Chapter 20
An Overview of Risk Assessment in a Marine Biosecurity Context

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20.1 Introduction

Our ability to manage the variety of human induced stresses in the marine environment is hampered by limited resources, a lack of fundamental knowledge and the absence of appropriate tools (Lubchenco et al. 1991; Norse 1993). This is particularly true when faced with introduced marine species. Structured and transparent evaluation techniques that both determine and justify management decisions are needed to effectively deal with introduced marine species in both an ecological and socio-political sense (as discussed by Hewitt et al., Chap. 33). Coupling this need with knowledge, resource and data limitations has led decision makers and management to use risk assessment as a means to direct their actions.

In simple terms, risk assessment is a method of evaluating the likelihood that an event may occur and the consequences of such an event. In general, ecological risk assessment proceeds by establishing the context (e.g., introduced species in a region; hazard analysis); identifying the risk, hazards and effects (e.g., impacts on core values); assessing those risks (analyse and evaluate the risks); and treating the risk(s) (e.g., incursion response activity, mitigation, Australian Risk Management Guidelines; Standards Australia 2000, 2004). A measure of risk is derived by multiplying likelihood by consequence. Hazard analysis (a technique often confused with risk assessment) determines the actions, events, substances, environmental conditions, or species that could result in an undesired event, but does not identify the likelihood or the level of consequence. Introduced species, vectors or transport pathways are all examples of hazards.

Likelihood is the probability that an event may occur. Typically, likelihood will range from rare occurrence to highly likely (or frequent). Consequence, on the other hand, measures the impact an event may have on the values being assessed and can be derived by measuring the change in value from a pre- and post impacted system. Although monetary units are often used to measure change in value (because they are easily understood and facilitate comparison) this does not have to be the unit of measure; semi-quantitative categorical ranking (e.g., low, medium, high value) is also possible.

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In general, when management uses risk assessment to evaluate introduced marine species, they ask the question "what is the likelihood that a species will arrive in our region", or "what impacts (consequences) will that species have on our native biota".

20.1.1 Defining Endpoints

Before undertaking a risk assessment, the risk endpoint must be identified and agreed. Endpoint selection will determine the null hypothesis that is tested during the analysis. With introduced species risk assessments, the endpoint tends to be either: (a) quarantine related – where the species has arrived, and therefore barrier control has been breached resulting in a quarantine failure; or (b) impact driven – where the risk assessment examines the effect, impact, and/or harm the introduced species will have as the basis of decision making.

If a quarantine stance is taken, then all introduced species consequences are classified as 'significant' and the likelihood must be determined to derive risk. The International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM 2005) approaches introduced marine species from a quarantine stance (see also Chap. 19, Hewitt et al.), which tends to blanket all introduced species as causing significant consequences. In reality this may not be the case, as species can be assessed against environmental, economic, social and cultural values. The convention identifies "harmful aquatic organism or pathogens" as the management target, implying that some impact assessment is necessary (BWM 2005; Gollasch et al. 2007).

If the assessment is determined to be impact driven, then both the likelihood of arrival (and survival) and the impact of the arrival (consequence) must be determined to derive risk. An impact approach is typically followed when determining if an incursion should be eradicated or managed based on its likely spread and subsequent impact. Similarly, an impact driven assessment will occur to identify species that have not yet arrived but are of greatest concern, a method similar to identifying a blacklist. If a species is seen as causing negligible to low risk, then it is likely to be monitored and no further action taken due to the cost of eradication being greater than the benefit (M. Cassidy, Biosecurity New Zealand, personal communication 2005).

20.1.2 Core Values

To aid the prioritisation of management actions for an introduced species incursion or an import request, the real and perceived impacts the species may have must be examined against core values (environment, economic, social, and cultural) in the import/incursion region and other potential regions that may be capable of sustaining the species of concern. Using core values increases the transparency of decision making and places management action into a context of objectively assessing introduced species across environmental and socio-political issues.

Individual core values have typically been assessed separately using tools such as species impact assessment (SIS) (New South Wales Department of Urban Affairs and Planning 1996, 2000; Thomas and Elliott 2005), economic valuation analysis (e.g., Costanza et al. 1997; Toman 1998; Pagiola 2004; Kalof and Satterfield 2005), social impact assessment (SIA) (Lang and Armour 1981; Thomas and Elliott 2005), environmental impact assessment (EIA) (Thomas and Elliott 2005), and strategic environmental assessment (SEA) (Marsden and Dovers 2002; Dalal-Clayton and Sadler 2005). Within the introduced species context, the effort is now being made to assess all core values under the one method (combining risk analysis and risk assessment) and defines the core values as such:

- Environment – everything from the biological to physical characteristics of an ecosystem being assessed, excluding extractive (economic) use and aesthetic value. Examples include floral and faunal biodiversity, habitat, rare, endangered and protected species and marine protected areas.
- Economics – components within an ecosystem that provide a current or potential economic gain or loss. Examples include the infrastructure associated with ports, marinas and shipping channels, moorings and allocated mariculture and fisheries areas.
- Social – the values placed on a location in relation to human use for pleasure, aesthetic, generational values. This value may also include human health. Examples include tourism, recreation, education and aesthetics.
- Cultural – those aspects of the marine environment that represent an iconic or spiritual value, including those that create a sense of local, regional or national identity.

Each core value consists of a variety of different subcomponents (examples given above) that will differ both spatially and temporally. A risk assessment can occur at the level of the core value or at the level of core value subcomponent(s).

20.1.3 Uncertainty and the Precautionary Principle/Approach

Regardless of the method used, risk assessment will have uncertainty surrounding the outcomes. Uncertainty exists because of natural and stochastic variation in our environments that are difficult to capture, and incomplete understanding of the biological, physical and anthropogenic systems (Cooney and Dickson 2005; Peel 2005). As ecosystems are highly complex and interconnected, varying both spatially and temporally, it is often impossible to predict ecosystem dynamics (see Burgman et al. 1993; Harwood and Stokes 2003).

Although uncertainty exists, there is a fundamental need for environmental management to make decisions. To aid decision makers to overcome uncertainty, the precautionary principle/approach was developed and has been widely adopted in environmental management (Gullett 1997; Cooney 2005; Peel 2005). As stated by Gullett (1997), the precautionary principle/approach imposes an environmental duty of care meant to prevent spatial and temporal damage. The principle/approach acknowledges the intrinsic value of ecosystems, the 'economic utilitarianism' of these systems (i.e., bequest value; Handl 1990), and the 'moral right' to protect these systems (Cameron 1993; Gullett 1997).

As various definitions exist for the precautionary principle/approach, in this paper I use the definition from Cooney (2005): "Complete certainty regarding an environmental harm should not be a prerequisite for taking action to avert it." This is a preferred definition as it addresses precaution from a Convention on Biological Diversity perspective and hence is more environmentally conservative, placing the environment as a higher priority than trade. I have also used the terms 'principle' and 'approach' interchangeably, although acknowledging the problems associated with both terms.

A poignant example of this dilemma can be seen in the differing management strategies implied by the legislative requirements of the Sanitary and Phytosanitary Agreement (SPS Agreement 1994), requiring a risk assessment before any restrictions can be imposed, and the guidelines of the Convention on Biological Diversity (CBD), which requires risk assessment before any new species should be admitted (introduced) to a country (Cooney 2004). The Sanitary and Phytosanitary Agreement was developed by the World Trade Organisation (WTO) and addresses the issue of food safety, animal and plant health (typically via importation of products) and is applicable to all current 151 WTO members. The WTO has no specific agreement on the environment, although it acknowledges the concept of sustainable development and environmental protection. Alternatively, the CBD was developed by United Nations Environmental Programme (UNEP) to conserve biological diversity, to use nature's components sustainably and to share equitably benefits arising from the use of genetic resources. Currently, the CBD is signed by 150 countries.

20.1.4 Quantitative vs Qualitative

Quantitative and qualitative risk assessment procedures have been used for marine introduced species in a number of countries such as Australia (Kahn et al. 1999; Hayes and Hewitt 2001; Hewitt and Hayes 2001, 2002; Hayes 2003; Anon 2005); Chile (Campbell 2005b; Hewitt and Campbell 2005; Hewitt et al. 2006); Germany (Gollasch 1996); New Zealand (Campbell 2005a, c); and Nordic waters (Gollasch and Leppäkoski 1999). Similarly, countries in the Mediterranean (through the Regional Activities Center for Specially Protected Areas of the UNEP Mediterranean Action Plan [RAC/SPA]) are now moving towards development of a standard risk assessment process for introduced marine species (Campbell 2005d). Many countries have developed risk assessment processes but they do not specifically address marine bioinvasions, or marine biosecurity (management) and hence are omitted from this chapter. Typically, quantitative risk assessment (e.g., Hayes and Hewitt 2001; Hewitt and Hayes 2002) is highly robust, but requires significant levels of data and information, which requires considerable input of funds and time. Semi-quantitative and qualitative risk assessment methods are useful when low or variable levels of information are available and the lack of quarantine failure in countries using these methods suggests their effectiveness (Kahn et al. 1999; Anon 2005; Campbell 2005a, c).

No matter if quantitative or qualitative methods are used, a trustworthy risk assessment can only be produced if well defined procedures for determining appropriate consequence and likelihood measures exist. These procedures need to establish, in a clear, transparent and scientific manner, a consistent process that identifies and evaluates risk, providing adequate and robust response mechanisms for the risk assessment outcomes. Typically, this involves informed stakeholder input, taking into account all available information, and explicitly stating uncertainties, assumptions and trade-offs.

This chapter provides an overview of qualitative and semi-qualitative risk assessment methods that have been applied in the context of introduced marine species management (i.e., marine biosecurity). Few quantitative methods are used at the decision making level[1] due to their onerous data and information requirements. Examples of where qualitative and semi-qualitative types of risk assessment are being successfully applied on an international and regional basis are also provided. This chapter is marine and management focused and, hence, introduced risk analyses that are freshwater in focus (e.g., Kolar and Lodge 2002; Herborg et al. 2007) and/or are not currently used by management (e.g., Lodge et al. 2006; Leung and Dudgeon 2007) are beyond the scope of this chapter.

20.2 Types of Risk Assessment

Introduced marine species risk assessment tends to use three approaches:

- *Species level risk assessments* that may be applied to intentional and unintentional introductions or translocations to help identify high risk introduced species, generally prior to importation
- *Vector based risk assessments* that allow for the differentiation within a vector of high risk items (e.g., vessels, pieces of gear, farms) or activities to aid management outcomes
- *Pathway level risk assessments* that allow for a cross comparison between different vectors or between different "**nodes**" such as ports and marinas

[1] A notable exception is the AQIS Decision Support System; based on the risk assessment developed by CSIRO (Hayes and Hewitt 2001; Hewitt and Hayes 2002).

20.3 Species Level Risk Assessment

There are a variety of circumstances for which species level risk assessment are suitable, such as assessing intentional introductions prior to import certification, or post-hoc analyses after an incursion (unintentional) has been detected. To undertake a species risk assessment successfully, Hewitt and Hayes (2001) suggest the following information is needed:

- Propagule pressure: the amount of biological material arriving into a specific location (e.g., country, state, region, port)
- The number of sites of release for the species
- The number of introduction events
- To a lesser extent, the environmental tolerances of a species' native distribution compared to the region being assessed

20.3.1 Species Level Risk Assessment Examples

Three common methods employed to assess a species level risk in both intentional and unintentional situations are the development of next pest lists (Hewitt and Hayes 2001; Hayes and Sliwa 2003), Organism Impact Assessments (for post-hoc assessments of incursions; Campbell 2005a), and the development of Import Health Standards (for intentional importation of species; Kahn et al. 1999; Anon 2005). A fourth method, the ICES Code of Practice for the Introduction and Transfers of Marine Organisms (ICES 2005), provides an example of a procedural methodology that incorporates the risk assessment and decision making process for intentional introductions. The ICES Code (ICES 2005) evaluates on the basis of individual planned species movements, with the intent to identify whether the target species is likely to cause harm, and whether any associated species living in, on, or with the target are likely to cause harm, including parasites, disease agents, and human pathogens. It is a useful tool for intentional introductions.

20.3.1.1 Next Pest Lists

Identification of species of concern is a difficult and often controversial task. Nonetheless, several countries (e.g., Australia, New Zealand) have adopted a target species approach to marine biosecurity (i.e., management context). Scientific approaches have also been applied to assess potential new pests but these have not been adopted by management at this point in time (e.g., Herborg et al. 2007; Leung and Dudgeon 2007) and/or lack a marine focus (e.g., Kolar and Lodge 2002; Rixon et al. 2005). The next pest lists approach generates target species that are "blacklisted" or identified as "unwanted organisms" and hence are unable to be imported into a country (through import health standards) unless an exemption is granted. This assessment uses a quarantine endpoint.

Development of next pest species lists rely on evaluating species against set-criteria. The criteria provide a clear, explicit, transparent and non-discriminatory method for evaluating and identifying potential species hazards. One possible set of criteria (based on hull fouling and ballast water) are (Hayes and Sliwa 2003):

- The species has been reported in a shipping vector or has a ship-mediated history
- The vector still exists
- The species has been responsible for environmental and/or economic harms
- The species is introduced to *[country/region]* or present in *[country/region]* but subject to official control (i.e., listed, restricted or otherwise legislated by an authorised national authority)

20.3.1.2 Organism Impact Assessments

An organism impact assessment (OIA) evaluates species risk using an endpoint of impact: does or will the introduction of the species cause an impact on environmental, economic, social, and/or cultural values? OIAs are used to evaluate potential impacts from the unintentional incursion of an introduced species using heuristic knowledge drawn from the literature and from expert panels/technical advisory groups (e.g., Campbell 2005a). This method is similar to a 'relative risk assessment' as discussed by Roberts et al. (2002).

If there is a paucity of published, empirical scientific data on the impacts of a particular introduced species, a *delphi* approach is adopted. The delphic approach utilises a number of focus groups from different regions, with focus group membership drawn from a range of stakeholder interest, thus representing a wide range of community perceptions. This approach creates a statistical population of beliefs that captures a wide range of community opinions with the central tendency being the perceived risk. A focus group aims to assess perceived value of an area and then assess the perceived impact(s) to this value if an introduced species incursion occurs in that region. The data collected from these focus groups is then analysed and a risk assessment of the introduced species impact on environmental, economic, social and cultural values is determined.

An important aspect of the OIA is the use of valuation methods to determine "value". Numerous methods exist for determining value and in general they fall into the categories of revealed preference, such as replacement cost, travel cost, hedonic pricing, or stated preference methods, such as contingent valuation and choice modelling (Pagiola 2004; Farber et al. 2005). Each method has its benefits and limitations and should be selected carefully to represent the value accurately. OIAs also have the ability to display uncertainty by providing the range of likelihood, consequence and valuation data as determined by the focus groups.

To a certain extent an OIA is subjective and imprecise; however it does have strong inherent advantages such as the ability to produce a result when empirical data is insufficient or lacking, stakeholder input across a range of regions leading to high stakeholder understanding and buy-in, transparency and education (data on introduced species and effects is provided to stakeholders), and stakeholder participation by providing perceived risk.

20.3.1.3 Import Health Standards (IHS)

IHS are legislative procedural documents that are established to ensure that the internationally agreed standard of quarantine (typically SPS agreement) and scientific evaluation are met to reduce the unwarranted restrictions of trade when importing goods. In this context, an IHS is used to assess risk associated with intentional introductions of species (Anon 2005). Because the species are being intentionally imported the likelihood is considered as 'almost likely' in every assessment, with the consequences on human, animal and plant health being assessed. Rarely is the impact that an import species may have on the environment assessed by management. For example, an IHS for 'vannamei' prawns (e.g., *Litopenaeus vannamei*) would examine if a pathogen listed by the World Organisation of Animal Health (OIE) is associated with the imported species. Consequently the risk posed by the associated pathogen to human, animal and plant health is assessed within the importing country (e.g., Biosecurity Australia 2000; Inland Water Resources and Aquaculture Services [FAO] 2003). The impact that *L. vannamei* has on local prawn or other native species is not assessed within an IHS. This is a failure of the IHS system where the focus is on the import species pathogens, rather than the impact the imported species may have on native populations.

IHS are similar to the ICES Code of Practice (ICES 2005), combining both risk assessment and the decision making process for intentional introductions.

When a request for an importation of a species is received, it initiates a series of steps that lead to both risk analyses and risk assessment being undertaken. In this instance the endpoint is to assess what impact this species will have on the values of the recipient region (most often defined as the widest possible range a species may attain; its fundamental niche). Most IHS assessments are species-specific; assessing the individual species and its possible associated species, however some are vector based. For example, a request to import adult oysters for aquaculture purposes would involve a risk analysis of the oyster species itself, and risk analyses of all possible epi- and endo-biont associated species (species growing on and in the imported species) known from the donor region. This would then involve overlaying the risk analysis outcomes with social, economic and cultural imperatives to provide a risk assessment. Both positive and negative impacts are assessed in the IHS process. Typically, low to negligible risk species are granted approval for importation, with moderate to extreme risk species being rejected. However, moderate to extreme risk species can be granted importation approval (through exemption) if quarantine/containment standards are applied, met, monitored and reported upon.

The outcome of the IHS and its associated analyses is a list of species ('white' list) that is appended to the IHS document. The white list contains negligible to low risk species that have been assessed and approved for importation. Once added to the white list a species is granted future importation approval, which allows the rigour of the risk analysis, risk assessment and importation process to be bypassed. To be effective the IHS document and its associated white list of exempted species need to be regularly re-evaluated and updated, especially when new information becomes available. Two examples of efficient and active IHS documents are the *Australian Import Risk Analysis for Live Ornamental Finfish* (Kahn et al. 1999) and the *New Zealand Import Health Standard for the Importation Into New Zealand of Ornamental Fish and Marine Invertebrates from All Countries* (Anon 2005).

20.4 Vector Based Risk Assessment

Vector based risk assessments identify which shipments or potential incursions are more risky than others (e.g., ballast water risk assessment undertaken in Australia). There are a large number of vectors that are known to be responsible for the transfer of marine introduced species (Carlton 2001; Chap. 5, Minchin et al.). Typically, the examples of ballast water and associated sediments, hull fouling and mariculture (aquaculture) have been concentrated upon (see Chap. 6, Hewitt et al.).

The most widely established vector based risk assessments have been applied to the management of ballast water and sediments. These assessments have been performed by a number of countries and organisations, and have been based on two primary types of assessment: environmental matching where two environments are compared for similarity (or dissimilarity) across a range of environmental variables believed to have ecological significance; and species based assessments where a chain-of-events model is used to determine the likelihood of a species arriving and establishing in the receiving environment (Hewitt and Hayes 2002). Both types of vector based risk assessments can be applied at varying geographic scales, such as at the bioprovince, down to smaller regions (e.g., nation, state, marine protected area).

Environmental matching typically evaluates similarity in a statistical sense, with no biological determinant of the cut-off between similar and dissimilar. Similarly, the selection of environmental parameters for evaluation is rarely based on species' requirements for survival, but instead are readily accessible environmental characteristics of the donor and recipient regions. As a result, while environmental matching assessments have a reduced data requirement, they typically result in less conservative outcomes with greater likelihood of Type I error (finding a difference where none exists, resulting in an erroneous low risk).

In contrast, species based risk assessments rely on detailed knowledge of the species' distributions, reproductive periodicity, physiological constraints and environmental preferences. Species level risk assessments have a high data requirement, and typically result in overly conservative outcomes with greater likelihood of Type II error (finding no difference where one exists resulting in an erroneous high risk).

The International Convention on the Management and Control of Ships Ballast Water and Sediments has developed a Risk Assessment Guideline (G7) that underpins the ability of a State to grant exemptions from the obligations of the Convention. The current formulation of G7 (adopted in July 2007; Resolution MEPC.162(56)) develops a framework in which both environmental matching and species based assessments are used. This formulation suggests that environmental matching risk assessments should be used only in circumstances where the environments are at biological extremes, such as between purely freshwater and purely marine environments. In these circumstances, those species that can survive at both extremes should be individually assessed.

In contrast, species based assessments should only be used within a single bioprovince (such as the Mediterranean) where the assumption is that the majority of native species are shared. In these circumstances, the unknown species can be assumed to be native, reducing the number of species assessments required. For donor ports, introduced species known to cause harm should be assessed for the ability to establish and cause harm in the recipient port (and adjacent localities). Harm should be assessed according to specific impact on core values and resources. Species based assessments need to be reviewed regularly because newly available information may alter the risk outcomes.

20.4.1 Vector Based Risk Assessment Examples

The development of import health standards (IHS) such as the New Zealand Import Health Standard for the Importation of Ballast Water (Biosecurity New Zealand), the Chilean Aquaculture Species Import Process and the New Zealand microalgae import decision tree, are examples of risk analyses that evaluate vector risks.

20.4.1.1 Import Health Standards

As previously stated, IHS work by investigating the validity and risk posed by all requests to import a species or a vector (i.e., the emphasis of the analysis is placed on the vector itself). There are a number of specific IHS that apply to vectors. A current example of a vector IHS is the ballast water exchange at sea requirements. Other vectors include fishing equipment, marine rock (including live rock from the aquarium trade), imported recreational vessels, ropes and anchors. Vector based IHS are used for regulatory purposes and when consequence has been demonstrated. They provide action to mitigate the likelihood, by providing information such as where ballast water exchange can occur, quarantine, and cleaning and dumping standards.

20.4.1.2 Aquaculture Species Import Model

Mariculture and aquaculture are growing global industries that are attempting to address the problem of expanding populations and decreasing fish stocks.

A number of regions have decided that economic stability and food security can be improved by utilising introduced marine species to either aid in providing food to the region's population, or aid in providing an export product that is highly valued elsewhere and therefore marketable. Both these reasons have merit, with the ethical use of introduced marine species needing to be considered against the social and economic security that such a use may provide. Few models exist that specifically target introduced species importation for aquaculture/mariculture purposes. The following model is one that has been adopted in Chile, South America, and has operated with reasonable success (Campbell 2005b; Hewitt and Campbell 2005; Hewitt et al. 2006). It has a quarantine endpoint.

The model is initiated when a request to import a non-indigenous species or non-indigenous genome occurs. The request is made using standardised templates, thus allowing a transparent assessment process. At a minimum, the request should include information that allows the decision makers to determine:

- *Species*: the species and associated species involved in the request; known impacts the target species has had elsewhere, if any; what the species will be used for; can a local species be used instead; will the target species require the importation of a specific food source that is also introduced.
- *Export facilities*: where does the importation originate from (bioprovince, water temperature, salinity, disease information); certification and quarantine procedures followed by the exporting region; how the importation will occur (specify whether it is importation of larvae, eggs, juveniles, adults; what measures will be taken to reduce fouling of adults; what practices are used to detect disease); are the imported stock from wild stocks, mariculture/aquaculture facilities; and are the imported stock genetically modified or been fed with a genetically modified food source.
- *Import Facilities*: who is making the request (person, company, local, regional, national, international); the containment and quarantine procedures that will be followed (if these need to be established, how will they be peer reviewed); does the facility meet regional, national, and/or international certification; information about the recipient aquaculture facility (is it an open or closed facility; filtration systems used; does translocation of species between facilities occur); is there any likely release of material into the marine environment; what emergency containment procedures exist; what contingencies exist for disease outbreak containment within the facility; are there any requirements for the transfer of species between facilities within the country (e.g., establishing a brood stock facility); and the proximity of the facility to high value areas, specifically those protected by national or international obligations.
- *Monitoring*: what type of environmental health monitoring will be established; what type of environmental monitoring will occur; what is the frequency of monitoring; is the monitoring peer reviewed and provided to a statutory body for assessment; and what provisions (contingency measures) exist if an accidental release of the introduced species occurs.

It is the role of the decision makers to use this import risk model. To be efficacious the risk process needs to define what impacts are unacceptable, what methods will be used for the risk assessments, set an acceptable level of risk, establish a scientific overview and review committee and develop contingency and action plans or guidelines to deal with the accidental release of a non-indigenous species (Fig. 20.1). The values (and/or the subcomponents) that the decision makers are attempting to protect and manage must be identified a priori. This can occur through a simple evaluation of national and international obligations (e.g., CBD), or it can be as complex as evaluations of individual subcomponents of the environmental, economic, social and cultural values. In order to have a clear, transparent and consistent process it's ideal to identify the values a priori, instead of identifying values with each solicitation.

In some instances, it may be necessary to conduct experimental trials with a species to determine its ability to survive, grow and be controlled in certain conditions. These may occur in the donor (risk minimisation) or recipient country. Upon completion of the risk assessment a decision maker is able to determine whether to reject an application or move into a second phase: a cost-benefit analysis. A cost-benefit analysis determines the net benefits of an introduced species to the ecosystem, economy, socially and culturally, and assesses the costs associated with an introduced species incursion (e.g., destruction of infrastructure, loss of jobs, loss of industry, loss of marine resources, extinction of species, etc.). Consistency is maintained across all solicitations by ensuring the valuation methodology and its limitations are stated a priori to the analysis. Finally, based on the outcomes of the cost-benefit analysis a decision is made whether to reject or accept the import request.

20.4.1.3 Microalgae Import Decision Tree Model

A further model that can be used in conjunction with IHS procedures is a decision tree that leads the decision maker through a series of questions with "if/then" statements to direct actions regarding whether to approve an importation or not. In New Zealand, a risk assessment process that uses a decision tree model exists for the importation of microalgae (native and non-indigenous species; Campbell 2004). By answering a series of simple yes/no questions the decision tree progress through the process indicating where importation should be rejected, approved with stipulations or approved without stipulations. The model can be qualitative, semi-quantitative or quantitative and is driven by the data input. As with IHS procedures, likelihood is almost certain since the species is being imported. Each step is assessed against a risk mitigation context (such as a management procedure) with the endpoint derived by the questions asked at each step in the process. Decision tree models invariably consider specific national and international obligations. In New Zealand, an eight-step model was developed for the importation of microalgae typically used for laboratory purposes (colour standards) and aquaculture feed that is released directly into the marine environment (Campbell 2004; Fig. 20.2). Such models are

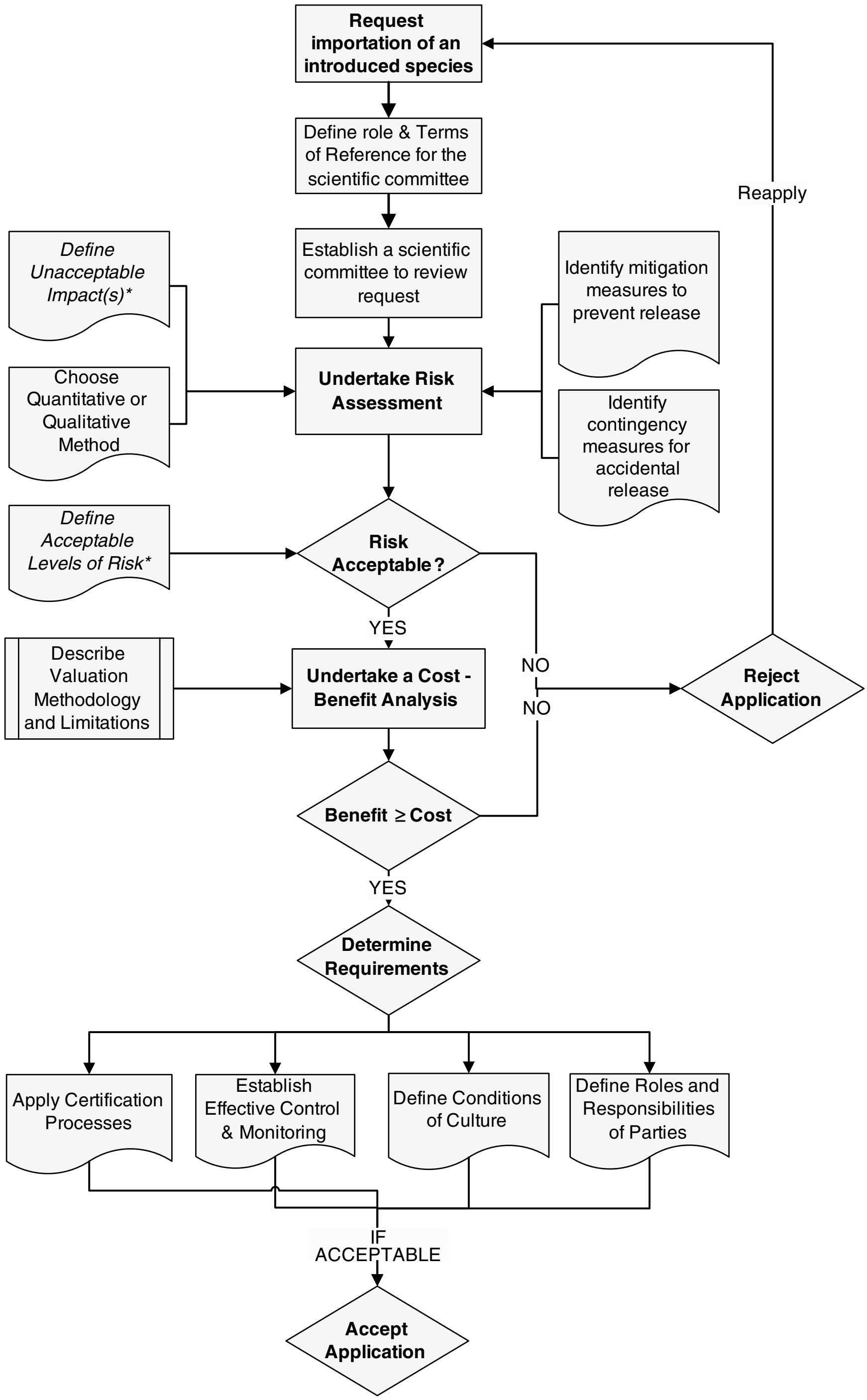

Fig. 20.1 Conceptual risk framework used in Chile for the importation of non-indigenous species for aquaculture purposes (modified from A. Brown, personal communication). * denotes actions that can occur a priori to the risk assessment

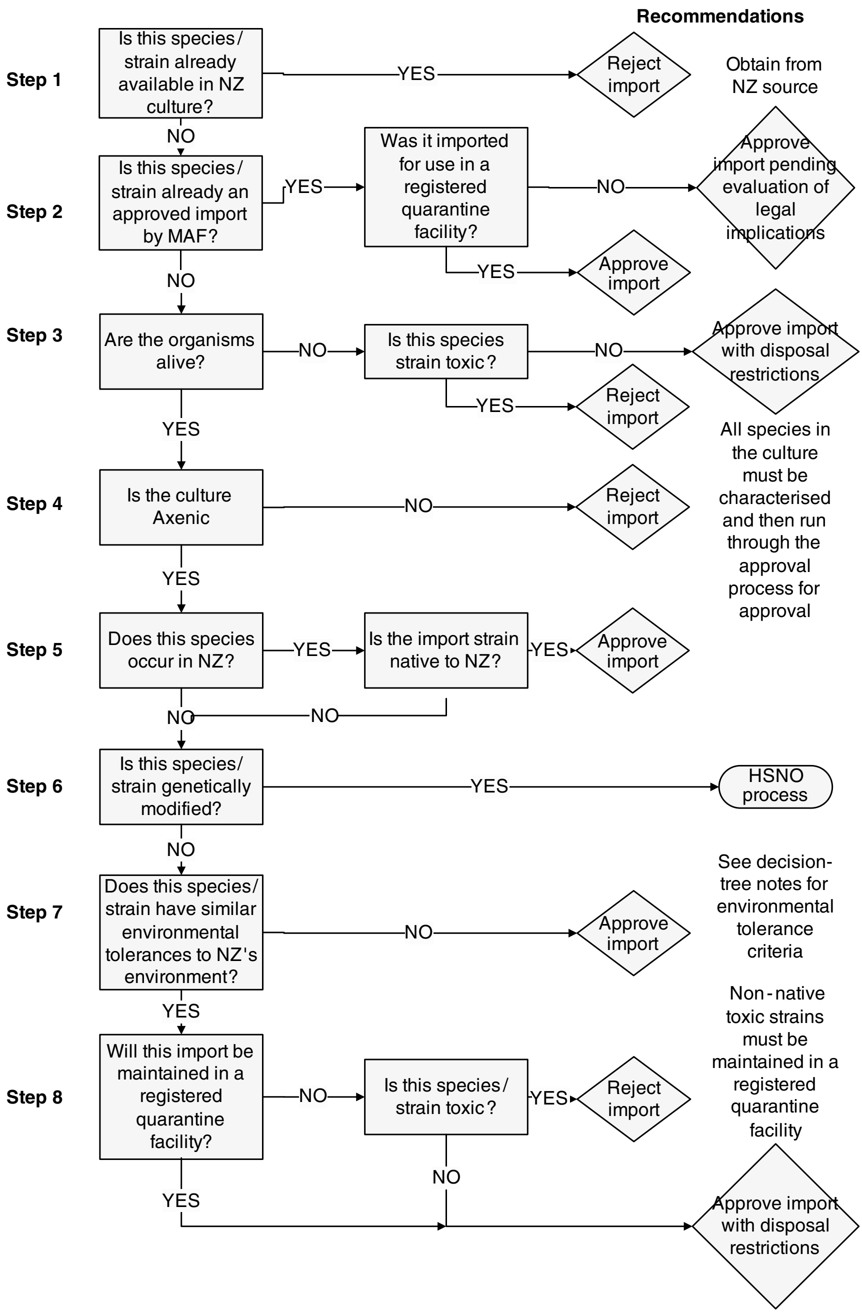

Fig. 20.2 Microalgae decision tree model used to assess the risk associated with the importation of microalgae in New Zealand. HSNO denotes the Hazardous Substances and New Organism Act (1996)

readily adaptable to other countries, regions and/or taxa (such as fish and invertebrates).

A strength of the decision tree model is the ability to incorporate multi-level analyses that deal with introduced species and genetically modified organisms. A further strength is that this model combines biological and social information, as well as legal obligations, into clear instructions for decision makers.

20.4.1.4 Fishing and Domestic Shipping

In both New Zealand and Australia, fisheries activities and the potential risk these activities pose via either entraining or translocating "pest" species are currently being investigated using vector risk assessments. These studies provide hazard information (e.g., vector movements by fishery, vessel type, time, origin, destination, etc.) that feed into the development of guidelines. It is envisaged that education about the problem of translocation via fishing and aquaculture methods, coupled with consultation will be required for the guidelines to be truly effective. Similarly, domestic or regional shipping is also being investigated in New Zealand and Australia, to develop vector risk assessments for differing shipping types. A general outcome of this research is the development of best practice guidelines that provide preventative advice for recreational vessel owners.

20.5 Pathway Risk Assessment

Pathway risk assessments combine aspects of species and vector assessments to identify their intersections and overlaps (e.g., Biosecurity New Zealand pathway analysis, GloBallast assessment). Typically, this method concentrates on nodes such as ports or marina's, the vector exposure strength and their transport corridors; examining which nodes are more likely to receive a new organisms. These analyses have a quarantine endpoint; attempting to assess risk before a species arrives within a region.

20.5.1 Pathway Risk Assessment Examples

Unlike the terrestrial environment (e.g., Andow 2003), few marine pathway analyses have been completed for the marine environment, although a number of research projects are currently attempting to elucidate the relationship between pathway strength, transport corridor and vector type. The following examples are of research that is currently underway in New Zealand and Australia and as yet remain unpublished.

20.5.1.1 Hull Fouling and Pathways

To capture fully the risk associated with hull fouling (or other vectors) requires robust, empirically derived data. The following example from New Zealand illustrates how a pathway analysis can be used to determine risk. Currently in New Zealand, a three-year study is underway to determine the realised risk associated with hull fouling (via vector and pathway analyses). This research examines the extent of fouling and fouling species identity on the hulls of arriving international vessels. Categories of vessels being examined are: fishing, passenger, merchant, slow-moving barges, oil platforms, and recreational vessels. The research investigates seasonal trends in vessel fouling for each vessel type, associated trade routes and target source/donor regions (IUCN bioregions) based on a priori analyses of previous shipping (merchant and recreational) history and customs data. This type of research is data and effort intensive but surprisingly inexpensive (NZ$<3 million) considering the detailed data that is generated and the multiplicity of this data's uses.

It is anticipated that the outcomes of this research will feed into 'realised' hazard and risk assessments associated with each port and marina dealing with international vessels within a country or region. This in turn greatly improves the ability of decision makers in the development of introduced marine species guidelines and standards.

20.5.1.2 Nodal Analysis

Nodal analyses aim to examine the strength of different vectors such as hull fouling (commercial and recreational), ballast water, and aquaculture into specific nodes (such as ports, marinas, protected areas). The nodal analysis investigates donor/recipient interactions and likely flow-on-effects. This type of analysis is currently being undertaken across Australia by the Department of Agriculture, Fisheries and Forestry.

20.5.1.3 Single Vector Pathway Analysis

One component of GloBallast risk assessment is a pathway analysis. In this instance, the GloBallast risk assessment concentrates on a single vector, examining the relative strength of ballast water movement (i.e., surrogate for propagule strength) between various source ports and receiving ports. These analyses were implemented for the six GloBallast ports in Brazil, China, India, Iran, South Africa and the Ukraine and are coupled with the GloBallast environmental matching exercise to aid in the recommendation of management strategies for ballast water management between ports (Awad et al. 2004; Alexandrov et al. 2004; Anil et al. 2004; Clarke et al. 2003, 2004a, b).

20.6 Conclusions

In conclusion, risk assessment for marine bioinvasions is not a single tool but a process that can be applied across a range of protected values (environmental, economic, social and cultural). As discussed above, there are a variety of different risk assessment methods that are currently used by decision makers to manage marine bioinvasions. Although assessment methods may differ, a number of commonalities exist: for example, risk assessments may evaluate species, vectors, or pathways; endpoints may be quarantine or impact driven; and the assessment may be quantitative, semi- quantitative, or qualitative.

Management has moved towards using risk assessment to seek a balance between complete environmental protection and the social use of public funds, while satisfying WTO obligations. It is insufficient for management to halt the importation of a species merely because it is non-indigenous, the burden of proof lies with the receiving nation to demonstrate that impact will deleteriously affect their economy. Current debate concerning national obligations to the CBD with respect to WTO limitations will continue into the foreseeable future. Similarly, incursion response is tempered by the realities of cost-benefit; a species must in all likelihood cause a high level of risk before management can stop its importation or before an incursion response can occur. This is driven by the fact that public funds are limited, managers require decisions to be made in a clear and transparent manner, with a minimum time delay; decisions must be scientifically robust under the WTO and CBD; and local, national and international obligations must be met.

As a consequence of the conflicting requirements placed upon managers and decision makers, risk assessment forms the basis for consistent and transparent decision making under a precautionary approach (as interpreted by national government). The current formulations of risk assessment are largely qualitative with limited data requirements in order to achieve functionality. Those few examples of quantitative marine bioinvasion risk assessments have been found too data onerous by decision makers and hence have been simplified or abandoned (e.g., international application of the Australian Decision Support System for Ballast Water Management). To achieve effective risk assessment based decision making in the future, both quantitative and qualitative methods will need to be developed that provide immediate results with robust information. To do this, significant research efforts must be undertaken that identify the linkages between species, vectors and pathways, as well an understanding of the likely degree of impact that individual species will have on specific values. This research agenda is significant and costly and will best be achieved through capacity building and information sharing between the World's nations.

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