# Introduced marine species risk assessment – aquaculture

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**ABSTRACT**

Risk assessment is a tool that has many applications in marine biosecurity. Its application to aquaculture has only recently moved from the protective standpoint of animal health (i.e. the World Organisation for Animal Health, OIE) to examining introduced species risks. Risks from aquaculture include use of non-native species as target stocks in aquaculture; the potential for introductions of hitchhiker (associate) species when importing new stocks; the use of non-native live, fresh or frozen feed stocks and the movement of aquaculture equipment. In contrast, the risks to aquaculture from marine bioinvasions from other sources (including other aquaculture operators) include pathogens, parasites, biofouling and harmful algal blooms. Herein, we present two types of risk assessment (non-probabilistic decision-trees and a qualitative/semi-quantitative organism impact assessment) that are currently used in the marine biosecurity system in New Zealand and Chile, but are readily applicable to other introduced species risk scenarios. These methods do not rely on quantitative risk assessment methods because sufficient quantitative data are often lacking for introduced marine species work. However, quantitative data can be used within the assessments to identify likelihoods or consequence.

## INTRODUCTION

Introduced marine species pose a significant threat to the native biodiversity, economy, sense of connectedness to the marine ecosystem and spirituality of individual countries. As such, the management of such threats has high priority at international, regional and national scales. The management of introduced species risk is often undertaken under the policy/management umbrella of biosecurity (biological security against the impacts of introduced species). Biosecurity is managed before or at the border in the form of quarantine, and post-border where both intentional and unintentional incursions are evaluated to undertake response, surveillance and monitoring.

Marine biosecurity has recently been identified by a number of international, regional and national bodies as a matter of significant urgency. Marine invasions are increasing in a number of regions throughout the world through a variety of different vectors such as shipping, recreational and fishing vessel movements, aquaculture, live food and aquarium trade. Shipping has been considered to be the most significant vector of invasions; however, aquaculture associated introductions have contributed the second largest number of invaders across several regions of the world. The contribution of aquaculture to new marine invasions is likely to increase with the global diversification and acceleration of aquaculture production, particularly in regions of the world where little production is occurring.

The need to pragmatically identify the relevant risks for management consideration is paramount given the significance and increasing perception of threat that marine invasions present to marine environmental, economic, social and cultural values, coupled with the reduction of available funds for managing the marine environment. Risk analysis is used to determine how often an event may occur and what the consequences would be of such an event. Within Australia and New Zealand, standards exist that provide best practice for risk management (Australian and New Zealand Standard Risk Management AS/NZ4360:2004).

Marine biosecurity risks associated with aquaculture activities can be differentiated as risks from aquaculture associated invasions and risks to aquaculture from marine biological invasions from other sources. Risks from aquaculture include the use of non-native species as target stocks in aquaculture; the potential for introductions of hitchhiker (associate) species when importing new stocks; the use of non-native live, fresh or frozen feed stocks and the movement of aquaculture equipment. In contrast, the risks to aquaculture from marine bioinvasions from other sources (including other aquaculture operators) includes pathogens, parasites, biofouling and harmful algal blooms.

In this context, a number of relevant risk assessment methods exist; however, these follow the classic risk analysis framework. The risk management standard (AS/NZ4360:2004) can be summarized in four steps: (i) establishing the context; (ii) identifying the risk (what are the hazards); (iii) assessing the risks (risk analysis and risk evaluation); and (iv) treating the risks, and assumes that a decision external to the risk analysis concerning identification of the end-point of the risk assessment and the Acceptable Level of Risk (ALOR) occurs.

## AQUACULTURE IN A MARINE BIOSECURITY CONTEXT

As the world's population increases, food security (e.g. secure access to sufficient, safe and nutritious food for all people, at all times (Maxwell and Frankenberger, 1992; FAO, 2002) has become an important goal for many nations, and consequently it has emerged on the agenda of many non governmental organizations (NGOs) and intergovernmental agencies (e.g. FAO, 2002, 2003; Southgate, Graham and Tweeten, 2007). Increased population growth puts pressure on our environment via (over) consumption of resources (Barrett, 1992; Krautkraemer, 1995), which in turn places additional demand on our agriculture and fisheries to increase production rates. A bleak outcome has been suggested that food demand will outstrip availability by 2020 (Pinstrup-Andersen and Pandya-Lorch, 1998).

World fisheries are an important global food source (Kent, 1997; Pinstrup-Andersen and Pandya-Lorch, 1998; Tidwell and Allan, 2001), providing almost 95 billion tonnes of food in 2000 (FAO, 2002). Yet total foodfish production is unable to keep up with the rate of global demand and production is decreasing at a global per capita rate (FAO, 2002). It is estimated that up to 70 percent of the world's marine fisheries are already overexploited (Pinstrup-Andersen and Pandya-Lorch, 1998; Enger and Smith, 2006), with depletion of stocks outpacing the ability of regulatory agencies to respond (Berkes *et al.,* 2006). In response to this growing demand, global aquaculture has grown swiftly over the past 50 years (Ahmed and Lorica, 2002; FAO, 2002). Thus aquaculture is now seen as a mechanism to increase food security while helping to alleviate pressure on wild capture fisheries and supporting local communities (Pinstrup-Andersen and Pandya-Lorch, 1998; Tidwell and Allan, 2001; Ahmed and Lorica, 2002; Tlusty, 2002).

Intensification within this industry has lead to a number of impacts such as increased eutrophication (Gowen, 1994), antibiotics entering waterbodies (Lalumera *et al.,* 2004), the intentional and accidental introduction of non-native species (Economidis *et al.,* 2000; Tlusty, 2002; Chapman, Miller and Coan, 2003), impacts on predators (Crowl, Townsend and Macintosh, 1992), the increased use of fishmeal that is derived from wild fish stocks (Kautsky *et al.,* 1997; Naylor *et al*., 2000; Tidwell and Allan, 2001; Tlusty, 2002) and the conversion of mangrove forests (highly productive natural systems) into aquaculture ponds (Tidwell and Allan, 2001; Seto and Fragkias, 2007).

Typically, aquaculture uses either native species (a species that has lived in an area where it has been present in geologic time or to which it arrived through nonhuman-mediated means) or introduced species (a species that has been recognizably transported by the agency of humans to a new biological region where it previously did not exist (*sensu* Carlton, 1996) as the target crop. For example, both the red and green abalone (*Haliotis rufescens* and *H. discus hannai*, respectively) were introduced to Chile in 1977 and 1982 for aquaculture purposes that target poverty alleviation (abalone is not consumed by the local community but instead is sold on the world market; A. Brown personal communication). The Chilean cultured abalone industry has been very successful and is now ranked 5$^{th}$ as a global producer (Flores-Aguilar *et al.,* 2007). Abalone in this region is potentially a serious space competitor to the native and locally eaten predatory gastropod *Concholepas concholepas*, and the environmental, economic and social threats are recognized by the Chilean Government (Hewitt, Campbell and Gollasch, 2006). However, the societal benefits of abalone aquaculture, through poverty alleviation and economic diversification, are seen to outweigh the costs of using an introduced species in this instance.

In some instances introduced species are also used as a source of live feed for aquaculture (Lavens and Sorgeloos, 1996; Campbell, 2007). For example, microalgal species such as *Isochrysis* sp., *Pavlova lutheri, Chaetoceros muelleri, C. calcitrans, Nannochloropsis oculata, Skeletonema costatum* and *Tetraselmis suecica* are used in aquaculture, and a variety of strains from various regions of the world are readily available for purchase online.[1] At present the use of live aquaculture feeds poses a great risk to the natural environment because it represents a typically unregulated mechanism for the introduction of non-native species (Campbell, 2007). As such, live aquaculture feeds represent a "silent-sleeper" that may pose significant risks to the environment and ultimately, to the economy.

In contained aquaculture situations, the use of introduced species for target stocks poses a low risk to the environment, as the probability of release into the surrounding environment can be managed in such a fashion as to make it minimal. Yet many aquaculture situations are not contained (e.g. shrimp pond aquaculture in Thailand (Dierberg and Kiattisimkul, 1996), abalone culture in Chile (Flores-Aguilar *et al.,* 2007) or managed and regulated in such a fashion as to provide sufficient assurances that the use of introduced species will not contaminate the local environment, creating a greater risk. In general, introduced species pose a significant threat to the native biodiversity and economic and social well being of all countries (Lubchenco *et al*., 1991, Pimentel *et al.,* 2000; Hewitt and Campbell, 2007). As such, the management of such threats has high priority at international, national and regional scales.

The use of introduced species in aquaculture complicates the social benefits received from aquaculture (food security and poverty alleviation) and must be weighed against

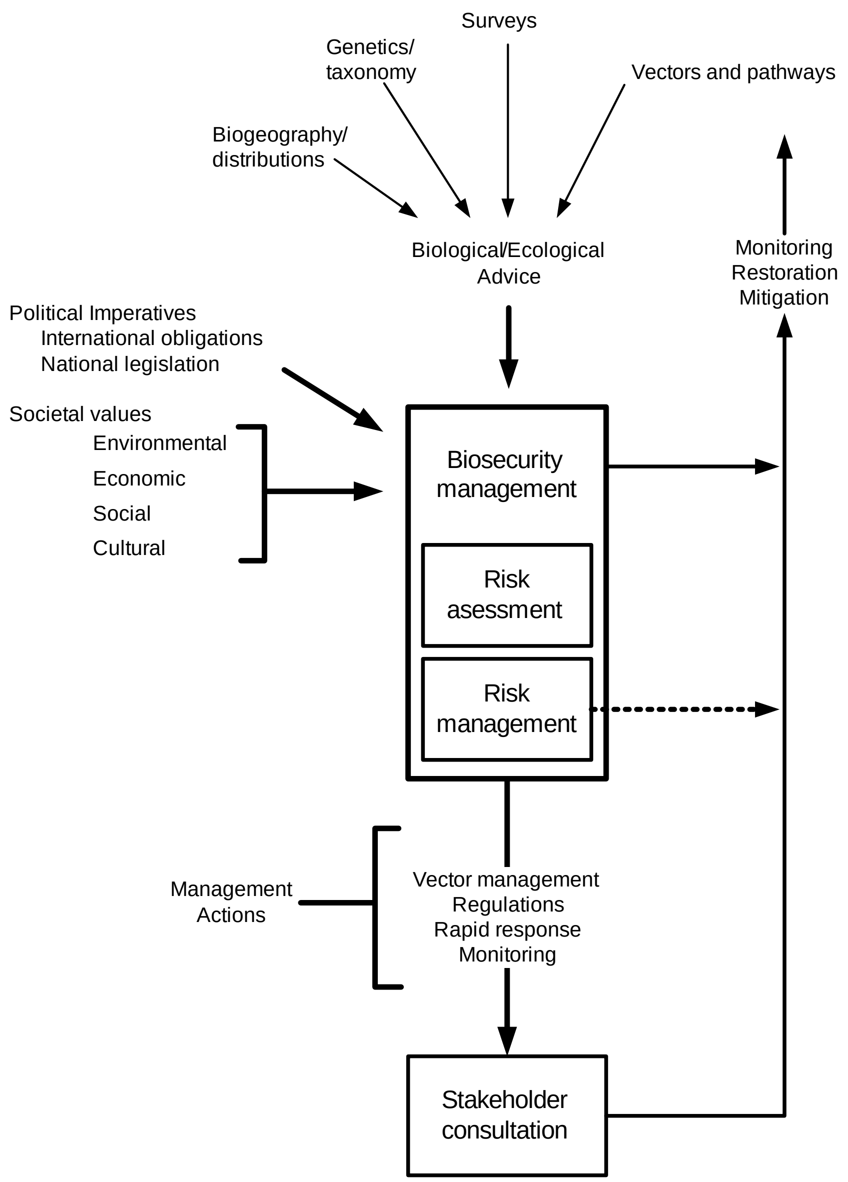
[1] For example, at http://www.cawthron.org.nz/seafood-safety-biotechnology/micro-algae-culture-collection.html; http://www.marine.csiro.au/microalgae/aquacul.html.

the impacts (costs) that introduced species may have if released into the natural environment (Hewitt, Campbell and Gollasch, 2006). A tool that is commonly used to assess the risk an introduced species poses to an area is risk analysis.

Risk analysis has become a popular tool for management because pragmatic decisions can be made that provide a balance between competing environmental and socio-economic interests, despite the limited availability of information. For example in New Zealand, risk analysis an integral component of the marine biosecurity system (Figure 1).

In this paper we describe the use of risk assessment in marine biosecurity (management of introduced marine species). We present pre-border (quarantine and import health standards) and post-border (surveillance and incursion response) examples of where risk analysis has been applied in a marine biosecurity context. Within an aquaculture context, introduced species can cause impacts to aquaculture facilities (including target species), or aquaculture can cause impacts to the natural environment via the use of

FIGURE 1
**The New Zealand marine biosecurity risk model**



introduced target marine species, introduced non-target marine species (referred to as “hitchhikers”), introduced live feed species and the inadvertent spread of introduced species via equipment transfer. This paper concentrates on the potential impacts that aquaculture may have on the natural environment through the use of introduced species and as such applies a precautionary approach from a Convention on Biological Diversity (CBD) ethos (i.e. it is preferable to make the mistake of denying entry to a non-pest than to allow entry of a pest, because a decision to admit a species is usually irreversible) instead of a World Trade Organization (WTO) ethos (i.e. it is preferable to allow trade unless there is a demonstrable and scientifically valid reason for not doing so).

## RISK ASSESSMENT IN A MARINE BIOSECURITY CONTEXT

Risk analysis as applied in marine biosecurity consists of four processes: risk assessment (the process of characterizing risk), risk management (the process of deciding what to do about risk), risk communication (the process of explaining risk) and risk policy (a meta-topic that spans across all processes and involves the development of regulatory guidelines). In a marine biosecurity context, risk assessment consists of five steps:

- identifying end-points,
- identifying hazards,
- determining likelihood,
- determining consequences and
- calculating risk.

This process is similar to the risk management standard (AS/NZ4360:2004) used in Australia and New Zealand (Standards Australia, 2000, 2004). This risk assessment process is explained below from a marine biosecurity perspective and is based upon a semiquantitative risk assessment procedure used by the authors to capture stakeholder and expert perceptions in a number of risk assessments across several developed and developing countries.

### Identifying end-points

The end-point of the risk analysis is a critical stage in scoping the context of the assessment and determines the detail of consequence analysis to be used. Typically risk analyses of unintentional introductions associated with target species, feed stocks and movement of equipment would consider quarantine end-points – that is, any unpermitted breach of the border. In contrast, the intentional importation of non-native species as target species for aquaculture or for food stocks will require an assessment of potential impacts through release. At this step an acceptable level of risk (ALOR) must be determined externally via socio-political imperatives, to set a benchmark by which all risk assessment outcomes are measured. By determining ALOR externally, transparency and consistency in the decision-making process is maintained.

### Identifying hazards

Hazards in marine biosecurity are non-native species that are requested for importation for aquaculture purposes and will cause a risk. These species are typically identified pre-border through examination of their presence in the source region from which the intended transfer will occur, coupled with a history of invasions in other regions, a demonstration of impacts and an evaluation of physiological compatibility between the species and the receiving region. For transfers of equipment, standardized import risk assessments will aid in identifying the association of species in the source region with the transport pathway on the basis of duration and timing (seasonality) of exposure, and conditions and duration of transfer that might restrict or limit survival of species present on or in the equipment.[2]

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[2] See, for example, http://www.biosecurity.govt.nz/imports/animals/standards/anieqpic.all.htm.

TABLE 2a
**Consequence matrix: environment, as defined by the subcomponents and Including biodiversity, species, habitats, natural character, aesthetics, etc.**

| Descriptor | Environmental impacts from introduced species |
|---|---|
| Insignificant | • Environment reduction is minimal (<10%) compared to loss from other human-mediated activities<br>• Reductions in environment subcomponents are not readily detectable (<10% variation)<br>• If the introduced species 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<br>• Reductions in environment subcomponents are <20%<br>• Environment reductions and area of introduced species impact is small compared to known areas of distribution (<20%)<br>• If the introduced species 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<br>• Reductions in environment subcomponents are <30%<br>• Environment reduction and area of introduced species impact is moderate compared to known area of distribution (<30%)<br>• If the introduced species was removed, recovery is expected in less than a year; loss of at least one keystone species or population, 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<br>• Reductions in environment subcomponents are <70%<br>• Environment reduction and area of introduced species impact is small compared to known area of distribution (<70%); likely to cause local extinction<br>• If the introduced species was removed, recovery is expected in less than a decade; loss of 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<br>• Reductions in environment subcomponents are >70%<br>• Environment reduction and area of introduced species impact is small compared to known area of distribution (>70%); likely to cause local extinction<br>• If the introduced species was removed, recovery is not expected; loss of multiple species or 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 |

*Source*: Modified from Campbell, 2005.

## Determining likelihood

The likelihood (or probability) of an event (intentional or unintentional release of a non-native species) occurring is determined using a standardized likelihood matrix (Table 1). The event is defined as an incursion (intentional or unintentional release of a species) when using a quarantine end-point or as an impact when using an impact end-point. Likelihood measures are typically represented as qualitative descriptions (ranging from rare to almost certain), or they can be represented as a probability.

To determine the likelihood for introduced target, non-target and feed species used in aquaculture the propagule strength, the likelihood of inoculation and establishment, and the likelihood of impacts are assessed. To assess the threat from equipment movement, the exposure of the equipment to the introduced species is assessed by determining the volumes or amount of exposure (frequency of exposure) and the timing of exposure (seasonality).

## Determining consequences

Consequence is determined via a number of different mechanisms. Typically in marine biosecurity a semiquantitative approach is used to capture stakeholder and expert perceptions and is combined with available quantitative data. Quantitative risk

TABLE 2b

**Consequence matrix: economy as defined by the subcomponents and including primary and secondary industry, tourism, education, intrinsic value, etc.**

| Descriptor | Economic impacts from introduced species |
|---|---|
| Insignificant | • Reduction in national income from introduced species impact shows no discernible change<br>• No discernable change in strength of economic activities<br>• If the introduced species was removed, recovery is expected in days |
| Minor | • Reduction in national income from introduced species impact is <1%<br>• Reduction of strength in individual economic activities is <1%<br>• Economic activity is reduced to 99% of its original area (spatial context) within New Zealand<br>• If the introduced species 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%<br>• Reduction of strength in individual economic activities is 1–5%<br>• Economic activity is reduced to less than 95% of its original area (spatial context) within New Zealand<br>• If the introduced species 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%<br>• Reduction of strength in individual economic activities is 5–10%<br>• Economic activity is reduced to less than 90% of its original area (spatial context) within New Zealand<br>• If the introduced species 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%<br>• Reduction of strength in individual economic activities is >10%<br>• Economic activity is reduced to less than 90% of its original area (spatial context) within the New Zealand<br>• If the introduced species was removed, recovery is not expected with the loss of multiple economic activities |

*Source*: Modified from Campbell, 2005.

TABLE 2c

**Consequence matrix: social as defined by the subcomponents and including aesthetics, family, individual and cultural activities, learning, etc.**

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

*Source*: Modified from Campbell, 2005.

TABLE 2d

**Consequence matrix: cultural as defined by the subcomponents and e.g. using New Zealand Maori values such as whakapapa (creation), wai tapu (sacred waters), waiora (spiritual waters), wai kino (tainted or bad waters), mahinga kai (food gathering areas)**

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

*Source*: Modified from Campbell, 2005

assessment is not common in a management context (although see Hayes and Hewitt, 1998; Hewitt and Hayes, 2001) because the data requirements are onerous, especially considering that little information is available for many introduced marine species impacts.

Introduced species impacts can affect a range of values (includes both use and non-use values). Hence, consequence matrices have been developed across four core values (environmental, economic, social and cultural) that explicitly delineate rankings of impact (consequence) from insignificant to significant (or catastrophic) to aid stakeholder and expert discussion (Tables 2a-d). These matrices provide multiple descriptions of impact at the various ranks to provide guidance in determining level of impact.

Thus, to assess the impacts of using introduced target, non-target and feed species in aquaculture, the impacts to core values are first identified (through expert opinion and data) and then evaluated. The probable impact to a region is then calculated for each introduced species. Finally, risk maps can be developed that evaluate the introduced species potential distribution if released, the species likely impacts and the core values. The resulting product of likelihood and consequence provides the risk ranking that is then compared against the ALOR identified through the external process.

## Calculating risk

Estimated risk is assessed for each core value against a standard risk matrix (Table 3). Risk is described in qualitative terms, ranging from negligible to extreme. Uncertainty is represented by presenting a range of estimated risk for a core value. The outcomes of the risk assessment feed into a risk management process, which is simplistically summarized in Table 4.

## EXAMPLES

Examples of relevant applications of marine biosecurity risk assessments are provided where the semi-quantitative procedure has been employed.

### Pre-border examples

Typically, pre-border impacts from aquaculture are focussed on aquatic animal health standards developed by the World Organisation for Animal Health.[3] These standards are focussed on animal disease only and ignore other threats that an imported introduced species may have on the receiving environment. Thus, the impact from the release of an introduced species is rarely evaluated. In Chile, the government has developed an iterative import system that defines acceptable and unacceptable levels of risk and assesses both the risk associated with a release of an introduced species and the cost:benefits associated with farming the species (A. Brown, pers. comm.; Campbell, in press). The Chilean assessment covers all core values and hence the environment is evaluated against the socio-economic aspects.

Live feed species for aquaculture can also be assessed through the import health standards. In some circumstances these species are omitted from the process due to regulation loopholes that allow species to be given import permission (permitted) before undergoing a rigorous risk assessment. Examples of instances where import health standards have failed to protect the native environment because the marine species standards were naive (due to a poor understanding of marine species biology) or lacked a marine biosecurity expertise input include the importation of fish bait that led to the herpes virus outbreak along southern Australia, resulting in large fish kills (Griffin *et al.*, 1997).

In New Zealand prior to 1996, 85 percent of importations of microalgae (used for multiple purposes including aquaculture live feed source) did not use containment or transition facilities, of which 39 percent of these importations were released directly into the marine environment (Campbell, 2007). Also, a large proportion of records (46 percent of cases) were insufficient in recording whether containment or release of the

TABLE 3
**Risk matrix**

| Likelihood | Consequence | | | | |
|---|---|---|---|---|---|
| | 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 |

Legend: N-negligible; L – low; M – moderate; H – high; E - extreme

TABLE 4
**Simplified risk management process**

| Risk | Likely scientific and management action(s) | Reporting |
|---|---|---|
| Negligible | Nil | Nil |
| Low | None specific | Required |
| Moderate | Specified scientific and management activities required | Required |
| High | Possible increases to scientific and management activities required | Required |
| Extreme | Additional scientific and management activities required | Required |

[3] Formerly the Office international des épizooties (OIE); http://www.oie.int/eng/normes/en_acode.htm?e1d10

TABLE 5
**The risk *Didymosphenia geminata* poses to the New Zealand core values. Likelihood is derived from Table 3 and consequence is derived from Table 4**

| | Stakeholder group region | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Southland | | | Top of the South | | | Hawkes Bay | | |
| | L | C | R | L | C | R | L | C | R |
| Environment | Likely | Significant | E | Possible | Major | H | Possible | Major | H |
| Economic | Likely | Significant | E | Possible | Significant | E | Possible | Significant | E |
| Social | Likely | Major | E | Possible | Moderate | H | Possible | Significant | E |
| Cultural | Likely | Major | E | Possible | Significant | E | Possible | Major | H |

Legend: L – likelihood; C – consequence; R – risk; E – extreme risk; H – high risk

Source: Campbell, 2005

imported species occurred (Campbell, 2007). Prior to 1996, risk assessments did not occur for importations of microalgae, with a permitting process that collected data but did not strenuously assess risk being used. In 1996, the Hazardous Substances and New Organism (HSNO) Act was passed. An outcome of this new legislation was that all new organisms imported to New Zealand should have been assessed via a risk assessment process undertaken by another government ministry. Yet risk assessments still only occurred on an *ad hoc* basis (personal observation) and were not fully implemented unless a member of the Marine Biosecurity team (different government ministry) was requested to undertake such an analysis.

To improve this process, a microalgae non-probabilistic decision-tree (Figure 2) was developed to assess whether importations of microalgae should occur and to determine the risk each importation posed to New Zealand's aquatic environment. This system was implemented in 2005 and works efficiently if the government ministries communicate effectively to ensure that an expert in marine biosecurity is involved in the risk assessment process.

Such failures of the pre-border biosecurity system represent an extreme management risk but also highlight how unknown vectors (live feed) can pose a threat in an aquaculture system, although the system is regulated and meets current biosecurity standards.

## Post-border example

In a post-border situation, an introduced species has been released from the aquaculture facility either unintentionally or intentionally and the end-point being assessed is impact. Risk assessments in this context determine the level of geographic spread and the level of impact to core values from the released introduced species. An example of a successful method used to assess risk in such circumstances is an Organism Impact Assessment (OIA). OIAs have been used in New Zealand to assess the risk of spread of the introduced diatom *Didymosphenia geminata* (Campbell, 2005), which was most likely introduced to New Zealand via recreational fishing equipment. OIAs have also been used to assess the risk posed by the invasive ascidian *Styela clava* (Kluza *et al.*, 2006) and to assess the threat of introduced species to high-value areas such as Marine Protected Areas (Campbell, 2006).

OIAs work by determining the likely geographic spread (likelihood) and impact (consequence) of a released species. To determine a species' potential spread, biological (e.g. environmental tolerances) and ecological (distribution and abundance) information about the released species is collated for both its realized and fundamental niche. The results of this analysis are placed into a geographic information system (GIS) to illustrate the spatial extent of the threat. For example, the likely spread of *D. geminata* in New Zealand, based on its fundamental niche, was 90 percent (26/29) of the river systems across both the North and South Islands (Campbell, 2005). Likelihood was then assessed against a standardized likelihood matrix (Table 1). Based on the species likely spread, core values (environmental, economic, social and cultural) are identified in likely affected regions. Evaluation of impacts can then occur for values that overlap with likely introduced species spread. Evaluation of impacts can be regionalized or cover an entire country.

In the *D. geminata* example, evaluations were regionalized over three zones, two in the South Island and one in the North Island of New Zealand and were examined for the 26 rivers that would likely be affected. At the time, very little literature was published on the impacts that this species had on the environment, with conflicting biological data also existing. Hence, a Delphic approach (exploring stakeholder and expert opinions and beliefs) was used to engage stakeholder groups (consisting of a cross section of society) from the three regions. Stakeholder groups determined the perceived value of each river and then the perceived change in value if *D. geminata* was introduced to the river (Atkinson and Rapley, 2005).

Uncertainty in the results was reflected by using ranges of peoples' value change. In some instances changes in perceived value could be illustrated using dollars (e.g. against economic core values), but in other instances changes in value were illustrated using a scale of low to medium (cultural values). The outcome of the perceived change in value for each core value was then assessed against the consequence matrices (Tables 2 a-d). The end result was that for the three regions a level of risk was determined based on heuristic methods (Table 5; Campbell, 2005), and from this outcome decision-makers could determine if an eradication attempt should be made.

## CONCLUSIONS

In conclusion, marine biosecurity risk assessments follow standardized risk procedures and can include qualitative, semi-quantitative and fully quantitative methods depending on the complexity required for decision making. Due to significant data limitations in the marine environment, particularly with regards to baseline biological data from trading partners, semi-quantitative and qualitative assessments remain more tractable.

The precautionary approach is employed for risk assessments of non-native species whereby the species is assumed to be guilty until proven innocent. In practical terms, this translates into an assumption of harm where information may not exist, particularly when importing a new species for release. Target species Organism Impact Assessments have proven extremely useful in identifying management options, even following an incursion event, however it should be noted that the ability to predict which species will invade or the potential impact of a species once it is introduced remains poor.

Lastly, the use of non-native food stocks as live, fresh or fresh-frozen material is likely to represent the "silent sleeper" of aquaculture-associated invasions. The unmanaged use of non-native microalgae, protists and invertebrates in flow-through hatcheries and open-environment farms is likely to have caused a large number of unrecognized invasions throughout the globe. These food stocks may also represent a poorly managed pathway of pathogen importation that can affect both cultured and wild stocks, as has been the case in the Australian and New Zealand pilchard kill in the mid 1990s.

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