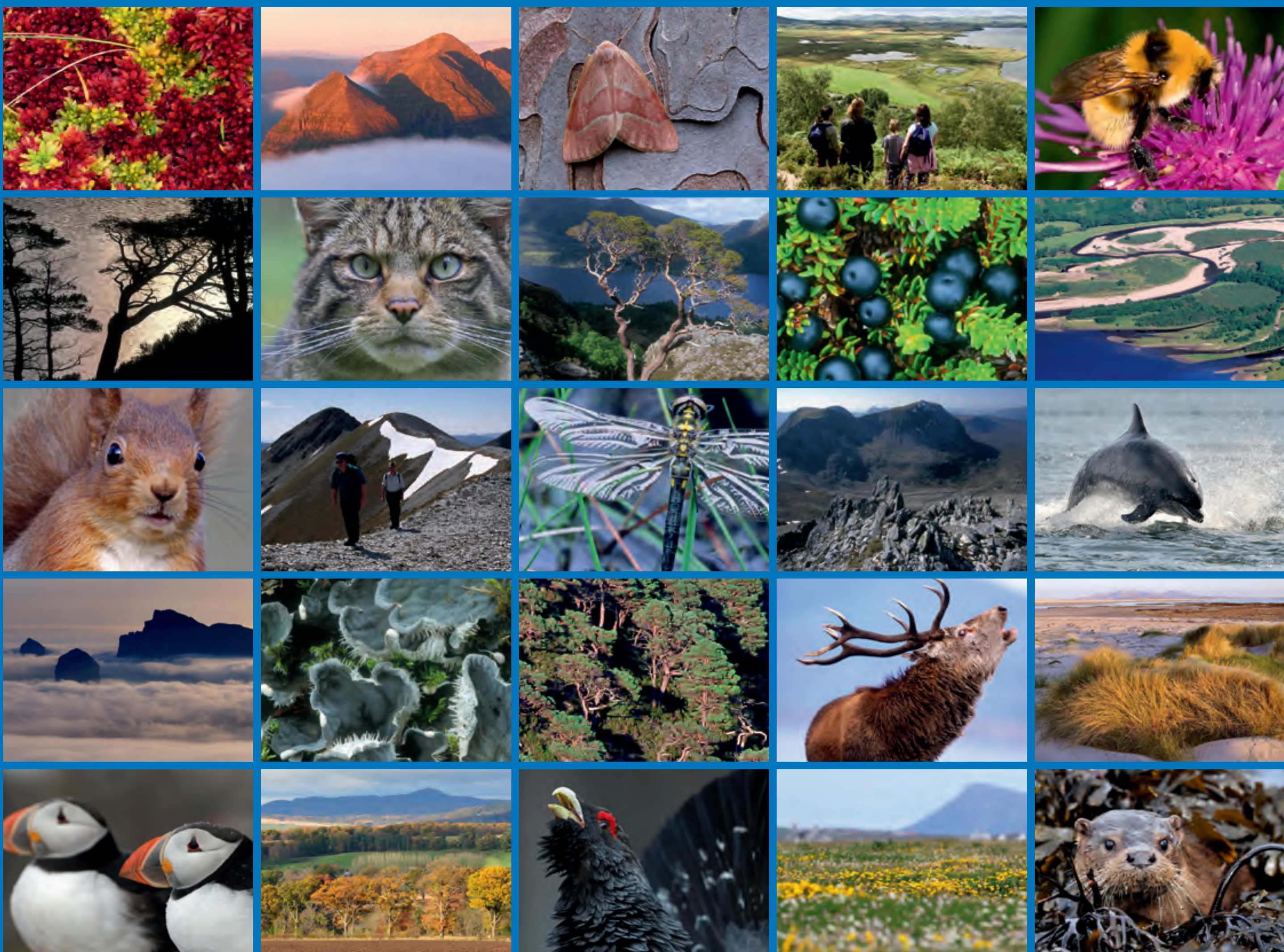
Scottish Natural Heritage
Commissioned Report No. 748

# Marine biosecurity planning – Identification of best practice: A review



# COMMISSIONED REPORT

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# Marine biosecurity planning – Identification of best practice: A review

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*This report should be quoted as:*

Cook, E.J., Payne, R.D. & Macleod, A. 2014. *Marine biosecurity planning – Identification of best practice: A review*. *Scottish Natural Heritage Commissioned Report No. 748.*

COMMISSIONED REPORT

# Summary

## Marine biosecurity planning – Identification of best practice: A review

**PLEASE NOTE:** This literature review was produced to support "Payne, R.D., Cook, E.J. and Macleod, A. 2014. Marine Biosecurity Planning – Guidance for producing site and operation-based plans for preventing the introduction of non-native species. Report by SRSL Ltd. in conjunction with Robin Payne to the Firth of Clyde Forum (S. Brown) and Scottish Natural Heritage - 39 pp."

**Commissioned Report No. 748**
**Project no: 14410**
**Contractor: Cook, E.J., Payne, R.D. and Macleod, A.**
**Year of publication: 2014**

**Keywords**

Clyde; marine; invasive non-native species; biosecurity; best practice; Wildlife and Natural Environment (Scotland) Act, 2011; species control measures; hazard analysis critical control point; marina; port.

**Background**

Non-native species (NNS) are those that have been intentionally or unintentionally introduced outside their native range as a consequence of human activity. Once established, if these species then threaten biodiversity and/or cause economic damage they are referred to as 'invasive'. Biological invasions are not only one of the greatest threats to marine biodiversity, but they can also cause massive economic and ecological damage. Their presence can also potentially lead to the failure of a water body to achieve good environmental status under the forthcoming EU Marine Strategy Framework Directive. As the rate of invasion in GB and Irish waters continues to increase, particularly in light of climate change, the emphasis is being placed on preventing an invasion occurring rather than on trying to control or eradicate a NNS once it has become established. Biosecurity plans are critical step in providing a framework to reduce the risk of the introduction of marine NNS.

The Firth of Clyde Forum produced a Biosecurity Plan for the Clyde area in 2011. Best practice and guidance on writing a marine biosecurity plan and undertaking pathway analysis and risk assessment at a site and/ or operation level, however, is now urgently required. The aim of this review, therefore, is to provide an overview of biosecurity planning for the marine environment, including the most current legislative background, pathway identification and risk assessment processes. It is intended that this review will be used in conjunction with the guidance document on how to prepare a biosecurity plan for a site or particular operation/ event. The potential impacts of marine NNS are reviewed, together with examples of practical biosecurity measures which have been used to control or eradicate these species. UK and international experience, including the success and failures of biosecurity planning, has been included. Literature from a variety of sources was reviewed, in addition to stakeholder and expert views sought via consultation both nationally and internationally. It is envisaged that this review will be applicable for a wide variety of maritime activities including; aquaculture, inshore fisheries, offshore power generation, construction, shipping, recreational boating, marina, slipway and boatyard operators, Government agencies, local councils and regional forums.

**Main findings**

- The unintentional introduction of species to a region outside their normal range can have serious socio-economic impacts on maritime industries.
- Biosecurity plans for NNS have been prepared in a variety of formats and range from countrywide strategic documents to plans for small sites and individual operations.
- The need to understand the pathways of invasion and the vectors which transport NNS from region to region is paramount in preparing a marine biosecurity plan.
- The need to be prepared to act rapidly if planned biosecurity measures for INNS fail has been widely acknowledged and is included in many biosecurity plans.
- Direct measurements of the success of biosecurity plans in preventing the introduction of NNS are extremely difficult to gather, especially at the site and operation level.

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**Acknowledgements**

The review team would like to express their thanks to the members of the Project Steering Group and all the stakeholders who provided advice, information, case history materials, reports and contact information during and/or before the drafting of this review.

## 1. INTRODUCTION

Non-native species (NNS) are those that have been intentionally or unintentionally introduced outside their native range as a consequence of human activity (CBD, 1992). Once established, if these species then threaten biodiversity and/or cause economic damage they are referred to as 'invasive' (INNS) (CBD, 1992, Wilcove *et al.*, 1998). Biological invasions are not only one of the greatest threats to marine biodiversity (Molnar *et al.*, 2008), but they can also cause massive economic and ecological damage (Vitousek *et al.*, 1997, Pimentel *et al.*, 2005). Increased international trade has caused an exponential increase in the spread of NNS around the world over the last few decades (Carlton, 2000, Hulme, 2009) and this trend has been observed in Britain (Roy *et al.*, 2012, Minchin *et al.*, 2013).

**The estimated cost of NNS to the economy in Great Britain is £1.7 billion a year (Williams *et al.*, 2010). The annual cost to 'marine-based' industries (e.g. shipping and aquaculture) in GB is estimated to be £39.9 million, although this is probably an underestimate, as there is little distinction made between native and non-native species during pest control operations (Williams *et al.*, 2010).**

More than ninety NNS have been identified from British and Irish (including Republic of Ireland and Northern Ireland) marine and brackish environments, of which seventeen are now established in Scotland (Minchin *et al.*, 2013, Cook *et al.*, 2013a). Their arrival has been principally due to shipping, including ballast waters and sediments, fouling of hulls and other associated hard structures, and imported consignments of cultured species (Minchin *et al.*, 2013). The majority of marine NNS in Britain originate from the North Pacific, followed by the North-west Atlantic (Minchin *et al.*, 2013). Many are initially reported from sites of anthropogenic activity, such as ports, marinas and aquaculture facilities, particularly in the English Channel, with a number subsequently spreading northwards to the North or Celtic Seas (Minchin *et al.*, 2013).

Biosecurity plans are critical in providing a framework to reduce the risk of the introduction of marine INNS and to help countries meet their obligations under the forthcoming EU Marine Strategy Framework Directive and/or Water Framework Directive. The International Maritime Organisation (IMO) recognised this importance and produced in 2011, a biofouling management plan and record book for the shipping industry (Marine Environment Protection Committee, 2011). At a national level, the GB Non-native Species Framework Strategy (DEFRA, 2008), the new Invasive Alien Species Strategy for Northern Ireland (DOENI, 2013) and the Scottish Government Code of Practice on Non-Native Species (Scottish Government, 2012), typically follow a 3-stage approach including (i) prevention, (ii) rapid response, (iii) control and containment. At a regional level, this approach has been adopted in the production of biosecurity plans by the Firth of Clyde Forum (Mills, 2012) and the Solway Firth Partnership (Solway Firth Partnership, 2013). Biosecurity plans for INNS are under development in Orkney (J. Kakkonen, pers. comm.) and the Isle of Man (F. Gell, pers. Comm.). Best practice and guidance on writing a marine biosecurity plan and undertaking pathway analysis and risk assessment at a site and/ or operation level, however, are now urgently required.

A few examples of how biosecurity planning can be practically implemented by maritime industries in the UK at the site or operation level do exist. The biosecurity planning guidance for finfish farmers/ traders and shellfish producers being notable examples (CEFAS, 2009a,b), however, these are highly specific to aquaculture activities. By contrast, in New Zealand and Australia their biosecurity measures for marine INNS are far better developed and have been far more integrated with plant and animal health, placing a strong emphasis on border control (i.e. prevention) and rapid response. These and other international examples of practical guidelines of how to minimise the introduction and spread of INNS for a wide variety of maritime activities need to be understood in the context of the Firth of Clyde and the wider GB setting.

The aim of this review, therefore, is to provide the background information which will enable users of the marine biosecurity guidance document to have a fuller understanding of why the guidance was produced and the processes that were followed at each step of the plan.

## 2. METHODOLOGY

### 2.1 Approach

This review provides an overview of biosecurity planning for the marine environment, including the most current legislative background, pathway identification and risk assessment processes. The potential impacts of marine NNS are reviewed, together with examples of practical biosecurity measures which have been used to control or eradicate these species. UK and international experience, including the successes and failures of biosecurity plans has also been explored in some detail.

Literature from a variety of sources has been reviewed, in addition to stakeholder and expert views sought via consultation both nationally and internationally.

This review has focused primarily on activities within the marine environment, in agreement with the steering group as follows:

- Aquaculture; including shell- and fin-fish
- Fisheries
- Offshore power generation
- Construction
- Shipping
- Recreational boating
- Operation of marinas, slipways and boatyards
- Government/ Local Council
- Regional Forums

### 2.2 Consultation

Consultation has provided important insight into the biosecurity planning process and also acted to disseminate information about this project to a wide variety of stakeholders. The stakeholders consulted during this project are presented in Annex 1.

## 3. WHY DO WE NEED BIOSECURITY PLANS FOR MARINE NON-NATIVE SPECIES?

The unintentional introduction of species to a region outside their normal range can have serious socio-economic impacts on maritime industries (Cook *et al.*, 2008), such as aquaculture, shipping and recreational boating, fisheries and power generation (Mineur *et al.*, 2012, Miller *et al.*, 2013). Their introduction is also widely recognised as a major threat to the environment (Worm *et al.*, 2006), arising from habitat modification, changes in ecosystem functioning, additional disease and parasitic introductions, and genetic effects, such as hybridisation with native species (Lovei, 1997).

### 3.1 Socio-economic impacts

#### *3.1.1* Aquaculture

In the UK, the most common impacts to the aquaculture industry by NNS are fouling, competition for resources, predation and vectoring of disease and parasites. These species are estimated to cost the aquaculture industry £7.1 million per annum, although it was highlighted that this is probably an underestimate as native and NNS are not distinguished during pest management operations. Moreover, non-native parasites known to have caused severe economic impact to the oyster (Brown et al. 2006) and eel fisheries (Kennedy and Fitch 1990) (i.e., *Bonamia ostreae* and *Anguillicola crassus*, respectively) were not included in this study (Williams *et al.*, 2010).

A number of NNS are currently found in British waters that may threaten the economic development of the UK aquaculture industry including; Veined rapa whelk *Rapana venosa*, which predates on oysters and mussels; the Slipper limpet *Crepidula fornicata*, which can significantly increase the harvesting costs for seabed grown mussels and oysters; Japanese wireweed *Sargassum muticum*, which can overgrow oyster trestles and clog cage netting, the ascidians *Styela clava* and *Didemnum vexillum,* which can overgrow mussel lines and phytoplankton, including the harmful dinoflagellate *Karenia mikimotoi*, which has led to numerous fish kills worldwide and is perceived to be increasingly prevalent in Scottish waters (Callaway *et al.*, 2012, Mineur *et al.*, 2012, Minchin *et al.*, 2013).

**CASE STUDY: CARPET SEA SQUIRT**

The Carpet sea squirt, *D. vexillum* (Figure 1) is particularly problematic for cultured bivalves and cultivation gear for both shellfish and finfish farms (Coutts and Forrest, 2007, Lambert, 2009) in New Zealand, impeding water exchange, increasing operating costs (Carman and Grunden, 2010) and reducing the reproductive output of bivalves, thus potentially impacting spat collection (Auker, 2010). Sinner and Coutts (2003) undertook a cost-benefit analysis of *D. vexillum* management in Shakespeare Bay, New Zealand and suggested that 10% of the green-lipped mussel lines would be impacted to a point where treatment would be necessary or compete loss occurred, assuming a spread of *D. vexillum* into the Marlborough Sound area. In the UK, significant bottom cultivation of blue mussels *Mytilus edulis* occurs in Welsh waters and a feasibility study into eradication or control of *D. vexillum* suggested a potential 40% coverage of mussel beds by *D. vexillum* and a 25% loss in production due to poor growth or mortality due to smothering (Kleeman, 2009). Likewise in Canada, heavy infestations of ascidians (understood to be *Styela clava*) in aquaculture operations have increased handling and processing costs (Daley and Scavia, 2008) and it is estimated that up to 20% of the market price of shellfish is the cost of labour to clean the produce (GISP, 2008).

*Figure 1. Carpet sea squirt Didemnum vexillum overgrowing mussel line, west coast Scotland, 2009. Photo © C. Beveridge (sams)*

*3.1.2* Commercial Shipping and Recreational Vessels

Williams et al. (2010) estimated that the annual cost of dealing with NNS by the shipping industry and recreational boat owners in GB was £32.8 million and £21.4 million, respectively. Ballast water management was highlighted as a significant cost for the shipping industry, particularly since the adoption of the International Maritime Organisation's (IMO) Ballast Water Management Convention in 2004 (Williams *et al.*, 2010), which was specifically introduced to prevent the spread of harmful aquatic species from one region to another. Once ratified, all ships of 400 gross tonnes or more will be required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. All ships will also have to carry a ballast water record book and an international ballast water management certificate (IMO, 2013).

Hull fouling is also considered to have a significant economic impact for both commercial and recreational vessel owners (Figure 2). Williams et al. (2010) estimated that 50% of the costs associated with this type of fouling (i.e., hull cleaning and anti-fouling application) could be attributed to NNS. In 2011, voluntary guidelines were introduced by the IMO for the control and management of ships' and recreational vessels' biofouling to minimise the transfer of invasive aquatic species (IMO, 2011), again including the production of a 'biofouling' management plan and completion of a biofouling record book. Albeit, voluntary, if made mandatory in the future, as in the case of the Ballast Water Management Convention, this is likely to impose significant additional costs on the industry (IMO, 2012).

*Figure 2. Bio-fouling on recreational vessel © E. Cook, SAMS*

### *3.1.3* Inshore capture fisheries

The full economic cost of the impact that NNS are having on the UK economy have not been calculated, however, in the USA, the impact of the Carpet sea squirt *D. vexillum* on inshore fisheries was considered significant, including the loss of earnings through the overgrowth of fish spawning grounds (Valentine *et al.*, 2007), the prevention of demersal fish species foraging on benthic prey (USGS, 2010) and the competitive exclusion of native species (Gittenberger, 2007).

NNS can also affect capture fisheries by fouling gear (namely creels or pots), smothering seabed habitats associated with commercially important shellfish species and increasing the vulnerability to predation of the shellfish species themselves (Dijkstra and Nolan, 2011). In New England, USA, the expansion of *D. vexillum* into valuable sea scallop fishing grounds has led to concern about the impact of this tunicate on economically important sea scallop habitat (Valentine *et al.*, 2007).

### *3.1.4* Power stations and offshore generation

In the UK, the Zebra mussel *Dreissena polymorpha* has been calculated as costing the water and power generation industry £551,400 per annum (Oreska and Aldridge, 2011). Costly modifications have been required by power stations to trap the mussels prior to entry into the water intake pipes and chlorination is typically used to remove any mussels that have settled in the pipes (Williams *et al.*, 2010). Albeit a freshwater species, this species demonstrates the potential economic costs that fouling NNS could cause to offshore power generation industries, in particular tidal current and wave renewable energy devices which will be vulnerable to colonisation by fouling species (Mineur *et al.*, 2012, Miller *et al.*, 2013).

## 3.2 Environmental Impacts

### *3.2.1* Habitat modification

The accidental or intentional introduction of NNS can cause significant changes to ecosystems (Ruesink *et al.*, 2006). For example, the Pacific oyster *Crassostrea gigas* was intentionally introduced for aquaculture purposes to the USA and Europe in 1928 and 1950s respectively. With increasing seawater temperatures, this oyster is now able to naturally recruit to uncultivated regions and can form dense intertidal hummocks of shell and live oysters (Herbert *et al.*, 2012). *Crassostrea gigas* has been found to substantially modify a habitat to provide additional structures for other species, however, it can also cause significant changes to the underlying sediment (Ruesink *et al.*, 2006). The Mediterranean mussel *Mytlius galloprovincialis* was also accidentally introduced to South Africa in the late 1970s. This species is now the dominant intertidal mussel on the west coast, where it has considerably modified the natural community composition (Robinson *et al.*, 2005). Finally the Carpet sea squirt *Didemnum vexillum* has been shown to have a negative impact on species diversity and abundance on the Georges Bank, northeast USA (Lengyel *et al.*, 2009) and in The Netherlands (Gittenberger, 2007).

#### *3.2.2* Ecosystem functioning

Ecosystem services are a set of ecosystem functions, many of which are critical to human survival (e.g., climate regulation, air purification and nutrient recycling (Kremen, 2005). Ecosystem functioning is intrinsically linked to biodiversity and thus, changes in biodiversity can cause significant changes to the functioning of a particular environment or system. Very few studies have clearly addressed this question, however, Levin et al. (Levin *et al.*, 2006) showed that invasion by the non-native *Spartina* hybrid in the USA, caused a shift in the system from an algae based to a predominantly detritus-based system. Furthermore, it changed the hydrodynamic regime in the estuary, which led to reduced survivorship of key species, which supported the migratory shorebirds in the region (Levin *et al.*, 2006).

#### *3.2.3* Impact on native species

There are many cases of intentional movements of stock introducing NNS, including parasites and disease. For example, the trematode *Gyrodactylus salaris* was transported with Atlantic salmon *Salmo salar* from Swedish hatcheries to Norway and this resulted in serious salmon mortalities in the native salmon populations in the recipient region (Johnsen and Jensen, 1991). The importation of the Japanese eel *Anguilla japonica* for cultivation trials in Europe also released a non-native nematode, which has gone on to cause significant damage to other eel species, such as the native eel *Anguilla anguilla* (Kennedy and Fitch, 1990). In addition, the non-native copepod *Mytilicola orientalis*, a gut parasite of bivalves has been found in Ireland (Holmes and Minchin, 1995), France (Goulletquer *et al.*, 2002), and the Netherlands (Wolff, 2005).

### 3.3 Legal drivers and legislative context

This section is not intended to be a comprehensive review of the complex set of Acts, Directives and Regulations covering NNS in the marine environment. Instead, it focusses on the main legal and regulatory drivers which will convince a site operator or developer that they should prepare a marine biosecurity plan for NNS.

Although there is no is no explicit legal or regulatory requirement for site operators and developers to produce a biosecurity plan for NNS several existing laws and regulations set a strong context for preparing and implementing marine biosecurity plans.

In Scotland, amendments to Section 14 of the Wildlife and Countryside Act in the Wildlife and Natural Environment Act (Scotland) (Scottish Government, 2011) and the accompanying Code of Practice On Non-Native Species (Scottish Government, 2012) have significantly strengthened the law in relation to NNS.

Two further offences have been added to the existing offence of releasing a non-native animal from captivity in the 1981 Act. The new offences which are:

- allowing an animal to escape from captivity outwith its native range, and:
- causing an animal to be in a place outwith its native range.

The ‘causing an animal’ offence can include the accidental transfer and spread of non-native animals that, for example, result from site operations and development work where biosecurity procedures are absent or inadequate.

For plants, a new offence has been created of planting or causing any plant species to grow in the wild outwith its native range. This offence includes situations where poor biosecurity in relation to site operation and development led to the spread of a non-native plant in the wild.

The Scottish offences in relation to non-native plants and animals are ‘strict liability offences’ so knowledge, intention, recklessness or negligence do not have to be proved. A legal defence that all reasonable steps were taken to prevent the offence and that all due diligence was exercised to avoid committing the offence can be made. The Code of Practice on Non-Native Species sets out in broad terms what ‘reasonable steps’ mean in this context and the advice includes (Box 1).

*Box 1. Reasonable steps as set out in the Code of Practice on NNS*

- Adopting a precautionary approach and not carrying out operations which might lead to the spread of NNS until there is a clear understanding of the situation.
- Carrying out risk assessments to understand the risk of spreading a NNS, setting out how to avoid it happening.
- Seeking advice and following good practice.
- Reporting the presence of NNS.

Although the Code stops short of specifying the need for a biosecurity plan many of the main elements of this type of plan are set out as good practice.

The amended Scottish legislation also provides powers to relevant government agencies to offer voluntary Species Control Agreements (SCA) and, if that fails, serve Statutory Species Control Orders (SCO) (Scottish Government, 2012). SCOs are intended for situations where an invasive species is present and must specify which operations should be carried out, who is to carry them out and when they must be carried out. SCOs and Emergency Species Control Orders (ESCO) made more rapidly in acute situations can both operate on the ‘polluter pays’ principle. If government agency staff or their contractors have to carry out the eradication, control or containment work, then the cost of this work can be recovered from the site operator.

Two other significant legal drivers for site operators and developers to develop and implement biosecurity plans are:

The Environmental Liability (Scotland) Regulations (SI 2009/226) (UK Government, 2009a) - these have established a civil law mechanism based upon the 'polluter pays' principle. Under the Regulations, certain operators who cause a risk of 'significant' damage or cause 'significant' damage to land, water or biodiversity will have a duty to avert such damage occurring or, where damage does occur, a duty to reinstate the environment.

The Biodiversity Duty – All public bodies have a duty under the *Nature Conservation (Scotland) Act 2004 (*UK Government, 2004*)* to 'further the conservation of biodiversity' as they carry out their work. The revised Scottish Biodiversity Strategy document *2020 Challenge for Scotland's Biodiversity - A Strategy for the conservation and enhancement of biodiversity in Scotland* provides a clearer view of the types of activities that should be considered with regard to that duty (Scottish Government, 2013). In relation to combating the threat of NNS, the 2020 document states “we must work to prevent their establishment and spread, identify their means and routes for invasion, raise awareness of the need for biosecurity, and implement legislation and international agreements". There is therefore a strong incentive for public bodies which operate and manage marine sites to consider a biosecurity plan for their operations.

The Aquatic Animal Health (Scotland) Regulations 2009 (UK Government, 2009b) and the equivalent Regulation for England and Wales implement the EU Council Directive 2006/88/EC (EU, 2006) on animal health requirements for aquaculture animals and products. The Regulations require Aquaculture Production Businesses (APBs), including shellfish and finfish farmers, as a condition of their authorisation, to produce and implement a *Biosecurity Measures Plan* for the operation of the site to restrict the spread of disease. Although not intended to cover NNS, the plan preparation process as well as the actions and precautions specified by the plan for diseases, also act to prevent the introduction and spread of NNS.

The Marine Strategy Framework Directive (EU, 2008) and the Water Framework Directive (EU, 2000) set a wider strategic and operational context for preventing the spread of NNS and their control, which feeds down to the operator and site level, but do act as direct drivers for the preparation of biosecurity plans.

A draft EU Regulation on Invasive Alien Species (EU, 2013) has recently been published. The draft regulation does not use the "biosecurity" at any point and it does not appear in the glossary. This may be to avoid confusion with biosecurity for pathogens. The components of marine biosecurity planning (risk assessment, pathway recognition, pathway management, prevention, containment, early detection) are, however, all mentioned and discussed. The draft regulation proposes a list of Species of Union Concern (SUC). Growing, breeding, selling or intentionally releasing these species will be banned across the EU. Member states will also list Invasive Alien species of Member State Concern for similar bans that would apply only within that Member State.

Action plans on the pathways of invasive alien species (i.e. INNS) are required by the draft Regulation and this has clear implications for marine biosecurity. Member States will be required to:

- analyse pathways of unintentional introduction and spread and
- identify "priority pathways" based on the volume or impact of the species moved by that pathway.

The plan will include awareness raising measures, regulatory measures to minimise contamination and transport, as well as, border checks. The plan must be reviewed regularly; the draft Regulation sets a review period of four years.

At this stage, with negotiations on-going, it is not easy to predict what the final Regulation will do in terms of driving the need for biosecurity at a site and operation level.

## 4. BIOSECURITY PLANNING FOR SITE / OPERATIONS

### 4.1 Biosecurity – a review of existing NNS plans

Biosecurity plans for NNS have been prepared in a variety of formats and range from countrywide strategic documents to plans for small sites and individual operations. Biosecurity, as a term applied to NNS to describe measures to prevent their introduction and stop their spread, is still relatively new. Previously, it had been more widely applied to plans for preventing the spread of pathogens. Consequently, plans which have a range of titles including Invasive Species Action Plans, Non-native Species Plans, Invasive Species management Plans or Species Response Plans may well be, at least in part, biosecurity plans for NNS.

Some NNS plans, which do include 'biosecurity' in their title, include actions on long-term strategic control and eradication. An alternative and perhaps more widely accepted view, is that measures contained within these plans apply to dealing with well-established NNS and not part of the wider 'prevention' measures which are bundled together as biosecurity. This distinction is particularly relevant to the marine sector where long-term strategic control and eradication are almost always technically impossible or not viable economically.

Biosecurity plans at the site or operations level usually contain the following sections, or combinations of them:

- Site Description
- Site Survey
- Analysis of activities/operations
- Early Detection and Surveillance
- Pathway recognition/analysis/management
- Risk assessment/analysis/management
- Biosecurity actions to manage risk
- Site monitoring
- Containment
- Rapid response and rapid eradication plans
- Individual species accounts
- Contingency planning
- Sign-off and Responsibilities
- Implementation and review

Table 1 sets out the range of different types of biosecurity plans for invasive NNS and gives examples of completed plans and current guidance for plan preparation. Plans at the national, regional and catchment level are more numerous. By contrast, plans at the operation or site level are rarer. National and catchment plan preparation has been driven by the policies of central government, agencies and NGOs. At a site and operation level there is currently no explicit regulatory requirement for biosecurity planning for INNS, which encapsulates the need for due diligence into planning policies or other environmental authorisations. A range of biosecurity guidance and Codes of Practice exist, but without a requirement for a biosecurity plan for NNS ensuring sign-off and accountability at an operational level there is no clear means to ensure guidance and Codes are followed.

*Table 1. Biosecurity plans for invasive non-native species by category*

| Biosecurity Plan Type | Typical Scope/Content | Examples of plans | Examples of Planning Guidance |
|---|---|---|---|
| National Plans | Strategic plans at a country or regional scale with actions specified at a sector level. | GB Framework Strategy (GBNNSS, 2008) New Zealand Biosecurity Management Action Plan (Ministry for Primary Industries, 2012) | A Toolkit for Developing Legal and Institutional Frameworks for Invasive Alien Species (Shine, 2008) |
| Sector Plans | Strategic Plans covering an industry or activity across at a country-wide scale | Biosecurity plan for Sea Angling and bait (Ward *et al.*, 2013) | Oil and Gas Industry –Guidance for Prevention and Management (OGP/IPIECA, 2010) |
| Area plans | Plans for a defined geographic area, often a catchment, estuary or coastal zone | Clyde Biosecurity Plan (Mills, 2012), Solway Biosecurity Plan (Solway Firth Partnership, 2013) | None encountered – new plans tend to use previous examples as a template. |
| Site plans | Plans to manage the risk of a range of ongoing and long term activities within a described site or facility. These plans may contain sections dealing with contingency and rapid response to a range of species threats | Pathogen Biosecurity Measures Plans shellfish and finfish | Cefas Biosecurity Measures Plan – Guidance for Shellfish farmers (CEFAS, 2009b)<br>Invasive species management for the construction industry(CIRIA, 2008) |
| Operation plans | Plans covering a defined short or medium term operation. | Planning by the Environment Agency and Port of London Authority for the influx of recreational boats to the Thames for the 2012 Olympics | Risk assessment protocol system for the transfer of mussel seed (Kelly and Maguire, 2009)<br>Event Biosecurity Support Pack (Cumbria Freshwater Invasive Non-Native Species Initiative, 2013) |
| Species Plans | Plans for the exclusion or containment of an individual species. This plan category also includes rapid response and contingency plans for single species | UK wide contingency planning for the salmon parasite *Gyrodactylus salaris* | Asian Hornet Response Plan (Anon, 2012) |

### 4.2 Biosecurity planning guidance

Few documents exist which provide guidance on how to plan biosecurity at a site or operation level and none which are specific to marinas, boatyards, slipways or shoreline developments.

- The Ciria manual (CIRIA, 2008) for the construction industry and infrastructure managers is one notable exception to this and includes much helpful guidance on survey, risk assessment, risk management and preventing invasion.
- The Cefas guidance (CEFAS, 2009b) for shellfish and finfish farmers, although restricted to pathogenic organisms provides a good model of how plan guidance can be presented in a simple and non-technical form.
- The Event Biosecurity Support Pack (Cumbria Freshwater Invasive Non-Native Species Initiative, 2013) gives good guidance on how to plan biosecurity for water-based recreation events

## 5. PATHWAY ANALYSIS

The need to understand the pathways of invasion (i.e., route between the source region and the region of release) and the vectors (i.e., specific means by which an invasive species moves within a particular pathway, for example shipping and recreational boating, intentional stock movements or anthropogenic flotsam), which transport NNS from one region to another is paramount in preparing a marine biosecurity plan. In the UK, a recent study found that the majority of NNS introduced to British waters since the 1850s originated from the North Pacific, particularly the north-west (e.g., Asia and Japan) followed by the North-west Atlantic (e.g., east coast of the USA) (Minchin *et al.*, 2013). This result is consistent with the findings of previous studies (Eno *et al.*, 1997, Minchin and Eno, 2002), suggesting that NNS from regions with similar temperature regimes to Britain are more likely to become established and widespread, as species would be physiologically adapted to the environmental conditions experienced in the recipient waters. Of course, there are always species which are able to tolerate a wide range of environmental conditions (e.g., Zebra mussel *D. polymorpha* and the tubeworm *Ficopomatus enigmaticus*), enabling them to survive in conditions outside the conditions typically experienced in their native range (Minchin *et al.*, 2013).

There are also a number of species where their introduction into British waters was likely to be a result of secondary spread (e.g., coastal or local shipping, fisheries, stock movements, or by natural means). For example, the Japanese skeleton shrimp *Caprella mutica* (Ashton *et al.*, 2008, Cook *et al.*, 2007) and the non-native bryozoan *Tricellaria inopinata* (Cook *et al.*, 2013b), were first recorded in mainland Europe prior to their appearance in the UK. Secondary spread via hull fouling and aquaculture activities is likely to have contributed to the rapid expansion of their distribution throughout the region.

Major vectors currently identified for marine NNS include vessels (ballast water and hull fouling – particularly slow moving vessels, such as barges, semi-submersible oil rigs or vessels berthed in one place over long periods); aquaculture activities, including intentional stock transfer and unintentional introductions via escapes and hitch-hikers (e.g., Carlton and Geller, 1993, Mooney and Cleland, 2001, Streftaris *et al.*, 2005, Pearce *et al.*, 2012, Aquenal Pty Ltd, 2009); and canals, such as the Suez Canal, which are a major conduit for the spread of NNS between separate biogeographical regions (Galil, 2000). In British waters, where only a single vector was identified, vessels and aquaculture activities were considered responsible for at least 47% and 30% of NNS introductions, respectively (Minchin *et al.*, 2013). Where the mode of arrival could have been via more than one vector, then vessels and aquaculture activities were still cited as major vectors along with other modes of transmission. Natural spread of NNS, can also be an important vector for the dispersal of certain species (e.g., Japanese wireweed *Sargassum muticum*) (Figure 3) (Harries *et al.*, 2007, Giesler, 2013) and non-native plankton species, although this vector has received significantly less attention to date than ballast water and hull fouling, with the exception of monitoring for the non-native phytoplankton *Karenia mikimotoi* (Davidson *et al.*, 2009).

*Figure 3. Sargassum muticum collected in Campbeltown, Mull of Kintyre © E. Cook, SAMS*

The majority of studies to date have identified the high risk pathways for a particular geographical region (2000), rather than on a site or operation level, based on literature reviews and expert knowledge. The recent work in the UK by CEFAS in identifying high risk pathways for the introduction and establishment of marine NNS across the UK and Ireland demonstrates the application of pathway analysis at this wider scale (Minchin and Eno, 2002). It is critical, however, that the pathways and vectors are identified and prioritised, based on their potential for transferring NNS, at a site and operation level, so that the high risk pathways can be reduced or intercepted to remove any NNS.

**Summary**

- NNS from regions with similar temperature regimes to Britain are more likely to become established and widespread, as species would be physiologically adapted to the environmental conditions experienced in the recipient waters
- Vessels and aquaculture activities are considered to be responsible for the largest proportion of NNS introductions to date

### 5.1 Risk Analysis

Risk is the likelihood of a harmful event (or hazard) occurring, multiplied by the magnitude of the consequences if the event occurs (e.g., economic loss, ecosystem damage etc.) and is a key component in biosecurity planning. Conventional risk analysis is typically involves four stages and includes measures of uncertainty in its results;

1. **Likelihood of Introduction** – Based on intensity of pathways/ vectors previously identified and previous knowledge on major pathways/ vectors of introduction for particular groups of NNS, if known.
2. **Likelihood of Establishment and Spread** – Based on environmental parameters and suitability of available substrate in the recipient environment and natural and anthropogenic means of dispersal.
3. **Potential Impacts –** Based on the potential harm that the NNS could cause in the recipient environment.
4. **Risk calculation and evaluation**

Risk can be estimated using a variety of methods, from inexpensive qualitative assessments, which can produce subjective results to more expensive semi- and qualitative methods, which focus on specific routes or taxa with known harmful characteristics and require detailed information that does not always exist (Hilliard, 2005). The following sections highlight some of the problems experienced in preforming these assessments.

### 5.2 Likelihood of introduction

**The greatest 'likelihood of introduction' or highest risk is typically where the vector has arrived from another ocean basin in the northern hemisphere (Minchin *et al.*, 2013) or from another port/ aquaculture site where NNS have been previously identified (ICES, 2005, Minchin *et al.*, 2005) (see Section 4.1).**

For example, in the case of the later, the movement of mussel 'seed' from an area known to contain the slipper limpet *Crepidula fornicata,* resulted in the transfer of this non-native limpet in to an important seabed lay mussel producing region of North Wales (Sewell *et al.*, 2008). A major issue with this, however, is the lack of baseline data throughout Europe to provide reliable evidence of the presence and distribution of NNS for this analysis (David *et al.*, 2013). At present, only 10 European ports out of 1200 from twenty-two coastal Member States have been surveyed and most of these have been comprised of a single survey, which provides an insufficient basis for pathway risk analysis (David *et al.*, 2013).

It has also been suggested that regions with experience large volumes of shipping (e.g., cross-Channel ferries, commercial container vessels), recreational vessels and importation of stock for aquaculture purposes, over many years, are likely to be high risk sites for NNS introductions (2013). However, a recent study of 16 large bays in the USA, found that there was no relationship between the quantity and frequency of ballast water discharges from foreign vessels and the number of NNS (Ruiz *et al.*, 2013). The volume of ballast water discharges was, therefore, not considered in a recent risk assessment process for ballast water management (David *et al.*, 2013) and although not proven for hull fouling or aquaculture activities, it should be considered that even small quantities of NNS could result in a successful introduction.

### 5.3 Likelihood of establishment & subsequent spread

**The greatest 'likelihood of establishment and subsequent spread' of a NNS in a recipient environment will be predominantly based upon the environmental characteristics (e.g., temperature, salinity, etc.) and the availability of suitable substrate at a site, if required.**

If environmental conditions are similar to the donor region and suitable substrate is provided, then there is a greater likelihood that a NNS will survive and become established (Cook *et al.*, 2013a, David *et al.*, 2013). In previous risk assessments, based upon 'environmental matching' a variety of environmental variables have been used (Chan *et al.*, 2013, Gollasch and Leppakoski, 1999, Keller *et al.*, 2011). However, due to the general lack of baseline data and life history knowledge for many NNS, a recent study has suggested that salinity is the most 'straight forward' parameter to use in the risk analysis process (David *et al.*, 2013). For example, the likelihood of a marine NNS becoming established in a freshwater environment (<0.5 PSU) is highly unlikely. The likelihood of a NNS surviving does increase, however, as the salinity increases and it has been suggested that as salinity reaches 18 PSU, the likelihood of establishment will increase (David *et al.*, 2013). For example, the Japanese skeleton shrimp *C. mutica*, is typically found in fully marine environments (>30 PSU), but a 100% mortality was found at salinities below 16 PSU (Ashton *et al.*, 2007). There are exceptions though, particularly for brackish water species, such as the Zebra mussel *Dreisenna polymorpha* (Carlton, 1993), and species, such as the Chinese mitten crab *Eriocheir sinensis* which migrates from freshwater to marine to spawn and complete their life-cycle (Clark *et al.*, 1998).

### 5.4 Potential impact

The potential impact from a NNS is considered to be greater if the species has already been shown to have had a deleterious effect on the environment, economy, human health, property or resources in another region in which it has been introduced. If the impact has also been considered 'severe' then this species could be classified as 'high impact' (David *et al.*, 2013). For example, the slipper limpet *C. fornicata* was classified in a risk assessment commissioned by the GB Non Native Species Secretariat, as likely to have a 'massive impact' both economically and environmentally, effecting fisheries and aquaculture, as well as, significantly modifying habitat and out-competing native species (Sewell and Sweet, 2011) (Table 2). The main issue, however, is that over 58 marine and brackish water species are established in British waters (Minchin *et al.*, 2013) and in a recent horizon scanning exercise a further nine marine species were identified as likely to arrive and to pose a high risk to native biodiversity in the UK (Roy *et al.*, in press). Only six GB NNSS risk assessments, however, have been completed to date (Table 2) and many of the NNS either established or likely to arrive in the UK will require identification by recognized experts. In addition, the life history strategies are poorly understood for many NNS, thus increasing the 'uncertainty' in the risk assessment process.

*Table 2. GB NNSS commissioned risk assessments for marine and brackish water species (completed).*

| Scientific Name | Common Name | Risk | Uncertainty | Reference |
|---|---|---|---|---|
| *Caprella mutica* | Japanese Skeleton Shrimp | Medium | Medium | (Cook, 2011) |
| *Crassostrea gigas* | Pacific Oyster | Medium | Medium | (Anon, 2010) |
| *Crepidula fornicata* | Slipper Limpet | High | Medium | (Sewell and Sweet, 2011) |
| *Didemnum vexillum* | Carpet Sea squirt | High | - | (Anon, 2011a) |
| *Eriochier sinensis* | Chinese mitten crab | High | Low | (Anon, 2011b) |
| *Rapana venosa* | Rapa Whelk | High | Medium | (Sweet and Sewell, 2011a) |
| *Ruditapes philippinarum* | Manila Clam | Low | Medium | (Sweet and Sewell, 2011b) |
| *Sargassum muticum* | Wireweed | Medium | Low | (Anon, 2011c) |

Methods for understanding the risks of NNS introduction and establishment are becoming more refined all the time (Carlton and Geller, 1993) as critical data gaps are filled via research and documented evidence. Earlier work assessing the risk of NNS in aquaculture at a European scale is a good example of this (Mooney and Cleland, 2001). However, with so many 'unknowns' and the difficultly in determining the potential 'harmfulness' of a particular species it has been suggested that a precautionary approach be adopted, treating all known and suspected NNS as potentially harmful and equally unwanted (Hewitt and Hayes, 2002).

One particular method of assessment, Hazard Analysis and Critical Control Point (HACCP) planning, however, has been produced that enables the production of biosecurity plans for specific activities and has been applied to managing the risk of spreading NNS between water bodies (Britton *et al.*, 2011).

HACCP was originally created for the food standard industry (Britton *et al.*, 2011). This procedure takes each activity on a site or within a wider operation, looks at it in detail and breaks it down into a series of tasks. At the heart of HACCP is the precautionary principle, so the risk calculation method which follows as the next stage in the process does not attempt to ascribe a value or rating to the severity or the potential impacts. The likelihood of invasion is considered, but the emphasis is not on the overall risk but on developing control measures for each activity to prevent the spread of NNS and defining the Critical Control Point when they are best applied.

These control measures are actions that can be used to reduce the probability that NNS may be introduced to a new area. To ensure that such control measures are functioning as intended, it is important to attach a set of measurable prescribed ranges, limits and/or criteria for control measures and detail corrective actions to use to safeguard against any mishaps.

The development of effective control measures, however, does require the pooling of resources from a number of sources. Perhaps the most important of these are informed personnel with the practical knowledge of the process involved in the activity, along with any constraints imposed. Knowledge of existing preventative measures required by law is also essential to include in control measures listed. A degree of specialist knowledge of potential non-target species is also required. Such knowledge might include the range of certain conditions that undesirable species can tolerate. Applying this type of information to the control measures included as part of the biosecurity plan greatly strengthens its effectiveness.

HACCP has already been used as the basis for pathogen biosecurity and INNS in mariculture (Kelly and Maguire, 2009). It could be simplified and combined with pathway management to become the basis for marine biosecurity planning at a site and operation level.

**The precautionary approach fits well with the marine environment where the information on potential invaders and the impact which they may have is often sparse and the focus on activities and tasks could fit well with the routine operations of marinas, slipways and boatyards.**

## 6. CONTINGENCY AND RAPID RESPONSE PLANS

The need to be prepared to act rapidly if planned biosecurity measures for INNS fail has been widely acknowledged and is included in many biosecurity plans. Rapid response and contingency plan format draw, at least in part, on experience from the response to pathogen threats (such as foot and mouth disease and avian influenza) and environmental threats such as oil spill planning. In practice, most biosecurity plans do not have a separate rapid response plan and the rapid response to the discovery of priority INNS is a set of logical actions which get under way immediately. Planning the activity only follows at a later stage if the process starts to stretch into the longer term.

**Well known and documented rapid responses to marine NNS threats include:**

- The rapid eradication of Slipper limpet (*Crepidula fornicata*) introduced with imported mussel spat in the Menai Straits (Wilson and Smith, 2008)
- The successful eradication of the black-striped mussel (*Mytilopus sallei*) in three marinas in Darwin Australia at a cost of $AUS 2.2 million (Bax *et al.*, 2002)
- The highly invasive seaweed *Caulerpa taxifolia* was eradicated from a lagoon on the coast of California (Anderson, 2005)
- The response by the Countryside Council for Wales (now Natural Resources Wales) to the discovery of carpet sea-squirt (*Didemnum vexillum*) in Holyhead harbor (Holt and Cordingley, 2011)

An example of a species level rapid response plan prepared in advance of the arrival of a highly invasive species is the Asian hornet Response Plan (Anon, 2012). This species occurs in France within relatively easy dispersal distance of the English Coast across the Channel. For marine invasions, it may be more difficult to predict the species likely to invade because of the long distances of marine pathways and more general rapid response plans covering a range of species will be more appropriate. At the national level, a Rapid Response Framework for NNS in Scotland (http://www.snh.gov.uk/docs/B1112876.pdf) sets out the government and agency response to a newly-discovered high risk species. Guidance for contingency planning at a site/operation level is scarce but the Cefas biosecurity measures guidance provides a template (CEFAS, 2009b).

## 7. MEASURING THE SUCCESS OF BIOSECURITY PLANS

Direct measurements of the success of biosecurity plans in preventing the introduction of NNS are extremely difficult to gather, especially at the site and operation level. In all but a very few cases, it may be not be possible to know with certainty if measures such as cleaning slow-moving vessels before they reach a new location have prevented the spread of NNS. The absence of any new NNS arriving at a site or during an operation can, however, be taken as an indication of success.

The failure of plans to halt the introduction and spread of NNS is more likely to provide a direct measure. This example of plan failure also reveals a measurable success.

American Signal Crayfish were discovered in a pool at the Ballachulish Quarry during routine monitoring by Highland Council Rangers in July 2011 (Baum and Ballantyne, 2012). The Lochaber Biosecurity Plan drawn up by the Lochaber Fisheries Trust in 2009 (Lochaber Fisheries Trust Ltd, 2009) recognises signal crayfish as a species currently absent from the plan area, but with a high risk of introduction. The Lochaber Plan included a Biosecurity Management Strategy with provision for early detection, surveillance, monitoring and rapid response. Signal crayfish are listed in the plan as a High Priority Local Response, however, no site-specific biosecurity measures were in place for this quarry before the discovery of signal crayfish. The plan aided the mounting of a local rapid response and the pool was treated with Pyblast, a specialist biocide. Subsequent monitoring has not detected any crayfish still present in the pool. Whilst the Plan failed to prevent the invasion, it did help to ensure the success of the rapid response.

Many other examples of successful rapid responses such as the slipper limpet *C. fornicata* eradication in the Menai Straight and the removal of Zebra mussel *D. polymorpha* in the Forth and Clyde Canal took place without biosecurity plans in place at the time.

Other potential methods to measure the success or failure of biosecurity plans include:

- implementation  of plan measures and actions;
- monitoring compliance with planned measures; and
- recording information in a biosecurity plan log.

## 8. PRACTICAL MARINE BIOSECURITY MEASURES

Various practical measures have been undertaken in the past to reduce the likelihood of a NNS being introduced or spreading from a site of introduction. These measures have predominantly used freshwater as either a preventative measure or as a control (i.e., through washing of structures). However, aerial exposure, chemicals, smothering and mechanical based measures have also been used, dependent on the particular activity.

### 8.1 Freshwater Source

**The proximity of the site/ operation to a freshwater source can significantly influence the likelihood of the successful establishment of a marine NNS.**

Studies have shown that many marine NNS have a broad tolerance to temperature, but will only tolerate a much smaller salinity range (Gollasch, 2006). For example, the Japanese skeleton shrimp *C. mutica* has been found to tolerate temperatures ranging from 2 – 20$^{o}$C, whereas high mortalities are experienced when salinities fall to 16 PSU (Boos *et al.*, 2011). It is, therefore, likely that a large proportion of marine NNS associated with shipping (i.e., transported either in ballast water or as hull fouling), will be excluded from sites with high freshwater input (Boos *et al.*, 2011). In a recent survey of 88 UK marinas which contained NNS, high freshwater input into the marina basin was highlighted as a significant feature in reducing the likelihood of NNS establishment. More specifically marinas located within 20m of a freshwater source had significantly fewer NNS than those sited over 1km away (Foster, 2013).

### 8.2 Removal & Prevention of Biofouling

Non-native species are highly opportunistic and robust, surviving for extended periods of time in the hostile environment of a ballast tank (Gollasch *et al.*, 2002) or out-competing native species in highly disturbed environments on a wide variety of artificial structures, as native species are often poorly adapted to the altered physical and biological environment both on and around these man-made objects (Bax *et al.*, 2003). Ballast water, vessel hulls, floating pontoons, navigation buoys, fin- and shell-fish cultivation infrastructure are particularly prone to inoculation by NNS (Connell, 2000), as they all provide a unique habitat for a variety of reasons, including isolation from surrounding waters or seabed, novel materials (e.g. plastics) and shading (Mineur *et al.*, 2012). The Japanese Skeleton shrimp *Caprella mutica* for instance, occurs in exceptionally high densities on artificial structures such as pontoons and aquaculture infrastructures, which are raised from the seabed where they are able to avoid benthic predators (Boos *et al.*, 2011). The likelihood of the successful establishment of a NNS, therefore, will be significantly increased by a reduction in the duration of the passage time or the presence of artificial structures.

**Any design features or maintenance practices that prevent the survival of NNS in ballast water and the accumulation of bio-fouling or can remove fouling from these artificial structures, without causing unintentional dispersal of the NNS, would reduce the risk of NNS establishment and spread.**

#### *8.2.1* Aerial Exposure

Aerial exposure is a practical measure that has been shown to successfully remove biofouling, including NNS from a wide variety of artificial structures for many years (Cook *et al.*, 2012). Novel designs, such as rotating pontoon floats are currently being trialed in North Wales, which would allow surfaces exposed above the water line to be air dried in sections for prolonged periods, thus killing the any fouling organisms attached to the floats (Holt and Cordingley, 2011). Locking pontoons are also in the conceptual phase. These could be ‘locked’ at the top of high tide, exposing the underside of the pontoon surface to the air when the tide drops (Holt and Cordingley, 2011). In addition, modular structures, which can easily be removed for air drying would also provide a practical solution for reducing the risk of NNS establishment.

### *8.2.2* Jet washing

Artificial structures that can be removed from the water, such as vessels, pontoon floats, navigation buoys and aquaculture infrastructure can be jet washed, preferably with fresh water to remove any biofouling. To minimise the likelihood of spreading NNS, any washing must be done in an appropriate enclosed area where there is no risk of runoff reaching the sea and that all debris is safely disposed of according to guidelines for biological waste. It is paramount that any washing is done on land and that the ‘in-water’ cleaning of anything beyond a light algal coating on the structures is discouraged, as certain NNS damaged by physical abrasion may be induced to spawn, while others can survive being dislodged or broken into fragments (Floerl *et al.*, 2005, Harries *et al.*, 2007, Nimmo *et al.*, 2012).

It is particularly important though to minimise the time and cost implications of out-of-water cleaning procedures. For recreational boat owners, boat hoists, such as the ‘Sealift2’ are able to lift and clean between 10 and 15 boats per day, upto 65ft and 50 tons (Sealift2, 2013) (Figure 4; left). Other designs under development include a wet-dock quarantine which a vessel could enter, have its hull treated with chemicals, and then depart without leaving the water (Holt and Cordingley, 2011). Both systems incorporate facilities to contain the waste water and any chemicals for appropriate disposal on land.


*Figure 4. Sealift2 in operation in Haslar marina, Gosport (www.sealift2.com) (left), Versadock at London boat show 2013 (www.versadock.com) (right).*

In addition, facilities which keep vessels and equipment out of the water until they are needed would reduce the likelihood of NNS establishing on the structures. Although this is not practical with large structures, systems such as Sunstream boat lifts for power boats and the ‘DrySail™ System’ by VersaDock for keel boats (Figure 4; right) are currently used to dry dock individual boats quickly and efficiently (Corp, 2013, Versadock, 2013).

### *8.2.3* Chemical treatments

Chemical treatments, such as biocides, chlorine, ozone, hydrogen peroxide, chlorine dioxide, acetic acid, etc. have been used to directly and indirectly treat for NNS. For example, a 'BioBullet' in which the biocide is encapsulated within a particle that is ingested by the NNS has been successful at eradicating the Zebra mussel *D. polymorpha* and the sea squirt *D. vexillum* (Aldridge *et al.*, 2006, Laing *et al.*, 2010) from enclosed environments. Chemical treatments have also been used to indirectly eradicate NNS, either via addition to ballast water or by the spraying or dipping of aquaculture infrastructure and stock (Denny, 2008, Locke *et al.*, 2009). Dipping seed mussels, coated with a non-native sea squirt *Didemnum* spp., in a 0.5% solution of bleach for 2 min was a 100% effective method of treatment for the invasive sea squirt and it left the mussels relatively unaffected (Denny, 2008). Trials in New Zealand, also found that acetic acid sprayed over a colonial sea squirt *Eudistoma elongatum*, was particularly effective at removing the sea squirt from oyster racks exposed at low tide. Spraying or immersion of infested structures with a saturated solution of hydrated lime (calcium hydroxide) or 5% acetic acid was also effective against the invasive solitary tunicate *Styela clava* in Prince Edward Island, Canada, which grows in dense aggregations on mussel lines (*Mytilus edulis*) and oyster racks (*Crassostrea virginica*) (Locke *et al.*, 2009). The dipping of dredged oysters, and associated species, in saturated or strong salt solutions is also a cheap, safe and effective treatment for non-native sea squirts and the macroalga *Sargassum muticum* without harming the oysters (NIMPIS, 2002). The main drawback of using certain biocides, however, is their potential effect on non-target organisms within the wider environment (Locke *et al.*, 2009).

### *8.2.4* Enclosure of artificial structures

For structures that are fixed to the seabed, or are unable to be removed from the water for logistical or other reasons, then enclosure with plastic film/bags has been shown to be effective at removing biofouling, including NNS (Coutts and Forrest, 2007, Holt and Cordingley, 2011). The enclosure technique prevents a supply of clean water to the biofouling and smothers it through lack of oxygen. A chemical accelerant has been found to be effective at reducing the application time, such as sodium hypochlorite, acetic acid, chlorine or freshwater for the invasive Carpet sea squirt *D. vexillum* (Denny, 2008, Kleeman, 2009, Laing *et al.*, 2010). The freshwater method is considered particularly effective though, since it reduces any risk of spillage and effect on the environment (Laing *et al.*, 2010).

For marina pontoons and other floating structures, such as vessels, specially manufactured plastic bags have been placed around the structures by dive teams and left in situ for a period of time. A detailed description of set-n-forget methodology, with no accelerant, is provided in Box 2. Accelerants, as mentioned above, can be added for structures in particular high demand or requiring rapid treatment. After the accelerant is added covers can be removed after 48 hours, although this depends on the accelerant.

*Box 2. "Set-n-forget" enclosure with tarpaulins or plastic covers (Kleeman, 2009)*

- PVC tarpaulins (see www.allplas.co.uk) could be used as covers to encapsulate pontoons of various sizes (Coutts and Forrest, 2007).
- At least 2 above water personnel would be required to fix the plastic to the smaller pontoons and for the larger pontoons, possibly 4 personnel in addition to two divers would be required to deploy the covers underneath the structures.
- Topside operators would be involved in pulling one side of the cover above the water

line and securing it to the pontoon using either PVC cellotape, ropes or a staple gun.

- Divers would displace as much of the water between the covers and the pontoons as topside operators secured all remaining sides.
- Covers would be removed after one month.
- Defouled material would be released to the surrounding environment to break down naturally or sent to landfill (depending on assessment of risk), while covers would be recycled to treat subsequent pontoons or where damaged, removed to landfill.
- Recycled covers would be used to treat subsequent "sweeps" of pontoons.

For pilings, these structures can also be treated by plastic wrapping, but rather than a bag, a plastic sheet can be wrapped around the piling, overlapping each successive wrap and securing with a joining material such as PVC tape (Fig. 5). Chains and moorings can also be treated by wrapping in plastic and securing with cable ties. In all cases, once the plastic wrapping is removed the defouled material would be released to the surrounding environment to break down naturally or sent to landfill (depending on assessment of risk).

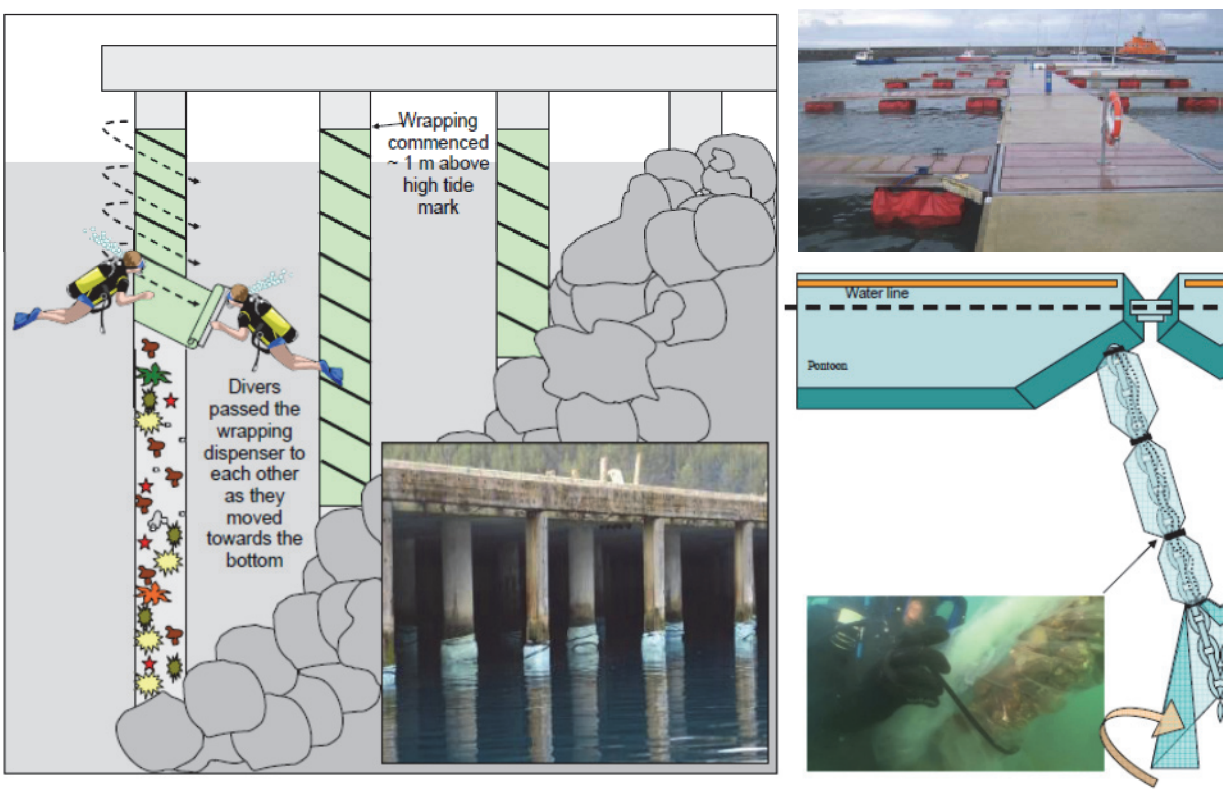


*Figure 5: Left: Schematic diagram of the method used to treat affected wharf piles and a picture of the completed wrapped wharf piles at Waimahara wharf, Shakespeare Bay (Pannel and Coutts, 2007). Right: Eradication in Holyhead Harbour, Wales. Showing wrapped pontoons (top) and cables (bottom) *(Holt and Cordingley, 2011)*

On a much larger scale, this enclosure technique is currently in the developmental phase for semi-submersible oil rigs in New Zealand (Aquenal Pty Ltd, 2009). Concerns regarding the introduction of NNS via this pathway in New Zealand, have led to the demand for fast acting biosecurity treatments for the pontoon floats of these oil rigs and associated supply boats. The technique, once fully developed, will not need on-shore facilities, only two work boats, few additional personnel and may be conducted with or without addition of chemical accelerants. It can be undertaken in sheltered waters en route and potentially during well completion operations before commencing an international relocation. Diver input will be minimal, primarily as observers, and confirmation inspection is only required to confirm complete mortality of all biofouling has been achieved. All contaminated water and dislodged biofouling can be collected for suitable treatment and safe disposal at sea (Figure 6).

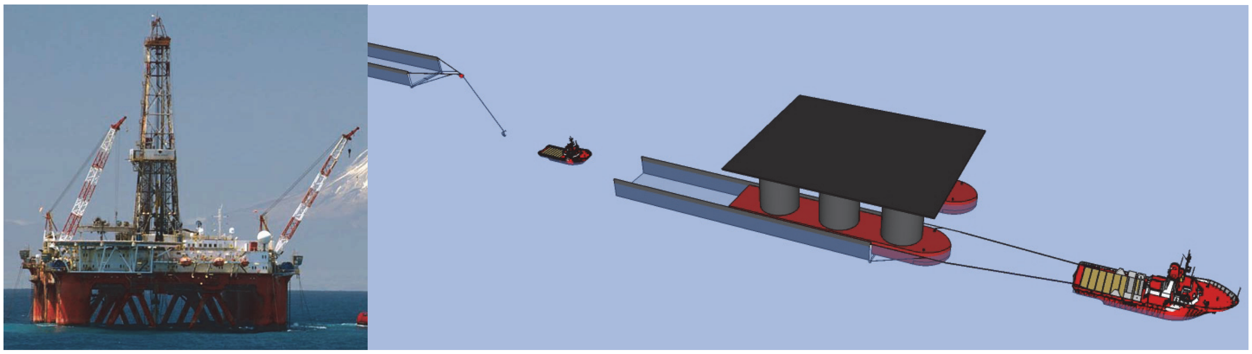

*Figure 6: Left: Semi-submersible oil rig in New Zealand. Right: Schematic diagram of the enclosure treatment on a semi-submersible oil rig using 'improtector' (Aquenal Pty Ltd, 2009).*

*8.2.5* Site Enclosure

For sites, such as harbours, marinas and canal systems which have their own lock gates, then there have been examples where the gates have been closed to allow for the rapid isolation and eradication of NNS. For example, when a non-native bivalve (*Mytilopsis* sp.) was identified in three Australian marinas, all the sites were quarantined by closing their lock gates and treated rapidly using chemicals, allowing the invasive species to be eradicated before it became established in a more open environment (Bax *et al.*, 2002). This follows a similar procedure used to successfully eradicate fresh and brackish water NNS from enclosed bodies of water, such as flooded quarries, reservoirs and cooling pipes (Aldridge *et al.*, 2006, Sandodden and Johnsen, 2010). As illustrated by the £4.2 million project at Bury Marina, Wales, although it is a costly process it is also possible to adapt existing enclosed harbours and marinas to have lock gates (Maritime Journal, 2002).

*8.2.6* Mechanical Clearance

Filtration is the most commonly used treatment for the removal of NNS from ballast water and it can be accomplished during ballasting operations using a shipboard filtration system. The physical separation and removal of organisms can be undertaken either whilst loading ballast water or during the voyage. Cyclonic separation can also be used. Depending on the design and application, the hydrocyclones require less pump pressure than screen filters and allow separation of sediments and other suspended solids to approximately 20μm (Tsolaki and Diamadopoulos, 2009). A combination of filtration and cyclonic separation have been shown to be over 90% effective at removing micro- and macro-zooplankton from the ballast water. However, phytoplankton removal was only 30% effective (Cangelosi *et al.*, 2001).

Following the unintentional introduction of the Slipper limpet *C. fornicata* to the Menai Strait, north Wales with seed mussels from a site in the English Channel in 2006, a successful eradication of this species was undertaken. This procedure involved; the removal of the mussel lay and as much of the associated material as practicable by dredgers, followed by the smothering of any remaining *C. fornicata* in the affected area, with a dense layer of mussels sourced from an unaffected area. As this species is unable to either burrow or reposition themselves once covered, it was highly unlikely that they would survive the smothering. Subsequent monitoring surveys have since found no sign of live limpets (Wilson and Smith, 2008).

The mussel industry in New Zealand has also found that the mechanical stripping, grading and re-stocking process that occurs between 6–12 months in the growth cycle is sufficient to control the growth of fouling organisms, including invasive tunicates. Occasionally, this process has had to be repeated later on in the cycle if a NNS is particularly abundant, but farms are generally reluctant to do this due to cost and difficulties in getting the larger mussels to re-attach securely to the lines (B. Forrest, pers. comm.). In Ireland, the rope-grown mussel industry have also successfully conducted a removal programme during the grading and harvesting process, when small quantities of the invasive sea squirt *D. vexillum* was found on the mussel ropes (Laing *et al.*, 2010).

#### *8.2.7* Anti-fouling Systems

Once surfaces have been cleaned of fouling, paints are generally applied to vessel hulls and finfish aquaculture cage netting which contain antifouling biocides. These paints prevent the settlement and growth of fouling organisms through the continual leaching of biocides, predominantly heavy metals such as Copper and Zinc into the surrounding water (Srinivasan and Swain, 2007). Although such antifouling paints have proven to be effective, factors such as paint age, damage or areas left unpainted can significantly decrease their efficiency. Studies have shown that paint age can have a significant influence on biofouling communities, with older paint allowing the establishment of greater quantities of fouling (Floerl and Inglis, 2005). Unpainted surfaces, such as those that evade actual paint coverage, e.g. regions covered by support frames whilst the vessel is in dry dock and niche areas such as the propeller shaft, may allow sufficient area to facilitate biofouling (Piola and Johnston, 2008). In addition, minor failures (<0.5cm wide) in the anti-fouling system, as a result of accidental damage during daily operations (e.g., anchor damage, vessel groundings or minor collisions) can also lead to the rapid establishment of fouling species, including NNS on the unprotected areas. Application of the anti-fouling paints to structures that are likely to remain in the water for extended periods of time, following manufacturers', guidelines is, therefore, critical to reduce the likelihood of NNS establishment.

### 8.3 Continuous surveillance and monitoring

**Continuous surveillance and monitoring for NNS will allow for the early identification of an introduction event at a particular site and to provide reliable baseline data on the presence and distribution of a particular species (David *et al.*, 2013).**

This is vital, as the management options to eradicate or mitigate the impacts of NNS decreases over time as populations become established and spread (Bax *et al.*, 2003). It has been found that within as little as 6 months between surveys, a new NNS can establish and rapidly colonise a site (Bax *et al.*, 2002).

The standardisation of sampling protocols, however, still needs to be improved between countries to enable the generation of reliable and comparable results (David *et al.*, 2013). In Australia and New Zealand, extensive surveys have been completed since the early 2000s in both international and domestic ports, including plankton, sedentary encrusting and benthic species and mobile species following the protocols developed by the Australian Centre for Research on Introduced Marine Pest (CRIMP) for baseline surveys of NNS in ports (Hewitt and Martin, 2001). These protocols have since been adopted by the International Maritime Organisation's (IMO) Global Ballast Water Management Programme and variations of this protocol have been applied to port surveys in many other countries (Inglis *et al.*, 2005). These surveys, however, are expensive and require expert taxonomic knowledge to complete. A cheaper, more targeted rapid assessment approach, in combination with a pre-survey literature review, has been used successfully for fouling NNS in marina surveys in the U.S. (Pederson *et al.*, 2003), U.K. (Ashton *et al.*, 2006) and Ireland (Nunn and Minchin, 2013). This approach, however, still requires expertise in taxonomic identification.

In addition to monitoring the site itself, closely monitoring the pathways of introduction (i.e., vessel and stock movements) is also crucial in preventing the introduction of NNS. The aquaculture industry already has a requirement to log any stock movements to restrict the spread of disease (CEFAS, 2009a, CEFAS, 2009b). The recent IMO voluntary guidelines for the control and management of ships' biofouling also includes the requirement for each commercial (IMO, 2013) and recreational (IMO, 2012) vessel and associated industries (i.e., shipbuilders, ship repair yards etc.) to complete a biofouling management plan and record book, detailing anti-fouling systems used, their maintenance and inspection history, plus any periods when the vessel has been laid up or inactive for extended periods of time. However, as these IMO guidelines are only voluntary, there is little evidence yet of their update by vessel owners.

In the meantime, one approach that has been developed for quarantine personnel in New Zealand, was a ranking scale used to quantify hull fouling on recreational vessels entering from international waters (Floerl *et al.*, 2005) (Table 3). This enables staff with minimal taxonomic expertise and training in the approach, to distinguish from a brief visual inspection of the hull from the surface, between vessels that carry, no, sparse or extensive fouling on their hulls. The staff member can then allocate each vessel a rank on arrival and those with a fouling rank of >2 (i.e., small patches of macrofouling), can then be subject to further biosecurity measures (Floerl *et al.*, 2005).

There is no substitute though for the willingness of staff, working at a particular site or activity, to report any 'unusual sightings' either to their environmental team or to the relevant environment agency. For example, the Zebra mussel *D. polymorpha* was prevented from entering a Sea Lock along the Forth and Clyde canal in October 2012, by staff working for a boat specialist company, who noticed the presence of an 'unusual' mussel on the hull of a narrowboat, reported its' presence and halted the launch of the boat (UKTAG, 2013).

*Table 3. Ranks of the ordinal fouling scale use to quantify hull fouling on private yachts arriving in New Zealand (Floerl et al., 2005).*

| Rank | Description | Visual estimate of fouling cover |
|---|---|---|
| 0 | No visible fouling. Hull entirely clean, no biofilm[a] on visible submerged parts of the hull. | Nil |
| 1 | Slime fouling only. Submerged hull areas partially or entirely covered in biofilm, but absence of any macrofouling. | Nil |
| 2 | Light fouling. Hull covered in biofilm and 1–2 very small patches of macrofouling (only one taxon). | 1–5 % of visible submerged surfaces |
| 3 | Considerable fouling. Presence of biofilm, and macrofouling still patchy but clearly visible and comprised of either one single or several different taxa. | 6–15 % of visible submerged surfaces |
| 4 | Extensive fouling. Presence of biofilm and abundant fouling assemblages consisting of more than one taxon. | 16–40 % of visible submerged surfaces |
| 5 | Very heavy fouling. Diverse assemblages covering most of visible hull surfaces. | 41–100 % of visible submerged surfaces |

*[a]Biofilm: Thin layer of bacteria, microalgae, detritus and other particulates.*

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ISBN: 978-1-78391-144-8

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