A risk based approach to non-native species management and biosecurity planning

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ABSTRACT

The introduction of non-native species (NNS) is becoming an increasing problem across the globe. The need to identify and manage the pathways of their introduction has been identified as a priority for biosecurity management. There is a clear role for marine spatial planning to provide a multi-sector framework to assist in this management. A risk-based approach to identifying pathways and areas of introduction has been developed for the Shetland Islands (north Scotland), as part of the Shetland Islands' Marine Spatial Plan, Scotland. Working closely with local stakeholders was key to this process, which incorporates local and national data sets to form a high resolution model. It has been successfully used within the SIMSP and to guide the development of the Biosecurity Plan for the Shetland Islands. It also highlights the requirements for national and local legislation and policy to address and reduce all pathways within a region.

Keywords: non-native species, biosecurity planning, marine management, marine spatial planning, risk modelling

1. INTRODUCTION

The distributions of marine taxa are limited by natural barriers to their dispersal [1], including geographical distance, temperature gradients, and current regimes. Over the last 150 years, human activities have increasingly been altering and bridging these barriers [2] leading to an increased and unnatural distribution of many species. Species which have been intentionally or unintentionally introduced outside their native range are referred to as 'non-native species' (NNS) [3].

The introduction of NNS has the potential to have significant impacts on biodiversity as well as serious economic and social consequence [4], with the rate of introduction increasing across Europe [5]. As a result a range of legislative measures have been developed which target the vectors and pathways of introduction of NNS, and their subsequent impacts [5]. Within the European Union the main policy and legislative drivers to target marine NNS are the Marine Strategy Framework Directive (MSFD), the Biodiversity Strategy [6,7], and EU Regulation No. 1143/2014 on Aquatic Invasive Species [8]. Internationally the Convention on Biological Diversity (CBD) sets a series of guiding principles to address the impacts of NNS [3].

The MSFD requires that all member states achieve 'Good Environmental Status' (GES) of marine ecosystems by 2020, evaluated across 11 descriptors [9]. The impacts of NNS are evaluated as one of these descriptors, with member states required to ensure that "non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem" [9]. Whilst the EU Biodiversity Strategy aims that by 2020 "Invasive alien species (IAS) and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new IAS" [7].

The CBD proposes a hierarchical structure for tackling the spread of NNS, with prevention identified as the initial most cost-effective strategy, with eradication, containment, control and mitigation necessary if an introduction occurs. The management of the pathways of NNS introduction is therefore central to preventative management [10].

Introduction pathways may involve either accidental or intentional movement of species as a consequence of human activities [11,12]. Ballast water and hull fouling, associated with maritime activity, are responsible for the vast majority of accidental marine translocations around the world [13,14,15,16]. Non-native species have also been introduced deliberately for aquaculture purpose, which has also caused the accidental introduction of other NNS as hitchhikers [17].

The ability for a NNS to survive and become established in a new area is dependent on a number of environmental factors such as temperature, pH, salinity and pollution levels [18]. However, manmade structures can act as stepping stones for NNS in areas where they otherwise would not be able to survive, through the provision of hard substrate. These physical habitats, or habitat-islands, (e.g. piers, breakwaters, seawalls, docks and marinas, boat hulls, and ballast tanks) often support assemblages that are distinct from neighbouring communities [19]. This can make them more susceptible to the establishment of NNS.

Reducing the risk of the introduction of a NNS through pathway management of NNS is complex, especially in the marine environment [20]. However, by identifying the areas around the coastline where there are high levels of activity related to introduction pathways it is possible to obtain an indication of the likelihood of a species being introduced at that location [20]. This approach has been used to identify introduction hotspots around the UK in 70 × 70 km grid squares [20]. The purpose of an assessment will influence the level of spatial detail or resolution that will be appropriate, however the availability, accuracy, and resolution of the underlying data may also have a significant influence. For strategic national decision making it is likely that a lower resolution would be adequate to drive decision making compared to more localised planning, where a higher resolution is likely to be required.

In Scotland management of NNS is primarily driven by the Wildlife and Natural Environment (Scotland) Act 2011 (WANE Act) and the Wildlife and Countryside Act (1981). The WANE Act places personal responsibility directly onto all marine users (both commercial and recreational users) to prevent the spread and introduction of NNS. Whilst the overarching management and use of the marine environment is primarily driven by the Marine Scotland Act 2010 (the 'Marine Act'). The Marine Act sets out a framework for the development of both a National Marine Plan for Scotland and also a series of 11 locally managed regional marine plans. These plans can help to provide an overarching multi-sector framework for the development of biosecurity plans, which can help to identify pathways of introduction to ensure compliance with both national and international legislative and policy requirements relating to NNS.

The National Marine Plan for Scotland was formally adopted in March 2015, and is now being followed by the phased development and implementation of regional marine planning. The first areas identified to develop regional marine plans are the Shetland Islands and the Clyde. One of the reasons these areas have been chosen is they initially trialled marine planning through a Scottish Government funded pilot 'Scottish Sustainable Marine Environment Initiative' (SSMEI) from 2006 to 2010. Since the end of the pilot scheme support form Marine Scotland has allowed their continued development. This has enabled both areas to integrate biosecurity planning into the marine spatial planning process through the development of biosecurity plans. These biosecurity plans have incorporated NNS monitoring, awareness raising, and advice on prevention and eradication of NNS.

To identify the areas of the Shetland coast subject to the highest risk of the introduction of NNS an assessment of pathways and stepping stones has been undertaken using 5 × 5 km grid square resolution. In addition, an assessment has been undertaken to identify areas which are most sensitive to the impacts from the introduction of NNS, either through their economic or ecological value to enable the monitoring of these areas. The model outputs will enable targeted monitoring for marine NNS. The outputs will also help the development of specific policies to reduce the risk of introduction of NNS, helping to guide decision making.

2. METHOD

2.1 Risk mapping

To identify spatially varying 'risk level' for the introduction and establishment of NNS a model was developed in ArcGIS® 10.2, using the spatial analysis toolbox and model builder. This was developed through a five step process:

- Identification of pathways and stepping stones (see Section 2.1.1)
- Collection and mapping of spatial data (see Section 2.1.2)
- Assigning a risk score to each activity (see Section 2.1.3)
- Model creation in ArcGIS
- Mapping overall risk

2.1.1 Identification of pathways and stepping stones

Potential pathways for the introduction of NNS were identified from the current literature. The pathways identified as relevant to the Shetland marine area were:

- Vessel biofouling
- Transport within ballast water
- The movement of farmed finfish and well boat water into Shetland from other parts of the UK and Europe

Other identified pathways include the import of live seafood, ornamental fish and bait. However these industries do not exist in Shetland. In addition the import of shellfish for aquaculture purposes can pose a biosecurity risk, however in Shetland this does not currently occur, with the shellfish industry relying on natural spat settlement.

Manmade structures that can form stepping stones for the establishment and spread of NNS were identified as:

- Marine access infrastructure e.g. marinas, jetties, breakwaters, piers
- Marine renewable devices
- Aquaculture equipment (finfish, shellfish, and seaweed farms)

2.1.2 Collection and mapping of spatial data

Data on the distribution of marine activities identified as potential NNS pathways and stepping stones were compiled from publicly available data held within the Shetland Islands' Marine Spatial Plan (SMSP) [21], with the exception of shipping data which utilised Automatic Identification System (AIS) data held by the NAFC Marine Centre but is not publicly available, Table 1. Prior to inclusion in the sub-models initial data manipulation was required to allow the data to be converted to intensity levels within 5 × 5 km grid squares using the 'fish net' tool in ArcGIS.

(*Table 1 about here*)

2.1.2.1 Shipping- Hull biofouling:

Spatial and temporal variation in shipping activity was calculated using AIS data collected from a single point receiver positioned centrally in Shetland [23]. AIS is a shipboard transponder which automatically transmits vessel information in a data package termed a ping, through VHF, as a ship to ship or ship to shore signal. Each ping provides information on the position of vessels every three minutes when steaming and every ten minutes when in port. It also provides a range of information including a vessel identifier, position, time stamp, speed, course, vessel type and dimensions, destination, and last port of call [24].

Processed AIS data collected from January to December 2013 was split into 11 shipping types; recreation/pleasure, aquaculture well boats (live fish transport), oil/chemical tankers, research/survey vessels, passenger, oil related, inter island ferries, harbour, fishing vessels, cargo ships and 'other'.

AIS data also provides information on the last port of call of each vessel, this information was used to establish the spatial distribution of shipping traffic and whether Shetland could be an initial introduction point for NNS or whether the secondary spread of already established NNS from elsewhere in Europe would be the primary pathway.

To calculate the risk of the NNS introduction from biofouling, shipping intensity was calculated from AIS data for 5 × 5 km grid squares for each shipping type. As shipping data was collected every three minutes, shipping intensity was converted to a daily risk level by dividing by 240.

2.1.2.2 Ballast water exchange

The volume of water released through ballast water exchange was calculated using published port statistics relating to the number and type of visiting vessel. Uniquely in the UK Sullom Voe records the volume of ballast water exchanged each year, although it will vary each year depending on the number of tanker visits [25]. For Lerwick and Scalloway harbours the size and type of the vessel can be used to estimate the volume of ballast likely to be exchanged from port statistics [26]. Only cargo vessels, tankers, passenger, oil related, and well boats were used to calculate ballast water exchange volumes as ships only need to exchange ballast when taking on board additional cargo. Ballast water exchange values were calculated for 5 × 5 km grid squares for Shetland's main harbours (Sullom Voe, Scalloway, and Lerwick).

2.1.2.3 Aquaculture species movement

In Shetland nearly all finfish farms bring smolts (juvenile fish) from the UK mainland every second year via live fish transfer in a well boat to sea sites for on-growing. To calculate the risk associated with fish import finfish farm intensity was calculated for 5 × 5 km grid squares.

2.1.2.4 Stepping stones

To calculate the increased risk of establishment of NNS from the provision of hard substrate the intensity of each type of manmade structures (marine access infrastructure, marine renewables, and aquaculture production sites) was calculated in 5 × 5 km grid squares.

2.1.3 Assigning risk scores

The risk score associated with each pathway and stepping stone was calculated using three criteria; probability of introduction through the activity, frequency of the activity, and the confidence in the data relating to the activity (Table 2). This approach has been adapted from the cumulative pressure risk mapping undertaken within the SMSP [27]. The probability of introduction was assessed from literature review including international reviews (e.g. [28, 29] and national assessments (e.g. [20,30,31.32]), whilst taking account local mitigation or local industry specific practices. The frequency of an activity and confidence in the data available was assessed from local data sets. Higher overall scores were associated with a higher risk (Table 3), a worked example for biofouling due to transportation for each vessel type is given in Table 4.

Risk scores were assigned within four distinct sub-models; the risk of introduction through biofouling, the risk of introduction through ballast water exchange, the risk of introduction due to the aquaculture species movement, and the risk of establishment through the presence of manmade structures (stepping stones). Risk scores from each sub-model were combined using the ‘weighted sum’ tool in ArcGIS, to produce a relative risk map for the Shetland Islands.

(*Table 2, 3, 4 about here*)

2.2 Sensitivity mapping

In order to identify spatially varying relative ‘sensitivity level’ to the introduction and establishment of NNS a risk model was developed in ArcGIS 10.2, using the spatial analysis toolbox and model builder. Data sources were identified and mapped in 5 × 5 km grid squares as per section 2.1.2. Sensitivity was identified through literature review [e.g. 33,34], with relative sensitivity mapping separated into two distinct sub-models, one focusing on economically sensitive areas and one focusing on ecologically sensitive areas.

2.2.1 Economic sensitivity

Marine activities that were identified as having the potential to be directly impacted by NNS were identified as finfish farms, shellfish farms, seaweed farms, and fisheries. The intensity of these economically important marine activities was calculated for 5 × 5 km grid squares using the ‘fish net’ tool in ArcGIS. A relative sensitivity score was assigned based on the relative likelihood each activity will be impacted by NNS, with a higher score associated with a higher risk (Table 5).

(*Table 5 about here*)

2.2.2 Ecological sensitivity

Areas considered of high ecological value were identified and their presence was calculated for 5 × 5 km grid squares. Sensitive areas were identified as those areas designated for nature conservation purposes including Special Areas of Conservation (SAC), Special Protection Areas (SPAs), Marine Protected Areas (MPAs), and Sites of Special Scientific Interest (SSSI). A relative score was assigned based on the ecological value of each area with a higher score associated with a higher risk (Table 6).

(*Table 6 about here*)

2.2.3 Sensitivity mapping

Relative sensitivity of areas to NNS was calculated by overlaying the economic and ecological sensitivity model outputs. Prior to overlaying fuzzy logic, a tool used in GIS to compare disparate features, was used to rescale the sensitivities range from 0 to 1 (with one being the highest sensitivity). This ensured that economic and ecological sensitivity were given equal weight.

2.3 Model testing

Model resilience was assessed for both risk and sensitivity mapping by doubling the weighting of each model component and comparing the results to the equal weighting model output. For the risk model, each of the potential pathways and stepping stones for NNS were doubled in the final summation step of the model. For the sensitivity model, the economic and ecological components were doubled in the final summation step of the model, and each model output re-scaled.

3. Results

3.1 Risk model

3.1.1 Model data

3.1.1.1 Shipping- ballast water exchange

Estimates of yearly ballast water exchange volumes indicated the highest volumes occurred in Sullom Voe, followed by Lerwick and Scalloway port areas (19.47 MMT, 5.0 MMT, 1 MMT), Figure 1.

(Figure 1 about here)

3.1.1.2 Shipping- biofouling

Processed monthly AIS data from 2013 recorded 731 614 vessel pings, which related to over 200 vessels, 84% of these were recorded within the 12 nm limit. AIS data indicated that the last port of call showed a large geographical spread, including north and central America, Europe, north Africa, Scandinavia, Russia, and the Middle East (Figure 2). Shipping intensity mapping showed highest densities around the Shetland coast are associated with the Lerwick and Scalloway port areas, Figure 1.

(Figure 2 about here)

3.1.1.3 Stock movement

There were 144 finfish farms located around the Shetland Islands in 2014. Geographic spread of farm sites covered the majority of the coast with the exception of the southeast of Shetland. High intensity areas included the larger sheltered sounds e.g. between Yell and Unst, voes e.g. Swarbacks Minn, and between islands e.g. Burra Isles, Figure 1.

3.1.1.4 Manmade structures

There were 342 marine access infrastructure points (including piers, jetties, marinas, and quays), 144 fish farms, 163 shellfish farms, 3 seaweed farms and 2 licensed renewable sites. The highest intensity of marine structures was focused on harbour areas (Lerwick, Scalloway, Sullom Voe) and to a lesser extent sheltered sounds and voes, Figure 1.

3.1.2 Model results

Model outputs were mapped for overall risk (Figure 3). Relative risk was grouped into five 'levels' using natural breaks (also known as natural jenks) broken down by: low (total risk score <5), low-medium (5≤ total risk score <20), medium (20≤ total risk score <50), high (50≤ total risk score <166), and very high (total risk score ≥166). Two grid squares were classified as 'very high' risk (Lerwick harbour), four as 'high' risk (Sullom Voe harbour, Scalloway harbour, and outer Lerwick harbour) and four 'medium' risk (outer Scalloway harbour, Swarbacks Minn, Vaila Sound, and Symbister harbour) a further 30 areas were classified as 'low-medium' risk. Visual assessment by stakeholders of the final model output confirmed the results were realistic, e.g. areas of high activity were areas of high risk.

(*Figure 3*)

3.2 Sensitivity model

3.2.1 Model data

3.2.1.1 Economic sensitive areas

The economic sensitivity sub-model indicated the highest economic sensitivity occurred in Scalloway, Burra Isle, Collafirth Ness, Vementry Sound, Swarbacks Minn, and Collievoe (Yell), Figure 4.

3.2.1.2 Ecologically sensitive areas

There were 53 areas in Shetland designated for their ecological importance (13 SAC, 13 SPAs, 25 SSSI, and two MPAs). Ecologically important areas were found all around the Shetland coast, with Fetlar, north Yell Sound, and Mousa showing the highest density of ecologically important areas, Figure 4.

(Figure 4 about here)

3.2.2 Model results

Model outputs were mapped for overall sensitivity to the introduction of NNS (Figure 5). Relative sensitivity was grouped into five 'levels' using natural breaks (Figures 5): low (total risk score <0.2), low-medium (0.2≤ total risk score <0.5), medium (0.5≤ total risk score <0.7), high (0.7≤ total risk score <1.0), and very high (total risk score ≥1.0). Three grid squares were classified as 'very high' sensitivity (south Unst, Hascosay sound, and Swarbacks Minn), seven as 'high' risk (north and west Fetlar, Ronas Voe, Vementry, Burra Isle, and Collafirth Ness) and 28 as 'medium' risk, with a further

38 areas classified as 'low-medium' risk. Visual assessment by stakeholders of the final model output confirmed the results were realistic, e.g. areas of high value were identified as areas of highest risk.

(*Figure 5 about here*)

3.3 Model resilience

The doubled weighting model outputs (Figures 6 and 7) were compared to the equal weighting model output (Figures 3 and 5) to assess model output resilience. Testing of the 'risk' model indicated that the areas associated with high risk or above did not alter when weighting of the ballast water exchange or aquaculture stock movement model was doubled (Table 7). However, a small increase in the number of areas of high risk and above was seen by doubling the weighting of the 'biofouling' sub-model, creating one additional grid square in the fishing harbour Symbister. Increasing the weighting of marine structures had the greatest impact (+2, Table 7), with outer Scalloway harbour and Vaila Sound (aquaculture production areas) also becoming classified as 'high' risk. Model iterations were visually compared to the equal weight model and whilst the change in model outputs were small it was felt the additional areas classified as 'high' did not accurately reflect additional risk, with the equal weighting model providing a better reflection of the relative risk levels.

(*Table 7 about here*)

Testing of the 'sensitivity' model indicated that the areas associated with high risk or above reduced when economic and ecological sensitivity was doubled, and then re-classified using natural break Table 7). The overall number of areas classified as relatively 'high' or 'very high' sensitivity decreased when model components were doubled. Model iterations were visually compared to the equal weight model and it was considered that the double weighted models under-represented sensitivity.

(*Table 7 about here*)

(*Figure 6 and 7 about here*)

4. Discussion

The modelled outputs indicate that the Shetland coastline has a spatially varying risk level and sensitivity to the introduction and establishment of non-native species (NNS). This spatial variation is not homogenous or random, with highest risk levels centred on the main ports, and inshore areas associated with highest levels of marine developments and activities (e.g. shipping, shore access points, and marine aquaculture). Economic, social, and cultural use of the marine environment are often focused in the near-shore environment, due to ease of access, costs and technical constraints associated with accessing resources further offshore [35]. It is therefore not surprising that these inshore areas are associated with the highest risk of introduction and establishment of NNS.

Areas of high economic sensitivity are not identical to areas of highest risk, this is because economically important activities are dispersed around the Shetland coast, whilst highest risk areas are associated with the main ports which act as hubs for transportation and as access points to activities which take place elsewhere (e.g. aquaculture or fisheries). In contrast, ecological sensitivity is widespread around the Shetland coast; however few ecologically sensitive areas were identified offshore. This may reflect that the majority of evidence on the presence of ecologically important features is often concentrated close to land, in part due to the technical and monetary constraints of surveying further offshore [35]. This bias may be particularly pertinent when considering the potential ecological impacts of offshore developments (e.g. marine renewables, oil and gas), both through their potential to introduce NNS and to provide a suitable habitat for their establishment. Thus, areas with low ecological sensitivity are not necessarily without ecologically important features.

The identification of areas of high risk of introduction and establishment of NNS, and areas of high sensitivity allows a targeted, evidence based approach to NNS monitoring, enabling resources to be directed where they will be most effective. Whilst for this study a relative threshold score of 'high' was chosen as a level at which monitoring should be initiated, it could be altered if surveying indicated the threshold for monitoring was too high or if resources to undertake monitoring became more constrained. However, this does not preclude initial introduction occurring in areas classified as lower risk. To help reduce the chance that an introduction goes undetected, guidance leaflets have been developed to raise awareness amongst marine users and businesses to allow for public detection of NNS outside of monitored areas.

An effective monitoring programme can allow early detection and potential eradication if a potentially harmful NNS is detected, helping to ensure compliance with the MSFD and EU Biodiversity Strategy requirements. However, it is recognised that prevention is the most cost effective strategy for NNS management [3]. Understanding the pathways of the spread of NNS can allow the development of regulation, policies, and guidance targeted at identified risks and an assessment of their effects. It can also be used to assess the impacts of these management measures. Effective targeting of pathways is a key aim of the EU Biodiversity Strategy.

In Shetland shipping and ballast water exchange were identified as the most significant pathway for the introduction of NNS, with AIS data identifying direct shipping routes from a range of international locations; with ballast water exchange levels in Sullom Voe, one of the highest in the UK. Whilst the Biosecurity Plan for the Shetland Islands provides advice to marine users on measures to reduce the risk of spreading NNS, it is more challenging to reduce risks associated with vessels travelling to Shetland from elsewhere. Control of national and international shipping pathways will need to be addressed through national and international policy and legislation. Once enacted the International Convention for Control and Management of Ships' Ballast Water and Sediment [36] will seek to reduce the spread of NNS through ballast water management and control, but it is yet to be adopted as at least 30 states that represent 35% of the World's shipping must first ratify the convention. However, once implemented, this convention has the potential to reduce the risks associated with ballast water exchange.

Establishment through stepping stones and reducing secondary spread are more easily targeted at a local level. The use of both local datasets and locally verified national datasets within this model has meant that it contains a more exhaustive list of features and activities within the Shetland region than could be replicated nationally. Within Shetland the use of AIS data to assess shipping movement proved to be particularly valuable. Whilst shipping statistics are available for larger ports, potentially detailing the number and type of visiting vessels, they are not normally available for smaller ports, marinas or private jetties. Subsequently for more remote or rural locations limited data may be available, and shipping levels are more accurately calculated using AIS rather than port statistics only.

Whilst AIS provided a useful resource for this study there are some limitations in its use. In some parts of Shetland the AIS data showed distinct shadows due to land elevation interfering with the AIS signal [23], potentially reducing the accuracy of the subsequent risk assessment. This could be easily overcome by installing a network of AIS receiver aerials at appropriate positions around Shetland in order to maximise coverage [23].

AIS transmitter systems are fitted by many commercial vessels as a statutory requirement, in addition some vessels who fall outside these regulations have chosen to voluntarily fit AIS tracking systems for safety purposes [23]. However, there will still be a number of smaller commercial and recreational vessels that do not have AIS fitted, and therefore have not been included in the model. For some regions this could represent a significant proportion of shipping traffic, however due to Shetland's remote location and frequent inclement weather the number of vessels visiting Shetland which are not fitted with AIS will be relatively small. Whilst there are a number of vessels based in Shetland without AIS, these do not normally leave Shetland and therefore do not pose a significant risk for the introduction of NNS from elsewhere, although they would have the potential to contribute to secondary spread within Shetland.

Due to the spatial resolution of the available data the model output has a higher resolution (5 × 5 km grid squares) than has been used in a UK wide assessment (70 × 70 km grid squares) [20]. This higher resolution allows the identification of specific areas for monitoring and more detailed local and project level decision making. Whilst a higher resolution could have been used in the model, 5 × 5 km grid squares were considered appropriate as this resolution incorporated the area equivalent to a harbour or cluster of marine use (e.g. aquaculture farms operated by one company). It should however be noted that country wide assessments are used to drive the distribution of national resources and identify risk over a large area and for this scale of assessment a lower resolution is likely to be sufficient.

As the model has been developed using ArcGIS model builder and is publicly available via the NAFC Marine Centre website, it can also be used by other regions to develop their own monitoring programmes and biosecurity plans. However, model outputs are only as good as the input data. Stakeholder engagement, data confidence assessments, and model testing are important considerations when using spatial data to guide decision making [37,38].

Whilst there were no significant data gaps identified during the development of this project, relative risk scores were based on information from the current literature, whilst considering local industry practice. The actual and perceived risk of the introduction of NNS may change over time as new data becomes available, new management measures are introduced, including the implementation of local and national policies and legislation, and as new marine industries evolve. This may be particularly pertinent as the model results are being pro-actively used to identify and target 'risks' to help with the development of management measures. The model is however easily adapted to incorporate new information and risk as new data and information becomes available.

Whilst the model focuses on human mediated movement only, once a NNS has been introduced to a new area secondary spread can also occur due to natural spread through range expansion. Natural spread was not incorporated due to the relatively large distances between the Shetland Islands and the nearest land masses, which makes spread through natural dispersal unviable and unlikely for many species. However, on mainland Britain and Europe it is likely to be a more significant consideration as the distances between suitable areas for establishment will be smaller.

It is acknowledged that other risk assessment methodologies for NNS exist [e.g.20], however the approach used in this model is consistent with other assessments used within the Shetland Islands' Marine Spatial Plan, for example to assess and map cumulative pressures [27]. Non-native species monitoring results undertaken in 15 locations across Shetland from 2012 to 2014 appear to correlate with model predictions, with the highest number of NNS found in the areas associated with highest risk [39]. In addition model testing ensured confidence in the model outputs.

Decision support tools, such as GIS, are useful aids in planning future spatial and temporal uses of the marine environment [40]. Whilst model limitations are recognised, models can provide useful tools to understand the impacts of multi-sector marine use and its management. This is particularly pertinent to understanding the potential effects of marine spatial planning, which aims to take an ecosystem based approach to marine management [41]. This emerging approach has the potential to provide a useful tool to achieve the requirements of a range of legislation across a multitude of sectors, replacing the historical sectorial approach. In Shetland the integration of biosecurity planning into an overarching management framework has helped to identify risks, target resources, and ensure both licensed (e.g. aquaculture, renewables) and spatially unlicensed (e.g. recreation, shipping) are considered equally and appropriately targeted. However, it has also highlighted the limitations of local management and where international and national legislation is also required.

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Table 1: Data sets used within the of the risk assessment model

Pathway/ stepping stone	**Risk**	**Dataset**	**Year**	**Source**	**Confidence assessment score***
Pathway	Vessel biofouling	AIS data	2013	NAFC Marine Centre	Medium-high
Pathway	Ballast water	Port statistics	2013	NAFC Marine Centre	High
Pathway	Aquaculture species movement	Finfish farm location	2014	SMSP / Shetland Islands Council	High

Stepping stone	Marine access infrastructure	marina, jetty, breakwater, pier locations	2014	Various compiled by SMSP	High
Stepping stones	Marine renewable devices	Works licence locations	2014	SMSP/ Shetland Islands Council	High
Stepping stones	Aquaculture equipment finfish, shellfish and seaweed farms	Site consent locations (planning consent or works licence)	2014	SMSP/ Shetland Islands Council	High

* Source: NAFC Marine Centre [22]

Table 2: Model risk assessment criteria for the probability of an introduction (A), frequency of activity (B), and confidence in the data (C)

A	Rating	Probability of introduction	Commentary
	5	Definite	Well documented evidence of risk of introduction of NNS occurring during normal operations
	4	Likely	Some evidence of impact risk of introduction of NNS under normal operations
	3	Possible	Unknown level of risk of introduction of NNS
	2	Unlikely	Very little evidence of risk of introduction of NNS
	1	Remote	No evidence of risk of introduction of NNS
B	**Rating**	**Frequency of Activity**	**Commentary**
	5	Continual	Occurs continually e.g. hull fouling
	4	Regular	Every week
	3	Intermittent	Approximately once a month
	2	Brief	One-off event - over several days
	1	One-off event	One-off event - up to one day duration e.g. ballast water exchange
C	**Rating**	**Confidence in data**	**Commentary**
	3	High	A fixed location where the scale / extent of activity is known
	2	Medium	A fixed location but questionable source or scale / extent of activity.
	1	Low	An estimated location and questionable source or scale / extent of activity.

Table 3: Risk assessment score assigned to each marine activity or structure

Activity/structure	Risk	Risk Score
Ballast water exchange:	pathway	
- Cargo		0.18
- Tankers		0.31
- Passenger		0.18
- Oil related		0.18
- Well boat		0.18
Biofouling:	pathway	

- Cargo		0.43
- Fishing		0.08
- Harbour		0.08
- Oil related		0.37
- Other		0.37
- Passenger		0.37
- Internal Ferry		0.08
- Pleasure		0.54
- Research		0.28
- Tankers		0.43
- Well boat		0.37
Stock movement	pathway	0.18
Manmade structures:	stepping stone	
Marine access infrastructure		0.77
Aquaculture equipment:		
- finfish		0.62
-shellfish		0.62
-algae cultivation		0.62
Marine renewable device		0.62

Table 4: Risk assessment scores for NNS introduction through shipping biofouling, based on criteria A-C (detailed in Table 2).

vessel type	A	B	C	Total (B-C)	A*	Score
Cargo	4.00	5.00	2.00	7.00	28.00	0.70
Fishing	1.00	5.00	2.00	7.00	7.00	0.18
Harbour	1.00	5.00	2.00	7.00	7.00	0.18
Oil related	4.00	5.00	2.00	7.00	28.00	0.70
Other	4.00	5.00	2.00	7.00	28.00	0.70
Passenger	3.00	5.00	2.00	7.00	21.00	0.53
Internal Ferry	1.00	5.00	2.00	7.00	7.00	0.18
Pleasure	5.00	5.00	2.00	7.00	35.00	0.88
Research	3.00	5.00	2.00	7.00	21.00	0.53
Tankers	4.00	5.00	2.00	7.00	28.00	0.70
well boat	3.00	5.00	2.00	7.00	21.00	0.53

Table 5: Relative economic activity score for economically important activities.

Activity	**Relative sensitivity score (0-1)**
Finfish aquaculture	0.75
Shellfish aquaculture	1.00
Seaweed aquaculture	0.75
Fisheries	0.25

Table 6: Relative economic activity score for ecologically important activities.

Activity	**Relative sensitivity score (0-1)**
Special Areas of Conservation (SAC)	1.0

Special Protection Areas (SPAs)	0.75
Marine Protected Areas (MPAs)	0.5
Sites of Special Scientific Interest (SSSI)	0.5

Table 7: Testing model resilience, 'risk' sub-models were doubled in weighting within the final model summation. The number of grid squares at each risk level and the change in number of grid squares rated as 'high' or 'very high' are displayed.

Model weighting	**Medium**	**High**	**Very high**	**Increase in high or very high**
Equal weight	4	4	2	N/A
Ballast water exchange	4	1	5	0
Biofouling	5	4	3	+1
Stock movement	5	4	2	0
Marine structures	13	6	2	+2

Table 8: Testing resilience, 'sensitivity' sub-models were doubled in weighting within the final model summation. The number of grid squares (5×5 km) at each risk level and the change in number of grid squares rated as 'high' or 'very high' are shown.

Model weighting	**Medium**	**High**	**Very high**	**Increase in high or very high**
Equal weight	30	9	4	N/A
Economic x2	11	4	4	-5
Ecological x2	30	7	3	-3

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Figure captions

Fig. 1 Relative risk levels for each activity of structure; (a) ballast water exchange, (b) biofouling, (c) stock movement, (d) manmade structures. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 2 Origin of vessels travelling to Shetland in 2013, detected using AIS data. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 3 Total risk level for the introduction of non-native species, calculated as a summed total of risk layers. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 4 Relative sensitivity levels for (a) economic and (b) environmental variables. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 5 Total sensitivity level to the introduction of non-native species, calculated as a summed total of sensitivity layers. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 6 Total risk level for the introduction of non-native species, with weighting doubled for (a) ballast water exchange, (b) biofouling, (c) stock movement, (d) manmade structures. *Contains Ordnance Survey data © Crown copyright and database right 2011*

Fig. 7 Total sensitivity level to the introduction of non-native species, with weighting doubled for (a) economic and (b) environmental variables. *Contains Ordnance Survey data © Crown copyright and database right 2011*