Science for social licence to arrest an ecosystem-transforming invasion

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Abstract  The primary role for scientific information in addressing complex environmental problems, such as biological invasions, is generally assumed to be as a guide for management decisions. However, scientific information often plays a minor role in decision-making, with practitioners instead relying on professional experience and local knowledge. We explore alternative pathways by which scientific information could help reduce the spread and impacts of invasive species. Our study centred on attempts to understand the main motivations and constraints of three local governance bodies responsible for the management of invasive (wilding) conifer species in the southern South Island of New Zealand in achieving strategic and operational goals. 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 reversal and prevention of both instrumental (e.g. reduced water availability for agriculture) and intrinsic (e.g. loss of biodiversity and landscape values) impacts of wilding conifer invasions as primary motivators behind wilding conifer control. 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. Scientific information provided via spread and impacts forecasting models was viewed as a key source of scientific information in gaining social licence. International experience suggests that invasive species control programmes often face significant external social barriers. Thus, for many biological invasions, the primary role of 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.
Keywords Biosecurity · Ecosystem services · Governance · Environmental policy · Invasion meltdown · Knowledge transfer · Science-policy interface · Invasive species management

Introduction

The role of scientific information 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 scientific information to guide environmental decision-making in the hope that this will lead to improved outcomes (Cvitkovic 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 scientific information in guiding environmental decision-making. If scientific information is not 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 how scientific information delivered through spread and impacts forecasting models might best support local governance bodies responsible for the management of an ecosystem-transforming woody weed invasion.

Social licence and biological invasions

There is no universally accepted definition for social licence (Bice and Moffat 2014; Edwards and Trafford 2016), but in the broadest sense it refers to ongoing support for an activity from local stakeholders (including landowners, community groups) directly affected by the activity and stakeholders who might influence the effectiveness or profitability of that activity (i.e. civil society and government agencies, Moffat et al. (2016), Edwards and Trafford (2016)). The term emerged in extractive industries—particularly mining—but is now being applied to a range of different collective action issues in which the public have a stake (Moffat et al. 2016; Edwards and Trafford 2016).

Dare et al. (2014) argue that social licence is best viewed as “…a continuum of multiple licences achieved across various levels of society”. This conceptualisation of social licence is well-suited to chronic, ecosystem-transforming biological invasions. The scale and breadth of impacts (both from invasive spread and control measures) mean that management decisions directly affect a large number and variety local stakeholders (Mason et al. 2021). Management decisions may also affect values (intrinsic, instrumental and relational, Chan et al. 2016), which are important to significant portions of civil society (and by extension government agencies, Mason et al. 2021).

Challenges to social licence (i.e. social resistance) in invasive species management can occur when stakeholders have contrasting perspectives on the value of invasive species, or the values invasive species threaten. For instance, in New Zealand invasive ungulates are viewed as a pest causing damage to indigenous forests, pastures and spreading bovine tuberculosis, but are also valued as a resource for recreational hunting and commercial harvest (Moloney et al. 2021; Fraser 2000). Ethical or safety concerns around management technologies, particularly toxins (pesticides and herbicides) and genetic modification, might also cause social resistance to invasive species management (Green and Rohan 2012; Kirk et al. 2020). Finally, the high costs of effective invasive species management, both at the societal and individual landowner level, can be a barrier to adoption (Marbuah et al. 2014; Yletyinin et al. 2021). Given this, we believe clearly demonstrating the benefits and cost-effectiveness of invasive species control programmes could help to overcome these and other sources of social resistance.

Wilding conifer invasions in New Zealand as a case study for exploring the role of scientific information 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 al. 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 National Programme aims to include all the stakeholders involved in wilding conifer control in order to develop and maintain social licence for management decisions and actions. In particular, the National Programme works with community and landholder groups to share key awareness messages and understand potential contentions with 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 (indigenous tribal entities), landowners, and central government agencies. Control costs are mostly co-funded by the National Programme and local partners. While, co-funding arrangements vary somewhat, landowners are usually expected to cover 20% of the total cost of removing wildings from their land. 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 (Fig. 1). 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 spread and impacts forecasts to stakeholders responsible for wilding conifer control in successfully achieving their strategic and operational goals. More generally, this study explores what the benefits of scientific information 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.

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1 Wilding conifer information system (WCIS) accessed February 2019. https://wildpines.linz.govt.nz/portal/apps/MapSeries/index.html?appid=107dc24b6a784d2a810ee664fa0a3036.
2 https://www.wildingconifers.org.nz/national-programme/.
3 https://www.beehive.govt.nz/release/budget-2020-jobs-and-opportunities-primary-sector.
4 https://www.landcareresearch.co.nz/discover-our-research/biosecurity/winning-against-wildings./
Fig. 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)
We conduct our enquiries within the context of workshops seeking feedback on the wilding conifer web tool and barriers to achieving strategic and operational 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 (Fig. 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

We used a purposive sampling strategy (Patton 2015) to select workshop participants. Participants were selected from 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 (Fig. 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 for provision of background information to participants. This enabled us to focus on rapid elicitation of high-quality feedback from participants. Workshops were organised in Queenstown and Alexandra on, respectively, 21 and 22 April 2021. Invitations were sent via e-mail and through phone calls. Accompanying invitations were:

- The workshop agenda
- An outline of the web tool
- A questionnaire (Table 1) 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. Attendee responses were grouped,
by consensus, into topics, corresponding to broad value categories impacted by wilding conifer invasions (e.g. biodiversity, heritage, local identity, water yield, wildfire threat, agriculture, tourism) and practical aspects of managing conifer invasions (e.g. the potential for rapid change, the opportunity cost of not acting in a timely manner). Individual responses were assigned to multiple topics where appropriate. 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 asked to provide feedback on four broad questions: (1) What uses do you see for the tool? (2) What is the audience for this tool? (3) 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)? (4) 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?

Data analysis

Qualitative data consisted of unique topics recorded during workshop discussions and unique questionnaire responses. These data were 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.

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 invasions and control activities near Queenstown and Alexandra. Any novel topics arising 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.

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? |
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 con-
   trol.

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 coni-
fer 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 (Fig. 4a) due to landscape transformation to
exotic conifer forests. Others had a direct influence on
ecosystems independent of impacts on human activi-
ties (i.e. intrinsic impacts). These included impacts on
biodiversity (Fig. 4b–d), aquatic ecosystems (due to
reduced water yield) and landscapes (Fig. 4a).

Workshop attendees were unanimous in identi-
fying 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 transforma-
tion). However, for most attendees, landscape impacts
were primarily a method of articulating the loss of
heritage or cultural identity associated with transfor-
mation 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 per-
sist 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 achiev-
ing 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 (Fig. 4e), regulatory or
policy frameworks, and workforce capacity. Work-
shop attendees expressed a sense of urgency, feel-
ing 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 achiev-
ing short-term management goals were viewed with
great concern.

Currently, landowner funding and permission is
required for conifer removal. Various reasons for indi-
vidual 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 plant-
ings of the high-risk species Douglas fir in extremely
vulnerable environments. Also of considerable con-
cern was resistance to removal of existing forestry
plantations and shelter belts including high-risk spe-
cies. This resistance is understandable as existing
plantations 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 district council consent process.

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.

Social resistance can come in many forms— 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. All photos taken by NWHM during post-workshop field visits near Queenstown and Alexandra.

Fig. 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-zelandiae, Poa cita and P. colensoi);
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 for ground-based control. 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 scientific information (as presented in the web tool) identified by participants was in providing counterfactual assessments of outcomes in the absence of wilding conifer control operations. This was contrary to expectations that the primary role of the scientific information 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 scientific information.
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 (Fig. 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 scientific information delivered through ecological forecasting models 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 of forecasting models 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 scientific information

Our results reveal the naivety of integrated research frameworks which assume that governance bodies within invasive species management programmes include all relevant stakeholders (e.g. Mason et al. 2021). In our study, this naivety contributed to the tacit assumption that the primary role of scientific information (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 (Estèvez et al. 2015; Head et al. 2015; Crowley et al. 2017).

Our findings add to recent literature (e.g. Kelly et al. 2018) suggesting that scientific information might 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 for 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. A recent multidisciplinary synthesis study (Shackleton et al. 2019) highlighted knowledge of impacts as a key factor shaping stakeholder perceptions of invasive species. This further suggests that forecasting models, by revealing the potential consequences of invasive species, may help to develop social licence for management. However, without further empirical studies we cannot be certain that information on wilding conifer impacts and future control costs would reduce social resistance.

Planning science for social licence—the importance of forecasts

Practitioner responses obtained during our study indicate that forecasting models might help to 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 scientific
information, 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, 2017). Similarly, improved data on the invasive spread of individual wilding conifer species (Wyse et al. 2019a, b; Wyse and Hulme 2021) are crucial in arguing for more stringent regulations to prevent establishment of conifer plantations in high-risk landscapes.

Communicating scientific information for social licence—targeting non-experts

Feedback from practitioners in our study suggests that the biggest implication for communication of scientific information 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 scientific information 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 scientific information 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 scientific information to support social licence.

A potentially fruitful avenue for future research may be in assessing the effectiveness of integrating forecasting model development and communication with stakeholder engagement processes such as structured decision making (Estévez et al. 2015) or serious gaming (e.g. Forrest et al. 2022) in building social licence. There is also an apparent lack of research considering how scientific information might best be used to capitalise on potential opportunities to enhance social licence or manage sources of social resistance revealed by qualitative social research methods (e.g. meta-ethnography, Gill et al. 2022). It would be interesting to empirically test the relative effects on social licence of a) involving stakeholders in model development b) use of forecasting models to assess the consequences of different management decisions and c) different methods for incorporating
scientific information in stakeholder engagement processes. Such studies could be particularly useful in planning scientific research to build social licence for invasive species management and prevent contrasting stakeholder attitudes from developing into “destructive” conflict (Crowley et al. 2017).

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 scientific information for arresting biological invasions may be to support social licence for management interventions rather than guiding management decisions. To support social licence, invasive species research programmes may need to focus not only on cost-effective control technologies and strategies, but also the benefits (both tangible and intangible) of invasive species control for society. Robust, well-communicated forecasting models will likely form a key component of efforts to communicate these benefits to stakeholders. This could be especially relevant for ecosystem-transforming invasions such as wilding conifers in New Zealand and globally.

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Declarations

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