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Research Article

Rapid assessment of marine non-native species in the Shetland Islands, Scotland

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Abstract

The Shetland Islands, northern Scotland, have a highly active and diverse maritime environment, and local marine industries form an important part of the local economy. The potential for damage caused by non-native species is high. As part of an assessment of the current status of non-native species in Shetland, a series of rapid assessment surveys, coupled with a settlement panel monitoring programme, were carried out at 18 sites between May 2012 and October 2014. Eight non-native species were detected in our surveys, three of which (*Corella eumyota* Traustedt, 1882; *Bugulina simplex* Hincks, 1886; and *Dasysiphonia japonica* (Yendo) Kim, 2012) had not been previously recorded. Observations by SCUBA also reported the first UK record of *Schizoporella japonica* Ortmann, 1890 growing on natural substrate. A literature review revealed three additional non-native species that have been documented in Shetland but were not detected in our survey work. The results from this study highlight the speed at which non-native species can spread over regional scales, and that more active harbours contain greater numbers of non-native species, indicating the potential of hull fouling and ballast water exchange for transporting non-native species.

Key words: invasive, United Kingdom, survey, tunicate, bryozoan, alga

Introduction

The potential for damage caused by non-native species (NNS: organisms that have been introduced to new environments outside their natural range via artificial means; Carlton 1996; Colautti and MacIsaac 2004) and the need for effective surveillance and monitoring, are becoming an increasing concern for governments, decision makers, industries, and conservationists (Mack et al. 2000; Hooper et al. 2005; Pimental et al. 2000). To ensure early detection of new introductions, and that managerial action is carried out appropriately and efficiently, it is important to assess the current status of NNS and identify potential pathways and threats (Hewitt et al. 2004).

In the Shetland Islands, northern Scotland, marine industries are fundamental to the local economy (Shetland Islands Council 2013) and have created a highly active and dynamic marine

economy (e.g. oil and gas, commercial shipping, fishing and aquaculture). Advances in marine technology and the globalisation of maritime trade have increased the number of international vessels visiting Shetland, particularly for shipping, oil and gas transportation, and tourism (Shelmerdine 2015), which has raised the potential for NNS introductions, particularly through hull fouling and ballast water exchange (Carlton and Geller 1993).

The high-level of international activity found in Shetland suggests it could be an initial point of entry to Europe for marine NNS from all over the world. Once introduced, the diverse array of national and regional maritime activity in Shetland could then spread NNS to other locations in the UK and Europe through secondary transportation (Clarke Murray et al. 2011; Sylvester et al. 2011). Likewise, the same links to mainland UK and Europe provide a pathway for NNS established in these areas to be introduced to Shetland.

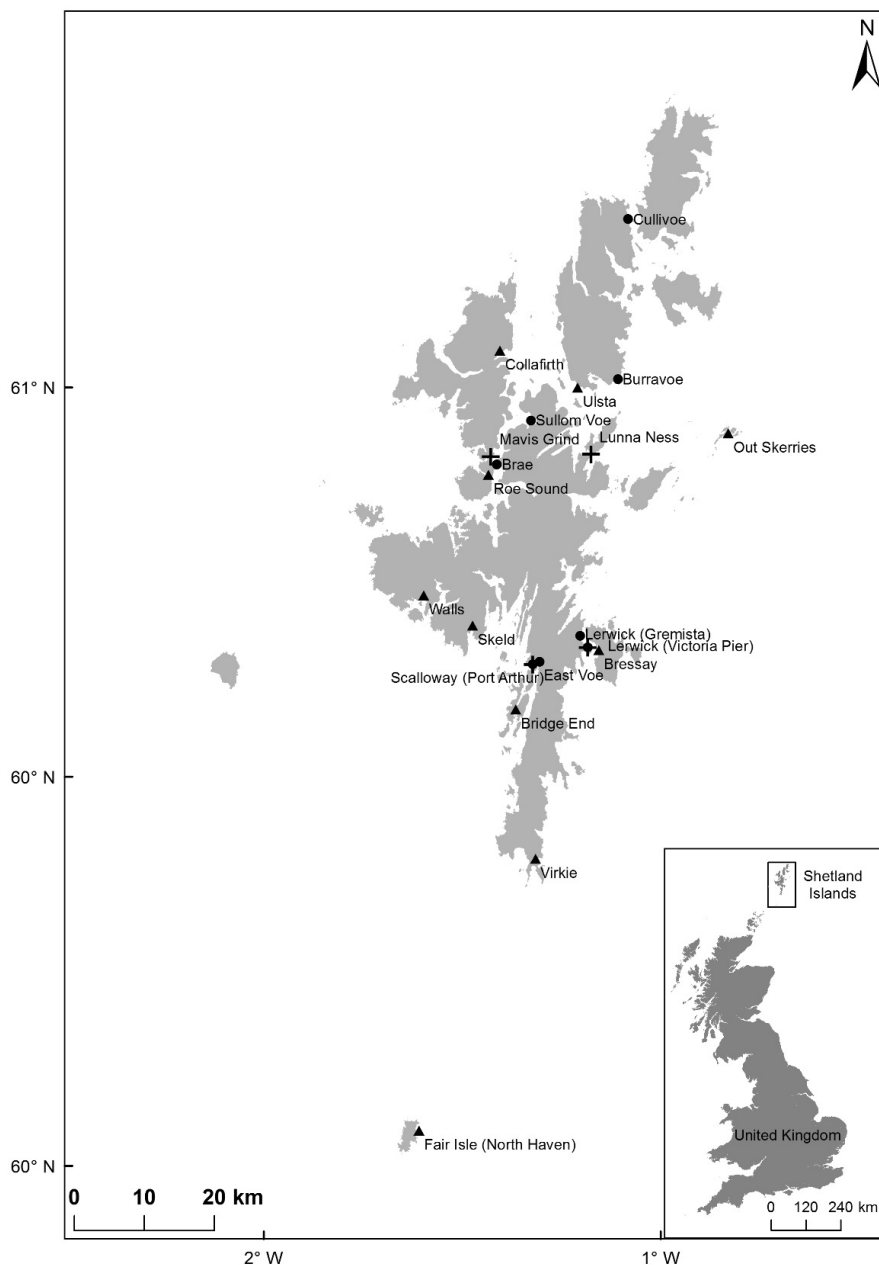


Figure 1. Map of the Shetland Islands and locations of the NNS rapid assessment surveys (triangle), survey sites used for monitoring (circle), and public SCUBA diver observations (cross). Contains Ordnance survey data © Crown copyright and database right 2011.

The potential for damage caused by NNS in Shetland is considerable. The economic threat posed to local marine industries, in particular to the local aquaculture industry (e.g. biofouling of mussel farms: Ramsay et al. 2008; Rius et al. 2011), is of concern. Additionally, the ecological threat to Shetland's nationally and internationally important (i.e. designated as Marine Protected Areas and Special Areas of Conservation) marine habitats and species (e.g. horse mussels, *Modiolus*

modiolus Linnaeus, 1758 and eelgrass *Zostera marina* Linnaeus, 1753), due to competition (Byers 2000), predation (Grosholtz et al. 2000), and altering the physical structure of native habitats (Gribben 2013), also creates cause for concern.

To ensure potential threats are detected early on, and management action is implemented rapidly, regular surveying and monitoring of high-risk sites (i.e., most likely sites of introduction) is required. As part of the Shetland Island's Marine

Spatial Plan (NAFC Marine Centre 2014), a rapid survey assessment of local marinas and docks was carried out by the NAFC Marine Centre to assess the current status of NNS in Shetland. In addition, a literature review was carried out to identify any potential threats from future introductions, and a monitoring programme of selected high-risk sites was established.

Methods

Rapid Assessment Survey

Rapid assessment surveys (Arenas et al. 2006; Minchin 2007) were carried out at 18 marinas and ports around Shetland between May 2012 and October 2014 (Figure 1 and supplementary material Table S1). A target list of NNS already present in northern Scotland (in particular Orkney, due to its proximity to Shetland) and those considered 'high risk', based on the Marine Aliens II Consortium's 'Identification Guide for Selected Marine Non-native Species' (Marine Aliens II Consortium 2014), was created prior to survey work.

The rapid assessment surveys consisted of visual inspections of pontoons, including floating and submerged items (buoys, ropes, and creels), as well as scrape samples from the pontoon sides (sampling an area of 30 × 30 cm down to 50 cm depth). When possible, a visual inspection of navigation buoys was carried out by boat (Sullom Voe, Scalloway harbour). In October 2014, complete visual surveys (including the undersides) of the pontoons at Port Arthur (Scalloway) and Victoria Pier (Lerwick) were carried out when the pontoons were removed for maintenance and winter storage.

All sites surveyed are used year round by recreational and commercial vessels, and have resident yachts and small leisure craft. Additionally, all sites contain floating pontoons (with constantly submerged surfaces) and provide hard substrate in sheltered environments that is suitable for the recruitment of fouling species. Large ports (e.g. Lerwick and Sullom Voe) that are regularly visited by international vessels were included in the rapid assessment survey, as well as smaller harbours that are important for the fishing and industries (e.g. Scalloway, Cullievoe). Surveying smaller harbours/marinas with local maritime activity provided valuable information on the current distribution of NNS in Shetland and also a warning of any secondary spread by means of local boating activity.

Additional information on NNS in Shetland was gathered through a public reporting programme. Non-native species identification guides containing

target species and background information were made available online via the NAFC Marine Centre website (NAFC Marine Centre 2015) and sent to various marine users, including: marinas, aquaculture companies, and recreational boaters. Samples of suspected NNS collected by the public were brought to the NAFC Marine Centre for identification.

Settlement panel monitoring

In conjunction with the rapid assessment survey, settlement panels were deployed at eight of the survey sites (Figure 1) to assist with detecting NNS that may not have been clearly visible in the initial survey (e.g. fouling species on the under-surfaces of pontoons). The eight sites were chosen based on the high level of local, regional, and international maritime activity (higher potential for NNS introduction and secondary spread).

The settlement panels consisted of two black, 3-mm thick, correx (polypropylene) plastic sheets (15 × 33 cm and 15 × 17 cm), which were scored, folded, and cable-tied together to create a single sampling unit (Marine Aliens Consortium UK 2010). The settlement panels provided vertically- and horizontally-oriented surfaces for recruitment (both shaded and non-shaded). By providing a variety of surface orientations, the probability of detecting a range of species is increased because larval behaviour during settlement is highly variable between species and factors such as light and gravity have been found to influence settlement (e.g. Bingham and Young 1993; Vermeij et al. 2006).

Two to three settlement panels were deployed at each site (depending on site size and accessibility) and were positioned at a depth of 1 m below the surface. Integrated weights ensured the panel remained at a constant depth throughout the deployment period. Settlement panels were left *in situ* for about three to six months (three-month periods during the summer [April – July – September] and for six months in winter [October – March]), to allow sufficient recruitment of resident species before being replaced with new panels. Collected panels were stored in seawater until examined (usually the same day). All organisms were identified to species level and recorded as presence/absence data.

Results

The field surveys confirmed the presence of eight non-native species in Shetland, five of

which were found only in visual surveys, two on settlement panels and in visual surveys, and only one (*Bugulina simplex* (Hincks, 1886)) found solely on settlement panels (Table 1). An additional three NNS had been previously recorded in Shetland (Table 2) but were absent in our survey: *Diadumene lineata* Verrill, 1869 (single record on muddy substrata in the Vadills in 2003, ERT (Scotland) Ltd. 2006); *Asparagopsis armata* Harvey, 1855 (single sighting in littoral pool close to Lerwick in 1973; Irvine et al 1975); and *Fenestrulina delicia* Winston, Hayward and Craig, 2000 (single record growing on a shell near Sullom Voe in 2012; Wasson and De Blauwe 2014). Although not detected in our survey, these three NNS were originally identified in surveys of Shetland's natural coastline and benthos; therefore, they may not be present in marinas.

Of the eight NNS detected in our rapid assessment survey and monitoring programme (Table 2), four species are considered to have been present in Shetland for many years: *Caprella mutica* Schurin, 1935; *Codium fragile* subsp. *fragile* (Suringar) Hariot, 1889; *Austrominius modestus* Darwin, 1854; and *Bonnemaisonia hamifera* Hariot, 1891). The remaining four species: *Corella eumyota* Traustedt, 1882; *Schizoporella japonica* Ortmann, 1890; *Dasysiphonia japonica* (Yendo) H.-S.Kim, 2012 (previously *Heterosiphonia japonica*); and *Bugulina simplex* are considered to be recent introductions.

Caprella mutica was found at the most locations (8), followed by *Codium fragile* subsp. *fragile* (7) and *Corella eumyota* (6) (Table 1). Victoria Pier (Lerwick) recorded the highest number of NNS (6), followed by Port Arthur (Scalloway) (5) and Sullom Voe (4). The higher number of NNS corresponds to higher levels of maritime activity at these sites. Of the sites surveyed, NNS were absent from only three sites: Walls, Skeld, and Fair Isle, most likely due to their isolation and/or low levels of maritime activity.

Public records collected by SCUBA divers (R. Shucksmith and B. Baldock) of *Dasysiphonia japonica* were submitted from Lunna Ness, Port Arthur (Scalloway), and Mavis Grind (southwest Sullom Voe). These records from the natural coastline and the substrates underneath marinas indicate that *D. japonica* is not reliant on artificial structures and its presence might be more widespread than monitoring results indicate.

Photographic records shared with the NAFC Marine Centre during a non-commercial SCUBA survey of Victoria pier (Lerwick) recorded the presence of *Dasysiphonia japonica* on submerged

structures (e.g. pier legs and marine litter) (R. Shucksmith, personal observation). *Corella eumyota* was also recorded on pier structures and on vessel hulls. The bryozoan *Schizoporella japonica* was recorded on the pier structure, vessel hulls, and on the bed rock and boulders within the harbour (J. Porter, personal communication).

The visual surveys of the pontoons removed from Victoria Pier (Lerwick) and Port Arthur (Scalloway) in November 2014 did not reveal any additional NNS, suggesting that the initial site surveys and settlement panels had provided an accurate representation of the NNS present in both Lerwick and Scalloway marinas.

Discussion

Recent discoveries of NNS in the Shetland Islands

In this study, the solitary ascidian *Corella eumyota* was first discovered on a settlement panel in Port Arthur marina, Scalloway, in August 2014. Following this discovery, *C. eumyota* was then detected at 5 other locations around Shetland: Lerwick, East Voe (Scalloway harbour), Sullom Voe, Burra Voe, and Ulsta. *Corella eumyota*'s widespread distribution around Shetland suggests that it was introduced prior to 2014. However, surveys carried out in 2012 and 2013 did not detect *C. eumyota*, which implies that either the population was small with a low probability of detection or it is a recent arrival (i.e., within the last two years).

Corella eumyota, native to the southern hemisphere (Lambert 2004) and was first detected in the UK along the southern coast of England in 2004 (Arenas et al. 2006). Since its arrival, *C. eumyota* successfully spread first to the south and east coasts of Ireland (Nagar et al. 2010; Minchin 2007) and then to the west and north coasts of Scotland and Orkney (Bishop 2011; Nall et al. 2015). The detection of *C. eumyota* in Shetland in 2014 indicates that it was able to spread and establish new populations along the entire length of the British Isles in less than 10 years.

The chronology of *C. eumyota* detections along the west coast of the UK suggests local maritime activity played an important role in its progressive spread north. Indeed Minchin (2007) found dense aggregations on boat hulls in Cork harbour, Ireland. *Corella eumyota* is a brooding species of ascidian that releases competent (ready to settle) larvae (Lambert 2004; Dupont et al. 2007), often resulting in dense clumps of individuals (Lambert

Table 1. Records of non-native species found in the Shetland Islands from the rapid assessment survey, monitoring programme, literature search, and public SCUBA diver records. *Historical records but not detected in this study; S, detected on settlement panel only; V, visual observation in rapid survey only; D, public SCUBA diver records. Abbreviations for species scientific names: Ce - *Corella eumyota*; Cm - *Caprella mutica*; Dj - *Dasyatis japonica*; Sj - *Schizoporella japonica*; Cf - *Codium fragile* subsp. *fragile*; Bs - *Bugulina simplex*; Dl - *Diadumene lineata*; Am - *Austrominius modestus*; Fd - *Fenestrulina delicia*; Bh - *Bonnemaisonia hamifera*; Aa - *Asparagopsis armata*.

	Ce	Cm	Dj	Sj	Cf	Bs	Dl	Am	Fd	Bh	Aa	Total
Brae				V						V		1
Bridge End		V			V							2
Bressay										V		1
Burra Voe	SV	V		V								3
Collafirth				V	V							2
Cullivoe		V										1
East Voe	V	V			V							3
Fair Isle												0
Lerwick: Gremista				S		S						2
Lunna Ness			D									1
Mavis Grind			D									1
Roe Sound					V					V		2
Scalloway: Port Arthur	SVD	V	VD		V					V		5
Skeld												0
Skerries		V										1
Sullom Voe	SV	V	VD					V	*			5
Ulsta	V											1
Lerwick: Victoria Pier	SVD	V	VD	SD	V	S					*	7
Vadills							*					1
Virkie					V							1
Walls												0
Total	6	8	4	5	7	2	1	1	1	4	1	

Table 2. Non-native species detected in the Shetland Islands, UK.

Non-native species	Date detected	Record	Current status	Substrata
<i>Asparagopsis armata</i>	1973	Irvine et al. 1975	Single record in Lerwick but expected to be widespread	Natural
<i>Austrominius modestus</i>	1977	Hiscock et al 1978	Widespread	Artificial
<i>Bonnemaisonia hamifera</i>	1949	Irvine (1949)	Widespread	Natural
<i>Bugulina simplex</i>	2012	NAFC Marine Centre	Only recorded in Lerwick	Artificial
<i>Caprella mutica</i>	2003	Nall et al. (2015)	Widespread	Artificial
<i>Codium fragile fragile</i>	2012	NAFC Marine Centre	Widespread	Natural & Artificial
<i>Corella eumyota</i>	2014	NAFC Marine Centre	Widespread	Artificial
<i>Dasyatis japonica</i>	2014	pers. comm. B. Baldock	Widespread	Natural and Artificial
<i>Diadumene lineata</i>	2003	ERT (Scotland) Ltd. 2006	Single record	Natural
<i>Fenestrulina delicia</i>	2012	Wasson et al. 2014	Single record but expected to become more widespread	Natural
<i>Schizoporella japonica</i>	2012	pers. comm. J Porter	Widespread	Natural and Artificial

2004). Although *C. eumyota* have been found settling on the natural coastline (Collin et al. 2010), this short planktonic period limits *C. eumyota*'s ability to disperse long distances or spread rapidly, which again suggests local maritime activity assisted with its relatively rapid establishment around the UK.

To date, *C. eumyota* has not had a significant economic or ecological impact but, as a fouling

species, it does pose a risk to aquaculture, particularly the mussel farming industry (Forrest et al. 2007). The high densities of native ascidians (*Ascidella aspersa* Müller, 1776, and *Ciona intestinalis* Linnaeus, 1767) already found on aquaculture structures and marinas in Shetland suggests that *C. eumyota* could contribute to the fouling community. This would increase cleaning costs (Locke et al. 2009) and potentially reduce

mussel yield by competing directly with shellfish for food and space (Daigle and Herbinger 2009).

The red filamentous algae, *Dasyisiphonia japonica* is native to the north-west Pacific Ocean and has been a successful invasive species on both sides of the North Atlantic Ocean (e.g. Husa et al. 2004; Newton et al. 2013; Savoie and Saunders 2013; Low et al. 2014). In Europe, *D. japonica* was first observed in France in 1984 (Sjötun et al. 2008) and has since become widespread, including the Netherlands, Norway, Sweden, Spain, Italy, and the UK (Sjötun et al. 2008; Gollash et al. 2009). In Scotland, *D. japonica* was first recorded at Arturlie Point, Moray Firth, in 2004 (Sjötun et al. 2008) and on the west coast in 2008, although thought to have been introduced to the west coast between 2005 and 2008 (Moore and Harries 2009). Similarly, the widespread establishment of *D. japonica* in both the natural environment and on artificial structures around Shetland suggests it was introduced some time prior to 2014 but went undetected.

A key characteristic of *Dasyisiphonia japonica* is its ability to disperse via fragmentation: the shedding of small branches (pseudolaterals) that are capable of developing rhizoids and attaching to the substrate (Husa and Sjötun 2006). Reproductive gametophytes of *D. japonica* have not been found in European populations, suggesting that asexual reproduction via vegetative or tetrasporophytic stages (Husa et al. 2004; Moore and Harries 2009) is the dominant (if not only) form of propagation in non-native populations. The ability to reproduce asexually is a valuable trait for non-native species and would have played a key role in *D. japonica*'s rapid spread from west Scotland to and around Shetland.

Dasyisiphonia japonica is generally found in sheltered to semi-exposed sites, and it can grow on rocks and epiphytically on other species of algae (Moore and Harries 2009). The sheltered voes, bays, and marinas/harbours found around Shetland provide suitable conditions for *D. japonica*. The ability of *D. japonica* to rapidly establish dense populations can be highly problematic for native communities. Newton et al. (2013) found *D. japonica* can occupy up to 80% of available space, and Moore and Harries (2009) described *D. japonica*'s dominance as a 'virtual monoculture'. These high abundance levels occur all year round (Haydar and Wolff 2011) and can impact native diversity by reducing species richness (Low et al. 2014) and abundance (Husa et al. 2008). In Shetland, *D. japonica* has not been observed in

the large dominating populations seen elsewhere and so far has only been observed in small patches or on kelp holdfasts. However, although no ecological effect is immediately apparent, it could pose an economic threat as its ability to attach to shellfish could pose a potential problem for the local shellfish aquaculture industry (Haydar and Wolff 2011).

The encrusting bryozoan *Schizoporella japonica* is native to Japan, although it can now be found as a non-native species in the North Eastern Pacific Ocean (Clarke Murray et al. 2011; Elahi et al. 2013; Ashton et al. 2014), in the UK (Sambrook et al. 2014; Ryland et al. 2014) and more recently in Norway (Porter et al. 2015). *Schizoporella japonica* was first recorded in the UK in Holyhead, Wales in 2010, but was also recorded in Orkney in 2011 (Ryland et al. 2014) and Shetland in 2012 (*pers. comm.* J. Porter). Its widespread distribution in the UK suggests it was either introduced some time ago and was late being detected or it was introduced at multiple sites around the same time.

Despite its recent detection in Shetland, *S. japonica* is already widespread, suggesting it has been present for some time. The rapid assessment surveys detected *S. japonica* within marinas and harbours, but additional observations from SCUBA divers also noted its presence on natural substrates within these areas. This is the first UK record of *S. japonica* growing on natural substrate. Previous observations by Sambrook et al. (2014) in Wales and Ryland et al. (2014) in Orkney found *S. japonica* growing only on artificial structures (i.e., buoys, pilings, boat hulls, and settlement panels), generally close to the water surface. In Shetland, *S. japonica* has also been found fouling boat hulls, again highlighting the potential for local boats to assist with the secondary spread of non-native species (Clarke Murray et al. 2011; Ashton et al. 2014).

Unlike many native sessile species found in Shetland, *S. japonica*'s reproductive season extends into the winter (Ryland et al. 2014), which allows for recruitment and growth with little competition from other species. *Schizoporella japonica* can rapidly form large, encrusting, foliose sheets (up to 20 cm in diameter), which, coupled with its short dispersal range, are capable of dominating the substrate (Ryland et al. 2014). This can be particularly problematic for marinas and harbours, as well as the aquaculture industry.

The erect bryozoan *Bugulina simplex* has successfully invaded many parts of the world: North West Europe, North East North America,

Australia, and New Zealand (De Blauwe and Faasse 2001). In the UK, *B. simplex* was first reported by Ryland (1958) in Holyhead Marina, Wales. In Shetland, *B. simplex* has been found growing on settlement panels in Gremista marina and Victoria pier, Lerwick. Its strong association with artificial habitats such as marinas and harbours (De Blauwe and Faasse 2001; Hayward and Ryland 1998; Ryland et al. 2011) and short dispersal potential (hours; Wendt 2000) suggest that vessel biofouling is the most likely vector of transportation, a view shared by De Blauwe and Faasse (2001) and Ryland et al. (2011).

Despite the lengthy period of time *B. simplex* has been present in the UK, it has been relatively slow to spread to Shetland, which could be the result of its short dispersal potential, misidentification, or a possible under-recording of its presence in the UK. *Bugulina simplex* is a highly seasonal species that experiences a high die-back during winter, which makes it harder to detect and could have contributed to its possible under-recording (Ryland et al. 2011).

Bugulina simplex is generally considered a low-impact fouling species in other invaded sites (Brock 1985; De Blauwe and Faasse 2001), and it is unlikely to have a significant impact on the native marine community or industries around Shetland. Indeed, to date only a few small individuals have been recorded.

Future threats

Surveys carried out along the northern Scottish coastline and Orkney have detected several NNS that are not yet present in Shetland, but have a high probability of being introduced. These species include the tunicate *Botrylloides violaceus* Oka, 1927 and the bryozoan *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985, which were both detected by Nall et al. (2015) in Orkney. In addition the brown algae *Sargassum muticum* (Yendo) Fensholt, 1955 (present in Western Scotland; Harries et al. 2007) and the highly invasive tunicate *Didemnum vexillum* Kott, 2002 (present in the Firth of Clyde, west Scotland; Beveridge et al. 2011) have been identified as high risk species. *Sargassum muticum* is capable of displacing native species and altering native community diversity (Harries et al. 2007) while *D. vexillum* is capable of completely smothering hard surfaces (Coutts and Forrest 2007). *Didemnum vexillum* is of particular concern in

Shetland because of its potential to disrupt the shellfish aquaculture industry through biofouling.

There is certainly a high probability of these NNS being introduced to Shetland but whether they will survive the local environmental conditions and establish self-sustaining populations is unknown. The environmental similarities between the northern Scotland coastline, Orkney, and Shetland, suggest any NNS established within this region is capable of establishing in Shetland and that a precautionary approach should be applied. However, the main threats posed by NNS in Shetland have been identified and the continuation of our current monitoring programme (both rapid assessment surveys and settlement panels) will increase the probability of detecting these threatening species early if they are introduced (Collin et al. 2015).

As future threats emerge, it is important that records of newly detected NNS are rapidly made available. When compiling information provided within this report, on both current and potential NNS, a combination of data collection and literature review surveyed, which included independent survey records. Through this process it became apparent that, although there are online data bases (e.g. National Biodiversity Network, MarLIN, and GBNNSS), many records of NNS are not available via these portals. For example, there were no available records of *D. japonica*'s presence in Scotland despite being initially detected in 2004 (eleven years ago). To improve our ability to monitor and manage NNS it is essential that all data on species location and abundance from all sources (e.g. independent ecological surveys, academic research, and governmental surveys) are made available.

Whilst Shetland has the potential to be the primary point of introduction, it is likely that most, if not all, the NNS observed in this study were initially introduced to the UK and Europe prior to secondary spread to Shetland. The rapid spread and establishment of NNS, such as *S. japonica* and *C. eumyota*, around the UK illustrates the need for rapid detection and containment for eradication of future harmful NNS to be feasible. The data presented within this study has been influential in guiding the development of the 'Biosecurity Plan for the Shetland Islands' (Collin et al. 2015) – an NNS assessment and management guidance document for marine users in the Shetland Islands – which forms part of the Shetland Islands' Marine Spatial Plan.

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References

- Arenas F, Bishop JDD, Carlton JT, Dyrinda PJ, Farnham WF, Gonzalez DJ, Jacobs MW, Lambert C, Lambert G, Nielsen SE, Pederson JA, Porter JS, Ward S, Wood CA (2006) Alien species and other notable records from a rapid assessment survey of marinas on the south coast of England. *Journal of the Marine Biological Association UK* 86: 1329–1337, <http://dx.doi.org/10.1017/S0025315406014354>
- Ashton G, Davidson I, Ruiz G (2014) Transient small boats as a long-distance coastal vector for dispersal of biofouling organisms. *Estuaries and Coasts* 37: 1572–1581, <http://dx.doi.org/10.1007/s12237-014-9782-9>
- Beveridge C, Cook EJ, Brunner L, MacLeod A, Black K, Brown C, Manson FJ (2011) Initial response to the invasive carpet sea squirt, *Didemnum vexillum*, in Scotland. Scottish Natural Heritage Commissioned Report No. 413, 32 pp
- Bingham BL, Young CM (1993) Larval phototaxis in barnacles and snails associated with bathyal sea urchins. *Deep-Sea Research* 40: 1–12, [http://dx.doi.org/10.1016/0967-0637\(93\)90051-4](http://dx.doi.org/10.1016/0967-0637(93)90051-4)
- Bishop JDD (2011) Orange-tipped sea squirt, *Corella Eumyota* Overview. GB Non-native Species Secretariat. <http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=902> (Accessed 16 February 2015)
- Brock BJ (1985) South Australian fouling bryozoans. In: Neilsen C, Larwood G (eds), Bryozoa: Ordovician to recent, proceedings of the 6th International Conference on Bryozoa, Vienna, 1983. Olsen and Olsen, Fredensborg, Denmark 1985, pp 45–51
- Byers JE (2000) Competition between two estuarine snails: implications for invasions of exotic species. *Ecology* 81: 1225–1239, [http://dx.doi.org/10.1890/0012-9658\(2000\)081\[1225:C BTESIJ\]2.0.CO;2](http://dx.doi.org/10.1890/0012-9658(2000)081[1225:C BTESIJ]2.0.CO;2)
- Carlton JT (1996) Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78: 97–106, [http://dx.doi.org/10.1016/0006-3207\(96\)00020-1](http://dx.doi.org/10.1016/0006-3207(96)00020-1)
- Carlton JT, Geller JB (1993) Ecological roulette: The global transportation of nonindigenous marine organisms. *Science* 261: 78–82, <http://dx.doi.org/10.1126/science.261.5117.78>
- Clarke Murray C, Pakhomov EA, Theriault TW (2011) Recreational boating: a large unregulated vector transporting marine invasive species. *Diversity and Distributions* 17: 1161–1172, <http://dx.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, <http://dx.doi.org/10.1111/j.1366-9516.2004.00061.x>
- Collin SB, Oakley JA, Sewell J, Bishop JDD (2010) Widespread occurrence of the non-indigenous ascidian *Corella eumyota* Trausted, 1882 on the shores of Plymouth Sound and Estuaries Special Area of Conservation, UK. *Aquatic Invasions* 5: 175–179, <http://dx.doi.org/10.3391/ai.2010.5.2.07>
- Collin SB, MacIver K, Shucksmith R (2015) A biosecurity plan for the Shetland Islands. NAFC Marine Centre, 55 pp
- Coutts ADM, Forrest BM (2007) Development and application of tools for incursion response: Lessons learned from the management of the fouling pest *Didemnum vexillum*. *Journal of Experimental Marine Biology and Ecology* 342: 154–162, <http://dx.doi.org/10.1016/j.jembe.2006.10.042>
- Daigle RM, Herlinger CM (2009) Ecological interactions between the vase tunicate (*Ciona intestinalis*) and the farmed blue mussel (*Mytilus edulis*) in Nova Scotia, Canada. *Aquatic Invasions* 4: 177–187, <http://dx.doi.org/10.3391/ai.2009.4.1.18>
- De Blauwe H, Faasse M (2001) Extension of the range of the bryozoans *Tricellaria inopinata* and *Bugula simplex* in the north-east Atlantic Ocean (Bryozoa: Cheilostomatida). *Nederlandse Faunistische Mededelingen* 14: 103–112
- Dupont L, Viard F, David P, Bishop JDD (2007) Combined effects of bottlenecks and selfing in populations of *Corella eumyota*, a recently introduced sea squirt in the English Channel. *Diversity and Distributions* 13: 808–817, <http://dx.doi.org/10.1111/j.1472-4642.2007.00405.x>
- Elahi R, Birkeland C, Sebens KP, Turner KR, Dwyer TR (2013) Limited change in the diversity and structure of subtidal communities over four decades. *Marine Biology* 160: 3209–3219, <http://dx.doi.org/10.1007/s00227-013-2308-3>
- ERT (Scotland) Ltd (2006) Site condition monitoring: surveys of lagoons in the Vadills lagoon Special Area of Conservation, July–August 2003. Scottish Natural Heritage Commissioned Report No. 209, 180 pp
- Forrest BM, Hopkins GA, Dodgshun TJ, Gardner JPA (2007) Efficacy of acetic acid treatments in the management of marine biofouling. *Aquaculture* 262: 319–332, <http://dx.doi.org/10.1016/j.aquaculture.2006.11.006>
- Gollasch S, Haydar D, Minchin D, Wolff WJ, Reise K (2009) Chapter 29: Introduced aquatic species of the North Sea coasts and adjacent brackish waters. In: Rilov G, Crooks JA (eds), Biological Invasions in Marine Ecosystems. Ecological Studies 204, Springer-Verlag Berlin Heidelberg, pp 507–528
- Gribben PE, Byers JE, Wright JT, Glasby TM (2013) Positive versus negative effects of an invasive ecosystem engineer on different components of a marine ecosystem. *OIKOS* 122: 816–824, <http://dx.doi.org/10.1111/j.1600-0706.2012.20868.x>
- Grosholtz ED, Ruiz GM, Dean CA, Shirley KA, Maron JL, Connors PG (2000) The impacts of a nonindigenous marine predator in a California bay. *Ecology* 81: 1206–1224, [http://dx.doi.org/10.1890/0012-9658\(2000\)081\[1206:TIOANM\]2.0.CO;2](http://dx.doi.org/10.1890/0012-9658(2000)081[1206:TIOANM]2.0.CO;2)
- Harries DB, Harrow S, Wilson JR, Mair JM, Donnan DW (2007) The establishment of the invasive alga *Sargassum muticum* on the west coast of Scotland: a preliminary assessment of community effects. *Journal of the Marine Biological Association UK* 87: 1057–1067, <http://dx.doi.org/10.1017/S0025315407057633>
- Haydar D, Wolff WJ (2011) Predicting invasion patterns in coastal ecosystems: relationship between vector strength and vector tempo. *Marine Ecology Progress Series* 431: 1–10, <http://dx.doi.org/10.3354/meps09170>
- Hayward PJ, Ryland JS (1998) Cheilostomatous Bryozoa: notes for the identification of British species. Shrewsbury: Field Studies Council, 366 pp
- Hewitt CL, Willing J, Bauckham A, Cassidy AM, Cox CMS, Jones L, Wotton DM (2004) New Zealand marine biosecurity: delivering outcomes in a fluid environment. *New Zealand Journal of Marine and Freshwater Research* 38: 429–438, <http://dx.doi.org/10.1080/00288330.2004.9517250>
- Hiscock K, Hiscock S, Baker JM (1978) The occurrence of the barnacle *Elminius modestus* in Shetland. *Journal of the Marine Biological Association UK* 58: 627–629, <http://dx.doi.org/10.1111/j.1472-4642.2011.00798.x>
- Hooper DU, Chapin Lii FS, Ewel JJ, 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, <http://dx.doi.org/10.1890/04-0922>
- Husa V, Sjøtun K, Lein TE (2004) The newly introduced species *Heterosiphonia japonica* Yendo (Dasyaceae, Rhodophyta): geographical distribution and abundance at the Norwegian southwest coast. *Sarsia* 89: 211–217, <http://dx.doi.org/10.1080/00364820410006600>
- Husa V, Sjøtun K (2006) Vegetative reproduction in “*Heterosiphonia japonica*” (Dasyaceae, Ceramiales, Rhodophyta), an introduced red alga on European coasts. *Botanica Marina* 49: 191–199, <http://dx.doi.org/10.1515/BOT.2006.024>

- Husa V, Sjøtun K, Brattnborg N, Lein TE (2008) Changes of macroalgal biodiversity in sublittoral sites in southwest Norway: impact of an introduced species or higher temperature? *Marine Biology Research* 4: 414–428, <http://dx.doi.org/10.1080/17451000.802232874>
- Irvine DEG (1949) British Phycological Society dataset of Seaweed data for Great Britain and Ireland: First record of *Bonnemaïsonia hamifera* in the Shetland Islands. Observation ID: 224163438
- Irvine DEG, Guiry MD, Tittley I, Russel G (1975) New and interesting marine algae from the Shetland Isles. *British Phycological Journal* 10: 57–71, <http://dx.doi.org/10.1080/00071617500650061>
- Lambert G (2004) The south temperate and Antarctic ascidian *Corella eumyota* reported in two harbours in north-western France. *Journal of the Marine Biological Association UK* 84: 239–241, <http://dx.doi.org/10.1017/S0025315404009105h>
- Locke A, Doe KG, Fairchild WL, Jackman PM, Reese EJ (2009) Preliminary evaluation of effects of invasive tunicate management with acetic acid and calcium hydroxide on non-target marine organisms in Prince Edward Island, Canada. *Aquatic Invasions* 4: 221–236, <http://dx.doi.org/10.3391/ai.2009.4.1.23>
- Low NHN, Drouin A, Marks CJ, Bracken MES (2014) Invader traits and community context contribute to the recent invasion success of the macroalga *Heterosiphonia japonica* on New England rocky reefs. *Biological Invasions* 17: 257–271, <http://dx.doi.org/10.1007/s10530-014-0724-z>
- Mack RN, Simberloff D, Lonsdale WM, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10: 689–710, [http://dx.doi.org/10.1890/1051-0761\(2000\)010\[0689:BICEGC\]2.0.CO;2](http://dx.doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2)
- Marine Aliens II Consortium (2010) http://www.marlin.ac.uk/marine_alien_research_detection.php (Accessed 16 February 2015)
- Marine Aliens II Consortium (2014) Identification Guide for selected marine non-native species. http://www.mba.ac.uk/bishop/wp-content/uploads/2014/09/84105-MBA-ID-Guide-38pp-A5-English_reduced-pdf.pdf (Accessed 16 February 2015)
- Minchin D (2007) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions* 2: 63–70, <http://dx.doi.org/10.3391/ai.2007.2.1.8>
- 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: 1–5, <http://dx.doi.org/10.1017/S1755267209990509>
- 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, <http://dx.doi.org/10.3391/ai.2015.10.1.11>
- NAFC Marine Centre (2014) Shetland Islands Marine Spatial Plan: Fourth edition. NAFC Marine Centre, 202 pp
- NAFC Marine Centre (2015) Introduced non-native marine species. <http://www.nafc.uhi.ac.uk/NNS> (Accessed 16 February 2015)
- Nagar AE, Huys R, Bishop JDD (2010) Widespread occurrence of the Southern Hemisphere ascidian *Corella eumyota* Traustedt, 1882 on the Atlantic coast of Iberia. *Aquatic Invasions* 5: 169–173, <http://dx.doi.org/10.3391/ai.2010.5.2.06>
- Newton C, Bracken MES, McConville M, Rodrigue K, Thornber CS (2013) Invasion of the red seaweed *Heterosiphonia japonica* spans biogeographical provinces in the western North Atlantic Ocean. *PLoS ONE* 8: 1–7, <http://dx.doi.org/10.1371/journal.pone.0062261>
- Pimental D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic cost of nonindigenous species in the United States. *Bioscience* 50: 53–65, [http://dx.doi.org/10.1641/0006-3568\(2000\)050\[0053:EAECON\]2.3.CO;2](http://dx.doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2)
- Porter JS, Spencer Jones ME, Kuklinski P, Rouse S (2015) First records of marine invasive non-native Bryozoan in Norwegian coastal waters from Bergen to Trondheim. *BioInvasions Records* 4: 157–169, <http://dx.doi.org/10.3391/bir.2015.4.3.02>
- Ramsay A, Davidson J, Landry T, Arsenault G (2008) Process of invasiveness among exotic tunicates in Prince Edward Island, Canada. *Biological Invasions* 10: 1311–1316, <http://dx.doi.org/10.1007/s10530-007-9205-y>
- Rius M, Heasman KG, McQuaid CD (2011) Long-term coexistence of non-indigenous species in aquaculture facilities. *Marine Pollution Bulletin* 62: 2395–2403, <http://dx.doi.org/10.1016/j.marpolbul.2011.08.030>
- Ryland JS (1958) *Bugula simplex* Hincks, a newly recognized polyzoan from British waters. *Nature* 181: 1146–1147, <http://dx.doi.org/10.1038/1811146b0>
- Ryland JS, Bishop JDD, De Blauwe H, Nagar AE, Minchin D, Wood CA, Yunnice LE (2011) Alien species of *Bugula* (Bryozoa) along the Atlantic coasts of Europe. *Aquatic Invasions* 6: 17–31, <http://dx.doi.org/10.3391/ai.2011.6.1.03>
- Ryland JS, Holt R, Loxton J, Spencer Jones ME, Porter JS (2014) First occurrence of the non-native bryozoan *Schizoporella japonica* Ortmann (1890) in Western Europe. *Zootaxa* 3780: 481–502, <http://dx.doi.org/10.11646/zootaxa.3780.3.3>
- Sambrook K, Holt RHF, Sharp R, Griffith K, Roche RC, Newstead RG, Wyn G, Jenkins SR (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, <http://dx.doi.org/10.1016/j.marpol.2014.03.018>
- Savoie AM, Saunders GW (2013) First record of the invasive red alga *Heterosiphonia japonica* (Ceramiales, Rhodophyta) in Canada. *BioInvasions Records* 2: 27–32, <http://dx.doi.org/10.3391/bir.2013.2.1.04>
- 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, <http://dx.doi.org/10.1016/j.marpol.2014.12.010>
- Shetland Islands Council (2013) Shetland in Statistics 40th Edition. Economic Development Unit, Shetland Islands Council, 62 pp
- Sjøtun K, Husa V, Peña V (2008) Present distribution and possible vectors of introductions of the alga *Heterosiphonia japonica* (Ceramiales, Rhodophyta) in Europe. *Aquatic Invasions* 3: 377–394, <http://dx.doi.org/10.3391/ai.2008.3.4.3>
- Sylvester F, Kalaci O, Leung B, Lacoursière-Roussel A, Clarke Murray C, Choi FM, Bravo MA, Therriault TW, MacIsaac HJ (2011) Hull fouling as an invasion vector: can simple models explain a complex problem? *Journal of Applied Ecology* 48: 415–423, <http://dx.doi.org/10.1111/j.1365-2664.2011.01957.x>
- Vermeij MJA, Fogarty ND, Miller MW (2006) Pelagic conditions affect larval behavior, survival, and settlement patterns in the Caribbean coral *Montastraea faveolata*. *Marine Ecology Progress Series* 310: 119–128, <http://dx.doi.org/10.3354/meps310119>
- Wasson B, De Blauwe H (2014) Two new records of cheilostome Bryozoa from British waters. *Marine Biodiversity Records* 7: 1–4, <http://dx.doi.org/10.1017/S1755267214001213>
- Wendt DE (2000) Energetics of larval swimming and metamorphosis in four species of *Bugula* (Bryozoa). *Biological Bulletin* 198: 346–356, <http://dx.doi.org/10.2307/1542690>

Supplementary material

The following supplementary material is available for this article:

Table S1. Survey locations for rapid assessment surveys, monitoring sites and public SCUBA diver observations of non-native species.

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