Marine biosecurity toolkit: Marine non-indigenous species management strategies and risk analysis framework

Document E

This document is the result of a review of existing literature on the potential mitigation and management strategies for reducing the impact of marine non-indigenous species (NIS) that are the focus of the Pacific Island countries and territories Marine Biosecurity Toolkit species ID guides. A risk analysis framework is also included to provide information on objective and sound methods of assessing the biosecurity risk associated with the arrival of vessels and the potential marine NIS those vessels may carry on their hull via biofouling or in ballast water.

For an NIS to have an impact in a new environment, it must first be transported to that environment and be able to establish self-sustaining populations there. If the species is not introduced or is unable to survive in the new area, then it will not be a risk to the environments there and the values that they sustain. All of the priority species listed below can be transported as biofouling or within the ballast water of ships. Risk mitigation measures to reduce the likelihood they will arrive and become established are contained in the previous Biosecurity toolkit documents on biofouling and ballast water assessment guidance (Documents A and B).

Mitigation and management strategies of marine NIS have been shown to have some success around the world. The intended use of this document is to help inform decision making about potential ways to mitigate and manage the marine NIS that do arrive. It should be noted that the approaches detailed may not always be appropriate or successful for implementation within Pacific Island countries and territories and that there are gaps for several species.

It will not always be possible to remove a species once it is present. Successful removal and/or management may depend on how abundant and widespread the species is when detected. Because of this, measures designed to prevent the transport of priority species and to detect them early are extremely important.

The table below provides a quick reference summary of potential management strategies for each of the priority species. These are strategies that have been employed in other countries where these species have invasive populations (Table 1). More detailed information on methods used to try to manage the species and relevant references are provided below. There have been relatively few truly successful eradication attempts once a species has been identified in a country's waters.

Table 1. Potential management strategies

Species	Name	Strategy
Microcosmus squamiger	Scaly tunicate	Physical removal not possible, introduction of native gastropods as predators may be effective.
Ruditapes philippinarum	Japanese carpet shell	Physical removal by hand[1] or with dredges.
Mytilopsis sallei	Black striped mussel	Anti-fouling paints, cleaning of submerged fittings, ballast water management and inspection of boats coming from areas of risk. Treat fouled equipment or vessel seawater systems with copper sulphate solution or liquid sodium hypochlorite.
Perna viridis	Asian green mussel	Anti-fouling paints, cleaning of submerged fittings, ballast water management and inspection of boats coming from areas of risk. Treat fouled equipment or vessel seawater systems with copper sulphate solution or liquid sodium hypochlorite.
Crassostrea virginica	Atlantic oyster	Physical removal by hand[1] or with dredges.
Magallana gigas	Pacific oyster	Physical removal by hand[1] or with dredges.

Species	**Name**	**Strategy**
Pinctada imbricata	Rayed pearl oyster	No obvious control methods known except hand removal. Hull cleaning during dry-docking, regular use of antifouling paint and ballast water exchange is recommended.
Amathia verticillata	Spaghetti bryozoan	Control methods could include vacuum removal or removal by hand. Hull cleaning during dry-docking, regular use of antifouling paint and ballast water exchange is recommended.
Amphibalanus amphitrite	Striped acorn barnacle	No species-specific control methods known. Hull cleaning during dry-docking, regular use of antifouling paint and ballast water exchange is recommended.
Amphibalanus eburneus	Ivory barnacle	No species-specific control methods known. Hull cleaning during dry-docking, regular use of antifouling paint and ballast water exchange is recommended.
Callinectes sapidus	Atlantic blue crab	Trapping using pheromones from live decoys or preferred food.
Charybdis (Charybdis) hellerii	Swimming crab	Trapping using pheromones from live decoys or preferred food.
Charybdis (Charybdis) japonica	Asian paddle crab	Trapping using pheromones from live decoys or preferred food.
Eriocheir sinensis	Chinese mitten crab	Trap designed especially for Chinese mitten crabs.
Hemigrapsus sanguineus	Asian shore crab	Citizen science reporting and manual removal.
Rhithropanopeus harrisii	Estuarine mud crab	Collecting units or traps, ballast water exchange.
Rapana venosa	Veined rapa whelk	No proven methods but nets and dredges and public eradication programmes have been used.
Carijoa riisei	Snowflake coral	Physical removal[1] from reefs.
Tubastraea tagusensis	Sun cup coral	Physical remova[1]l from reefs.
Sargassum muticum	Japanese wireweed	Regular use of antifouling paint. Physical removal[1].
Sargassum polycystum	Brown seaweed	Regular use of antifouling paint. Physical removal[1]. Apply improved land-based management strategies that would reduce potential eutrophication and prevent loss of water quality, stressors that increase abundance.
Acanthophora spicifera	Red seaweed	Regular use of antifouling paint. Physical removal[1].
Eucheuma denticulatum	Red seaweed	Underwater vacuum system, hand removal[1], hatchery raised native sea urchins.
Gracilaria salicornia	Knobbly agar weed	Underwater vacuum system, hand removal[1], hatchery raised native sea urchins.
Halophila stipulacea	Halophila seagrass	Physical removal[1]. Smothering/ removal of light. Apply improved land-based management strategies that would reduce potential eutrophication and prevent loss of water quality, stressors that increase abundance.
Kappaphycus alvarezii	Red seaweed	Underwater vacuum system, hand removal, hatchery raised native sea urchins.
Mycale grandis	Orange keyhole sponge	Manual removal[1]

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[1] The physical removal of biofouling organisms by hand or using small handheld tools. Manual removal may include use of hand-held scrapers, brushes, or pads. All collected material should be disposed of via landfill to eliminate the risk of further spread in the marine environment.

Potential management strategies

Scaly tunicate *Microcosmus squamiger*

Once established, this species is hard to control as it is small and can reach large abundances. Native gastropods in the Mediterranean Sea were more abundant in areas with large biomass of *M. squamiger*, suggesting that predatory gastropods could be useful as a biological control agent (Rius et al. 2009).

Japanese carpet shell *Ruditapes philippinarum*

Management options for the non-indigenous Japanese carpet shell are minimal as this is one of the top commercial shellfish harvest industries in countries where it has been introduced. This species is known to compete with native bivalves and has been shown to cause their decline in many places in Europe. Its arrival has also been documented to lead to the introduction of non-indigenous invertebrates and algae. Because their presence has been seen as valuable in the past, little information on management strategies are available (Savini et al. 2010; Shean 2011).

Black striped mussel *Mytilopsis sallei*

Containment and eradication of *M. sallei* has been successful in Australia, but this success was dependent on the invasion stage and location of invasion. The Australian government has full rapid response documents that provide information on the species, environmental tolerances and various methods that may be used for an attempted eradication and/or management of *M. sallei* (Marine Pest Sectoral Committee 2015).

Asian green mussel *Perna viridis*

Containment and eradication of *P.viridis* has also been successful in Australia, but again this success was dependent on the invasion stage and location of invasion. The Australian government has full rapid response documents that provide information on the species, environmental tolerances and various methods that may be applicable for an attempted eradication and/or management of *P. viridis* (Marine Pest Sectoral Committee 2015).

Atlantic oyster *Crassostrea virginica*

As this is a commercially harvested species most research has been aimed at aquaculture tolerances and managing the fishery. *C. virginica* has a wide geographic distribution and can survive freezing winter waters to temperatures over 36 ºC in the Gulf of Mexico and even periods at exposed intertidal sites over 50 ºC. They can also survive weeks in freshwater and consistently grow at salinities up to 40 ppt. Destruction of reef habitat as a direct result of fishing practices is having detrimental effects in native habitats. Dredging and manual removal in likely to be an effective management strategy if the arrival of *C. virginica* is detected early (National Research Council 2004; Hewitt et al. 2009).

Pacific oyster *Magallana gigas*

Several attempts have been made in the Oosterschelde estuary in the Netherlands to remove the *M. gigas.* Large scale removal attempts have been unsuccessful but the control of oysters with mussel dredges at locations where there is abundant growth could be feasible. Early detection is important, as after extensive establishment it was determined by many European countries that no eradication and control methods for *M. gigas* are possible without extensive damage to the native ecosystem (Nehring 2011).

Rayed pearl oyster *Pinctada imbricata*

Work has been done to examine new populations of this oyster in Greece; thermal and salinity tolerance and overall condition has been examined. However, although this species has been listed as one of the worst alien invaders in Europe, little work has been done by authorities to form guidelines for its management (Theodorou et al. 2019).

Spaghetti bryozoan *Amathia verticillata*

This species is a documented invader in many countries however, there are a limited number of methods which have proven effective for its management. Once established, this species is thought to be difficult to manage and impossible to eradicate (Amat and Tempera 2009; Farrapeira 2011; McCann et al. 2015; Jeba Kumar et al. 2017).

Striped acorn barnacle *Amphibalanus amphitrite*

Management for the striped acorn barnacle largely involves regular dry docking, cleaning, and regular anti-fouling of contaminated vessels. It is estimated that a U.S. Navy destroyer spends over $50 million a year just in fuel costs due to drag from the presence of barnacles such as *A. amphitrite*. A newly painted vessel would lose 2 knots of speed every six months if not scraped and cleaned and this is suspected to double when the vessel is in tropical waters (Cleere 2001; Alaska Center for Conservation Science 2017; Carlton et al. 2021).

Ivory barnacle *Amphibalanus eburneus*

Environmental tolerances of *A. eburneus* have also been researched, however, like *A. amphitrite*, management of barnacles largely involves regular dry docking, cleaning, and antifouling to minimise costs and impacts it will have on vessel speed and performance (Koçak and Kucuksezgin 2000; Osca and Crocetta 2020).

Atlantic blue crab *Callinectes sapidus*

There appears to have been no attempts to manage blue crabs in areas that they have been introduced, though the fishery in Turkey is managed with a minimum legal size (Jensen 2010). Using live decoys has also been suggested as a way to lure swimming crab conspecifics into traps, they were more effective than baited traps and eliminated unwanted organisms that feed on bait. However, live decoys are likely only effective during times of year when mating occurs. Trapping also has inherent biases that influence the effectiveness of this technique (e.g. age, gender, etc.). Repeated and concerted trapping effort would be required as a management strategy (Vazquez Archdale 2008).

Swimming crab *Charybdis (Charybdis) helleri*

Live decoys have also been suggested as a way to lure *C. helleri* conspecifics into traps, they were more effective than baited traps and eliminated unwanted organisms that feed on bait. *C. helleri* has a relatively long larval life, short generation time, and the females have the ability to store sperm and produce multiple broods from a single insemination so a frequent and repetitive trapping effort would be required as a management strategy (Vazquez Archdale 2008; Fowler and McLay 2013).

Asian paddle crab *Charybdis (Charybdis) japonica*

Invasive populations of *C. japonica* share many of the life history attribute as *C. helleri.* As a result, management strategies for the two species would be similar, see above (Vazquez Archdale 2008; Fowler and McLay 2013).

Chinese mitten crab *Eriocheir sinensis*

Eriocheir sinensis is one of the top invasive species in Europe, it is one of 49 species listed in EU Regulations (EU Regulation No 1143/2014) and management options for controlling this species have been limited to various forms of trapping or hand fishing. However, these crabs can travel up to 15 km a day and after two hours of hand fishing on a river in Germany over 750,000 crabs were caught. New trap designs have been tested that are aimed at reducing the number of crabs migrating between sea and freshwater areas to control the population. Early results appear successful and one trap caught over 1 million crabs in 2 years (Rudnick et al. 2000; Schoelynck et al. 2021).

Asian shore crab *Hemigrapsus sanguineus*

Research has also been conducted on the physiological responses under different environmental conditions of the Asian shore crab *H. sanguineus*. Parasites which help control native populations are not present in other invaded locations, but seagulls and some species of fish are known to prey on the Asian shore crab. Few other methods of management are known for this species (Epifanio 2013; Hudson et al. 2018).

Estuarine mud crab *Rhithropanopeus harrisii*

Certain pest control agents such as juvenile hormone analogues (fenoxycarb) have been examined on larval development of *R. harrisii*. Significant mortality occurred in the first four zoeal stages, however, this would not be species specific and would be effective on all species of crabs and other organisms containing chitin (e.g. bacteria, other crustaceans, and molluscs). The use of a chitin synthesis inhibitor (Diflubezuron) has also been trialled and shown to be lethal by inhibiting chitin synthesis through moulting and development stages, however, this type of management strategy lacks specificity and can take several weeks to degrade. Biological control using the castrating rhizocephalan *Loxothylacus panopaei* has also been suggested. Parasitic barnacles infect their crab hosts at the larval stage (cyprid or cypris larva), develop as an endoparasite, and then produce an external reproductive body called the externa. Rhizocephalans stunt growth in their hosts and cause castration in both males and females, preventing future reproduction. *R. harrisii* experimentally infected with *L. panopaei* had significantly affected rates on the survival. However, in the native range of *L. panopaei* it is considered to be hosted in at least nine different species of panopeid crabs. It could infect other species not just the intended target and further studies are necessary to determine whether *L. panopei* is a viable candidate for biological control of *R. harrisii* in its introduced range (Christiansen and Costlow 1982; Cripe et al. 2003; Roche et al. 2009; U.S. Fish and Wildlife Service 2018; Jensen).

Veined rapa whelk *Rapana venosa*

It is thought that the prospects for control or eradication of *R. venosa* are limited. The complex lifecycle and size dependent transition from epifaunal to infaunal habit creates multiple avenues in which this species can persist. Work is being done on using side scan sonar to detect large mating aggregations on open sandy substrate in the lower Chesapeake Bay. Targeting one susceptible stage of the life cycle may prove useful, however, as with all other marine NIS early detection is key to potential success (Mann and Harding 2002; ICES 2004; Mann et al. 2004; Giberto et al. 2006).

Snowflake coral *Carijoa riisei*

The snowflake coral has been described as the most invasive of the 287 non-indigenous marine invertebrates in Hawai'i, and there are few management options for this species. The aeolid nudibranch *Phyllodesmium poindimiei* was thought to make a good candidate as a biocontrol agent of *C. riisei*, however, results of experiments have shown that while the damage caused by the feeding activity of *P. poindimei* may affect *C. riisei* negatively and reduce its overall fitness, the predation does not have a large enough impact on the biomass of *C. riisei* and sponge overgrowth protects *C. riisei* from nudibranch predation. Polyps of *C. riseii* are particularly susceptible to low salinities, and greater than 50% mortality occurred in salinities of 25 ppt in less than two days and with decreases in salinity the time until mortality increased, with freshwater causing the death of 50% of *C. riisei* polyps in one and a half minutes. Location will be important in determining if freshwater may be an option to manage *C. riisei* (Toonen et al. 2007; Wagner et al. 2009; Concepcion et al. 2010; Sanchez and Ballesteros 2014; Crivellaro et al. 2021).

Sun cup coral *Tubastraea tagusensis*

T. tagusensis in Brazil causes tissue necrosis and partial mortality of native corals due to contact with the invader. Manual removal by divers, with a chisel and hammer, retaining colonies in plastic bags to prevent dispersal of fragments and larvae, is the most common method of removal. The Sun-Coral Project (PCS) was launched in 2006 as an outreach and management strategy for dealing with sun corals in Brazil (two species: *Tubastraea coccinea* and *T. tagusensis*). Collectors have been trained to manually remove corals from the seabed and earn extra income by selling the skeletons, which can be used in craftwork. Over 143,000 people have been involved in the work and 8.5 tonnes have been manually removed (Miranda et al. 2016; Creed et al. 2017a, b; De Paula et al. 2017; Luz and Kitahara 2017; Crivellaro et al. 2021).

Japanese wireweed *Sargassum muticum*

After clearance operations began in Britain in 1973, using volunteers and the public, over 30 tonnes of wet *S. muticm* was removed. The operations continued until 1976 and experiments also included using tractors with harrows, cultivators, and front end loaders. After this time, it was determined that removing by hand is extremely time-consuming and needs to be repeated, probably indefinitely. Removal by trawling, cutting and suction have also been tested. The results from testing herbicides were similar to most chemical treatments, there was a lack of selectivity and large doses were needed to control populations. Predation by small grazers has little effect on this large seaweed. This alga reproduces and grows quickly resulting in very few effective management strategies, although cutting and suction is the preferred method (Critchley et al. 1986; Harries et al. 2007; Eno et al.).

Brown seaweed *Sargassum polycystum*

The persistence of macroalgal dominance by *S. polycystum* appears to be the result of the feedback loop where it acts in a self-reinforcing manner. Its presence positively promotes the survival and growth of its own species. *S. polycystum* prefers to be in shallow waters that are high in nutrients. It is often found on hard substrata close to densely populated areas that tend to leach nutrients into the water. Research in Thailand indicates that the monsoon drives the seasonal patterns of growth and reproduction and its greatest growth and maturation occurs under calm sea conditions with sufficient solar radiation. Action to alleviate coastal run-off that causes high nutrient leaching is recommended. Harvest of the seaweed is an option as there are several uses for the large biomass this species can create. These include applications in vegetable farming where seaweed extracts provide better water retention, improvement of growth, stress resistance, insect reduction, and protection against oxidative stress. Compost and biofuel are also considered potential uses (N'Yeurt and Lese 2015; Dell et al. 2016; Noiraksar et al. 2017; Kumari Charan 2017).

Red seaweed *Acanthophora spicifera*

Acanthophora spicifera has proven difficult to manage in Hawai'i, but controlling its spread is thought to be feasible. Manual removal is labour intensive but depending on the location and stage in the invasion process may prove effective. Complete eradication would only be possible if *A. spicifera* was detected early. This species grows rapidly (~ 1cm a week) and fragmentation begins to occur when the species is 15 cm high, removal efforts should occur before fragmentation, therefore approximately every three months to prevent recolonisation. The use of tarpaulins to create shade, reduced algal growth and caused a decrease in height, but if the shade is removed growth promptly resumes. The combination of rotating shade and manual removal needs more investigation. Biological control using local herbivorous fish has also been investigated in Hawai'i. The use of local Hawai'ian knowledge to create fish shelters or refuges, known as *imu*, were used to provide shelter and habitat to increase herbivorous fish populations. The resulting increase in herbivorous fish were able to keep *A. spicifera* at a cropped state. This reduced biomass from fish grazing combined with the use of manual removal may be an effective management strategy. Some species of algae can survive digestion by reef fish, more work needs to be done to examine if this is also the case with *A. spicifera* (Weijerman et al. 2010; Neilson et al. 2018).

Red seaweed *Eucheuma denticulatum*

Most research on the red seaweed *E. denticulatum* centres around cultivation and farming of this species for carrageenan. However, if it escapes aquaculture areas it can create thick algal mats that carpet coral reefs and restrict the light received by coral polyps, ultimately stopping photosynthesis within the polyp. Once photosynthesis stops the colony dies beneath the algal mat. In cultured situations, *E. denticulatum* growth rates decreased in waters with a higher pH and high light intensities, but the by-product of this stress was destructive hydrogen peroxide. Manual removal is difficult because it adheres to hard substrates and can reproduce via fragmentation, however repeated manual removal with the aid of vacuum system has shown to be effective (see below) (Mtolera et al. 1995; Neilson et al. 2018).

Knobbly agar weed *Gracilaria salicornia*

Agar weed *G. salicornia* has similar properties to *E. denticulatum.* It creates thick algal mats and reduces light received by coral polyps, which stops photosynthesis and causes death. It can have multiple attachment points on hard substrata, making removal difficult. A two tiered approach was used to control this species along with *E. denticulatum* and *Kappaphycus* spp. in Hawai'i. This included manual removal by divers aided by an underwater vacuum system ("the super sucker"), combined with hatchery raised juvenile sea urchins (*Tripneustes gratilla*, a native species). Approximately 19,000 kg of algae was removed and ~99,000 urchins were out-planted on a reef that was around 24,000 m^2 which resulted in an 85% reduction in algal cover over two years (Rodgers and Cox 1999; Smith et al. 2004; Yang et al. 2013; Neilson et al. 2018).

Halophila seagrass *Halophila stipulacea*

Tropical seagrass species, *H. stipulacea*, can adapt to a range of new conditions and has been shown to have a remarkable tolerance of salinities from freshwater to salinities around 60 ppt. Tests on temperature tolerance have shown that under predicted climate change conditions, *H. stipulacea* were un-affected and may have even had enhanced performance under thermal stress. High radiance levels were also tolerated by the species but research on the effects of zinc, titanium dioxide and silver show that they cause mortality under laboratory conditions. These treatments lack selectivity and are unlikely to be practical in the natural environment. If detected early, dredging, or manual removal, shading/smothering may be successful. The application of coarse sea salt at a concentration of 50 kg/m^2 was effective at rapidly killing another species of non-indigenous seagrass (*Caulerpa taxifolia*), it had relatively minor effects on the native biota and was relatively inexpensive (Malea et al. 1995; Glasby et al. 2005; Willette and Ambrose 2009, 2012; Sharon et al. 2011; Ruiz et al. 2017; Nguyen et al. 2020; Winters et al. 2020; Mylona et al. 2020b, a).

Red seaweed *Kappaphycus alvarezii*

This red seaweed has been introduced to many areas as, like *E. denticulatum and G. salicornia*, it is commercially important for the production of carrageenan. It also creates thick algal mats that cause coral mortality. The two tiered approach to control used in Hawai'i involving manual removal by divers aided by a suction system and enhanced sea urchin grazing was successful in controlling this species. However, in India manual removal was unsuccessful and drifting fragments resulted in further establishment of the species, and the reduction in coral and native algal cover in the area. Control methods for this species need to account for fragmentation and potential regeneration from small segments left behind after removal (Rodgers and Cox 1999; Kamalakannan et al. 2014; Kasim and Mustafa 2017; Neilson et al. 2018).

Orange keyhole sponge *Mycale grandis*

In Hawai’I, several management strategies have been tested against *M. grandis*. Manual removal was trialled but was considered highly ineffective and unfeasible because of the need to remove significant amounts of coral at the same time. The sponge could not be eliminated completely and grew back to cover a larger percentage of the area while causing the decline of more coral. Air injection techniques have also been tested on surfaces where sponges had been removed. A 10 cm long bone necrosis needle was used to inject on that surface. This technique resulted in a mean reduction of sponge cover of up to 73% a month later. Gastropod cowries have also been tested as a control method and the Hawai’ian tiger cowry (*Cypraea tigris*) has been seen to consume the sponge under aquarium conditions (Coles et al. 2007; Coles and Bolick 2007; Shih 2018).

Risk Analysis

The movement of vessels between countries involves a certain level of risk and the aim of a risk analysis is to provide country officials with an objective and defensible method of assessing the biosecurity risk associated with the arrival of vessels and the potential organisms those vessels may carry on their hull via biofouling or in ballast water. The risk analysis should be transparent, which means comprehensive documentation, communication of all data, information, assumptions, methods, results, discussions, and conclusions should be clear and available. This is necessary to justify any reasons for refusal of entry and for record keeping when systems may be reviewed.

This section provides recommendations and principles for conducting a transparent and objective risk analysis considering maritime transport via biofouling or ballast water as the entry mechanism for marine NIS. There are four key elements to a risk analysis: *hazard identification, risk assessment, risk management* and *risk communication* (Figure 1.)

Information gathered on species should include (where possible) temperature tolerance, salinity tolerance, depth range, known distributions, larval period, or reproductive mechanisms and whether the species was known to be part of a biofouling community. If information on impacts exist, they should be segregated into the four core values: environmental, economic, social and cultural, or human health impacts. Any notes on general invasiveness should also be recorded and any references kept. The collation of this information can be used as a starting point to assess whether enough data exist on a species to be able to perform a risk assessment based on the four core values.

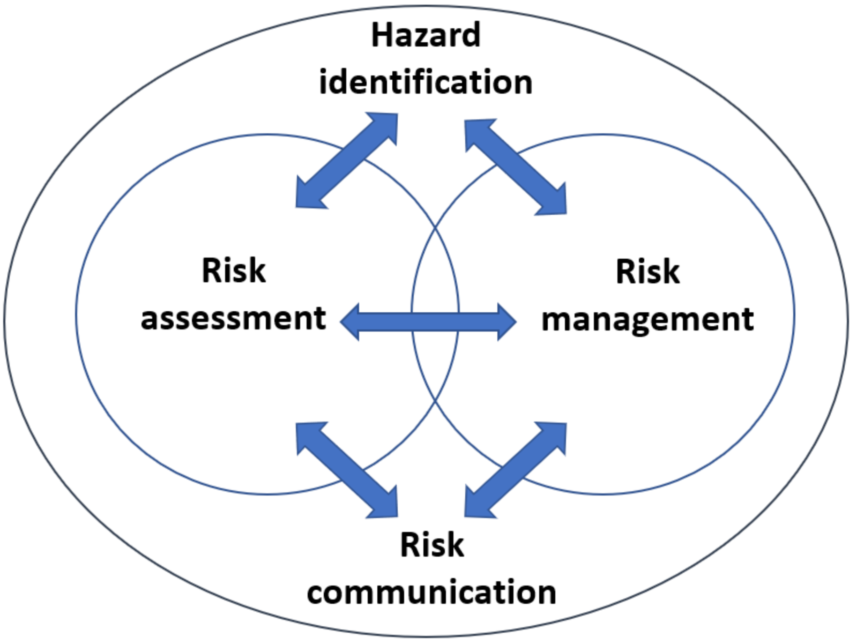


Figure 1. Key components of a risk analysis.

Hazard identification

During this exercise, the *hazard identification* was deemed to be any species with a recognised invasion history, currently known to be present in some but not all Pacific island countries and territories as well as those species that are not currently known to be present but could be introduced to the Pacific.

If the location of the assessment already has the species known to be present, and there are no control or mitigation measures in place, then the assessment can be concluded.

Risk assessment

The *risk assessment* component of the analysis, in this case, estimates the biosecurity risk associated with each particular hazard. This analysis should be based on the best information available. It should document uncertainties and assumptions, be consistent and well documented. It should also be reviewed when new information becomes available.

The biosecurity risk can be broken down into three categories: introduction, survival, and impact.

Introduction

In other risk assessments, the risk of introduction is considered to be the invasion potential for a species. It can be calculated from vessel movements, ballast discharge and latitudinal differences from source and arrival habitats. In previous studies, the likelihood of a vessel transporting a marine NIS on their hull or in their ballast was calculated using duration in overseas ports as a measurement of settlement opportunity and accurate data on the number of vessel arrivals and the species present within the port can be used. Unfortunately, this type of data is not always available.

Based on generally limited voyage history information we recommend assigning species to categories, (where possible) that are based on the known distributions of marine NIS source populations, such as:

- 3 – Species present in a country with a direct transport link.
- 2 – Marine NIS known from the Pacific Island region but not currently known to be on a transport route.
- 1 – All other species where no transport link between a source population and the location of interest is identified.

Invasion potential also relies on information about the life cycle of a species, the general type of species it is, and how it is able to travel on or in a vessel. This needs to be considered when assessing the risk of introduction.

Whether the information is gathered and documented and assigned to categories or scored qualitatively for overall values, both risk assessment methods are valid. Documenting the process, ensuring fairness, rationality, and consistency is the most important factor.

Survival

Several marine NIS identified as priority species may not have recorded impacts or do not currently occur within tropical or sub-tropical regions. These can still be included in the risk assessment as many factors influence the establishment and spread of a marine NIS. Although they may be unlikely to survive in tropical environments given current information, survival and establishment should be considered ‘possible’, as many marine species are very tolerant of warmer temperatures do not realise their full potential in their native range but can adapt in new locations.

To take this information into account categories can also be assigned based on how a species might survive in a new location, such as:

- 0 – Unlikely to survive – environmental conditions including temperature and salinity did not match known tolerances of the species being assessed.
- 1 – Possibility of survival – inferred temperature and salinity tolerances suggest this species may survive the conditions of the area, but it is uncertain.
- 2 – Likely to survive – this species is known to already be present in the Pacific Island region or another tropical location.

These categories can be based on information about the species' current distribution, its temperature and salinity tolerances and how they correspond with the ranges of those environmental conditions in the Pacific Island region. For example, the Chinese mitten crab, *Eriocheir sinensis*, is a top global invader with recorded impacts in many countries, but they have a freshwater lifecycle. As such, all Pacific Island countries and territories that do not have major bodies of freshwater are unlikely to sustain populations of the Chinese mitten crab, so this species would be assigned a survival score of zero.

Impacts

Information on impacts for each species can be derived from recorded impacts in other counties. While these impacts are a good indicator, they may not necessarily represent the impacts that would occur if the species were to arrive in a Pacific Island country or territory or the importance (i.e., weighting) that might be given to them in a different social, cultural or economic context. Past information about impacts is, however, the best way to estimate any consequences.

Impacts or consequences can be:

Direct–

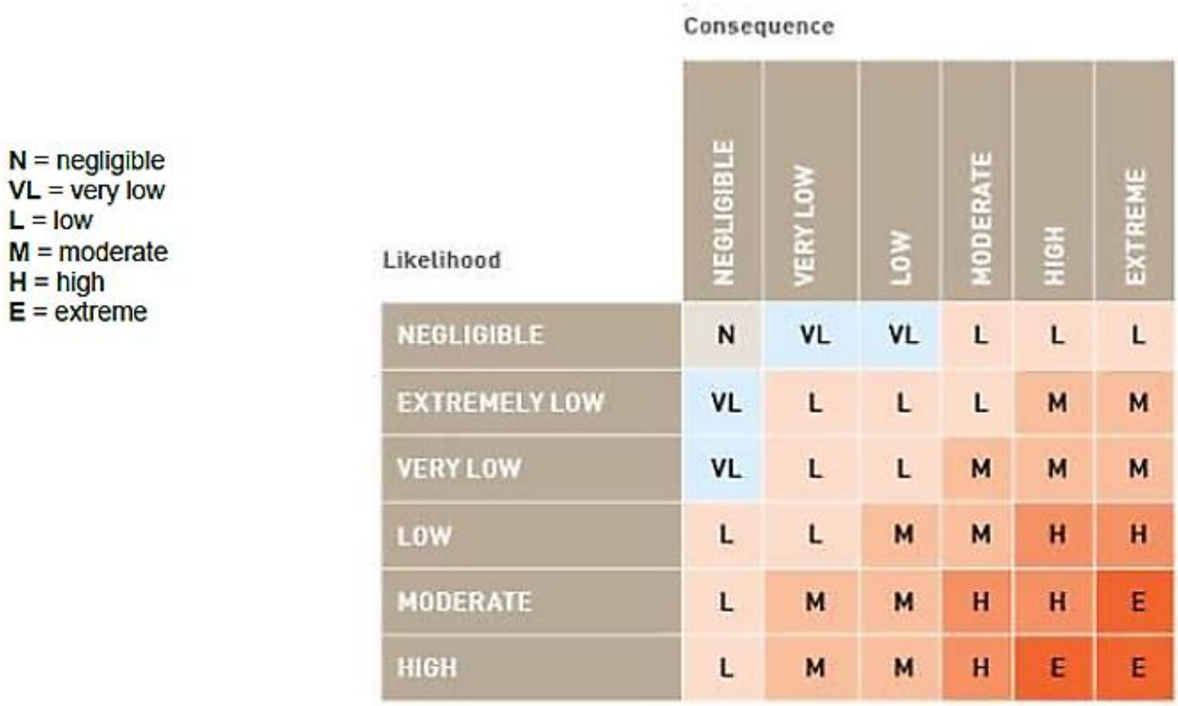
- habitat losses
- production losses
- human health impacts

or Indirect–

- monitoring and control costs
- compensation costs
- potential trade losses
- adverse effects on the environment

One of the four core values considers impacts on social and cultural practices. These assessments are generally assessed according to the impact the species has had in other countries where it is currently present. These generally include impacts on food gathering, water quality and changes to the native ecosystem around abundance and distribution of native species. The social and cultural practices and values in individual countries and territories can be difficult to translate to local values and practices.

Risk matrices are often used to assess impacts and categorise them based on their likelihood of occurring and the overall consequence. Many examples exist of risk matrices and they are a useful way to document the rationale used when making decisions in this area (Figure 2.).



N = negligible
VL = very low
L = low
M = moderate
H = high
E = extreme

	Consequence					
Likelihood	NEGLIGIBLE	VERY LOW	LOW	MODERATE	HIGH	EXTREME
NEGLIGIBLE	N	VL	VL	L	L	L
EXTREMELY LOW	VL	L	L	L	M	M
VERY LOW	VL	L	L	M	M	M
LOW	L	L	M	M	H	H
MODERATE	L	M	M	H	H	E
HIGH	L	M	M	H	E	E

Figure 2. Risk calculation matrix (example from: Hewitt et al. 2009). Risk was estimated using this matrix by multiplying the likelihood of inoculation (based on available data about potential vectors and arrival rates of foreign vessels) by their consequence (which was gathered from literature assessments of documented impacts). To aid in collecting the data and creating an overall risk score, a rating was assigned to each risk level (1 = moderate, 2 = high, 3 = extreme).

Ideally, frameworks used to assess impact should include consideration of the values of affected parties so that the calculations are weighted relative to the importance of the affected values (see risk communication steps below).

If using a qualitative scoring system, the risks associated with each of these categories can be combined with the probability of establishment being conditional upon the probability that the species will be introduced. The probability of a species having an impact is conditional on the probability that it becomes established in the area.

Put simply, we can calculate a biosecurity risk score as.

Probability (Introduction) x Probability (Survival) x Impact[2]**.**

Overall impact scores can be multiplied by survival likelihood scores and probability of introduction scores to give a **Total biosecurity risk** (Table 2.).

If quantitative assessments are being used, key factors in the local determination of a potential new species deemed to be high risk should be documented.

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[2] Colours are based on the example shown in Table 2.

Table 2. Biosecurity risk analysis example. Grey = values to assess impact, yellow = impact scores of four core values, orange = probability of survival, blue = probability of introduction, green = overall total biosecurity risk.

Organism	Habitat impacts	Trophic interactions	Biodiversity Impacts	Valuable species impacts	Social	Cultural	National Image	Aesthetic	Economic	Asset impacts	Human health impacts	Environmental Sum	S &C sum	Economic sum	HH sum	Env risk	S &C risk	Economic risk	HH risk	Total risk	Transport mechanism	Survival likelihood	Present	Transport link	Transport working	Transport Final	Prob Introduction	Total Rank
Seaweed – Kappaphycus alvarezii	5	3	5	5	4	4	4	4	4	5	1	18	16	9	1	5	5	3	0	13	4	2	0	1	1	2	8	208

Principles of risk mitigation

Risk mitigation is the process of deciding upon and implementing measures to address the risks identified in the risk assessment, whilst at the same time ensuring that negative effects are minimised. The objective is to manage the risk appropriately to ensure that a balance is achieved between a country's desire to minimise the likelihood or frequency of a marine NIS establishing in a country and their consequences and its desire to import commodities and fulfil its obligations under international trade agreements.

Risk mitigation components – the following steps comprise the elements of the risk management considerations.

- *Risk evaluation* - the process of comparing the risk estimated in the risk assessment with the reduction in risk expected from the proposed risk management and mitigation measures.
- *Option evaluation* - the process of identifying, evaluating the efficacy and feasibility of, and selecting measures to reduce the risk associated with a particular species. The efficacy is the degree to which an option reduces the likelihood or magnitude of adverse environmental and economic consequences. Evaluating the efficacy of the options selected is an iterative process that involves their incorporation into the risk assessment and then comparing the resulting level of risk with that considered acceptable. The evaluation for feasibility normally focuses on technical, operational, and economic factors affecting the implementation of the risk management and mitigation options.
- *Implementation* - the process of following through with the risk management decision and ensuring that the risk management or mitigation measures are in place.
- *Monitoring and review* - the ongoing process by which the risk management/mitigation measures are continuously audited to ensure that they are achieving the results intended. The final stage in the risk assessment process is then effective communication.

Risk communication

Risk communication is the process by which information and opinions regarding hazards and risks are gathered from potentially affected and interested parties during a risk analysis, and by which the results of the risk assessment and proposed risk management measures are communicated to the decision-makers and interested parties. It is a multidimensional and iterative process and should ideally begin at the start of the risk analysis process and continue throughout (e.g., Figure 3.) (Kumschick et al. 2012). For example, some might weight human health impacts as of greater concern than potential impacts on biodiversity.

The principal participants in risk communication include all the involved stakeholders and participation should be encouraged to make sure all voices are heard.

The communication of the risk should be an open, interactive, iterative, and transparent exchange of information that may continue long after initial contact. They should also be weighted based on stakeholder assessment.

The assumptions and uncertainty in any risk model, model inputs and the risk estimates of the risk assessment should be communicated.

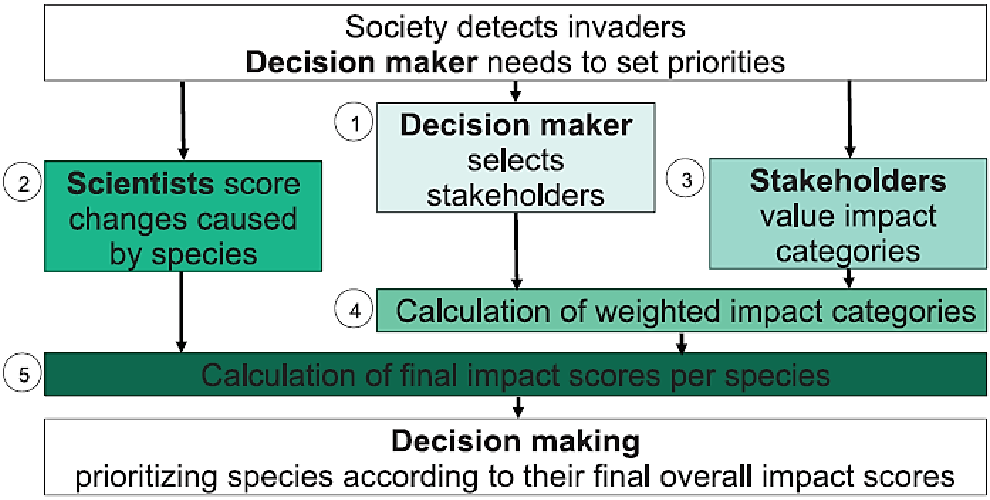

Figure 3. Schematic overview of the conceptual framework to assess change in different impact categories for each species, capture stakeholders' interests and weigh stakeholders and calculate final impact score for each species.

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