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Research Article

Protecting high-value areas from introduced marine species

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Abstract

We developed two risk models to investigate the movement of introduced marine species into High-value areas (HVAs), using *Undaria pinnatifida* invasions in New Zealand as a model system. This process focussed on the secondary transfer of *Undaria* into the HVAs, as it is already introduced to New Zealand. The first model was a qualitative, theoretical risk assessment based on expert opinion, and was used by management to re-assess the potential impacts of *Undaria* on values associated with a set of six, expert identified, HVAs. The risk re-assessment process identified that *Undaria* posed an extreme risk to a majority of values in all evaluated HVAs. Based on this outcome, a realised risk assessment model was developed and is described that uses quantitative vessel and propagule strength data to examine secondary transfers of *Undaria* into HVAs. The realised risk assessment is the next stage in the process of delineating the risk *Undaria* poses to New Zealand HVAs. The intent of this process was to provide salient, credible and legitimate information to decision-makers in a transparent manner because direct impact data is limited and uncertain. Both models presented are readily applicable to *Undaria* invasions in different regions and countries, with the original re-assessment model having been used by biosecurity managers.

Key words: biosecurity; marine protected area; non-indigenous species; risk assessment; *Undaria pinnatifida*; vectors

Introduction

The identification and management of high-value areas (HVAs) require trade-offs between competing economic, environmental, social and cultural needs. High-value areas are a global phenomenon with examples classified in numerous ways such as marine protected areas (e.g., Great Barrier Reef Marine Park, Australia; http://www.gbrmpa.gov.au), marine reserves (Kermadec, New Zealand; http://www.doc.govt.nz/parks-and-recreation/places-to-visit/auckland/kermadec-islands/kermadec-islands/), marine National Monuments (e.g., Papahanaumokuakea, USA; http://www.papahanaumokuakea.gov), World Heritage Areas (Gough and Inaccessible Islands, United Kingdom and Northern Ireland; http://whc.unesco.org/en/list/740), RAMSAR sites (Runde, Norway; http://ramsar.wetlands.org/Database/SearchforRamsarsites/tabid/765/Default.aspx), Special Areas of Conservation (Obain Loch Euphoirt, Scotland; http://jncc.defra.gov.uk/ProtectedSites/SACselection/sac.asp?EUcode=UK0017101), Particularly Sensitive Sea Areas (The Galapagos Archipelago, Ecuador; http://whc.unesco.org/en/list/1), and UNESCO Biosphere Reserves (Wakatobi, Indonesia; http://www.unesco.org/new/en/media-services/multimedia/photos/mab-2012/indonesia/).

The conservation focus of HVAs manages for perceptions of ideal (or special) attributes to which humans are attracted; these attributes include values such as beautiful, untouched wilderness or resources that offer vast economic, social or cultural wealth. High-value area management plans are a priority, especially for those areas that are considered at risk, with particular focus on threats including human use, threatened species or habitat management. More recently this focus has shifted to include environmental effects such as climate change impacts and the management of introduced species (i.e., biosecurity) (e.g., Byers 2005; Hewitt et al. 2005; Department of Conservation 2006; Klinger et al. 2006; Wyatt et al. 2005).

Introduced species are ranked as one of the top five-threats to biodiversity (Lubchenco et al. 1991; Mooney and Hobbs 2000) and when coupled with the synergistic effects of climate change (McLachlan et al. 2007; Hellmann et al. 2008; Rahel and Olden 2008; Rahel et al. 2008) it is likely that the threat from introduced species will increase, not diminish. This may be particularly true for HVAs that were initially considered "safe" from particular introduced species threats due to environmental and biogeographic constraints including higher diversity related to biotic resistance and isolation from primary invasion points. Our increased understanding of invasion ecology, coupled with the rapidly changing environment, suggests that a re-assessment of the risks posed by introduced species to these areas, and a re-evaluation of the management actions and options to protect such areas from introduced species, is needed (Hewitt and Huxel 2002; Byers 2005; Wyatt et al. 2005; Klinger et al. 2006; Lewis et al. 2004).

Marine invasions are currently recognised as pervasive throughout the world's oceans (e.g., Ruiz et al. 1997, 2000; Carlton 2001; Leppäkoski et al. 2002; Hewitt et al. 2004a, 2004b; Orensanz et al. 2004; Castilla et al. 2005; Hewitt and Campbell 2010) with significant recognised impacts to all four core values (environmental, economic, social and cultural). Intentional introductions of species (e.g., fisheries and aquaculture stocking) are relatively simple to manage and can be controlled via quarantine measures (e.g., import health standards) and/or containment (i.e., maintained in a quarantine facility; Kahn et al. 1999; Campbell 2011) though once released into the environment, unanticipated impacts may occur. Unintentional introductions of species are more problematic and need to be managed at the level of the vector (transport mechanism), the pathway (route of transfer) and the species by understanding the anticipated risk (e.g., Hayes and Sliwa 2003; Campbell 2008). Knowing the risk that a vector, pathway, or species poses is the initial step in controlling the problem, as effective management must be adaptive, broad and transparent to cater to changes in socio-political imperatives and to meet changes in scientific perspectives. Often the management of unintentional introductions is rife with uncertainty and hence risk assessment is a management tool implemented to overcome this uncertainty.

Within a New Zealand context, the Biosecurity Act (1993) was established to protect New Zealand from introduced species (Biosecurity Strategy 2003). This Act focuses on unintentional introductions with pre-border (e.g., quarantine) and post-border (e.g., incursion response and surveillance) management options (Parliamentary Counsel Office 2008). Once an introduced species is detected and determined as likely to become a pest, it is listed as an "Unwanted Organism" – a status that governs strict management actions under the Act (Hewitt and Campbell 2007). There have been instances of a species incursion with no management action occurring. But when the species becomes problematic management is re-assessed. Such a case is the introduction and subsequent spread of *Undaria pinnatifida* (Harvey) Suringer to New Zealand.

1.1 Model System Species: Undaria pinnatifida

Undaria pinnatifida (herein referred to as *Undaria*) is an introduced marine kelp species that was first detected in New Zealand waters in the 1980's (Hay and Luckens 1987). It is known to be introduced in more than nine countries (Schaffelke et al. 2005) and has been the focus of a number of eradication attempts (Curiel et al. 2002; Thornber et al. 2004; Wotton et al. 2004; Hewitt et al. 2005), many of which have failed. *Undaria* is cultured in its native (e.g., China, Korea and Japan; Zemke-White and Ohno 1999) and introduced ranges (e.g., Australia, France; Perez et al. 1984; Zemke-White and Ohno 1999; Floc'h et al. 1991). This species has broad salinity and temperature tolerances (Akiyama 1965; Saito 1972; Peters and Breeman 1993; Wallentinus 1999; Casas et al 2004; Nyberg and Wallentinus 2005). Its response to desiccation is variable. Saito (1960) has demonstrated zoospore, gametophyte and sporophyte tolerance to desiccation was low (measured in minutes to hours), with Forrest and Blakemore (2006), finding a high (days) tolerance to desiccation.

This species has a propensity to foul vessels (Lewis 1999) and its broad thermal tolerance (Henkel and Hofmann 2008) have implications for domestic transfer once it becomes established within a country and thus poses a potential threat to HVAs and the associated tourist trade. For example, in Argentina *Undaria* is established in central Patagonia (Graciela et al. 2004; Raffo et al. 2009) at Golfo Nuevo; a popular tourist whale watching destination (Schluter 2001; Sironi et al. 2005). In the United Kingdom, *Undaria* has been noted as a pest in marinas (Farrell and Fletcher 2006), with suggestions that it will cover substantial amounts of the coastline in nine-years (Farrell 2003) via recreational vessel movement.

Similarly in the United States, *Undaria* is located on the west coast near important recreational boating marinas (e.g., Long Beach Harbors), ports (e.g., Los Angeles) and coastal regions that were considered relatively pristine (e.g., Catalina islands) and/or socially important (e.g., Monterrey Bay) (Silva et al. 2002; L. Anderson pers. comm.). In the Mediterranean Sea, *Undaria* is located in ports and embayment's associated with commercial and recreational traffic (e.g. Boudouresque et al. 1984; Cecere et al. 2000; Curiel et al 2002). In Australia, the initial *Undaria* incursion was located in the woodchip export wharf at Triabunna, directly opposite a marine protected area (Maria Island), where the species colonised and has since expanded (Bryant 2011). On mainland Australia, a different haplotype of *Undaria* has been introduced to ports and recreational marina's within Port Phillip Bay (Voisin et al 2005) and has recently been transferred via recreational vessels to marinas on the Victorian coastline (Primo et al. 2010; Younger 2011).

Within New Zealand, initially this species was not listed as an Unwanted Organism (a legislative term that enables regulation and management control of the species) because it was deemed to be broadly established with management actions underway. However, in 2003 *Undaria* was listed as an Unwanted Organism. What triggered this late listing was the sinking of the FV *Seafresh* in the remote Chatham Islands of New Zealand during 2000 (Wotton et al. 2004). The hull of the FV *Seafresh* was known to be infected with *Undaria* from previous surveys on the main islands of New Zealand (Wotton et al. 2004).

The Chatham Islands are deemed an HVA by the New Zealand Department of Conservation; they are remote, relatively pristine and have a high marine biodiversity with significant marine endemicity. *Undaria* was not known to be present in the Chatham Islands, and a preliminary assessment had identified that the introduction of *Undaria* to the Chatham Islands would cause significant, and potentially catastrophic, impact. Thus, the species was listed as an Unwanted Organism to enable eradication under the Biosecurity Act. The eradication attempt was successful in 2001 (Wotton et al. 2004) and the species is now managed as an Unwanted Organism. This incident highlighted the vulnerability of HVAs to introduced species and instigated a re-evaluation of how HVAs were being managed with regards to marine biosecurity.

Further compounding this re-evaluation of management was that although *Undaria* had been present in New Zealand waters for more than two-decades and has broad ecological tolerances (summarised in Schaffleke et al. 2005), its range expansion had yet to fully utilise all available niche space (e.g., it was not present on the west coast of the South Island at the time of the study and had yet to reach the north of the North Island). In 2005, the species was detected in Auckland Harbour, an area originally thought to be unlikely to sustain the species based on surface water temperature (Sinner et al. 2000). The detection of *Undaria* in Auckland strongly suggested that it was still capable of further expanding its range within New Zealand. Again this focussed concern that HVAs within New Zealand were potentially unprotected from introduced species and management plans needed to be updated. To better understand these risks and to improve management plans, a risk assessment that used expert opinion was undertaken by the CTO Marine Biosecurity (CLH) to address the hazard posed by *Undaria* to HVAs.

This paper describes the initial risk re-assessment process to evaluate whether *Undaria,* an Unwanted Organism, posed a risk to the values in a set of six HVAs identified by Biosecurity New Zealand (now Ministry of Primary Industries). It also describes a secondary risk model for use to examine secondary transfer of this species to HVAs. This paper focuses on New Zealand, as a model system, however the threat *Undaria* poses to HVAs in other countries is apparent and as such the risk method presented is applicable to both *Undaria* introductions in other countries and introductions of other species. Based on the outcome of the risk assessment the conservation management options to protect these HVAs were re-assessed. The objective of these risk assessments was to provide salient, credible and legitimate information to decision-makers in a transparent manner because impact data was limited and uncertain.

Although alluded to (e.g., Edgar et al. 1997), few studies have empirically examined the impact *Undaria* has on native species in invaded locations (e.g., Forrest and Taylor 2002; Casas et al. 2004; Russell et al. 2008) creating persistent uncertainty about the real impact. As a consequence of this uncertainty, the initial risk assessment we present is based on the use of expert heuristic opinion to qualitatively identify likely impact, representing the theoretical risk *Undaria* poses to HVAs. Within the discussion we present a model to then calculate the realised risk that *Undaria* poses to HVAs.

1.2 Identified High-Value Areas in New Zealand

The risk assessment targets a subset of previously established HVAs (including marine protected areas, conservation areas, World Heritage Sites) that were identified by scientific and marine biosecurity experts as falling within the revised distributional limits of *Undaria*. An expert focus group was convened to provide opinions and judgements about likelihood and consequence in an approach similar to that used in other marine biosecurity risk assessments (e.g., Campbell 2008, 2009; Dahlstrom et al. 2012; further described below). Six HVAs (Chatham Islands, Hauraki Gulf, Fiordland; the Poor Knights, the Sub-Antarctic Islands and the Three Kings) were identified by the Department of Conservation as potentially threatened by *Undaria.* These sites were evaluated to determine the likely impact *Undaria* would have on environmental, economic and social core values within these regions.

Of the six HVAs, two (Sub-Antarctic Islands and Fiordland, as a component of Te Wahipounamu) are recognised as internationally important through their inclusion in the World Heritage Estate. Several others, the Poor Knights, the Three Kings, components of Fiordland (Piopiotahi and Te Awaatu Channel), and Hauraki Gulf, are recognised nationally as environmentally important and classified as marine reserves with protection under the Fisheries Act.

Risk was assessed across the core values from the Biosecurity Strategy (2003), which are summarised as: i) environment - the biological to the physical characteristics of an ecosystem being assessed, excluding extractive use and aesthetic value; ii) economic - components within an ecosystem that provide a current or potential economic gain or loss; iii) cultural - those aspects of the aquatic environment that represent an iconic or spiritual value, including those that create a sense of local, regional or national identity and; iv) social - the values placed on a location in relation to human use for pleasure, aesthetic, generational values. In this instance and due to cultural (indigenous) sensitivities, cultural and social core values are combined, with indigenous values being removed from the assessment. Each core value consists of a number of subcomponents. Subcomponents are broad ranging, differing between stakeholders due to perceptions, and vary both spatially (from region to region) and temporally (through time).

Methods: Risk Assessment Process

We implemented a five step risk assessment process through a one-day workshop/focus group format where experts were asked to share knowledge, discuss concepts, test theories and run scenarios. Eight experts from within New Zealand were invited to participate based on their biological, taxonomic (algae) and marine biosecurity expertise, acknowledging that they did not have the capacity to undertake robust economic, social or cultural evaluations. These eight experts were selected because they regularly provided advice to the marine biosecurity Chief Technical Officer (CTO) and hence provided the main scientific advice base for marine biosecurity in New Zealand at the time of the study.

The first step of the process involved the participants identifying the relevant subcomponents that made up each of the three core values, resulting in the specification of four environmental, four economic and three social subcomponents. In the second step, qualitative measures of likelihood (Table 1) were presented to the workshop participants with the participants using these to determine the likelihood that *Undaria* would arrive (and establish), and cause impact upon each identified subcomponent, within each the six HVAs.

Next, the consequences (degree of impact) that *Undaria* would have on the subcomponents were explored by examining belief systems (extracting heuristic knowledge) from the workshop participants. Initially, consequences were assessed across all of New Zealand, but within the risk assessment they are extrapolated to the HVAs only, which was the focus of the risk assessment. Predetermined consequence matrices, similar to those used in other marine biosecurity risk analyses (e.g., Kluza et al. 2006; Campbell 2008; Cliff and Campbell 2012; Davidson et al. 2013) and fisheries contexts (Fletcher 2005; Campbell and Gallagher 2007), were presented to the workshop participants and modified by consensus (Tables 2a-c). Alterations to the consequence matrices were driven by open discussion and consensus.

The consequence matrices use linguistically qualitative descriptors that can be assessed using either quantitative or qualitative data. They are derived from the Australian and New Zealand Standards (Standards Australia 2000, 2004) and

Table 1. Likelihood matrix to assess if *Undaria pinnatifida* will have an impact.

Descriptor	Description	Probability of Impact
Rare	Impact will only occur in exceptional circumstances	<5%
Unlikely	Impact could occur but not expected	25%
Possible	Impact could occur	50%
Likely	Impact will probably occur in most circumstances	75%
Almost Certain	Impact is expected to occur in most circumstances	>95%

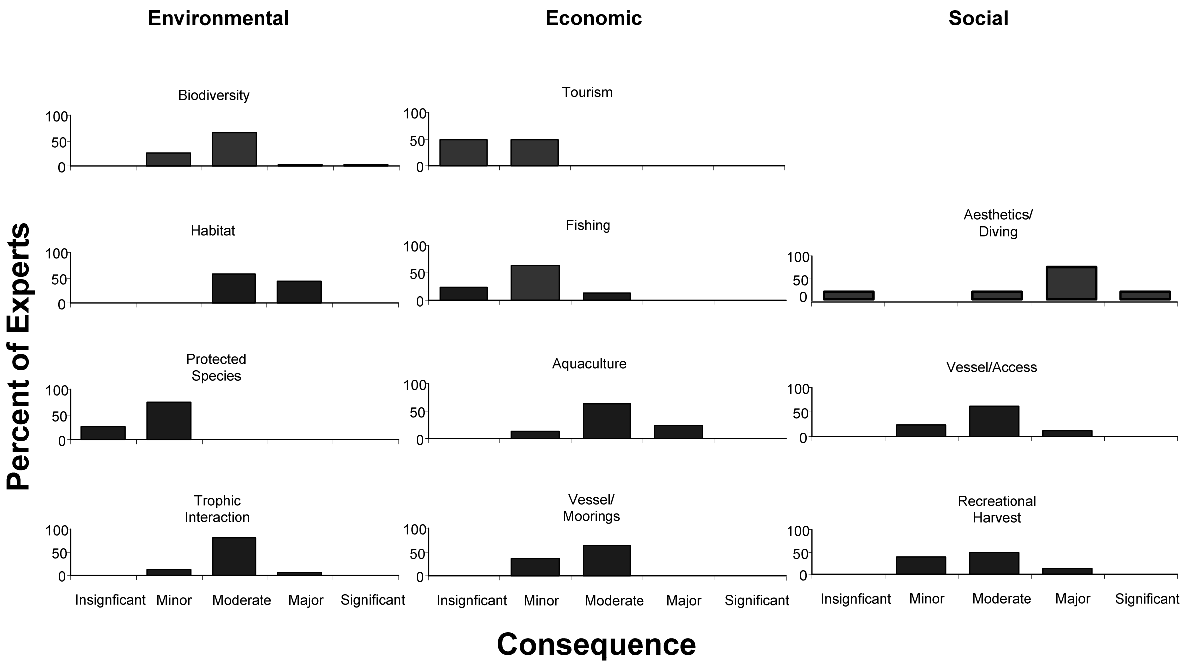

Figure 1. Range of consequence outcomes assessing impact of *Undaria pinnatifida* on: environment; economic and social subcomponents.

have then been modified to a biosecurity context. Each level within the consequence matrix has a threshold measure (represented by the % values) that provides a benchmark of acceptable level of impact. The threshold values were arbitrarily derived from New Zealand policy heuristics that set the acceptable level of impact within a biosecurity context. The threshold values have been through numerous iterations taking into account feedback received from practitioners in the field, researchers, and government officials from New Zealand. The matrices act to provide a standard and hence consistent manner to assess impact for all introduced species.

During the workshop experts were provided axes for each subcomponent and asked to place a mark on the continuum, from insignificant to significant, representing their opinion of the level of consequence *Undaria* would represent. The outcomes of all participants' opinions of the consequence assessment are presented as histograms (Figure 1). Here we have considered the range of opinions to represent the level of uncertainty. For all core values, the range represents the degree of different opinion between workshop participants, however, we used numerical scores for categories (ranging from insignificant = 1 to significant = 5) and calculated the average and 95th percentile to represent the measure of central tendency and the conservative (upper limit) of deviation. The average value and the 95th percentile for each subcomponent were therefore used to categorise consequence.

In the fourth step, a measure of risk was derived by multiplying likelihood by consequence (Table 3), thus determining how often an event

Table 2a. Consequence matrix for environment core values, as defined by the subcomponents and consisting of biodiversity, habitat, protected species and trophic interactions.

Descriptor	Environmental Impacts
Insignificant	• Environment reduction is minimal (<10%) compared to loss from other human-mediated activities. • Reductions in environment subcomponents are not readily detectable (<10% variation). • If *Undaria* was removed, recovery is expected in days; no discernible change in the environment.
Minor	• Environment reduction is <20% compared to loss from other human-mediated activities. • Reductions in environment subcomponents are <20%. • Environment reductions and area of introduced species impact is small compared to known areas of distribution (<20%). • If *Undaria* was removed, recovery is expected in days to months; no loss of keystone species populations, no discernible change in geological form and function; no local extinctions.
Moderate	• Environment reduction is <30% compared to loss from other human-mediated activities. • Reductions in environment subcomponents are <30%. • Environment reduction and area of introduced species impact is moderate compared to known area of distribution (<30%). • If *Undaria* was removed, recovery is expected in less than a year ; loss of at least one keystone species or populations, loss of geological form and function, no loss of primary producers; local extinction events.
Major	• Environment reduction is <70% compared to loss from other human-mediated activities. • Reductions in environment subcomponents are <70%. • Environment reduction and area of introduced species impact is small compared to known area of distribution (<70%); likely to cause local extinction. • If *Undaria* was removed, recovery is expected in less than a decade; loss several keystone species or populations, changes in trophic levels, loss of primary producer populations, loss of geological form and function; multiple local extinction events; one regional extinction.
Significant	• Environment reduction is >70% compared to loss from other human-mediated activities. • Reductions in environment subcomponents are >70%. • Environment reduction and area of introduced species impact is small compared to known area of distribution (>70%); likely to cause local extinction. • If *Undaria* was removed, recovery is not expected; loss of multiple species of populations causing significant local extinctions and loss of trophic levels, potential trophic cascades resulting in significant changes to ecosystem structure, alteration to biodiversity patterns and changes to ecosystem function, loss of geological form and function; global extinction of at least one species.

Table 2b. Consequence matrix for economic core values as defined by the subcomponents and consisting of tourism, fishing, aquaculture and vessels and their associated moorings.

Descriptor	Economic Impacts
Insignificant	• Reduction in national income from introduced species impact shows no discernible change. • No discernable change in strength of economic activities. • If *Undaria* was removed, recovery is expected in days.
Minor	• Reduction in national income from introduced species impact is <1%. • Reduction of strength in individual economic activities is <1%. • Economic activity is reduced to 99% of its original area (spatial context) within New Zealand. • If *Undaria* was removed, recovery is expected in days to months, no loss of any economic industry.
Moderate	• Reduction in national income from introduced species impact is 1-5%. • Reduction of strength in individual economic activities is 1-5%. • Economic activity is reduced to less than 95% of its original area (spatial context) within New Zealand. • If *Undaria* was removed, recovery is expected in less than a year with the loss of at least one economic activity.
Major	• Reduction in national income from introduced species impact is 5-10%. • Reduction of strength in individual economic activities is 5-10%. • Economic activity is reduced to less than 90% of its original area (spatial context) within New Zealand. • If *Undaria* was removed, recovery is expected in less than a decade with the loss of at least one economic activity.
Significant	• Reduction in national income from introduced species impact is >10%. • Reduction of strength in individual economic activities is >10%. • Economic activity is reduced to less than 90% of its original area (spatial context) within the New Zealand. • If *Undaria* was removed, recovery is not expected with the loss of multiple economic activities.

Table 2c. Consequence matrix for social core values as defined by the subcomponents and consisting of aesthetics and diving, vessels and access to vessels, and recreational harvest.

Descriptor	Social Impacts
Insignificant	• Social activity reduction is minimal (<1%). • No discernable change in strength of social activities. • If *Undaria* was removed, recovery is expected in days.
Minor	• Social activity reduction is <10%. • Reduction of strength in separate social activities is <10%. • Social activity is reduced to less than 90% of its original area (spatial context) within the region. • If *Undaria* was removed, recovery is expected in days to months, no loss of any social activities.
Moderate	• Social activity reduction is <20%. • Reduction of strength in separate social activities is <20%. • Social activity is reduced to less than 80% of its original area (spatial context) within the region. • Social activity reduction is restricted to the region of incursion/impact. • If *Undaria* was removed, recovery is expected in less than a year and loss of at least one tourism activities.
Major	• Social activity reduction is <40%. • Reduction of strength in separate social activities is <40%. • Social activity is reduced to less than 70% of its original area (spatial context) within the region. • Social activity is reduced in neighbouring regions. • If *Undaria* was removed, recovery is expected in less than a decade and loss of at least one tourism activities.
Significant	• Social activity reduction is >40%. • Reduction of strength in separate social activities is >40%. • Social activity is reduced to less than 60% of its original area (spatial context) within the region. • Social activity is reduced in neighbouring countries. • If *Undaria* was removed, recovery is not expected and loss of multiple tourism activities.

Table 3. Risk matrix denoted by N = negligible; L = low, M = moderate; H = high; and E = extreme.

	Consequence				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Significant**
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost Certain	N	M	E	E	E

may occur and what the consequences of such an event might be. Risk was assessed for each subcomponent in each of the HVAs. When a range of likelihood was given, the most conservative (highest likelihood) likelihood level was used to maintain a precautionary approach. However, we've presented risk as a range to account for the average and the 95th percentile consequence measures: in some instances the range of consequences is encompassed by one risk measure due to the structure of the risk matrix.

By using the most conservative estimate of risk we potentially overestimate risk, which may misallocate management resources and hamper the decision support process (Possingham et al. 2002; Davidson et al. 2013). The alternative to overestimating likelihood is to allocate the likelihood to the lowest category, which would potentially have the opposite effect of underestimating risk. We feel that underestimating risk may represent potential management cost-savings but it does not provide adequate protection of the environment or meet the New Zealand regulations. Given the devastating nature of many introduced species invasions we believe that overestimation is preferred to underestimation of risk. This stance is supported directly through Australian and New Zealand Biosecurity regulations and implicitly by these countries signatories to the Convention on Biological Diversity.

Finally, uncertainty, which typically reduces the confidence in the outcomes, was explored and delineated. Uncertainty can exist as statistical variation, measurement error, ignorance and indeterminacy (Klinke and Renn 2002), but it can also exist because natural and stochastic variation exists in the environment that is difficult to capture or the knowledge base is missing. This is particularly true for introduced species (Hellmann et al. 2008; Rahel et al. 2008). A quantitative approach that identifies the direct impacts either through empirical or manipulative experiments was not utilised in this study because it would take multiple years, cost several million dollars and the ethical limitations associated with the use of introduced species for manipulative experiments which in turn may result in limited power to discern impact.

Instead, we determined the perceived value and change in perceived value in a qualitative fashion by exploring expert knowledge, opinions and beliefs. Biosecurity agencies in New Zealand and Australia often use focus group interviews consisting of lay people, scientists, economist, indigenous groups and recreational users to collect qualitative data on perceptions, opinions and/or judgements (e.g., Kluza 2006; Campbell 2008). The representation of these focus groups varies according to the aims of the task. In this instance, the focus group was comprised of scientific experts with *Undaria* knowledge. Data was collected via a workshop setting where experts were asked to provide opinions, discuss issues and revise opinions in a facilitated manner. The CTO Marine Biosecurity (CLH) moderated the workshop to ensure that advice that would inform legislative requirements was collected in a non-confrontational manner.

It must be noted that the focus group was an interview, not a decision-making or a problem solving group. Because this is an interview setting, the participants hear each other's responses and have the opportunity to make additional responses as the interview evolves and they hear other participant's comments. A focus group interview aims to enhance data quality as the "participants are able to provide checks and balances on each other" (Krueger and Casey 2000). Unlike a Delphi method (Dalkey and Helmer 1963; Linstone and Turoff 1976), the aim of the focus group interview was not consensus but the collection of information in a social context. The collected information was then used by a risk assessor to re-evaluate *Undaria's* risk ranking, *Undaria's* likely impact on HVAs, and to provide input into the risk management of this species.

The questions posed during the workshop were open-ended and developed to collect information about both the experts knowledge (factual information about *Undaria*), opinion, and judgment (exploring beliefs about the spread of *Undaria*, areas at risk, and whether the risk methodology used could be modified to improve management effectiveness). The workshop ran in a four step process:

1. Problem setting: Provided the background to the workshop; delineated the scope of the workshop; introduced the HVA concept and identified HVAs that are within *Undaria*'s revised range; and discussed the latest knowledge about *Undaria*.
2. Likelihood evaluation: Collected individual's opinions and judgements about the likelihood (potential) of *Undaria* reaching the identified HVAs.
3. Consequence evaluation and modification: Introduced the use of consequence matrices and how the presented consequence matrix was developed; discussed core values and their associated subcomponents that might be impacted upon; and collected individual's opinions and judgements about impacts and suggested alterations to the consequence matrix.
4. Scenario testing: Ran scenarios about what would, or would not, be impacted at each of the identified HVAs if *Undaria* reached that region.

Uncertainty is prevalent in focus interview approaches because the group is comprised of people with different levels of knowledge, opinions, and perceptions. Despite this, focus group interviews are a method of choice for ecosystem valuation in terrestrial, freshwater and marine systems and has been used consistently by the World Bank, numerous governments, non-government organisations (e.g., Nature Conservancy), quasi-autonomous non-government and inter-governmental organisations (e.g., IUCN, ASEAN) for the last 2-decades (see MacCraken and Abaza 2001; Anon 2004; Emerton and Bos 2004; MacKinnon et al. 2004; Pagiola et al. 2004), and is commonly used in qualitative research (e.g., Merton et al. 1956; Merton 1987; Morgan 1997; Patton 2002).

The focus group interview approach created a statistical population of opinions or beliefs that were then evaluated using classic statistics and acknowledging uncertainty. We applied a conservative stance (or worst-case scenario) in order to gain the most protection for the environment (thus meeting the legislative requirements). When dealing with introduced species, precaution (i.e. to treat all possible threats as probable; e.g., Miller and Gunderson 2003; Ikeda

Table 4. Identified core value subcomponents that are potentially affected by *Undaria pinnatifida.*

Core value	Subcomponent	Description
Environment	Biodiversity	Floral and faunal species that comprise the ecosystem
	Habitat	Structure (biotic and abiotic) that provides habitat for flora and fauna
	Protected species	Species protected under New Zealand legislation, as well as rare, endangered, vulnerable and threatened species
	Trophic interactions	Ecosystem function, food webs, benthic-pelagic coupling and bentho-pelagic coupling etc
Economic	Tourism	Commercial activity that targets tourists (domestic and international). Often relies on iconic status of an area or activity to draw tourists in.
	Fishing	Commercial fisheries
	Aquaculture	Commercial aquaculture and mariculture
	Vessels/moorings	Cost of running and maintaining vessels and moorings
Social	Aesthetics/diving	Natural character/beauty of a region and its use by divers
	Vessel/access	Increased costs of running and maintenance for recreational vessels and cost of access
	Recreational harvest	Fishing and collecting species as a recreational pursuit

Table 5. Likelihood measures outcomes for *Undaria pinnatifida* impacting each subcomponent of the environment, economic and social core values, in the six high-value areas.

Core-value Subcomponent	Likelihood High Value Region					
	Chatham Islands	Hauraki Gulf	Fiordland	Poor Knights	Sub-Antarctic	Three Kings
Environment core value						
Biodiversity	Almost certain	Almost certain	Likely	Almost certain	Almost certain	Almost certain
Habitat	Almost certain	Almost certain	Almost certain	Almost certain	Almost certain	Almost certain
Protected Species	Possible	Rare	Possible	Rare	Possible	Rare
Trophic interaction	Likely	Likely	Likely	Likely	Likely	Likely
Economic core value						
Tourism	Possible	Likely	Possible	Almost certain	Almost certain	Unlikely – Likely*
Fishing	Likely	Unlikely – Likely*	Possible	Possible	NA	Unlikely
Aquaculture	NA	Almost Certain	NA	NA	NA	NA
Vessel / moorings	Almost certain	Almost certain	Almost certain	Almost certain	Almost certain	Likely
Social core value						
Aesthetics / diving	Possible	Likely	Likely - almost certain*	Almost certain	Rare	Likely - almost certain*
Vessel / access	Possible	Almost certain	Almost certain	Almost certain	Likely	Unlikely – likely*
Recreational harvest	Likely	Almost certain	Unlikely	Possible	NA	Rare

* represents where consensus was not reached and therefore a range of likelihoods are provided. NA denotes high-value areas that are protected from fishing and or aquaculture, and therefore these subcomponents are not relevant to this area.

2006) is paramount with the most conservative approach typically recommended.

As stated previously, we measured uncertainty or differences in expert opinion, by presenting a range of views which resulted in a range of risk being presented for specific outcomes. In the present data, some uncertainty existed in the opinions of likelihood that *Undaria* would impact upon the different core value subcomponents (see Table 3). Although uncertainty existed, the most conservative level was selected for this risk analysis given that *Undaria* is already present in New Zealand, has a demonstrable ability to spread and is a known pest species (Schaffelke et al. 2005; Wotton et al. 2004; Russell et al. 2008). Uncertainty also existed in the consequences of the impact (Figure 1; Table 2). These two elements of uncertainty meant that a range of risk values were

Table 6. Summary of the perceived consequences of the impact of *Undaria pinnatifida* has on the environment, economic and social core values.

Subcomponent	Consequence	
	Average	95th percentile (conservative)
Environment core value		
Biodiversity	Moderate	Major
Habitat	Moderate	Major
Protected Species	Minor	Minor
Trophic interaction	Moderate	Major
Economic core values		
Tourism	Insignificant	Minor
Fishing	Minor	Moderate
Aquaculture	Moderate	Major
Vessel / moorings	Moderate	Moderate
Social core values		
Aesthetics / diving	Major	Significant
Vessel / access	Moderate	Major
Recreational harvest	Moderate	Major

Table 7. The outcomes of the perceived risk *Undaria pinnatifida* poses to environmental, economic, and social core values in the six high-value areas.

Subcomponent	Risk High Value Region					
	Chatham Islands	Hauraki Gulf	Fiordland	Poor Knights	Sub-Antarctic	Three Kings
Environment core value						
Biodiversity	E	H-E	E	E	E	E
Habitat	E	E	E	E	E	E
Protected Species	L	L	L	L	L	L
Trophic interaction	H-E	H-E	H-E	H-E	H-E	H-E
Economic core value						
Tourism	N-L	N-M	N-L	N-M	N-M	N-M
Fishing	M-H	M-H	L-H	L-H	NA	L-M
Aquaculture	NA	E	NA	NA	NA	NA
Vessel / moorings	E	E	E	E	E	H
Social core value						
Aesthetics / diving	H-E	E	E	E	M	E
Vessel / access	H	E	E	E	H-E	H-E
Recreational harvest	H-E	E	M-H	H	NA	L-M

NA denotes regions where this activity does not occur or is regulated.
Risk is denoted by N = negligible; L = low, M = moderate; H = high; E = extreme.

assigned, where appropriate, for environmental, economic and social core value subcomponents at each HVA.

To manage and reduce the levels of uncertainty, the experts were provided pre-developed consequence matrices and asked to follow a simple, staged process to: i) assess the consequence matrices for accuracy, suggesting changes based on opinion and discussion; ii) using the revised consequence matrices to provide a judgement as to what the consequence was; iii) as a group, discuss the consequences of *Undaria* on value; and iv) revisit their consequence ranking to make changes to individual rankings.

With the environment, economic and social subcomponents, only one alteration occurred after step iii: this occurred in the aesthetics and diving subcomponent, where one person altered their judgment of consequence from insignificant to moderate. In general, the experts validated their perceptions despite gaining knowledge of other's reasoning.

3. Results: Risk Assessment Outcomes

Eleven subcomponents were identified (Table 4). Likelihood measures were reached by group consensus and are presented in Table 5. The perceived consequence assessment and subsequent risk derivations are summarised in Tables 6 and 7, respectively. The most evident pattern observed in the risk assessment is that the perception of risk varies between and within regions and between value subcomponents. This is not unexpected as activities and environments are dynamic, changing from place to place and through time.

3.1 The Core Values

Seven general trends were present when assessing the risk *Undaria* poses to the environmental, economic and social core values. First, biodiversity, habitat and trophic interactions are deemed to be at high to extreme risk. These subcomponents have both use- and non-use value: they are used in direct consumptive fashion (fishing, watersports etc) and they have option value (to be used now or in the future), bequest value (to be left for our heirs) and existence value (for just being). In general these subcomponents are seen as necessary for an ecosystem to function and have high importance in all ecosystems in all regions. They are deemed vulnerable to impacts from introduced species.

New Zealand protected species are at low risk from *Undaria*. Protected species have a non-use value; having importance for option, bequest and existence value. Often protected species have an iconic attachment and are considered more important than other species (e.g., Walton 2006).

However, there are few New Zealand protected species that were considered to be directly impacted by the presence of *Undaria*.

Vessels, moorings and aquaculture are at high to extreme risk. Vessels, moorings and aquaculture are all direct consumptive use of an ecosystem. Vessels, moorings and aquaculture are currently targeted by management as potential *Undaria* vectors. Thus, they have a maintenance cost associated with them (ensuring the *Undaria* is cleaned from their surfaces) and restrictions are placed on their movement in a management effort to control these vectors.

Fishing risk varies from low to high. Fishing is a direct consumptive use of an ecosystem and in some circumstances also involves option value (when a region is protected from fishing for a period of time). A wide variety of commercial fisheries operate in different areas and at different capacities between and within areas, hence different perceptions of risk occurred across the HVAs. For example, fishing is not permitted within the coastal areas of Sub-Antarctic Islands and hence the presence of *Undaria* in this region would not affect this value.

Tourism risk varies from negligible to moderate. Tourism is a direct consumptive use of an ecosystem. Much like commercial fishing, tourism activities vary between and within regions and through time (follow activity trends) and therefore a range of risk was expected and captured. However, it is important to note that the experts used for this analysis have a biological focus and identified that their perceptions of tourism value may be over- or understated.

Aesthetics, diving and vessels are at high to extreme risk. These subcomponents encompass direct use, indirect use, option value and existence value. They vary between and within regions and through time. People feel that these types of activities directly impact upon their leisure/time and therefore any threat to their leisure/time is considered significant.

Finally, recreational harvest varies from low to extreme risk. Recreational harvest involves direct consumptive use of an ecosystem and therefore threats upon this direct use is considered to diminish an individual's pleasure, rights or usage. Again, some HVAs, such as the Three Kings, do not allow recreational harvest and hence the risk in these areas is low.

3.2 The High-Value Areas

Perceptions of risk differ between core values and core value subcomponents. By adopting a precautionary approach (as required under the Biosecurity Strategy in New Zealand) and by addressing the core values, if a level of extreme risk is derived for one subcomponent then the entire core value is considered to be at extreme risk. However, to encapsulate the uncertainty in the data the discussion below presents the range of risk that was derived from the participants. The same precautionary approach is applied when assessing the risk *Undaria* poses to the area: one ranking of extreme is enough to state that that area is at extreme risk, and a range is provided to show the uncertainty in the data. The expert consensus was that the HVAs considered here are not vulnerable to the natural spread of *Undaria* over a decadal scale and therefore proximity to shipping regions is thought to increase risk. Thus, from a regional perspective the following trends are apparent in the six HVAs.

The Chatham Islands are at high to extreme risk from *Undaria* in 70% of subcomponents, with the exception of both protected species and tourism, which are at negligible to low risk (Table 7). The Chatham Islands are not a large marine tourist destination, thus explaining this risk measure. Likewise, there are few protected species in this area that would be affected by *Undaria*. Aquaculture is not applicable in the region because it has yet to be developed, fisheries are regulated in all or part of the area, distance or extreme conditions reduce access or marine reserves exist in all or part of the area.

The Hauraki Gulf is at high to extreme risk across 73% of subcomponents, with the exception of protected species, tourism and fishing (Table 7). Activities within the Hauraki Gulf include tourism, fishing (commercial and recreational) and marine biodiversity protection. The Hauraki Gulf is situated in the Auckland region, which has a high population density, a major shipping port and a resulting high concentration and wide distribution of vessels making this area potentially vulnerable to *Undaria* through vessel vectoring. Based on environmental matching this area was initially evaluated as not being vulnerable to *Undaria* (Sinner et al. 2000) yet, the species was subsequently detected in Auckland Harbour. Its spread to this region could be based on natural spread or, more likely; it is linked to the proximity of shipping regions (see Uwai et al. 2006).

Fiordland is at high to extreme risk from *Undaria* in 50% of subcomponents (Table 7), with the exception of protected species and tourism. Endemicity in Fiordland is low compared to the other HVAs; however it represents a unique environment of iconic significance and is part of the World Heritage Estate (Becken 2005). Tourism in this region is high yet few people visit Fiordland to dive and therefore experts felt that few people would notice if an introduced macroalgae was present. Therefore impacts on tourism were considered to be negligible to low. Aquaculture does not occur in this region; however commercial fishing vessels and recreational yachts frequent the region and use the various fiords and sounds as safe anchorage. These vessels suggest a potential vector and pathway into this HVA. We note that after this research was undertaken that *Undaria* was introduced to Fiordland in 2009. It was detected in low numbers and has been managed towards eradication.

The Poor Knights are at high to extreme risk from *Undaria* in 50% of subcomponents (Table 7), with the exception of protected species and tourism. There are few protected species in this region that would be vulnerable to *Undaria*. Commercial fishing is restricted in this area for conservation reasons (marine reserve). Tourism is considered to be of highest value, second only to biodiversity conservation in this region. The Poor Knights are considered to have high species diversity and endemism with National obligations for protection. Aquaculture does not exist in this area at present, but like commercial fisheries, it is likely to be restricted for conservation reasons.

The Sub-Antarctic Islands are at high to extreme risk from *Undaria* in 62.5% of subcomponents, with the exception of protected species, tourism, and aesthetics/diving. The risk to protected species is low, with the risk to tourism and aesthetics/diving being negligible to moderate (Table 7). As yet, the Sub-Antarctic Islands are not a large tourist destination. Because of its low tourism usage, the aesthetics and diving scored relatively lowly. Again, there are few protected species in this area that would be impacted by *Undaria*. Endemicity is low, but the "combination of species" (diversity) is considered "interesting" by the experts. Both fisheries and aquaculture are not permitted in this area.

The Three Kings are at high to extreme risk from *Undaria* in 57% of subcomponents (Table 7), with the exception of protected species, tourism and fishing. Once again, the experts felts that there are no protected species that are at threat from *Undaria*. The Three Kings are considered to have high species diversity and endemism with National obligations for protection. Both fishing and tourism and are considered to be at negligible to moderate risk (Table 7). Aquaculture and recreational harvest are not permitted in this area.

4. Discussion

Risk assessment is not a new method within a conservation context. However its use in a marine biosecurity context is relatively new in some regions (e.g., Barcelona Convention has produced a biosecurity risk manual [Campbell 2007; UNEP/MAP-RAC/SPA 2008]). The choice of qualitative, semi-quantitative, and quantitative models is often predicated by data constraints, funding, and time availability. For example, in a post-border scenario a pragmatic decision on whether to attempt eradication often needs to occur within a short time-frame (weeks) that doesn't allow the collection of empirical data to fill knowledge gaps. Thus, decisions are made with the best available information. If time, funds and data are available, quantitative risk models (e.g., Hayes and Hewitt 1998, 2000; Kolar and Lodge 2002; Acosta et al. 2010) are a good management choice for robust risk assessments. When data is lacking, qualitative (e.g., Johnson et al. 2001; Daehler et al. 2004) or semi-quantitative (e.g., Campbell 2008, 2009; Hewitt et al. 2009b; Campbell and Hewitt 2011; Campbell 2011; Davidson et al. 2013) methods need to be applied (Hewitt and Campbell 2007). This paper presents a qualitative risk assessment process that is used by management to improve how HVAs can be better managed to protect against introduced marine species.

The core value subcomponents of vessels, moorings and vessel access consistently ranked as high to extreme risk, reflecting a need for improved vector management in relation to *Undaria*. The current management of hull fouling within New Zealand is controlled via voluntary guidelines (Hewitt et al. 2009a) that have had a number of reported failures. The management of hull fouling via mandatory cleaning practices has been successfully implemented in the Northern Territory, Australia, after the introduction and successful eradication of *Mytilopsis sallei* (Recluz, 1849) (Hewitt et al. 2009a). As a consequence of this risk assessment outcome, the recommendation presented to the CTO Marine Biosecurity was to adopt more stringent vector management practices that do not rely upon voluntary compliance reflecting stakeholder concerns.

Similarly, core value subcomponents associated with specific transport pathways (e.g., fishing, vessels and diving) were categorised as moderate to extreme risk, suggesting a lack of pathway management which further complicates vector management (Hewitt and Campbell 2007). Borders, whether international or domestic, are an important tool in the regulation of pathways. The presence of internal borders can add a further level of biosecurity protection, however New Zealand lacks geo-political borders, having no States, though Regional Councils have local jurisdiction. In a similar manner, Europe's open borders have created strategic biosecurity/ homeland security issues that have been suggested can be overcome by moving responsibility towards a top-down, command and control approach (Sundelius and Gronvall 2004). Within New Zealand, this would suggest that the Ministry of Primary Industries (formerly known as Biosecurity New Zealand) would need to have greater responsibility over this issue.

Given the significance of HVAs and the recognition that the lack of internal borders can be a weakness in biosecurity management, experts identified the need for a system of internal, domestic borders, specifically focussed on preventing translocations into the HVAs identified here. Further research on this has occurred since this risk assessment, with Forrest et al (2009) developing a model for internal borders within New Zealand based on natural, ecological barriers acting to halt the dispersal of introduced species. Similarly, "Biosecure" (Barker et al. 2003) has been created to model species realised niche data, spatial data, and landscape patterns, suggesting where imposed internal borders can be used within a risk a management context. At present this model has not been applied to aquatic ecosystems as the lack of quantitative data for these ecosystems has reduced the models efficiency.

Both of these models represent good ecological biosecurity tools. However, a dearth of tools exist that incorporate the social and economic components of biosecurity or present realised risk in a manner that can value-add to a qualitative risk model. Consequently, we suggest a further risk assessment (realised risk assessment) that builds upon the theoretical risk assessment presented here. The realised risk assessment requires the incorporation of information regarding recreational and commercial activities that occur in the HVAs and as such identifies social and economic values that may be impacted.

4.1 Realised Risk Model

We have not undertaken a realised risk assessment for HVAs but instead we created and present a vector model that can be utilised to assess the realised risk of arrival (likelihood of arrival equation: Equation 1) based on exposure, infection rates and mitigation (cleaning activities). This model focusses on the ability of a species to arrive, not on the ability of that species to survive.

$$\mathrm{L} = ((P_{Exposure}) \times (W_{Infection}) - (1 - P_{Mitigation}) \quad (1)$$

where L = likelihood; $\boldsymbol{P}_{Exposure}$ = probability that the HVA is exposed to *Undaria*; $\boldsymbol{W}_{Infection}$ = categorical weighting function associated with a vessel becoming infected; $\boldsymbol{P}_{Mitigation}$ = likelihood that mitigation (vessel/ equipment cleaning activity) has occurred.

The risk factors incorporated into the realised risk assessment are summarised as follows:

$P_{Exposure}$ is determined across multiple lines of evidence as outlined below:

1. HVA exposure to vessel traffic (exposure factor). Based on Bernoulii's Theorem it's more likely that an incursion will occur as the exposure to shipping increases;

2. HVA exposure to promiscuous vessels (exposure factor). Vessels that travel to a diverse range of destinations are more likely to introduce species due to an increased exposure to introduced species (Johnson et al. 2001; Floerl and Inglis 2005; Hewitt et al 2009b);

3. HVA exposure to vessels from risk regions (i.e., areas known to contain *Undaria*) (exposure factor). Vessels arriving directly from an area that has *Undaria* present are more likely to be infected and thus act as a vector;

Similarly, $W_{Infection}$ is determined across multiple lines of evidence as in points 4–6 below:

4. Vessel duration in last port of call (infection factor). Port residence time may influence the level of biofouling (Davidson et al. 2009; Hewitt et al. 2009b);

5. Vessel paint characteristics (infection factor). Paint age (Floerl and Inglis 2005), type (Mineuer et al. 2008), and condition of vessel paint (Piola and Johnson 2008; Piola et al. 2009) influences the likelihood of biofouling and hence the likely spread of biofouling species such as *Undaria*;

6. Vessel type (infection factor). Different vessels may pose a different level of risk based on their behaviours, such as speed (Davidson et al. 2009; Coutts et al 2010; Campbell and Hewitt 2011) and wettable surface area (Davidson et al. 2009); and mitigating actions ($P_{Mitigation}$) consisted on two measurements:

7. Vessel hull cleaning (mitigation factor). Determine if the vessel hull had been cleaned within 2 days (based on known desiccation rates for zoospores, gametophytes and sporophytes of *Undaria*; Forrest and Blakemore 2006) prior to arrival at the HVA. Vessel biofouling is a known vector and has been implicated in the movement of introduced marine species (Gollasch 2002; Godwin 2003; Coutts and Taylor 2004; Ashton et al. 2006; Mineur et al. 2008; Hewitt et al 2009b; Davidson et al. 2009; Hopkins and Forrest 2010; Campbell and Hewitt 2011); and

8. Cleaning of activity related (e.g., recreational, scientific) and vessel associated (e.g., ropes) equipment (mitigation factor). Vessel equipment has been associated with the vectoring of introduced species (Lewis et al. 2006). Identify what types of equipment are used in each of the HVAs. Determining if the equipment on board the vessel has been cleaned three-hours before arrival at the HVA based on *Undaria* desiccation data from Saito (1960).

The next step in this research is to apply this realised risk model to each of the HVAs to clarify the actual risk posed by *Undaria*.

4.2 Wider applications of the risk models

The theoretical risk model presented here is qualitative, relying on expert opinion to fill knowledge gaps. The theoretical risk model could be applied to investigate the risk associated with movement of *Undaria* along the west coast of North America, or at a smaller scale such as movement within San Francisco Bay. Similarly, this model could be used to attempt to discern potential sites at risk such as in South America (e.g., Chile, Argentina), and mainland Australia. The realised risk assessment then builds upon expert knowledge to explore both vector exposure and propagule strength (based on vessel and risk activity equipment). This would require the collection of quantitative data such as vessel movement and frequency of vessel movement from infected regions to HVAs, and types of risk activities that occur in those regions.

The outcomes of the realised risk model can be used to develop a hub and spoke transportation model (i.e., hub networks; O'Kelly 1987; Bryan and O'Kelly 1999) that represents the threat of secondary movement of *Undaria* from source areas to HVAs, with major infection pathways being exposed. The major infection pathways would potentially represent areas that require management action. In a similar manner, Azmi (2010) utilised shipping data to develop a hub and spoke model to illustrate the secondary movement of introduced marine species from Jakarta Bay, Indonesia, to other Indonesia domestic ports. The combination of a theoretical and realised risk assessment creates a robust biosecurity tool that utilises both expert opinion (when data is lacking), and quantitative vector and activity data.

Conclusions

Undaria has demonstrable impact on a number of values and, despite efforts to eradicate, control, or restrict the species; it has spread throughout populated areas of both North and South Islands of New Zealand. This species has also spread along coastlines in Australia, North and South America and Europe. The qualitative risk assessment presented here represents a first step to elucidate theoretical knowledge and apply this to a risk assessment model to obtain a theoretical risk estimate of *Undaria* to HVAs. The theoretical risk assessment provided a transparent process to gather information to inform biosecurity and conservation decision making. The theoretical risk outcomes suggest that *Undaria* has a potential for increased and significant impact in HVAs throughout New Zealand.

We also described a realised risk assessment model that can be used as a second stage in the *Undaria* risk assessment for HVAs. The realised risk assessment requires quantitative data about vector (shipping) and risk activities that occur in the different HVAs. Undertaking the realised risk assessment is the next step in the process of trying to manage the threat that *Undaria* poses to the many regions of New Zealand and to regions in other countries.

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