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Research Article

Perception as a tool to inform aquatic biosecurity risk assessments

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Abstract

We set out to explore whether the inclusion of perceptions into risk assessment might be a key to unlocking the human factor in the vectoring of aquatic non-indigenous species. To this end, we developed a risk assessment model that used people's perception of concern and stated behavioural intentions to measure consequence. We trialled this risk model using a test scenario of the non-indigenous species *Didymosphenia geminata* (a freshwater diatom) being introduced to Tasmania, Australia: a location where it is currently not present. Likelihood was determined by calculating the probability of *Didymosphenia* entering the test region based on exposure to *D. geminata* (travel history of arriving air passengers and the passenger's participation in freshwater recreational activities) and mitigation activities (whether their recreational equipment had been washed). The likelihood of a *Didymosphenia* incursion into Tasmania was determined to be rare. Consequence was determined by targeting three recreational user groups that participate in activities related to the movement of this species in other countries: trout anglers, hikers, and kayakers. Consequence was measured as respondent's level of concern and stated behavioural intentions if the respondent was confronted with an incursion of *Didymosphenia.* The consequence of a *Didymosphenia* incursion ranged from moderate to catastrophic. Thus, the total derived risk was determined to be low-medium. The use of perception to inform the consequence component of the risk assessment proved useful as individuals behaviours are often attributable to the introduction of species, and thus are an important consideration for risk management and education. At a local level these outcomes provide direction to biosecurity of unregulated pathways. At a global level, this risk assessment is a useful tool to assess the potential vectoring of a non-indigenous aquatic species, and potential human actions that might impede the management of a non-indigenous species once it crosses a border.

Key words: introduced species; diatom; risk analysis; social impacts; *Didymosphenia geminata*; biosecurity management

Introduction

Evaluating people's opinions and their intuitive risk judgements is an effective and well established technique that assists with proactive decision making and creating future predictions. It is a particularly useful tool to help understand how stakeholders consider risk when it is too difficult (costly or otherwise), or even impossible to obtain empirical data (Dalkey 1969; McDaniels et al. 1997). Understanding how people perceive risk, and how that may change their behaviour, can assist with reducing the amount of economic, environment, social and cultural loss that a hazard may cause. This information can then be used by conservation and biosecurity (i.e., non-indigenous species management) managers to reduce the introduction of unwanted pest species and to control the spread of these pests.

Understanding people's perceptions is becoming more important when dealing with natural and anthropogenic hazards that impact on humans and the environment (e.g., McDaniels et al. 1995; McDaniels et al. 1997; McFarlane 2005), as it enables decision-makers to understand and anticipate peoples responses to a hazard (Slovic 1987, 2000). Information about perceptions can feed into risk perception, which is often categorised as being psychometric focused (e.g., Fischoff et al. 1978; Kahneman and Tversky 1982; Slovic 1987; Kahneman and

Lovallo 1993; Slovic et al. 2000), having a 'cultural theory' basis (i.e., anthropology and sociology; Douglas and Wildavsky 1982; Douglas 1992), or having an interdisciplinary approach (i.e., social amplification of risk; Frewer 2003; Pidgeon et al. 2003). Psychometric risk perception focuses on heuristics and cognition by measuring subjective attributes of sources of risk (i.e., the nature and controllability of risk; Slovic et al. 2000). Alternatively, Cultural Theory examines how a person's beliefs and subsequent behaviours are governed by their social contexts (e.g., Dake and Wildavsky 1991; Wildavsky and Dake 1990; Sjoberg 2002). The social amplification of risk focuses on both social and individual factors (controlled by heuristics and cognition) and how these act to increase or reduce risk perceptions (e.g., Pidgeon et al. 2003).

The utility of people's perceptions to biosecurity risk assessment lies in the fact that understanding people's perceptions can help to ascertain their motivations, actions, and beliefs (Slovic 1987, 2000; Sheeran and Orbell 1999), which are related to the main driving factors associated with both intentional and unintentional introductions and spread of species (e.g., Campbell 2009), the potential flow-on affects (e.g., Kuhar et al. 2009), and support for management activities (Perrings et al. 2002; Hewitt and Campbell 2007; McFarlane and Witson 2008). Within a biosecurity frame, all forms of risk perception (psychometric, cultural theory and social amplification) are of interest however, when attempting to manage the vectoring of species by human actions, the ability to know and understand risk behaviours is an important foundation step that will provide useful insights to manage this risk. By understanding risk behaviours, risk managers are able to control the amplification of risk and create effective risk communication about hazards (e.g., Frewer 2003). To date, a limited number of researchers (e.g., Delabbio 2003; Casal et al. 2007; Heffernan et al. 2008; McFarlane and Witson 2008; Campbell 2009; Kuhar et al. 2009) have focused on the inclusion of perception to manage biosecurity issues such as the introduction and the secondary movement (i.e., vectoring) of non-indigenous species.

Methods to control the entry and spread of non-indigenous species include developing white lists (Kahn et al. 1999; Biosecurity Australia 2000; Anon 2009), developing next pest lists (Hayes and Sliwa 2003), undertaking Organism Impact Assessments (Campbell 2008), using risk based decision-trees (Campbell 2011) and risk models (Barker et al. 2003). Although these methods are valuable and meet specific biosecurity needs, they fail to target the human nature of the vector and thus fail to address this management aspect. Hence, adding perception to risk assessments within a biosecurity process can fill a knowledge gap that can provide further assistance to quarantine (risk management) or education (including risk communication) actions (Campbell 2008; Kuhar et al. 2009).

In this study, we use *Didymosphenia geminata* (Lyngbye) M. Schmidt, a freshwater diatom, as a test case to determine if the inclusion of consequence derived from peoples level of concern and behavioural intention (i.e., a person indicates that they will perform a particular behaviour; e.g., Ajzen 1991; Conner and Armitage 1998) is a viable tool for biosecurity in a pre- and post-border risk assessment context. *Didymosphenia geminata* mode of transport (vector) to different regions is thought to be items that can retain water, with quarantine targeting recreational equipment such as fishing gear (e.g., rods, jackets, waders; Bothwell et al. 2009), hiking boots, gaiters, and kayaks (Kirkwood et al. 2007). We developed and undertook a risk assessment that uses both quantitative risk data and people's perception data to assess if *D. geminata* poses a risk to Tasmania. The determination of risk follows standard risk practices (Standards Australia 2000, 2004), however we have developed a new risk equation and a consequence matrix to determine the measures of likelihood and consequence, respectively.

The test region for this analysis is Tasmania, Australia, where *D. geminata* is currently not present. However, we emphasise that although the test case is based in Tasmania *D. geminata* is a recognised pest species in more than 14 countries, including the United States and parts of Europe, and has been cited from more than 50 countries (Tomas et al. 2010). As such, the risk assessment that we present has a broad scale, global implications being readily adaptable to other countries and other non-indigenous species or quarantine/customs target species.

Test case species: Didymosphenia geminata

Didymosphenia geminata is a unicellular freshwater diatom native to mountainous, forested, or alpine regions from the Ponto-

Caspian region, the Faroe Islands and certain parts of Europe (Kawecka and Sanecki 2003; Ellwood and Whitton 2007; Bhatt et al. 2008; Tomas et al. 2010). It is a successful invader because it can survive, spread and bloom in many environmental conditions (wide environmental tolerances; Shea et al. 2007; Bhatt et al. 2008; Kilroy et al. 2008; Kumar et al. 2008). It is not a noxious pest, but instead is classified as a nuisance species being aesthetically unpleasing (it resembles untreated sewerage) and causing itchy skin in swimmers due to its siliceous frustules that can also abrade fish gills (Bhatt et al. 2008; Kilroy 2004; Larned et al. 2006). In New Zealand, it is believed that the diatom could affect the abundance of native fish such as the galaxiids and non-indigenous freshwater fish, such as rainbow or brown trout (Bhatt et al. 2008; McDowall 2006). Similar research in Quebec (Gillis and Chalifour 2010) has concluded that it can influence the aquatic food web of invaded rivers.

There are various possible social impacts that this species may cause such as the loss of tourism in an infected area due to it being unsightly (e.g., Mahala 2008; Department of Conservation *Te Papa Atawhai* 2011), or its potential impacts on high tourist-attracting species such as, platypus (Gust and Griffiths 2010). Other reasons why people, and especially anglers, may not return to a river that contains a *D. geminata* bloom, is that the clumps and mats of *D. geminata* reduce water visibility, thus diminishing the ability of anglers to see the targeted trout in the water (Stuart-Smith et al. 2004). New Zealand economists felt that impacts on the trout fishing industry would cause large flow-on financial losses within the tourism industry (Branson 2006). This is of concern, as tourism in New Zealand brings in 9% of the Gross Domestic Product (GDP) each year (Kilroy et al. 2008; Spaulding and Elwell 2007) and in Tasmania it brings in approximately 4.9% Gross State Product (GSP) annually (Tourism and Transport Forum 2009). By blocking water filters, *Didymosphenia* has also caused major economic problems for irrigation and hydro-water supplies in New Zealand and Poland (Kawecka and Sanecki 2003; Kilroy et al. 2008). Little work has been done to investigate the cultural impacts of this species, with the exception of Campbell (2008). This work indicated that Maori in New Zealand considered the species to represent a variable risk (high to extreme) to cultural values such as creation (Whakapapa), sacred waters (Wai tapu), and food gathering areas (Mahinga Kai). The risk variability was associated with spatial characteristics of the individual Iwi (i.e., tribe) involved in the surveys (Campbell 2008).

Over the past century *D. geminata* has been introduced to a number of regions including parts of Europe, Asia, North America, and Canada (Campbell 2008; Shea et al. 2007; Beltrami et al. 2008; Kumar et al. 2008; Gillis and Chalifour 2010; Tomas et al. 2010). However, it was unknown from the Southern Hemisphere until October 2004, when the first evidence of *D. geminata* was discovered in the South Island of New Zealand (Kilroy et al. 2006a). In this incursion, *D. geminata* was detected in the lower Waiau River in the Southland region and not long after this discovery it spread over 150km into the Mararoa River (Campbell 2008; Kilroy et al. 2008). Within 2 years it had spread to 12 rivers within the South Island (Spaulding and Elwell 2007). Once introduced to New Zealand it formally became an Unwanted Species, under the *Biosecurity Act* 1993, and its widespread distribution led to it being considered a global problem (Campbell 2008; Spaulding and Elwell 2007; Bothwell and Spaulding 2008).

Didymosphenia geminata is transferred from one location to another either naturally (by water flow, or birds), or by becoming attached or caught in recreational equipment, where it is unintentionally vectored between waterways. It is resilient and can survive up to 8-months in sub-optimal survival conditions (low light, wet, ~5°C); with survival being further reduced when the cells are in damp, dry conditions, warmer temperatures and with no light (Kilroy et al. 2006b).

Test case location: Tasmania, Australia

Tasmania was selected as the test case location due the regions strong quarantine stance and its linkages (via tourism and travel) with infected areas in New Zealand. When *Didymosphenia* was detected in New Zealand, it put Australia on high quarantine alert to attempt to prevent the entry of this species (Spaulding and Elwell 2007; Australian Quarantine and Inspection Services 2010a). It is thought that Tasmania is highly vulnerable to invasion by *D. geminata* because of the similar environmental conditions and ecological niches that both regions share (Winterbourn et al. 1981). Both locations are on the same latitude; both are large islands with pristine waterways and elevated alpine mountainous regions; and both endorse similar outdoor recreational activities (MacDonald 2008). In the 2008–09 financial year 15,900 people entered Tasmania from New Zealand (Tourism Tasmania 2010) and it is assumed that a number of these people undertook recreational activities within National or World Heritage Parks (unpubl. data).

Framework for this paper

Within this paper we have developed a risk assessment that uses perception (measured by human behavioural intent and concern) and is tested against a scenario of a global nuisance species (*D. geminata*) being introduced into a relatively pristine location, Tasmania, Australia. This was done to investigate how people's perceptions can influence the movement of pest species and hence to understand how social factors (behavioural intent and concern) will influence biosecurity and conservation management. This information is then used to recommend management options to prevent the entry of pest species and if entry occurred, to control its subsequent spread. As such, the species and location are a test case but the risk assessment model is relevant to other species and locations.

Methods

Study sites

Three study sites were selected to sample travellers (Launceston airport), anglers (Liawenee) and hikers (Cradle Mountain-Lake St Clair National Park). Questionnaires (surveys) were used to collect data from each of three study sites. Data collected at the airport was used for the assessment of likelihood, whilst data collected from Liawenee and the Cradle Mountain-Lake St Clair National Park was used to assess consequence. Likelihood questionnaires were undertaken at the Launceston Airport arrivals terminal (in the luggage retrieval area) over a four week period in late May and early July 2009. Launceston airport was selected because it is major airport in Tasmania, with a 1.1 million annual throughput of passengers during 2007–2008 (Australian Bureau of Statistics 2010).

Consequence questionnaires occurred at Liawenee to target trout anglers (known vector of *D. geminata*; Kilroy et al. 2008). The Tasmanian Inland Fisheries Service holds an annual trout fishing weekend at this township that attracts thousands of recreational trout anglers (Inland Fisheries Service 2010). A consequence survey was used to collect data during this weekend, with sampling occurring over both days of the trout weekend that occurred in late May 2009. Similarly, consequence questionnaires targeted hikers (known vectors of *D. geminata*; Segura 2011) at the Cradle Mountain-Lake St Clair National Park. Cradle Mountain is located in the central highlands of Tasmania, and surveys were undertaken at the northern access point (Dove Lake trail head and car park) located in the Cradle Valley. This area receives a large number of visitors year round, with an estimated 170,000 people come through this access point each year (Parks and Wildlife Service 2010). Questionnaires occurred over two weekends in July 2009. Email surveys were used to collect consequence data from a target recreational user group (kayakers) that were difficult to access in the field.

Sampling methods

Survey questions were developed to acquire information from "lay" people and did not involve respondents assessing risk but rather gave the respondents an opportunity to provide information that could subsequently be used by a risk assessor to undertake the risk assessment. Both the likelihood and the consequence derivations are discussed below.

<u>Likelihood questionnaire</u>

The likelihood questionnaire was used to determine the level of awareness of *Didymosphenia,* the likelihood of an incursion (the species entering the state), and to provide descriptive statistics of this stakeholder group. Surveys were undertaken as face to face interviews (using a skip-interval method) that targeted arrival passengers only. Completion of the questionnaire was measured as all questions on the survey instrument being responded to. A standardised likelihood matrix (Table 1) was used to determine the quantitative measure of likelihood, using the data collected during the surveys.

Table 1. Likelihood measures used to derive a level of probability that *Didymosphenia geminata* would enter Tasmania.

Descriptor	Description	Probability
Rare	Incursion only in exceptional circumstances	<1%
Unlikely	Incursion could occur but not expected	2-4%
Possible	Incursion could occur	5-24%
Likely	Incursion probable in most circumstances	25-50%
Almost certain	Incursion expected in most circumstances	>50%

The likelihood questionnaire examined travelling patterns to risk regions (a country already infected with *D. geminata*) by asking survey respondents:

1. Whether they had travelled overseas in the past 14 days. A 14-day time frame was selected to capture activities that occurred within the known desiccation time frames for *D. geminata* (Kilroy et al. 2006b);
2. Where they had travelled to (risk regions [where the species is known to already occur] or non-risk regions);
3. Whether they had participated in any of the following six risk activities:
   a. i) trout fishing;
   b. ii) camping;
   c. iii) inland boating;
   d. iv) inland waterskiing;
   e. v) hiking; and/or
   f. vi) bushwalking, during the last 14-days;
4. If they undertake these activities in general; and
5. If they wash their recreational equipment as directed by the Australian Quarantine and Inspection Service regulations (Australian Quarantine and Inspection Service 2010b; Inland Fisheries Service 2010).

Consequence questionnaire

A consequence questionnaire was used to determine people's perception of *D. geminata*. In this instance, consequence was triangulated by assessing people's level of concern related to an incursion of *D. geminata* and their stated subsequent behavioural intentions in response to a *D. geminata* incursion. This triangulation produced a measure of what we refer to as perception. Perception should provide a risk assessor with an understanding of the respondents concerns and information to enable the assessor to anticipate a respondent's response to a hazard (*sensu* Slovic 1987) and as such to determine if a person might act as a vector of a non-indigenous species. The consequence questionnaire targeted three different recreational user groups: anglers, hikers, and kayakers. These user groups were selected because they could inadvertently vector *D. geminata* between freshwater systems.

A five-point Likert scale (1 = very low level of concern to 5 = very high level of concern) was used to measure the level of concern felt by respondents. Respondents were provided with educational information pertaining to eight impacts that *D. geminata* may have if introduced to Tasmania. The eight potential impacts queried were:

1. Reduced aesthetic value: *D. geminata* has been described as "rock snot" (http://www.biosecurity.govt.nz/files/pests/didymo/didymo-research-03-06.pdf) and is likely to result in respondents feeling that the areas aesthetic beauty is reduced by an incursion. Research also suggests that pollution also reduces angler enjoyment (Ready et al. 2003);
2. Reduced water visibility: *D. geminata* supposedly reduces water visibility making the spotting of fish difficult for anglers;
3. Potential reduction in the size (via smothering of the trouts food, altering the fishes diet [Shearer et al. 2006], and reducing available oxygen and altering water temperatures by altering the trout bed hydrodynamics; Bickel and Closs 2008) and quality of trout: Angler enjoyment is influenced by impacts to fish size and quality (e.g., Lawrence 2005);
4. Changes in quantity of native insects (Shearer et al. 2006; Gillis and Chalifour 2010) via altering the water temperature and available oxygen (e.g., Bickel and Closs 2008), which could affect the animal food chain (e.g., Spaulding and Elwell 2007);
5. Reduced tourism in the area;
6. Nuisance of large scratchy "Didymo" mats;
7. Change in ecological processes such as changes in water flow: Has the potential to influence kayakers, anglers and hikers; and

8. Hydropower and irrigation issues: Tasmania obtains its power from hydro-electric power plants and its primary industry is reliant on irrigation systems.

Respondents were then asked to rate their level of concern for each of these potential impacts on a Likert scale. This information was used to capture how respondents viewed *D. geminata* as an impact. Analyses followed those types used for Likert scale assessments (e.g., Gillham 2007, 2008) where the five-point scale data is pooled into low (1 and 2) and high (4 and 5) levels of concern categories. In general, the middle response rate (representing a neutral level of concern; Kulas et al. 2008; Kulas and Stachowski 2009) was low, yet neutrality or ambivalence to non-indigenous species may represent a threat of vectoring. Therefore, middle response rates were added to the low concern category. The level of concern was used as one component of the measure to derive consequence (i.e., concern being used as a surrogate for recreational user confidence; Table 3). Use of 'concern' as a measure of impact stems from research that indicates that people that are concerned about ecological impacts, may alter their behaviour (Stern 2000), either positively or negatively, which may have flow-on impacts on the environment, economy, or social values.

Within the consequence matrix both levels of concern and behavioural intent were assessed (Table 3). The theoretical threshold measures (% values) within the consequence matrix provide a benchmark of acceptable level of concern with this probability measure representing an increase in concern as people felt that the described incursion event moved from causing them an insignificant level of concern, to the event causing them high levels of concern (Table 3). The probability for concern based on the Likert-scale analysis (i.e., realised threshold measure) was used to allocate a category within the consequence matrix (Table 3). Theoretical threshold measures were arbitrarily developed based on Australian government benchmarks within a biosecurity context. Feedback and subsequent alterations to these threshold levels had been received from practitioners in the field, researchers, and government officials.

Changes in behavioural intention were used as a second measure of consequence. Behavioural intent was used in a simple manner and did not involve social psychology investigation into attitudes, subjective norms, or perceived behaviour control (e.g., Sheeran and Orbell 1999). It was determined by asking the respondent a hypothetical question (If "Didymo" was introduced to some of Tasmania's rivers, lakes and streams, would you return to these river/lake systems? If yes, indicate frequency of return) that measured impact (consequence) via the surrogate measure of changed behavioural intention. The probability of changed behavioural intention was measured against the theoretical threshold measure (% value) within the consequence matrix to allocate a response to a category within the consequence matrix (Table 3). The measure of change in behavioural intention concentrated on respondents that would not return to the site after an incursion.

Biases

A number of biases may have inadvertently occurred in our study due to the sampling methods we used. We used a non-random purposive sampling method to target potential vectors of *D. geminata* and as such may have introduced sampling bias into our results. We felt that this type of bias was justified as we sought to sample people that undertake recreational activities and have travel patterns that would increase their potential of being a vector of *D. geminata*. From a biosecurity perspective it is the people that undertake risk activities that are of interest and hence we targeted our sampling design to gain access to these individuals. Consequently, our results are based on an overrepresentation of the three recreational user groups and people that have travelled into Launceston airport during the sampling period.

Similarly, kayakers were interviewed using email surveys, which may have introduced a selection bias into our sampling design as the email survey may not have perfectly represented the kayaker population. We acknowledge this weakness however feel that the information gained will provide useful insights into this user group and hence have retained this data in our analyses.

To overcome issues relating to recall bias (Szklo and Nieto 2007) each respondent was briefed on *D. geminata* prior to beginning the questionnaire. The information we provided was readily available at Tasmania airports, quarantine websites, and is provided to licensed recreational anglers. As such, some respondents may have been previously exposed to information pertaining to *D. geminata*. By briefing all

Table 2. Consequence matrix used to assess the impact* of *Didymosphenia geminata* on Tasmania recreational user groups.

Descriptor	Impact
Insignificant	
Concern	There is minimal (<10%) concern about *Didymosphenia* entering Tasmania's environment
Behavioural modification	If *Didymosphenia* was introduced in an area <10% of people would change their behavioural intention
Minor	
Concern	There is an increase (11%-20%) in concern about *Didymosphenia* entering Tasmania's environment
Behavioural modification	If *Didymosphenia* was introduced in an area 11%-20% of people would change their behavioural intention
Moderate	
Concern	There is an increase (21%-30%) in concern about *Didymosphenia* entering Tasmania's environment
Behavioural modification	If *Didymosphenia* was introduced in an area 21%-30% of people would change their behavioural intention.
Major	
Concern	There is an increase (31%-70%) in concern about *Didymosphenia* entering Tasmania's environment
Behavioural modification	If *Didymosphenia* was introduced in an area, 31%-70% of people would change their behavioural intention.
Catastrophic	
Concern	There is an increase (>70%) in concern about *Didymosphenia* entering Tasmania's environment
Behavioural modification	If *Didymosphenia* was introduced in an area, >70% of people would change their behavioural intention.

* Impact is measured as level of concern and change in behavioural intention.

Table 3. Risk matrix used to determine the final risk ranking that *Didymosphenia geminata* poses to Tasmania.

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Rare	Negligible	Low	Low	Medium	Medium
Unlikely	Negligible	Low	Medium	High	High
Possible	Negligible	Low	High	High	Extreme
Likely	Negligible	Medium	High	Extreme	Extreme
Almost certain	Negligible	Medium	Extreme	Extreme	Extreme

respondents we ensured that all respondents were exposed to the same data pertaining to *D. geminata*. We also verified if respondents were aware of *D. geminata* prior to commencing the survey.

Questionnaire biases were overcome by ensuring that we didn't use leading questions, trialling the questionnaire in a pilot study, and using a Likert scale to categorise values. Four interviewers were used, but each was trained to standard protocols (to ensure replicability; Stewart and Cash 2008), with one interviewer being in charge of quality control and quality assurance of interview techniques.

The risk model

Our risk assessment determined the likelihood and consequence of an incursion of *D. geminata* in Tasmania, which was then used to derive a measure of risk. Likelihood was determined by evaluating the probability that *D. geminata* would be introduced into Tasmania via air-passengers entering Tasmania at Launceston airport. Data collected in the likelihood evaluation was used in a probability equation (Equation 1) that was assessed against a likelihood matrix (Table 1). Equation 1 was developed for this assessment to capture a measure of propagule pressure based on travel patterns and recreational activities undertaken when travelling. Consequence of a non-indigenous species is often measured as the realised or potential impact a species can cause (Campbell 2009). Data collected in the consequence survey was used to determine the perceived consequence (impacts) that *D. geminata* could have on the targeted recreational user groups (trout anglers, hikers, and kayakers). Perceived consequence was measured as a respondent's self-stated level of concern and changes in their behavioural intention (would they return to an infected site and consequently increase the potential of spreading *D. geminata*).

Equation 1

$L = ((P_{TA}) \times (P_{RE})) \times ((P_{RA1}) \times (P_{RA2})) \times (1\text{-}P_{M})$

Where:
L = likelihood
P_{TA} = probability of travel abroad exposure
P_{RE} = probability of risk region exposure
P_{RA1} = probability of risk activity
P_{RA2} = probability that people arrived from a high risk region and had undertaken a risky activity within the past 14 days; and
P_{M} = probability of mitigation (equipment cleaning activity)

There are a number of known environmental impacts that *D. geminata* has, based on incursions in New Zealand (Kilroy et al. 2006a, 2006b; Shearer et al. 2006). Yet social impacts of this species have been less well studied, with some exceptions (Campbell 2008). Thus, this risk assessment focuses predominantly on the social aspect related to level of concern and changes in behavioural intent that may influence potential vectors.

<u>Deriving risk</u>

A derived measure of risk was determined by looking at opportunities for this species to be introduced (likelihood; Table 1) and then measuring the perceived social impacts (consequence; Table 2) that an incursion would have. Hence, we've used Equation 2 and a standard risk matrix (e.g., Standards Australia 2000, 2004; Table 3) to derive a quantitative measure of risk that is presented in a linguistically qualitative manner. This method follows standard biosecurity risk assessment processes (Campbell 2008; Kluza et al. 2006; Therriault and Herborg 2008; Hewitt et al. 2009; Hewitt and Campbell 2010; Campbell and Hewitt 2011).

Equation 2

Risk = Likelihood × Consequence.

Results

394 respondents completed questionnaires, with slightly more males (51.77%) responding than females (47.97%). Overall for the study, there was an 83% response rate (excluding kayakers). This consisted of 194 people completing the likelihood questionnaire from a total of 235 people that were asked to participate in the study (82.5% respondent response rate). At Liawenee, a total of 153 people, both trout anglers and visitors to the event, were asked to participate in the study with a total of 120 respondents completing the survey (78.4% respondent response rate). A total of 65 people visiting the Cradle Mountain-Lake St Clair National Park were asked to participate in the study, with 62 surveys being completed (95.4% respondent response rate). There were a total of 18 respondents from the emailed kayaker user group (response rate unknown).

Likelihood outcomes

The main element of the likelihood assessment was to assess how many people that travelled into Launceston had visited *D. geminata* high risk regions (where the alga is known to occur) and undertook high risk activities (such as fishing, hiking, kayaking) while at those locations. Approximately 13% (n = 25) of respondents had travelled internationally in the past 14-days, before arriving in Launceston. Out of those 25 people, 16 had visited a high risk region (64%). Out of the 16 people that visited high risk regions, 12 respondents generally undertook risk activities that bought them into contact with freshwater systems (75%). Two respondents that had visited a high risk region had undertaken risk activities while they were visiting the high risk region. Few people (6.2%) cleaned their gear. Likelihood was determined by applying Equation 1, which examines population level characteristics:

$L = ((P_{TA} = 0.128) \times (P_{RE} = 0.640)) \times ((P_{RA1} = 0.06195) \times (P_{RA2} = 0.166)) \times (1\text{-}\ P_{M} = 0.938)$

$L = 0.00079$

The likelihood probability from Equation 1 (0.00079) was then assessed against the likelihood matrix (Table 1). The derived likelihood probability outcome was rare (<1%) when applying this likelihood value to the likelihood matrix (Table 1).

Table 4. Consequence outcomes regarding respondents level of concern about *Didymosphenia geminata* for each surveyed recreational user group and pooled across all-three recreational user groups.

Group	n	Actual threshold values	Consequence
Anglers	112	0.828	Catastrophic
Hikers	62	0.802	Catastrophic
Kayakers	17	0.844	Catastrophic
Pooled consequence	193	0.8205	Catastrophic

Table 5. Consequence outcomes regarding respondents change in behavioural intention* for each surveyed recreational user group and pooled across all-three recreational user groups.

Group	n	Return to site? No	Return to site? Yes	Probability of behavioural intention* change	Consequence
Anglers	112	67	45	40%	Major
Hikers	56	16	40	71%	Catastrophic
Kayakers	15	11	4	27%	Moderate
Pooled consequence	183	94	89	49%	Major

*Behavioural intention is represented by respondent's willingness to return to a site once a site was infested with the non-indigenous species *Didymosphenia geminata.*

Table 6. Derived risk outcomes of *Didymosphenia geminata* entering Tasmania for each surveyed recreational user group and pooled across all-three recreational user groups.

Group	Likelihood	Consequence	Total Risk
Anglers	Rare	Major- Catastrophic	Medium
Hikers	Rare	Catastrophic	Medium
Kayakers	Rare	Moderate- Catastrophic	Low-Medium
Pooled risk	Rare	Major- Catastrophic	Medium

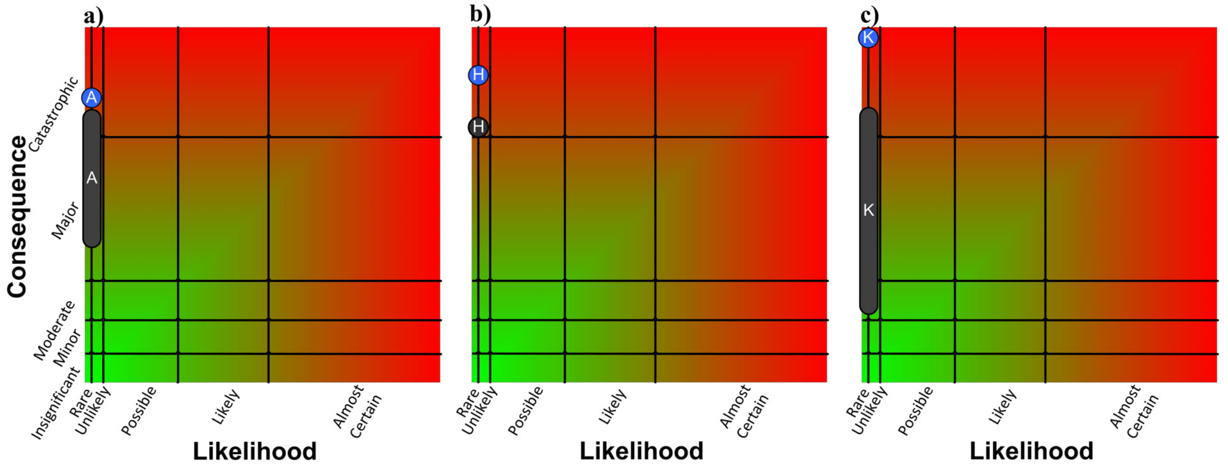

Figure 1. Derived risk outcomes for the three recreational user groups: a) anglers; b) hikers; and c) kayakers. The x-axis is based on probability outcomes from the likelihood equation and the y-axis is based on consequence outcomes from Tables 4 and 5. Green represents a low risk, and red represents a high risk. Blue circles represent concern and black circles represent behavioural intention. A= anglers, H = hikers, and K = kayakers.

Consequence outcomes

Kayakers (84%), anglers (82%) and hikers (80%) all stated that they felt concern regarding *D. geminata* entering Tasmania. When assessed against the consequence matrix (Table 2), this level of concern for each group represents a catastrophic level of consequence (Table 4). Similarly, if we pooled all user groups, the level of concern is 82%, representing a catastrophic level of consequence (Table 4). The results of the concern component of the consequence outcomes demonstrate that across all recreational user groups there is a similar perception that an introduction of *D. geminata* would have catastrophic consequences.

Although the level of concern was consistently high across the different user groups, the resulting behavioural intent (measured as intent to return to a *D. geminata* infected site) varied across user groups. The majority of hikers (71%) stated that they would return to a site once it was infected with *D. geminata* (Table 5). This probability of behavioural intent is then assessed against Table 2, to derive a consequence ranking of catastrophic. Fewer anglers (40%) would return to an infected waterway (Table 5), representing a major consequence (Table 2). Kayakers were the least willing user group to return to an infected site (27%) (Table 5), representing a moderate consequence (Table 2). Pooling across all user groups produces a 49% probability of a user returning to an infected waterway (Table 5), representing a major consequence (Table 2). Thus the behavioural intention consequences ranged from moderate (kayakers) to catastrophic (hikers) (Table 5) across user groups.

Kayaking and angler respondents typically felt more concern and would alter behavioural intentions if an incursion occurred. Alternatively, hikers felt high levels of concern but were less likely to change their behavioural intention if an incursion occurred (Table 5). Thus, the hypothetical scenario of *D. geminata* being present in Tasmania appears to have had a moderate-catastrophic influence on people's behavioural intention across all three recreational user groups.

Combining these two measures of consequence (concern and behavioural intention) provided a total consequence measure of moderate (kayakers' behavioural intention) to catastrophic (concern for all user groups and hikers behavioural intent) (Table 5).

Derived risk

To derive risk, the likelihood and consequence probabilities were assessed against Table 3. Anglers represent a medium risk (Table 6, Figure 1), with a rare likelihood of *D. geminata* entering Tasmania and a major to catastrophic consequence based on concern and behavioural intentions of the respondents. Similarly, hikers represent a medium risk (Table 6, Figure 1), with a rare likelihood and a catastrophic consequence. Kayakers represented the lowest risk (low-medium), based on the rare likelihood and the moderate-catastrophic levels of concern and behavioural intent. Pooled risk (derived risk regardless of user activity) was medium (Table 6, Figure 1), with a rare likelihood and a major to catastrophic level of concern and behavioural intent. To represent the uncertainty, or range of perceptions, the derived risk of a *D. geminata* incursion in Tasmania was considered to be low-medium.

Discussion

This study aimed to develop and test a risk assessment model that could be used for improving conservation and biosecurity management of non-indigenous species by focussing on the hazard humans present (via their concerns and behavioural intentions) as vectors for a non-indigenous species. A test scenario of *D. geminata* being introduced to Tasmania, Australia was used to explore how the risk model will work with the input of perceptions. Although we have used a test species and location the risk model is potentially valid for other locations and for different species as it focuses on propagule strength (exposure and mitigation) and people's stated reactions (behavioural intent) to an introduction to derive measures of likelihood and consequence, respectively.

Managing aquatic biosecurity risks

Our assessment relied on quantitative data obtained from surveys and incorporated people's perception data to examine social impacts of a potential *D. geminata* incursion and potential spread mechanisms. With regards to the test scenario (Tasmania), we determined that the risk associated with a *D. geminata* incursion was low-medium. We were also able to ascertain that certain unregulated recreational user groups may pose a threat of vectoring this species due to their self-admitted behavioural intentions even when they know *D. geminata* is present in a water-body. This information could then be used in a pro-active manner to create an improved risk education program that specifically targets identified risk user groups.

To place this into context, we draw on two important management points which have been made by Perrings et al. (2002) in their synopsis about the economic perspective of invasion risks and the public good. The first is that risk is controlled to a certain extent by how people react to the possibility of an incursion (Perrings et al. 2002) (which is driven by perceptions), with the implication being that management directions are potentially at the public's whim. For example, if people show little concern for an incursion then there is no moral imperative by people to do the right thing with regards to cleaning equipment, or following management directions. In this study, this is partially reflected by some people indicating their intention to continue to return to an infected water body or not taking mitigation steps such as cleaning their equipment. Similarly, people may indicate concern but then fail to act on this concern. Our study also found a high (<80%) proportion of all respondents indicated that they felt concern about introduced species, but few respondents would undertake mitigation action with regards to cleaning of equipment (<7% of survey population clean equipment), or avoiding impacted areas (e.g., 71% of hikers questioned will return to infected areas). This indicated that there seems to be a disjunct between people's perception and their behavioural intent. Therefore, how the public reacts to an incursion is variable and may be influenced by other factors that were not studied here.

We also note that in some circumstances policy is informally driven by the community, such as stakeholders, interest groups, and the general public, via a bottom up process (e.g., McCay and Jentoft 1996; Crawford et al. 2006), and hence neglect by the community can be responsible for neglect within a policy or management framework (e.g., Sabatier 1986, 1991).

Secondly, Perrings and colleagues (2002) suggest that people are the weakest link in prevention and control of non-indigenous species. This statement is certainly reinforced by research that illustrates that people act as vectors of non-indigenous species (e.g., Lonsdale et al. 1994; Vitousek et al. 1997; Lewis et al. 2005). Again, this concept was evident in our research, where people informed of an incursion were concerned, but to some user groups, such as hikers, this concern did not translate into avoidance behaviour (such as avoiding an infected water body, or cleaning equipment). Thus, we can link hiker's refusal to change behaviours to individuals that have a risk-taking propensity. Similar risk-taking behaviours have been identified in psychology research (e.g., Gladis et al. 1992), medical studies (e.g., Zuckerman et al. 1990), and recreational pursuits (e.g., Thomas and Raymond 1998; Parkin and Morris 2005), where people are aware of risks but chose to still participate in the risk activity regardless of the risks involved.

Numerous studies have attempted to understand risk-taking propensity (e.g., Slovic 1964; Jackson et al. 1972; Baird and Thomas 1985; Lyng 1990; Weber et al. 2002; Parkin and Morris 2005). However, risk-taking in recreational pursuits such as hiking, fishing and kayaking is not generally linked to biosecurity. Therefore, it is a challenge to managers to create a biosecurity connection in recreational users about their actions or intended behaviours and the potential to spread pest species. To achieve this, biosecurity and conservation managers need to understand how and why humans spread non-indigenous species, which includes understanding how behavioural intent and concern may influence a person's actions.

The first step in this process is gauging whether participants are aware of non-indigenous species, and that they are participating in a risk activity that could spread a non-indigenous species. General awareness of non-indigenous species is especially important in this situation given that biosecurity risks can be ephemeral or occur rapidly (e.g., Willan et al. 2000), leaving little chance of risk education reaching an audience. To begin addressing this, the risk assessment we have developed here aims to ameliorate Perrings et al. (2002) weakest link concept by assessing whether perceptions (concern and behavioural intent) are valid variables within a risk assessment model. Our results indicate that these two variables are able to pinpoint user groups that could be categorised as weak links and thus risk education could pro-actively target these user groups for long-term biosecurity education.

The examination of perception in biosecurity is not uncommon in terrestrial and veterinary contexts (e.g., Casal et al. 2007; Heffernan et al. 2008; McFarlane and Witson 2008), but is less frequently employed in an aquatic biosecurity context (see Delabbio 2003; Kuhar et al. 2009) and has not been incorporated in published freshwater or marine biosecurity risk assessments to date. The inclusion of people's perceptions in the consequence analysis provided useful insight into different user group behavioural patterns that, as stated above, can now be utilised by conservation and biosecurity managers to target educational programs and risk management initiatives. As such, the perception data analysed here indicates how these user groups would potentially respond to a hazard, in a manner that is useful to conservation and biosecurity (i.e., encourage users not return to an infected site until infection is under control).

However, it must also be noted that questionnaires are vulnerable to people that may not tell the truth, or state what they believe to be socially acceptable (social desirability response bias; e.g., Randall and Fernandes 1991; Lajunen and Summala 2003; Pauls and Crost 2004) when undertaking self-report style questionnaire surveys (e.g., Brace 2008). Lying would decrease the reliability of our survey outcomes yet; this aspect cannot be fully factored out of any questionnaire survey (Brace 2008). We suggest that further research that links behavioural intentions and a person's attitude, subjective norms, and perceived behavioural control (e.g., Sheeran and Orbell 1999) would provide clarity about whether behavioural intent is a robust consequence measure and whether behavioural intent is a valid indicator of humans as pest transfer mechanisms or pathways in aquatic biosecurity.

Risk behaviours and management implications

Since human decision making is based on the "here and now," long-term consequences (i.e., those that are delayed) are typically discounted (i.e., perception of risk is reduced or considered less serious e.g, Gattig and Hendrickx 2007; Waage and Mumford 2008). Contrary to other forms of risk (e.g., economic), environmental risks such as aquatic biosecurity incursions tend to have long-term consequences but are often not-discounted by people (Gattig and Hendrickx 2007) or they produce a no-delay effect (i.e., consequences are not delayed; Hendrickx and Nicolaij 2004; Bohm and Pfister 2005; Gattig and Hendrickx 2007). In our research, we found evidence of discounting of *D. geminata* consequences by one recreational user group (hikers) but anglers and kayakers showed no discounting of the consequences. The discounting of aquatic biosecurity risks has not been fully explored and we strongly urge further research in this area as it directly relates to the vectoring of pest species.

The perceived consequence (impact) of *D. geminata* clearly represents a management concern. Within this study, many of the fisher and kayaker respondents indicated that they would change their behaviour by not returning to a site after an incursion event, which would have a positive biosecurity outcome but potential negative direct flow-on affects to tourism and local economies. Tourism in Tasmania provides approximately 4.9% to the GSP, and is projected to be worth over AUD 1.024 billion, providing over 13,696 jobs within the state (Tourism and Transport Forum 2009). Trout fishing, hiking and kayaking all contribute to the GSP. An incursion of *D. geminata* in Tasmania could also impact upon the regions "pristine" status (clean, green image), which could potentially result in future economic loss within the tourism industry. To date, this region has effectively harnessed its clean, green image to attract tourists (McKim 2005; Vanormelingen et al. 2008), with non-indigenous species impacts potentially having severe affects on the environment, economy and the well being of people in the area (Fallon and Kriwoken 2003).

Similarly, research on red tides in Florida has shown that economic impacts generated by tourist perceptions after a non-indigenous species event can have a large bearing in a tourist focussed region (Kuhar et al. 2009). Considering that the costs of non-indigenous species are large, for example, US$120 – 130 billion per annum in the United States (US) (Pimentel et al. 2000, 2005); we also need to recognise that pest species can cause both environmental and economic impacts, yet the number of non-indigenous species that cause a discernible impact is unknown in many regions, such as the United Kingdom (UK) (e.g., Manchester and Bullock 2000). Given these high costs and high uncertainty, understanding and better management of these issues is imperative.

Of further concern is the secondary transfer of *D. geminata* once an incursion has occurred. In the UK and US, human mediated secondary transfer has been blamed for the movement of pest species such as *Dreissena polymorpha* and

D. bugensis, between water bodies (e.g., Johnson et al. 2001; Thorp et al. 2002; Minchin et al. 2003). Unintentional primary transfer of pest species often occurs at the scale of large transport mechanisms, such as ships. Yet, human mediated secondary transfer tends to occur at more manageable scales, such as a person's individual boat, or fishing equipment (Minchin et al. 2006, 2009), that are directly controlled by people's actions. Although 'risk user' groups are often identified, research often doesn't concentrate on behavioural patterns or social mechanisms that might act as drivers for the movement of pest species (except see Ludwig and Leitch 1996; Johnson et al. 2001). In Australia, aquatic risk user groups are often identified via expert opinion (S. Gowland, pers. comm.) but it's rare that quantitative studies are used to indicate potential and realised risk user groups. In this study and from a risk management perspective, of particular concern is that the hiker user group would not alter their behavioural intent significantly (71% of hikers would still return to the infected site; Table 5) and thus this user group represents a secondary transfer vector that can spread this species from an initial incursion site to other sites. At present this user group is unregulated in a biosecurity context.

We did not quantitatively explore why hikers felt that they would not alter their behavioural intentions once an incursion occurred, but qualitative comments made by the respondents suggest that this is related to hikers not perceiving themselves as freshwater users (i.e., they are terrestrial users) and thus they are estranged from the potential risk that their activities create. This highlights a cognitive failure of these users to understand the relationship between their activities and biosecurity. At a fundamental level, this also belies the dichotomy of risk orientation shown by people: spectrum of risk-takers to risk-avoiders (averse). Seventy-one percent of hikers in this study fail to translate their stated concern into a behavioural intent of avoiding an infected area (i.e, they are risk-takers). Whereas anglers and kayakers, tend to be risk averse, having stated a high level of concern and also indicating strong risk avoidance behaviours. Hikers may be risk-takers because they assume that their activities amount to risk reduction (i.e., they don't interact with freshwater systems). However, in reality hikers ford rivers and visit lakes to collect drinking water, for example, all of which brings them into contact with freshwater systems that may be infected.

The general risk paradigm (also known as a reward/risk conflict) is that people will seek a balance between perceived reward (i.e., personal benefit) and perceived risk (i.e., personal cost) (Zuckerman and Kuhlman 2000; Weber et al. 2002; Hansson 2003). Thus, a person's actions can be motivated by a perceived benefit that will outweigh any costs associated with a hazard (Kahneman and Lovallo 1993; Weber et al. 2002; Hansson 2003), with these actions becoming habituated if gratification is easily attained (Zuckerman and Kuhlman 2000). Risk-taking behaviour is context dependent (e.g., Byrnes et al. 1999; Weber et al. 2002) and has also been linked to age and gender (e.g., Wilson and Daly 1985; Byrnes et al. 1999), personality traits such as sensation seeking and impulsivity (e.g., Zuckerman and Kuhlman 2000), and loss aversion (e.g., Tversky and Kahneman 1991). So, why do hikers fail to avoid the risk of infected rivers? Unfortunately, this is a question that we can't answer with this data set. Answering this question will require further studies into the risk perception of hikers and other user groups, combining both social and psychometric analyses to determine the factors that influence risk behaviour. From a management perspective knowing that these failures (risk-taking behaviours within a population of risk activities) are present is an important first step to ensure that risk management and subsequent non-indigenous species risk education programs are effective.

Much like fisheries management (Quinn 1992), biosecurity managers need to move beyond just collecting biological information (Perne et al. 2008; Flöder and Kilroy 2009; Whitton et al. 2009), start to adopt initiatives that accurately elucidate all risk user groups, and combine this information in a holistic fashion to obtain effective risk management and risk education outcomes. For example, angler surveys in North Dakota have been used to identify risk activities and to determine the likelihood of non-indigenous species releases related to this recreational user group to highlight the need for policy measures to control this pathway and manage this vector (Ludwig and Leitch 1996). Johnson et al. (2001) interviewed boaters and sampled their vessels and associated trailers to estimate the risk of zebra mussels (*Dreissena polymorhpa*) being transported by recreational boating.

In Tasmania, anglers receive *D. geminata* education material when they receive their recreational trout licence (S. Hepworth pers. comm.). Similarly, all travellers entering Tasmania and international Australian ports (airports and seaports) are exposed to *D. geminata* quarantine educational material in the form of billboards and pamphlets. Yet, hiking and kayaking are unregulated activities and thus participants in these activities have not been targeted by educational biosecurity material. Thus, we suggest that the current pro-active risk education strategy needs to be expanded to target unregulated user groups such as hikers and kayakers. Because user groups have different perceptions, diverse awareness programs are needed for effective outcomes.

To date, some studies have highlighted risk behaviours and risk groups, but the motivation and beliefs that cause these behaviours is yet to be fully elucidated. The inclusion of perception into biosecurity risk assessments should achieve two objectives that will aid the risk management process: 1) identify presently unknown risk activities and risk behaviours; and 2) identify the values (including beliefs, norms, attitudes, and heuristics) that control or motivate those risk behaviours. This will produce a broad picture of behavioural intent with regards to the vectoring of introduced species. It must be noted that risk perception and its influencing factors are complex (Sjöberg 2000); yet failing to address perception will diminish the effectiveness of risk assessment for introduced species.

Thus, the utility of including perception (via concern and behaviours) in this study is justified via the identification of a previously unknown risk activity (hikers) and their stated behaviour of returning to infected water bodies, within a *D. geminata* context. The next step in this process is to expand the risk assessment to investigate what motivates risk behaviours by investigating the psychometric elements of introduced species perception.

Conclusions

In conclusion, we anticipate that our findings will assist biosecurity managers with future decisions regarding, at a local level, how to prevent *D. geminata* entering Tasmania by indicating that a risk exists and that some recreational user groups pose a previously unrealised risk. More importantly, and at a broader scale, this study has shown how the inclusion of perceptions, in particular behavioural intent and concern, can help pinpoint risk user groups (such as hikers). This type of assessment could readily be applied to other pre-border biosecurity management actions that currently lack a social perspective, or where vector and pathway management is not fully elucidated or understood in both pre- and post-border contexts (i.e., control of movement once a species is introduced). As such, combining perception into a biosecurity risk assessment has proved effective in this scenario and we feel that it is potentially a viable tool that could be used within a biosecurity risk analysis framework to improve efficiencies.

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