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ORIGINAL PAPER

Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments

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Abstract Invasions by invasive non-native species (INNS) can have profound consequences for natural environments, impacting on biodiversity and the biophysical landscape in ways that can endanger other species, human wellbeing and infrastructure. The financial costs of dealing with established INNS populations can be extremely high. Biosecurity measures (simple procedures designed to reduce the risk of human activities spreading INNS to new areas) are being promoted in order to minimize these negative impacts and associated costs. This paper reports on research undertaken with stakeholder organisations that operate within UK natural environments. It aims to evaluate stakeholder perceptions of their role in INNS biosecurity practice in the UK, and the implications of this for INNS strategy more broadly. Semi-structured interviews were undertaken with organisation representatives to explore current practices and communications about INNS and perceptions of barriers and opportunities to implement better biosecurity. Whilst participants generally agreed on the need for biosecurity, there were variations among participants in levels of knowledge about INNS (related to background) and the capacity of organisations to engage in biosecurity practices (related to organisational size). Critical barriers to biosecurity were identified as costs, lack of clear guidance, difficulties changing attitudes and implementing collective responsibility, and reactionary versus precautionary approaches. As a result, partnership working on INNS is difficult and action tends to focus on individual species perceived as the most threatening to a particular organisations' interests. In this way, action on INNS biosecurity faces the kinds of barriers that are common to many environmental problems where individuals/organisations prioritise self-interest despite the potential to obtain greater benefits if collective action could be achieved.

Keywords Invasive non-native species · Perceptions · Social barriers · Collective action · Biosecurity · Awareness

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Introduction

Invasive non-native species (INNS) are plants and animals that have been purposefully or accidentally introduced, mainly by human activity (Anderson et al. 2014b), to areas outside of their natural range and have the ability to spread causing damage to the environment, the economy, human health and the way we live (GBNNSS 2015). The term is equivalent to the term

Invasive Alien Species used by the IUCN, and may also be used to encompass non-native microbes such as bacteria, viruses and fungi, which negatively impact human, animal and plant health. INNS are increasingly recognised as a significant and potentially very costly threat to environments across the globe, with efforts to control and prevent harm from their growing populations estimated to run into billions of dollars (Anderson et al. 2014b; Mcleod et al. 2015).

Biosecurity is key to preventing and/or slowing the spread of INNS. Biosecurity refers to protection against biological threats (Armstrong and Ball 2005) and is the term given to measures designed to prevent the spread of INNS to new areas. Essentially it involves employing simple hygienic practices including the use of duplicate sets of equipment and employing cleaning measures that ensure environment users do not transfer INNS propagules [individuals released into an environment where they are not native (Lockwood et al. 2005)] between sites on their equipment, vehicles, clothing and footwear (Dunn and Hatcher 2015; Anderson et al. 2014b). The potential gains from achieving widespread adoption of effective biosecurity measures are clear. By preventing the spread of INNS in the first place we can avoid damage to the environment and the expense of implementing control measures, along with the associated ethical complexities concerning extermination. Whilst controls that eliminate INNS in their entirety from invaded areas can be successful, particularly in island contexts, control measures do not always succeed in fully eradicating invaders from areas where they have become established, can themselves cause environmental damage, and do not necessarily result in the successful re-establishment of the native ecosystems that existed prior to invasion (Zavaleta et al. 2001). By contrast, biosecurity avoids these problems and therefore presents a much more attractive option. However, as with any new technology, idea or approach, getting people to adopt biosecurity measures involves a gradual process of behaviour change which may take time to be adopted as a social norm (Rogers 2003). The complexity of social values and very high levels of uncertainty surrounding INNS management (Liu et al. 2011) are likely to complicate the adoption of biosecurity measures by stakeholders.

Regulation 1143/2014 on Invasive Alien Species is the first piece of EU legislation on biodiversity for more than 20 years and entered into force in 28 States on 1st January 2015. Within the regulation three types of intervention are described (prevention, early detection and eradication), and management and co-ordination of responses to INNS, especially across national boundaries, is strongly advised (Genovesi et al. 2015). Biosecurity measures operate at the prevention stage, by reducing the risk of transferring INNS to new areas.

In the UK a large number of terrestrial and aquatic plant and animal species are considered to qualify as INNS and official steps have been taken by government to build capacity to identify and monitor them, undertake control measures and prevent their spread to new areas, most notably through the creation of the GB non-native species secretariat (GBNNSS) in 2006. Recent campaigns launched by Defra (The UK Department for Environment, Food and Rural Affairs) to encourage public awareness and action on INNS include Check Clean Dry (www.nonnativespecies.org/checkcleandry/) and Be Plant Wise (www.nonnativespecies.org/beplantwise/). Check Clean Dry is aimed at encouraging watercourse users to employ measures to prevent the transfer of aquatic INNS to new areas, with users advised to check their equipment and clothes for the presence of animal or plant fragments, clean them and ensure items dry out thoroughly in between visits to aquatic sites. Be Plant Wise is aimed at pond owners, gardeners and the horticultural trade in aquatic plants for ponds and aquariums and seeks to raise awareness of the negative impacts that can result from allowing ornamental aquatic plants to spread into the wild.

Over the last decade the tide of literature concerning INNS issues has risen, with many articles focusing on questions of ecological and evolutionary interest including species and environmental traits contributing to invasiveness and invasibility (van Kleunen et al. 2010), the consequences of genetic bottlenecks for invading populations (Dlugosch and Parker 2008; Simberloff 2009) and the potential impacts of changes to climate upon invasions (Broennimann et al. 2007; Rahel and Olden 2008). However, despite clearly constituting a socio-ecological problem, to date relatively little has been published about the social dimensions of INNS (García-Llorente et al. 2008) and the influence of humans on the incidence and outcome of invasions. Recent studies have investigated the behaviours of recreational users of

waterways in relation to the spread of INNS (Anderson et al. 2014b) and the attitudes and beliefs of recreationists in relation to behaviours that reduce the spread of INNS (Prinbeck et al. 2011). However, where social issues are considered, the majority of research has concerned control measures rather than prevention, with research often exploring public support for action on existing INNS (Schüttler et al. 2011; Shine and Doody 2011). To date research has yet to investigate the attitudes of organisations, which represent key stakeholders working in natural environments, to biosecurity and preventing the spread of INNS.

Today's globally burgeoning INNS problem is closely related to ever-proliferating levels of human cross-global trade and travel (Bradley et al. 2012; Tobin et al. 2013), and its solutions are likely to face collective action problems. Collective action problems occur when there is conflict between individual and group interests and are widespread in relation to the environment. Individual selfish actions often harm the environment whereas groups benefit from environmental protection, and it often requires groups of people to work together to achieve positive outcomes (Ostrom 1990). Introduction of INNS may result from the actions of only one individual, whereas biosecurity practice will require both individuals and organisations to work together to prevent the spread of INNS.

Here we report on research undertaken with UK stakeholder organisations to better understand biosecurity's current role and future potential in INNS action in the UK. Our aim is to evaluate stakeholder perceptions of their role in INNS biosecurity practice in the UK and the implications for INNS strategy by: (1) exploring awareness and perceptions of INNS risk amongst participants; (2) exploring perceived barriers to biosecurity uptake that impact on organisations; (3) identifying drivers and opportunities for implementing biosecurity with stakeholders; and (4) considering the mechanisms by which the identified barriers may be overcome and opportunities exploited.

Materials and methods

This research was conducted with the aim of better understanding organisational engagement in invasive species management, and specifically to explore perceptions of barriers to and motivations for biosecurity uptake. Because of this, the research team elected to employ a qualitative approach to data collection and data analysis. Users of UK natural environments decide whether or not to undertake biosecurity based on their attitudes and identities, both of which grow out of the experiences they have undergone. In this way, biosecurity decisions are similar to decisions about whether to employ other pro-environmental behaviours, and can be best understood with insights into the experiential knowledge held by individuals in organisations. Whilst it is not impossible to collect some forms of data on experiential knowledge quantitatively, the complexity and uniqueness of the lived experience means that qualitative methods are often better placed to elicit a greater level of understanding (Fazey et al. 2006).

Qualitative methods often rely on dialogue as a mode of data collection (Morgan 2011) and the qualitative method chosen here was to conduct semi-structured interviews with participants using a topic guide. Unlike set questionnaires, semi-structured interviews benefit from being loosely structured, allowing the interviewer to guide the discussion around topics of interest, but to remain sensitive to the fact that their initial understandings may change as the interview progresses (Morgan 2011). This approach also gives greater agency to the participants, allowing them to spend time discussing areas of particular interest to them, or to raise new issues. This leads to a scenario where interviewer and participant can develop a rapport, and participants are more likely to reveal their underlying views and motivations, or express nuanced, complicated information about the topics being discussed. Whilst this enables insights that might otherwise be missed, it results in interview transcripts that are unique and non-equivalent, with some areas of discussion covered only by some participants and not others. As such, the resulting interview transcripts produce a dataset that is analysed narratively and thematically, rather than to produce a quantitative representation of views. As such, the results of the research do not claim or attempt to proportionally represent organisational stances on biosecurity, but rather to provide insights into the nature of the range of positions expressed by participants which will be useful for understanding the issue of biosecurity uptake.

A stakeholder analysis (Reed et al. 2009) was used to identify a range of organisations that carry out

activities in natural environments in the UK. A total of 38 stakeholder organisations were identified and representatives from all organisations were contacted for interview. Contacts focused predominantly on organisations operating within the Yorkshire Dales area, which enabled the research team to exploit links to a local environment network by using contacts as organisational gatekeepers. One representative each from a total of 10 national and 5 regional organisations (but representative of regional organisations found across the country) were interviewed, including business (2), leisure (3), conservation (4), education (1) and public bodies (5). Interview participants were encouraged to speak about their perceptions of local, regional and national level action on biosecurity within their organisation.

Semi-structured interviews were carried out in April–September 2015, by a single interviewer, at locations convenient to the participant, often their place of work, and ranged in duration from 45 to 90 min (depending on the responses given by participants). The interviewer guided the interview according to a pre-determined topic guide, which had been co-produced by the five members of the research team. The guide explored participants' awareness of INNS, current biosecurity practice and policy within their organisation, and their perceptions of barriers to effective biosecurity and opportunities for improving the uptake of biosecurity measures. Participants were guaranteed anonymity for themselves and their organisation in order to encourage them to speak openly about their views and to raise any additional related issues they considered important.

The interviews were recorded and then transcribed to create a dataset. The transcribed interviews were analysed using open coding of the data into categories, some pre-determined by the focus of the research but with others emerging from the data (Bhattacherjee 2012). These categories were risk, biosecurity policy, biosecurity practice, barriers, opportunities, motivations/reputation, communication pathways, species of concern, other environmental/health and safety issues, partnership working and awareness. Axial coding was then used to identify connections between categories and over-arching themes emerging from the categories (Bhattacherjee 2012) in the context of collective action. The validity of the analysis was evaluated through a process of triangulation where two researchers carried out analysis of the data simultaneously to enable categories and themes to be cross-checked. Initial findings were also discussed with the respondents to further validate the results.

Results

Awareness of INNS risk

All interview participants recognised that INNS pose major risks to the environment. However, they displayed varying levels of awareness of the pathways by which specific INNS can be spread (especially of the risks attached to the kinds of activities the organisations themselves were carrying out). Some (6/15) also displayed poor knowledge of the types of negative impact brought about by specific INNS. These differences in knowledge and awareness were largely attributable to staff expertise on the subject. Participants that had background qualifications in ecology knew a great deal about INNS, whilst those without were less aware of how their organisation's activities might contribute to the spread of INNS and were confused about the impacts associated with particular species.

The risks associated with INNS were identified as both the risks of negative impacts of INNS, and also the risk of contributing to the spread of INNS through field activities. Negative impacts could be both direct and indirect, with direct impacts having measurable financial repercussions for organisations' operational capacity. Direct impacts such as riverbank erosion due to burrowing Signal Crayfish or the dieback of Himalayan Balsam monocultures, public health and safety issues caused by phytotoxicity of Giant Hogweed, loss of timber due to tree diseases, damage to infrastructure and associated flooding risks, and impacts on drinking water quality and supply from Zebra Mussel infestations of reservoirs, were all identified. Indirect impacts (relating mainly to environmental effects such as biodiversity loss), whilst not always causing immediate financial problems, were still recognised as undesirable. For example, for those organisations with a remit to encourage public enjoyment of natural areas, biodiversity loss was perceived as a threat to visitor numbers:

> *If we start losing native species that are in decline then it could have significant impacts* [on visits] (Interview participant K).

Indirect impacts also included the risks of reputational damage and possible prosecution for failing to act on INNS.

Many activities were identified as risky for spreading INNS, including travel between sites and the re-use of equipment. Generally, greater awareness was displayed of the risks associated with field activities involving aquatic environments (such as ecological monitoring using nets, dredging and reservoir safety tests). A theme identified by all participants was that greater risk was attached to activities carried out by members of the public and contractors because these groups were considered to be less aware of (or inclined to implement) biosecurity measures.

A degree of ambivalence about INNS was evident for a small number of participants (2/15), who suggested that over longer timespans INNS may be assimilated ecologically so that they are eventually no longer considered INNS. But participants more commonly agreed (9/15) that it was important to act early in order to stop new INNS invasions before they became established.

Some of the larger organisations represented by participants (7/15) had taken the step of employing dedicated biosecurity personnel or explicitly including responsibility for biosecurity within the remit of specific staff members, but for smaller organisations (which were often membership-based and leisure-focussed) taking such a step wasn't possible. Moves towards the development of official INNS strategies had also been taken by some of the larger organisations (5/15), with some engaged in the process of producing detailed risk assessments on a species by species basis (6/15). Detailing the risks associated with individual species was identified as a way that priority action (and budget allocation) could be initiated. However, this style of approach also aligned with a tendency to react to specific threats rather than to implement general preventative action.

Barriers to biosecurity uptake

Inevitably costs are associated with implementing biosecurity, and can act as impediments to adoption by organisations and their networks. Monetary costs identified related to purchasing duplicate sets of equipment, paying for awareness-raising placards to be put up in natural areas and the costs of paying for and transporting cleaning equipment. Additionally there were issues of time costs for staff employing biosecurity measures or undertaking spot checks to assess biosecurity compliance, as well as space costs for equipment drying. Logistical difficulties with washing large pieces of machinery and vehicles were also identified as a difficult cost barrier to overcome. Environmental employees can feel '*overworked and underpaid*' (interview participant H) and requirements that add to workloads were considered to be unpopular. Other priorities may also outweigh biosecurity considerations within organisations:

> *£X million* [for biosecurity] *sounds like a lot of commitment but our business value is £X billion, so it's small potatoes in terms of the risk to the company* (Interview participant G).

The existence of conflicting guidance within the public domain about which biosecurity measures are effective, the lack of a well-developed, co-ordinated national strategy and adequate legislation, and poorly thought out and utilised communication channels were identified as particular problems. The lack of targeted information can result in information overload and individual inaction:

> *I think that there is information overload at times… so there is lots of information coming in from various directions and sometimes there is so much that people are so busy in their day to day stuff that it is probably not read…cascading some of that information onto other staff isn't always as effective as it might be, only because whoever does it doesn't do it as well or because people aren't listening or interested or whatever* (Interview participant D).

At the same time inadequate guidance can lead to a lack of action on the part of organisations against staff or contractors failing to comply with biosecurity:

> *There's no real penalty there. How many people do you see prosecuted by the Environment Agency for non-compliance of biosecurity?* (Interview participant F).

It can be difficult to get many people, each with their own identities and related beliefs, values, interests

and attitudes, to collectively implement the same, or complementary, behaviour change. Whilst some individuals were acknowledged to have a passion for biosecurity, others were simply not interested and had other priorities, and ultimately convincing them to employ biosecurity would not happen overnight:

> *Yes. Well they are all stuck in their ways, it is a change of behaviour which takes time.* (Interview participant C).

As a result it can feel futile to be undertaking biosecurity when others are failing to do the same:

> *I think the main internal and external barrier that I see is the Catch 22 of people being sceptical saying, 'unless everyone's doing it then there is no point*' (Interview participant D).

In this respect, groups of people who only sporadically visit resources, such as contractors and members of the public are of particular concern:

> *So it becomes a little bit of a difficult job because you are trying to get all your staff to do all this, but there are far more anglers than you have staff who will be going to different waterways wearing the same boots, using the same keep net, using the same rod. So it's very difficult, you can do your absolute best every day of your life, but your impact will be diluted enormously by the activities of all the people who use your water* (Interview participant F).

It was widely agreed (9/15) that it is important to act early by employing precautionary measures in order to prevent new INNS invasions before they become established:

> *The older ones that have been around for a while, some of them it is debatable to whether they are necessarily invasive… but in many respects the damage is already done with those species. New species coming into the area potentially have impacts that cause more damage, and it would be easier and will cost less to get rid of them to begin with* (Interview participant H).

Despite this recognition that a precautionary approach should be guiding biosecurity commitments, in reality organisations were much more likely to undertake actions in response to specific known threats with the potential to directly impact on their organisation's interests:

> *I work at the coal face so for me it is all about what impacts on us, but XXXX would give you a high level national answer… They would say 'It is the species that we could have most influence over, just arrived' and 'the species that have the greatest impact on Water Framework Directive'* (Interview participant O).

Some interviewees (7/15) commented that before their organisation would be likely to formally request biosecurity measures from environment users (staff, contractors, members of the public and tenants) they would need clear, scientific evidence about how their activities might be associated with pathways of spread, and about the efficacy of the biosecurity measures being undertaken to combat this:

> *We don't do anything on a precautionary principle because then people think 'What are we doing this for?'… We just need to have the evidence to back it up and a pretty solid basis for asking people to do it otherwise they won't* (Interview participant B).

Linked to this are issues around the visibility of species and impacts. On one hand pathogens and many INNS propagules are invisible to the naked eye and therefore unlikely to be a conscious concern for many environment users:

> *Part of the problem with a lot of these issues is that, it's a bit like radiation, a lot of the problem is you can't see it. So people don't understand. They tend to think if they can't see it why are they doing it?* (Interview participant F).

On the other hand, established invasions can be highly visible, with the risk of public criticism and reputational damage for not dealing with visible infestations, such as Japanese Knotweed, Giant Hogweed and Himalayan Balsam:

> *Hogweed and some of the plant diseases are health and safety risks where it's an offence to spread them on the land. And Water Framework Directive is very clear, where we could get an ASBO, that's a significant reputational issue* (Interview participant G).

Action to protect an organisation's reputation and to avoid alienating public support is often a priority, particularly given that most organisations now rely directly on support from the public in the form of membership fees, volunteer contributions, charitable donations or customer payments:

> *We tend to spend our money on things like Japanese Knotweed and Hogweed because the health and safety element of Giant Hogweed means you've got to treat it because from a reputation point of view if you've got Giant Hogweed and it's growing next to somebody's access… then it looks like it's just negligent management, so we have to do it, and that's why we prioritise it* (Interview participant F).

But reputation as a key motivator for biosecurity has its downsides. The fear of scrutiny can prevent an organisation from disseminating biosecurity messages:

> *We have got to get our house in order, how on earth can we preach to other people if our own land is not properly treated?* (Interview participant O).

Another problem with biosecurity efforts being driven by concerns for reputation was the potential for a separation between the front of 'good practice' presented by organisations and what is happening in reality. For example, whilst contractors are often awarded contracts on the basis that they promise to employ adequate biosecurity measures, respondents (9/15) were sceptical about how much such measures were actually employed on the ground and highlighted that the only way organisations can ascertain if measures are being undertaken is by implementing spot-checks, which are costly in terms of staff time. In addition, where non-compliance was discovered during routine checks, procedures were lengthy, paperwork-heavy and not rigorously employed. There was some cynicism about the degree to which organisations are genuinely committed to biosecurity (7/15), with suggestions that the bureaucracy of administration could be used to deflect the focus from their own shortcomings or to pass the responsibility on to someone else:

> *Part of the trick you see is that you pass on the responsibility to your contractor. We can smugly say, oh we've got policy here, this is what we want to see, go out and do it, but we won't then be making sure that our staff are doing that. And this is part of the problem* (Interview participant F).

A similar issue was raised relating to the degree of biosecurity information put out by organisations:

> *I'm being cynical, if you're seen to be circulating things it looks like you are doing stuff, but actually, the things which have an effect are the stuff right up on the coal face here…* (Interview participant F).

Drivers and opportunities

Whilst behavioural change tends to be a gradual and complex process involving communication pathways, awareness-raising activities and changes to norms and attitudes, there were mechanisms identified by which individuals could be influenced to undertake biosecurity. First, the role of positive peer pressure and the need for organisations to protect their reputation:

> *It sounds bad but through peer pressure… if someone sees you doing something wrong then they will be like, 'Hang on why are you doing this, this is affecting everyone else'. So peer pressure in a positive way rather than a negative way* (Interview participant B).

Whilst many participants (10/15) admitted that they felt their own biosecurity undertakings might not achieve effective results because of the activities of others, they still acknowledged that their organisation needed to be seen to be employing biosecurity in order to set a good example:

> *We do need to try to show good practice and hope that that will slowly rub off on some other people* (Interview participant D).

Second, social relationships between staff members of organisations were identified as an important mechanism for sharing information about INNS:

> *We chat regularly so they would inform us of anything coming into the area* (Interview participant D).

Third, experiential learning in the field, where first-hand experience, such as observing the damage caused by an INNS or comparing natives and invasives, worked to convince people of the need to take action.

Fourth, Several interviewees (9/15) noted the importance of capitalising on the energy that some enthusiastic and passionate staff and volunteers have about INNS issues. Face to face communication about INNS issues was considered to be more effective than the use of impersonal emails. As such the benefits brought about by key individuals and opportunities for partnership working were emphasized:

> *We need to find some people who are really interested in this, it's just finding them. And then we can say, well here's a project, develop a strategy and a policy for us and we could have, we've got a really good comms* [communication] *team and we could say why don't we have a publicity campaign about biosecurity* (Interview participant F).

Finally, the normalisation of biosecurity was identified as an important mechanism, similar to the process of Health and Safety regulations gradually being adopted in the past:

> *We went through a campaign… because our health and safety record wasn't brilliant, what happened was our staff then all got trained up to a really good standard, and what they would do is they would shop the contractors if they saw them infringing health and safety practice on site… It's empowered people, once we'd done the formal training we did, they launched a campaign… which was aimed at you, not being told by line managers 'you should be wearing a life jacket when you are close to water', but that it's your responsibility to take responsibility for your co-workers* (Interview participant F).

However, currently there are often limited opportunities to incentivize good biosecurity. In light of this there were calls for the development of an accredited national biosecurity standard.

Discussion

The barriers and opportunities described by participants centred on (i) uncertainty about potential impacts and the actions of others, (ii) costs (in financial, temporal and spatial terms) and competing priorities, (iii) the nature of legislative, strategic and regulatory support for biosecurity within an enabling environment, (iv) the complex role of communications in influencing social change and (v) issues around consensus about INNS risks across the organisational landscape. These barriers and opportunities will now be examined in turn in order to identify possible mechanisms for enhancing the uptake of biosecurity measures amongst environment users.

(i) *Uncertainty about potential impacts and the actions of others.* Uncertainty characterises the situation for those considering whether or not to undertake biosecurity in two important ways. Firstly, preventative biosecurity hinges on the presence of uncertainty. Biosecurity has the most to gain where it prevents new invasions of as yet unestablished INNS from gaining a foothold in the environment. As such, biosecurity operates on the precautionary principle where, if a threat is recognised action is mandatory regardless of uncertainty (Sandin 1999). However, our evidence suggests that environment users may not undertake biosecurity unless strong scientific evidence is available to demonstrate that their specific activities constitute a risk and that the specific biosecurity actions they are being advised to undertake will effectively prevent this risk. This presents a problem for biosecurity uptake because where potentially problematic species have yet to establish in a new environment, scientific knowledge about the pathways they may take to spread through that environment, the local risks of their impacts and how they can be most effectively contained or killed, is often in its infancy. The need for greater evidence about INNS pathways and biosecurity measures to exist before action can be initiated reveals an asynchronism between ecological and social timeframes in relation to INNS invasions; the rate of our social response (which, despite the rhetoric, in reality eschews the precautionary principle) is likely to be much slower than the ecological rate at which INNS populations develop a stronghold (Crooks 2005; MacMynowski 2007; Scheffer et al. 2000). This

suggests that some level of environmental damage must necessarily be incurred before action can be initiated.

As important as uncertainty about the scientific evidence supporting biosecurity is uncertainty about the biosecurity actions of others. This uncertainty strongly undermines environment users' confidence in the efficacy of their own biosecurity measures (Mcleod et al. 2015). Because a lapse in biosecurity practice by even a single individual can result in the release of the progenitor of a snowballing INNS population, the risk that individual biosecurity efforts will be in vain is heightened. The low visibility of propagules coupled with their potential to multiply exponentially make biosecurity a particularly intractable kind of collective action problem. The failings of environment users to undertake biosecurity measures are unlikely to be observed by others since they are likely to take place in sparsely populated natural areas. For this reason, and because INNS may reach new areas without human involvement, it is particularly difficult to trace invasions back to individual biosecurity failures. Calculating accountability is therefore problematic and there is little recourse to the polluter pays principle. In contrast to the low visibility of biosecurity actions in the field, responsive actions to INNS infestation take the form of visible control and eradication measures that when successful have a noticeable, and measurable, impact. For organisations concerned with projecting a good public image, control measures may present a more attractive investment since they produce a measureable change. The success of preventative actions, on the other hand, produces none, resulting in no change (the absence of INNS invasions in the environment). Without clear evidence that invasions are being thwarted, organisations, and the individuals they oversee, may feel that their investments in biosecurity are not reaping tangible rewards. However, concentrating on responsive controls rather than preventative biosecurity will do little to ensure that INNS do not spread throughout the environment. The tendency for organisations to prioritise reactive rather than anticipatory risk-handling, acting foremostly to protect their specific, individual interests reflects collective action failings elsewhere, wherein short-term, self-interested, rational behaviour wins out and greater gains are foregone (Ostrom 1998).

Scholars have identified a number of structural variables which enhance the chances that collective action will succeed in sustainably managing environmental resources (Cox et al. 2010; Ostrom 1990). These include well-defined resource boundaries, the ability to match rules to local needs and conditions, the ability of users to determine the rules governing behaviour, and for these rules to be respected by external authorities, the capacity for users to monitor the behaviour of other users, the ability to employ sanctions upon those that violate rules, accessible and affordable means to resolve disputes, and the nesting of interconnected governance structures from the local level upwards. Whilst some of these structural variables are naturally weak in relation to biosecurity management (for example, resource boundaries are likely to be fuzzy, and opportunities for monitoring and employing sanctions are quite scarce), it should be possible to improve the operation of others. Enhancing participation in decisions about INNS strategy through consultation with environment users across the board and using public research to determine how to match biosecurity requirements to users' capacities should result in the production of increasingly adoptable biosecurity strategies. Support should be given for employing sanctions where possible (for example encouraging organisations to blacklist contractor companies that fail to employ biosecurity measures), and these sanctions should be publicised as widely as possible. According to scholars of collective action, campaigns that encourage environment users to increase their expectations of a lasting association with the resource should also help encourage biosecurity efforts (Ostrom 1998).

(ii) *Costs (in financial, temporal and spatial terms) and competing priorities*. The concerns that participants voiced about costs and competing

priorities illustrated the cost–benefit analysis that most were undertaking in determining whether or not to invest time and resources in biosecurity. This supports findings elsewhere that show environmental behaviour to be strongly influenced by economic incentives (Diekmann and Preisendörfer 2003). In order to increase the uptake of biosecurity, strategies that reduce the individual costs of undertaking measures (such as the provision of cleaning stations), increase the perceived individual costs of non-compliance (sanctions for those that fail to undertake biosecurity), and raise awareness of the collective costs to all (through campaigns and training) should be employed. Beyond this, rational economic decisions about whether to undertake biosecurity also hinge upon beliefs about whether other environment users are participating or not (since non-participation by any single environment user can introduce INNS, thereby undermining the efforts of others). As discussed, these suspicions about inaction present a particularly difficult barrier to overcome (and one typically found at the core of collective action problems) (Chant and Ernst 2008). However, our evidence of the need for organisations to be seen to be doing the right thing could incentivise biosecurity regardless of the failings of others. As such, reputational issues and the need to consolidate public support also feature in rational decision-making about biosecurity, providing an area of leverage that could be exploited in biosecurity campaigns. Researchers have reported that environmental campaigns that attempt to affect moral conscience can be successful at overcoming economic criteria determining environmental behaviour (Carrus et al. 2008; Diekmann and Preisendörfer 2003). As such, biosecurity campaigns that emphasize moral responsibility for doing the right thing may increase uptake beyond those that only raise awareness about negative impacts.

(iii) *The nature of legislative, strategic and regulatory support for biosecurity within an enabling environment.* Studies of collective action have underscored the necessity of building responsibility for resource management into well-connected nested tiers from the local up to the highest level (Ostrom 1990). In the context of INNS biosecurity New Zealand is at the forefront of biosecurity internationally, and the development of regional partnerships in combination with national legislation have been identified as key components of the country's approach to INNS (Anderson et al. 2014a). In Europe, steps towards shaping this kind of regulatory structure are being taken through the development of recent EU-wide legislation (Genovesi et al. 2015). However, there are conflicts between high-level national promotion of preventative biosecurity and local-level preferences for prioritising responses to immediate threats. Understanding how to overcome disparities between preferences for these different types of action on INNS will be key to implementing effective biosecurity management. Collective action research has also emphasized the importance that resource users are empowered to determine rules of management and also that rules are well matched to local needs and conditions (Ostrom 1990). As such, local level environment users must feel they have the opportunity to influence INNS policy and structures must be put in place to enable effective communication and consultation between the levels of the nested hierarchy. The development of local environmental forums and networks that focus on biosecurity enhances opportunities for this. Whilst such platforms are in existence, funding to further the scale and reach of their operations could enable wider participation and ensure better processes of communication and consultation.

(iv) *The complex role of communications in influencing social change.* Our findings suggest that it is not the communication of pure facts about INNS that determine biosecurity uptake, but rather the characteristics of how information about INNS is communicated that ultimately influences adoption. This reflects research findings elsewhere which suggest that increasing factual awareness of environmental problems may not lead to desired results (Yamashita 2014). The points raised by participants about how biosecurity messages are most effectively delivered reflect aspects of the communications theory underpinning the 'Diffusion of

Innovations' framework (Rogers 2003). As such, face-to-face communications and the observability of biosecurity behaviour in the field were both highlighted as effective ways to persuade people to uptake biosecurity, whilst mass mail outs such as newsletters and electronic communications were considered less effective. Participants also discussed the roles of peer pressure and social norms and highlighted the importance that information is delivered by the right person and complements the recipient's level of interest and enthusiasm. These points reflect Rogers' (2003) emphasis on interpersonal communication channels, the role of opinion leaders and the concept of a 'critical mass' being reached from whence a behaviour change becomes a self-propelling norm that spreads throughout a social system. As such, facilitating opportunities for communications about INNS between environment users at meetings, events and forums, expanding the reach of key individuals and those that span organisational boundaries to help spread INNS messages, and finding ways to publicise instances of biosecurity uptake, should all help to persuade more individuals to employ measures.

(v) *Issues around consensus about INNS risks across the organisational landscape*. In order for successful collective action to occur, a key condition is for stakeholders to agree that the problem at hand is a serious one (Ostrom 2004). Research participants displayed a lack of consensus about the nature and seriousness of the risks posed by INNS, and varying levels of knowledge and understanding characterised the landscape of perceptions about biosecurity. These differences were consolidated by differences in organisational capacities to employ staff with specialist knowledge. For effective action to be taken on biosecurity, awareness-raising measures and opportunities for expertise-sharing are likely to be needed to smooth out some of these differences. However, because participants reported relatively individualist interpretations of INNS risks, targeted awareness-raising campaigns may do more to align perceptions of the seriousness of INNS than more generalist approaches.

Conclusion

Whilst prevention may be better than cure where INNS are concerned, which warrants the uptake of biosecurity measures, this research highlights the barriers to adoption of biosecurity amongst environment users. These include: financial constraints linked to a lack of knowledge about invasion pathways and control measures, a focus on managing already established and visible INNS, and collective action problems if others fail to undertake biosecurity. The costs associated with implementing biosecurity mean that there is a reluctance to commit financially to undertaking biosecurity without the certainty of a return on investment. This would not only require more scientific evidence about specific INNS pathways of spread and the efficacy of measures for controlling them (which may not yet exist in the case of new INNS invasions), but more difficult still, would require certainty about the actions of other individuals whose activities may spread INNS in the environment. Additionally, there is little recourse to impose punishments on those who fail to undertake biosecurity, with many organisations failing to strictly enforce biosecurity compliance amongst staff and contractors. The low visibility of INNS propagules, limited measurability and attributability of successful biosecurity, and limited opportunities for monitoring biosecurity actions in the field, contribute to an out of sight out of mind attitude to INNS.

Preventative biosecurity offers the best chance to slow the rate of INNS invasions and protect valued environments from their impacts. However, as this research has shown, its uptake constitutes a tough collective action problem that will require carefully targeted policy to overcome. According to the findings of this research, those seeking to devise effective policy and strategy around biosecurity should consider shaping biosecurity campaigns that focus on moral conscience rather than negative impacts alone. Umbrella groups should facilitate social networking amongst users of natural areas, ensure effective two-way communications between management hierarchies overseeing natural areas, and encourage strong levels of participation in decisions on biosecurity strategy from environmental field workers. Campaigns should be shaped to target specific user groups and steps should be taken to enhance the visibility of successful biosecurity through national accreditations

and as well as increasing awareness of the sanctions imposed on those who fail to undertake biosecurity.

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