alexandra. Comments shared during field visits were recorded. In total 17 people attended at least one of the workshops. We received 14 responses to the questionnaire. All the questionnaire respondents also attended at least one of the workshops.

Data analysis

The qualitative data collected through the two workshops and questionnaires were then analysed using thematic analysis, the process of identifying themes across a dataset. Braun and Clarke (2006, p.10) describe a theme as capturing “something important about the data in relation to the research question, and represents some level of *patterned* response or meaning within the dataset”. To identify themes, we used a mixed inductive-deductive approach inspired by Fereday and Muir-Cochrane (2006). This mixed approach allowed us to deductively identify themes that were relevant to our research questions and topic, as well as inductively identify themes that we were not anticipating. Table 1 lists questions from the questionnaire. The responses to these questions were included in thematic analyses.

Table 1: Questionnaire questions included in thematic analyses

Immediate needs
Q1) Thinking about this most recent control season, will you complete everything that you wanted to? Why or why not?
Q2) What are the pinch points in your most recent control season (i.e., time, ineffective herbicide brews, labour shortage, etc.)?
Q3) What resources limit you? You can mention funding as a limiting resource, but are there other resources that you need (i.e. project management or data entry/ GIS support)?
Q4) What guidance have you found helpful, and what guidance do you need or lack currently?
Long-term goals and challenges
Q1) In five years’ time, what control objectives do you hope to have achieved? E.g. a certain % of your area permanently cleared of wildings with minimal chances of wilding reinvasion.
Q2) Thinking about your group’s strategy and vision, what are the risks or challenges to achieving that vision?

Two researchers (NK/RS) coded the dataset. During this coding process, the researchers identified features of the dataset that appear interesting or help answer our research questions (Boyatzis 1998). After the first round of coding, the researchers convened to discuss overlaps and omissions between their coding efforts. Following this, the researchers coded the dataset a second time before identifying themes as a research group (NM/NK/RS). In the results section, we describe these themes and how they contribute to our understanding of the science needs for wilding conifer control of the three regional wilding conifer groups involved in our study.

Results

Across the two workshops and questionnaire responses three key themes were identified:

1. The impacts of wilding conifers and goals for wilding conifer control
2. Barriers to achieving medium- and long-term goals
3. Science needed to support wilding conifer control.

Theme 1 – The impacts of wilding conifers and GOALS FOR WILDING CONIFER CONTROL

Participants at the workshops and questionnaire respondents listed a variety of impacts from wilding conifer spread as key motivators behind wilding conifer control within their areas of interest. Some impacts had a direct influence on humans or human activities (i.e. instrumental impacts). These included economic opportunity cost from reduced water yield, damage to infrastructure from wildfires and reduced tourist activities (Figure 4a) due to landscape transformation to exotic conifer forests. Others had a direct influence on ecosystems independent of impacts on human activities (i.e. intrinsic impacts). These included impacts on biodiversity (Figure 4b–d), aquatic ecosystems (due to reduced water yield) and landscapes (Figure 4a).

Workshop attendees were unanimous in identifying landscape impacts as a reason for controlling wilding conifers. Further investigation of this during discussions revealed that this somewhat overlapped with concerns about biodiversity loss (i.e. loss of native species habitat due to landscape transformation). However, for most attendees, landscape impacts were primarily a method of articulating the loss of heritage or cultural identity associated with transformation from non-forest ecosystems to exotic conifer forests. Some examples are: “Dominance of a conifer monoculture leading to a sense of loss” and “Loss of New Zealand identity”.

Several attendees countered that these cultural or heritage values might equally be employed as reasons to retain wilding conifers in the landscape. This was especially noted in instances where landowners were born and raised in countries where conifer forests form an important component of “natural” landscapes.

The primary long-term goal for wilding conifer control was to prevent or avoid the above impacts by removing all seed sources of high-risk conifer species from the landscape. Removing all significant seed sources was seen as key to achieving long-term goals since landowners, volunteers and local government are unlikely to successfully contain wilding conifer spread if significant seed sources are allowed to persist in the landscape.

Theme 2 – Barriers to achieving MEDIUM- AND LONG-TERM goals

Persistence of wilding conifer seed sources in the landscape was identified as the major threat to achieving the long-term goals identified in Theme 1. The primary barriers to removal of seed sources identified by workshop attendees and questionnaire respondents centred on resistance from landowners or neighbours to wilding conifer removal (Figure 4e), regulatory or policy frameworks, and workforce capacity. Workshop attendees expressed a sense of urgency, feeling that timely removal of conifer seed sources from the landscape is vital to the long-term success of the programme. There was also a feeling that the current boost in funding for wilding conifer control might be the last, and best chance to knock wilding conifers back to a manageable level. Thus barriers to achieving short-term management goals were viewed with grave concern.

Currently, landowner funding and permission is required for conifer removal. Various reasons for individual landowner resistance to removal of wilding conifer seed sources on private land were identified by workshop attendees. Perhaps the most concerning source of resistance identified was the establishment of new seed sources in the form of new forestry plantings of the high-risk species Douglas fir in extremely vulnerable environments. Also of considerable concern was resistance to removal of existing forestry plantations and shelter belts including high-risk species. This resistance is understandable as existing plantation may be an important component of long-term financial planning for landowners, and shelter for livestock is a valuable ecosystem service provided by exotic conifers in high country landscapes. One workshop attendee noted that removal of high-risk plantations may require a lead-in time of 5–6 years, even when the trees are at harvestable age, due to the lengthy consent process with district councils.

During both fieldtrips, specific properties were identified where landowners originating from Europe viewed the exotic conifers on their land as a welcome reminder of home. In another instance, a landowner had retained large Douglas fir trees to provide visual screening for their house from a power pylon. Some landowners were unwilling to pay their portion (20%) of the removal costs or wanted compensation for the costs of stump removal and loss of amenity or practical values provided by the conifers on their land. There was also resistance from some landowners and neighbours to certain conifer control methods – particularly helicopter boom spraying of herbicides.

Stricter regulatory tools, or more stringent enforcement of existing tools, were identified as a key component of strategies to overcome landowner resistance to conifer removal. In theory, landowners resisting removal of a pest plant species (i.e. a plant species listed in the Regional Pest Management Plan) could be liable for prosecution under the Biosecurity Act. During the workshops it was noted that this theory had yet to be tested in court with regards to wilding conifers. A wilding conifer “risk calculator” is used to prevent establishment of high-spread risk conifer plantations. However, workshop attendees observed that this regulatory tool was so vague as to be easily “gamed by forestry consultants” to gain regulatory approval for establishment of conifer plantations in high-risk environments. A novel regulatory idea to emerge from the workshops was a “liability calculator”, whereby landowners wishing to retain conifers on their land for whatever reason would be liable for any subsequent containment costs.

Greater policy flexibility was identified as another key pathway for reducing landowner resistance to conifer removal. For instance, there were concerns that the requirement for landowners to cover part of the removal cost might reduce cost-effectiveness of the control programme in the long run. This is because increases in future removal and containment costs from seed sources due to landowner resistance may be much greater than the money saved by requiring landowners to share costs. Navigating New Zealand’s Emissions Trading Scheme (ETS) was identified as a major impediment to removal of forestry plantations acting as wilding conifer seed sources. One attendee suggested it might be more cost-effective for the control programme to simply incur any liabilities arising from plantation removal under the ETS. Similarly, it was suggested that purchasing and spraying pre-harvest-aged

forestry plantations might be more cost effective than permitting these seed sources to remain in the landscape.

Three main areas of capacity limitation were identified by workshop attendees and questionnaire respondents – project management, skilled contractors, and willing labourers. Insufficient project management capacity was identified as a significant bottleneck, particularly in the Whakatipu Conifer Group, due to the complexity of planning and overseeing individual control operations (e.g. negotiating prices and conditions with contractors, gaining access to land, regulatory compliance). Workshop attendees noted that a comparatively small range of contracting companies were able to perform the required work, particularly when significant helicopter flight time was required. This caused challenges in scheduling and led to potential competition between wilding conifer control groups for the narrow talent pool. Due to the physically challenging nature of the work, turnover among labourers was identified as a significant risk to maintaining labour capacity. The need to spend long periods in remote rural locations was also identified as a difficulty in filling available positions.

Finally, a major concern among workshop attendees was that funding timeframes may be too short to achieve the level of seed source removal required to permit effective containment under reduced future funding levels. It was suggested that due to landowner resistance and capacity constraints, greater flexibility around funding timelines is needed for long-term success of the control programme.

Theme 3 – Science NEEDED to support wilding conifer control

Given the overwhelmingly social and regulatory nature of barriers to success, the primary role for science identified by participants was in providing counter-factual assessments of outcomes in the absence of wilding conifer control operations. This was contrary to expectations that the primary role of the science would be to guide management decisions, such as prioritisation of management effort, or overcome technical barriers. Further, attendees were satisfied that the web tool covered the main types of wilding conifer impact relevant to their area of interest. Although the web tool does not cover “landscape” impacts, attendees did not feel that modelled forecasts of landscape impacts were needed. Consequently, much of the discussion on science needs within workshops focussed on improving accessibility of existing scientific information to a non-expert audience rather than performing additional science or improving the accuracy of existing science.

A major communication issue raised during the field trip in the Whakatipu area was that successful efforts to contain spread from existing seed sources reduced the public perception of threat from wilding conifer invasions (Figure 4f). For instance, “...the WCG [Whakatipu Conifer Group] has controlled tens of thousands of trees, but people can’t see those trees, so can’t tell there’s a problem”. Workshop attendees viewed the return-on-spend estimates provided by the web tool as a useful method for communicating the value of removing wilding conifer seed sources in a timely manner, and the wider landscape-scale risks of individual landowners retaining seed sources on their properties.

Forecasts of ecosystem impacts, particularly relating to biodiversity loss, water yield reduction, and wildfire hazard, were also seen as important pathways for communicating the value of timely wilding conifer removal to the public. Water yield reduction was a particular concern in the Alexandra workshop, since the surrounding area is the driest in New Zealand, and economic activities are already highly constrained by access to water.

Much of the feedback on the web tool related to improving the clarity and user-friendliness of the tool for increased public engagement with the scientific information it provides. Feedback included requests to supply help buttons to activate dialogue boxes describing the data presented by each thematic layer, and methods used to derive those data. Another simple practical suggestion was to provide a start-up dialogue box outlining the web tool's functionality and the information it provides.

Workshop attendees also provided suggestions to make the scales and units of thematic layers displayed by the web tool more accessible to non-experts. For instance, one attendee at the Alexandra workshop suggested that the wildfire hazard layer (expressed as head fire intensity – energy output per unit length of the most rapidly advancing fire front) could be rescaled to reflect guidelines for appropriate firefighting methods, which are directly determined by head fire intensity. Another suggestion was to present aggregate water yield reduction values (for catchments and management units) as a percentage of total current water yield for the area of interest rather than in cubic metres per second (the standard metric for quantifying river flow rates), so that conifer impacts on water yield could be easily interpreted without recourse to additional data.

Several technical limitations were also identified by workshop attendees. Mismatches between the wilding conifer infestation database and local knowledge of infestations were raised as a serious issue in specific locations. Attendees identified initiation of a workflow to incorporate up-to-date infestation data in producing forecasts as a high priority. Lack of recognition of spread risks from non-wilding seed sources such as shelter-belts, plantations and amenity plantings was also raised as a significant limitation of the forecasts provided by the web tool. Finally, attendees questioned whether inclusion of erosion reduction from wilding conifer invasions was relevant to their local contexts. The contention here was that erosion reduction might be more relevant in areas of the North Island where deforestation had greatly increased erosion above pre-human levels.

Attendees expressed interest in development of finer-scale spread models than those underpinning the web tool in order to develop a “liability calculator”, whereby liability for control costs imposed on neighbours due to retention of seed sources could be estimated. Such calculations may then permit forcible or voluntary internalisation of control liabilities by landowners retaining seed sources on their properties.

Discussion

Our findings suggest that science or scientific information may not be the primary knowledge source used to inform management decisions on complex environmental problems such as biological invasions

within individual landscapes or ecosystems. Rather, based on our results, it appears practitioners are more likely to rely on professional experience and local knowledge in planning and prioritising management interventions. Further, our results suggest that social and regulatory barriers, rather than knowledge deficits, may often pose the greatest threat to practitioners achieving their long-term goals. Consequently, in many, perhaps most, instances the primary role for science might be to achieve social licence (e.g. Edwards and Trafford 2016; Kelly et al. 2018) and regulatory support for the long-term goals of invasive species control programmes and the management interventions required to achieve those goals. Below, we consider the implications of our findings for integrated knowledge frameworks, prioritisation of research, and communication of research findings in addressing complex environmental problems.

How breadth of governance Bodies alters the role of science

Our results reveal that the “Knowledge Ecologies” framework of Mason et al. (2021) is somewhat naive in neglecting the broader social and political context surrounding invasive species management programmes. They assumed that governance bodies would include all relevant stakeholders. This contributed to the tacit assumption that the primary role of science (delivered in the form of wilding conifer spread and impact forecasts) is to guide management decisions, rather than to demonstrate the value of management interventions.

Differences in attitudes among stakeholders toward wilding conifers have been clearly demonstrated in survey-based studies (e.g. Kirk 2019), and for many other plant invasions (Dickie et al. 2014a; Head 2017). Our study suggests that stakeholders with positive attitudes to wilding conifer invasions are absent from regional governance bodies within the National Wilding Conifer Control Programme, and that this has led to unanticipated external social resistance in achieving the programme’s objectives.

Where governance bodies do not represent the full range of stakeholder viewpoints, external social resistance to invasive species management objectives should perhaps be expected. However, it may be undesirable to include all stakeholder viewpoints in governance groups overseeing environmental management programmes, since those stakeholders with conflicting interests may obstruct the decision-making process (Bodin 2017). Consequently, many invasive species management programmes experience significant external social resistance (Estévez et al. 2015; Head et al. 2015).

Our findings add to recent literature (e.g. Kelly et al. 2018) suggesting that science can play a major role in countering external social resistance to environmental management programmes among key stakeholders such as landowners, regulatory authorities, and politicians. Practitioners viewed the main benefit of our forecasts of wilding conifer spread and impacts to be in demonstrating the value of management interventions in reducing future control costs and avoiding environmental impacts which large sections of the community care about (i.e. biodiversity loss, reduction in water yield and agricultural productivity, increased wildfire risks). This information was considered crucial to encouraging increased landowner participation, implementing more stringent regulatory frameworks and securing future funding.

Planning science for social licence – the importance of forecasts

Practitioner responses obtained during our study indicate that forecasting models can help build social licence for invasive species management programmes. Forecasting models can also greatly benefit fundamental ecological research both by demonstrating the relevance of individual research advances for things the public or key stakeholders care about and channelling research effort towards areas of high uncertainty about key parameters or processes (Houlahan et al. 2017; Mason et al. 2021).

Unfortunately, interest in forecasting models among ecologists has declined in recent years (Houlahan et al. 2017), perhaps due to the inherent complexity of ecological systems. However, general ecological forecasting good practice guidelines are emerging (e.g. Dietze et al. 2018; Schuwirth et al. 2019). Among these, probably the most relevant consideration for use of forecasting to support social licence is the ability to demonstrate the impact of actual and potential management interventions or scenarios (Schuwirth et al. 2019). This will permit counterfactual analyses of economic or environmental impacts of allowing invasive species to spread unchecked, or report on the value of control programmes in avoiding such impacts. Given that building social licence is likely to be a major area where practitioners need support from science, we argue that providing reliable forecasts of spread, impacts, and the effect of management interventions in reducing these should be a key goal of research aiming to support invasive species management programmes.

In emphasising the importance of forecasting, we must be careful not to dismiss the potential for fundamental or technical research in gaining social licence for invasive species control programmes. For instance, primary research aimed at reducing the amount or toxicity of herbicides required for wilding conifer control (Rolando et al. 2021) may reduce social resistance to herbicide-based control methods (Edwards et al. 2020). Further, there is clear evidence that changes in soil biota and nutrients caused by even low-moderate density wilding conifer invasions of native-dominated ecosystems lead to dominance of exotic species following conifer removal, rather than restoration of the original native species (Dickie et al. 2014b). Thus, unless new invasions are prevented (by removal of seed sources) or rapidly detected and removed, significant post-control effort is likely to be required to restore pre-invasion biodiversity values (Dickie et al. Pre-print). This further emphasises the need for urgency in removing wilding conifer seed sources – especially in vulnerable landscapes of high biodiversity value (Mason et al. 2021; Mason et al. 2017). Similarly, improved data on the invasive spread of individual wilding conifer species (Wyse et al. 2019a; Wyse and Hulme 2021; Wyse et al. 2019b) are crucial in arguing for more stringent regulations to prevent establishment of conifer plantations in high-risk landscapes.

Communicating science for social LICENCE – Targetting non-experts

Feedback from practitioners in our study suggests that the biggest implication for communication of science to support social licence (c.f. management decisions), is the need to tailor information to audiences who may lack experience in interpreting data from environmental forecasting models (e.g. rural landowners, urban residents, government officials, and politicians). In practical terms, informatic tools for delivering scientific information might be best to focus on clear illustration (Murchie et al. 2020)

of the tangible and intangible benefits of wilding conifer management rather than supporting detailed scenario explorations via a complicated user interface. Also, different modes of communication may be more effective for enhancing the accessibility and transparency of scientific information to different audiences (e.g. National Academies of Science 2017; Kelly et al. 2018) – community meetings or other in-person engagement for rural landowners; news or other popular articles for urban residents; policy briefings or cost-benefit analyses for government officials and politicians. Further, while we have focussed on the role of science in supporting social licence, we recognise that many other factors – especially the level of trust and strength of relationships between invasive species programmes, the general public, local communities or private landowners (Edwards et al. 2020; Estévez et al. 2015; Ogilvie et al. 2019; Stronge et al. 2019) – may strongly influence social licence for invasive species control efforts.

Our findings concur with those of a systematic literature review (Estévez et al. 2015) that found provision of localised forecasts for a wide range of impacts of interest to stakeholders and local communities is likely to be a useful pathway for science to support social licence for invasive species control programmes. Previous studies have emphasised the need for forecasts on multiple ecosystem properties in engaging communities in ecosystem-based management (e.g. Delacámara et al. 2020; Makey and Awatere 2018), suggesting that focussing on a single impact or outcome in forecast models may often reduce the ability of science to support social licence.

Conclusions

Social resistance, rather than knowledge deficit, may often be the main barrier to success of invasive species management programmes. Consequently, the main benefit of science for arresting biological invasions will often be to support social licence for management interventions rather than guiding management decisions. To support social licence, invasive species research programmes must focus not only on cost-effective control technologies and strategies, but also the benefits (both tangible and intangible) of invasive species control for society. This will be especially relevant for ecosystem-transforming invasions such as wilding conifers in New Zealand and globally.

Declarations

This work was funded by the New Zealand Ministry of Business, Innovation and Employment through the “Winning Against Wildings” Endeavour research programme.

The authors have no relevant financial or non-financial interests to disclose.

Acknowledgements

We thank the Whakatipu Wilding Conifer Control Group, Mid Dome Wilding Trees Charitable Trust, and Central Otago Wilding Conifer Control Group for contributing their time and expertise during workshops and field visits. Peter Edwards provided valuable feedback on an earlier draft. We thank the New Zealand

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Figures

Figure 1

A knowledge ecology structure for biological invasions in New Zealand composed of individual knowledge ecosystems in distinct research domains: Pākehā (non-Māori) values: social, ethical, economic, governance and policy research within a Pākehā world view; Māori (indigenous) values: social, ethical, economic and policy research within a Māori world view, employing indigenous (kaupapa Māori) research methods; Management technologies: scientific research on control and detection technologies; Spread and impacts: scientific research on conifer demography and ecosystem impacts; Operational logistics: scientific, social and economic research on the safe, efficient and ethical deployment of management technologies. The boxes with dashed borders represent the key collaborative actions via which individual knowledge ecosystems communicate: The double-headed arrows symbolise two-way knowledge exchange between knowledge ecosystems via collaborative actions.

¹Adapted from Henare (1998).

²Adapted from Dash et al. (2017).

Figure 2

Screenshot of wilding conifer forecast web tool highlighting major features. The tool is publicly available at <https://wildingconifers.landcareresearch.co.nz/>

Figure 3

Management units covered by each management group. Landcover is expressed following the reclassification applied to Landcover Database version 4 by Mason et al. (2021).

Figure 4

A tourist takes in a sweeping vista synonymous with the treeless landscapes of the South Island high country (A); Conifer invasions threaten a wide range of native plant species in these treeless landscapes, including short-statured herbaceous species and sub-shrubs (e.g. *Geranium sessiliflorum*, *Pernettya macrostigma* and *Leucopogon fraserii*; B); light-demanding shrubs (e.g. *Gaultheria crassa*; C) and large herbaceous species (e.g. *Aciphylla aurea*; D) in addition to the structurally dominant tussock-forming grasses (*Chionochloa* spp., *Festuca novae-zealandia*, *Poa cita* and *P. colensoi*); Social resistance can come in many forms (E) – the conifers in the foreground have not been removed due to objections from a neighbouring landowner, while in the background boom-spraying halted at the boundary between a willing and non-willing landowner; Wilding conifer control operations aim to remove trees before they produce cones, when invasions have yet to become apparent through casual observation from a distance (F). All photos taken by NWHM during post-workshop field visits near Queenstown and Alexandra.