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Management in Practice

Developing biosecurity plans for non-native species in marine dependent areas: the role of legislation, risk management and stakeholder engagement

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Abstract

The rapid growth of marine trade and associated activities has led to an ever-increasing number of non-native species (NNS) being transported around the globe. Once established, NNS can be further spread by human activities. The spread of NNS is a trans-boundary challenge that must be met through a range of management measures operating over international and local scales. In contrast, the responsibility of managing NNS post-introduction often fall on marine managers working within localised areas of jurisdiction, such as ports and marinas. Here we examine how legislative frameworks, risk management and perception, influence the ability to develop and implement biosecurity planning in an offshore, semi-autonomous island community; the Shetland Islands. We propose a holistic approach to biosecurity management by integrating risk management methodologies into the wider management process of marine spatial planning. The challenges and opportunities created by a bottom-up approach to management are assessed within the context of global, pan-European, national and local management measures (e.g. regulations, treaties and policies). This paper sets out a framework for managing risk in an environment where the actions of many actors are outside the direct control of those tasked with managing the ecological and socio-economic impacts of marine NNS.

Key words: Shetland, invasive, policy, ecosystem-based management, trans-boundary, marine planning

Introduction

Advances in marine technology and the expansion of international trade have broadened the scope for human travel and maritime activity, which, in turn, has led to widespread transportation of marine species around the globe (Carlton 1996; Hulme 2009). The threats created by marine non-native species (NNS)—species that have been artificially introduced to environments outside of their native range (Colautti and MacIsaac 2004)—to marine communities and industries has become a concern for governments, decision makers, industries, and conservationists (Hooper et al. 2005; Mack et al. 2000; Pimentel et al. 2000).

Although the impacts of problematic "invasive" NNS (also referred to as "INNS", "invasive alien species" or "IAS") have been known for some time

(Elton 1958), the process of managing this biosecurity risk is a comparatively new concept in the marine environment. Biosecurity can be defined as the managerial efforts to "prevent harm from both intentional and unintentional introductions of organisms to human health and infrastructure and the environment" (Meyerson and Reaser 2002b: p. 594). The term "biosecurity" was originally used in agricultural and disease contexts, but in recent years has been applied in a more holistic approach to environmental risk management, encompassing, amongst other concerns, NNS (Meyerson and Reaser 2002a).

In the marine environment, the management of NNS is particularly challenging, due, in part, to the large volume and diversity of maritime activity capable of transporting marine species (e.g. Carlton and Geller 1993; Naylor et al. 2001; Weigle et al. 2005; Clarke Murray et al. 2011). The high potential for long and short distance transportation of NNS makes predicting where and when introductions will occur difficult. In most cases, environmental managers are ill prepared for dealing with new NNS detections and non-native populations can establish unimpeded (Simberloff et al. 2005), as seen with the sea squirt *Didemnum vexillum* Kott, 2002, (Locke et al. 2009).

The risks posed by marine NNS are elevated in coastal regions that contain a diverse range of marine industries and maritime activities, as the potential for NNS introduction is heightened (Bax et al. 2003). The risks associated with marine NNS can be significant and, therefore, biosecurity planning can be regarded as a form of risk management (Lyall and Tait 2004; Mills et al. 2011; Reed and Curzon 2015). In high-risk coastal areas, the implementation of an effective biosecurity plan can prevent and/or control the establishment and spread of unwanted NNS.

The comprehensive and precautionary approach to risk management that forms the basis of biosecurity planning is well suited to NNS management. It focuses on identifying and prioritising risks, and implementing preventative and responsive protocols aimed at reducing, if not eliminating, these risks. This framework provides an opportunity to manage risk in an environment where the actions of many actors are outside the direct control of those tasked with managing the ecological and socio-economic impacts of NNS.

Approaches to biosecurity planning were tested within the semi-autonomous Shetland Islands (herein Shetland) – an archipelago located approximately 160 km north of mainland Scotland. Shetland is a maritime dependent community, with over 75% of economic output directly linked to the sea (Shetland Marine Planning Partnership 2019). Marine industries within Shetland are wide ranging and include: Europe's largest oil terminal, which receives tankers from North and South America, Africa, and Asia (Shelmerdine 2015), aquaculture, commercial fishing, recreational boating, and wildlife tourism. In addition, the marine environment supports

a highly diverse range of internationally and nationally important marine species and habitats (Shucksmith et al. 2014), which, in addition to their biodiversity value, support a range of ecosystem services such as supporting commercially important fish and shellfish species, sequestering carbon, and providing coastal protection. Maintaining a healthy, functioning marine ecosystem is essential for ensuring the continued delivery of many of these goods and services to Shetland.

In Shetland, the use of the marine environment is guided by the Shetland Islands' Marine Spatial Plan (SIMSP) from mean high water springs to the 12 nm limit. The overarching aim of which is to manage marine use and activities to meet the long terms needs of nature and people (NAFC Marine Centre UHI 2014). A policy requiring developers to consider the risks of their proposals on the introduction, spread and management of NNS was first introduced in 2007 and was updated in subsequent editions (NAFC Marine Centre UHI 2014; Shetland Marine Planning Partnership 2019). To support this policy, the NAFC Marine Centre UHI (herein NAFC) initiated an NNS monitoring programme in 2012 to provide a baseline of known NNS in Shetland (Collin et al. 2015). In addition, guidance documents for specific user groups and the wider public were created, covering species identification and "best practice" measures to reduce the risk of introduction and spread of NNS.

In 2015, the SIMSP advisory group identified the need for a Shetland-wide biosecurity plan to align the implementation of the SIMSP NNS policy and the NNS monitoring work streams. The development of the "Biosecurity Plan for the Shetland Islands" (hereafter referred to as the Biosecurity Plan) was led by the Marine Spatial Planning team at the NAFC. It was guided by a sub-set of the SIMSP advisory group, the "Biosecurity Working Group", which comprised of decision makers, regulators, industry and community representatives, and Non-Government Organisations (NGOs).

Here we propose a holistic approach to biosecurity planning and NNS management by integrating biosecurity risk assessment methodologies into the wider local management processes of marine spatial planning. As the use of marine spatial planning as a management tool expands (UNESCO 2021), consideration of how to integrate these processes becomes of increasing importance. The challenges and opportunities created within a bottom-up approach to management are assessed within the context of global, pan-European, national and local management measures (e.g. regulations, treaties and policies). In addition, we examine the opportunities for local communities and users to reduce the risks of NNS.

Methods and results

Selection and creation of a NNS risk management framework

To identify an appropriate framework design, the Biosecurity Working Group reviewed the existing management framework for marine activities

in Shetland, primarily the Shetland Islands' Marine Spatial Plan (SIMSP). It was determined that the SIMSP did not adequately provide the risk management required to tackle NNS through creation of new or amended policies as it only applies to activities which require a marine licence (i.e. aquaculture developments, renewable energy sites) but not to activities such as recreation, fisheries or shipping. Therefore, guidance documents were reviewed, including, environmental management frameworks, biosecurity guidance documents and biosecurity plans developed in other regions (Supplementary material Table S1) Search terms "marine biosecurity plan", "marine biosecurity guidance" were utilised to find relevant resources.

All documents reviewed used risk identification and management mechanisms. In all cases this was done through variations on risk management procedures. Documents developed by SAMS SRSL Ltd. (Cook et al. 2014, 2015) advocate the use of the Hazard Analysis and Critical Control Point (HACCP) process, a modified risk assessment procedure. All biosecurity plans contained timelines for plan implementation, as well as public engagement and awareness raising.

To manage all risks, including those outside the scope of the licensing process, an ecosystem-based management strategy (ie. Ehler and Douvere 2009) was adapted to more directly reflect a risk management framework (i.e. Cormier et al. 2013). Ecosystem-based management recognises the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation (Christensen et al. 1996). The framework comprises five key stages: 1) management context; 2) risk identification; 3) risk analysis; 4) risk evaluation; and 5) risk treatment (Figure 1). This ecosystem-based management process also contains a continuous monitoring and re-evaluation loop for identifying future risks.

The risk of activities acting as pathways or stepping-stones in NNS introduction and establishment were considered on an activity basis over the four key stages of the invasion process: 1) transportation; 2) introduction; 3) local establishment; and 4) widespread establishment. Within each stage an assessment was carried out to identify the person (individual, agency or body) responsible for managing the risk, the roles of managers and marine users, and the relevant legislation. Where possible, existing local industry practice was reviewed to inform these assessments e.g. extent risk or management measures align with published literature.

Biosecurity plan structure and components

To align the Biosecurity Plan and the SIMSP, the Biosecurity Working Group agreed that the management area should align with that of the SIMSP, which includes the territorial waters seaward of the mean high-water spring (MHWS) out to 12 nautical miles from Shetland. For this reason, it was agreed that the Biosecurity Plan should be limited to marine

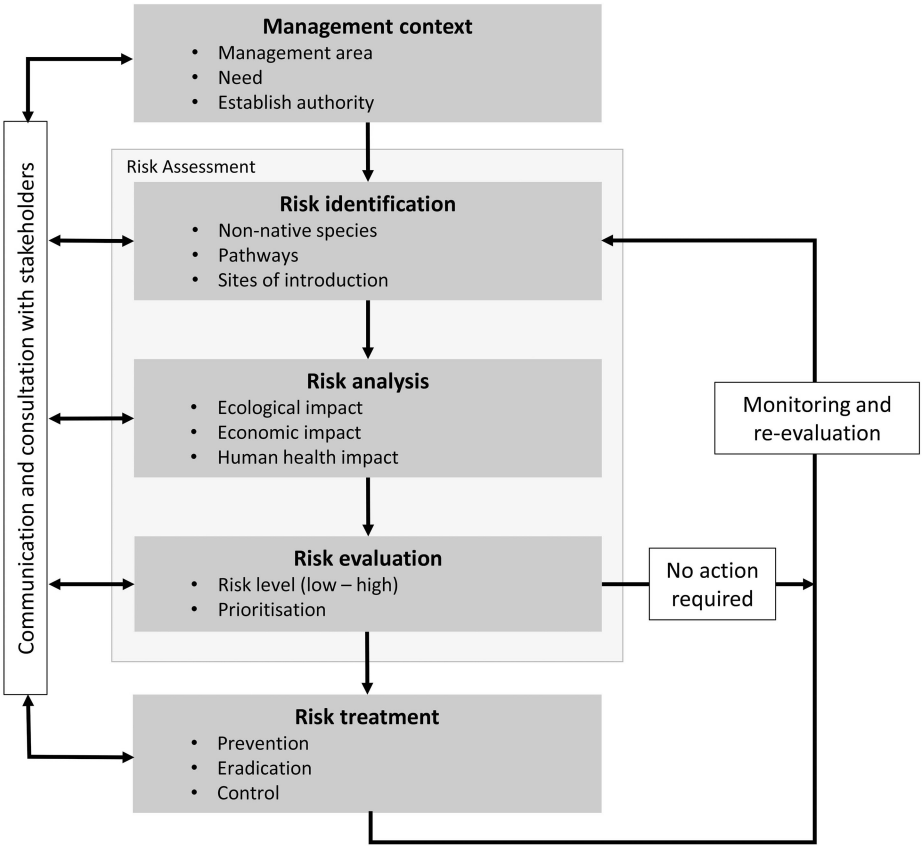

Figure 1. Five-stage approach for risk assessment management of NNS in Shetland, adapted from the ecosystem-based risk management framework (Cormier et al. 2013).

species only, and not consider freshwater aquatics or terrestrial species. The Biosecurity Plan scope was proposed to include all commercial marine users required to adhere to the SIMSP, and commercial and non-commercial marine users that fall outside the management remit of the SIMSP but have a key role in NNS management.

The Biosecurity Working Group identified five key management objectives that should be fulfilled by the Biosecurity Plan:

- reduce the potential for NNS introduction and establishment;
- ensure NNS monitoring is cost effective, efficient, and follows national and international guidelines;
- reduce the impacts of NNS on local marine industries, non-commercial use, and biodiversity;
- conserve natural habitats and ecosystems that are of local, national, and international importance; and
- ensure all marine users are aware of codes of best practice for managing NNS.

Following the review, the Biosecurity Plan layout was organised into four key chapter themes:

- An introduction to non-native species and the need for biosecurity (including policy and legislation);

- Biosecurity concerns- current and potential NNS threats;
- Management of NNS;
- Sector specific guidance.

Risk Identification

Pathways and steppingstones

Workshops were held with the Biosecurity Working Group where members were asked to identify potential pathways of introduction of NNS to Shetland and activities they considered could act as stepping-stones and assist in the local introduction and spread of NNS. Stepping-stones for NNS are manmade features which may provide a habitat offering more favourable growth conditions than the surrounding environment, therefore facilitating the spread of the NNS and are therefore considered crucial in long distance dispersal of NNS (Alharbi and Petrovskii 2019). Analysis of Automatic Identification System (AIS) data held by the NAFC was also undertaken to identify shipping types, routes, and ports of origin of vessels travelling to, past and from Shetland (Shelmerdine 2015; Shucksmith and Shelmerdine 2015).

Activities identified by the Biosecurity Working Group considered to potentially pose a risk of NNS introductions were:

- ballast water exchange at the Sullom Voe Oil Terminal – due to the volume of ballast exchange within the harbour when tankers take on oil from the terminal
- commercial boat biofouling and cleaning
- recreational boat biofouling and cleaning
- aquaculture – equipment fouling, boat and stock movement
- fisheries, specifically large pelagic fishing boats – due to their size (all over 40 m), concern over ballast water exchange and vessels landing in Scandinavian ports

The risks identified within the workshop were examined by the NAFC through literature review and communication with sector specialists to determine current practice (e.g. fisheries trade bodies). Reviewed literature sources used within this assessment are summarised (Table 1). Search terms "non-native species introduction", "marine non-native species introduction", "hull fouling", "fouling marine non-native species", "ballast water exchange non-native species" and "aquaculture non-native species" were used to initially identify literature. Search terms were repeated with non-native species replaced with "NNS", "INNS", "invasive species" and "alien species". Upon further analysis of risk and discussion with fisheries representatives, fishing boats were not considered to pose a significant risk. Most vessels operate within Shetland waters, returning to and from their home ports. Investigations found that fishing boats do not normally or regularly undertake ballast exchange in port. This identified risk was therefore not considered further.

Table 1. Published literature reviewed to determine the risks posed by activities and infrastructure in the introduction and spread of NNS.

Risk type	Activity	Literature sources
Pathway	Recreational boating (biofouling)	Floerl et al. 2005; Ashton et al. 2006; Minchin et al. 2006; Pearce et al. 2012
Pathway	Commercial shipping-biofouling and ballast exchange	Hay 1990; Carlton and Geller 1993; Apte et al. 2000; Gollasch 2002; Fofonoff et al. 2003; Minchin and Gollasch 2003; Coutts and Taylor 2004; Enshaei and Mesbahi 2009; Blyth-Skyrme 2010; Williams et al. 2010; Pearce et al. 2012
Pathway	Aquaculture species movement	Diederich et al. 2005; Ruiz et al. 2011; Pearce et al. 2012
Stepping stones	Marina and ports	Bax et al. 2002; Ashton et al. 2006; Pearce et al. 2012
Stepping stones	Marine renewables	Adams et al. 2014
Stepping stones	Aquaculture equipment	Weigle et al. 2005; Pearce et al. 2012

Table 2. Identified risks posed by activities and infrastructure in the introduction and spread of NNS.

Risk type	Risk	Activity
Pathway	ballast water exchange	Tanker ballast water exchange at Sullom Voe due to taking on oil
		Commercial vessel ballast water exchange at all port
Pathway	biofouling	Hull fouling commercial vessels
		Hull fouling commercial recreation
Pathway	Stock movement	Aquaculture
Stepping stone	biofouling	Aquaculture equipment
Stepping stone	Biofouling	Marina and port infrastructure
Stepping stone	Biofouling	Marine renewable infrastructure

Based on literature review and Biosecurity Working Group feedback, four potential pathways of introduction and three potential stepping stones were initially identified as requiring further consideration within the subsequent risk analysis stages (Table 2).

Established NNS

Prior to the development of the Biosecurity Plan, a Shetland-wide assessment of the presence of NNS had been initiated. A series of rapid assessment surveys (PVC settlement panels and visual surveys of pontoons, buoys, and boat hulls) of four harbours/ports and 14 marinas was conducted between May 2012 and October 2014. A literature review was also undertaken to identify NNS species that had historically been detected, and to understand the current geographical spread of NNS in Shetland (Collin et al. 2015). Rapid assessment surveys revealed the presence of eight NNS in Shetland. Additionally, a literature review revealed three more NNS that had previously been detected in Shetland but were not identified in the rapid assessment surveys. All three records were one-off observations from the natural coastline in areas not included in the rapid assessment surveys. Of the eleven NNS species, five were found to have been present for over 10 years. It was noted that no single source of information could be utilised to identify all NNS currently present in Shetland.

In addition to the survey effort, members of the public were encouraged to report NNS sightings, or potential sightings to the NAFC. NNS identification guides developed by the NAFC (NAFC Marine Centre UHI 2014) were made

Table 3. Published literature, guides and organisations consulted to determine the distribution and risks posed by NNS.

Type	Sources accessed
Peer-reviewed publications	Irvine et al. 1975; Hiscock et al. 1978; Eno et al. 1997; Ashton et al. 2006; ERT (Scotland) Ltd. 2006; Moore and Harries 2009; Beveridge et al. 2011; Ryland et al. 2014; Nall et al. 2015; Wasson and De Blauwe 2014; Loxton et al. 2017
Guides	Marine Aliens II Consortium (2014) Identification guide for selected marine non-native species.
Online sources	Marine Life Information Network (MarLin) www.marlin.ac.uk National Biodiversity Network www.nbn.org.uk GB Non-native species Secretariat http://www.nonnativespecies.org/factsheet/index.cfm
Organisations Consulted	Heriot Watt University Orkney Islands Council University Highlands and Islands Marine Scotland Science

available online and hard copies distributed amongst commercial industries, recreational users, public bodies, and NGOs. Observations from the public, from the natural environment (see Collin et al. 2015) and from surveys targeting manmade structures by the NAFC, all resulted in increased knowledge on the geographical spread of several species.

Potential NNS introductions

To identify a target list of potential NNS, an assessment was made of existing NNS, their distribution in the UK, and their potential vector of introduction. This information was used to consider which other NNS could arrive via the same route. All the NNS detected in the rapid assessment surveys in Shetland were present in mainland Britain before Shetland, and so secondary spread was considered the most likely route of introduction. Therefore, it is considered probable that new NNS introductions will also occur primarily from secondary spread rather than primary introduction.

Potential NNS were identified from literature review, including published articles and online sources, and identified species already present elsewhere in the UK or Scandinavia but not present in Shetland (Table 3). Search terms "non-native species, UK, Scotland, Norway" were used, and additionally references used in online resources were also reviewed. These results generated a list of potential NNS that could be introduced to Shetland. It was noted there was no single source of information which contained up-to-date or complete data sets for the UK and Europe.

These species were screened for likelihood of survival and establishment in Shetland which has much colder sea temperatures than much of the UK, varying between 4–13 °C winter to summer, and lacks estuarine environments or extensive river systems. From the list of potential NNS identified, a target list of eight species (based on likelihood of introduction) were considered within the Risk Analysis and Evaluation stages: *Sargassum muticum* ((Yendo) Fensholt, 1955), *Watersipora subatra* (Ortmann, 1890), *Didemnum vexillum* Kott, 2002, *Styela calva* Monniot et al., 1976, *Tricellaria inopinata* d'Hondt & Occhipinti Ambrogi, 1985, *Botrylloides violaceus* Oka, 1927 and *Bugula neritina* (Linnaeus, 1758).

Table 4. Legislative and policy measures to reduce risks posed by marine activities.

Activity	Key legislation/ policy	Biosecurity Plan	Gaps and limitations
Commercial shipping – Ballast	International Convention on the Control and Management of Ships' Ballast Water and Sediments	No additional measures	Legislation not yet fully implemented
Commercial shipping – Biofouling	International Maritime Organization (IMO) Guidance for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species (Biofouling guidance) Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act).	Limited local capacity. Plan includes details to allow for detection of NNS. Most likely to be effective on locally based commercial vessels.	Capacity and infrastructure to clean boats or refuse entry
Recreational boating – Biofouling	International Maritime Organization (IMO) Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act).	Plan includes details to allow for detection of NNS on recreational vessels and details for organisers of events which attract visiting boats.	Capacity and infrastructure to clean boats or refuse entry to Shetland
Aquatic species movement	COUNCIL REGULATION (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture	No additional measures	None identified
Marinas and ports – stepping stones	Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act).	Plan includes best practice information to help minimise the level of biofouling at marinas and ports.	Need and cost of retrospective technical measures to reduce fouling potential
Marine renewables – stepping stones	Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act).	Plan includes best practice information to help minimise the level of biofouling.	Need and cost of technical measures to reduce fouling potential
Aquaculture equipment – stepping stones	Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act).	Plan includes best practice information to help minimise the level of biofouling.	Need and cost of technical measures to reduce fouling potential

Risk Analysis and Evaluation

Pathways and stepping-stones

The pathways and stepping-stones identified in the "risk identification" stage, were assessed in the context of literature review, including published articles and online sources (Table 1), local practice or management measure and existing legislation, policies, and agreements (Table 4, Table S2).

Of the transportation and introduction risks identified, only marine aquatic species movement is considered to be fully managed by legislation (Table 4). The risks of commercial and recreational boat fouling can be reduced via regularly cleaning and effective antifouling. An assessment of legislation and regulation indicated limited national or international specific requirements tackling hull fouling, particularly of smaller vessels (Table 4). In Shetland, slipways are present at marinas and can be accessed freely by berth holders, allowing boats to be easily removed for onshore cleaning, however there is no requirement for boat owners to do so. For small and medium sized commercial vessels (those under over 360 tonne or 35 m in length) commercial slipways are available at two locations for boat repairs and maintenance. For larger vessels, there are no facilities

available in Shetland for boat removal, cleaning and re-antifouling. These vessels must access facilities on the Scottish mainland, Norway or Denmark. No in-water cleaning facilities are available in Shetland for any vessel size. Therefore, risks from boat fouling were not considered to be fully managed. AIS data provides a range of data relating to vessel movement, including information on boat type (e.g. fishing, tanker, recreation), last port of call and position. This data allows for an assessment of the relative risk of NNS introduction by boat fouling (see Shucksmith and Shelmerdine 2015).

In consultation with industry users, vessels which undertake ballast exchange were identified and found to be limited to tankers taking on oil at Sullom Voe Oil Terminal. It was noted that some, but not all tankers, undertake ballast water exchange at sea, in some instances primarily due to legislative requirements of other nations (including the USA). At the time of the Biosecurity Plans development, the International Convention on the Control and Management of Ships' Ballast Water and Sediments (https://www.imo.org/en/MediaCentre/HotTopics/Pages/Implementing-the-BWM-Convention.aspx) was not ratified. Therefore, the risks associated with transportation and introduction by ballast water exchange were not considered to be fully managed.

Consultation with the aquaculture sector revealed that, salmon smolts are grown on Shetland and also imported from the Scottish mainland via wellboats. During wellboat transfer, water is exchanged regularly (for fish welfare), reducing the risk of the transfer of planktonic species. The shellfish industry only grows the native species *Mytilus edulis* Linnaeus, 1758 – blue mussels. Spat is normally collected naturally during seasonal spat settlement. Legislation preventing import of NNS from outside of the UK was considered adequate to prevent future NNS imports, Table 4. Transportation of NNS (other than by hull fouling), was therefore considered to be low risk by the aquaculture industry.

To assess the risk of marina and port infrastructure acting as stepping-stones for the establishment of NNS, cleaning and antifouling operations at ports and marinas were observed. Navigation buoys are regularly removed for cleaning and re-antifouled before significant fouling can occur. Antifoulant appeared to be effective for two years, and its effectiveness is monitored by the harbour authorities. At the end of the summer visiting yacht season, temporary berths in Lerwick harbour are removed, dried and thoroughly cleaned before being stored for the winter. Observations of cleaning practices across Shetland's permanent marinas, which are operated by community groups, indicated that marinas were cleaned regularly by volunteers, with fenders and buoys removed from the water. However, it was noted that pontoons and floats could not be removed for cleaning and the marinas had not been designed with NNS eradication in mind. At some locations, natural freshwater influx during heavy rainfall caused the death of some fouling species, in particular tunicates. An examination of legislation

highlighted that, while future marina design may be required to consider NNS more explicitly, there is no requirement on retrospective NNS measures to be applied, nor monitoring for the presence of NNS (Table 4). Therefore, local establishment of NNS at marinas was considered a risk.

Aquaculture sites were found to have existing biosecurity measures in place to tackle disease transfer and some were found to have incidental benefits for NNS species management. This included the separation of the Shetland coast into discreet management units, with stock, boats, and equipment not being moved between these areas, and synchronous fallowing of sites (where fish and nets are removed) taking place biennially. To aid waterflow nets are anti-fouled and regularly cleaned. Boats are cleaned and re-antifouled sporadically, but feed barges (present at each site) are not regularly cleaned. No specific legislation was noted which required equipment to be cleaned, however national legislation requires consideration to equipment movement (Table 4). Aquaculture sites were therefore considered a risk for local establishment of NNS, with the location and number of sites mapped to identify areas of highest intensity and risk (Shucksmith and Shelmerdine 2015).

There is one tidal array site in Shetland, with equipment serviced and cleaned at an adjacent pier. No specific legislation was noted which required equipment to be cleaned, however national legislation requires consideration to equipment movement (Table 4). The tidal array was considered a risk of local establishment.

Risk factors including, vector type (e.g. ballast water exchange), presence of stepping-stones (e.g. artificial structures), introduction probability (i.e. the likelihood of NNS being released), and the frequency of possible introduction events (i.e. propagule pressure) were used to score areas around the Shetland coast as low to very high relative risk of NNS introduction. These were presented at a scale of 5 × 5 km grid squares. From the assessment, the three most active harbours were identified as the highest risk areas ranging from "very high-risk" (Lerwick and Scalloway) to "high-risk" (Sullom Voe) (see Shucksmith and Shelmerdine 2015), (Figure S1).

Current and potential NNS introductions

An assessment of the risk posed by NNS to economic activity and the marine environment in Shetland was undertaken based upon the GB NNS secretariat risk analysis template (http://www.nonnativespecies.org/index.cfm?pageid=143) and GB NNS secretariat species assessments http://www.nonnativespecies.org/home/index.cfm). Literature review of activities and species, (Tables 2, 3), in the context of local conditions (environmental and industry practice) were used to review the assessment in the GB NNS secretariat process, and assess whether any local differences would alter the risk assessment outcomes.

Table 5. Scoring criteria for environmental and economic impacts of NNS in Shetland.

Score	Introduction	Environmental	Economic
Low	Pathway to introduction absent or receiving environment unsuitable (absence of habitat, temperature prevent survival)	No or limited evidence that the species could establish in Shetland and/ or cause wide scale impact on habitats or environments found in Shetland e.g. smothering, displacement, competition.	No or limited evidence that species could establish in Shetland and cause wide scale impact on habitats or environments which support economic activity e.g. via smothering, competition or displacement.
Medium	Pathways for introduction present but limited (e.g. occasional or mitigation in place), receiving environment sub-optimal for survival	Some evidence that species will cause impacts impact on habitats or environments found in Shetland e.g. smothering, displacement, competition but impacts are confined to localized areas and not fully displace native flora or fauna.	Likely to occur on habitats or environments which support economic activity and may cause some economic harm but impacts are likely to be localized or overcome at moderate cost.
High	Pathways for introduction present, receiving environment suitable for species survival	Evidence to suggest that species will cause large scale impacts on habitats or environments found in Shetland or localized impacts on protected habitats e.g. smothering, displacement, competition.	Likely to occur on habitats or environments which support economic activity and impacts may reduce economic viability of the activity or create significant cost e.g. high levels of smothering of aquaculture equipment resulting in significantly higher cleaning costs.

Environmental harm was considered in the context of the prevalence of suitable habitat for establishment and perceived importance of the habitat (e.g. protected status). For instance, species which require low salinity were considered to be of low environmental risk to Shetland where brackish water and estuaries are of very limited extent. Economic impact was considered in the context of the presence and value of marine industries in Shetland e.g. aquaculture, fisheries. Scorings were presented on a three-point scale (low, medium, high) to assist communication, scoring criteria (Table 5).

The risk assessment was used to determine whether known NNS would require specific control or eradication measures. Those with either a medium risk of spread to Shetland or a medium risk to the marine environment or local industry were considered in the Biosecurity Plan. The Plan details potential economic and environmental risks associated with the species, management measures and risks for these species. Species considered low risk were excluded in order that the Biosecurity Plan focused on management measures on species which were considered potential threats. For NNS identified as potential future threats, consideration was given to whether the species could spread to Shetland through natural dispersal or whether transportation via marine activity was necessary.

The detection of a species previously unknown to the UK would require immediate contact with Marine Scotland to determine the risk posed, and would include an assessment of the species reproductive requirements and invasion history elsewhere.

All the 11 NNS species detected in Shetland were rated as low-medium threats to the environment and to the economy (Table 6). Of the NNS species identified as present in Scotland but not in Shetland, six were of medium to high risk of introduction to Shetland (Table 7). Of those found

Table 6. Risk assessment scores for NNS detected in Shetland.

Species	Status	Environmental threat	Economic threat
Corella eumyota	Widespread in harbours and marinas	Medium	Low
Schizoporella japonica	Widespread in harbours and marinas	Medium	Medium
Caprella mutica	Widespread on manmade structures	Low	Low
Bugula simplex	Lerwick harbour	Low	Low
Codium fragile ssp. *fragile*	Widespread along natural coastline	Medium	Low
Dasysiphonia japonica	Widespread along the natural coastline and manmade structures	Medium	Low
Diadumene lineata	Vadills lagoon	Low	Low
Austrominius modestus	Widespread in harbours and marinas	Low	Low
Bonnemaisonia hamifera	Widespread in Shetland	Low	Low
Asparagopsis armata	Widespread in Shetland	Low	Low
Fenestrulina delicia	Single observation in Sullom Voe	Low	Low

Table 7. Risk assessment scores for NNS not present in Shetland but present elsewhere in Scotland.

Species	Risk of introduction	Environmental threat	Economic threat
Sargassum muticum	High	Medium	Medium
Watersipora subatra	Medium	Medium	Medium
Didemnum vexillum	High	High	High
Styela clava	Medium	Medium	Medium
Tricellaria inopinata	Medium	Low	Low
Botrylloides violaceus	Medium	Medium	Medium
Bugula neritina	Low-medium	Low	Low
Magallana gigas	Low	Medium	Medium

in Scotland, but not in Shetland, only *Didemnum vexillum* was considered potentially high risk to both the environment and the economy. From these species, those with the potential to have a medium or high impact on local industries and/or the environment were categorised as "priority" species for inclusion in the Biosecurity Plan. These priority species were considered further in the risk assessment process and included in identification guides to encourage public reporting.

Risk treatment

Risk reduction within introduction pathways and stepping-stones

Risks and potential management measures were detailed in the Biosecurity Plan on a sector-by-sector basis. This assisted in identifying and raising NNS awareness amongst users of potential measures which can be implemented to reduce the risks of spreading NNS, including legal responsibilities (Table 4). For marine activities which require a marine licence, adherence to the Plan, whilst not compulsory, assists with adherence to the policies within the SIRMP.

Non-native species control and eradication

Early detection through increased user awareness and a regular targeted monitoring programme co-ordinated by the NAFC Marine Centre, has been implemented to ensure a rapid response to new threats can be initiated. Monitoring sites were selected through a risk assessment of Shetland's coastal area (Shucksmith and Shelmerdine 2015).

A target list of potential NNS species requiring a rapid response are included within the Biosecurity Plan. A review of control and eradication methodologies was undertaken and considered in the context of these species. Methods of identification of NNS were also considered, including whether expert identification or DNA analysis (in the case of cryptic or polymorphic species) may be required.

For existing and future species, detailed information on species identification, likely pathway(s) of introduction, and potential impacts were included in the Biosecurity Plan. Clear protocols were also included along with NNS identification guides and information leaflets produced by the NAFC, to ensure members of the public and industry know who to contact in the event of a potential NNS detection, including "unknown" species.

From the rapid survey assessments and literature review performed between 2012 and 2014, none of the species currently found in Shetland were categorised high risk. Therefore, no additional action was considered necessary to remove or control the NNS.

Monitoring, implementation and evaluation

The Monitoring and Implementation phase was initiated once the Biosecurity Plan was launched in February 2015. The Biosecurity Plan was made available online at the NAFC website (https://www.nafc.uhi.ac.uk/research/marine-spatial-planning/non-native-species-and-biosecurity-planning/) and hard copies of the Plan were sent to local stakeholders. On publication of the Biosecurity Plan, it became a requirement for all new marine applications to the Shetland Islands Council to consider biosecurity as part of the application process, and use of the Biosecurity Plan guidance began to be monitored.

The NAFC are responsible for the ongoing monitoring, implementation and evaluation of the Biosecurity Plan, the scope of which includes:

- monitoring the use of the Biosecurity Plan in marine licence applications
- responding to applications (as a consultee) for marine licenced activities (from Marine Scotland) that have the potential to spread NNS
- continued collection of field data to assess the spread of existing NNS and detect the introduction of new species
- monitoring of existing activities and industry practice in relation to NNS
- horizon scanning through continued literature review to identify new NNS threats in the UK and their potential for spreading to Shetland
- monitoring of new legislative requirements and implications for management and risk

Current and potential NNS threats

Continued monitoring effort by the NAFC has detected the spread of NNS between marina locations. Two species were observed to have increased

their distribution around the Shetland coast, *Corella eumyota* Traustedt, 1882 was detected at Cullivoe marina (Yell) in April 2018, and *Schizoporella japonica* Ortmann, 1890 was newly detected at East Voe and Port Arthur marinas (both Scalloway) in December 2018. Additionally, *Corella eumyota* was detected on the shore adjacent to Port Arthur in August 2018 (Shucksmith *pers. obs.*) and by a member of the public in 2020 on a beach 200 m from the marina (reported by L. Humphrey), however during subsequent surveys it has not detected, and it is not certain whether it is widely established in the natural environment. Monitoring has not detected any economic or ecological impacts of the NNS at this time.

In 2016, an additional NNS, the Pacific oyster (*Magallana gigas* (Thunberg, 1793)), was identified after detection of two individuals growing on mussel lines (Shelmerdine et al. 2017). Emerging records from across Scotland suggests this species is now wildly established, against previous research suggesting temperatures of 18 °C are required for successful reproduction (Eno 1994).

Outside of Shetland, a number of NNS have been noted to have expanded their range. For example, the non-native sea squirt *Asterocarpa humilis* (Heller, 1878) has now been detected in Orkney (Kakkonen et al. 2019). At this time there are no reports of significant economic impact or ecological impact. Also in Orkney, the seaweed *Sargassum muticum* (wireweed) had previously been observed in unattached form, however recent monitoring suggests that it has not become established (Kakkonen et al. 2019).

Monitoring the implementation of the SIMSP NNS policy and the Biosecurity Plan

During the marine licence application process, the SIMSP policy, Biosecurity Plan and guidance documents have been used by consultees, regulators and/or developers. Examples include:

- Advice and conditions have been applied to activities or developments which require a marine licence, including where developers intend to move equipment from an area with known NNS present to an area with no recorded NNS.
- Permission was refused to move equipment known to be fouled with NNS (detected by NAFC monitoring programme) without prior cleaning/decontamination. In this instance, the legislative requirements of Wildlife and Natural Environment (Scotland) Act 2011 (also known as the WANE Act) which prohibits the movement of NNS from one area to another, provided a strong legal underpinning to the decision.

Additionally, the Biosecurity Plan and supporting baseline data have been used by developers when creating site-specific biosecurity plans (three occasions), including marine renewables and the movement of equipment.

Monitoring legislation changes

Since the implementation of the Biosecurity Plan, the International Convention for the Control and Management of Ships' Ballast Water and Sediments came into force on 8th September 2017, with standards for new ships and existing vessels which seeks to reduce the risk of NNS transportation and introduction via ballast water.

Discussion

The Biosecurity Plan represents the culmination of marine spatial planning, stakeholder interests, and environmental management working towards safeguarding marine industries and environments from NNS introductions. Integrating biosecurity management into marine planning has utilised an existing stakeholder forum and management framework. Although the Biosecurity Plan supports the SIMSP, it is not itself a policy document and, therefore, it is not mandatory for all marine users to adhere to the suggested practices. It does, however, support marine users by providing advice on how to meet the policy requirements found within the SIMSP and wider legislation. Subsequently, it brings together licenced and non-licenced activities in the same framework for the first time.

The ecosystem-based management approach that forms the basis of the Biosecurity Plan provides not only a transparent process for the identification and assessment of risks, but also provides a framework for the creation of practical guidance on how all marine users can contribute to mitigating these risks. Our ability to detect and manage newly introduced NNS improves vastly when marine users from all sectors and industries are involved in decision making. This includes measures which can support risk prevention, mitigation and recovery.

Effectively identifying, analysing and systematically representing stakeholders is crucial to the design of participation and communication strategies to improve biosecurity (Reed and Curzon 2015). To ensure all management measures suggested in the Biosecurity Plan were realistic, practical, and cost-effective, stakeholders were regularly involved and consulted throughout its development and implementation. Stakeholder participation was essential for gaining marine-user cooperation and support for the Biosecurity Plan.

Throughout the development of this Biosecurity Plan, the incorporation of a diverse range of sources of knowledge, from scientific resources to locally specific information on environmental factors that might promote NNS, has improved its implementation and adoption. Additionally, the involvement and support of local and national stakeholders, including decision-makers, regulators, NGOs, local industry, and community representatives has encouraged compliance by both commercial and non-commercial marine users. Ultimately, the implementation of the

Biosecurity Plan should benefit all parties involved and assist marine users and regulatory bodies meet their legal obligations for NNS management.

There is growing evidence in Shetland that biosecurity is receiving greater consideration by developers and decision makers in the licensing process and analysis of specific licensing decisions highlights the importance of a legislative basis for decisions (primarily through the WANE Act in Scotland). Reports of NNS sightings to the NAFC by industry and the public, indicate there is a growing awareness of the problems associated with NNS and a willingness to report them. This increased reporting raises the likelihood of detecting a potentially high-risk NNS early and commencing actions to manage it. Early detection and action to address NNS is considered critically important to management success (Piola and McDonald 2012; Sambrook et al. 2014). Protocols within the Biosecurity Plan help to ensure that marine users are aware of the need to report potential sightings rapidly and ensure that protocols can be implemented rapidly.

In Scotland biosecurity plans are voluntary, produced both for specific areas and for specific events. As most of these plans contain high level objectives, compliance can be difficult to assess. However, there are examples of effective use of voluntary measures. As part of the Commonwealth games celebrations, held in Glasgow in 2014, visiting vessels wishing to take part in a flotilla were asked to arrive clean, or face mandatory cleaning (at owners costs) (Staurt 2014). This request was complied with by participating vessels, which were inspected and found to be clean on arrival. Ensuring continuous compliance over larger scales poses a more substantial challenge, particularly where management measures are voluntary, and where costs and belief in effectiveness of these measures can be barriers (Vye et al. 2020). Within the fisheries sector the creation of voluntary management measures developed by stakeholders has been found to be key to their successful development and design, but a statutory underpinning was found to be necessary to ensure universal compliance (Shelmerdine et al. 2017).

Identifying which NNS are the most likely candidates for introduction forms a key part of the risk management process as this refined list can assist with monitoring design and effort, and early eradication action if detected within the plan's region. The Shetland Biosecurity Plan assists in reducing the establishment of all NNS by providing sector specific guidance. However, detailed species-specific information is only given for NNS which have been introduced elsewhere, rather than identifying species which may be introduced in the future. For effective horizon scanning of potential NNS, records of NNS and their potential to spread, either naturally or via human activity, needs to be readily and publicly available. The absence of these data, both within the UK and Europe, has been a continuous problem in the development of the Biosecurity Plan,

and increases the challenges associated of planning for the "unknown". The NAFC addressed this problem through regular contact with researchers and practitioners in adjacent regions and taking responsibility for species monitoring in Shetland. Concerns over data availability have been highlighted elsewhere (Collin et al. 2015; Lehtiniemi et al. 2015; Shelmerdine et al. 2017), with records of new detections often taking years to become publicly available.

Monitoring efforts that operate at an international scale often result in a focused effort in a small number of key locations within a nation (Hellmann et al. 2008; Lehtiniemi et al. 2015; Oswalt et al. 2021). This has meant that smaller, marine dependent areas such as Shetland, are not subject to national monitoring effort, despite their relative economic and environmental fragility to marine NNS. The targeted approach to species surveillance undertaken in Shetland, whilst being cost efficient and assisting in public engagement, means that new NNS (ones previously undetected in the UK) may go undetected. This challenge can often be exacerbated by an incomplete understanding of baseline biodiversity data for the majority of the world's marine and estuarine areas (Campbell et al. 2018). However, the targeted local monitoring programme using both settlement panels and rapid assessment surveys by marine biologists based at the NAFC increases the likelihood of other NNS being detected, despite not being specifically targeted.

This study highlights the role marine regions can play in tackling the threat of NNS and contributing to the international biosecurity agenda. However, it also highlights the challenges marine regions and countries face in tackling transportation and introduction without widespread collaboration between countries and regions. For all marine regions, a challenge exists in implementing preventative measures which are strict enough to tackle the threat posed by NNS, but not so strict that marine development is displaced to neighbouring competitors (countries or regions) where the burden of biosecurity measures is perceived as less arduous. Displacement of marine activity has the potential to cause economic costs to developers and communities, for instance through lost revenue. For marine dependent regions such as Shetland it poses dichotomous risks, loss of income through stricter measures, or potential loss of income through environmental impacts if a harmful NNS is introduced. This decision challenge is reflected at national and regional scales. In the UK the estimated cost of marine NNS is £39.9 million (Williams et al. 2010).

This study identifies the variety of international agreements and legislation that set commitments to reduce the impacts of NNS (including the Marine Strategy Framework Directive and Convention for Biodiversity), but also the relatively few pieces of legislation aimed at directly tackling specific risks through explicit implementable measures e.g. a requirement to put boat cleaning infrastructure in place in each region, or a requirement

to keep boats clean. Internationally, the significant delay in bringing the Ballast Water Convention into force (13 years after its adoption) demonstrates both this reluctance to introduce costly measures to tackle NNS, and the lack of readily available affordable technological solutions. Monitoring the role-out of the Ballast Water Convention will affect the scoring of the risk areas for introduction, with the potential for Sullom Voe, home to Europe's largest Oil Terminal and high levels of ballast water exchange, to be reclassified. This may change monitoring prioritisation in Shetland and highlights the importance of reassessing risks once interventions have been put in place. The use of a risk management framework allows for adaptive management to be implemented, reflecting changing international and local practice.

The NAFC Marine Centre UHI has taken on the responsibility of the maintaining the biosecurity plan, monitoring for the presence of NNS and responding to licence applications as part of its role within the Shetland Marine Planning Partnership. However, monitoring compliance by ports and harbours and marina users to these voluntary management measures is beyond the resources of the marine planning partnership. Enforcing biosecurity measures relating to vessel movement (e.g. ballast exchange and hull fouling) would be most effectively achieved at an individual marina or port/harbour level. Resourcing and assigning responsibility for this enforcement and monitoring has not been addressed within the UK, undermining biosecurity planning.

Here we highlight the role marine communities play in reducing the risks posed by NNS and biosecurity planning using a framework which can be replicated in other regions. However, without international collaboration and agreed measures, many communities primary defence against the risks posed by NNS are post-border control, which is considered the least effective way to tackle NNS with many control or eradication attempts unsuccessful (Forrest et al. 2009). Legislation and high-level policy (national or international) need to continue to move beyond aspirational goals and expand to specific measures and infrastructure to reduce the risks posed by NNS.

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Authors' contribution

Rachel Shucksmith was responsible for securing funding for this research, and research conceptualisation. She was responsible for some elements of data analysis and collection, and co-writing the manuscript. Samuel Collin was responsible for the developing the biosecurity plan, investigation and data collection. He was responsible for co-writing the manuscript.

Ethics and permits

All work was undertaken to NAFC Marine Centre UHI ethics standards and protocols.

References

Adams TP, Miller R, Aleynik D, Burrows M (2014) Offshore Marine Renewable Energy Devices as Stepping Stones across Biogeographical Boundaries. *Journal of Applied Ecology* 51: 330–338, https://doi.org/10.1111/1365-2664.12207

Alharbi W, Petrovskii S (2019) Effect of Complex Landscape Geometry on the Invasive Species Spread: Invasion with Stepping Stones. *Journal of Theoretical Biology* 464: 85–97, https://doi.org/10.1016/j.jtbi.2018.12.019

Apte S, Holland BS, Godwin SL, Gardner JPA (2000) Jumping Ship: A Stepping Stone Event Mediating Transfer of a Non-Indigenous Species Via a Potentially Unsuitable Environment. *Biological Invasions* 2: 75–79, https://doi.org/10.1023/A:1010024818644

Ashton G, Boos K, Shucksmith R, Cook E (2006) Rapid Assessment of the Distribution of Marine Non-Native Species in Marinas in Scotland. *Aquatic Invasions* 1: 209–213, https://doi.org/10.3391/ai.2006.1.4.3

Bax N, Hewitt C, Campbell M, Thresher R (2002) Man-Made Marinas as Sheltered Islands for Alien Marine Organisms: Establishment and Eradication of an Alien Invasive Marine Species. In: Veitch CR, Clout MN (eds), Turning the Tide: The Eradication of Invasive Species. IUCN SSC Invasive Species Specialist Group. Gland Switzerland and Cambridge, UK, pp 26–29

Bax N, Williamson A, Aguero M, Gonzalez E, Geeves W (2003) Marine Invasive Alien Species: A Threat to Global Biodiversity. *Marine Policy* 27: 313–323, https://doi.org/10.1016/S0308-597X(03)00041-1

Beveridge C, Cook EJ, Brunner L, MacLeod A, Brown C, Manson FJ (2011) Initial Reponse to the Invasive Carpet Sea Squirt, *Didemnum vexillum*, in Scotland. Scottish Natural Heritage Commissioned Report No. 413, 32 pp

Blyth-Skyrme RE (2010) Options and Opportunities for Marine Fisheries Mitigation Associated with Windfarms. Final Report for Collaborative Offshore Wind Research Into the Environment Contract FISHMITIG09. London, 125 pp

Campbell M, Lenoard K, Primo, Hewitt C Marine Biosecurity Crisis Decision-Making: Two Tools to Aid "Go"/"No Go" Decision-Making. *Frontiers in Marine Science* 5: 331, https://doi.org/10.3389/fmars.2018.00331

Carlton JT (1996) Pattern, Process, and Prediction in Marine Invasion Ecology. *Biological Conservation* 78: 97–106, https://doi.org/10.1016/0006-3207(96)00020-1

Carlton JT, Geller JB (1993) Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. *Science* 261: 78–82, https://doi.org/10.1126/science.261.5117.78

Christensen NL, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, Franklin JF, MacMahon JA, Noss RF, Parsons DJ, Peterson CH, Turner MG, Woodmansee RG (1996) The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Applications* 6: 665–691, https://doi.org/10.2307/2269460

Clarke Murray C, Pakhomov EA, Therriault TW (2011) Recreational Boating: A Large Unregulated Vector Transporting Marine Invasive Species. *Diversity and Distributions* 17: 1161–1172, https://doi.org/10.1111/j.1472-4642.2011.00798.x

Colautti RI, MacIsaac HJ (2004) A Neutral Terminology to Define 'Invasive' Species. *Diversity and Distributions* 10: 135–141, https://doi.org/10.1111/j.1366-9516.2004.00061.x

Collin SB, Tweddle JF, Shucksmith RJ (2015) Rapid Assessment of Marine Non-Native Species in the Shetland Islands, Scotland. *Bioinvasions Records* 4: 147–155, https://doi.org/10.3391/bir.2015.4.3.01

Cook EJ, Payne RD, Macleod A (2014) Marine biosecurity planning - Identification of best practice: A review. Scottish Natural Heritage Commissioned Report No. 748, 46 pp

Cook EJ, Macleod A, Payne RD, Brown S (2015) Marine Biosecruity Planning Guidance for Producing Site and Operation-Based Plans for Preventing the Introduction and Spread of Invasive Non-Native Species in England and Wales Edited by Natural England and Natural Resources Wales, 35 pp

Cormier R, Kannen A, Elliott M, Hall P, Davies IM (2013) Marine and Coastal Ecosystem-Based Risk Management Handbook. ICES Cooperative Research Report No. 317, 60 pp

Coutts ADM, Taylor MD (2004) A Preliminary Investigation of Biosecurity Risks Associated with Biofouling on Merchant Vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 38: 215–229, https://doi.org/10.1080/00288330.2004.9517232

Diederich S, Nehls G, van Beusekom JEE, Reise K (2005) Introduced Pacific Oysters (*Crassostrea gigas*) in the Northern Wadden Sea: Invasion Accelerated by Warm Summers? *Helgoland Marine Research* 59: 97–106, https://doi.org/10.1007/s10152-004-0195-1

Ehler C, Douvere F (2009) Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-Based Management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Gudies No. 53, ICAM Dossier No. 6, UNESCO, Paris, 96 pp

Elton CS (1958) The Ecology of Invasions by Animals and Plants. Springer, Boston, MA, 181 pp, https://doi.org/10.1007/978-1-4899-7214-9

Eno C (1994) Monitoring the Temperature Regimes of Which the Pacific Oyster *Crassostrea gigas* Is Subject to in Coastal Inlets in Britain (The Fleet Lagoon and Teign and Dart Estuaries) in Relation to Their Reproductive Success. Report for the JNCC, 17 pp

Eno CN, Robin CA, Sanderson WG (1997) Non-Native Marine Species in British Waters : A Review and Directory. Joint Nature Conservation Committee, 136 pp

Enshaei H, Mesbahi E (2009) The Control of Spread of Non Indigenous Species through Ballast Water - RP577- Part A, Newcastle University, UK, 58 pp

ERT (Scotland) Ltd. (2006) Report No. 209 Site Condition Monitoring: Surveys of Lagoons in The Vadills Lagoon Special Area of Conservation, July-August 2003 (ROAME No F02AA409c) Commissioned Report No. 209, 172 pp

Floerl O, Inglis G, Hayden BJ (2005) A Risk-Based Predictive Tool to Prevent Accidental Introductions of Nonindigenous Marine Species. *Environmental Management* 35: 765–778, https://doi.org/10.1007/s00267-004-0193-8

Fofonoff PW, Ruiz GW, Steves B, Carlton JT (2003) In Ships or on Ships? Mechanisms of Transfer and Invasion for Non-Native Species to the Coasts of North America. In: Ruiz GM, Carlton JT (eds), Invasive Species: Vectors and Management Strategies, Island Press, Washington, DC, pp 152–182

Forrest BM, Gardner JPA, Taylor MD (2009) Internal Borders for Managing Invasive Marine Species. *Journal of Applied Ecology* 46: 46–54, https://doi.org/10.1111/j.1365-2664.2008.01544.x

Gollasch S (2002) The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. *Biofouling* 18: 105–121, https://doi.org/10.1080/08927010290011361

Hay CH (1990) The Dispersal of Sporophytes of *Undaria pinnatifida* by Coastal Shipping in New Zealand, and Implications for Further Dispersal of *Undaria* in France. *British Phycological Journal* 25: 301–313, https://doi.org/10.1080/00071619000650331

Hellmann JJ, Byeres JE, Bierwagen BG, Dukes JS (2008) Five Potential Consequences of Climate Change for Invasive Species. *Conservation Biology* 22: 534–543, https://doi.org/10.1111/j.1523-1739.2008.00951.x

Hiscock K, Hiscock S, Baker JM (1978) The Occurrence of the Barnacle *Elminius modestus* in Shetland. *Journal of the Marine Biological Association of the United Kingdom* 58: 627–629, https://doi.org/10.1017/S0025315400041278

Hooper DU, Chapin III, Ewel J, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardle DA (2005) Effects Of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. *Ecological Monographs* 75: 3–35, https://doi.org/10.1890/04-0922

Hulme PE (2009) Trade, Transport and Trouble: Managing Invasive Species Pathways in an Era of Globalization. *Journal of Applied Ecology* 46: 10–18, https://doi.org/10.1111/j.1365-2664.2008.01600.x

Irvine DEG, Guiry MD, Tittley I, Russell G (1975) New and Interesting Marine Algae from the Shetland Isles. *British Phycological Journal* 10: 57–71, https://doi.org/10.1080/00071617500650061

Kakkonen JE, Worsfold, TM, Ashelby CW, Taylor A, Beaton K (2019) The Value of Regular Monitoring and Diverse Sampling Techniques to Assess Aquatic Non-Native Species: A Case Study from Orkney. *Management of Biological Invasions* 10: 46–79, https://doi.org/10.3391/mbi.2019.10.1.04

Lehtiniemi M, Ojaveer Henn, Matej D, Bella G, Gollasch S, McKenzie C, Minchin D, Occhipinti-Ambrogi A (2015) Dose of Truth - Monitoring Marine Non-Indigenous Species to Serve Legislative Requirements. *Marine Policy* 54: 26–35, https://doi.org/10.1016/j.marpol.2014.12.015

Locke A, Carman M, Lambert G (2009) Adventures of a Sea Squirt Sleuth: Unraveling the Identity of *Didemnum vexillum*, a Global Ascidian Invader. *Aquatic Invasions* 4: 5–28, https://doi.org/10.3391/ai.2009.4.1.2

Loxton J, Macleod AK, Nall CR, McCollin T, Machado I, Simas T, Vance T, Kenny C, Want, A, Miller RG (2017) Setting an Agenda for Biofouling Research for the Marine Renewable Energy Industry. *International Journal of Marine Energy* 19: 292–303, https://doi.org/10.1016/j.ijome.2017.08.006

Lyall C, Tait J (2004) Shifting Policy Debates and the Implications for Governance. In: Lyall C, Tait J (eds), New Modes of Governance: Developing an Integrated Policy Approach to Science, Technology, Risk and the Environment. Ashgate, Aldershot, UK, pp 1–18

Mack RN, Simberloff D, Lonsdale W, Evans M, Clout H, Bazzaz M, Fakhri A (2000) Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications* 10: 689–710, https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Meyerson L, Reaser J (2002a) A Unified Definition of Biosecurity. *Science* 295: 44, https://doi.org/10.1126/science.295.5552.44a

Meyerson L, Reaser J (2002b) Biosecurity: Moving toward a Comprehensive Approach. *BioScience* 52: 593–600, https://doi.org/10.1641/0006-3568(2002)052[0593:BMTACA]2.0.CO;2

Mills PR, Dehnen-Schmutz K, Ilbery B, Jeger M, Jones G, Little R, MacLeod A, Parker S, Pautasso M, Pietravalle S, Maye D (2011) Integrating Natural and Social Science Perspectives on Plant Disease Risk, Management and Policy Formulation. *Philosophical Transactions of the Royal Society B: Biological sciences* 366: 2035–2044, https://doi.org/10.1098/rstb.2010.0411

Minchin D, Gollasch S (2003) Fouling and Ships' Hulls: How Changing Circumstances and Spawning Events May Result in the Spread of Exotic Species. *Biofouling* 19: 111–122, https://doi.org/10.1080/0892701021000057891

Minchin D, Davis MH, Davis ME (2006) Spread of the Asian Tunicate *Styela clava* Herdman, 1882 to the East and South-West Coasts of Ireland. *Aquatic Invasions* 1: 91–96, https://doi.org/10.3391/ai.2006.1.2.7

Moore CG, Harries DB (2009) Appearance of *Heterosiphonia japonica* (Ceramiales: Rhodophyceae) on the West Coast of Scotland, with Notes on *Sargassum muticum* (Fucales: Heterokontophyta). *Marine Biodiversity Records* 2: e131, https://doi.org/10.1017/S1755267209990509

NAFC Marine Centre UHI (2014) Shetland Islands' Marine Spatial Plan. NAFC Marine Centre, UK, 202 pp

Nall CR, Guerin AJ, Cook EJ (2015) Rapid Assessment of Marine Non-Native Species in Northern Scotland and a Synthesis of Existing Scottish Records. *Aquatic Invasions* 10: 107–121, https://doi.org/10.3391/ai.2015.10.1.11

Naylor RL, Williams SL, Strong DR (2001) Aquaculture - A Gateway for Exotic Species. *Science* 294: 1655–1656, https://doi.org/10.1126/science.1064875

Oswalt S, Oswalt C, Crall A, Rabaglia R, Schwartz MK, Kerns BK (2021) Inventory and Monitoring of Invasive Species. In: Poland TM, Patel-Weynand T, Finch DM, Miniat CF, Hayes DC, Lopez VM (eds), Invasive Species in Forests and Rangelands of the United States: A Comprehensive Science Synthesis for the United States Forest Sector. Springer International Publishing, Cham, pp 231–242, https://doi.org/10.1007/978-3-030-45367-1_10

Pearce F, Peeler E, Stebbing P (2012) Modelling the Risk of the Introduction and Spread of Non-Indigenous Species in the UK and Ireland. Project Report for E5405W, CEFAS, UK, 47 pp

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and Economic Costs of Nonindigenous Species in the United States. *BioScience* 50: 53–65, https://doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2

Piola RF, McDonald JI (2012) Marine Biosecurity: The Importance of Awareness, Support and Cooperation in Managing a Successful Incursion Response. *Marine Pollution Bulletin* 64: 1766–1773, https://doi.org/10.1016/j.marpolbul.2012.06.004

Reed MS, Curzon R (2015) Stakeholder Mapping for the Governance of Biosecurity: A Literature Review. *Journal of Integrative Environmental Sciences* 12: 15–38, https://doi.org/10.1080/1943815X.2014.975723

Ruiz GM, Fofonoff PW, Steves B, Foss SF, Shiba SN (2011) Marine Invasion History and Vector Analysis of California: A Hotspot for Western North America. *Diversity and Distributions* 17: 362–373, https://doi.org/10.1111/j.1472-4642.2011.00742.x

Ryland JS, Holt R, Loxton J, Jones Spencer Jones ME, Porter JS (2014) First Occurrence of the Non-Native Bryozoan *Schizoporella japonica* Ortmann (1890) in Western Europe. *Zootaxa* 3780: 481–502, https://doi.org/10.11646/zootaxa.3780.3.3

Sambrook K, Holt R, Sharp HF, Rowland G, Roche K, Newstead RC, Wyn RG, Jenkins G, Stuart R (2014) Capacity, Capability and Cross-Border Challenges Associated with Marine Eradication Programmes in Europe: The Attempted Eradication of an Invasive Non-Native Ascidian, *Didemnum vexillum* in Wales, United Kingdom. *Marine Policy* 48: 51–58, https://doi.org/10.1016/j.marpol.2014.03.018

Shelmerdine RL (2015) Teasing out the Detail: How Our Understanding of Marine AIS Data Can Better Inform Industries, Developments, and Planning. *Marine Policy* 54: 17–25, https://doi.org/10.1016/j.marpol.2014.12.010

Shelmerdine RL, Mouat B, Shucksmith RJ (2017) The Most Northerly Record of Feral Pacific Oyster *Crassostrea gigas* (Thunberg, 1793) in the British Isles. *BioInvasions Records* 6: 57–60, https://doi.org/10.3391/bir.2017.6.1.09

Shetland Marine Planning Partnership (2019) Draft Shetland Islands Regional Marine Plan. NAFC Marine Centre UHI, 162 pp

Shucksmith RJ, Shelmerdine RL (2015) A Risk Based Approach to Non-Native Species Management and Biosecurity Planning. *Marine Policy* 59: 32–43, https://doi.org/10.1016/j.marpol.2015.05.001

Shucksmith RJ, Gray L, Kelly C, Tweddle JF (2014) Regional Marine Spatial Planning - The Data Collection and Mapping Process. *Marine Policy* 50: 1–9, https://doi.org/10.1016/j.marpol.2014.05.012

Simberloff D, Ingrid MP, Windle PN (2005) Introduced Species Policy, Management, and Future Research Needs. *Frontiers in Ecology and the Environment* 3: 12–20, https://doi.org/10.1890/1540-9295(2005)003[0012:ISPMAF]2.0.CO;2

Staurt J (2014) Commonwealth Flotilla Biosecurity Plan RYAS Management Committee. Royal Yachting Association Scotland, 6 pp

UNESCO (2021) "UNESCO". http://msp.ioc-unesco.org/world-applications/overview/ (accessed 4 July 2021)

Vye S, Wynne-Jone S, Masterson-Algar P, Jenkins S.(2020) Exploring perceptions of marine biosecurity interventions: insights from the commercial marina sector. *Marine Policy* 118: 104027, https://doi.org/10.1016/j.marpol.2020.104027

Wasson B, De Blauwe H (2014) Two New Records of Cheilostome Bryozoa from British Waters. *Marine Biodiversity Records* 7: e123, https://doi.org/10.1017/S1755267214001213

Weigle SM, Smith LD, Carlton JT, Pederson J (2005) Assessing the Risk of Introducing Exotic Species via the Live Marine Species Trade. *Conservation Biology* 19: 213–223, https://doi.org/10.1111/j.1523-1739.2005.00412.x

Williams F, Eschen R, Harris A, Djeddour D, Pratt C, Shaw RS, Varia S, Lamontagne-Godwin J, Thomas SE, Murphy ST (2010) The Economic Cost of Invasive Non-Native Species on Great Britain. Report number CAB/001/09, CAIB, Wallingford, 198 pp

Supplementary material

The following supplementary material is available for this article:

Table S1. Environmental management frameworks, biosecurity plans and guidance reviewed to develop biosecurity management framework.

Table S2. International, national and local legislation and policy reviewed to guide biosecurity plan requirements and structure.

Figure S1. Total risk level and sensitivity for the introduction of non-native species.

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