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ORIGINAL ARTICLE

Compliance with kauri forest protection in New Zealand's regional parks: the mediating role of trust on local versus visitor populations

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Abstract
Realising behavioural change in long invested environmental practices is often difficult to achieve, especially when scientific understanding of the issues is still unfolding. Having confidence in one's action requires knowledge that actions will be effective in improving environmental outcomes. Currently, we know little about the role of social trust in mediating complex and uncertain knowledge of environmental problems and the required actions needed to address them. In this quantitative study, we surveyed 472 users of endangered kauri forests in New Zealand to better explore the role of trust in relation to pro-environmental behaviours (PEB) designed to mitigate effects of the devastating plant disease, kauri dieback. Findings show uncertainty about the scientific knowledge of the issue, recommended actions and efficacy of proposed solutions significantly influenced PEB for both residents and visitors of forests; however, this relationship was partially mediated by trust, particularly among locals residing within 5 km of infected forest areas. These findings indicate the need for closer engagement with local residents to develop institutional and scientific trust in kauri dieback interventions. We outline activities that may help build trust and recommend new areas of research to support higher compliance with environmental protection initiatives.

Keywords Trust · Biosecurity · Protected area management · Pro-environmental behaviours · Scientific uncertainty

Introduction

The ability to influence pro-environmental behaviours (PEB) to protect native forests can be impeded by a lack of trust and uncertainty in actions proposed by conservation science and have implications more broadly for behaviour change initiatives (Chen et al. 2019; Irwin and Berigan 2013; Schultz 2011). Such issues are becoming increasingly important as we look to mitigate and adapt to the effects of climate change (Duff et al. 2022; Kettle and Dow 2016), as well as respond to environmental risks such as pest and disease and their impacts on biodiversity (Niemiec et al. 2017; Pearce et al. 2022). It has previously been recognised that trust is important to the acceptance of forest management practices regarding species protection (Cvetkovich and Winter 2003; Stern 2008; Erickson and Biedenweg 2022). However, the extant research on PEB has typically focused on intentions and attitudes with less known about actual behaviours or specific contexts in which behavioural choices are made (Esfandiar et al. 2022; Steg and Vlek 2009; Xu et al. 2022). Trade-offs between competing values and priorities experienced by individuals and collectives in response to environmental risks such as accessing nature and protecting against human impacts on nature are also less well understood (Cvetkovich and Winter 2003; McShane et al. 2011).

In PEB research, environmental issues that are prominent in terms of biodiversity loss, restoration, and protection of native species have received less attention than consumption and pollution. Although the environmental effects of climate change feature more prominently, studies are limited in terms of analysing actual behavioural antecedents of PEB

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(Duff et al. 2022; Kettle and Dow 2016). Some research that has delved into conservation or environmental protection is often referred to as protected area research (Esfandiar et al. 2022), with mixed results on what types of interventions best encourage PEB (Irwin and Berigan 2013; Pearce et al. 2022; Zhang et al. 2020). More specifically, there has been limited research addressing PEB in relation to threats to native tree species posed by plant pathogens (Aley et al. 2023; Lindsay et al. 2023).

Studies focused on people's relationships with nature are increasing (Chan et al. 2018), exploring a range of nature values (Hoelle et al. 2022; Xu et al. 2022) and different practices impacting nature conservation or protection (Irwin and Berigan 2013; Schultz 2011). These studies are also important for understanding and designing policies in which greater environmental protection can be achieved. However, the effect of policies and regulation on local users and people living within or alongside protected areas also needs to be considered, to enable and support compliance with and commitment to environmental protection. Typically, subjects of PEB research are assumed to be a homogenous group rather than a diverse set of environmental actors driven by sometimes competing interests. Enactors of PEB need to be better understood including whether their values, needs, and motivations are influenced by residential status or geographical proximity to the issue. For example, residents (those living in close proximity to protected areas) may have more at stake and be more likely to suffer the consequences of changes to their immediate environment introduced by environmental protection interventions (including disrupted social practices). Thus, examining behaviour in relation to parks or conservation areas without understanding residential status and type of user (e.g. recreational, vocational, or otherwise) provides an incomplete or inaccurate picture of PEB and its antecedents.

Kauri dieback is a fatal plant disease affecting kauri forests in New Zealand. Kauri trees are an iconic indigenous species that are both culturally significant and socially and economically valued for both instrumental and intrinsic purposes (Lindsay et al. 2023). Kauri dieback is caused by a pathogen (*Phytophthora agathadicida* [*PA*]) first discovered in New Zealand in the early 1970s (Beever et al. 2007) (although originally misdiagnosed), and later observed to lead to kauri tree mortality in a protected regional forest reserve area in the late 1980s (Bradshaw et al. 2020). Since then, the disease has been found in other areas and thought—based on the tracking of the pathogen in soil—to be largely spread through human movement (Lambert et al. 2018). While scientists have made significant progress in understanding kauri dieback, there is ongoing research to further comprehend the disease complexities and develop effective strategies to manage its spread and impact. Despite collaborative efforts involving multiple stakeholders, including scientists, government agencies, conservationists, and the general public, controversy over both the cause of kauri dieback and effectiveness of recommended solutions has impacted public adherence to mitigation measures such as staying on tracks, avoiding closed areas and sterilising footwear (Lindsay et al. 2023). In general, strategies designed to increase compliance have been recognised as largely ineffective (Aley et al. 2023).

A key objective of this research has been to understand the limitations of actions when scientific knowledge of an environmental issue is incomplete or perceived to be incomplete—in this case, knowledge of how and why *Phytophthora agathadicida* is impacting kauri forests. Prior qualitative research examining the values and behaviour of people living with kauri dieback in a peri-urban area of New Zealand—a richly diverse middle range but changing socio-economic mix—led to certain theoretical speculations about the role of trust and uncertainty in relation to the issue (Lindsay et al. 2023). Controversy and tensions between community members and agencies invested in kauri protection are prevalent in local areas (Lindsay et al. 2023). Appreciating that environmental identities based on values (values-based identities) (Stern and Dietz 1994; Stern 2000; Schultz and Zelezny 1998; Schultz et al. 2005) and specific emotional or cognitive attachments to place (place attachments) have been identified as important factors in other literature around conservation and PEB (Hernández et al. 2010; Knez et al. 2020; Ramkissoon et al. 2012), Lindsay et al. (2023) found place attachment was not enough to ensure compliance with local kauri protection measures. Rather trust and uncertainty (institutional and scientific) appeared to impact confidence in kauri protection efforts, even though there was great concern and value for kauri trees in their neighbourhood. The current study expands on these findings by examining the key constructs of PEB, uncertainty, and trust through analysis of quantitative data on kauri protection measures.

Background

Environmental problems are growing, both in terms of their underlying causes but also in terms of social responses and their inadequacy for addressing the scale of impacts (Kettle and Dow 2016; Schultz 2011; Smith and Mayer 2018). Underpinning much of our environmental concern is the separation of people from nature and the normalisation of human constructed environments, increasingly through technological advances that limit opportunity for nature experiences (Riggs et al. 2018; Kothari and Arnall 2019; Truong and Clayton 2020). The instrumental use of nature by humans for extractive or recreational purposes (Bataille et al. 2021; De Vos et al. 2018), and more individualistic approaches to social organisation (Tam and Chan 2018) limit the creation of social norms for environmental protection (Smith and Mayer 2018). Furthermore, in many advanced democracies with market-based governing systems, collective action is deprioritised and, in some cases, delegitimised due to concerns about disruption to the status gained in individual autonomy or freedom of choice (Girerd et al. 2020; Jost et al. 2017).

Improving our relationship with nature relies upon the endorsement and enactment of pro-environmental behaviours (PEBs), defined as "any behavior undertaken with the intention to positively change—or avoid harming—the natural environment" (Lindsay et al. 2023, p.2; see also Steg and Vlek 2009). PEB leads to better environmental outcomes and includes consumer behaviours such as recycling, purchase choices, and transport or energy use (Carrus et al. 2008; Peattie 2010; Ro et al. 2017; Whitmarsh et al. 2018). In the context of nature protection or conservation, PEB can include activities such as nature restoration (Niemiec et al. 2019; Richardson et al. 2020) and control of pests or polluting activities including agricultural or industrial practices (Hine et al. 2020; Linklater et al. 2019; Rezaei-Moghaddam et al. 2020) but also recreational activities such as responsible use of protected areas (Aley et al. 2023; Pearce et al. 2022; Sun et al. 2022). The antecedents of PEB are widely recognised as complex, reliant upon a diverse combination of internal (values, beliefs, knowledge) and external factors (public policy, systems of support, social norms) that are often specific to the context under investigation (Esfandiar et al. 2022; Linder et al. 2021; Steg and Vlek 2009).

At the same time as a growing concern for loss of biodiversity and declining quality of natural environments, trust in science and institutions is declining globally (Kasperson 2014; Marozzi 2014). Defined as a "willingness, in expectation of beneficial outcomes, to make oneself vulnerable to another based on a judgment of similarity of intentions or values" (Earle et al. 2007, p.4), trust is understood as a central element of public order. Yet it is difficult to assess and increasingly difficult to attain and maintain, particularly in the current era of "fake news" or disinformation, misinformation, and information overload (Al-Rawi et al. 2021; Bermes 2021; Prasad 2019). An erosion of public trust has been particularly noted around medical advice (Meyer 2015; Meyer et al. 2014) but also in relation to scientific assessments of risks such as climate change and decision-making around environmental issues (Addison et al. 2013; Smith and Mayer 2018).

In the environmental sphere, Brewer and Ley (2013) explored which key values predicted trust in various sources of scientific information about the environment. Focusing on political ideology and support for environmental regulation, they looked at whether and what political values predicted trust in scientists and how specific sources impacted on scientific credibility of information. They found that trust varied across different sources of scientific information and with the predictor variables they found conservative political ideology expressing less trust in scientists. They also found religious participation negatively predicted trust in science relations; and that trust in government was not significantly related to trust in scientists. The results were consistent with the premise that trust judgements reflect similarity of values (Earle et al. 2007; Siegrist and Cvetkovich 2000; Siegrist et al. 2002). One pattern suggested by these results was that declining general trust in government may damage credibility of some science information providers if they were thought to be aligned with government (Schroeder et al. 2021). In a similar trust-based study exploring the influence of values on science and policy, Cologna et al. (2022a, b) found greater acceptance of values in categorical sense (defining values) and less acceptance of the expression of scientists' values in an instrumental sense (applying values). In other words, people are happy for scientists to determine the state of things, but not to be the author of policies or programmes. This is a challenge for science-driven policy when facts are influenced by or influential on values (Resnik and Elliott 2016; Dietz 2013). A better understanding of the effect of new knowledge or science on values is an important dimension for engaging diverse publics in policy change or design of new policies, e.g. on climate change or in response to new pests or pathogens.

Sharp et al. (2013) reported on research conducted in Australia following bushfires in the North East region of Victoria in 2006–2007. Common themes in previous research on trust were noted, including uncertainty, vulnerability, risk, expectations, and interdependence of trusting parties. Community members defined trust in several ways including something that is present within or resulting from a constructive relationship between communities and agencies, such as law enforcement through policing. Being able to rely on someone or something to happen when norms are disrupted is important to trusted relationships between communities and public services, e.g. during disaster or crisis. In contrast to quantitative studies, Sharp et al. (2013)'s qualitative findings did not see trust as an antecedent but existing in a specific relationship with uncertainty. Yet reduction of uncertainty in a bushfire setting played an important role including in personal confidence or self-reliance in judgement of risk. Furthermore, information provision through one-way communication was important for when people needed to know how to act under risk conditions. The more comprehensive or complete that information, the more it helped to strengthen community-agency trust. This highlights the importance of trusted relationships during crisis events, and how under urgency, there is little time to build such relationships.

Trotsuk's (2016) examination of trust identified key elements for the sociological study of trust as cause and effect, as well as determinants, types, and levels of trust. In this case, trust is viewed as coping with uncertainty. Exploring different methods of trust analysis, Trotsuk (2016) emphasises the importance of narrative and understanding how we discursively construct problems and their solutions as critical to building trust. Thus, trust may not be something developed externally of people's experience. Social interactions are a core element that underpin determinants of trust (Singh 2012). As indicated by Esfandiar et al. (2022), we need to consider what matters to people in different contexts of trust relations (Trotsuk 2016). Van Noort and Schotanus (2015) also note the value of developing solutions socially, arguing that social innovation (e.g. where changes in programme delivery are designed with communities) can assist with managing uncertainty. Building and maintaining trusted relations are important. It is the interactive aspects of trust that lead to or help build and maintain social order and confidence in decisions that are made (Dietz 2013). When trust is breached and expectations not met, there is need for repair if a continuing relationship is desired.

Underpinning many failures in communicating risk is the salience of trust (Earle et al. 2007; Kasperson et al.1999; Slovic 1993). Kasperson (2014) and others (Fischhoff 1995; Leiss 1996; Renn 2014; Siegrist 2014) have long established knowledge through research on communicating risk that perceptions differ between lay persons and scientists. These authors and others show, for example, how it is not just access to knowledge or information (Frewer 2004; Renn and Levine 1991) but the different kinds of concerns (Cvetkovich and Nakayachi 2007; Hyer and Covello 2017; Poortinga and Pidgeon 2003) and confidence that risk is adequately being managed (Earle 2010; Lofstedt 2012; Siegrist et al. 2005; Slovic 1999) that distinguish between scientific understanding and public perceptions of risk. Despite the extensive research conducted on risk perception and communication (including relationships of trust), changes in practice have been limited (Árvai 2014; Kasperson 2014; Siegrist 2014). Bostrom (2014) argues that there has been greater evidence, new strategies, and improved efforts to communicate uncertainty. However, recognising that scientific knowledge and associated uncertainties play a role in communicating risk but not the only role in alleviating public risk concerns is an important precondition to effectively communicate risk (Árvai 2014; Fischhoff 2014). Rickard (2019), for example, argues a dual function for risk communication to send direct messages and to recreate the meaning of risk in each social context. Appreciating the systemic failures of engaging people through scientific communication of risk needs to be better considered in environmental psychology and development of PEB. In this study, we take steps towards understanding the relationship between trust, uncertainty, and PEB in a specific setting, as a basis for further exploring these relationships in other contexts.

We explore trust in a context where PEB is recommended in absence of well-developed and widely accepted scientific knowledge of the environmental issue. We do not assume an accepted level of public confidence in science will guide actions but instead situate science in a network of relationships that both reveal and conceal certain aspects of the problem. In this case, understanding of kauri dieback is evolving alongside the implementation of strategies to address it. This dynamic interaction bears resemblance to other intricate environmental challenges, such as climate change.

We also recognise that forest users are not a homogenous group, and differing audience segments may be influenced by different values, needs, and motivations. Based on objective observations and intercept surveys at 15 different locations, Aley et al. (2023) noted that various kauri dieback compliance interventions were only partially effective. Furthermore, differential impacts were noted between visitor and local populations suggesting that socio-cultural influences (values, norms, identities, beliefs), perhaps driven by proximity to the issue, requires deeper examination (Esfandiar et al. 2022). Specifically, we wanted to explore aspects of knowledge about kauri dieback, understanding of how kauri dieback works, and perceived efficacy of interventions relative to scale items of trust and PEB. Thus, we focused on two key research questions.

Q1: When knowledge is uncertain, what role does trust play in influencing PEB? Do people comply or not depending on their trust in science and institutions?
Q2: Secondly do people as residents living close to an environmental issue differ in their PEB, level of trust, and uncertainty compared to visitors?

Method

Study design Titirangi is a small peri-urban community situated within a kauri protection area and a suburb of Auckland which is nested within and adjacent to the Waitakere Ranges, one of the kauri forested sites in New Zealand. It was the original site for qualitative research from which we deduced core aspects of our survey methods. This community was selected because of anecdotal evidence that local community residents were not complying with kauri protection measures. Our quantitative research was designed to test that assumption within Titirangi and other communities close to infected kauri forests (IKF) as well as collect data from those who travelled from other areas of New Zealand to visit IKF (Fig. 1). Assignment to either the local or visitor group was determined by the residential postcode entered by

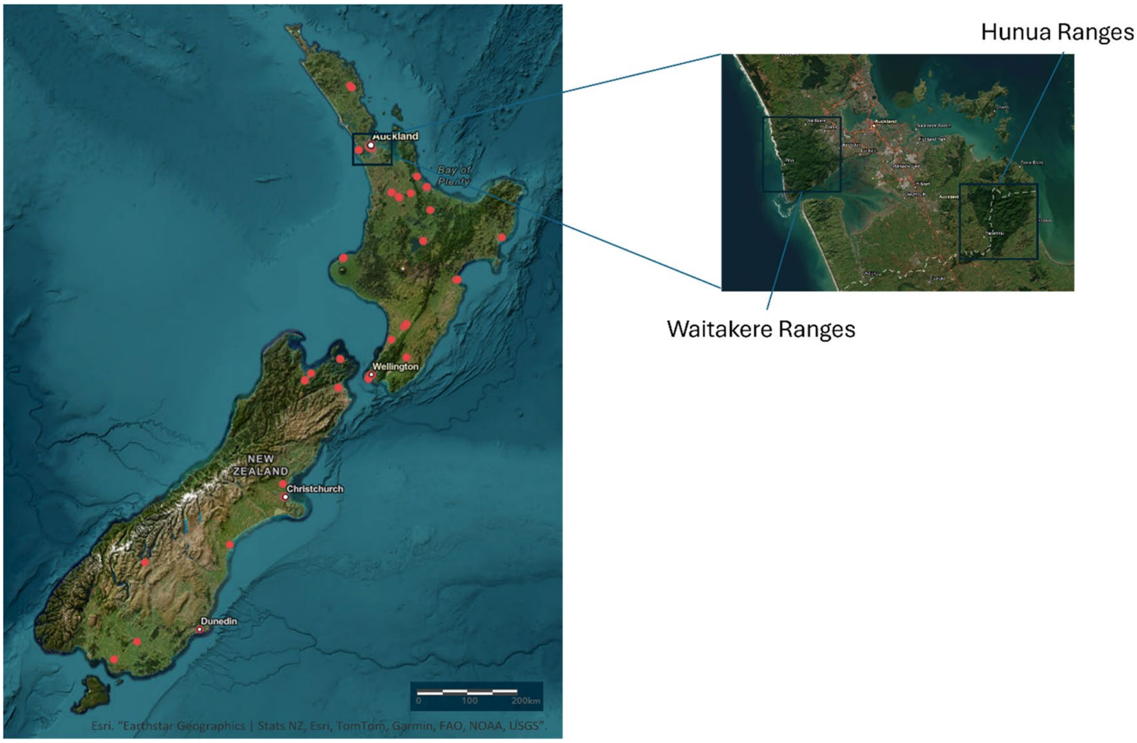

Fig. 1 Map of New Zealand showing postcodes entered and forest areas (inset) visited by participants (Esri. "Earthstar Geographics | Stats NZ, Esri, TomTom, Garmin, FAO, NOAA, USGS" Postcode locations of sampled population (arcgis.com) (June 23, 2024))

the participant. Those residing in areas within 5 km of an IKF were deemed to be local. Those residing outside these areas were deemed to be visitors.

Procedure Prior to data collection, ethics approval was obtained by the University of Canterbury Human Ethics Committee (Ethics no. HREC 2022/12/LR). Data collection occurred via an online questionnaire developed using the Qualtrics software, accessible via a weblink. The link was posted across various Facebook community sites based in Titirangi and was shared via professional and acquaintanceship networks over a 3-month period. Approximately 600 flyers advertising the research were also distributed via a letterbox drop in the Titirangi area and posted on community noticeboards. The flyer included a QR code (barcode) providing immediate access to the questionnaire via smart phone. Other locations throughout New Zealand (representing the visitor sample) were recruited via a targeted Qualtrics recruitment panel. Informed consent was electronically obtained prior to participants completing the questionnaire.

Participants In total, 472 members of the general New Zealand population aged 18 years and older completed the survey. One hundred and thirty participants formed the local resident group, and 342 formed the visitor group.. All participants reported having accessed a protected kauri forest (e.g. the Waitakere or nearby Hunua Ranges in the North Island of New Zealand) over the previous 4 years. The total sample had a mean age of 40.90 years (local, 48.53; visitors, 37.99 years). The majority (60.6%) of participants were female (locals, 63.80%; visitors, 59.40%). For the overall sample, 30.8% had a professional or post-graduate degree (locals, 53.8%; visitors, 23.4%), 25.4% had an undergraduate degree (locals, 20%; visitors, 27.5%), 42.6% had a high school diploma or trade certificate (locals, 26.2%; visitors, 48.8%), and 0.3% had no qualifications (locals, 0%; visitors, 0.2%). The majority (83.7%) of participants accessed the forest for recreational purposes, 6.8% were landowners with kauri on their property or lived in the forest, 5.3% were incidental users (shortcuts/commuting between locations), 3.6% were vocational users, and 0.6% indicated other.

Measures

The survey was composed of key demographic questions and several measures assessing pro-environmental behaviours, environmental uncertainty, and environmental trust (Appendix A).

Pro-environmental behavior Pro-environmental behaviour (PEB) in relation to kauri dieback was assessed according to whether the participant adhered to two key mitigation strategies aimed at preventing the spread of the PA pathogen: boot cleaning and track usage (staying on tracks and avoiding closed areas). The 7-item measure captured responses via a Likert-type scale ranging from 1 (*never*) to 5 (*always*). Examples items included "When accessing the forests in the Waitakere and/or Hunua Ranges, I avoid walking on the closed tracks" and "When visiting the forests in the Waitakere and/or Hunua Ranges, I clean all the soil off my footwear at the boot cleaning stations". Responses were summed to yield an overall total score, with higher scores indicating a greater level of adherence, or PEB. A Cronbach alpha score indicated a high level of internal reliability ($\alpha = 0.86$).

Uncertainty Uncertainty regarding the science of kauri dieback, the effects of kauri dieback, and perceived effectiveness of current solutions was based on the 4-item Uncertainty subscale of the Psychological Distance measure developed by Spence et al. (2012). Wording was modified slightly to suit the current context. For instance, the words "climate change" were changed to "kauri dieback". Example items included "In my opinion, the science about kauri dieback and its effects is far from settled" and "I am uncertain whether current strategies to manage kauri dieback are effective". These questions were supplemented by two additional items developed for the current study, specifically relating to effectiveness of kauri dieback interventions, for example, "I am not confident that my boot cleaning behaviour can make a difference to kauri dieback". Using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), a total score was calculated with higher values indicative of a greater level of uncertainty. A Cronbach alpha score indicated an acceptable level of internal reliability (Cronbach's $\alpha = 0.68$).

Trust Public trust in scientists and local government authorities was assessed using an 8-item measure adapted from Kettle and Dow's 13-item questionnaire tapping scientific and institutional trust in relation to climate change (Kettle and Dow 2016). The questions included in the present research were selected according to findings of prior qualitative research conducted by the current authors (i.e. questions deemed to be most relevant), with wording adapted to suit the context. For instance, the question "Scientists have the necessary skills to predict how climate will change" was changed to "Scientists have the necessary skills to predict the effects of Kauri Dieback". A 5-point Likert scale was used, with values ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). A global trust score combining the two was calculated as well as scores for each dimension of trust—scientific and institutional trust. Higher scores indicated a greater level of trust. Alphas for the total scale were 0.69, 0.68, and 0.63 for total scores, institutional trust, and scientific trust respectively, indicating slightly marginal but adequate levels of reliability.

Table 1 Total sample range, means, standard deviations (SD), and Cronbach's alphas (α) for pro-environmental behaviour (PEB), uncertainty, global trust, and institutional and scientific trust in relation to kauri dieback

Measure	Range	Total mean (SD)	α
PEB ($N = 460$)	9–35	31.08 (4.84)	.86
Uncertainty ($N = 369$)	9–30	18.24 (4.06)	.68
Trust ($N = 460$)	10–38	26.13 (4.68)	.69
Scientific	4–20	13.93 (2.76)	.63
Institutional	4–20	12.20 (3.06)	.68

Table 2 *T*-test results for pro-environmental behaviour (PEB), uncertainty, global trust, and institutional and scientific trust in relation to kauri dieback according to local (resident) and visitors groups

Measure	Resident Mean	Visitor Mean	*t*	*df*	*r*
PEB	31.14	31.13	− 0.012	343	− 0.00
Uncertainty	18.97	18.17	− 1.32	139	− 0.18
Trust	24.16	26.24	3.60**	175	0.42
Institutional	10.11	12.25	6.53**	458	0.69
Scientific	14.05	13.99	− 0.167	166	− 0.02

$^{*}p < .05$ $^{**}p < .001$

Effect sizes: $r = .10$ is considered small, $r = .30$ is considered medium, and $r = .50$ is considered large

Analysis

Data were analysed using SPSS version 27. Pearson's correlation coefficients, ANOVAs, and *t*-tests assessed associations between the scales, differences between visitor and local resident groups, and relationships with demographic variables. Multiple Linear Regressions and Simple Mediated Regressions analysed the relationship between trust, uncertainty, and PEB, and determined the predictor variables for PEB.

Results

Table 1 outlines the range, means, standard deviations, and Cronbach's alphas for each measure. For example, the range of scores for 7 items measuring PEB was 9–35, total mean was 31.08, and standard deviation was 4.84. Table 2 shows the *t*-test results for each measure including Pearson's correlation and effect sizes.

Pro-environmental behaviour

Demographic differences

One-way ANOVAs, *t*-tests, and Pearson's correlations assessed relations between demographic variables and PEB scores. For the total sample, a significant positive correlation was found for age and overall PEB scores ($r = 0.12$, $p = 0.008$), with older participants reporting greater adherence to the rules, with small effect. A two-tailed *t*-test also found significant differences by gender, with females more likely to enact PEB ($t(198) = -3.92$, $p < 0.001$, $r = -0.48$), with medium effect. A one-way ANOVA highlighted significant differences between type of forest user and PEB, $F(4, 454) = 6.15$, $p < 0.000$, $\eta^2 = 0.05$) with small effect. Tukey's post hoc analysis showed incidental users (M = 3.96) and vocational users (M = 3.96) had significantly lower means than recreational users (M = 4.52), suggesting these groups were less likely to adhere to the rules.

For the local sample, the significant difference by gender remained, with very large effect, $t(40) = -3.01$, $p < 0.001$, $r = -0.80$; however, there was no correlation between age and PEB. For visitors, a significant positive correlation was found for age and PEB with moderate effect ($r = 0.19$, $p < 0.003$). A *t*-test also found a significant difference by gender, with female visitors more likely to enact PEB ($t(168) = -2.50$, $p = 0.012$, $r = -0.35$) with medium effect.

Locals vs visitors

No significant differences were found between locals and visitors in terms of PEB.

Uncertainty

Demographic differences

For the total sample, males were more likely to report feelings of uncertainty ($t(365) = 2.74$, $p < 0.006$, $r = 0.29$) with small effect. Those with lower levels of education were also more likely to feel uncertain ($r = -0.11$, $p < 0.04$), with small effect.

A one-way ANOVA found significant differences between type of forest user and uncertainty, $F(4, 363) = 4.22$, $p < 0.002$, $\eta^2 = 0.04$) with small effect. Tukey's post hoc analysis showed incidental users (M = 22.32) had significantly higher mean scores than recreational users (M = 18.22), vocational (M = 17.09), and landowners (M = 17.90) suggesting incidental users had higher levels of uncertainty than other groups.

For locals, there were no demographic differences for the variable of uncertainty.

For visitors, there was a significant difference by gender ($t(264) = 2.33$, $p < 0.02$, $r = 0.29$) with small effect, suggesting male visitors had greater levels of uncertainty.

Locals vs visitors

An independent samples *t*-test was conducted to assess for any statistical difference between the sample mean of visitors and locals. No significant difference between groups was found, suggesting locals and visitors had approximately similar levels of uncertainty with respect to kauri dieback. Both groups demonstrated slightly above mid-scale levels of uncertainty.

Uncertainty and pro-environmental behaviour

A significant negative correlation was found for uncertainty and PEB total scores, suggesting greater feelings of uncertainty resulted in lower adherence to kauri management interventions, with moderate effect ($r = -0.31$, $p < 0.001$).

Trust

Demographic differences

For the total sample, males had less trust in science compared to females ($t(309) = -2.84$, $p < 0.005$, $r = 0.74$) with very large effect. There was also a positive correlation between age and trust in science with small effect ($r = 0.11$, $p < 0.02$), and a small positive correlation between education and trust in science ($r = 0.11$, $p < 0.02$). These findings suggested older females with higher levels of education were more likely to trust the science of kauri dieback.

Trust was also significantly, positively correlated with geographical distance from the nearest infected kauri trees (determined by postcode), ($r = 0.17$, $p < 0.001$) with small effect, suggesting the closer the participant lived to an infected kauri area, the less trust they had. In particular, trust in institutions decreased with reduced distance ($r = 0.29$, $p < 0.001$).

Locals vs visitors

A significant difference was found between locals and visitors. An independent sample *t*-test revealed visitors had a higher level of overall trust with medium effect, $t(175) = 3.60$, $p < 0.001$, $r = 0.42$) and higher institutional trust with large effect, $t(458) = 6.53$, $p < 0.001$, $r = 0.69$).

Trust and pro-environmental behaviour

For the total sample, trust was positively correlated with PEB ($r = 0.27$, $p < 0.001$) with small effect, suggesting higher trust resulted a greater adherence to the rules. Scientific trust was significantly, positively correlated with PEB ($r = 0.31$, $p < 0.001$) with medium effect. No correlations were found between PEB and institutional trust.

For locals, the relationship between trust and PEB was more pronounced. A moderate, positive correlation between PEB and total trust scores ($r = 0.46$, $p < 0.001$), and PEB and scientific trust ($r = 0.45$, $p < 0.001$) was observed. A significant positive correlation between PEB and institutional trust with small effect was also evident ($r = 0.23$, $p < 0.001$).

For visitors, a small, positive correlation between PEB and total trust scores ($r = 0.15$, $p < 0.02$) and scientific trust ($r = 0.22$, $p < 0.001$) was observed.

For the local sample, a significant negative correlation was also found for trust scores and uncertainty ($r = -0.46$, $p < 0.001$) with moderate effect, indicating those with greater uncertainty had lower trust, and/or vice versa. Table 3 outlines Pearson's correlation coefficients between measures.

Predictor variables for pro-environmental behaviour

Standard Multiple Linear Regressions were performed to determine what factors predicted greater PEB for the overall sample, locals, and visitors. Due to their significance at the bivariate level, the independent variables of trust, uncertainty, age, gender, education, and forest user type were entered into each model using the enter method. For the total sample, results indicated these variables explained 13.7% of the variance in PEB scores, ($R^2 = 0.14$, $F(5{,}362) = 11.47$, $p < 0.001$). For locals, these variables explained 24.9% of the variance ($R^2 = 0.25$, $F(5{,}100) = 5.25$, $p < 0.000$). For visitors, the variables explained 11.2% of the variance ($R^2 = 0.11.2$, $F(4{,}283) = 8.80$, $p < 0.000$). Table 4 shows the factors that contributed significantly to each model.

A simple mediated regression (Hayes 2018; Preacher and Hayes 2004) was conducted to better explore the role of trust in the relationship between uncertainty and PEB for the total sample. With PEB entered as the dependent variable, the overall model for the total effect was significant, $F(2, 457) = 19.64$, $p < 0.001$, $r^2 = 0.08$. Results showed that the relationship between uncertainty and PEB was partially mediated by trust. As Fig. 2 illustrates, the standardised regression coefficient between uncertainty and trust scores was statistically significant ($p < 0.001$), as was the standardised regression coefficient between trust scores and PEB scores ($p < 0.001$). There was a significant indirect effect of uncertainty on PEB mediated by trust, $b = 0.06$, 95%, CI [−0.04, −0.01].

Table 4 Multiple linear regression for pro-environmental behaviour (PEB)* and uncertainty, forest user type, trust, and demographic variables

Predictors	*B*	*Std. Error*	*Beta*	*t*	*p*
PEB total sample					
Age	0.006	0.002	0.130	2.590	0.010
Gender	0.147	0.067	0.109	2.174	0.030
Education	0.002	0.031	0.003	0.055	0.957
Forest user type	− 0.046	0.035	− 0.064	− 1.289	0.198
Trust	0.126	0.059	0.118	2.129	0.034
Uncertainty	− 0.036	0.008	− 0.239	− 4.275	0.000
PEB visitors					
Age	0.006	0.002	0.146	2.454	0.015
Gender	0.091	0.075	0.073	1.212	0.227
Education	− 0.011	0.035	− 0.019	− 0.325	0.745
Forest user type	− 0.058	0.061	− 0.057	− 0.952	0.342
Trust	0.041	0.069	0.038	0.599	0.549
Uncertainty	− 0.038	0.010	− 0.236	−3.665	0.000
PEB locals					
Age	0.005	0.005	0.091	0.947	0.346
Gender	0.287	0.154	0.175	1.859	0.066
Education	0.026	0.073	0.034	0.359	0.720
Forest user type	− 0.063	0.053	− 0.115	−1.190	0.237
Trust	0.321	0.124	0.296	2.594	0.011
Uncertainty	− 0.024	0.015	− 0.177	−1.559	0.122

*Staying on designated tracks and boot cleaning

Discussion

While other interacting factors such as gender and age significantly predicted PEB in our overall sample, trust appeared to play a significant role in influencing people's attitudes, beliefs, and actions, particularly under conditions of uncertainty. Our findings continue to suggest that both scientific and institutional trust are integral for encouraging uptake of environmental protection strategies (Brewer and Ley 2013; Cologna et al. 2022a, b). In the current study, this was especially important for local residents, who demonstrated significantly lower institutional trust compared to

Table 3 Pearson's correlation coefficients for pro-environmental behaviour (PEB), uncertainty, global trust, and institutional and scientific trust in relation to kauri dieback

	PEB	Uncertainty	Trust	Institutional trust	Scientific trust
PEB	1				
Uncertainty	− 0.313**	1			
Trust	0.266**	− 0.461**	1		
Institutional trust	0.103*	− 0.263**	0.815**	1	
Scientific trust	0.331**	− 0.474**	0.778**	0.270**	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

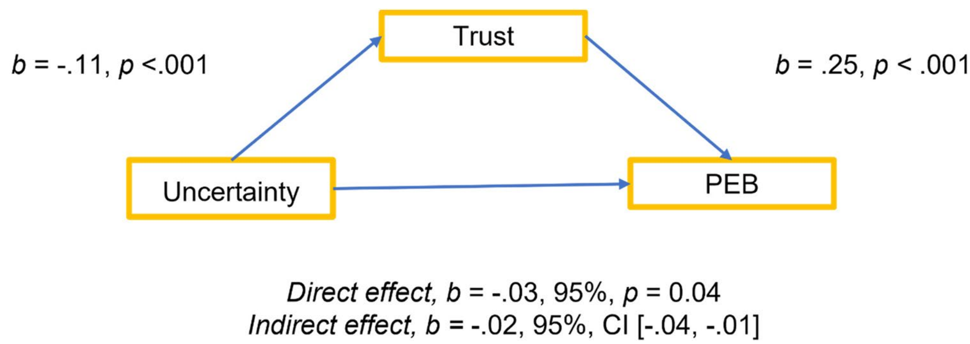

Fig. 2 Model of uncertainty as a predictor of pro-environmental behaviour (PEB), partially mediated by trust (the confidence interval for the indirect effect is a BCa bootstrapped CI based on 5000 samples)

visitors, to the extent that trust was the only significant predictor of local behaviour. Moreover, trust was significantly, positively correlated with geographical distance from the nearest infected kauri trees—in other words, trust decreased the closer the individual was to the issue. These findings indicate a greater need to consider the impacts of interpersonal and institutional trust on PEB. Presumably, proximity to the issue results in greater exposure to community dialogue about the matter, whether peer to peer or through local institutional networks. If the communication is poor, inconsistent, or conflicts with personal values, an erosion of trust may occur (Cologna et al. 2022a, b; Cvetkovich and Winter 2003; Kasperson et al. 2010). Trust in science may be more related to the institutional setting in which knowledge is being used. However, in a small country such as New Zealand, interpersonal relations and peer persuasion may also influence trust in science. Word of mouth and hearsay narratives about environmental issues may carry more weight and influence among smaller audiences (Maki and Raimi 2017; Southwell and Murphy 2014).

Given knowledge about kauri dieback is still evolving, understanding how to build and maintain trust under conditions of uncertainty seems important. Smith and Mayer (2018) hypothesised that trusting individuals will more likely take PEB actions in responding to climate change, and that in societies that are more trusting, climate action is more common (p. 142). However, they found that high trust can blunt the effects of risk perception, or uncertainty, that might otherwise lead to precautionary PEB to address climate change. Smith and Mayer (2018) were specifically interested in the interrelated nature of trust and risk perceptions to understand patterns of collective action. Whilst they examine two forms of trust—social (interpersonal) and institutional—alongside risk perception, they discuss the interactions between trust and risk perception known as a “social trap” (Rothstein 2005) on policies and behaviours. While they found insignificant interaction between risk perception and trust on policies, they did speculate that an independent and additive relationship may exist between risk perception and trust. They found the converse of a social trap where risk perception mediated the positive effect of social trust on behaviours, but that institutional trust negatively interacted to reduce the effect of risk perception on behaviours (Smith and Mayer 2018, p. 148). We take this as a cautionary signal for local communities living in proximity to kauri forests and the importance of building trustworthy relationships with authorities and scientists.

The need for more engaged approaches when working with low systems knowledge (the specifics around the environmental problem and how it works) is important not just for issues like kauri dieback where knowledge is still evolving but also for wider societal changes, e.g. in response to climate change. Trotsuk (2016) has found the need to consider deliberative approaches for building trust, as does Dietz (2013) to bring factual knowledge together with value-based assessments, including the use of narrative to analyse and develop understanding between local actors and decision-makers,. The research by Sharp et al. (2013) on bushfire in Australia found that trust is not a static concept but evolves through different stages of threat and its management. Although this is likely to be different for non-emergency situations, such a processual view of trust invites thinking about when trusting relationships can be facilitated, both in early stages of threat, as a well as at times when they need urgent attention. Perhaps the same applies for environmental protection, especially as it impinges on lifestyles and practices of kauri forest users. Trotsuk (2016) cautions not to separate interaction-based trust from institution-based trust as both views are needed for a thorough analysis. Trotsuk (2016) and Dietz (2013) both indicate that skills in interaction as well as appreciating the limits of knowledge are important in building trust. For agencies and scientific communities involved in protection of kauri forests, more time needs to be invested with local communities to build understanding and levels of confidence in measures to protect kauri forests..

Dietz (2013) argues that when communicating science, we need to think more about the social learning of interactions that help with interpreting factual information and for appreciating local values. Values can underpin differences in preferences over one course of action or another. Greater transparency and open processes for reporting scientific results may be required to help build confidence in science and institutions. Ensuring public input to the types of questions addressed by research and having early engagement with scientists and decision-makers are important to building and maintaining trust. Allowing for a range of values to influence decision-making can also be important to accompanying scientific knowledge. Furthermore, Dietz (2013) argues that we need to ensure that value-based arguments are carefully differentiated from scientific assessments. Clarity may be needed to demonstrate where proposed actions are grounded in both an understanding of facts and of their impact on values.

These findings have implications for other contexts of uncertainty such as the development of new genetic technologies (Kjeldaas et al. 2022) and climate change (Cologna et al. 2022a, b). Understanding the relationships between trust, uncertainty, and PEB in different contexts, particularly the interactions between trust and uncertainty, will help with the design of policies for encouraging PEB. Deepening understanding of trust and uncertainty will help build confidence in participatory democratic processes, not just when managing and mitigating the effect of plant pathogens on forests but for other controversies involving scientific uncertainty and public trust. Subsequent opportunities to influence wider social or environmental outcomes and build relationships for nature protection will benefit from understanding the relationship between trust and uncertainty with differently impacted human populations.

Limitations

Several limitations of this study must be acknowledged. Notably, survey findings were reliant upon self-selected samples and self-reporting. Given our topic investigates environmental behaviour that could potentially involve breaking the law or displaying anti-social tendencies, participant responses may have been prone to social desirability, or the desire to present oneself in a more favourable light (Vesely and Klöckner 2020). Although the anonymous nature of the survey may have offset some of these effects, perhaps providing a more accurate reflection of behaviour than direct in-person surveying, the possibility of response bias must be considered. Similarly, self-selection may have introduced biases, with participants interested in kauri protection more likely to respond. Recruitment of a sufficient sample of residents presented difficulties, taking much longer than expected despite the use of multiple recruitment channels. This possibly reflects general audience fatigue related to kauri dieback (Aley et al. 2023), alongside growing disinterest with the topic. Kauri dieback is recognised as a controversial issue in Titirangi and tensions between community members and agencies invested in kauri protection are high (Lindsay et al. 2023). Data may therefore be skewed in favour of PEB, reflecting a higher rate of compliance than what might be gathered using probabilistic samples or observational methods.

Conclusion

We explored the influence of trust and uncertainty on PEB within the context of biosecurity, specifically the protection of indigenous kauri trees in New Zealand. As new environmental risks emerge and their impacts become clearer, there is a growing need to understand how to effectively promote compliance with protective initiatives, even when the science is still evolving. Previous research has identified but not determined the complex interplay between trust and uncertainty in influencing PEB. We found trust to partially mediate the relationship between uncertainty and PEB in the context of kauri dieback, with trust significantly determining PEB in local residents. Moreover, the need for trust, particularly institutional trust, appeared especially important for those closest to the issue. Loss of trust in institutions is often a reflection of poor or a lack of engagement with members of the public, and poor understanding of the contexts in which they experience interventions for environmental protection.

Currently, trust is a weakly appreciated dimension in supporting PEB for protected areas and needs further exploration for PEB more broadly. We recommend the development of future research that can test this behavioural model against other explanatory models in different contexts of environmental problems. Furthermore, we suggest that systems knowledge (knowledge of the causes and effects of the environmental issue) needs to be more strongly considered in relation to PEB, and as a factor influencing the success of any environmental intervention. Finally, current approaches to community engagement for complex environmental problems need to build capacity for engaging with mixed and diverse communities. Our study of residential and visitor communities as well as various user types revealed differential impacts on PEB. These disparities underscore the need for more comprehensive exploration of subpopulations in future research endeavours.

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Data Availability The data that support the findings of this study are available from the corresponding author [AG] upon reasonable request.

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