Risk assessment of non-indigenous marine species, Ireland: including those expected in inland waters

A Report undertaken for:

The Centre for Environmental Data and Recording (CEDaR), Department of Natural Sciences, National Museums, Northern Ireland (NMNI) and the Department of Arts, Heritage and the Gaeltacht, Ireland

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TABLE OF CONTENTS

APPENDICES

Appendix 1 Summaries of the highest impacting target species spreading in Ireland and those expected to arrive

Alexandrium catanella
Alexandrium tamarense
Bonamia ostreae
Corbicula fluminalis
Corbicula fluninea
Corella eumyota
Crassostrea gigas
Crepidula fornicata
Didemnum vexillum
Dikerogammarus haemobaphes
Dikerogammarus villosus
Dreissena bugensis
Ensis directus
Epizootic Haematopoietic necrosis (**EHVN**)
Eriocheir sinensis
Gyrodactylus salaris
Hemigrapsus sanguineus
Hemigrapsus takanoi
Heterosigma akashiwo
Infectious haematopoietic necrosis virus (**IHN)**
Infectious salmon anaemia (**ISA**) virus
Marenzellaria viridis
Marteilia refringens
Mnemiopsis leidyi
Neogobius melanostomus
Ocenebra inornata
Ostreid herpesvirus 1-microvariant (**OsHV-1 μvar**)
Pseudorasbora parva
Sphaerothecum destruens
Styela clava
Undaria pinnatifida
Vibrio cholerae

Appendix 2 Evaluation of the principal pathways to Ireland

The pathways of transmission
Assessing ports in Ireland
Assessing marinas and aquaculture sites in Ireland
Discussion

EXECUTIVE SUMMARY

This account examines the principal pathways through which non-indigenous species (NIS) are spread, what the impacting species are likely to be and how and/or where they might be revealed on the island of Ireland. This reflects the European Commission's requirement for the monitoring of NIS under Descriptor 2 of the Marine Strategy Framework Directive (MSFD).

NIS gain entry and develop populations in Irish waters at specific points. These range from marine to freshwater sites according to the physiological tolerance of each NIS. Vessel traffic constitutes the most significant pathway and vessel routes operate across the full salinity ranges present within European waters. In this account, the pathway attributed to 'vessels' constitutes platforms, commercial vessels, barges etc., and recreational craft. For assessment purposes these have been categorised into 1) recreational craft and 2) all other vessels, based on the different dispersal patterns evident from previous NIS appearances. Their likely arrival points are marinas and ports, especially on the east and south Irish coasts. In contrast, NIS associated with salmon culture are most likely to appear on the south-west to north-west coasts, reflecting the locations where the industry is broadly concentrated. The cultivation of mussels and oysters is undertaken on all coasts. Other pathways operate at lower frequencies and include for example: the stocking of wild fisheries, fishing activities, dredge spoil displacement and habitat management.

The natural spread of NIS is poorly understood and is especially significant for planktonic and floating/drift species, or for those NIS that have life-history stages transmittable by migrating birds. Natural spread may be a more important mechanism for NIS dispersal than has previously been recognised.

The high impacting target NIS that have been selected in this study are those that are likely to be of importance in the next decade, or soon after, and include some already reported as present in Ireland, together with others that are considered likely to arrive from Britain and northern Europe. The selected target NIS include pathogens of humans and animals, toxin producing species as well as those impacting directly upon human activities or the environment. These have been classified as high risk (N=32 NIS) or moderate risk (N=32) according to their arrival and perceived impact. However, ecosystem impacts of the majority of NIS remain generally unknown except for a few. As a result the impacts used in this account do not relate to a quantified magnitude of impact. What has been used are based on fifteen different criteria and an added one that impacts upon animal health. An examination of an initial list of 800+ globally impacting NIS was subsequently reduced to 300+ species from which the final selections were made. While some seemingly benign NIS have not been included in target lists, there is a possibility that some of these might develop nuisance populations at some future time.

It is recommended that monitoring should examine hubs where targeted NIS are likely to occur, using rapid assessment methods in order to strike a balance between methodological practicality and cost effectiveness. Each high impacting target NIS, with a known life-history, will have a likely pathway and salinity tolerance for specific hub sites or regions. Some specialist monitoring of toxic and pathogenic organisms, including non-native arrivals, is already undertaken, but there is likely to be additional scope to incorporate surveillance for NIS in other existing data collection programmes. These could include species collected on power station cooling water thrash racks, the current sampling programme under the requirements of the Water Framework Directive, sampling undertaken for young fish surveys, or sampling of fouling biota on navigation buoys. Sampling methods in the 'field'

are designed to concentrate on the most impacting NIS that may be present. No single method is appropriate for sampling all NIS that are likely to arrive and subsequently become established in Irish waters, so a wide range of sampling methods are needed. When a high impacting NIS is discovered, a more specific follow-up survey may, however, be required so that a direct management response may be defined.

Records of NIS are to be reported to the ICES Working Group on the Introductions and Transfers of Marine Organisms from 2015 using the database AquaNIS in order to accumulate up-to-date information. The AquaNIS database is a repository for data on NIS introduced to Europe and neighbouring regions and will provide information on currently expanding NIS of concern by region and port. While this desk study deals mainly with possible NIS arrivals over the next decade there are longer-term scenarios that are of consequence for Ireland and northern Europe. These are:

- high impacting Ponto-Caspian NIS spreading westward in Europe;
- increases in the spread of hull fouling species following the re-commissioning of vessels idle during the recent economic slump;
- arrival of North Western Pacific species following the seasonal opening of the Arctic shipping corridors;
- gradual movement northwards of NIS as a result of climate change;
- human population density increases and migration, with associated biota of ornamental and cultural significance, and releases to the wild, and
- further incursions to the Mediterranean Sea as a result of enlargement of the Suez Canal, with possible extensions of range to northern Europe.

It is inevitable that further impacting NIS will arrive in Ireland, while others already established have yet to be identified. Some of the arrivals will be impacting; but it is likely some will be of economic value.

Disclaimer

The information presented in this document are opinions of the author based on field experience, international collaboration and reading of the literature to the time of the submission date. The statements do not necessarily reflect the opinions of the Centre for Environment Data and Recording, Northern Ireland or that of the Department of Arts, Heritage and the Gealtacht, Ireland.

NON-INDIGENOUS AQUATIC SPECIES PATHWAYS DESK STUDY

1.1 INTRODUCTION

The Marine Strategy Framework Directive (MSFD) establishes a framework within which EU Member States are required to take measures to achieve or maintain Good Environmental Status (GES) in the marine environment by 2020. The Directive aims to protect Europe's marine waters by applying an ecosystem-based approach to the management of human activities, while enabling the sustainable use of the marine environment for present and future generations. Member States are required to determine a set of characteristics for GES on the basis of Qualitative Descriptors. Descriptor 2 for Non-indigenous species (NIS) specifically expresses the objective: "*Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems*".

The European Parliament and the Council on 22 October 2014 have developed a new regulation to come into force on 1 January 2015 that deals with the prevention and management of the introduction and spread of invasive alien species (Regulation EU No 1143/2014)*1*. The development of "*Action plans on the pathways of invasive alien species*" has been incorporated within the Regulations under Article 13. "*Invasive alien species*" in the Regulations are defined as "*alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services*".

This study relates to both Northern Ireland and the Republic of Ireland, referred to here as the island of Ireland, Ireland, and has been commissioned by the Centre for Environmental Data and Recording, Department of Natural Sciences, National Museums, Northern Ireland and the Department of Arts, Heritage and the Gaeltacht, Ireland (DAHG). The work is to:

1. ***Identify relevant sites and/or activities and to prioritise these based on relative risks (high to low risk), characteristic environmental conditions, arrival pathways and patterns of previous invasions.***
   This task addresses the principal pathways and where the relative risks of NIS arrival are likely to occur, based on past knowledge and the literature.

2. ***Develop a list of high impacting species (both ecological and commercial).***
   Lists of species already established in Ireland, those that are likely to arrive and those perceived to be of concern to Atlantic coastal states of the European Union. Also discussed are the likely 'waves' of introduction that may take place in the future. Recommendations for the further development of an information system and current use of a database specifically designed for aquatic NIS records is discussed.

1 Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species.

3. ***Make recommendations for a cost-effective and efficient rapid monitoring programme. This should include, based on item 1 (above), the identification of suitable indicator sites and/or activities which may require monitoring.***
   Rapid-assessment monitoring, with examples for specific high risk entry habitats, are outlined.

Non-indigenous species (NIS) are spread as a result of trade, economic, social and political events. Their arrival follows their transport and a subsequent release, or escape, to the wild. Their numbers continue to increase within European seas (Galil *et al.* 2014). Once established, NIS may continue to be spread by humans and by natural spread. Their arrival, and further range expansion, will depend on different life-history characteristics and the behaviour of each NIS, as well as their economic value. Dispersal will also occur through inadvertent or unauthorised transmissions. Given the capability of natural mechanisms to spread NIS once they have arrived, some may be managed whilst most will spread despite any practical management action to prevent their spread.

Management concerns should be prioritised towards impacting species, or invasive alien species (IAS), that change environmental processes, alter biodiversity and/or impact upon human activities and human health and the wellbeing of organisms that form food resources. IAS are part of a subset of the NIS component in a region that result in a high level of impact. Managers may also need to take account of public perception in relation to NIS-induced aesthetic changes to the environment. The high impacting species listed in this account are considered to be equivalent to IAS; but will depend on how they behave following their arrival. It is not always easy to distinguish those IAS likely to cause major impacts because not all of those observed as being invasive in one location, will behave in the same way in a new environment. Some species considered to be benign elsewhere, may evolve populations that then go on to become of concern within a different geographic region. The addition of NIS can increase the biodiversity of a region, but this may not always be the case.

There are very few accounts of marine extinctions due to NIS (Carlton *et al.* 1999). The total numbers of NIS for any region are imperfectly known, as many habitats have not been effectively studied, such as the interstitial fauna and habitats that are difficult to access. For some taxonomic groups the knowledge of the native and NIS component is more complete, but is ‘blurred’ by cryptogens (species whose identity as being native or non-indigenous remains unclear) (Carlton 1996). Some accounts of IAS have included impacting cryptogens. However, not all experts agree on the status of some cryptogenic species.

Matching donor areas across Britain and Europe with Irish sites, as well as examining specific pathways, according to traded volume and frequency of imports, may also be used in assessing risk, taking into account the proximity of impacting NIS in northern Europe. As a NIS spreads, more opportunities arise for it to disperse ever more widely because this may involve additional pathways. The development of a European database of marine biota AquaNIS (http://www.corpi.ku.lt/databases/index.php/aquanis/) provides opportunities for evaluating the risk of NIS that may arrive. This database also has an impact module, BINPAS (http://www.corpi.ku.lt/databases/index.php/binpas/), where the relative environmental impact of a species can be evaluated based on the biopollution assessment method (Olenin *et al.* 2007).

Routes for the dispersal of NIS species have changed over time and are likely to continue to do so. The rate of marine and brackish NIS establishment in Europe has been calculated at about one species arriving and colonising every month (ICES 2005). However, the real rate is likely to be greater as many arrive undetected. A large component of NIS arrived *via* the Suez Canal from the Erythrean region

(Galil *et al*. 2014) and have spread into the Mediterranean Sea with some reaching the northern regions of this sea (Occhipinti-Ambrogi 2007). A component of these may be expected to arrive in northern European waters over time.

This account is not confined to the marine realm. The MSFD Directive covers a wide range of salinities from 36+ psu in Mediterranean lagoons to the almost freshwater conditions within the Baltic Sea. As a result shipping may transfer freshwater biota through marine conditions to be released in low salinity ports within the European Union. Such ports also occur in Ireland. For this reason, NIS capable of tolerating low salinities have been included. This overlap with the delineated areas for the Water Framework Directive could lead to a common monitoring approach for targeted NIS

Species that arrive by natural means lie beyond the capability of authorities to manage. NIS once having initially arrived in one European state may subsequently spread naturally. As natural spreading capabilities are not sufficiently studied, some past NIS arrivals may not be clearly distinguished as having been introduced either by natural pathways or by anthropogenic transmissions.

Some NIS introduced by humans, and having established themselves, can lie beyond the capability of any management action to reduce their abundance or spread. Whereas these might be controlled at some point before they arrive or before they become released to the wild.

In this desk study, the risk of NIS arriving is assessed using an environmental approach based on where the pathways, and their vectors, are likely to be operating. It also takes account of the life history stages of NIS, their tolerance to varying salinities, likely sites where they may be found and how monitoring might be achieved. Additional information may be found in Lehtineimi *et al.* (2015).

1.2 RELEVANT SITE ACTIVITY/IDENTIFICATION AND PRIORITISATION

The ICES Code of Practice (ICES 2005) was the guiding document for purposeful introductions for aquaculture products, but has now been superseded by a European Directive incorporating many of the ICES recommendations (EC 2008). However, not all of the risk assessment protocols incorporated within the ICES Code have proved secure. Predictions that the occurrence of *Porphyra yessoensis* on the coast of Maine, USA and *Undaria pinnatifida* on the coast of Brittany would be unlikely to lead to establishment in the wild were incorrect. NIS bivalve production, which is often dependent upon the on-growing of hatchery spat, has resulted in successful recruitment in the wild. This has been assisted by increases in sea temperatures, allowing the establishment of viable populations in northern latitudes, as in the case of *Crassostrea gigas* and *Ruditapes philippinarum* (Spencer *et al.* 1994; Jensen *et al,* 2004). Predictions of low risk of establishment in the wild of these bivalves were based on the known environmental tolerances and reproductive capability at the time of introduction and on previously published environmental records.

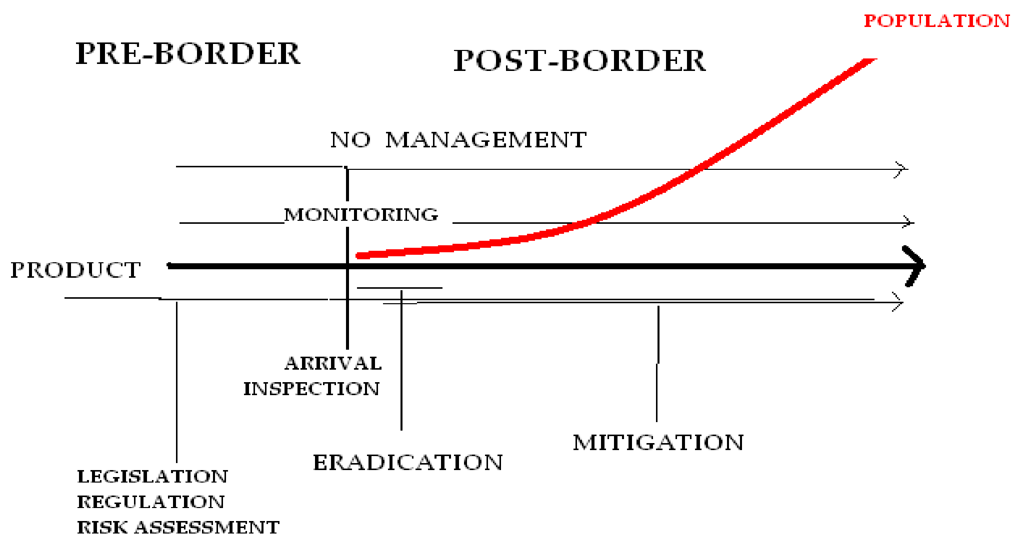

Figure 0.1 - Three principal stages at which an NIS might be managed (pre-border, at the border and post-border). Post-border options become more limited as a population spreads and expands (after Minchin, 2010)

Monitoring of commercially imported species is most practical and cost effective at the pre-border and border stages (**Figure 1.1**). For some commercial imports there are licencing requirements which may have as a condition their subsequent confinement to ensure they are not released to the wild, as in the case of live American lobsters, *Homarus americanus* (Minchin 2007). Legislative measures and border inspections can prevent some introductions from taking place. The level of risk before and at entry depends, in part, on the frequency and efficacy of inspections; but not all consignments can be inspected. Should the mode of entry be known, then the monitoring for specific NIS can be more practically and effectively undertaken. There is usually good knowledge of those NIS deliberately introduced and the additional biota that may be associated with them. The risk of introducing associated biota should be evaluated depending on the origin of a consignment.

Nevertheless, inadvertent and unauthorised introductions also take place, and these do not normally become apparent until they have become established (post-border) some years after their arrival. The routes for their arrival and subsequent dispersal may in the meantime have enabled them to become dispersed over wider areas. Monitoring is critical for providing the information on the state of an impacting NIS as, without this information, the options for its management cannot be appropriately considered.

1.2.1 The pre-border stage

Imported consignments involving NIS can be controlled in advance of an arrival and may be denied entry, their numbers reduced, or otherwise permitted but requiring a veterinarian's certificate to state each product is free of listed unwanted species. However, some NIS of concern may not be included in these lists or could remain elusive to inspections. NIS most easily managed at the pre-border stage include aquaculture species, live human and animal foods, live baits and ornamental species.

Ships' ballast water, when treated, takes place on uptake usually before departure. The mortality of the organisms taken up depends upon the treatment method and efficiency of the operating system (David and Gollasch 2014). In addition, those organisms surviving uptake sustain mortalities in accordance with the duration of the ships voyage. Even within untreated water there is a high mortality by the third day (Gollasch *et al.* 2000). Treatments considerably reduce risks of transmissions over long voyages. Whereas short ship passages between nearby ports still pose risks of ballast water transmissions of NIS that have not yet spread, because not all ports have the same NIS in common (David *et al.* 2013).

Within the European Union, the free movement of goods is allowed through common trading agreements, therefore open trade within, and between, the different biological provinces has made it more difficult to control the spread of NIS. Of current concern is the spread of the Ponto-Caspian species from Eastern Europe expanding through continental canals networks (Bij de Vaate *et al.* 2002) and through the movement of leisure craft (Pollox *et al* 2003). The arrival of these species is, in part, predictable and restrictions on selected forms of trade may reduce risks of importations.

1.2.2 The border stage

Inspections that take place at a port, airport, or close to the site of deployment, may be able to control the spread of some NIS. Such inspections have taken place in Ireland, where consignments are examined before being released to the wild (Minchin, 2000 a-c). This may be particularly effective in the case of the stocking of mussels, imports of Pacific oysters or ornamentals from Continental Europe. Fouled leisure craft arriving from a different world region could be hoisted and cleaned at the first port of call.

1.2.3 The post-border stage

This is the stage where NIS issues are most commonly encountered; the situation where a NIS has arrived, increased its population size and has normally already expanded its range (**Figure 1.1**). Eradication is normally only possible soon after a NIS has been introduced and remains confined within a small area. Due to the current levels of monitoring in Ireland, the recent arrival of a NIS is not normally recognised and when found is most often at a stage of expansion, commonly during its late expansion. Very often this is at a time when it is visibly obvious or is causing a noticeable impact.

Where an NIS impacts upon a local industry, mitigation may be the only practical response. Biocontrol in the marine environment may not be easily achieved except within confined conditions

1.3 THE LEVELS OF CERTAINTY AS TO HOW AN NIS ARRIVED

The arrival of an NIS has often been assigned to a presumed pathway. This may be incorrect as several authors have implicated ballast water without full knowledge that this was actually the case. In some cases only a single pathway may prevail or there may be several possible pathways that may add to the uncertainly of an arrival. Little is known about natural dispersal mechanisms and as a result an indication of the level of certainty should be applied to a pathway and vector, where possible. Unless accurate assessments for a mode of entry can be determined, the subsequent management measures used may prove ineffective because a missed or unidentified activity may continue to extend the range of a NIS. A scheme to overcome this difficulty has been suggested (**Table 1.1**) based on Olenin *et al.*

2010. The most secure basis for ascribing a pathway is where there is direct evidence or where an introduction is very likely to have taken place.

Table 0.1 - Different levels of certainty used to describe the arrival of an NIS (based on Olenin et al., 2010).

Level of certainty	Certainty evaluation	Examples
1. Direct introduction	Evidence of introduction: imported species, their associates, parasites and diseases found on/soon after arrival	Alien species introduced for aquaculture, human or animal food or NIS traded as ornamentals. [*i.e. Crassostrea gigas, Homarus americanus*]
2. Likely introduction	Arrival of a species known to have taken place elsewhere by such an activity and where this same activity takes place in the immediate area of an arrival.	Alien species with a known biogeography introduced with ships and leisure craft [*i.e.* hull fouling species, *Corella eumyota, Styela clava, Undaria pinnatifida, Bugula neritina*]
3. Possible introduction	A number of opportunities for an arrival by different pathways that might include natural spread	NIS, and some cryptogenic species and where there may also be confusion with arrival by natural means.
4.Unknown introduction mode	No specific route of arrival is known and where the arrival might involve natural spread	Often cryptogenic species; alien species recently revealed after a long period of establishment and having unexplained distributions

1.4 THE BIOLOGICAL AND ENVIRONMENTAL ELEMENTS IN ASSESSMENTS

1.4.1 Life-history stages

The different pathways and their vectors have varying abilities to transport NIS according to different life-history stages (**Table 1.2**). NIS may remain benthic or attached to a substrate for their lifetime whilst others have an entirely free-living habit or are sedentary with different durations of free-living stages, usually as larvae or spores. NIS with both pelagic and sedentary stages have a wide range of dispersal opportunities. Those with entirely pelagic lives may not be possible to manage due to the extent of natural dispersal, and also for those with fertile floating stages. These can be carried considerable distances with surface water and wind currents.

NIS that lack a pelagic phase may be spread naturally by storm events or by being dragged by currents or arising from their own abilities. Such species often remain within confined regions unless anthropogenically spread. In Britain there are coastal zones for managing shellfish, with licencing associated with any transfers. This has been an effective management approach preventing the spread of some entirely benthic species (for example the American tingle, *Urosalpinx cinerea*) to other areas within Britain (Utting and Spencer 1992).

Some NIS require a critical number of adults to be present to form a founder colony. Barnacles require a partner to be sufficiently close to enable internal fertilisation (Munroe and Noda 2009). In contrast, some self-fertile NIS can form extensive clones as in the case of the circum-Antarctic tunicate *Corella eumyota* which can also cross-fertilise (Collin *et al.* 2010).

NIS behaviour can make them prone to be preferentially 'captured' as in the case of those leaving sediments during night-time to become entrained in ballast water uptake, to later become discharged elsewhere.

Table 0.2 - Evaluation possibilities of introducing different life-history stages according to separate pathways and their vectors. 0 = very unlikely, 1 = possible, 2 = likely. Values of 10 or greater indicate a greater range of life-history opportunities to become spread by a stated vector of a pathway. Shaded numbers indicate NIS life history stages most likely to be conveyed by a specific pathway vector. Diverted water includes water for stocking, transport by vivier trucks etc.

		Sessile stages				Mobile stages				
Pathway	**Vector**	**Resting stages**	**'Larvae'**	**Juveniles**	**Adults**	**'Larvae'**	**Juveniles**	**Adults**	**possible risk**	**Previous Evidence of risk**
Natural	birds	2	2	1	1	1	1	1	9	incomplete
Natural	currents	1	0	0	0	2	2	2	7	incomplete
Ships	ballast	2	2	2	1	2	2	2	13	12
Ships	fouling	1	2	2	2	1	1	1	10	9
Craft	fouling	1	2	2	2	1	1	1	10	6
Canals	dispersal	0	0	0	0	2	2	2	6	2
Canals	water flow	1	1	1	1	2	2	2	10	4
Shellfish	in tissues	2	2	2	2	1	1	1	11	10
Shellfish	in cavity	2	2	2	2	1	2	2	13	10
Shellfish	on shell	2	2	2	2	2	2	2	14	8
Shellfish	equipment	1	1	2	2	1	2	2	11	2
Finfish	in tissues	2	2	2	2	0	0	0	8	8
Finfish	on surface	2	0	0	0	2	2	2	8	4
Finfish	equipment	2	2	2	2	2	2	2	14	
Angling	stocking	2	0	0	0	1	2	1	6	2
Angling	baits	0	0	0	0	0	1	2	3	
Angling	gear	2	2	2	1	1	2	2	12	
Ornament	tissues	2	2	2	2	1	2	2	13	
Ornamentals	species	1	1	2	2	1	2	2	11	6
Ornamentals	water	2	1	1	1	2	2	2	11	
Biocontrol		1	1	2	2	1	2	2	11	
Water	diverted	2	1	1	1	2	2	2	11	
Research		1	1	1	1	1	1	1	7	

1.4.2 Physical tolerances

It has been presumed most temperate biota are generally intolerant of the temperatures of tropical seas and therefore have an inherently low survival rate for ship transportation through the Indo-pacific region. Air-freight has, however, enabled North-western Pacific NIS to become established, especially those moved with aquaculture consignments without having to be challenged by these tropical conditions.

European coasts are already experiencing increased sea temperatures which is leading to northward shifts in the ranges of both native and NIS (Beaugrand and Reid 2003: Boelens *et al.* 2005). Such trends are likely to result in the further expansions of NIS, currently established south of Ireland.

Tolerance of NIS to different salinity ranges is better understood. Those requiring freshwater-brackish conditions are unlikely to colonise coastal areas, and vice-versa. Although during different stages of a life history a wide range of salinities can be tolerated by some NIS, even brackish to hyper-saline environments in the case of some. However, for the majority of NIS the tolerance is confined to specific salinity ranges. It is for this reason that salinity ranges have been considered here. Tolerances of some notable invaders are shown in **Figure 1.2**.

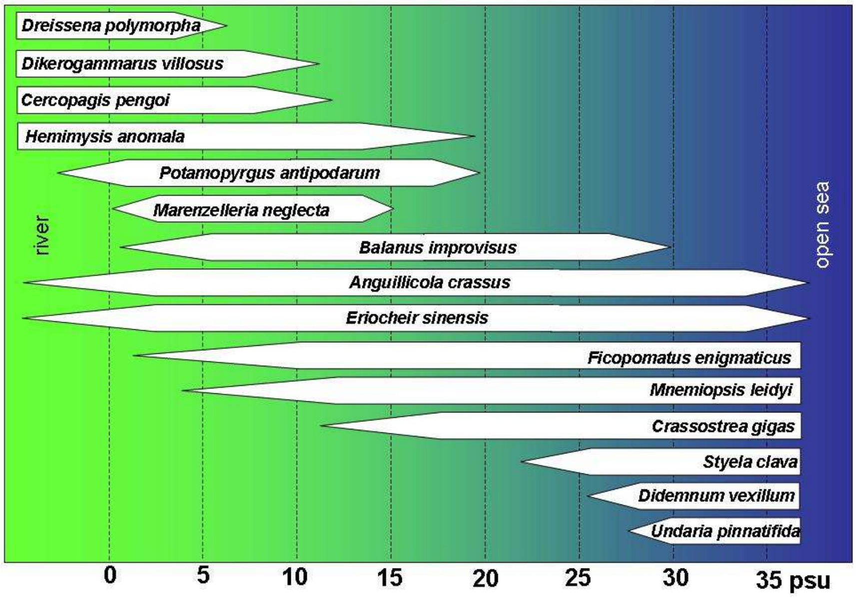

Figure 0.2 - Salinity tolerance for a range of impacting NIS (from: Olenin and Minchin, 2011)

1.4.3 Patterns and distributions of NIS spread

In summer, circulation in the Celtic Sea, Irish Sea and western Irish Shelf is driven by narrow, near surface, fast flowing currents (Hill *et al*. 1996; Horsburgh *et al*. 2000; Brown *et al*. 2003; Fernand *et al*. 2006) associated with temperature differences or salinity changes. These currents reach average speeds of 20.5 cm s^{-1}, 18.7 cm s^{-1} and 4.5-14.9 cm s^{-1} in the Celtic Sea, the Irish Sea, and the western Irish Shelf, respectively (summarised in Hill *et al*. 2008). The fast flowing currents on the western Irish Shelf, in combination with similar features found in the Celtic Sea (Brown *et al*. 2003), reflect the presence of the Irish Coastal Current in summer, which extends from the Isles of Scilly to Malin Head (**Figure 1.3**). The average flow of the Irish Coastal Current along the west coast of Ireland is greater than 7.5 cm s^{-1}. In shelf waters to the west and south of Ireland, tidal mixing is weak and stratification occurs during the spring and summer warming season (June-September) (Huang *et al*. 1991; McMahon *et al*. 1995). During the breakdown of the stratification of the water column in the late autumn, the density-driven circulation ceases and the flow reverts to a primarily wind-driven situation (Fernand *et al.* 2006).

In the shelf waters to the southwest of Ireland, winds blowing from the east result in a strong clockwise flow around south-western Ireland (**Figure 1.3**), while winds from the southwest can result in a south-southeast flow of approximately 5 cm s^{-1} (Raine and McMahon 1998). On the outer Celtic shelf, a weak counter-current flowing south-eastward has been observed (Pingree and LeCann 1989). These currents are most likely to involve the natural spread of NIS that have life-history stages that can be so dispersed. Currents may aid spread from continental Europe and Britain as is likely to have been the case of the arrival of the dinoflagellate *Karenia mikimotoi.* Natural drift of disseminules (Nelson 2000) and of some sessile biota originating from the Americas also occurs from time to time with strandings on Irish shores that include molluscs and crustaceans associated with flotsam carried *via* the North Atlantic currents assisted by wind vectors (Minchin 2007).

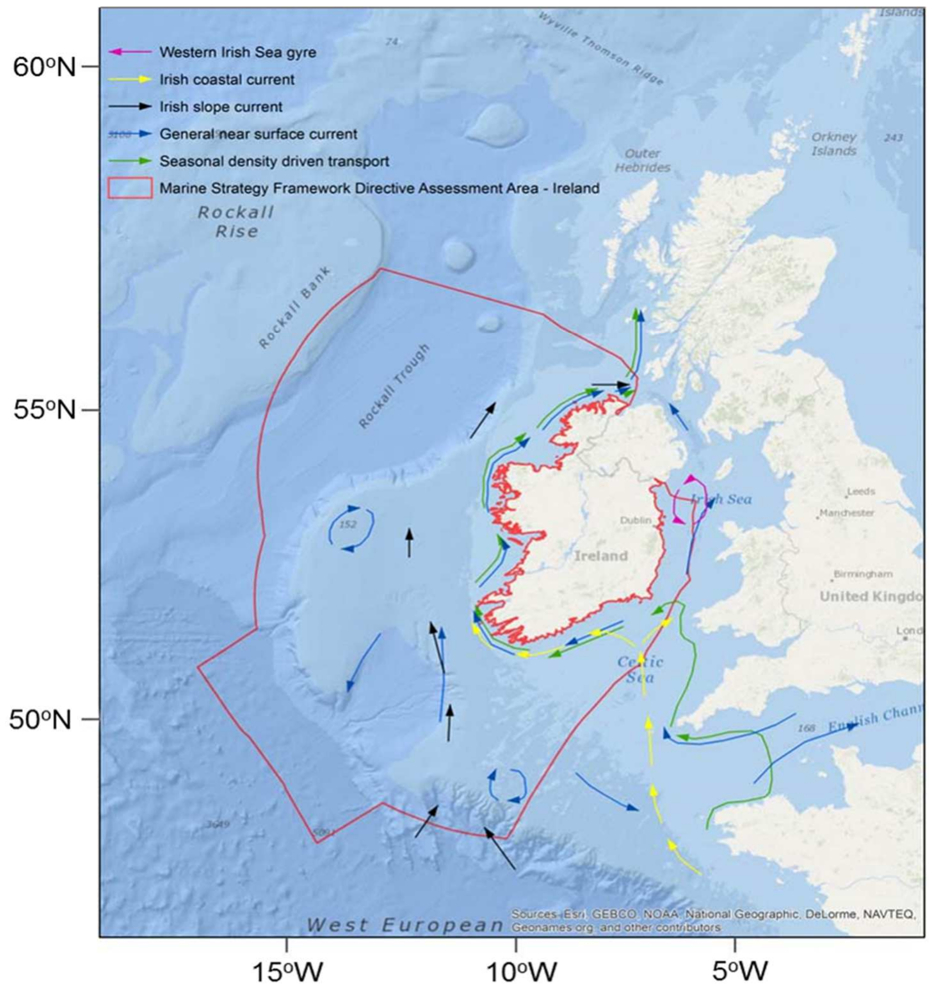

Figure 0.3 – General current circulation within Ireland's MSFD Assessment Area (Source; PAD, 2013 as presented in the MSFD Article 19 Report, DECLG/Marine Institute, 2013)

The flow of coastal water about the Irish coast is well understood, as outlined above. Plumes from estuaries can provide an indication as to which direction pelagic stages of an NIS might spread. From some port regions this was indicated by tracing the dispersal of tri-butyl tin, a once widely used antifoulant agent in paints on vessels, causing imposex in the intertidal predatory snail *Nucella lapillus* (Minchin 2010). Westward plumes were indicated by moderate levels of imposex from Cork Harbour to Kinsale. Due to the vertical mixing in the tidal race south of the Old Head of Kinsale very little contamination was found further west. This could mean a confinement of an NIS to within the Cork-Kinsale region since propagules become sufficiently diluted to the west of the Old Head peninsula to sufficiently disperse propagules so that subsequent reproduction becomes less likely. Thus it is possible that some NIS may remain confined unless anthropogenically spread. Within this Cork-Kinsale 'cell' is the NIS, *Cryptonemia hibernica*, a red alga, not known to have dispersed beyond this region since it was first recognised in 1971 (Cullinane and Whelan 1980).

1.5 MAKING ASSESSMENTS

Regional assessments for the introduction of a species will depend upon the origin of the pathway process, what level of 'contamination' there is at the site of origin, prevailing physical conditions, the seasonality of the vector involved in spread, life-history stages of a carried NIS and the conditions at the receptor site. The principal features of the receptor site are the pathways present, salinity, shelter and proximity to other receptor sites. An aid to evaluating the potential spread of species is the AquaNIS database which covers Europe and neighbouring regions (*www*.corpi.ku.lt/databases/index.php/**aquanis**). This database is currently being developed and further modules from different Large Marine Ecosystems (LME) (**Figure 1.4**) will be released over the coming year. The Celtic Seas LME entries are almost completed within this database and Irish species data are currently available to view. The database enables the assessment of the NIS present within each LME region and it is intended to be maintained as a living database system (Olenin *et al.* 2014). The identified localities within Ireland and the broader Celtic Seas LME where NIS are most likely to arrive are considered in Box 1.

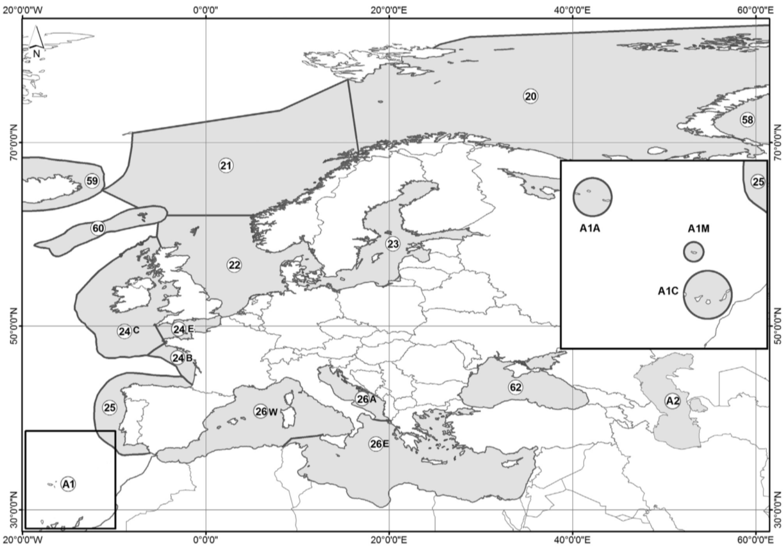

Figure 0.4 – The Large Marine Ecosystems which are covered and being developed in the AquaNIS database.

Box 1. From this desk study the principal target sites are:

Sites where target NIS are most likely to be found *(see also: Appendices 1 and 2).*

Ports: in sheltered environments with a high level of water retention with a wide range of habitats. Based on previous surveys and the wide range of environmental conditions and habitats **Cork Harbour** and **Belfast Lough** should be considered as 'hot-spot' regions for NIS introductions. Assessment of potential NIS arrivals should take account of ferry activity at each specific port together with, ro-ro trade, with Britain and northern Europe, including the Baltic Sea.

Marinas: where many craft lie idle over long periods and acquire a hull fouling burden, as do the floating pontoon units and other structures at marina sites. Marinas may be in close proximity to berthed ships and so may acquire NIS introduced by them. Historically, more NIS have been found in fully **marine salinities** on the **east coast of Ireland** than in areas with lower salinity.

Aquaculture sites: for the native oyster (*Ostrea edulis*) and the Pacific oyster (*Crassostrea gigas*) and areas where there are **stock movements** of molluscs, crustaceans or fishes. These species are subject to mainly **pests, parasites and diseases**.

Other sites where target NIS may be found

Sites arising from trade in living biota: existing saltwater **holding ponds** such as used for lobsters; but may include other live-food imports.

Sites of aquarium releases: This is more of a problem for the release of cold-water freshwater species. However, some NIS may have greater tolerance ranges than are generally known. Releases are likely to take place close to **centres of human population**.

Sites where angling takes place: This most usually takes place in freshwater environments. In brackish and marine conditions the use of imported **live-baits**, such as annelid worms, may take place.

Sites where dredging and construction takes place: Barges and other **slow moving vessels** are not maintained in the same way as ocean-going vessels and hull fouling NIS may be extensive. Dredgers and barges may distribute sediments containing NIS.

Sites exposed to natural spreading processes: These are sites on **bird migration routes** and in areas with long-distance residual current flow and persistent winds. Exceptional **meteorological and tectonic events** may be of importance.

The coastal regions where introductions are known to take place:

Few offshore introductions are known. Most NIS occur in sheltered environments close to the coast. Should they occur offshore they may have originated from inshore or are pelagic species.

Sheltered bays: provide opportunities for establishment. In such areas there may be a wide range of human activities. **Shellfish and salmonid culture** often take place in such areas. There may be local fisheries, marina installations and boat moorings.

Estuaries: are productive and so associated NIS of cultivated species may predominate

Extensive intertidal shores: where there is a large tidal amplitude with extensive low-gradient shores. There is correspondingly less risk in areas with tidal nodes in Ireland.

Deep water coastal inlets: are likely to have some levels of shipping; but aquaculture activities and leisure craft may also be present.

Lagoons: are very often important for **migrating birds** with a capability for NIS transmissions, but may also have launching areas for trailered **small craft.**

2.1 DEVELOPMENT OF A HIGH IMPACTING TARGET LIST OF NIS FOR IRELAND

There are many NIS present in northern Europe and it is only practical to deal with a subset of these considered to be of sufficient impact to be entered onto a high impacting species list for Ireland, together with a moderate list composed of species considered to be less impacting. NIS listed in a high category are those that have been identified as requiring possible management action over the coming decade, or soon after. Those in the moderate list are those that may require management at some undefined time or are considered to be of lower impact. Classifying all NIS as high impacting is not a practical approach as the target species should be those that have notable impacts, regardless of the difficulty in initiating control measures.

Some high impacting species already occurring in Irish waters may spread further. These have been included in this study. NIS with known impacts in nearby geographical regions are generally better known and such species are likely to have a significant impact following an arrival in Ireland. An effective predictor of likely NIS introductions to Ireland, is the list of NIS that have colonised British waters (Minchin *et al.* 2012). A component of these NIS will have arrived from Europe and there may be direct transfers from this region to Ireland.

To qualify as a 'target' NIS, an NIS should have some level of impact at a sufficient level to be of management concern. Evaluating the impacts of NIS are not easily undertaken because there are difficulties in assessing such impacts. The application of a consistent or reliable scientific approach to impact measurement has not yet been undertaken for many species (Ojaveer and Kotta 2014). For some species there is evidence of impact both on human activities and on the environment. However, the magnitude of their impact has seldom been described. Here the fifteen criteria used by Hayes and Sliwa (2003) has been used. To this, animal and plant health, has been added. Explanations for each of the criteria are outlined below.

Human and animal health

- Human health: species that may be consumed or infect humans requiring medical intervention.
- Animal and plant health: pests, parasites, diseases and disease agents that significantly compromise animal and/or plant populations of significance to humans.

Human activities

- Impacts on human transport (i.e. hull fouling).
- Impacts on abstraction of water (i.e. fouling, clogging of intakes, toxins in water).
- Loss of aquaculture/commercial/recreational harvest (i.e. from toxin producing dinoflagellate blooms).

Undertaken for: The Centre for Environmental Data and Recording (CEDaR), Department of Natural Sciences, National Museums, Northern Ireland (NMNI) and the Department of Arts, Heritage and the Gaeltacht [Ref: NIS-2014#1] By: Dan Minchin, Marine Organism Investigations, Ballina, Killaloe, Co Clare.

- Loss of public/tourist amenity (i.e. foot laceration, coelentrate stings, beach fouling).
- Damage to marine structures/archaeology (i.e. wood boring, fouling).

Environmental impacts

- Detrimental habitat modification (i.e. bioengineering changes).
- Alters trophic interactions or food webs (i.e. species that result in trophic cascades).
- Dominates/outcompetes and limits resources of native spp. (i.e. completion).
- Predator of native species (i.e. changes to communities).
- Introduces/facilitates new pathogens or parasites (i.e. carriers of pathogens and/or diseases that may impact native biota).
- Alters bio-geochemical cycles (i.e. burrowing organisms and redox discontinuity layer changes).
- Induces novel behavioural or eco-physiological responses in native spp. (i.e. exclusion).
- Genetic impacts such as hybridisation and introgression.
- Herbivory (i.e. impacts from grazers, including suspension feeders).

The impacts of most marine biota have not been formally studied, although some NIS are reported to have impacts. In most cases a direct cause and effect has not been experimentally shown although some impacts are convincing, or even obvious, as in the case of blockages of abstraction pipework from fouling NIS. While all NIS will have some impact in a new environment this may not be practical to measure, but become obvious when there are dramatic changes within a food-web as in the case of *Mnemiopsis leidyi* in the Black Sea (GSAMP 1997). The literature was examined in relation to the above criteria to create the 'target' list of NIS and some references that relate to each high impacting NIS are summarised in **Appendix 1**. The selected 'target' NIS **in Tables 2.1, 2.2** and **2.3** were divided into high and moderate impacting species. An NIS at an early stage may not produce a recognisable impact but may do so once a population has expanded in size and in geographical extent. Some, especially those with a short life cycle and a high reproductive capability, may rapidly develop to nuisance levels. It is not always certain that a selected NIS will evolve to such levels because environmental conditions, at the site of release, may not be fully compatible with its requirements. This may change with alterations to an environment, as in the case of climate change.

All high impacting NIS fulfilled two or more of the sixteen criteria. Some of the above criteria do not appear within the selection, as in the case of hybridisation, which is also a matter of concern. Releases of the American lobster *Homarus americanus* to the wild in Europe have already resulted in reports of hybrids with the European lobster *H. gammarus*. This might be of consequence for the European population (A-L Agnalt in Stebbing et al., 2012); but presently there is no account of hybrid lobsters occurring in Irish waters and the records of their occurrence in the wild elsewhere are very few.

In the **Tables 2.1, 2.2, 2.3** there are two levels of impact indicated. Those where impact is likely to have taken place in some world region(s) and possible impact.

There are concerns that some NIS of significance have been incorrectly omitted from target listings. This concern arises as a result of new knowledge or because a prominent NIS has only recently been recorded. It is known that NIS arrivals in northern Europe are frequently encountered and the high and moderate categories of any target list should be flexible enough to accommodate the removal of species that are no longer considered to be of sufficient impact and to enable the addition of other species thereby maintaining the 'currency' through a periodic updating process.

Ireland's, intrinsic island setting, isolated from continental coastlines has some advantages in the management of NIS, whereas the progression of NIS along European coasts is more difficult to manage. In Ireland there is the ability to manage purposeful introductions in trade, although there is limited ability to manage species spread by shipping and leisure craft. This could change as effective ballast water treatments becomes standardised and with improved antifouling technologies.

To undertake an assignment of the high impacting and moderate impacting species lists for Ireland, a two-step approach was undertaken. This involved an extensive examination of international literature for species that have been observed as impacting, widely spread and in particular those recorded in close proximity to Ireland. The sixteen separate criteria relating to the type and level of impact (Hayes and Sliwa, 2003) were used to assign each NIS to a high or moderate impacting category.

NIS species lists were examined from Belgium (Kerckhof *et al.* 2007), Denmark (Jensen and Knudsen 2005), Germany (Gollasch and Nehring 2006), France (Goulletquer *et al.* 2002), The Netherlands (Wolff 2005; Gittenberger 2007), Norway (Hopkins 2002), the Baltic countries (Olenin 2005), and from regional seas. These comprised: the North Sea (Reise et al. 1999; Gollasch *et al.* 2009), White Sea (Berger and Naumov 2002), together with semi-enclosed seas: the Baltic (Olenin and Leppäkoski 1999; Leppäkoski *et al.* 2002; Leppäkoski *et al.* 2009) and Wadden Sea (Reise *et al.* 2005). Other European regions included: Greece (Pancucci-Papadopoulou *et al.* 2005), Italy (Occhipinti-Ambrogi 2002), Ukraine (Alexandrov *et al.* 2007) and the Aegean Sea (Zaitsev and Öztürk 2001), Black Sea (Zaitsev and Öztürk 2001; Gomoiu *et al.* 2002), Caspian Sea (Zaitsev and Öztürk 2001; Aladin *et al.* 2002; Grigorovich *et al.* 2003), Marmara Sea (Zaitsev and Öztürk 2001; Öztürk 2002), Mediterranean Sea (Rilov and Galil, 2009; Galil and Zenetos 2002; Galil *et al.* 2002; Golani *et al.* 2002; Zenetos *et al.* 2004; Verlaque *et al.* 2010) provided some overlaps with species occurring in northern European regions. In addition, European databases AquaNIS (www.corpi.ku.lt/databases/aquanis/), DAISE (www.europe-aliens.org/), and in the Baltic region (www.nobanis.org; www.corpi.ku.lt/nemo/mainnemo.html), and worldwide accounts in ISSG (www.issg.org/worst100_species.html), GISP (www.invasivespecies.net/database), OIE (www.oie.int/) including Hayes and Sliwa (2003) were examined.

Over eight-hundred NIS were examined from different international regions and those that have arrived, or were expanding in Europe, were given special attention. Species were removed from the list based on the following criteria:

- Little or no indication of impact on humans or the environment from the literature
- No concerns stated of any impact in the literature
- The rate of spread of an NIS that is likely to result in its appearance in Ireland beyond the next few decades
- Unlikely to become established in Ireland
- That the pathways and their vectors are not directly involved in trade with Ireland

The outcome was a shortened list of over three-hundred species, from which the final selections for the Irish high and moderate impacting lists were compiled. The selection criteria outlined above were applied to these records and the most prominent impacting species, with raised level of concern for management, were identified and listed as: a) high and moderate impacting NIS established in Irish waters (**Table 2.1**), b) high and moderate NIS established in Britain and expected to arrive in Ireland (**Table 2.2**) and c) high and moderate NIS established in northern European waters that might arrive in Ireland (**Table 2.3**). Those high and moderate impacting NIS, not currently known in Ireland, all have some capability of arriving in Irish waters. Sixty-four species were selected and apportioned into the high and moderate risk categories. The thirty-two high impacting NIS from **Tables 2.1, 2.2** and **2.3** appear in **Appendix 1**. The nomenclature of NIS listed follows that of WORMS (www.marinespecies.org/) where appropriate.

While it is possible an NIS may arrive in Ireland from any world region, the trend in the past is for many NIS established in Britain to ultimately arrive in Ireland by shipping and other pathways (Minchin and Eno 2002). Nevertheless, direct introductions from northern Europe are also known (Holmes and Minchin 1995). Recent studies in relation to shipping indicate connections of even small ports with trade ranging from the Arctic to the Mediterranean Sea (Ware *et al.* 2014). NIS might also arrive from beyond northern Europe. These NIS have not been listed as it is more likely that the arrivals to Ireland will come from Britain and northern Europe. It should be noted, however, that many impacting NIS that are abundant in the lagoons in the northern Mediterranean Sea also have impacting populations and are already widely established in some northern European regions. Some of these appear within the Irish target lists. It is generally assumed that only temperate and northern hemisphere species have the capability of becoming established around Ireland, but some species records demonstrate that this is not always the case. The semi-tropical serpulid *Ficopomatus enigmaticus*, originating from the Indian Ocean, has well-established populations in northern Europe; as has the circum-Antarctic tunicate *Corella eumyota*. Both species have well established populations in Ireland and were found in Britain before being recorded in Ireland.

NIS that at one time were high impacting, such as the slime mould disease *Labyrinthula zosterae* which considerably reduced the extent of *Zostera marina* meadows in Europe (Den Hartog 1987), including in the shallow waters around Ireland (Whelan and Cullinane 1987), have not been included in this account. Nor have species in northern Europe thought to have died out following brief appearances, although these might appear again, e.g. the disease gaffkaemia, *Aerococcus viridans var. homari* of lobsters. Erythrean species expanding within the Mediterranean Sea are not considered likely to arrive in the short-term and physiologically may not be as able to form extensive populations due to the lower water temperatures around the Irish coast.

The selected target species for Ireland are ranked into two classes, high and moderate, with less weight being given to those in the moderate category. Species not selected from the original list of 800 species, are not examined any further. However, there is a likelihood that some of these NIS will emerge on target lists in the future and reviews of the current list, and those that might become of concern, should take place as such information becomes available. Selection of the high impacting NIS is often driven by opinion according to the weight given to impacts on human activities or the environment. Nevertheless, while the species selected to appear on target lists are often generally agreed, disagreements on ranking is common between experts. Some species in the moderate impact list might be moved to the high category based on new information or may be assigned that status as a result of an alternative opinion.

Following the target species selection for Ireland (as per **Tables 2.1, 2.2 and 2.3**), the life history modes and likely pathways/vectors were developed for each of the high impacting NIS (**Table 2.4**) and moderately impacting NIS (**Table 2.5**) for both species already in Ireland and those expected to arrive. These are scored according to the possible levels of transmission within and to Ireland ranging from 0, equating to having a low possibility of spread to 2 equating to likely transmission.

Commercial culture of some NIS and possible roles as sentinel species

Some of the target species in the high, moderate or lower impact levels have benefits that can be exploited as in the case of *Crassostrea gigas* and *Ruditapes philippinarum* important in shellfish food production. The Marine Stewardship Council have given a sustainability label for the exploitation of the American razor clam *Ensis directus* (www.msc.org/) although there are debates as to whether commercial NIS should be provided with this label (Galil *et al.* 2013). Other NIS constitute a different type of resource; *Asparagopsis armata* (Harpoon weed), for example, is cultivated for pharmaceutical properties (Kraan and Barrington, 2005). Species such as the zebra mussel *Dreissena polymorpha* and the Asian clam *Corbicula fluminea*, despite their impacts, may have some uses in the monitoring of human micro-parasites (Graczyk *et al*. 2008). Other NIS may act as indicators of climate change such as the bryozoan *Bugula neritina* (Maggs *et al.* 2011).

Table 2.1. High and moderate impacting species established in Irish waters

In bold/shaded the high impacting target species already in Irish waters. Impacts: 1, human health; 2, animal health; 3, aquatic transport; 4, fouling abstraction; 5, loss of harvest; 6, loss of amenity; 7, damage to structures; 8, detrimental to habitat; 9 trophic alteration; 10, outcompetes natives;11, predator; 12, introduces pathogens/parasites; 13, alters geo-chemical cycle; 14, alters native species behaviour; 15, hybridisation; 16, herbivory. Impacts: bold = impact, italics = possible impact.

Species	Common name	native range	taxon	Status	Functional group	Distribution	Impact	Reference
Alexandrium tamarense		unknown	dinoflagellate	cryptogen	phototroph	localised	**1,5**	Tylor *et al.* 1995,
Bonamia ostreae	Bonamia	W Pacific	protozoan	NIS	endoparasite	localised, not E coast	**2,5**	Culloty *et al*. 2007
Corbicula fluminea	Asian clam	SE Asia	bivalve	NIS	suspension feeder	Barrow, Shannon catchments	*4*,**9,10,13**,*14,16*	Caffrey *et al.* 2011
Corella eumyota	orange-tipped squirt	Circum Antarctic	tunicate	NIS	suspension feeder	widespread	*3,4,5,9,***10**	Minchin & Nunn 2013
Crassostrea gigas	Pacific oyster	NW Pacific	bivalve	NIS	suspension feeder	widespread, sheltered bays	*3,4*,**5,6,9,10,12**,*16*	Kochmann *et al.* 2013
Crepidula fornicata	slipper limpet	NW Atlantic	gastropod	NIS	suspension feeder	NE coast only	**5,8,9,10**,*16*	McNeill *et al.* 2010
Didemnum vexillum	carpet sea-squirt	NW Pacific	tunicate	NIS	suspension feeder	regional, E and W coasts	**5,8**,*9*,**10**,*14*	Minchin & Nunn 2013
Heterosigma akashiwo		unknown	flagellate	cryptogen	phototroph	localised W coast	**2,5**	Pybus & McGrath 1992
Ostreid herpesvirus		NW Pacific	virus	NIS	virus	S coast	**2,5**	Lynch *et al.* 2013
Styela clava	club tunicate	NW Pacific	tunicate	NIS	suspension feeder	localised, not W coast	**3,4,5,10**,*16*	Nunn & Minchin 2009
Undaria pinnatifida	Japanese kelp	NW Pacific	brown alga	NIS	phototroph	NE coast	*3,8,***10**	Minchin & Nunn 2013
Anguillicoloides crassus	eel-bladder nematode	NW Pacific	nematode	NIS	parasite	probably widespread	**2,5**,*14*	Evans & Mathews 1999
Aphanomyces astaci	crayfish disease	N America	fungus	NIS	parasite	possibly extinct	**2,5**	Lyons & Kelly-Quinn 2003
Balanus improvisus	bay barnacle	unknown	cirripede	cryptogen	suspension feeder	localised, estuaries, all coasts	**3,4**,*9,10,16*	Minchin, 2007
Botrylloides violaceum	orange sheath squirt	NW Pacific	tunicate	NIS	suspension feeder	localised E coast	*5,8,10*	Minchin, 2007
Caprella mutica	Japanese skeleton shrimp	NW Pacific	caprellid	NIS	suspension feeder	widespread	**10,**	Minchin & Holmes, 2006
Chelicorophium curvispinum	Caspian mud shrimp	Ponto-caspian	amphipod	NIS	deposit feeder	Shannon catchment	*8*,**10**	Lucy *et al.* 2004
Dreissena polymorpha	zebra mussel	Ponto-caspian	bivalve	NIS	suspension feeder	freshwater, estuaries, local	**3,4**,*6*,**8,9,10,12**,*16*	Zaiko *et al.* 2014

Species	**Common name**	**native range**	**taxon**	**Status**	**Functional group**	**Distribution**	**Impact**	**Reference**
Ficopomatus enigmaticus	Australian tubeworm	Indian Ocean	serpulid	NIS	suspension feeder	lagoons, estuaries, localised	**3,4,***8,9,10,16*	Minchin 2007
Gracilaria vericulophylla		NW Pacific	red alga	NIS	phototroph	NE coast, localised	**8,10**	Minchin & Nunn 2013
Hemimysis anomala	bloody-red mysid	Ponto-caspian	mysid	NIS	predator, deposits	freshwater, Shannon & Erne	**10,11**	Penk & Minchin 2014
Heterosiphonia japonica		NW Pacific	red alga	NIS	phototroph	Local, W & N coasts	**10,**	Guiry 2012
Karenia mikimotoi		NW Pacific	dinoflagellate	cryptogen	phototroph	offshore, widespread	**2,9,10**	Raine *et al.* 2001
Sargassum muticum	Japanese wireweed	NW Pacific	brown alga	NIS	phototroph	widespread	*6*,**8,9,10**	Loughnane & Stengel 2002
Spartina anglica	common cord-grass	Europe	vascular plant	NIS	phototroph	widespread in estuaries	**8,9,***14*	Reynolds 2002

Table 2.2. High and moderate impacting species established in British waters expected in Ireland.

In bold/shaded the high impacting target species already in British waters. Impacts: 1, human health; 2, animal health; 3, aquatic transport; 4, fouling abstraction; 5, loss of harvest; 6, loss of amenity; 7, damage to structures; 8, detrimental to habitat; 9 trophic alteration; 10, outcompetes natives;11, predator; 12, introduces pathogens/parasites; 13, alters geo-chemical cycle; 14, alters native species behaviour; 15, hybridisation; 16, herbivory. Impacts: bold = impact, italics = possible impact.

Species	**Common name**	**native range**	**taxon**	**Status**	**Functional group**	**Distribution**	**Impact**	**Reference**
Dikerogammarus villosus	killer shrimp	Ponto-caspian	amphipod	NIS	predator	Midlands, Broads, Bristol Channel	*9*,**10,11**	MacNeil *et al.* 2010
Dikerogammarus haemobaphes	demon shrimp	Ponto-caspian	amphipod	NIS	predator	Midlands and Severn Estuary	*9*,**10,11**	Bovy *et al*. 2014
Dreissena bugensis	quagga mussel	Ponto-caspian	bivalve	NIS	suspension feeder	Colne River, Surrey	**3,4,8,9,10,16**	Ward & Ricciardi 2007
Ensis directus	American razor-clam	NW Atlantic	bivalve	NIS	suspension feeder	local E,S & W coasts	*1*,**5**,**7**,*9*,*10*,*16*	Gollasch *et al.* in press
Eriocheir sinensis	Chinese mitten crab	NW Pacific	decapod	NIS	predator	local, E,S & W coasts	**5,7,8,9,12**	Herborg *et al.* 2005
Infectious salmon anaemia virus		unknown	virus	NIS	pathogen	NW Britain	**2,5**	Rodger *et al.* 1998
Marenzellaria viridis	red-gilled mud-worm	NW Atlantic	polycahete	NIS	deposit feeder	North Sea	*8*,*9*,**10**,*13*	Zettler 1997
Pseudoraspbora parva	top-mouthed gudgeon	W Asia	teleost	NIS	predator, detritivore	midland catchments	**11,12**	Gozlan *et al.* 2010
Sphaerothecum destruens		N. America	protozoan	NIS	parasite	southern Britain	**2,5**	Andreou *et al.* 2011
Balanus amphitrite	striped barnacle	circum-tropical	cirripede	NIS	suspension feeder	Celtic seas, Channel	**3**	Pitombo 2004
Mercenaria mercenaria	hard-shelled clam	NW Atlantic	bivalve	NIS	suspension feeder	Local, E, S & W coasts	**10**	Cox 1991
Mytilopsis leucophaeta	brackish-water mussel	W Atlantic	bivalve	NIS	suspension feeder	Bristol Channel	**4**,*10*	Bamber & Taylor 2002
Pacifastacus leniusculus	American crayfish	W North America	decapod	NIS	scavanger	inland Britain	**2,8,10,12**	Souty-Grosset *et al.* 2006
Palaemon macrodactylus	Oriental shrimp	NW Pacific	decapod	NIS	predator, scavenger	Broads, North Sea	*10*	Worsfold & Ashelby 2008
Petricola pholadiformis	American piddock	NW Atlantic	bivalve	NIS	suspension feeder	North Sea, Channel	*8,10*	Eno 1998
Solidobalanus fallax	warm-water barnacle	W Africa	cirripede	NIS	suspension feeder	Channel, St Georges Channel	**8**	Southward *et al.* 2004
Rhithropanopeus harrisii	dwarf crab	NW Atlantic	decapod	NIS	predator	Bristol Channel	*11*	Minchin *et al.* 2013
Urosalpinx cinerea	American oyster drill	NW Atlantic	gastropod	NIS	predator	SE Britain	**11**	Gibbs *et al.* 1991

Table 2.3. High and moderate impacting species established in northern European waters expected to ultimately spread to Britain and Ireland

In bold/shaded the high impacting target species already in northern European waters. Impacts: 1, human health; 2, animal health; 3, aquatic transport; 4, fouling abstraction; 5, loss of harvest; 6, loss of amenity; 7, damage to structures; 8, detrimental to habitat; 9 trophic alteration; 10, outcompetes natives;11, predator; 12, introduces pathogens/parasites; 13, alters geo-chemical cycle; 14, alters native species behaviour; 15, hybridisation; 16, herbivory. Impacts bold= impact, italics = possible impact. Nearest locality/region/state indicated for distribution.

species	common name	native range	taxon	status	functional group	distribution	impact	Reference
Alexandrium catenella		W Pacific	dinoflagellate	NIS	phototroph	Galicia, Spain	**1,5,**	Lilly *et al.* 2001
Ocenebra inornata	Japanese oyster drill	NW Pacific	gastropod	NIS	predator	Brittany France	**5,11**	Martel *et al.* 2004
Corbicula fluminalis		Asia and Africa	bivalve	NIS	suspension feeder	River Rhine	*4*,**9,10,13,***14,16*	Rajagopal *et al.* 2000
Epizootic haematopoietic necrosis		N. America & Asia	virus	NIS	virus	France	**2,5**	Ariel *et al.* 1999
Gyrodactylus salaris	salmon fluke	Northern Baltic	trematode	NIS	ectoparasite	Baltic Sea	**2,5,**	Johnsen & Jensen 1991
Hemigrapsus takanoi	brush-clawed shore crab	NW Pacific	decapod	NIS	predator	Normandy, France	**10,11**	Landschoff *et al.* 2013
Hemigrapsus sanguineus	Asian shore crab	NW Pacific	decapod	NIS	predator	Normandy, France	**5,10,11,12**	Landschoff *et al.* 2013
Infectious haematopoietic necrosis		Pacific	virus	NIS	virus	France	**2,5**	Bootland & Leong 1999
Martelia refringens		NW Pacific	protozoan	NIS	endoparasite	Brittany, France	**2,5**	Berthe *et al.* 2004
Mnemiopsis leiydi	warty comb-jelly	W Atlantic	ctenophore	NIS	pelagic predator	Southern North Sea	**5,9,11**	GESAMP 1997
Neogobius melanostomus	round goby	Ponto-caspian	teleost	NIS	predator, scavenger	River Scheldt	**9,10,11**	Kornis *et al.* 2012
Vibrio cholerae	Cholera	Asia	bacterium	NIS	bacterium	Sweden	**1**	Anderson *et al.* 2006
Callinectes sapidus	blue crab	W Atlantic	decapod	NIS	predator	southern North Sea	**5,11**	Gennaio *et al.* 2006
Caulerpa racemosa	sea grape	Australia	green alga	NIS	phototroph	Macaronesia	**10**	Klein & Verlaque 2008
Celtodoryx ciocalyptoides		NW Pacific	sponge	NIS	suspension feeder	Brittany, France	**4**	Perez *et al.* 2006
Cercopagis pengoi	fishhook waterflea	Ponto-caspian	cladoceran	NIS	pelagic predator	Baltic Sea	**5,9,***10,11*	Ojaveer *et al.* 2004
Megabalanus coccopoma	titan acorn barnacle	E Pacific	cirripede	NIS	suspension feeder	Belgium	**3**	Kerckhof & Cattrijsse 2001

species	common name	native range	taxon	status	functional group	distribution	impact	Reference
Pfiesteria piscicida		NW Atlantic	dinoflagellate	NIS	phototroph	Norway	**1,2,5,**	www.oie.int/
Pseudostylochus ostreophagus		NW Pacific	polyclad	NIS	predator	Brittany, France	*5*,**11**	Ventilla 1984
Rangia cuneata	common rangia	W Atlantic	bivalve	NIS	suspension feeder	Antwerp, Belgium	**9,10, 16**	Rudinskaya *et al.* 2014
Rapana venosa	Asian rapa whelk	W Pacific	gastropod	NIS	predator	Brittany, France	**11**	ICES 2004
Synidotea laticauda		NW Pacific	isopod	NIS	omnivore	Gironde, France	**11**	Bushek & Boyd 2005

Table 2.4 High impacting species already in Ireland and those expected to arrive according to life history stage (x) and transmission.

Pathway/vector mode: ? = unclear; 0 = low possibility; 1= possible; 2=likely

			Sedentary stages				Mobile stages			Pathway/vector mode to/within Ireland																		
Species	in Britain/Europe	in Ireland	Resting stage/capsule	sedentary 'larvae'	Juveniles	Adults	Larvae'	Juveniles	Adults	Wildlife	Natural currents	Ships ballast	Ships fouling	Craft fouling	Dredge spoil	Canals dispersal	Soft tissues	Shellfish cavity	Shellfish, epibionts	Shellfish equipment	Stocking	Angling baits	Fishing gear	Ornamentals	Water diverted	Research	Habitat management
Alexandrium catenella	●		x						x			2			1		2	2		0	2						
Corbicula fluminalis	●			x	x	x						0			1							1	2	0		0	0
Dikerogammarus haemobaphes	●						x	x	x			?		1									2	1			
Dikerogammarus villosus	●						x	x	x			?		1									2	1			
Dreissena bugensis	●				x	x	x					1	1	2	1								1				0
Ensis directus	●				x	x	x				?	2															
Epizootic haematopoietic necrosis	●											?									2			1			
Eriocheir sinensis	●		x				x	x	x			1	1										0				
Gyrodactylus salaris	●			x	x	x						?									2						
Haplosporidium nelsoni (MSX)	●																2				2						
Hemigrapsus penicillatus/takanoi	●		x				x	x	x			1						2			2		0				
Hemigrapsus sanguineus	●		x				x	x	x			1						2			2		0				
Infectious haematopoietic necrosis (IHN)	●																										
Marenzellaria viridis	●				x	x	x					2			1												
Martelia refringens	●		x			x				1	2	2					2	1			2		?				
Mnemiopsis leiydi	●						x	x	x		2	2															
Neogobius melanostomus	●		x				x	x	x			2	1											0			
Ocenebra inornata	●			x	x	x													2		2						
Pseudoraspbora parva	●		x				x	x	x			1	1										2	2			
Vibrio cholerae	●									?	?	2			?	1	1	2							1		
Alexandrium tamarense		●	x						x		?	1					2	2			2						

			Sedentary stages				Mobile stages			Pathway/vector mode to/within Ireland																	
Species	in Britain/Europe	in Ireland	Resting stage/capsule	sedentary 'larvae'	Juveniles	Adults	Larvae'	Juveniles	Adults	Wildlife	Natural currents	Ships ballast	Ships fouling	Craft fouling	Dredge spoil	Canals dispersal	Soft tissues	Shellfish cavity	Shellfish, epibionts	Shellfish equipment	Stocking	Angling baits	Fishing gear	Ornamentals	Water diverted	Research	Habitat management
Bonamia ostreae		●				x							?				2				2						
Corbicula fluminea		●		x	x	x					2	?			1	2					1	1	2	0	1	0	
Corella eumyota		●			x	x	x						2	2					2	2	2		1				
Crassostrea gigas		●			x	x	x						1	1							2						
Crepidula fornicata		●			x	x	x						1	1	1				2		2		0				
Didemnum vexillum		●			x	x	x						1	2	1				2	2	2		1				
Heterosigma akashiwo		●							x		1										?						
Infectious salmon anaemia virus		●											1				2				2		?				
Ostreid herpesvirus-1 microvariant		●				x											2				2						
Styela clava		●			x	x	x					?	2	2	1				2	2	2		2				
Undaria pinnatifida		●			x	x	x				1	?	2	2					2	2	2		1				

Table 2.5 Moderate impacting species already in Ireland and those expected to arrive according to life history stage (x) and transmission.

0 = low possibility; 1= possible; 2=likely: of transmission

			Sedentary stages				Mobile stages			Pathway/vector mode to/within Ireland																	
Species	Britain/Europe	Ireland	Resting stage	sedentary 'larvae'	Juveniles	Adults	Larvae'	Juveniles	Adults	Wildlife	Natural currents	Ships ballast	Ships fouling	Craft fouling	Dredge spoil	Canals dispersal	Soft tissues	Shellfish cavity	Shellfish, epibionts	Shellfish equipment	Stocking	Angling baits	Fishing gear	Ornamentals	Water diverted	Research	Habitat management
Aphanomyces astaci	●		x			x	x			?		?									2		1	2	1		
Balanus amphitrite	●				x	x	x					1	2	2	1				2	2	2						
Callinectes sapidus	●						x	x	x			1	1														
Celtodoryx ciocalyptoides	●				x	x	x						?		0			0	2	2	2					0	
Cercopagis pengoi	●		x				x	x	x	?	0	2			?												
Martelia refringens	●						x			?	?	1					2				2					0	
Megabalanus coccopoma	●				x	x	x					1	2	1													
Mercenaria mercenaria	●				x	x	x					?			1						2					2	
Mytilopsis leucophaeta	●				x	x	x					1	2	2	1												
Pacifastacus leniusculus	●						x	x	x												1			1			
Palaemon macrodactylus	●						x	x	x		0	2	?								?			?			
Petricola pholadiformis	●				x	x	x					1	1	1				1		1	1						
Pfiesteria piscicida	●		?						x	?	1	1			1		1	1			1						
Pseudostylochus ostreophagus	●				x	x												2	2		2						
Rangia cuneata	●				x	x	x					1	1		2							0		0			
Rapana venosa	●				x	x	x								1						2		0	0		1	
Rhithropanopeus harrisii	●				x	x	x					1	2	1													
Slidobalanus fallax	●				x	x	x				2	1	1	1						0			2				
Synidotea laticauda	●									?	1	2	1	1					0		0						
Urosalpinx cinerea	●			x	x	x									0			1	2	1	2						
Anguillicoloides crassus		●					x			2	2	1				2	2					0			2		
Balanus improvisus		●			x	x	x			0	2	1	2	2					2	2			1				
Botrylloides violaceum		●			x	x	x				0		2	2					2	2	2						

			Sedentary stages				**Mobile stages**			**Pathway/vector mode to/within Ireland**																	
Caprella mutica		●					x	x	x		2	0	2	2					2	2	2						
Chelicorophium curvispinum		●					x	x	x	0	2	1	1	2		2			0				0		1		
Dreissena polymorpha		●					x	x	x	1	2	2	2	2	2	2			2			0	2		2	2	1
Ficopomatus enigmaticus		●			x	x	x				1		2	2									0				
Gracilaria vericulophylla		●					x	x	x		2									1	1		1			1	
Hemimysis anomala		●					x	x	x		2	1				2								1	0		
Heterosiphonia japonica		●			x	x	x				x		2	2					1	1	1						
Karenia mikimotoi		●	?						x		2	?			?												
Sargassum muticum		●			x	x			x*		2	?	0	0					2	1	2						
Spartina anglica		●			x	x																					1

Undertaken for: The Centre for Environmental Data and Recording (CEDaR), Department of Natural Sciences, National Museums, Northern Ireland (NMNI) and the Department of Arts, Heritage and the Gaeltacht [Ref: NIS-2014#1] By: Dan Minchin, Marine Organism Investigations, Ballina, Killaloe, Co Clare.

3.1 MONITORING FOR THE TARGET SPECIES

When establishing a monitoring protocol for particular target species, it is highly advantageous for them to be identifiable in the field. This is usually the case for macro-biota, but small specimens usually require microscopic examination in a laboratory. Much depends upon the sampling technique and surveyor vigilance under field conditions. The ability to record some taxa may be challenging. Options for different sampling approaches are discussed below

3.1.1 Food-security sampling

Sampling for toxin producing phytoplankton and biotoxins in shellfish already takes place in Ireland as a service delivered by the Marine Institute (McMahon *et al.* 2008). Periodically such toxins can accumulate within wild and cultivated mussels and oysters, principally caused by dinoflagellates, most of which are considered to be native. The status of the naked dinoflagellate *Karenia mikimotoi* is unclear and should be considered cryptogenic. It appears to have characteristics of an NIS as its first appearance in Ireland was on the south-east coast in 1976 (Ottway *et al.* 1979) and subsequently spread to the south-west by 1978 (O'Sullivan 1978) and later appeared off the west coast of Ireland. This species has the ability to produce an ichthyotoxin that can result in losses of caged salmonids. Some toxins are harmful to humans and the paralytic shellfish toxin produced by *Alexandrium tamarense* has on occasion resulted in the suspension of bivalve harvesting. Both toxic and non-toxic populations of this species occur and future introductions of toxic populations to Ireland are indeed possible. Other toxin producing dinoflagellates exist elsewhere and may colonise at a future date. Following the account by Gomez (2008), the status of many non-indigenous phytoplankton are now considered to be cosmopolitan

3.1.2 Veterinary sampling

The health of cultivated fish species is generally monitored throughout the year by the Marine Institute under a surveillance programme targeting specific diseases (www.fishhealth.ie). The sampling may involve selective sampling of fish behaving abnormally or standardised tissue and/or organ sampling of apparently healthy fishes as specified by the protocols of the World Organisation for Animal Health (www.oie.int/).

3.1.3 Opportunistic monitoring

Sampling for selected target species may be undertaken in association with existing sampling or surveillance activities. Rotating screens of power plants obtain, apart from thrash, a wide range of organisms collected throughout the day and night. These collections include fishes, crabs and drift algae. Screens require cleaning and the contents may provide useful information on NIS, as has happened in the monitoring of the Chinese mitten crab on the Thames River in Britain (Morritt *et al.* 2013). Young fish surveys undertaken for gadoids, on the east and north-west coasts, and plaice, in the Irish Sea, also provide opportunities for monitoring NIS and are likely to be of special value because these cover large areas of seabed over a a wide geographical area (Ojaveer *et al.* 2014). The extensive buoyage system about the coast, and in port regions, are serviced at prescribed times and the attached fouling communities may also provide information on the extent of invasions. Buoys have been used in the monitoring of NIS off the Belgian coast (Kerckhof and Caltrijsse 2001) and offshore (Cook *et al.* 2007). Sampling under the Water Framework Directive (Directive 2000/60/EC) covers rivers, lakes, transitional and coastal waters. This region covers the main regions where NIS are likely to be found. While not specifically targeting NIS in these studies, the opportunities arise for including these within the sampling programme involving different monitoring levels (surveillance, operational, investigative) of the water column and benthos. Currently under the monitoring programme the Chinese mitten crab is specified as an alien of concern (EPA 2006).

3.1.4 Field sampling

This involves direct surveillance of target species and the sampling will vary according to the habitat and behaviour of each NIS. This includes examination of consignments of half-grown oysters (Brenner *et al.* 2014) and aquarium species (Padilla and Williams 2004). Sampling for benthic species may require a dredge (Minchin 2014), grab (Thomsen *et al*. 2009) or corer (Zettler 1995). Small fishes and decapods may be captured using baited or baitless traps ("condos") (Morrisey *et al.* 2007). The floating pontoons of marinas, landing stages and berthed craft are effective sites for early detection of sessile biota and their associates (Arenas *et al*. 2006; Ashton *et al.* 2006; Minchin 2007; Minchin and Nunn 2013; Minchin and Sides 2007; Nall *et al.* 2014). Overland transportation of small craft can spread sessile NIS on the hull, in bait wells, bilges or with angling equipment. Cruisers lifted from water and imported by ferry and overland pose risks for fouling species and what may be retained in pumped toilet water. Shore surveys can reveal remains of molluscs and crabs in strandline detritus, while intertidal monitoring may reveal a wide range of NIS in estuaries and around aquaculture and boating areas. Plankton sampling offshore using a Gulf III plankton sampler may reveal crustaceans and fishes, although fragile gelatinous zooplankton may require specialised methods.

When sampling for the highest impacting species (**Table 3.1**), moderate impacting species (**Table 3.2**) may also be revealed. For example, when examining imported oyster consignments there are approximately eight macro-species likely to be found and a further twelve species (of the moderate risk category) that could be targeted at the same time. During intertidal monitoring, much greater numbers of NIS may be encountered, but this will largely be dependent upon the sampling methods employed.

Where there are coastal regions with distinct hubs of aquatic activities, there are usually a wide range of structures where NIS may be encountered (Mineur *et al.* 2012). While all regions should be examined for impacting NIS the priority should be for those areas that already have the most known NIS present as experience has shown that areas with high numbers of NIS are more likely to receive more. The areas about the Irish coast are examined in relation to different human activities (**Table 3.3**). The relative levels of activity within each of these areas are scored, when present, on a three point scale. These have been ranked at three levels based on the relative level of human activity within each region. However, the ranked levels between activities should not be seen to be the same and only provide a relative indication for each specific activity. The principal regions for general monitoring of NIS involve six port areas (Belfast Lough, Carlingford Lough, Dublin Bay, Waterford Estuary, Cork Harbour and the Shannon Estuary) and an area with several marinas, Strangford Lough. These regions have varying salinity ranges and habitats which need to be considered in relation to the target species being sought (**Appendix 1**). The next level for general monitoring involves mainly south coast and west coast regions. However, monitoring for specific target NIS associated with a human activity, as in the case of finfish culture, involves sites that do not lie within the suggested principal locations for general monitoring (**Table 3.3**).

While there are particular approaches for the sampling of NIS that will require separate monitoring methods there are activities that already take place that could be used to enhance the surveillance of NIS in Irish waters.

Table 3.1 Sampling methods for the highest impacting species in Ireland and those expected to arrive in Ireland

xx = most effective sampling, x= NIS might be obtained.

	Specialist		Opportunistic				Field studies							
SPECIES	food-security sampling	veternarian sampling	rotating screens	bouyage	young fish surveys	WFD sampling	stock consignments	trailered boat inspections	fishing/angling equipment	intertidal surveys	marinas	trap/net sampling	grab/core /drag sampling	plankton sampling
Alexandrium catenella	**xx**													
Alexandrium tamarense	**xx**													
Bonamia ostreae		**xx**					**x**							
Corbicula fluminalis						**xx**		**x**		**xx**			**xx**	
Corbicula fluminea						**xx**		**x**		**xx**			**xx**	
Corella eumyota				**x**		**xx**		**x**		**xx**	**xx**			
Crassostrea gigas				**x**		**xx**	**xx**	**x**		**xx**	**xx**			
Crepidula fornicata				**x**	**xx**	**xx**	**xx**			**xx**	**xx**		**x**	
Didemnum vexillum			**x**	**xx**	**x**	**xx**	**xx**			**xx**	**xx**		**xx**	
Dikerogammarus haemobaphes				**x**		**xx**		**xx**	**xx**		**x**	**xx**	**x**	
Dikerogammarus villosus				**xx**		**xx**		**xx**	**x**		**x**	**xx**	**x**	
Dreissena bugensis			**x**	**x**		**xx**		**xx**	**x**	**xx**	**xx**		**xx**	**x?**
Ensis directus					**xx**					**xx**			**x**	
Epizootic haematopoietic necrosis		**xx**												
Eriocheir sinensis			**xx**		**xx**	**xx**			**xx**	**xx**		**xx**	**x**	**x**
Gyrodactylus salaris		**xx**					**xx**							
Hemigrapsus sanguineus			**x**		**x**	**xx**	**xx**		**x**	**xx**		**x**	**x**	**x**
Hemigrapsus takanoi			**x**		**x**	**xx**	**xx**		**x**	**xx**		**xx**	**x**	**x**
Heterosigma akashiwo	**xx**											**xx**		**x**
Infectious haematopoietic necrosis (IHN)		**xx**					**x**							
Infectious salmon anaemia virus		**xx**					**x**		**xx**					
Marenzellaria viridis						**xx**				**xx**			**xx**	**x**
Martelia refringens		**XX**												

	Specialist		Opportunistic				Field studies							
SPECIES	food-security sampling	veternarian sampling	rotating screens	bouyage	young fish surveys	WFD sampling	stock consignments	trailered boat inspections	fishing/angling equipment	intertidal surveys	marinas	trap/net sampling	grab/core /drag sampling	plankton sampling
Mnemiopsis leiydi														xx
Neogobius melanostomus			xx		xx	xx				XX		xx	x	
Ocenebra inornata						xx	xx			xx		xx	x	
Ostreid herpesvirus-1 microvariant		x												
Pseudoraspbora parva			x			x	xx	x	xx			xx		
Sphaerothecum destruens		xx					x							
Styela clava			x	xx	x	x	xx	x	x	xx	xx		x	
Undaria pinnatifida			xx	xx	x	xx		x	x	xx	xx		x	
Vibrio cholerae	xx	xx												

Table 3.2 Sampling methods for the moderate impacting species in Ireland and those expected to arrive in Ireland

XX = most effective sampling, X = species might be obtained.

	Specialist		Opportunistic				Field studies							
SPECIES	food-security sampling	veternarian sampling	rotating screens	bouyage	young fish surveys	WFD sampling	stock consignments	trailered boat inspections	fishing/angling equipment	intertidal surveys	marinas	trap/net sampling	grab/core /drag sampling	plankton sampling
Anguillicoloides crassus		XX												
Aphanomyces astaci		XX												
Balanus amphitrite			X	XX	X	X	XX	XX	X	XX	XX		X	
Balanus improvisus			X	XX	X	XX		XX		XX	XX		XX	
Botrylloides violaceum			X	XX	X	XX	XX	XX		XX	XX		X	
Callinectes sapidus						X	XX			X		XX		
Caprella mutica				XX		XX		X			XX	X	X	X
Celtodoryx ciocalyptoides					X	X	XX			XX	X		X	
Cercopagis pengoi						X								XX
Chelicorophium curvispinum				XX		XX		XX	X		XX		XX	
Dreissena polymorpha				XX		XX		XX	XX	XX	XX		XX	X
Ficopomatus enigmaticus				X		XX		XX			XX		X	
Gracilaria vericulophylla			XX		XX	XX	XX	X	X	XX	X		X	
Hemimysis anomala						X						XX		XX
Heterosiphonia japonica						X	X	X		XX	XX		X	
Karenia mikimotoi	XX													XX
Megabalanus coccopoma				XX		X		X			X			
Mercenaria mercenaria						X	XX			XX			X	
Mytilopsis leucophaeta			X	XX		XX		X		X	XX		X	
Pacifastacus leniusculus			X		X	XX	X					XX		
Palaemon macrodactylus					XX	XX				X		XX		X
Petricola pholadiformis					X	X	X			XX			X	
Pfiesteria piscicida	XX					X								XX
Pseudostylochus ostreophagus						X	XX							

	Specialist		Opportunistic				Field studies							
SPECIES	food-security sampling	veternarian sampling	rotating screens	bouyage	young fish surveys	WFD sampling	stock consignments	trailered boat inspections	fishing/angling equipment	intertidal surveys	marinas	trap/net sampling	grab/core /drag sampling	plankton sampling
Rangia cuneata					X	XX				XX			XX	
Rapana venosa					XX	X	X			X		X	X	
Rhithropanopeus harrisii						XX					XX	X	X	
Sargassum muticum			XX	X	X	XX	X	X	X	XX	XX		X	
Slidobalanus fallax					X	X			XX				X	
Spartina anglica						XX				XX				
Synidotea laticauda						XX				X	X	?	XX	XX
Urosalpinx cinerea					X	X	XX			XX			X	

Table 3.3. Principal coastal regions for the undertaking of surveys on impacting NIS in relation to human activities.

Regions of relative expected importance according to human activities: X = some NIS records possible, XX records of NIS likely, XXX = highest risk for NIS. Local regions with the greatest likelihood of receiving NIS (in red), other areas with high expectation of NIS arrivals (in yellow).

Local region	Port(s)	Docks	Drydock	Dredging	Hoists	Marina	Moorings	Wild oysters	Trestle oysters	Wild mussels	Stocked mussels	Longlines mussel	Finfish culture	estimated psu range	Target region rank	Coastal region
Balfast Lough	XX		X	X		XXX					X			20-35	1	E
Carlingford Lough	XX			X	X	XXX	XX		XX	X	X			20-35	1	E
Cork Harbour	XXX		X	X	X	XXX	XXX		X					2-35	1	S
Dublin Bay	XX		X	X	X	XXX	XX							15-35	1	E
Malahide Estuary				X	X	XXX	X							20-35	2	E
Shannon Estuary	XX	X		X	X	XX	X							0-35	1	W
Strangford Lough						XXX	XXX	X	X					20-35	1	E
Waterford Estuary	XX			X	X	X	X		X	X				0-35	1	S
Bantry Bay	XX			X	X	X	X					X	X	30-35	2	S
Donegal Bay	X			X	X		XX						X	25-35	2	W
Galway Bay	X	X		X	X	X	XX	X	X					5-35	2	W
Kenmare Bay							XXX					X	X	25-35	2	S
Kilmore Quay	X			X		X								33-35	2	S
Kinsale Harbour	X				X	X	X							5-35	2	S
Lough Foyle	XX			X	X	X			X					5-35	2	N
Tralee Bay	XX				X	X	X	X						15-35	2	W
Bannow Bay									X					25-35	3	S
Bertrabouy Bay							X	X	X				X	25-35	3	W
Clew Bay	X						X						X	25-35	3	W
Dingle Bay	X			X	X	XX	XX		X	X	X			15-35	3	W
Dungarvan Bay				X			X		XX					30-35	3	S
Dunmanus Bay							X							25-35	3	S

Local region	Port(s)	Docks	Drydock	Dredging	Hoists	Marina	Moorings	Wild oysters	Trestle oysters	Wild mussels	Stocked mussels	Longlines mussel	Finfish culture	estimated psu range	Target region rank	Coastal region
Kilkieran Bay							X	X	X				X	25-35	3	W
Killary Harbour							X					X	X	10-35	3	W
Lough Swilly						X	X	X		X			X	15-35	3	N
Mulroy Bay				X			X					X	X	25-35	3	N
Roaringwater Bay	X			X		X	XX		X			X		10-35	3	S

3.2 RECORDING AND SAMPLING

A rapid assessment approach should be undertaken with a selected set of target species and a survey methodology that is suitable for finding and recording the species set. There are two possible methods for recording NIS species. A simple assessment of NIS presence or absence can be determined, but this does not necessarily enable a comparison between different sites, or over time, as some level of relative abundance is lacking. The gathering of abundance and distribution range (ADR) data, does, however provide this capability. The ADR methodology is part of the biopollution assessment method (Olenin *et al*. 2007) and has been used to evaluate the impact of a single species over a wide area (Olenina *et al*. 2010) or the impact of many species (Zaiko *et al*. 2011). The ADR has been found to be useful in lagoons (Wittforth and Zettler 2013), lakes (Minchin 2014; Minchin and White 2014), rivers (Minchin and Zaiko 2013) and marinas (Minchin 2012; Minchin and Nunn 2013).

The biopollution method first requires a decision on the extent of the assessment unit in which the NIS occurs. This is decided by the field worker. This may be a marina, a fish farm, an area of shore or buoyage within a bay and is delineated for a defined time period such as a year, or less, in the case of a seasonal NIS. The assessment is based on the abundance of the NIS and its frequency of occurrence over all of the stations examined, where one or more NIS might be expected to occur, within the selected assessment unit. A representative number of samples should be taken in order to obtain a meaningful ADR level. Abundance can be *'low'* where it makes up only a small part of a community, *'moderate'* where it is frequent but less than half of the abundance of the native community and *'high'* should it exceed half of the overall abundance and hence dominate the local community. The distribution scales for each assessment unit range from *'local'*, where it occurs at one station, '*several localities'* where it is present in less than half of the stations , '*many localities'* where it is found in more than half of the available localities and '*all localities'* where it occurs at all stations. Combinations of abundance and distribution provide a scale that ranges from *'A'* representing few individuals at one locality to *'E'* where a species occurs in high numbers in all localities (**Table 3.4**). Generally macro-biota are the most easily scored using this system as small species may need to be examined in the laboratory.

Table 3.4 Demonstrating the five different levels A-E of the abundance and distribution scheme for an assessment area and for a specific time.

ADR Class	Few localities	Several localities	Many localities	All localities
Low	**A**	**A**	**B**	**C**
Moderate	**B**	**B**	**C**	**D**
High	**B**	**C**	**D**	**E**

It is important to record what represents a low number of an individual NIS so that comparisons can be meaningfully made when subsequently monitoring. The sampling method in each case should also be recorded.

Calculating the Biopollution level, takes considerably more time. The impacts can be measured at the level of impact on the community (C), habitat (H), and/or ecosystem function (E). For each of these there are five states that range between 0 and 4. These are: 0 = no measureable impact, 1 = weak impact, 2 = moderate impact, 3 = strong impact and 4 = massive impact. The greatest impact level dictates the overall impact state within the chosen assessment unit. Levels of biopollution can be determined using the free online service *Biological Invasion Impact/Biopollution Assessment System* (BINPAS) available at http://corpi.ku.lt/databases/binpas/ and described by Narščius *et al.* (2012). The method has been sufficiently robust to quantify impacts in a standard and repeatable way where there is adequate information, and in some cases the ADR may act as a proxy for the biopollution levels within a studied assessment area (Minchin and Zaiko 2013).

4 CURRENT AND FUTURE NIS INVASION PATTERNS

Predictions in relation to when, and how, NIS arrive are not easily determined. Nevertheless, it is certain that further arrivals will involve vessels of many kinds, ranging from barges and floating platforms to conventional craft. These may introduce NIS, not just from northern Europe; but from distant Large Marine Ecosystems. Whereas recreational craft usually spread NIS locally, aquaculture involves movements over large as well as nearby areas. While these pathways are obvious, there are others that include trade in live foods, baits, and ornamentals that require more attentive surveillance. Information and awareness need to be provided to those involved in the different industries especially those involved in transportation. There are known cases where imports of shellfish consignments have been refused and will have been inappropriately disposed of in coastal waters. Those involved in such transport need to know of the consequences of live transport and how such consignments should be disposed of when refused because these actions could lead to the establishment of, in particular, pests, parasites, diseases and disease agents.

4.1 PONTO-CASPIAN SPECIES ARE SPREADING WESTWARD IN EUROPE

Over geological time, some aquatic communities have adapted to successive de-watering of sea basins resulting in more robust species with an increased ability to tolerate a wide range of environmental conditions. This may explain why the physiological abilities of Ponto-Caspian basin biota are greater than our native biota. With the gradual linkage of separate river catchments by canals since the late 1700s, there has been an incremental spread of these species from the Black and Caspian seas catchments. Biological dispersal from this region has taken place *via* three main canal routes (Bij de Vaate *et al.* 2002), the most important of these is the route termed the southern corridor. Since 1992, for example, the Danube has been linked to the Rhine by the Main canal system. This has enabled a 'wave' of Ponto-Caspian species to enter the Rhine and form a bridgehead close to Britain.

The European canal systems have over time been progressively deepened and widened to accommodate larger vessels and this has provided greater opportunities for NIS spread. NIS may passively disperse along these routes or become transported with river traffic.

Some Ponto-Caspian species have already arrived in Ireland such as the zebra mussel *Dreissena polymorpha*, the bloody red shrimp *Hemimysis anomala* and the amphipod *Chelicorophium curvispinum.* Others have recently arrived in Britain, such as the amphipods *Dikerogammarus haemobaphes* and *Dikerogammarus villosus* and the quagga mussel *Dreissena bugensis.* These are likely to arrive to Ireland soon. Gallardo and Aldridge (2014) postulated that there is a significant threat from this bio-geographical region and other species are expected to arrive in Britain, for example *Echinogammarus ischnus, Jaera istri, Limnomysis benedeni* and *Dikerogammarus bispinosus* awaiting in The Netherlands to establish themselves in Britain While some of these may need to be included on a future target list for Ireland, their behaviour in Britain should provide foresight on the level of threat they will pose (Godard *et al.* 2013). Of concern is the collection of such robust species that could develop a community that will sufficiently alter the aquatic realm.

4.2 SPREAD OF FOULING SPECIES FOLLOWING RE-COMMISSIONING OF VESSELS DURING THE RECENT ECONOMIC DECLINE.

Hull fouling is now accepted as being as, or more important than, ballast water transmissions world-wide (Minchin and Gollasch 2003). Fouling has become of greater concern since the cessation in the use of aggressive chemical antifouling agents – organotins, such as *tri-butyl-tin* (TBT) – for hull paint coatings. Alternative coatings have been less effective leading to a greater level of fouling depending on duration of immersion. Floerl and Coutts (2009) reported that, in early 2009, between 10% and 25% of all container and refrigerator vessels lay at anchor for periods of greater than three months. The potential to spread sessile species on return to service is of special concern. While the exact influence of the global economic decline cannot be readily assessed, some idle vessels will continue to act as an invasion reservoir inoculating those ports they subsequently visit.

4.3 ARRIVAL OF NW PACIFIC SPECIES VIA ARCTIC SHIPPING CORRIDORS.

North Western Pacific biota have already shown themselves to be impacting species following the many introductions associated with stock movements used in shellfish cultivation and the few that have arrived by other means. Several of these are now targeted species in Europe. North Pacific species when carried with vessels would have been challenged by the warmer water of the Indo-Pacific sub-tropical and tropical seas when *en route* to northern Europe. Few would have survived such transport. Whereas the development of a cold water route is more likely to see successful transmissions of biota occurring from the temperate, and cool-temperate, coastal regions of the North Pacific as polar surface sea-ice recedes. These NIS are likely to survive these cold routes and be directly transported to the main European shipping ports from which a secondary spread to other European regions may be expected. Temperate species are capable of enduring cold winters, especially those on the eastern side of continents; such a passage is unlikely to result in a complete mortality of a hull-fouling assemblage. In addition NIS endurance of cold conditions may enable a gradual spread of NIS into polar-regions aided by human activities, as in the case of movements of oil platforms or range expansions arising from fishing discards, as new areas for exploitation become available.

4.4 NORTHWARD RANGE EXPANSIONS OF NIS.

It is inevitable that, with persistent climate warming, species adjusted to environmental conditions to the south of Ireland will now have opportunities to extend their ranges. On account of Ireland's island status this extension, for many, is likely to involve anthropogenic transmissions because unless an NIS has a prolonged pelagic phase it is unlikely to arrive in Ireland by natural means. While this pole-ward spread of species may take place slowly, notable range expansions have already been recorded for intertidal species in Britain (Mieszkowska *et al.* 2005; Cook *et al.* 2013). Northward progressions have been noted for shore biota from either side of the North Atlantic (Sorte *et al.* 2010) and for those with prolonged pelagic life history stages (Beaugrand *et al.* 2002). While these northward expansions are predominantly of species native to European seas, some will be of NIS established south of Ireland or will be of NIS from elsewhere.

4.5 HUMAN POPULATION DENSITY INCREASES AND MIGRATION AND THEIR ASSOCIATED CULTURAL INTERESTS

The world-wide movement of humans and the associated migration of cultural traditions, beliefs and preferences has led to the release of species to the wild. Some of these introductions will be species for which there are food preferences, whereas others involve ceremonial releases of animals termed 'prayer animal releases'. Such ceremonial releases often involve NIS obtained in pet stores, and such occasions may involve many multiple releases (Severinghaus and Li, 1999), which may lead to establishment.

4.6 FURTHER INCURSIONS INTO THE MEDITERRANEAN SEA AND SPREAD TO NORTHERN EUROPE.

The Suez Canal has enabled a large component of NIS to arrive and spread within the Mediterranean Sea with a wide range of impacts (Galil *et al.* 2014). While some have been profitably utilised, others, including those that are noxious, poisonous or venomous have caused threats to human and animal health (Galil 2007). The current plan to build a further and larger canal is a cause for concern, as the new route is expected to have a greater shipping capacity than the present canal. This expansion will almost certainly cause a wide range of further impacts to the Mediterranean Sea (Galil *et al,* 2014), and ultimately may have consequences for northern Europe, including Ireland.

Attitudes towards NIS will benefit from a more pragmatic approach to their arrival and should seek opportunities for their utilisation, as has occurred in the terrestrial environment. Not all high impacting species can be removed, and some provide employment as in the case of the Pacific oyster. Measures to control some NIS may reduce their populations using fishing effort as in the case of *Ensis directus* off the Dutch coast, and the predatory snail *Rapana venosa* in the Black Sea (ICES 2004). Currently the arrival of NIS to the Irish marine environment has resulted in an increase in species richness. The recovery since the last glacial period will have been principally from re-invading biota and this process continues, albeit with human help. Climate change may be expected to result in further increases of NIS that will arrive to Ireland. Not all NIS should be considered to be harmful and some will be of ultimate economic benefit as developments in biotechnology and 'new' sources of food.

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6 REFERENCES

Aladin NV, Plotnikov IS, Filippov AA (2002) Invaders in the Caspian Sea. pp 351-359. In: Leppäkoski E, Gollasch S, Olenin S (eds), *Invasive Aquatic Species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Alexandrov B, Boltachev A, Kharchenko T, Lyashenko A, Son M, Tsarenko P, Zukinsky V (2007) Trends of aquatic alien species invasions in Ukraine. *Aquatic Invasions,* 2: 215-242.

Andersson Y, Ekdahl K. (2006) Wound Infections due to *Vibrio cholerae* in Sweden after swimming in the Baltic Sea, summer 2006. *Euro Surveillience,*11(8): E060803.2.

Andreou D, Hussey M, Griffiths SW, Gozlan RE (2011) Influence of host reproductive state on *Sphaerothecum destruens* prevalence and infection level. *Parasitology*, 138(1): 26-34.

Arenas F, Bishop JDD, Carlton JT, Dyrynda 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 of the United Kingdom,* 86: 1329-1337.

Ashton G, Boos K, Shucksmith R, Cook E (2006a) Rapid assessment of the distribution of marine non-native species in marinas in Scotland. *Aquatic Invasions,* 1: 209-213.

Bamber RN, Taylor JD (2002) The brackish water mussel *Mytilopsis leucophaeta* (Conrad 1831) (Bivalvia: Dreissenidae) in the River Thames. *Journal of Conchology,* 37: 403–404.

Beaugrand G, Reid PC, Ibañez F, Lindley JA, Edwards M (2002) Reorganization of north Atlantic marine copepod biodiversity and climate. *Science*, 296: 1692–1694.

Beggel S, Cerwenka AF, Brandner J, Geist J (2014) Shell morphological versus genetic identification of quagga mussel (*Dreissena bugensis*) and zebra mussel (*Dreissena polymorpha*). *Aquatic Invasions*, 9 (in press)

Berger VJA, Naumov AD (2002) Biological invasions in the White Sea. pp 235-239. In: Leppäkoski E, Gollasch S, Olenin S (eds), *Invasive aquatic species of Europe, Distribution, Impacts and Management.* Dordrecht, Boston and London, Kluwer Academic Publishers.

Bij de Vaate A, Jazdzewski K, Ketelaars HAM, Gollasch S, Van der Velde G (2002) Geographical patterns in the range extension of Ponto-Caspian macroinvertebrate species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences,* 59(7): 1159-1174.

Boelens R, Minchin D, O'Sullivan G (2005) Climate Change: Implications for Ireland's marine environment and Resources. *Marine Foresight Series* No 2, Marine Institute, Oranmore, Co Galway 40pp.

Bory HC, Barrios-O'Neill D, Emmerson MC, Aldridge DC, Dick JTA (2014) Predicting the predatory impacts of the 'demon shrimp *Dikerogammarus haemobaphes*, on native and previously introduced species. *Biological Invasions*. DOI 10.1007/s10530-014-0751-9

Brenner M, Frazer D, Van Nieuwenhove K, O'Beirn F, Buck BH, Mazurié J, Thorarinsdottir G, Sanchez-Mata A, Strand Ø, Flimlin G, Miossec L, Kamermans P (2014) Bivalve aquaculture transfers in Atlantic Europe. Part B: Environmental impacts of transfer activities. *Ocean and Coastal Management,* 89: 139-146.

Brown J, Carillo L, Fernand L, Horsburgh KJ, Hill AE, Young EF (2003) Observation of the physical structure and seasonal jet-like circulation of the Celtic Sea and St. George's Channel of the Irish Sea. *Continental Shelf Research*, 23: 533-561.

Buhle ER, Ruesink JL (2009) Impacts of invasive oyster drills on Olypia oyster (*Ostrea lurida* Carpenter, 1864) recovery in Willapa Bay, Washington, United States. *Journal of Shellfish Research*, 28(1): 87-96.

Bushek D, Boyd S (2005) The Potential Impact of the Asian Isopod, *Synidotea laevidorsalis* (Miers 1881), on the Delaware Bay, USA. *Biological Invasions*, 8: 697-702.

Carlton JT (1996) Biological invasions and cryptogenic species. *Ecology,* 77: 1653-1655.

Carlton JT, Geller JB, Reaka-Kudla ML, Norse EA (1999) Historical extinctions in the Sea. *Annual Review of Ecological Systems,* 30: 515-538.

Collin SB, Oakley JA, Sewell J, Bishop JDD (2010) Widespread occurrence of the non-indigenous ascidian *Corella eumyota* Traustedt, 1882 on the shores of Plymouth Sound and estuaries special area of conservation, UK. *Aquatic Invasions,* 5: 175-179.

Cook EJ, Ashton G, Campbell M, Coutts A, Gollasch S, Hewitt C, Liu H, Minchin, D, Ruiz G, Shucksmith R (2008) Non-native Aquaculture Species Releases: Implications for Aquatic Ecosystems, pp 155-184. In: Holmer M, Black K, Duarte CM, Marbà N, Karakassis I (eds) *Aquaculture in the Ecosystem*. Springer, The Netherlands.

Cook EJ, Jenkins S, Maggs C, Minchin D, Mineur F, Nall C, Sewell J (2013) Impacts of climate change on non-native species. *Marine Climate Change Impacts Partnership: Science Review,* 2013: 155-166.

Cook EJ, Jahnke M, Kerckhof F, Minchin D, Faasse M, Boos K, Ashton G (2007) European expansion of the introduced amphipod *Caprella mutica* Schurin 1935. *Aquatic Invasions,* 2(4): 411-421.

Cox J (1991) Dredging for the American hardshell clam, the implications for nature conservation. *Ecos: a Review of Conservation,* 12: 50–54.

Cullinane J, Whelan P (1981) Ecology, distribution and spread of *Cryptonemia hibernica* Guiry *et* Irvine on the south coast. *Proceedings of the International Seaweed Symposium*, 10: 259-264.

David M, Gollasch S (2014) Global maritime transport and ballast water management, issues and solutions. *Invading Nature, Springer Series in Invasion Biology,* 8, 306pp.

David M. Gollasch S, Leppäkoski E (2013) Risk assessment for exemptions from ballast water management – the Baltic Sea case study. *Marine Pollution Bulletin,* 75: 205-217.

Den Hartog C (1987) "Wasting disease" and other dynamic phenomena in *Zostera* beds. *Aquatic Botany,* 27(1): 3-14.

Eno CE (1998) Non-native marine species in British waters: effects and controls*. Aquatic Conservation: Marine and Freshwater Ecosystems,* 6: 215–228.

Eno NC, Clark RA, Sanderson WG (1997) *Non-native species in British waters: a review and dictionary*. Peterborough, Joint Nature Conservation Committee, 152 pp.

EPA (2006) *Ireland, Water Framework Directive Monitoring Programme*. Environmental Protection Agency, Johnstown Castle, Co Wexford, 195pp.

Evans DW, Mathews MA (1999) *Anguillicola crassa* (Nematoda, Dracunculoidea); first documented record of this swimbladder parasite of eels in Ireland. *Journal of Fish Biology*, 55: 665-668.

Fernand L, Nolan GD, Raine R, Chambers CE, Dye SR, White M, Brown J (2006) The Irish coastal current: A seasonal jet-like circulation. *Continental Shelf Research*, 26: 1775-1793.

Floerl O, Coutts A (2009) Potential ramifications of the global economic crisis on human-mediated dispersal of marine non-indigenous species. *Marine Pollution Bulletin,* 58: 1595-1598.

Galil BS, Genovesi P, Ojaveer H, Quilez-Badia G, Occhipinti A (2013) Mislabeled: eco-labelling an invasive alien shellfish fishery. *Biological Invasions,* 15: 2363-2365.

Galil BS (2007) Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. *Marine Pollution Bulletin,* 55:314–322.

Galil BS, Boero F, Campbell ML, Carlton JT, Cook E, Fraschetti S, Gollasch S, Hewitt CL, Jelmert A, Macpherson E, Marchini A, McKenzie C, Minchin D, Occhipinti-Ambrogi A, Ojaveer H, Olenin S, Piraino S, Ruiz GM (2014) 'Double trouble@: the expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. *Biological Invasions* DOI 10.1007/s10530-014-0778-y

Galil BS, Marchini A, Occhipinti_Ambrogi A, Minchin D, Narščius A, Ojaveer H, Olenin S (2014) International arrivals: widespread bioinvasions in European seas. *Ethology Ecology and Evolution,* 26(2-3): 152-171.

Galil BS, Zenetos A (2002) A sea of change: exotics in the Eastern Mediterranean Sea. pp 325-336. In: Leppäkoski E, Gollasch S, Olenin S (eds) *Invasive aquatic species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Gallardo B, Aldridge CC (2014) Is Great Britain heading for a Ponto-Caspian invasional meltdown? *Journal of Applied Ecology* doi: 10.1111/1365-2664.12348

Gennaio R, Scordella G, Pastore M (2006) Occurrence of blue crab *Callinectes sapidus* (Rathbun, 1896 Crustacea, Brachyura), in the Ugento Ponds area (Lecce, Italy). *Thalassia Salentina*, 29: 29-39.

Gibbs PE, Spencer BE, Pascoe PL (1991) The American oyster drill *Urosalpinx cinerea* (Gastropoda): evidence of decline in an imposex-affected population (R. Blackwater, Essex). *Journal of the Marine Biological Association of the United Kingdom,* 71: 827–838.

Gittenberger A (2007) Recent population expansions of non-native ascidians in the Netherlands. *Journal of Experimental Marine Biology and Ecology,* 342: 122-126.

Godard MJ, Davison PI, Copp GH, Stebbing PD (2013) Review of invasion pathways and provisional pathway management plan for non-native ponto-caspian species of potential invasion risk to Great Britain. *Cefas Contract Report* C5524, 60pp.

Golani D, Orsi-Relini L, Massutí E, Quignard JP (2002) *CIESM atlas of exotic species in the Mediterranean* Volume 1 Fishes. In: Briand F (ed.), Monaco, CIESM Publishers, 256 pp.

Gollasch S, Nehring S (2006) National checklist for aquatic alien species in Germany. *Aquatic Invasions,* 1: 245-269.

Gollasch S, Haydar D, Minchin D, Wolff WJ, Reise K (2009) Introduced aquatic species of the North Sea coasts and adjacent brackish waters. pp 507-525. In: Rilov G, Crooks J (eds), Biological Invasions in marine ecosystems: Ecological, management and geographic perspectives. *Ecological Studies,* 204. Heidelberg, Springer.

Gollasch S, Kerckhof F, Craymeerch J, Goulletquer P, Jensen K, Jelmert A, Minchin D (in press) Current status of invasions by the marine bivalve *Ensis directus*. *Species Alert Report*, ICES 29pp.

Gollasch S, Rosenthal R, Botnen H, Hamer J, Laing, I, Leppäkoski E, Macdonald E, Minchin D, Nauke M, Olenin, S., Utting, S., Voigt M, Wallentinus I (2000): Fluctuations of zooplankton taxa in ballast water during short-term and long-term ocean-going voyages. *International Review in Hydrobiology*, 85: 5-6, 597-608.

Gómez F (2008) Phytoplankton invasions: comments on the validity of categorising the non-indigenous dinoflagellates and diatoms in European seas. *Marine Pollution Bulletin,* 56: 620-628.

Gomoiu M-T, Alexandrov B, Shadrin N, Zaitsev Y (2002) The Black Sea - a recipient, donor and transit area for alien species. pp 341-350. In: Leppäkoski E, Gollasch S, Olenin S (eds), *Invasive aquatic species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Goulletquer P, Bachelet G, Sauriau PG, Nöel P (2002) Open Atlantic coast of Europe – a century of introduced species into French waters. pp 276-290. In: Leppäkoski E, Gollasch S, Olenin S (eds), *Invasive aquatic species of Europe. Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Graczyk T, Lucy FE, Tamang L, Minchin D, Miraflor A (2008) Assessment of waterborne parasites in Irish river basin districts – use of zebra mussels (*Dreissena polymorpha*) as bioindicators *Aquatic Invasions,* 3(3): 305-313.

Grigorovich IA, Therriault TW, MacIsaac HJ (2003) History of aquatic invertebrate invasions in the Caspian Sea. *Biological Invasions,* 5: 103-115.

Grigorovich IA, Therriault TW, MacIsaac HJ (2003) History of aquatic invertebrate invasions in the Caspian Sea. *Biological Invasions,* 5: 103–115.

Hayes K, Sliwa C (2002) Identifying potential marine pests - a deductive approach applied to Australia. *Marine Pollution Bulletin*, 46, 91-98.

Hopkins CCE (2002) Introduced marine organisms in Norwegian waters, including Svalbard. pp 116-119. In: Leppäkoski E, Gollasch S, Olenin S (eds), *Invasive aquatic species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Holmes JMC, Minchin D (1995) Two exotic copepods imported into Ireland with the Pacific oyster *Crassostrea gigas* (Thunberg). *The Irish Naturalists' Journal,* 25: 17-20.

Horsburgh KJ, Hill, AE, Brown J, Fernand L, Garvine RW, Angelico MMP (2000) Seasonal evolution of the cold pool gyre in the western Irish Sea. *Progress in Oceanography*, 46: 1-58.

Huang WG, Cracknell AP, Vaughan RA, Davies PA (1991) A satellite and field view of the Irish Shelf front. *Continental Shelf Research*, 11: 543-562.

Husa V, Sjotun K, Lein TE (2004) The newly introduced species *Heterosiphonia japonica* Yendo (Dasyaceae, Rhodophyta) geographical distribution and abundance at the Norwegian southwest coast. *Sarsia*, 89(3): 211-217.

ICES (2004) Alien species alert: *Rapana venosa* (veined whelk). Mann R., A. Occhipinti, and J.M. Harding (eds) *ICES Cooperative Research Report* No. 264, 14 pp.

ICES (2005) ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005, 30 pp

ICES (2005c) Vector Pathways and the Spread of Exotic Species in the Sea. Minchin D, Gollasch S, Wallentinus I (eds) *ICES Cooperative Research Report,* 271: 1-25.

Kerckhof F, Caltrijsse A (2001) Exotic cirripeda (Balanomorpha) from buoys off the Belgian coast. *Senckenbergiana maritime,* 31(2): 245-254.

Kerckhof F, Haelters J, Gollasch S (2007) Alien species in the marine and brackish ecosystem: the situation in Belgian waters. *Aquatic Invasions,* 2: 243-257.

Klein J, Verlaque M (2008) The *Caulerpa racemosa* invasion: a critical review. *Marine Pollution Bulletin*, 56(2): 205-225.

Kraan S, Barrington KA (2005) Commercial farming of *Asparagopsis armata* (Bonnemaisoniaceae, Rhodophyta) in Ireland, maintenance of an introduced species? *Journal of Applied Phycology,* 17: 103-110.

Jensen A, Humphreys J, Caldow R, Grisley C Dyrynda PEJ (2004) Naturalisation of the manila clam (*Ruditapes philippinarum*), an alien species and establishment of a clam fishery within Poole Harbour, Dorset. *Journal of the Marine Biological Association of the United Kingdom,* 84: 1069-1073.

Jensen KR, Knudsen J (2005) A summary of alien marine benthic invertebrates in Danish waters. *Oceanological and Hydrobiological Studies,* 34 (Suppliment 1) 137-162.

Lehtiniemi M, Ojaveer H, David M, Galil B, Gollasch S,McKenzie C, Minchin D, Occhipinti-Ambrogi A, Olenin S, Pederson J (2015) Dose of truth – monitoring marine non-indigenous species to serve legislative requirements. *Marine Policy,* 54: 26-35.

Leppäkoski E, Gollasch S, Gruszka P, Ojaveer H, Olenin S and Panov V (2002) The Baltic – a sea of invaders. *Canadian Journal of Fisheries and Aquatic Sciences,* 59: 1175-1188.

Leppäkoski E, Olenin S (2000) Xenodiversity of the European brackish water seas: the North American contribution. pp. 107-119. In: Pederson J (ed), *Marine bioinvasions. Proceedings of the First National Conference*, January 24-27, 1999. Cambridge, MA, MIT, 427 pp.

Leppäkoski E, Shiganova T, Alexandrov B (2009) European enclosed and semi-enclosed seas. pp 529-547. In: Rilov G, Crooks J. (eds), Biological Invasions in marine ecosystems: Ecological, management and geographic perspectives. *Ecological Studies* 204. Heidelberg, Springer.

Loughnane C, Stengel D (2002) Attached *Sargassum muticum* (Yendo) Fensholt found on the west coast of Ireland. *Irish Naturalists' Journal*, 27(2): 70-72.

Lucy F, Minchin D, Holmes JMC, Sullivan M (2004) First records of the Ponto-caspian amphipod *Chelicorophium curvispinum* (Sars, 1895) in Ireland. *Irish Naturalists' Journal*, 27: 461-464.

Lyons R, Kelly-Quinn M (2003) An investigation into the disappearance of *Austropotamobius pallipes* (Lereboullet) populations in the headwaters of the Nore River, Ireland, and the correlation to water quality. *Bulletin France Pêche Pisciculture,* 370-371: 139-150.

McMahon, T., Raine, R., Titov, O. and Boychuk, S. (1995) Some oceanographic features of northeastern Atlantic waters west of Ireland. *ICES Journal of Marine Science*, 52: 221-232.

McMahon T, Deegan B, Silke J, O'Cinneide M (2008) Proceedings of the 8th Shellfish Safety Workshop. *Marine Environment and Health Series* No 33. 64pp Marine Institute, Galway.

MacNeil C, Platvoet D, Dick JTA, Fielding N, Constable A, Hall N, Aldridge D, Renals T, Diamond M (2010) The Ponto-Caspian 'killer shrimp', *Dikerogammarus villosus* (Sowinsky, 1894), invades the British Isles. *Aquatic Invasions,* 5(4): 441-445.

Maggs C, Mineur C, Bishop J, McCollin T (2011) Non-natives. Marine Climate Change Impacts Partnership ARC Science Review 2010-2011. 11 pp.Minchin D (2007) A checklist of alien and cryptogenic aquatic species in Ireland. *Aquatic Invasions,* 2(4): 341-366.

Mieszkowska N**,** Leaper R**,** Moore,P**,** Kendall MA**,** Burrows MT**,** Lear D**,** Poloczanska E**,** Hiscock K**,** Moschella PS**,** Thompson RC**,** Herbert RJ**,** Laffoley D**,** Baxter J**,** Southward AJ, Hawkins SJ (2005) Marine biodiversity and climate change: assessing and predicting the influence of climatic change using intertidal rocky shore biota. *Final report for United Kingdom funders. Marine Biological Association Occasional Publication*, 20: 1–53.

Mineur F, Cook EJ, Minchin D, Bohn K, Macleod A, Maggs CA (2012) Changing coasts: marine aliens and artificial surfaces. *Oceanography and Marine Biology,* 50:189-234.

Minchin D (2000a) Examination of native and Pacific oysters in the North Channel of Cork Harbour. A review of some organisms associated with oyster cultivation. 25-26 October 2000. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 10/2000, 9pp.

Minchin D (2000b) Examination of Pacific oysters from Woodstown Strand, Waterford, originating from Arcachon France. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 8/2000, 4pp.

Minchin D (2000c) Examination of Pacific oyster wild seed arriving at Crooke, Waterford from Arcachon, France, 29 April 2000. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 2/2000, 8pp.

Minchin D (2007) Aquaculture and transport in a changing environment: overlap and links in the spread of alien biota. *Marine Pollution Bulletin,* 55: 302-313.

Minchin D (2007) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions,* 2(1): 63–70.

Minchin D (2010) Managing alien aquatic species. Chapter 10-6 In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kuhn I (eds). *Atlas of Biodiversity Risk*. Pensoft. Sofia. pp. 244-247.

Minchin D (2010) Do declines in the use of the organotin (TBT), used as an antifoulant, result in an increase in aquatic alien species establishment? Chapter 09-7. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kuhn I (eds). *Atlas of Biodiversity Risk*. Pensoft. Sofia. pp. 220-223.

Minchin D (2012) Rapid assessment of the bryozoan, *Zoobotryon verticillatum* (Delle Chiaje, 1822) in marinas, Canary Islands. *Marine Pollution Bulletin,* 64(10): 2146-2150.

Minchin D (2014) The distribution of the Asian clam *Corbicula fluminea* and its potential to spread in Ireland. *Management of Aquatic Invasions,* 5(2): 165-177.

Minchin D, Cook EJ, Clark PF (2012) Alien species in British brackish and marine waters. *Aquatic Invasions,* 8(1): 3-19.

Minchin D, Eno C (2002) Exotics of coastal and inland waters of Ireland and Britain. In*: Invasive Aquatic Species of Europe: Distribution, Impact and Management*. (eds): Leppäkoski, E., Gollasch, S. & Olenin, S., Kluwer Press, Dordrecht, pp 267-275.

Minchin D, Gollasch S, Wallentinus I (eds) (2005) Vector pathways and the spread of exotic species in the sea. *Co-operative Research Report* No. 271. ICES Copenhagen 29pp.

Minchin D, Holmes JMC (2007) The first record of *Caprella mutica* Schurin, 1935 (Crustacea: Amphipoda) from the east coast of Ireland. *Irish Naturalists' Journal*, 28(8): 321-326.

Minchin D, Nunn, JD (2013) *Rapid assessment of marinas for invasive alien species in Northern Ireland*. Northern Ireland Environment Agency Research and Development Series No. 13/06.

Minchin D, Sides E (2006) Appearance of a cryptogenic tunicate, a *Didemnum* sp. fouling marina pontoons and leisure craft in Ireland. *Aquatic Invasions,* 1(3): 143-147.

Minchin D, White B (2014) A rapid assessment method for an invasive mollusk in an Irish lake. *Management of Biological Invasions,* 5(1): 63-72.

Minchin D, Zaiko A (2014) Variability of the zebra mussel (*Dreissena polymorpha*) impacts in the Shannon River system. In: T. Nelapa and D. Schlosser (eds) *Quagga and zebra mussels: biology, impacts and control.* Taylor and Francis. pp 587-598.

Morrisey D, Peacock L, Inglis G, Floerl O (2007) Surveillance for early detection of unwanted exotic marine organisms in New Zealand: Summer 2005-2006 MAF BNZ Research Project ZBS2001/01. *MAF Biosecurity New Zealand Technical Paper* 2007/02, pp 1–171.

Morritt D, Mills H, Hind K, Clifton-Dey, Clark PF (2013) Monitoring downstream migrations of *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Brachyura: Grapsoidea: Varunidae) in the River Thames using capture data from a water abstraction intake. *Management of Biological Invasions,* 4(2): 139-147.

Munroe, D.M, and T. Noda. 2009. Spatial pattern of rocky intertidal barnacle recruitment: comparison over multiple tidal levels and years. *Journal of the Marine Biological Association of the United Kingdom,* 89(2): 345-353.

Nall CR, Guerin AJ, Cook EJ (2014) Rapid assessment of marine non-native species in northern Scotland and a synthesis of existing Scottish records. *Aquatic Invasions,* 9 (in press)

Narščius A, Olenin S, Zaiko A, Minchin D. (2012) Biological invasion impact assessment system: from idea to implementation. *Ecological Informatics,* 7(1): 46-51.

Nelson EC (2000) *Sea beans and nikar nuts: a handbook of exotic seeds and fruits stranded on beaches in north-western Europe*. Botanical Society of the British Isles, London, Handbook No 10, 156pp.

Occhipinti-Ambrogi A (2002) Current status of aquatic introductions in Italy. pp 311-324. In: Leppäkoski E, Gollasch S, Olenin S (eds) *Invasive aquatic species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Occhipinti-Ambrogi A (2007) Global change and marine communities: alien species and climate change. *Marine Pollution Bulletin,* 55: 342–352.

Ojaveer H, Galil BS, Minchin D, Olenin S, Amorim A, Canning-Clode J, Chainho P, Copp G, Gollasch S, Jelmert A, Lehtiniemi M, McKenzie C, Mikus J, Miossec L, Occhipinti-Ambrogi A, Pećarević M, Pederson J, Quilez-Badia G, Wijsman J, Zenetos A (2014) Ten recommendations for advancing assessment and management of non-indigenous species in marine ecosystems. *Marine Policy,* 44:160-165.

Ojaveer H, Kotta J (2014) Ecosystem impacts of the widespread non-indigenous species in the Baltic Sea: literature survey evidences major limitations in knowledge. *Hydrobiologia*. doi: 10.1007/s10750-014-2080-5

Ojaveer H, Simm M, Lankov A (2004) Population dynamics and ecological impact of the non-indigenous *Cercopagis pengoi* in the Gulf of Riga (Baltic Sea). *Hydrobiologia,* 522: 261-269.

Olenin S (2005) *Invasive aquatic species in the Baltic States*. Monograph. University of Klaipeda, Coastal Research and Planning Institute, 42 pp.

Olenin S, Minchin D, Daunys D (2007) Assessment of biopollution in aquatic ecosystems. *Marine Pollution Bulletin,* 55(7-9): 379-394.

Olenin S, Leppäkoski E (1999) Non-native animals in the Baltic Sea: alteration of benthic habitats in coastal inlets and lagoons. *Hydrobiologia,* 393: 233–243.

Olenin S, Minchin D (2011) Biological introductions to the systems: macroorganisms In: M. Elliott and MJ Kennish. Volume 8: Human-induced problems (uses and abuses) *Treatise on Estuarine and Coastal Science*. Elsevier, pp 149-183.

Olenin S, Alemany F, Cardoso AC, Gollasch S, Goulletquer P, Lehtiniemi M, McCollin T, Minchin D, Miossec L, Occhipinti Ambrogi A, Ojaveer H, Rose Jensen K, Stankiewicz M, Wallentinus I, Aleksandrov B (2010) Marine Strategy Framework Directive, Task Group 2 Report – non-indigenous species (April 2010). *Joint Report ICES and JRC European Commission* EUR 24342 –EN 2010.

Olenin S, Narščius A, Minchin D, David M, Galil B, Gollasch S, Marchini A, Occhipinti-Ambrogi A, Ojaveer H, Zaiko A (2014) Making non-indigenous species information systems practical for management and useful for research: An aquatic perspective. *Biological Conservation,* 173: 98-107.

Olenina I, Wasmund N, Hajdu S, Jurgensone I, Gromisz S, Kownacka J, Toming K, Vaicinte D, Olenin S (2010) Assessing impacts of invasive phytoplankton. The Baltic Sea case. *Marine Pollution Bulletin,* 60(10): 1691-1700.

Ottway B, Parker M, McGrath D, Crowley M (1979) Observations on a bloom of *Gyrodinium aureolum* Hulburt on the south coast of Ireland, summer 1976, associated with mortalities of littoral and sub-littoral organisms. *Irish Fisheries Investigations Series* B, No 18, 9pp.

O'Sullivan AJ (1978) red tide on the south coast of Ireland. *Marine Pollution Bulletin,* 9(12): 315-316.

Öztürk B (2002) The Marmara Sea, a link between the Mediterranenan and the Black Sea. pp 337-340. In: Leppäkoski E,Gollasch S, Olenin S (eds), *Invasive aquatic species of Europe, Distribution, Impacts and Management*. Dordrecht, Boston and London, Kluwer Academic Publishers.

Pollux B, Minchin D, Van der Velde G, Van Allen T, Moon-Van der Staay SY, Hackstein J (2003) Zebra mussels (*Dreissena polymorpha*) in Ireland, AFLP- fingerprinting and boat traffic both suggest an origin from Britain. *Freshwater Biology,* 48: 1127-1138.

Padilla DK, Williams SL (2004) Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. *Frontiers in Ecology and the Environment,* 2(3): 131-138.

Pancucci-Papadopoulou MA, Zenetos A, Corsini-Foka M, Politou CY (2005) Update of marine aliens in Hellenic waters. *Mediterranean Marine Science,* 6: 147–158.

Penk MR, Minchin D (2014) Seasonal migration of a glacial relict mysid (Crustacea) into the littoral zone and its co-occurrence with an introduced competitor in Lough Derg (Ireland) *Hydrobiologia,* 726:1-11.

Perez T, Perrin B, Carteron S, Vacelet J, Boury-Esnault N (2006) *Celtodoryx girardae* gen. nov. sp. nov., a new sponge species (Poecilosclerida, Demospongiae) invading the Gulf of Morbihan (North East Atlantic, France). *Cahiers de Biologie Marine* 47**:** 205-214.

Pingree RD, Le Cann B (1989). Celtic and Armorican Slope and Shelf Residual currents. *Progress in Oceanography* 23: 303-338.

Pitombo FB (2004) Phylogenetic analysis of the Balanidae (Cirripedia: Balanomorpha). *Zoologica Scripta,* 33: 261–276.

Puntila R, Heyer K, Stelzer K, Faber E (2012) *Helcom aliens 2: non-native species survey protocols, target species selection and risk assessment tools for the Baltic Sea*. Helsinki Commission, Finland 39pp.

Raine R, McMahon T (1998) Physical dynamics on the continental shelf off southwestern Ireland and their influence on coastal phytoplankton blooms. *Continental Shelf Research*, 18: 883 – 914.

Raine R, O'Boyle S, O'Higgins T, White M, Patching J, Cahill B, McMahon T (2001) A satellite and field portrait of a *Karenia mikimotoi* (Hulbert) bloom off the south coast of Ireland, August 1998. *Hydrobiologia*, 465: 187-193.

Rajagopal S, Van der Velde G, de Vaate B (2000) Reproductive biology of the Asiatic clams *Corbicula fluminalis* and *Corbicula fluminea* in the River Rhine. *Archiv für Hydrobiologie,* 149(3): 403-420.

Reise K, Dankers N, Essink K (2005) Introduced species. pp 155-161. In: Essink K, Dettmann C, Farke H, Laursen K, Lüerßen G, Marencic H, Wiersing W (eds), *Wadden Sea water quality status report 2004*. Wadden Sea Ecosystem No. 19. Wilhelmshaven, Common Wadden Sea Secretariat, 359 pp.

Reynolds SCP (2002) *A catalogue of alien plants in Ireland*. National Botanic Gardens, Glasnevin, Dublin, 414pp.

Rilov G, Galil BS (2009) Marine bioinvasions in the Mediterranean Sea – history, distribution and ecology. pp 549-576. In: Rilov G, Crooks J (eds), *Biological Invasions in marine ecosystems: Ecological, management and geographic perspectives*. Ecological Studies 204. Heidelberg, Springer.

Rodger HD, Turnbull T, Muir F, Millar S, Richards RH (1998) Infectious salmon anaemia (ISA) in the United Kingdom. *Bulletin of the European Association of Fish Pathologists*, 18(4): 115-116.

Rudinskaya LV, Gusev AA, Aleksandrov SV, Semenova AS (2014) The impact of recent large-scale invasions on the structure of the benthic community in the open part of the Vistula Lagoon in 1985-2013. 12th International Conference Littoral 2014, 22-26 September 2014 Klaipeda, Lithuania, poster presentation and abstract p 130.

Severinghaus LL, Chi L (1999) Prayer release in Taiwan. *Biological Conservation,* 89(3): 301-304.

Sorte CJB, Williams SL, Carlton JT (2010) Marine range shifts and species introductions: comparative spread rates and community impacts. *Global Ecology and Biogeography,* 19(3): 303-316.

Southward AJ, Hiscock K, Kerckhof F, Moyse J, Elfimov AS (2004) Habitat and distribution of the warm-water barnacle *Solidobalanus fallax* (Crustacea: Cirripedia) *Journal of the Marine Biological Association of the United Kingdom*, 84: 1169-1177.

Spencer BE, Edwards DB, Kaiser MJ, Richardson CA (1994) Spatfalls of the non-native Pacific oyster (*Crassostrea gigas*) in British waters. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 4: 203-217.

Stachowitz JJ, Terwin JR, Whitlach RB and Osman RW (2002) Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. *Proceedings of the National Academy of Science,* 99: 15497-15500.

Stebbing P, Johnson P, Delahunty A, Clark PF, McCollin T, Hale C, Clark S (2012) Reports of American lobsters, *Homarus americanus* (H. Milne Edwards. 1837), in British waters *BioInvasion Records,* 1(1): 17-23.

Thomsen MS, Wernberg T, Silliman BR, Josefson AB (2009) Broad-scale patterns of abundance of non-indigenous soft-bottom invertebrates in Denmark. *Helgoland Marine Research,* 63: 159-167.

Utting SD, Spencer BE (1992) Introductions of marine bivalve molluscs into the United Kingdom for commercial culture - case histories. *ICES Marine Science Symposium,* 194: 84-91.

Verlaque M, Ruitton S, Mineur F, Boudouresque C-F (2010) CIESM atlas of exotic macrophytes in the Mediterranean Sea http://www.ciesm.org/atlas/appendix4.html (visited 22 October 2014).

Ward JM, Ricciardi A (2007) Impacts of *Dreissena* invasions on benthic macroinvertebrate communities: a meta-analysis. *Diversity and Distributions* 13(2): 155-165.

Ware C, Berge J, Sundet JH, Kirkpatrick JB, Coutts ADM, Jelmert A, Olsen SM, Floerl O, Wisz MS, Alsos IG (2014) Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. *Diversity and Distributions,* 20: 10-19.

Whelan PM, Cullinane JP (1987) The occurrence of 'wasting disease' of *Zostera* in Ireland in the 1930's. *Aquatic Botany*, 27: 285-289.

Wittfoth AKJ, Zettler ML (2013) The application of a Biopollution Index in German Baltic estuarine and lagoon waters. *Management of Biological Invasions,* 4(1): 43–50.

Wolff WJ (2005) Non-indigenous marine and estuarine species in the Netherlands. *Zoologische Mededelingen* 79: 1-11

Worsfold TM, Ashelby CW (2008) Additional UK records of the non-native prawn *Palemon macrodactylus*. *Marine Biodiversity Records,* 1: e48.

Zaiko A, Lehtiniemi M, Narščius A, Olenin S (2011) Assessment of bioinvasion impacts on a regional scale: a comparative approach. *Biological Invasions,* 13:1739–1765.

Zaiko A, Minchin D, Olenin S (2014) “The day after tomorrow”: anatomy of an ‘r’ stratagist aquatic invasion. *Aquatic Invasions,* 9(2): 145-155.

Zaitsev Y, Öztürk B (eds) (2001) *Exotic species in the Aegean, Marmara, Black, Azov and Caspian Seas*. Istanbul, Turkish Marine Research Foundation, 267 pp.

Zenetos A, Gofas S, Russo G, Templado J (2004) CIESM atlas of exotic species in the Mediterranean Vol 3 *Molluscs*. In: Briand F (ed), Monaco, CIESM Publishers 376 pp.

Zettler ML (1995) Successful establishment of the spionid polychaete, *Marenzellaria viridis* (Verrill, 1873), in the Darss-Zingst Estuary (Southern Baltic) and its influence on the indigenous macrozoobenthos. *Archives Fisheries Marine Research,* 43(3): 273-28

APPENDIX 1

SUMMARIES OF THE HIGHEST IMPACTING TARGET SPECIES SPREADING IN IRELAND AND THOSE EXPECTED TO ARRIVE

Appendix 1.

Summaries of the highest impacting target species spreading in Ireland and those expected to arrive based on the high impacting species identified from Tables 2.1, 2.2 and 2.3.

List of non-indigenous species selected:

1. *Alexandrium catenella* (Whedon and Kofoid) Balech [DAISIE]
2. *Alexandrium tamarense* (Lebour) Balech [GISP]
3. *Bonamia ostreae* Pichot, Comps, Tíge, Grizel & Rabouin, 1980. Bonamiosis [OIE]
4. *Corbicula fluminalis* (O.F. Müller, 1774), Asian clam
5. *Corbicula fluninea* (O.F. Müller, 1774). Asian clam [DAISIE; GISP]
6. *Corella eumyota* Traustedt, 1882. orange tipped sea squirt
7. *Crassostrea gigas* (Thunberg, 1793). Pacific oyster [DAISIE, GISP, NOBANIS]
8. *Crepidula fornicata* Linneaus, 1758). slipper limpet [DAISIE; GISP; NOBANIS]
9. *Didemnum vexillum* Kott, 2002. carpet sea-squirt {GISP]
10. *Dikerogammarus haemobaphes* (Eichwald, 1841). the demon shrimp
11. *Dikerogammarus villosus* (Sowinsky, 1894). killer shrimp [DAISIE]
12. *Dreissena bugensis* Andrusov, 1897. quagga mussel [GISP]
13. *Ensis directus* (Conrad, 1843). American razor, jack-knife clam [DAISIE; NOBANIS]
14. Epizootic Haematopoietic necrosis virus (**EHVN**) [OIE]
15. *Eriocheir sinensis* H. Milne Edwards, 1853. Chinese mitten crab [DAISIE; GISP; NOBANIS]
16. *Gyrodactylus salaris* von Nordmann, 1832, gyrodactylosis [DAISIE; NOBANIS; OIE]
17. *Hemigrapsus sanguineus* (De Haan, 1835). Asian shore crab [GISP]
18. *Hemigrapsus takanoi* Asakura & Watanabe, 2005. Hairy-clawed shore crab
19. *Heterosigma akashiwo* (Y.Hada) Y.Hada ex Y.Hara & M.Chihara
20. Infectious haematopoietic necrosis virus (**IHN**) [OIE]
21. Infectious salmon anaemia virus (**ISA**) [OIE]
22. *Marenzellaria viridis* (Verrill, 1873). Red-gilled mud-worm
23. *Marteilia refringens* Grizel, Bonami, Cousserans, Duthoit & Le Pennec, 1974. Aber disease [OIE]
24. *Mnemiopsis leidyi* A. Agassiz, 1865. American comb jelly [DAISIE; GISP; NOBANIS]
25. *Neogobius melanostomus* (Pallas, 1814). round goby [DAISIE; GISP; NOBANIS]
26. *Ocenebra inornata* (Récluz, 1851). Japanese oyster drill [GISP]
27. Ostreid herpesvirus 1-microvariant (**OsHV-1 µvar**), causing summer mortality syndrome in Pacific oysters [OIE]
28. *Pseudorasbora parva*, top-mouthed gudgeon, stone morocco, false harlequin [DAISIE; NOBANIS]
29. *Sphaerothecum destruens,* Arkush, Mendoza, Adkison, & Hedrick, 2003. rosette agent
30. *Styela clava* Herdman, 1881. club tunicate [DAISIE; GISP; NOBANIS]
31. *Undaria pinnatifida* (Harvey) Suringar, 1873. Japanese kelp, wakame [DAISIE; GISP]
32. *Vibrio cholorae* Pacini 1854. cholera

The target species are recognised as impacting in the following databases:

- AquaNIS, www.corpi.ku.lt/databases/**aquanis**/ *[all species above]*
- DAISIE, *www.europe-aliens.org/*
- GISP, www.issg.org/database/welcome/
- OIE, www.oie.int/animal-health-in-the-world/
- NOBANIS, http://www.nobanis.org/Factsheets.asp

Not all of the above target species are included in the above databases either because some do not register micro-organisms, the databases have not been updated, or do not consider species that may pose a threat to Ireland.

Invasive species have some general predictors:

1. The NIS has a habitat it can colonise.
2. The NIS has been found to be invasive in a similar climate
3. The NIS can arrive with sufficient propagule numbers in order to colonise
4. The NIS has an opportunity to be delivered
5. The NIS can survive the transport route

The target species:

1. Should be recognisable in the field where possible (not always possible for diseases)
2. Can be sampled in a specific way
3. Has a known life-history appearance

Levels of certainty as to introduction mode follows that of Table 1.1. Probability of spread to Ireland rated as High, moderate risk or low.
References following each species provide useful addition information on a species that can include impacts and sampling methodology.

1: *Alexandrium catenella* (Whedon and Kofoid) Balech.

Chromista, Dinophyceae, Gondiodomataceae

Previously known as: *Protogonyaulax catenella* (Whedon *et* Kofoid) Taylor 1979

Current status: NIS, not recorded in Ireland.

Native range: Thought to be temperate regions of the North Pacific Ocean.

Established in Ireland: Not established in Ireland.

First record in Europe: In the Thau Lagoon, French Mediterranean in 1998 misidentified as *A. tamarense*.

Pathway: Possibly distributed in ballast water sediments or with sediments associated with shellfish movements. Cysts have been found in the sediment of ballast tanks.

Level of certainty of pathway: Possible. Stated to have been introduced in ballast water to the Thau Lagoon but it is equally possible it was introduced with consignments of Pacific oysters air-freighted from Japan.

Further spread: Spreading in the north-west Mediterranean.

Probability of spread to Ireland: Moderate risk.

Known occurrence: Known to have produced toxic episodes in extensive blooms off the coasts of Chile, Japan, western USA. Known also from Argentina, western South Africa, Russia, and Australia. It is expanding its range in the Mediterranean Sea. It has been recorded in the NE Atlantic and the North Sea. While considered to be a cold-water species being seldom present in sea water temperatures of >12°C, it has occurred in the Mediterranean Sea at temperatures >20°C. In the Mediterranean Sea it appears to be confined to harbours and lagoons in France, Greece, Sardinia, Spain and Tunisia.

Not known in: Britain, Ireland.

Impact: This dinoflagellate is associated with paralytic shellfish poisoning (PSP) events known to affect humans, mammals, fishes and birds. Can impact upon fish as a result of an ichthyotoxin. PSP toxins have also been found in crabs and lobsters. Events result in cessation of aquaculture production and may also result in losses of stock.

Expected: May become introduced with ballast sediments, with port dredged materials or with consignments of bivalve molluscs.

Monitoring localities: Post-border. In harbours, lagoons and sheltered bays.

Monitoring method: Specialist knowledge required and microscopic examination.

Field characteristics: This is a chain forming species normally made up of 2 to 8 cells. It produces a colourless ellipsoidal resting cyst as is found in *A. tamarense*. Single cells are almost round and 20-48µm in length, 18-32µm in width. It tolerates salinities of 20 to 37psu, with optimal conditions at 30-35psu.

References

Bravo I, Vila M, Maso M, (2008) *Alexandrium catenella and Alexandrium minutum* blooms in the Mediterranean Sea: toward the identification of ecological niches. *Harmful Algae,* 7: 515- 522.

Bornet B, Antoine E, Françoise S, Marcaillou-Le Baut C (2005) Development of sequence characterized amplified region markers from intersimple sequence repeat fingerprints for the molecular detection of toxic phytoplankton *Alexandrium catenella* (Dinophyceae) and *Pseudo-nitzschia pseudodelicatissima* (Bacillariophyceae) from French coastal waters. *Journal of Phycology,* 41: 704-711.

Collos Y, Vaquer A, Laabir M, Vaquer A (2007) Contribution of several nitrogen sources to growth of *Alexandrium catenella* during blooms in Thau lagoon, Southern France. *Harmful Algae*, 6: 781–789.

Fukuyo Y (1985) Morphology of *Protogonyaulax tamarensis* (Lebour) Taylor and *Protogonyaulax catenella* (Whedon and Kofoid) Taylor from Japanese coastal waters. *Bulletin of Marine Science,* 37: 529-537.

Hallegraeff GM, Marshall JA, Valentine J Hardiman S (1998) Short cyst-dormancy period of an Australian isolate of the toxic dinoflagellate *Alexandrium catenella*. *Marine and Freshwater Research*, 49(5):415–420.

Lilly EL, Kulis DM, Gentien P, Anderson DM (2002) Paralytic shellfish poisoning toxins in France linked to a human-introduced strain of *Alexandrium catenella* from western Pacific: evidence from DNA and toxin analysis. *Journal of Plankton Research*, 24: 443–452.

Navarro JM, Muňoz MG Contreras AM (2006) Temperature as a factor regulating growth and toxin content in the dinoflagellate *Alexandrium catenella*. *Harmful Algae*, 5: 762–769.

Nishitani L, Chew K (1988) PSP toxins in the Pacific coast states: monitoring programs and effects on bivalve industries. *Journal of Shellfish Research*, 7: 653-669.

Ogata T, Kodama M (1986) Ichthyotoxicity found in cultured media of *Protogonyaulax* spp. *Marine Biology*, 95: 217-220.

Penna A, Garcés E, Vila M, Giacobbe MG, Fraga S, Lugliè A, Bravo I, Bertozzini E and Vernesi C (2005) *Alexandrium catenella* (Dinophyceae), a toxic ribotype expanding in the NW Mediterranean Sea. *Marine Biology*, 148(1): 13-23.

Turki S, Balti N (2005) Detection of toxic *Alexandrium catenella* (Whedon & Kofoid) Balech in clam production zone of North Lake and Channel, Tunisia. *Harmful Algae News*, No 28: 1-3.

Vila M, Garces E, Maso M, Camp J (2001) Is the distribution of the toxic dinoflagellate *Alexandrium catenella* expanding along the NW Mediterranean coast? *Marine Ecology Progress Series*, 222:73-83.

2: *Alexandrium tamarense* (Lebour) Balech.

Chromista, Dinophyceae, Goniodomataceae

Current status: Cryptogen.

Native range: Unknown, widely distributed and probably cosmopolitan.

Established in Ireland: Local populations exist in Ireland.

First record: First recorded in Ireland in Cork Harbour in 1986. Almost certainly established before this date as red-brown water discolouration had been noted in the 1960s.

Pathway: Unknown, may be a native population. In the 1880sto 1920s large numbers of American oysters *Crassostrea virginica* were laid in the Cork Harbour region where blooms are known to have occurred.

Level of certainty on pathway: unknown.

Further spread: It is possible that it could be spread with dumping of dredge spoil offshore or carried with ships ballast sediments or even moved with oyster consignments.

Probability of further spread in Ireland: moderate risk.

Known occurrence: Two populations are known occurring in Belfast Lough and Cork Harbour. Known on the south coast of Britain from where it was first described. Cysts have been recovered from Bantry Bay but no blooms are known to have taken place in this region.

Not known in: many sheltered bays about the Irish coast.

Impact: Paralytic shellfish poisoning is known in some populations. Harvesting of shellfish may be suspended during bloom events.

Expected: Further blooms are expected and new strains may be introduced from different world regions.

Monitoring localities: **'**Post-border'. Monitoring of water samples should take place in areas where blooms are known to have occurred.

Monitoring method: Specialist knowledge required. Sampling of sea-water and of shellfish tissues for toxins regularly takes place. Individuals range in size from 25-46µm and are generally spherical in shape.

Field characteristics: Red-brown discolouration of inshore water may relate to blooms of this species.

References

Blanco EP, Lewis J (2014) A comparative study of *Alexandrium tamarense* cyst distribution in Belfast Lough. *European Journal of Phycology,* 49(2): 255-263.

Brown L, Bresnan E, Graham J, Lacaze J-P, Turrell E Collins C (2010) Distribution, diversity and toxin composition of the genus *Alexandrium* (Dinophyceae) in Scottish waters. *European Journal of Phycology,* 45(4): 375-393.

Collins C, Graham J, Brown L, Bresnan E, Lacaze J-P Turrell EA (2009) Identification and toxicity of *Alexandrium tamarense* (Dinophyceae) in Scottish waters. *Journal of Phycology,* 45(3): 692-703.

Fauchot J, Levasseur M, Roy S, Gagnon R, Weise AM (2005) Environmental factors controlling *Alexandrium tamarense* (Dinophyceae) growth rate during a red tide event in the St. Lawrence Estuary (Canada). *Journal of Phycology,* 41: 263-272.

Gagnon R, Levasseur M, Weise AM, Fauchot J, Campbell PGC, Weissenboeck BJ, Merzouk A, Gosselin M, Vigneault B (2005). Growth stimulation of *Alexandrium tamarense* (Dinophyceae) by humic substances from the Manicouagan River (Eastern Canada). *Journal of Phycology,* 41: 489-497.

Higman WA, Stone DM, Lewis JM (2001) Sequence comparisons of toxic and non-toxic *Alexandrium tamarense* (Dinophyceae) isolates from UK waters. *Phycologia,* 40: 256-262.

John U, Cembella A, Hummert C, Elbrachter M, Groben R, Medlin L (2003) Discrimination of the toxigenic dinoflagellates *Alexandrium tamarense* and *A. ostenfeldii* in co-occurring natural populations from Scottish coastal waters. *European Journal of Phycology,* 38(1): 25-40.

Lilly EL, Halanych KM, Anderson DM (2007) Species boundaries and global biogeography of the *Alexandrium tamarense* complex (Dinophyceae). *Journal of Phycology,* 43: 1329-1338.

Tylor TJM, Lewis J and Heaney SI (1995) A survey of *Alexandrium* sp. cysts in Belfast Lough, 1992. In Lassus P, Arzul G, Erard E, Gentian P and Marcaillou C. *Harmful Agal Blooms*. Lavoisier, Intercept Ltd, 835-840.

Toebe K, Alpermann TJ, Tillmann U, Krock B, Cembella A, John U (2013) Molecular discrimination of toxic and non-toxic *Alexandrium* species (Dinophyta) in natural phytoplankton assemblages from the Scottish coast of the North Sea. *European Journal of Phycology,* 48(1): 12-26.

3: *Bonamia ostreae* Pichot, Comps, Tíge, Grizel & Rabouin, 1980. Bonamiosis

Haplosporidiidae, Ascetosporea, Cercozoa

Current status: NIS, widely established in separate bays in Ireland.

Native range: North Pacific Ocean.

Established in Ireland: It is established on the south, west and north coasts.

First record: in Ireland was in 1986, North Channel of Cork Harbour but probably had arrived some time before. It was thought that it was introduced with an unapproved consignment of oysters having arrived in West Cork and previously procured in Brittany. In Europe it was first recorded in Brittany, France in 1979. Since then it has spread to The Netherlands and Denmark. It arrived in south-west Britain in 1982. The parasite will have originated in California in the NE Pacific Ocean. From here there are thought to be two separate inoculations in Europe, to Brittany and northern Spain.

Pathway: Infected stock movement of *Ostrea edulis*. It might be transferred with infested oysters on vessel hulls. The complete life-cycle of this haplosporidian remains unknown and there may be other invertebrates that might act as carriers for the disease. It is suspected that there is a further life-history stage, perhaps a resting spore. Some other studied bivalves are not thought to harbour a life-history stage. The Pacific oyster is not known to develop bonamiosis.

Level of certainty of pathway: stock movements of infested oysters are very likely to result in the parasite transmission.

Further spread: with stocks of oysters being moved between bays. Such movements will almost certainly be unapproved. The related *B. exitosa* has been recorded in the Mediterranean Sea.

Probability of further spread in Ireland: High.

Known occurrence: it is known from Cork Harbour, Tralee Bay, Galway Bay, Clew Bay, Achill Sound, Belmullet, Lough Swilly and Lough Foyle. In Britain it is known on the south-east to southwest coasts, north of Wales and the west of Scotland.

Not known in: Larne Harbour, Strangford Lough, Carlingford Lough, Bannow Bay, Dungarvan Bay, the south-west coast, Donegal Bay and Mulroy Bay.

Impact: Native oysters may suffer mortalities as much as 90%. *B. ostreae* parasitizes the blood cells and gill tissue and the disease can be spread to neighbouring oysters most probably being filtered from the water by the gills.

Expected: Bio-security measures with current knowledge may not be sufficient to prevent the spread of this disease should the unknown life-history stage remain unrecognised. For example, should a spore stage exist dredge spoil might transfer the disease, also with the increased summer temperatures transmission of infested flat oysters settling on the hulls of vessels may spread the disease.

Monitoring localities: Post-border**.** There is a surveillance program about the coast managed by the Marine Institute.

Monitoring method: Specialist veterinarian knowledge required.

Field characteristics: Where there are large numbers of gaping oysters with watery tissues such a disease could be suspected. In Cork Harbour in 1986 shells were found with many crab chelae marks, possibly due to the weakened state of the gaping oysters.

References

Arzul I, Joly JP (2011) EURL (European Union Reference Laboratory) for Molluscs Diseases: *Bonamia* sp. Web page hosted by Ifremer. URL: http://wwz.ifremer.fr/crlmollusc/Main-activities/Tutorials/Bonamia-sp.

Arzul I, Gagnaire B, Bond C, Chollet B, Morga B, Ferrand S, Robert M, Renault T (2009) Effects of temperature and salinity on the survival of *Bonamia ostreae*, a parasite infecting flat oysters *Ostrea edulis*. *Diseases of Aquatic Organisms,* 85: 67–75.

Arzul I, Langlade A, Chollet B, Robert M, Ferrand S, Omner E, Lerond S, CouraleauyY, Joly JP, François C, Garcia C (2011) Can the protozoan parasite *Bonamia ostreae* infect larvae of flat oysters *Ostrea edulis*? *Veterinary Parasitology,* 179: 69-76.

Balseiro P, Conchas RF, Montes J, Gómez-León J, Novoa B, Figueras A. 2006. Comparison of diagnosis techniques for the protozoan parasite *Bonamia ostreae* in flat oyster *Ostrea edulis*. *Aquaculture,* 261: 1135-1143.

Carnegie RB, Barber BJ, Distel DL (2003) Detection of the oyster parasite *Bonamia ostreae* by fluorescent *in situ* hybridization. *Diseases of Aquatic Organisms,* 55: 247-252.

Cigarría J, Elston R (1997) Independent introduction of *Bonamia ostreae*, a parasite of *Ostrea edulis* to Spain. *Diseases of Aquatic Organisms,* 29: 157-158.

Culloty SC, Mulcahy MF (1996) Season-, age-, and sex-related variations in the prevalence of bonamiasis in flat oyster (*Ostrea edulis* L.) on the south coast of Ireland. *Aquaculture,* 144: 53-63.

Culloty SC, Mulcahy MF (2007) *Bonamia ostreae* in the native oyster *Ostrea edulis*. A review. *Marine and Environmental Health Series,* 29: 1-36.

Culloty SC, Cronin MA, Mulcahy MF (2003) Possible limitations of diagnostic methods recommended for the detection of the protistan, *Bonamia ostreae* in the European flat oyster, *Ostrea edulis*. *Bulletin of the European Association of Fish Pathologists,* 23: 67-71.

Culloty SC, Cronin MA, Mulcahy MF (2004) Potential resistance of a number of populations of the oyster *Ostrea edulis* to the parasite *Bonamia ostreae*. *Aquaculture* 237: 41-58.

Howard AE (1994) The possibility of long distance transmission of *Bonamia* by fouling on boat hulls. *Bulletin of the European Association of Fish Pathologists* 14: 211-212.

Lallias D, Arzul I, Heurtebise S, Ferrand S, Chollet B, Robert M, Beaumont AR, Boudry P, Morga B, Lapègue S (2008) *Bonamia ostreae*-induced mortalities in one-year old European flat oysters *Ostrea edulis*: experimental infection by cohabitation challenge. *Aquatic Living Resources,* 21: 423–439.

Lynch SA, Armitage DV, Wylde S, Mulcahy MF Culloty SC (2005) The susceptibility of young, pre-spawning oysters, *Ostrea edulis*, to *Bonamia ostreae. Journal of Shellfish Research,* 24: 1019-1025.

Lynch SA, Armitage DV, Coughlan J, Mulcahy MF, Culloty SC (2007) Investigating the possible role of benthic macroinvertebrates and zooplankton in the life cycle of the haplosporidian *Bonamia ostreae*. *Experimental Parasitology,* 115: 359-368.

Lynch SA, Mulcahy MF, Culloty SC (2008) Efficiency of diagnostic techniques for the parasite, *Bonamia ostreae*, in the flat oyster, *Ostrea edulis*. *Aquaculture,* 281: 17-21.

Lynch SA, Abollo E, Ramilo A, Cao A, Culloty SC, Villalba A (2010) Observations raise the question if the Pacific oyster, *Crassostrea gigas*, can act as either a carrier or a reservoir for *Bonamia ostreae* or *Bonamia exitiosa*. *Parasitology,* 137: 1515-1526.

McArdle JF, McKiernan F, Foley Hand D, Jones DH (1991) The current status of *Bonamia* disease in Ireland. *Aquaculture,* 93: 273-278.

Morga B, Arzul I, Faury N, Segarra A, Chollet B, Renault T (2011) Molecular responses of *Ostrea edulis* haemocytes to an *in vitro* infection with *Bonamia ostreae*. *Developmental and Comparative Immunology,* 35: 323-333.

Narcisi V, Arzul I, Cargini D, Mosca F, Calzetta A, Traversa D, Robert M, Joly JP, Chollet B, Renault T, Tiscar PG (2010) Detection of *Bonamia ostreae* and *B. exitiosa* (Haplosporidia) in *Ostrea edulis* from the Adriatic Sea (Italy). *Diseases of Aquatic Organisms,* 89: 79–85.

OIE, 2009. World Animal Health Information Database - Version: 1.4. World Animal Health Information Database. Paris, France: World Organisation for Animal Health. http://www.oie.int

Pichot Y, Comps M, Tigé G, Grizel H, Rabouin MA (1980) Recherches sur *Bonamia ostreae* gen. n., sp. n., parasite nouveau de l'huître plate *Ostrea edulis* L. *Revue des Travaux de l'Institut des Pêches Maritimes,* 43: 131-140.

4: *Corbicula fluminalis*, (O.F. Müller, 1774). Asian clam

Corbiculidae, Bivalvia, Mollusca

Once considered to be a morph of *C. fluminea*, and a synonym of this species, is now generally accepted as being a separate species.

Current status: NIS, not known in Ireland.

Native range: west and central Asia, Africa.

Established in Ireland: NIS, not known in Ireland.

First record: Not known in Ireland but has occurred in the fossil record in Britain.

Pathway: Potentially may spread as angling bait, with dredge spoil or perhaps as an unauthorised introduction. Disposal from an aquarium might take place, but there is no evidence of it being for sale in Ireland. In Europe it will have spread through the lacework of canals. In Poland, Switzerland and Ukraine it will have been carried overland, possibly with entanglement on fishing gear.

Level of certainty of pathway: Possible.

Further spread: It is likely to spread further within Europe and may appear in Britain before it is recorded in Ireland.

Probability of spread to Ireland: Moderate risk.

Known occurrence: Nearest known locations are France and The Netherlands. It is widespread in the Rhine, Wesser, Mosel, Odder and Danube rivers.

Not known in: Britain.

Impact: Biofouling of abstraction pipework and power-plant cooling systems as for *C. fluminea*. When in abundance can lead to trophic competition and alter habitats.

Expected: in lakes, rivers, canals or in upper reaches of estuaries

Monitoring localities: Pre-border, unlikely. At border possible from monitoring ornamental and aquarium outlets, otherwise post-border. May be encountered with general Water Framework Directive monitoring.

Monitoring method: grab, basket-dredge and intertidal surveys.

Field characteristics: The morphological features are that *C. fluminalis* has a greater height to shell length ratio and so not as rotund as *C. fluminea.* Nevertheless some confusion between the two species remains. Shells have distinct concentric ridges and are generally smaller than *C. fluminea*. *C. fluminalis* seems to be better adapted to salinities of 18 psu and more exposed conditions. Shells of both species may be washed ashore in windrows or appear when water levels are low. Both species might be found together in the same locality.

References:

Counts, C. L., III. 2006. *Corbicula*, an annotated bibliography. http://www.carnegiemnh.org/mollusks/corbicula.doc: 436 pp.

Csánai B. 1998–1999. Spreading invaders along the Danubian highway: first record of *Corbicula fluminea* (O. F. Müller, 1774) and *C. fluminalis* (O. F. Müller, 1774) in Hungary (Mollusca: Bivalvia). *Folia Historico Naturalia Musei Matraensis,* 23: 343–345.

Ciutti F, Cappelletti C (2009) Firsty record of *Corbicula fluminalis* (Muller, 1774) in Lake Garda (Italy), living in sympatry *with Corbicula fluminea* (Muller, 1774). *Journal of Limnology*, 68(8): 162-165.

Haesloop U (1992) Establishment of the Asiatic clam *Corbicula* cf. *fluminalis* in the tidal Weser River (N. Germany). *Archiv für Hydrobiologie,* 126(2): 175-180.

Korniushin AV (2004) A revision of some Asian and African freshwater clams assigned to *Corbicula fluminalis* (Müller, 1774) (Mollusca: Bivalvia: Corbiculidae), with a review of anatomical characters and reproductive features based on museum collections. *Hydrobiologia*, 529: 251- 270.

Mouthon J, Parghentanian T (2004) Comparison of the life cycle and population dynamics of two *Corbicula* species, *C. fluminea* and *C. fluminalis* (Bivalvia: Corbiculidae) in two French canals. *Archiv für Hydrobiologie,* 138: 267-287.

Paunović M, Csányi B, Knežević S, Simić V, Nenadić D, Jakovčev-Todorović D, Stojanović B, Cakić P (2007) Distribution of Asian clams *Corbicula fluminea* (Müller, 1774) and *C. fluminalis* (Müller, 1774) in Serbia. *Aquatic Invasions*, 2: 99-106.

Rajagopal S, Van der Velde G, Bij de Vaate A (2000) Reproductive biology of the Asian clams *Corbicula fluminalis* and *Corbicula fluminea* in the River Rhine *Archiv für Hydrobiologie,* 149(3): 403-420.

5: *Corbicula fluminea* (O.F. Müller, 1774). The Asian clam

Corbiculidae, Bivalvia, Mollusca

Current status: NIS, established and spreading

Native range: SE Asia, Australia and Africa.

Established in Ireland: Five separate established concentrations known.

First record: Freshwater tidal region of the Barrow and Nore rivers, first recorded in 2010 but will at this time have been established for some years.

Pathway: Unknown, but a deliberate unapproved introduction is suspected.

Level of certainty of pathway: Possible.

Further spread: Angling equipment is a possible source of transmission as four of the sites where the species has been found to-date are regions where angling takes place and hold international events. Anglers keep nets, fouled with small clams and stored in bags, might then spread the clam to new angling sites. It is possible that wading birds could have spread young individuals, as clams produce mucus sticky threads which may attach to the legs of birds in areas where clams become exposed. Since all of the known clam concentrations occur on the inland navigation, leisure craft transmissions are implicated, although there is no evidence to support this contention since clams have not been found fouling boat hulls.

Probability of further spread in Ireland: High.

Known occurrence: Barrow and Nore rivers tidal freshwater region, the Shannon River at Carrick-on-Shannon, Lanesborough, Upper Lough Derg and in Dromineer Bay, Lough Derg. Shell of the Asian clam was found on the Grand Canal but it is thought that the small numbers found may have expired during a period of cold weather at a time when the canal was covered in ice ~30cm in thickness. Widely distributed in Europe from Portugal to the Black Sea and present in Britain.

Not known in: All other Irish freshwater or estuarine localities outside of the Barrow-Nore and Shannon navigation.

Impact: trophic competition and habitat modification of sediments. The clam is a suspension feeder but can also extract nutrients using its foot from sediments. Alterations to the trophic web are likely to ensue. Fouling of water abstraction pipework and power-plant heat exchangers may be expected.

Expected: The Asian clam is expected to expand its range within the Barrow and Shannon catchments. There is a need for a public awareness campaign to reduce its rate of spread to isolated water bodies. Growth is from 10°C and reproduction from 15°C and tolerates temperatures from <1°C to 34°C and salinities of 5psu, but may tolerate salinities of up to 14psu for short periods.

Monitoring localities: Post-border**.** Should be part of all general river and lake surveys and estuaries. Clams tend to be more abundant in rivers.

Monitoring method: basket-dredge and grab sampling, shore surveys in tidal regions.

Field characteristics: Tan coloured globular shell with distinctive concentric ridges with an extendable foot. May have a byssus when of a small size and known to grow to 30mm shell length in Ireland, most are ~16-22mm.

References:

Barbour JH, McMenamin S, Dick JTA, Alexander MF, Caffrey J (2013) Biosecurity measures to reduce secondary spread of the invasive freshwater Asian clam, *Corbicula fluminea* (Muller, 1774). *Management of Biological Invasions,* 4(3): 219–230.

Byrne RA, McMahon RF, Dietz TH (1988) Temperature and relative humidity effects on aerial exposure tolerance in the freshwater bivalve *Corbicula fluminea*. *Biological Bulletin,* 175(2): 253–260.

Caffrey JM, Evers S, Millane M, Moran H (2011) Current status of Ireland's newest invasive species – the Asian clam *Corbicula fluminea* (Müller, 1774). *Aquatic Invasions,* 6(3): 291–299.

Elliott P, zu Ermgassen SE (2008) The Asian clam (*Corbicula fluminea*) in the River Thames, London, England. *Aquatic Invasions,* 3: 54–60.

Hayden B, Caffrey JM (2013) First recording of the Asian clam (*Corbicula fluminea* (Müller, 1774) from the River Shannon, with preliminary notes on population size and size class distribution. *Irish Naturalists' Journal,* 32(1): 29–31.

Karatayev AY, Padilla DK, Minchin D, Boltovskoy D, Burlakova LE (2007) Changes in global economies and trade: the potential spread of exotic freshwater bivalves. *Biological Invasions,* 9: 161–180.

Lucy FE, Karatayev AY, Burlakova LE (2012) Predictions for the spread, population density and impacts of *Corbicula fluminea* in Ireland *Aquatic Invasions,* 7(4): 465–474.

Minchin D (2013) *Corbicula fluminea* (Müller) (Mollusca: Bivalvia) arrives in Lough Derg, River Shannon. *Irish Naturalists' Journal,* 33(1):

Minchin D (2014) The distribution of the Asian clam *Corbicula fluminea* and its potential to spread in Ireland. *Management of Aquatic Invasions,* 5(2): 165-177.

Prezant RS, Chalermwat K (1984) Floatation of the bivalve *Corbicula fluminea* as a means of dispersal. *Science,* 225: 1491–1493.

Sousa R, Antunes C, Guilhermino L (2008) Ecology of the invasive Asian clam *Corbicula fluminea* (Muller, 1774) in aquatic ecosystems: an overview. *Annales de Limnologie International Journal of Limnology,* 44: 85–94.

Sweeney P (2009) First record of Asian clam *Corbicula fluminea* (Müller, 1774) in Ireland. *Irish Naturalists' Journal,* 30(2): 147–148.

6: *Corella eumyota* Traustedt, 1882. Orange-tipped sea squirt

Corellidae, Ascidiacea, Tunicata

Current status: NIS, widespread on Irish south, east and north coasts and expanding.

Native range: a circum-Antarctic species known from The Antarctic Peninsula, Argentina, Chile, Peru, South Africa, Namibia, Australia, New Zealand.

Established in Ireland: Yes and expanding rapidly.

First record: 2005, from Fenit Harbour.

Pathway: Leisure craft hulls and with stock movements of shellfish.

Level of certainty on pathway: Very likely, colonies have been found attached to small craft and to areas where small craft berth.

Further spread: Certain to spread to the west coast of Ireland.

Probability of further spread in Ireland: High.

Known occurrence: Known on the south coast and south-east coasts of Britain and in Oban Scotland. Elsewhere in Europe it is known in France, Spain and Portugal.

Not known in: the west of Ireland except at Fenit Harbour Marina.

Impact: The species can form extensive clusters fouling boat hulls and aquaculture structures. It also colonises the lower shore and sub-tidally. May foul pipe-work used for abstracting water.

Expected: to occur on anthropogenic and natural structures. Despite having a short larval period the species is spreading rapidly. It attached to the lamina of kelps which may be dragged by tidal movements.

Monitoring localities: Post-border**.** Marinas, aquaculture installations in areas with marine conditions.

Monitoring method: Intertidal surveys and scraping of marina pontoons and pillars.

Field characteristics: This is a non-colonial sea-squirt but can create clones of many individuals that can be fused together by their smooth semi-transparent tunics. Not every colony will have orange tips to their siphons. Distinctive is the way in which they lie attached to the substrate by having the exhalent siphon displaced to the right. However, when in tight clusters may be attached by the distal end to the substrate. Sometimes these can form extensive monospecific carpets. The gut forms a smooth curve at its distal end. Individuals may attain up to 8cm in body length, specimens are usually 3 to 4cm.

References:

Arenas F, Bishop JDD, Carlton JT, Dyrynda 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 of the United Kingdom*, 86: 1329-1337.

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.

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 of the United Kingdom*, 84: 239-241.

Minchin D (2007) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions*, 2(1), 63-70.

Minchin, D. and Nunn, J.D. (2013) *Rapid assessment of marinas for invasive alien species in Northern Ireland*. Northern Ireland Environment Agency Research and Development Series No. 13/06.

Sewell J, Pearce S, Bishop J, Evans JL (2008). Investigations to determine the potential risk for certain non-native species to be introduced to North Wales with mussel seed dredged from wild seed beds. *CCW Policy Research Report*, 835, 82 pp., Countryside Council for Wales.

7: *Crassostrea gigas* (Thunberg, 1793). Pacific oyster

Ostreidae, Bivalvia, Mollusca

Current status: NIS, Widely distributed being cultivated on lower shores and sub-tidally on trestles. Produced as spat in hatcheries. Feral populations exist in shallow bay regions.

Native range: Oysters originate from Miyagi Prefecture in Japan and from British Columbia where it had been introduced in the 1920s.

Established in Ireland: Recruiting in some shallow water bays.

First record: 1969 to Cork Harbour.

Pathway: Deliberate introductions of wild stock from Japan to France in the 1960s for cultivation, and from Canada to Britain through quarantine. It has been recorded attached to ships' hulls and larvae have been recorded in ballast water.

Level of certainty of pathway: Direct evidence.

Further spread: It is a widely cultivated oyster in more than 40 countries. It continues to be spread about the coast together with its associates that include pests and diseases.

Probability of further spread in Ireland: High.

Known occurrence: Feral populations are known to occur in Strangford Lough, Loughs Swilly and Foyle and in the Shannon Estuary. Recruitment is known to take place in many inlets very often at a low level and not in every year.

Not known in: open coastal areas.

Impact: Its cultivation provides for an important industry. This species is responsible for the main biomass of oyster production in Europe. Some Irish sites receive half-grown stock in large consignments by truck coming from the European continent and pose a risk for the further spread of pests, parasites and disease organisms as will have happened following the open trade of oysters from January 1993. Feral populations have established at low population levels in the shallows of bays and may in time become more abundant as has happened in The Netherlands and Denmark, thought to be due to alteration in climate. In such areas wild mussel landings have been considerably reduced. Bathing can be affected as shells can lacerate feet.

Expected: to become more abundant in shallow bays.

Monitoring localities: Further consignment monitoring at pre-border and at border, otherwise post-border. Sites occur in sheltered bays, rias and estuaries.

Monitoring method: Consignments of imported stock, intertidal surveys, monitoring of navigation buoys.

Field characteristics: Both shells usually convex, oval to elongate in outline with shell frills and purple markings. Shells 8–31 cm in length with irregular radial folds. The only other established oyster is the distinctive native flat oyster *Ostrea edulis* which has a rounded outline and flatter 'upper' shell. C*rassostrea virginica* and '*C. angulata* ' no longer exist in Irish waters but were once in cultivation, in some areas remains of their shells may exist.

References:

Boelens R, Minchin D, O'Sullivan G (2005) Climate change implications for Ireland's marine environment and resources. *Marine Foresight Series* No. 2, Marine Institute, Galway.

De Grave S, Moore SJ, Burnell G (1998) Changes in benthic macrofauna associated with intertidal oyster, *Crassostrea gigas* (Thunberg) culture. *Journal of Shellfish Research,* 17: 1137-1142.

Holmes JMC, Minchin D (1995) Two exotic copepods imported into Ireland with the Pacific oyster *Crassostrea gigas* (Thunberg). *Irish Naturalists' Journal,* 25: 17-20.

Kennedy RJ, Roberts D (1999) A survey of the current status of the flat oyster *Ostrea edulis* in Strangford Lough, northern Ireland, with a view to the restoration of its oyster beds. *Biology and Environment: Proceedings of the Royal Irish Academy,* 99B:79–88.

Kochmann J, Carlsson J, Crowe TP, Mariani S (2012). Genetic evidence for the uncoupling of local aquaculture activities and a population of an invasive species? A case study of Pacific oysters (*Crassostrea gigas*). *Journal of Heredity*, 103, (5): 661-671.

Kochmann J, O'Beirn F, Yearsley J, Crowe T (2013). Environmental factors associated with invasion: modelling occurrence data from a coordinated sampling programme for Pacific oysters. *Biological Invasions*, 15: 2265-2279.

Malham SK, Cotter E, O'Keeffe S, Lynch S, Culloty SC, King JW, Latchford JW, Beaumont AR (2009) Summer mortality of the Pacific oyster, *Crassostrea gigas*, in the Irish Sea: The influence of temperature and nutrients on health and survival. *Aquaculture,* 287:128–138.

McGonigle C, Cavanagh M, Santiago R (2011) *Native oyster stock assessment Lough Foyle*. The Loughs Agency (Foyle, Carlingfordand Irish Lights Commission), Londonderry, Carlingford.

Minchin D (1996) Management of the introduction and transfer of marine molluscs. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 6: 229-244.

Minchin D (2007) Aquaculture and transport in a changing environment: overlap and links in the spread of alien biota. *Marine Pollution Bulletin,* 55: 302-313.

8: *Crepidula fornicata* Linneaus, 1758). Slipper limpet

Calyptraeidae, Gastropoda, Mollusca

Current status: NIS.

Native range: East coast of North America.

Established in Ireland: in a single embayment, Belfast Lough. This population has 'chains' of individuals indicating that they are reproducing. Specimens are distributed over a wide area.

First record: 1902 from Ballinakill Bay. Several other records since this time may have died out.

Pathway: Stock movements of oysters.

Level of certainty on pathway: Direct evidence.

Further spread: Likely to take place with stock movements and might be spread on the hulls of vessels or attached to flotsam. Larval dispersal also takes place.

Probability of further spread in Ireland: High.

Known occurrence: Belfast Lough. Widely distributed in the south and south-east of Britain with isolated populations on the west coast. Known in France and the Portugal and northern Spain, The Netherlands, Germany, Denmark and more recently in Norway.

Not known in: other Irish bays, although there are previous accounts of its existence**.**

Impact: Can occur at densities >1,700/m^2=10 kg/m^2 and result in trophic competition leading to reduced growth of commercial bivalves. Their abundance alters sediments to mud due to deposits of faeces and pseudofaeces and where there are currents can result in shell drifts, thus altering habitats. May also affect the recruitment of some benthic commercial fishes. It has not been developed successfully as a food. It is often associated with oyster layings and scallop beds. It can also foul artificial structures in port regions.

Expected: it is likely to appear in shallow bays and inlets where there is on-bottom cultivation of mussels and oyster layings. Small males have been found associated with imported half-grown Pacific oysters from France that are cultivated in bags held on trestles. These become crushed within the bags. Direct layings on the sea-bed could result in their establishment.

Monitoring localities: Consignments examined at pre-border and at border, otherwise post border. **M**arine to brackish bays and estuaries with on-bottom cultivation of shellfish.

Monitoring method: Intertidal on the lower shore, examining of dredged shellfish. Imported consignments of mussels for relaying and of stocks of imported oysters.

Field characteristics: The slipper limpet has an asymmetrical shell with a large aperture with an obvious inner shelf. It can attain 5 cm. It is a suspension-feeder occurring within sheltered coastal bays and estuaries and sometimes occurs in deeper water. It attaches firmly to objects with its muscular foot. Individuals may attach to each other to form 'chains' with the largest, usually female snail underneath. No other mollusc in European waters forms such 'chains'.

References:

Arnold DC (1960) Occurrence of the slipper limpet, *Crepidula fornicata* L. in Ireland. *Nature,* 196: 95.

Blanchard M (1997) Spread of the slipper-limpet (*Crepidula fornicata*) in Europe. Current state and consequences.*Scientia Marina,* 61 (2 sup.): 109-118.

McNeill G, Nunn J, Minchin D (2010) The slipper limpet *Crepidula fornicata* Linnaeus, 1758 becomes established in Ireland. *Aquatic Invasions,* 5 *Supplement* 1: S21-25.

Minchin D, McGrath D and Duggan CB (1995) The slipper limpet *Crepidula fornicata* (L.) in Irish waters with a review of its occurrence in the north-eastern Atlantic. *Journal of Conchology,* 35: 247-254.

Quiniou F, Blanchard M (1987) Etat de la prolifération de la crepidule (*Crepidula fornicata* L.) dans le secteur de Granville (Golfe Normano-Breton – 1985). *Haliotus,* 16: 513-526.

Sewell J, Pearce S, Bishop J, Evans JL (2008) Investigations to determine the potential risk for certain non-native species to be introduced to North Wales with mussel seed dredged from wild seed beds. *CCW Policy Research Report* No. 06/3. pp 82.

Spicer JI (1923) The slipper limpet; an enemy of the oyster. *Fisheries Technical Report*, Dublin. 4 pp.
Sykes ER (1905) The molluscs and brachiopods of Ballinakill and Bofin harbours, Co Galway, and the deep water off the west and south-west coasts of Ireland. *Annual Reports for Fisheries*, Ireland 1902-03, Part 2: 53-92.

Walne PR (1956) The biology and distribution of the slipper limpet *Crepidula fornicata* in Essex rivers with notes on the distribution of larger epibenthic invertebrates. *Fisheries Investigations Londo,* (2) 20: no 6: 1-52.

9*:* *Didemnum vexillum* Kott, 2002. Carpet sea-squirt

Didemnidae, Ascidiacea, Chordata

Current status: NIS, expanding in Ireland.

Native range: NW Pacific.

Established in Ireland: known from the east and west coasts of Ireland.

First record: October 2005 at the Malahide Marina.

Pathway: Hull fouling on recreational craft but there is the possibility that a barge used in the development of the marina at Malahide may have been the original source. Hull fouling is a mode of spread.

Level of certainty on pathway: Very likely.

Further spread: Fragments can be dispersed by currents either on their own or should it be attached to kelp may be dispersed with currents. The larval duration in the plankton is of hours. The main mode of dispersal over distances would seem to be to marina sites thereby implicating leisure craft and elsewhere with the movement of oysters. Colonies have been seen attached to the hulls of leisure craft and associated with oyster bags on trestles.

Probability of further spread in Ireland: High.

Known occurrence: Malahide Marina, Carlingford Marina, Strangford Lough, Westport Bay, Galway Bay. It is almost certainly occurring elsewhere and its full distribution in Ireland is remains unknown on account of its similarity to small colonies of other *Didemnum* species.

Not known in: the south and north coasts of Ireland.

Impact: The species has the capability of fouling anthropogenic submerged structures. Elsewhere it is known to attach to *Zostera marina* leaves in shallows and can occur to depths of 80m over gravels. The concern is that should it form extensive carpets over gravels this may impact on scallop recruitment and hinder effective spawning of herring. Shellfish stock in lantern nets and plastic trays can become encased by colony growths that could result in reduced water flow with a subsequent loss in growth and increased mortality. In finfish culture nets may need to be changed more frequently. Fouling on leisure craft and slow moving vessels will create drag and increase maintenance costs.

Expected: to continue its expansion about the coast and to eventually appear offshore.

Monitoring localities: May be present with consignments of shellfish at border, otherwise post-border. Marinas, aquaculture sites and immersed structures and lower shore.

Monitoring method: Marinas, intertidal surveys, shellfish consignments, young fish surveys, navigation buoys.

Field characteristics: colonies are made up of small zooids linked within an off-white, beige to orange brown mass of consistent colour. Fine white spots appear where siphons are present, which are made-up of clusters of fine calcareous spicules, distinctive of the *Didemnum* genus. Colonies can form pendulous growths which may extend to a metre in length when attached to floating structures where there are currents but also will form a carpet covering other fixed biota. There are distinct canals that lead to pores on the surface. It may also occur on seaweeds. Identification requires confirmation and depends on the time when larvae are held within the colony. Larvae have four ampullae whose shape and form aid identification. To-date the best confirmation has been from genetic evidence.

References:

Carman MR, Grunden DW (2010) First occurrence of the invasive tunicate *Didemnum vexillum* in eelgrass habitat. *Aquatic Invasions,* 5: 23–29.

Coutts ADM, Sinner J (2004) An updated benefit-cost analysis of management options for *Didemnum vexillum* in Queen Charlotte Sound. *Cawthron Report* No. 925, Biosecurity New Zealand, Wellington, 29 pp.

Lambert G (2009) Adventures of a sea squirt sleuth: unravelling the identity of *Didemnum vexillum*, a global ascidian invader. *Aquatic Invasions,* 4: 5–28.

Minchin D (2007) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions,* 2: 63–70.

Minchin D, Sides E (2006) Appearance of a cryptogenic tunicate, a *Didemnum* sp. fouling marina pontoons and leisure craft in Ireland. *Aquatic Invasions,* 1: 143–147.

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.

Stefaniak L, Lambert G, Gittenberger A, Zhang H, Lin S, Whitlatch RB (2009) Genetic conspecificity of the worldwide populations of *Didemnum vexillum* Kott, 2002. *Aquatic Invasions,* 4: 29–44.

Switzer SE, Therriault TW, Dunham A, Pearce CM (2011) Assessing potential control options for the invasive tunicate *Didemnum vexillum* in shellfish aquaculture. *Aquaculture,* 318: 145–153.

Valentine PC, Carman MR, Dijkstra J, Blackwood DS (2009) Larval recruitment of the invasive colonial ascidian *Didemnum vexillum*, seasonal water temperatures in New England coastal and offshore waters, and implications for spread of the species. *Aquatic Invasions,* 4: 153–168.

Valentine PC, Collie JS, Reid RN, Asch RG, Guida VG, Blackwood DS (2007) The occurrence of the colonial ascidian *Didemnum* sp. on Georges Bank gravel habitat ecological observations and potential effects on groundfish and scallop fisheries. *Journal of Experimental Marine Biology and Ecology,* 342: 179–181.

10: *Dikerogammarus haemobaphes* (Eichwald, 1841). Demon shrimp

Gammaridae, Amphipoda, Crustacea

Current status: NIS, not known in Ireland.

Native range: Ponto-Caspian.

Established in Ireland: NIS, not known in Ireland.

First record: found in Britain in the Severn in 2012. Later found in the Trent catchments and in the associated canals and has spread to Anglia and the Thames catchment. It is now well established over the midlands of Britain.

Pathway: Has been distributed through canal systems and rivers in Europe. Its mode of introduction to Britain is unknown but leisure craft might have been involved. Its arrival by means of ballast water to an estuarine port cannot be excluded. Its spread with ornamental species is possible.

Level of certainty on pathway: very likely for canal transmissions and possible transmission with leisure craft.

Further spread: On arrival to Ireland it is inevitable that it will rapidly spread through the canal system to different water catchments.

Probability of spread to Ireland: High.

Known occurrence: Known to be widely distributed in 2012 in the canals in the midlands of Britain

Not known in: Scotland.

Impact: This predatory species feeds on native and introduced amphipods and is likely to become dominant soon after arrival. It is also cannibalistic. It acts as an important prey for native fishes. While impacting it may not have the high level of impact expected from the arrival of *D. villosus* and may locally be replaced by it.

Expected: The species may be transported with imported leisure craft associated with hull fouling, in bait wells or in toilet water and movements of fishing gear.

Monitoring localities: Examination of ornamental consignments and leisure craft at the border, otherwise post-border. This species is more common in still water sites such as canals and those areas with soft sediments and areas where clusters of zebra mussels may be found. Artificial structures such as fish passes and bank reinforcements are thought to be likely sites to find them. It may appear at the top of estuaries as the species can tolerate salinities of up to 8 psu.

Monitoring method: sweeping of aquatic vegetation with dip nest, use of scrapers on hard surfaces and deployment of traps.

Field characteristics: Can attain 18mm in body length. The Urosome (tail) segments 1 and 2 have distinctive conical projections that confirm the species as being of the Genus *Dikerogammarus. D. haemobaphes* has the conical projections not as high as long the anterior cone has two stout spines on each cone and has six chaetae on the first cone and three on the second. The antenna 2 has short setae in sparse groups throughout its length.

References:

Aldridge DC (2013) GB Non-native Organism Rapid Risk Assessment for *Dikerogammarus haemobaphes* (Eichwald, 1841). www.nonnativespecies.org.

Bovy HC, Barrios-O'Neill D, Emmerson MC, Aldridge DC, Dick JTA (2014) Predicting the predatory impacts of the 'demon shrimp' *Dikerogammarus haemobaphes*, on native and previously introduced species. *Biological Invasions,* DOI 10.1007/s10530-014-0751-9

Dobson M (2012) *Identifying invasive freshwater shrimps and isopods*. Freshwater Biological Association, The Ferry Landing, Far Sawrey, Ambleside, Cumbria, UK. 32pp https://secure.fera.defra.gov.uk/nonnativespecies/downloadDocument.cfm?id=720

Gallardo B, Aldridge DC (2013) The 'dirty dozen': socioeconomic factors amplify the invasion potential of 12 high risk aquatic invasive species in Great Britain and Ireland. *Journal of Applied Ecology,* 50: 757–766.

Gallardo B, Aldridge DC (2013) Priority setting for invasive species management: risk assessment of Ponto-Caspian invasive species into Great Britain. *Ecological Applications,* 23: 352–364.

Kititsyna LA (1980) Ecological and physiological pecularities of *Dikerogammarus haemobaphes* (Eichw.) in the region of the Tripolye State Supercentral Electric Station heated water discharge. *Gidrobiologicheskij Zhurnal,* 16: 77-85.

Kobak, J., T. Kakareko, M. Poznanska, and J. Zbikowski. 2009. Preferences of the Ponto-Caspian amphipod *Dikerogammarus haemobaphes* for living zebra mussels. *Journal of Zoology,* 279: 229-235.

Rewicz T, Grabowski M, MacNeil C, Bącela-Spychalaska K (2014) The profile of a ‘perfect’ invader – the case of the killer shrimp, *Dikerogammarus villosus*. *Aquatic Invasions* 9(3): 267-288.

11: *Dikerogammarus villosus* (Sowinsky, 1894). Killer shrimp

Gammaridae, Malacostraca, Crustacea

Current status: NIS, not known in Ireland.

Native range: Ponto-Caspian region.

Established in Ireland: no records for Ireland.

First record: In Britain was to Grafham Water in September 2010. It arrived in northern continental Europe following the opening of the Main-Danube Canal in 1992 and was found in the upper Danube in the same year. It then colonised the Rhine and is now present in France, The Netherlands, Belgium and Germany.

Pathway: In ships' ballast water or in fishing equipment as well as snagged materials, such as ornamental aquatic weeds, in which this amphipod may reside. The species takes refuge in cryptic environments and perhaps could be transported in toilet water of recreational craft as has been found for *G. tigrinus*.

Level of certainty on pathway: Possible.

Further spread: since it reproduces at temperatures that exceed 13°C and can reach maturity within 4 to 8 weeks it has the potential for a rapid increase of its population once introduced. Its rate of spread in continental Europe has been >100km per year on river systems. In Ireland it is likely to spread rapidly to several river catchments that are connected by canals. Entry might take place following transport from a continental port to an Irish brackish or freshwater port in ballast water.

Probability of spread to Ireland: High.

Known occurrence: Known in Grafham Water, Cambridgeshire and Cardiff Bay and Eglwys Nynydd in Wales.

Not known in: Scotland.

Impact: invaded areas in Western Europe have experienced notable changes to the native biota following invasion. It is an opportunistic omnivore and voracious predator and may reduce populations of mayflies, damselflies, chironomids, cladocera and isopods. It also feeds of fish eggs and larvae. Not all that are preyed-upon are devoured. Produces more offspring than native amphipods leading to a re-organisation of the food web and likely alterations to fisheries. The species can act as a host for acanthocephalan parasites that can have impacts on fish populations. It is tolerant of a wide range of environmental conditions.

Expected: while it is unknown as to how the species arrived in Britain it is clear that overland transport will have involved the spread to alpine lakes on continental Europe and this mode of transmission may take place with leisure craft being ferried from Britain or the continent to Ireland.

Monitoring localities: Trailered craft examined at pre-border and at border, otherwise post border. **I**n areas with <20 psu to freshwater where there are boulders to cobble substrates and tree roots in shallows.

Monitoring method: Examination of boat hulls on arrival in Ireland. Use of specialised traps in stony areas or use of porous house bricks, which are likely to be used as refugia. When present in abundance the species is obvious often occurring about the edge of waterbodies**.**

Field characteristics: Can attain 30mm in body length, with either a striped or uniform body colouration. The Urosome (tail) segments 1 and 2 have distinctive conical projections that confirm the species as being of the Genus *Dikerogammarus. D. villosus* has the conical projections as high as long the anterior cone has at least three spines and this may not be as many on the second cone. The setae on the antenna 2 has dense tufts of setae on the last third of its length.

References:

Bollache L, Devin S, Wattier R, Chovet M, Beisel JN, Moreteau JC, Rigaud T (2004) Rapid range extension of the Ponto-Caspian amphipod *Dikerogammarus villosus* in France: potential consequences *Archiv für Hydrobiologie,* 160,57-66.

Bruijs MCM, Kelleher B, van der Velde G, Bij de Vaate A (2001) Oxygen consumption, temperature and salinity tolerance of the invasive amphipod *Dikerogammarus villosus*: indicators of further dispersal via ballast water transport. *Archiv für Hydrobiologie,* 152: 633–646.

Devin S, Piscart C, Beisel JN, Moreteau JC (2004) Life history traits of the invader *Dikerogammarus villosus* (Crustacea : Amphipoda) in the Moselle River, France *International Review of Hydrobiology,* 89: 21-34.

Dick JTA, Platvoet D (2000) Invading predatory crustacean *Dikerogammarus villosus* eliminates both native and exotic species *Proceedings of the Royal Society of London, Series B Biological Sciences* 267, 977-983.

Dick JTA, Platvoet D, Kelly DW (2002) Predatory impact of the freshwater invader *Dikerogammarus villosus* (Crustacea: Amphipoda) *Canadian Journal of Fisheries and Aquatic Sciences* 59, 1078-108.

Dobson M (2012) *Identifying invasive freshwater shrimps and isopods*. Freshwater Biological Association, The Ferry Landing, Far Sawrey, Ambleside, Cumbria, UK. 32pp

Gergs, R, Rothhaupt, KO (2008) Effects of zebra mussels on a native amphipod and the invasive *Dikerogammarus villosus*: the influence of biodeposition and structural complexity *Journal of the North American Benthological Society* 27, 541-548

MacNeil C, Platvoet D (2013) Could artificial structures such as fish passes facilitate the establishment and spread of the 'killer shrimp' *Dikerogammarus villosus* (Crustacea: Amphipoda) in river systems? *Aquatic Conservation-Marine and Freshwater Ecosystems,* 23: 667–677.

MacNeil C, Platvoet D, Dick JTA, Fielding N, Constable A, Hall N, Aldridge D, Renals T, Diamond M (2010) The Ponto- Caspian 'killer shrimp', *Dikerogammarus villosus* (Sowinsky, 1894), invades the British Isles. *Aquatic Invasions,* 5: 441– 445.

MacNeil C, Boets P, Platvoet D (2012) 'Killer shrimps', dangerous experiments and misguided introductions: how freshwater shrimp (Crustacea: Amphipoda) invasions threaten biological water quality monitoring in the British Isles. *Freshwater Reviews,* 5: 21–35.

MacNeil C, Boets P, Lock K, Goethals PLM (2013) Potential effects of the invasive 'killer shrimp' (*Dikerogammarus villosus*) on macroinvertebrate assemblages and biomonitoring indices. *Freshwater Biology,* 58: 171–18.

Ovcharenko, MO, Bacela, K, Wilkinson, T, Ironside, JE, Rigaud, T, Wattier (2010) *Cucumispora dikerogammarz* n. gen. (Fungi: Microsporldia) infecting the invasive amphipod *Dikerogammarus villosus*: a potential emerging disease in European rivers*. Parasitology,* 137, 191-204.

Platvoet, D, van der Velde, G, Dick, JTA, Li, SQ (2009) Flexible omnivory in *Dikerogammarus villosus* (Sowinsky, 1894) – amphipod pilot species report (AMPIS) Report 5 *Crustaceana,* 82, 703-720.

Pockl, M (2009) Success of the invasive Ponto-Caspian amphipod *Dikerogammarus villosus* by life history traits and reproductive capacity *Biological Invasions,* 11: 2021-2041.

Rewicz T, Grabowski M, MacNeil C, Bącela-Spychalaska K (2014) The profile of a 'perfect' invader – the case of the killer shrimp, *Dikerogammarus villosus*. *Aquatic Invasions,* 9(3): 267-288.

12*: Dreissena bugensis* Andrusov, 1897. Quagga mussel

Dreissenidae, Bivalvia, Mollusca

Current status: NIS, rapidly expanding in Europe.

Native range: Ponto-Caspian from the Ukraine region in the lower Dnieper Rivers and the southern part of the Bug River.

Established in Ireland: Not known in Ireland.

First record: In Britain it was found in a reservoir and river near Egham in Surrey in 2014. It is present in most northern European countries.

Pathway: Arrival on the hulls of leisure craft from an infested area or with contaminated fishing gear that has snagged druses, or weed with attached juveniles.

Level of certainty on pathway: Very likely.

Further spread: to Ireland from water craft ferried from Britain as has been shown for the zebra mussel that arrived during the 1993/4 period. Other modes of transport include the movements of fishing gear.

Probability of spread to Ireland: High.

Known occurrence: In Britain it was found in a reservoir and river near Egham in Surrey. Its identity was confirmed in October 2014.

Not known in: Scotland or Wales.

Impact: This species has a wider habitat tolerance when compared with the zebra mussel and is likely to result in further trophic competition, especially within lake and reservoir systems where quagga mussels are likely to replace zebra mussels. This replacement rate may occur approximately four years following arrival. Quagga mussels have lower respiration rates, faster growth and greater ability to assimilate suspended matter with notable declines of crustacean zooplankton including copepods and cladocera. Their selective filtration may lead to toxic algal blooms. Quagga mussels are likely to foul abstraction pipework and other raw water users.

Expected: in Ireland arriving on the hulls of used trailered craft transported by ferry.

Monitoring localities: Examination pre-border and at the border, otherwise post-border. Upper reaches of estuaries, where salinities do not exceed 8psu and can reproduce at, and below, 3 psu, occurring in rivers, lakes and canals, especially in alkaline areas where there are boating activities.

Monitoring method: Inspection of boat hulls and fishing equipment and snagged plants. Samples collected in plankton nets are unlikely to be distinguished from those of the zebra mussel unless genetic techniques can be used. Scraping vertical surfaces of buttresses, navigation poles, quays and floating pontoons. Imports of ornamental plants may have attached mussels.

Field characteristics: Similar to the zebra mussel but with less pronounced striped markings. The shell is more rotund, is wider, and the shell margins have a wavy edge where they meet near to where the byssus protrudes.

References:

Aldridge, David C., Elliott, Paul, Moggridge, Geoff D (2006) Microencapsulated BioBullets for the control of biofouling zebra mussels. *Environmental Science and Technology*, 40(3):975-979.

Baldwin BS, Mayer MS, Dayton J (2002) Comparative growth and feeding in zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis*): implications for North American lakes. Canadian *Journal of Fisheries and Aquatic Sciences,* 59: 680-694.

Bij de Vaate A, Jazdzewski K, Ketelaars HAM, Gollasch S, Van der Velde G (2002) Geographical patterns in the range extension of Ponto-Caspian macroinvertebrate species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences,* 59(7): 1159-1174.

Edwards WJ, Babcock-Jackson L, Culver DA (2000) Prevention of the spread of zebra mussels during fish hatchery and aquaculture activities. *North American Journal of Aquaculture*, 62(3): 229-236.

Gallardo B, Aldridge DC (2013) Priority setting for invasive species management: risk assessment of Ponto Caspian invasive species into Great Britain. *Ecological Applications,* 23: 352-364.

Kissman CEH, Knoll LB, Sarnelle O (2010) Dreissenid mussels (*Dreissena polymorpha* and *Dreissena bugensis*) reduce microzooplankton and macrozooplankton biomass in thermally stratified lakes. *Limnology and Oceanography,* 55: 1851-1859.

Matthews RF, McMahom RF (1995) Survival of zebra mussels (*Dreissena polymorpha*) and Asian clams (*Corbicula fluminea*) under extreme hypoxia. *Technical Report EL353 to USACE*.

Molloy DP, bij de Vaate A, Wilke T, Giamberini L (2007) Discovery of *Dreissena rostriformis bugensis* (Andrusov 1897) in Western Europe. *Biological Invasions,* 9: 871–874.

Nalepa TF, Fanslow DL, Lang GA (2009) Transformation of the offshore benthic community in Lake Michigan: recent shift from the native amphipod *Diporeia* spp. to the invasive mussel *Dreissena rostriformis bugensis*. *Freshwater Biology*, 54(3): 466-479.

Spidle AP, Mills EL, May B (1995) Limits to tolerance of temperature and salinity in the quagga mussel (*Dreissena bugensis*) and the zebra mussel (*Dreissena polymorpha*) *Canadian Journal of Fisheries and Aquatic Sciences,* 52: 2108-2119.

Therriault TW, Orlova MI, Docker MF, MacIsaac HJ, Heath DD (2005) Invasion genetics of a freshwater mussel (*Dreissena rostriformis bugensis*) in eastern Europe: high gene flow and multiple introductions. *Heredity*, 95: 16–23.

Thorp HJ; Alexander JE Jr., Cobbs GA (2002). Coping with warmer, large rivers: a field experiment on potential range expansion of northern quagga mussels (*Dreissena bugensis*). *Freshwater Biology,* 47: 1779–1790.

Van der Velde G, Platvoet D (2007) Quagga mussels *Dreissena rostriformis bugensis* (Androsov, 1897) in the Main River (Germany). *Aquatic Invasions,* 2: 261-264.

Wilson AB, Nalsh K-A, Boulding EG (1999) Multiple dispersal strategies of the invasive quagga mussel (*Dreissena bugensis*) as revealed by microsatellite analysis. *Canadian Journal of Fisheries & Aquatic Sciences,* 56(12): 2248-2261.

Wilson KA, Howell ET, Jackson DA (2006) Replacement of zebra mussels by quagga mussels in the Canadian nearshore of Lake Ontario: The importance of substrate, round goby abundance, and upwelling frequency. *Journal of Great Lakes Research*, 32(1): 11-28.

Wright DA, Setzler EM, Magee JA, Kennedy VS, McIninch SP (1996) Effect of salinity and temperature on survival and development of young zebra (*Dreissena polymorpha*) and quagga (*Dreissena bugensis*) mussels*. Estuaries,* 19(3): 619-628.

13: *Ensis directus* (Conrad, 1843). American razor, jack-knife clam

Pharidae, Bivalvia, Mollusca

Current status: NIS, not known in Ireland.

Native range: east coast of North America. European populations, based on genetic studies, are originally from Shinnecock Bay, Long Island Sound and Cobscook Bay, Bay of Fundy.

Established in Ireland: No known records in Ireland.

First record: No known records in Ireland.

Pathway: May arrive as a result of natural spread as it has done following its colonisation in the southern North Sea. Larvae might be spread in ballast water transfer. It may have arrived in Europe by this pathway.

Level of certainty on pathway: Possible.

Further spread: Likely, the species is spreading within the North Sea and is now in the eastern part of the Irish Sea.

Probability of spread to Ireland: High.

Known occurrence: Nearest localities are Liverpool Bay and Milford Haven in Britain.

Not known in: Scotland or North Wales.

Impact: An abundant species in winnowed sands. May displace other razor clams. It has provided an important fishery in the southern North Sea; and in The Netherlands has the Marine Stewardship Councils certification.

Expected: on the east coast of Ireland off sandy bays.

Monitoring localities: Post border. Sandy environments with winnowed sands in open bays.

Monitoring method: Intertidal surveys, shells may be taken in young fish surveys. Shell remains on the high shores of extensive sandy bays.

Field characteristics: The shell is slightly curved and seldom exceeds 20cm in length and is wider than *E ensis*. In *E. directus* the pallial sinus has straight narrow edges and the lower part of the sinus scar is oblique.

References:

Beukema JJ, Dekker R (1995) Dynamics and growth of a recent invader into European coastal waters: the American razor clam, *Ensis directus*. *Journal of the Marine Biological Association of the United Kingdom,* 75: 351–362.

Dansey P (2011) *Ensis directus* (Conrad 1843) (Bivalvia: Solenoidea) found in Liverpool Bay (Sea area S24). *Journal of Conchology,* 40: 679.

Essink K (1985) On the occurrence of the American jack-knife clam *Ensis directus* (Conrad, 1843) (Bivalvia, Cultellidae) in the Dutch Wadden Sea. *Basteria,* 49: 73-80.

Palmer DW (2004) Growth of the razor clam *Ensis directus,* an alien species in the Wash on the east coast of England. *Journal of the Marine Biological Association of the United Kingdom,* 84: 1075–1076.

Swennen C, Leopold MF, Stock M (1985) Notes on growth and behaviour of the American razor clam *Ensis directus* in the Wadden Sea and the predation on it by birds. *Helgoländer Meeresuntersuchungen,* 39: 255-261.

Vierna J, Jensen KT, Gonzalez-Tizon AM, Martinez-Lage A (2012) Population genetic analysis of *Ensis directus* unveils high genetic variation in the introduced range and reveals a new species from the NW Atlantic. *Marine Biology,* 159: 2209-2227.

14. Epizootic Haematopoietic necrosis (EHVN)

Current status: NIS.

Native range: unknown, but perhaps Australia.

Established in Ireland: Not known in Ireland.

First record: from Australia in 1986.

Pathway: with fish stocks, probably with infested salmonids or contaminated water.

Level of certainty on pathway: Very likely.

Further spread: Might be spread by aquatic birds, including those that are piscivorous, the virus is likely to survive after feeding on infested fish. The virus is not thought to be able to endure the inner body temperature of birds. Transport of infested rainbow trout fingerlings or salmon smolts.

Probability of spread to Ireland: Moderate risk.

Known occurrence: This virus has been isolated from freshwater and marine fishes: *Ictalurus melas* in France, *Siluris glanis* in Germany, and turbot in Denmark. Known to occur in *Perca fluviatilus, Oncorhynchus mykiss, Carassius auratus, Cyprinus carpio,* and *Esox lucius.* Atlantic salmon may act as a carrier. It is also known in North America and eastern Asia.

Not known in: Ireland, Britain.

Impact: Can result in mortalities of rainbow trout reared in freshwater or the sea. There is no vaccination available to prevent such events from taking place.

Expected: The virus is very resistant to drying out and can survive a number of months in water. It can also persist in frozen fish tissue for more than a year. Such resistance is likely to mean that it will survive in water long after there has been an event.

Monitoring localities: Post-border. Known at fish farm sites.

Monitoring method: Specialist veterinarian knowledge required. Infests hepatocytes, haematopoietic cells and endothelial cells in several organs, microscopic examination required.

Field characteristics: Not easily detected in living fish as the virus may be present at a low prevalence. On rainbow trout farms where there is poor husbandry and fish have broken skin, infestations may occur, normally at temperatures of 11° to 20°C.

References

Langdon JS, Humphrey JD (1987). Epizootic Hematopoietic Necrosis a New Viral Disease in Redfin Perch *Perca fluviatilis* L. in Australia. *Journal of Fish Diseases*, 10: 289–298.

Langdon JS, Humphrey JD, Williams LM (1988) Outbreaks of an EHNV-like iridovirus in cultured rainbow trout, *Salmo gairdneri* Richardson, in Australia. *Journal of Fish Diseases*, 11: 93–96.

Reddacliff LA, Whittington RJ (1996) Pathology of epizootic haematopoeitic necrosis virus (EHNV) infection in rainbow trout (*Oncorhynchus mykiss* Walbaum) and redfin perch (*Perca fluviatilis* L.). *Journal of Comparative Pathology,* 115: 103–115.

Whittington RJ, Philby A, Reddacliff GL, MacGowan AR (1994) Epidemiology of epizootic haematopoietic necrosis virus (EHNV) infection in farmed rainbow trout, *Oncorhynchus mykiss* (Walbaum): findings based on virus isolation, antigen capture ELISA and serology. *Journal of Fish Diseases*, 17: 205–218.

15: *Eriocheir sinensis* H. Milne Edwards, 1853. Chinese mitten crab

Varunidae, Decapoda, Crustacea

Current status: NIS, casual, only one event known.

Native range: NW Pacific.

Risk category: High.

Established in Ireland: not thought to be established.

First record: Waterford Harbour.

Pathway: shipping, carried as larvae in ballast water or juveniles in sea chests.

Level of certainty of pathway: Possible.

Further spread: Expected in large estuaries. It is most likely to arrive in estuaries as larvae or mature adults. It has a prolonged freshwater stage.

Probability of spread to Ireland: High.

Known occurrence: in Britain established in the Tyne, Humber and Thames, occasional casual records of small numbers elsewhere. Recent single record on the west coast of Scotland of a berried female. Established in northern Europe and there are records from the Baltic Sea.

Impact: Known to burrow into banks in freshwater tidal areas causing bank erosion and resulting in increased sedimentation in shipping channels. In fish ponds it is a predator, and may have adverse effects on river communities. This crab is the second intermediate host for the human lung-fluke parasite *Paragonimus westermani* which has not been recorded in European waters.

Expected: Further casual records may appear. Should they become established adults descend rivers in September to November and release their larvae in February-March and move upstream in June to September. Adults die in the late spring and their remains might be found on the high shore.

Monitoring localities: Post-border. All large Irish estuaries where there is shipping.

Monitoring method: rotating screens, traps, young fish surveys, shore surveys, fish shops.

Field characteristics: A tan coloured crab of ~5cm carapace width, with fur-like growths on chelae. Only crab of this size likely to be found in rivers.

References:

Clark PF (2011) The commercial exploitation of the Chinese mitten crab *Eriocheir sinensis* in the River Thames, London: damned if we don't and damned if we do. In: Galil BS, Clark PF, Carlton JT (eds), In the wrong place – alien marine crustaceans: distribution, biology and impacts. Invading Nature. *Springer Series in Invasion Ecology,* 6 Springer, London, pp 537–580.

Dittel AI, Epifanio CE (2009) Invasion biology of the Chinese mitten crab *Eriocheir sinensis*: a brief review. *Journal of Experimental Marine Biology and Ecology,* 384: 79–92.

Gilbey V, Attrill MJ, Coleman RA (2008) Juvenile Chinese mitten crabs (*Eriocheir sinensis*) in the Thames estuary: distribution, movement and possible interactions with the native crab *Carcinus maenas. Biological Invasions,* 10: 67– 77.

Herborg L-M, Rushton SP, Clare AS, Bentley MG (2005) The invasion of the Chinese mitten crab (*Eriocheir sinensis*) in the United Kingdom and its comparison to continental Europe. *Biological Invasions,* 7: 959–968.

Herborg L-M, Bently MG, Clare AS, Last KS (2006) Mating behaviour and chemical communication in the invasive Chinese mitten crab, *Eriocheir sinensis*. *Journal of Experimental Marine Biology and Ecology,* 329: 1–10.

Minchin D (2006) First Irish record of the Chinese-mitten crab *Eriocheir sinensis* (Milne-Edwards, 1854) (Decapoda: Crustacea). *Irish Naturalists' Journal,* 28(7): 303-304.

Morritt D, Mills H, Hind K, Clifton-Dey, Clark PF (2013) Monitoring downstream migrations of *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Brachyura: Grapsoidea: Varunidae) in the River Thames using capture data from a water abstraction intake. *Management of Biological Invasions,* 4(2): 139-147.

16: *Gyrodactylus salaris* von Nordmann, 1832. Gyrodactylosis

Gyrodactylidae, Gyrodactylidea, Platyhelminthes

Current status: NIS, not known in Ireland.

Native range: Northern Baltic Sea and rivers.

Established in Ireland: Not recorded in Ireland.

First record: No records for Ireland.

Pathway: Moved to Norway from Sweden with stock movements.

Level of certainty of pathway: Direct evidence.

Further spread: Possible movements with salmonid parr/smolts or of damp equipment being moved from an infested area.

Probability of spread to Ireland: Moderate risk. Sufficient pre-border awareness is likely to reduce the risk of importation.

Known occurrence: Known to have been introduced to Norway. Some sixteen rivers were purged of the parasite following rotenone treatment in Norway. Reported from north Finland and the White Sea area. Also recorded in Denmark.

Not known in: Britain. Reports from Spain, Portugal, France and Germany require confirmation.

Impact: The small <1mm flatworm infests the skin and gills of salmonids. The species is viviparous and populations can expand rapidly leading to damage to tissues leaving the salmonid open to infections which can result in high mortalities. This ectoparasite can cause a total loss of salmon parr.

Expected: With imports of live salmonids coming from infested regions with salinities <7 psu.

Monitoring localities: Pre-border and border, also post-border. Consignments on arrival of salmon smolts from regions known to have the parasite should be inspected.

Monitoring method: Specialist, veterinarian. There are many species of *Gryrodactylus* and these can morphologically seem very similar and so difficult to identify. The parasite is small and may be easily overlooked. Genetic methods may be required.

Field characteristics: Specialist knowledge needed. Heavily infected fish normally have damaged fins, in particular the dorsal, caudal and pectorals and there may be copious mucus production. Infested fish are normally lethargic.

References:

Bakke TA, MacKenzie K (1993) Comparative susceptibility to native Scottish and Norwegian stocks of Atlantic salmon, *Salmo salar* L. to *Gyrodactylus salaris* Malmberg: Laboratory experiments. *Fisheries Research,* 17: 69-85.

Bakke TA, Harris PD, Hansen H, Cable J, Hansen LP (2004) Susceptibility of Baltic and East Atlantic salmon *Salmo salar* stocks to *Gyrodactylus salaris* (Monogenea). *Diseases of Aquatic Organisms,* 58 (2-3): 171-177.

Bakke TA, Cable J, Harris PD (2007) The biology of gyrodactylid monogeneans: The "Russian-doll killers". *Advances in Parasitology*, 64: 161-376.

Buchmann K, Bresciani J (1997) Parasitic infections in pond-reared rainbow trout *Oncorhynchus mykiss* in Denmark. *Diseases of Aquatic Organisms,* 28: 125 – 138.

Hansen H, Bakke TA, Bachmann L (2007) DNA taxonomy and barcoding of monogenean parasites: lessons from *Gyrodactylus*. *Trends in Parasitology*, 23: 363-367.

Harris PD, Jansen PA, Bakke TA (1994) The population age structure and reproductive biology of *Gyrodactylus salaris* Malmberg (Monogenea). *Parasitology,* 108: 167 - 173.

Harris PD, Bachmann L, Bakke TA (2011). Freshwater charr (*Salvelinus alpinus*) as hosts for *Gyrodactylus salaris*: implications for management. *Veterinary Record*, 168: 161.

Jansen PA, Bakke TA (1991) Temperature-dependent reproduction and survival of *Gyrodactylus salaris* Malmberg, 1957 (Platyhelminthes; Monogenea) on Atlantic salmon (*Salmo salar* L.). *Parasitology,* 102: 105 - 112.

Jørgensen LVG, Heinecke RD, Kania P, Buchmann K (2008) Occurrence of gyrodactylids on wild Atlantic salmon, *Salmo salar* L., in Danish rivers. *Journal of Fish Diseases*, 2: 127-134.

Peeler E, Thrush M, Paisley L, Rodgers C (2006) An assessment of the risk of spreading the fish parasite *Gyrodactylus salaris* to uninfected territories in the European Union with the movement of live Atlantic salmon (*Salmo salar*) from coastal waters. *Aquaculture*, 258: 187-197.

Soleng A, Bakke TA (1997) Salinity tolerance of *Gyrodactylus salaris* (Platyhelminthes, Monogenea): laboratory studies. *Canadian Journal of Fisheries and Aquatic Sciences,* 54: 1837 - 1845.

17: *Hemigrapsus sanguineus* (De Haan, 1835). Asian shore crab

Varunidae, Decapoda, Crustacea

Current status: NIS, not known in Ireland.

Native range: NW Pacific from Sakhalin Island along the Russian, Korean and Chinese coasts to Hong Kong and the Japanese archipelago and Taiwan.

Established in Ireland: not known in Ireland.

First record in Europe: near La Havre in 1999 and thought to have settled in, or before, 1998. In 1999 it was found in the Oosterscheld, The Netherlands.

Pathway: Might have arrived as larvae discharged from ballast water and may have arrived in the Channel islands as a result of natural dispersal of their four week pelagic phase, or with shellfish, or small craft movements.

Level of certainty of pathway: Possible.

Further spread: It is unclear whether the specimens found in Britain represent an establishment in Britain or whether these are casuals.

Probability of spread to Ireland: High.

Known occurrence: found in South Wales and Kent in the spring of 2014. It occurs on the northern coasts of continental Europe from France to Denmark and has been recorded in the Adriatic Sea in the Mediterranean and Black Sea.

Not known in: Scotland.

Impact: A very tolerant small omnivorous crab with a broad diet and has the ability to feed on polychaetes, small crustaceans, small fishes, shellfish and eelgrasses and filamentous and sheet-like algae. The majority of the diet is made-up of algae. It may dominate invaded habitats and cause declines in the native shore crab. May feed on commercial shellfish species of a small size. It has the capability of disrupting intertidal food webs. In North America in New Jersey and New York they may attain densities of >300m^2.

Expected: in port estuaries and in areas where shellfish are cultivated occurring inter-tidally and in the shallow sub-tidal.

Monitoring localities: Pre-border and at border with consignments of shellfish, otherwise post border. Salt-marshes and intertidal habitats in estuaries and sheltered shore in areas of 20+ psu.

Monitoring method: inter-tidal surveys, traps and consignments of imported shellfish and in port areas. This crab occurs on shallow or intertidal rocky habitats, mussel beds and armoured sea defences often found beneath stones or rock crevices at low water of low energy beaches. They may occur in *Zostera* meadows, salt marshes and artificial structures. Might occur within dead shell spaces of vacant shells in shellfish consignments.

Field characteristics: Adults range from 35mm to 42mm carapace width and males have a small fleshy swelling (vesicle) at the base of the dactylus of the cheliped. This is absent in juveniles and females. The vesicle collapses when placed in alcohol. The carapace colour is mottled or dotted with brown, green or dark purple areas. The dorsal part of the chelipeds have purple-red dots. Periopods have alternating dark and light banding. There are three distinct teeth on the carapace behind each eye which are more acute than in *H. takanoi*.

References:

Breton G, Faasse M, Noel P, Vincent T (2002) A new alien crab in Europe. *Hemigrapus sanguineus* (Brachyurea: Grapsidae). *Journal of Crustacean Biology,* 22(1): 184-189.

Brousseau, D.J., and Goldberg, R. 2007. Effect of predation by the invasive crab *Hemigrapsus sanguineus* on recruiting barnacles *Semibalanus balanoides* in western Long Island Sound, USA. *Marine Ecology Progress Series,* 339: 221–228.

Dauvin J (2009) Establishment of the invasive Asian shore crab *Hemigrapsus sanguineus* (De Haan, 1835) (Crustacea: Brachyura: Grapsoidea) from the Cotentin Peninsular, Normandy, France. *Aquatic*

Invasions, 4: 467–472.

Dauvin J (2009) Asian shore crabs *Hemigrapsus* spp. (Crustacea: Brachyura: Grapsoidea) continue their invasion around the Cotentin Peninsula, Normandy, France: status of the *Hemigrapsus* population in 2009. *Aquatic Invasions,* 4: 605–611.

Dauvin J, Rius AT, Ruellet T (2009) Recent expansion of two invasive crab species *Hemigrapsus sanguineus* (de Haan, 1835) and *H. takanoi* Asakura and Watanabe 2005 along the Opal Coast, France. *Aquatic Invasions,* 4: 451–465.

Jensen GC, McDonald PS, Armstrong DA (2002) East meets west: competitive interactions between green crab *Carcinus maenas*, and native and introduced shore crab *Hemigrapsus* spp. *Marine Ecological Progress Series,* 225: 251-262.

Klassen, G. 2012. A biological synopsis of the Asian shore crab, *Hemigrapsus sanguineus*. *Canadian Manuscript Report, Fisheries and Aquatic Sciences*, 2978: 43 p.

Micu D, Nita N, Todorova V (2010) First record of the Japanese shore crab *Hemigrapsus sanguineus* (de Haan, 1835) (Brachyura: Grapsoidea: Varunidae) from the Black Sea. *Aquatic Invasions,* 5: Supplement 1: S1–S4.

Schubart CD (2003) The East Asian shore crab *Hemigrapsus sanguineus* (Brachyura: arunidae) in the Mediterranean Sea: an independent human-mediated introduction. *Scientia Marina,* 67: 195–200.

18: *Hemigrapsus takanoi* Asakura & Watanabe, 2005. Hairy-clawed shore crab

Varunidae, Decapoda, Crustacea

Current status: NIS, not known in Ireland.

Native range: NW Pacific, from northern Japan to Russian and Chinese coasts.

Established in Ireland: no records known in Ireland.

First record: No records for Ireland but the first occurrence is from La Rochelle, France in 1994.

Pathway: There is some indication that this crab may have been transported directly from Asia on the hulls of specialised ships. Other possibilities include their association with consignments of oysters arriving from the north-west Pacific coast.

Level of certainty of pathway: Possible.

Further spread: the crab's association with shellfish cultivation and its occurrence in the immediate area of ports suggest that two likely transmissions will either be with shipping, carrying their larvae in ballast water or on ship hulls as was found in one study, or with consignments of half-grown, or larger, oysters transferred within the European Union.

Probability of spread to Ireland: High.

Known occurrence: The species is known on shores from France to Denmark.

Not known in: Britain.

Impact: This is a highly competitive crab displacing the native shore crab when abundant.

Expected: intertidally and subtidally and beneath stones and among rock armour sea defences and groynes.

Monitoring localities: Pre-border and at border with consignments of shellfish, otherwise post border. Estuaries of ports and aquaculture sites where shellfish are laid or on-grown in areas where there have been shellfish imports.

Monitoring method: Intertidal surveys, examination of importations of oysters and should include examination of vacant shells and floors of trucks involved in consignments coming from northern Europe. Traps may also be used. Young fish surveys in shallow water may encounter specimens.

Field characteristics: most usually 10 to 25mm carapace width but up to 60mm. The carapace is rounded and lacks frontal spines between the eyes. There are three distinct spines behind each eye. The underside of the body is white. There is a hairy tuft on each chela. The crab is aggressive and occurs on rocky to muddy bottoms, especially in sheltered areas, and can occur in salinities from 10 psu to marine conditions. Very often may be found beneath stone and boulder spaces. Specimens < 8mm are difficult to identify between the two *Hemigrapsus* species in the field. Habitats occupied are often those where *H. takanoi* may also be found. Genetic methods may be needed to distinguish *H. penicillatus* from its sibling species *H. takanoi*. These two species were distinguished from each other for the first time in 2005. Previous records to 2005 in Europe were recorded as *H. penicillatus*.

References:

Asakura A, Watanabe S (2005) *Hemigrapsus takanoi*, new species, a sibling species of the common Japanese intertidal crab *H. penicillatus* (Decapoda: Brachyura: Grapsoidea). *Journal of Crustacean Biology,* 25: 279–292.

Dauvin JC (2009) Asian shore crab *Hemigrapsus* spp. (Crustacea: Brachyura: Grapsoidea) continue their invasion around the Cotentin Peninsula, Normandy, France: status of the *Hemigrapsus* population in 2009*. Aquatic Invasions,* 4: 605– 611.

Dauvin JC, Tous Rius A, Ruellet T (2009) Recent expansion of two invasive crabs species *Hemigrapsus sanguineus* (De Haan, 1853) and *H. takanoi* Asakura an Watanabe, 2005 along the Opal coast, France. *Aquatic Invasions,* 4: 451–465.

Dauvin JC, Delhay JB (2010) First record of *Hemigrapsus takanoi* (Crustacea: Decapoda: Grapsidae) on the western coast of northern Cotentin, Normandy, western English Channel. *Marine Biodiversity Records,* 3: e101.

Gollasch S (1999) The Asian decapod *Hemigrapsus penicillatus* (de Haan, 1835) (Grapsidae, Decapoda) introduced in European waters: status quo and future perspective. *Helgoländer Meeresuntersuchungen,* 52: 359-366.

Jensen GC, McDonald PS, Armstrong DA (2002) East meets west: competitive interactions between green crab *Carcinus maenas,* and native and introduced shore crab *Hemigrapsus* spp. *Marine Ecology Progress Series,* 225: 251–262.

Landschoff J, Lackschewitz D, Kesy K, Reise K (2013) Globlisation pressure and habitat change: Pacific rocky shore crabs invade armoured shorelines in the Atlantic Wadden Sea. *Aquatic Invasions,* 8(1): 77-87.

Noël P, Tardy E, d'Udekem d'Acoz C (1997) Will the crab *Hemigrapsus penicillatus* invade the coasts of Europe? *Comptes Rendus de l'Académie des Sciences. Série 3, Sciences de la vie,* 320: 741–745.

Obert B, Herlyn M, Grotjahn M (2007) First records of two crabs from the North West Pacific *Hemigrapsus sanguineus* and *H. takanoi* at the coast of Lower Saxony, Germany. *Wadden Sea Newsletter,* 2007-1: 21–22.

19. *Heterosigma akashiwo* (Y.Hada) Y.Hada ex Y.Hara & M.Chihara.

Previously known as 'flagellate x'

Chromista, Raphidophyceae, Chattonellaecae

Current status: Cryptogen, widely distributed world-wide and may be cosmopolitan.

Native range: unknown, however sablefish in the North Pacific are immune to blooms of this species, this may be an adaption to the toxins produced and so it may be originally from this region. Genetic analysis of separate worldwide populations suggest a conformity of Pacific and Atlantic populations. The arrival to the Atlantic may be as a result of a historical natural spread or an introduction by humans.

Established in Ireland: Known bloom events in Ireland.

First record: In Ardbear Lough, Co Galway in the 1980s as 'flagellate x' which may have been *H. akashiwo*. Subsequently recorded from Mulroy Bay and from the south coast of Ireland. In Europe it was first recognised as *H. akashiwo* in Spanish rias in 1982 and was thought at the time to have been introduced. However, blooms of 'Flagellate x' had been recorded earlier in the Oslofjord in 1964.

Pathway: not known.

Level of certainty of pathway: unknown.

Further spread: The species forms cysts which may be spread in ballast sediments, dredge spoil or with shellfish movements or the flagellate stage may be spread by natural means with coastal currents.

Probability of further spread in Ireland: High

Known occurrence: known from the coasts of Ireland, Scotland, Sweden, Norway, Shetlands, Iceland, Portugal, France, Spain, Japan, Hong Kong, Australia and New Zealand, the United States, Canada, Chile, The Netherlands.

Impact: produces an ichthyotoxin responsible for causing fish kills of caged salmon during bloom events. A brevetoxin is produced during such events. Events frequently occur at sites where fish are cultivated but it is unknown whether there is a cause-and-effect of this relationship.

Expected: most probably during summer periods in shallow bays; but blooms elsewhere about the world are known at temperatures from 1°C to 30°C.

Monitoring localities: 'Post-border'.

Monitoring method: Specialist knowledge required and microscopic examination.

Field characteristics: Red-brown colour in shallow water might relate to an occurrence of this species. Cysts require temperatures of ~15°C in order to germinate in areas where there is a relatively high salinity and influenced by runoff. Motile cells are small 18µm to 34µm in diameter. The species forms rare sporadic bloom events.

References

Doyle J, Parker M, Dunne T, Baird D, McArdle J (1984) The impact of blooms on mariculture in Ireland. *ICES (Copenhagen), Special Meeting* CM/D8, 14 pp.

Dunne T (1984) Observations on a bloom of flagellate "X" in the west of Ireland. *ICES (Copenhagen), special meeting* CM/D12Haque SM, Onoue Y (2002) Effects of salinity on growth and toxin production of a noxious phytoflagellate, *Heterosigma akashiwo* (Raphidophyceae). *Botanica Marina,* 45: 356-363.

Hara Y, Chihara M (1987) Morphology, ultrastructure and taxonomy or the Raphidophycean alga *Heterosigma akashiwo*. *Botanical Magazine, Tokyo,* 100: 151-163.

Hennige SJ, Coyne KJ, MacIntyre H, Liefer J, Warner ME (2013) The photobiology of *Heterosigma akashiwo*. Photoacclimation, diurnal periodicity, and its ability to rapidly exploit exposure to high light. *Journal of Phycology,* 49(2): 349-360.

Khan S, Arakawa O, Onoue Y (1997) Neurotoxins in a toxic red tide of *Heterosigma akashiwo* (Raphidophyceae) in Kagoshima Bay, Japan. *Aquaculture Research,* 28: 9–14.

Pybus C, McGrath D (1992) Large scale *Phaeocystis* blooms off the west coast of Ireland in 1990. *Irish Fishery Investigations, Series B* No 39 13pp.

Silke J, Jackson D (1993) Harmful and nuisance algal blooms in Irish coastal waters 1990-1993. *ICES Biological Oceanographic Committee* CM (1993) L31. 11 pp.

Strom SL, Harvey EL, Fredrickson KA, Menden-Deuer Sm (2013) Broad salinity tolerances as a refuge from predation in the harmful raphidophyte alga *Heterosigma akashiwo* (Raphidophyceae). *Journal of Phycology,* 49(1): 20-31.

Watanabe M, Kohata K, Kunugi M (1988) Phosphate accumulation and metabolism by *Heterosigma akashiwo* (Raphidophyceae) during diel vertical migration in a stratified microcosm. *Journal of Phycology,* 24: 22-28.

20: Infectious haematopoietic necrosis virus (IHN)

Novirhabdoviridae/Rhabdoviridae,

Current status: NIS, Virus, no known records in Ireland.

Native range: north-eastern Pacific Ocean.

Established in Ireland: not known in Ireland.

First record: It was first described from North America in 1950. It was recorded in Germany in 1982 and Italy and France in 1987.

Pathway: The European events are due to introductions from the NW coast of North America. The movement of stock fishes within freshwater or marine conditions is with a horizontal transmission of the virus arising from direct contact, or by the virus being released from infected fish. This takes place normally within the temperature range of 8º to 15º C. Downstream transmission is known to be capable of infesting farms to 10 km away with infestation taking between two to six weeks following an upstream event.

Level of certainty of pathway: Direct evidence.

Further spread: It is possible that the virus may become spread with consignments of fish or of water carried by vivier trucks.

Probability of spread to Ireland: Moderate risk.

Known occurrence: No recent events caused by this virus in Europe are known.

Not known in: Britain or Ireland.

Impact: Salmonids from the fry stage to the adult are susceptible with > 90% losses of stock in severe outbreaks. There are accounts of the disease occurring in young pike. Outbreaks may last up to twenty-two weeks; but peak over a six to eight week period. Older fish may act as carriers and infect smolts that are introduced to the same water body. Atlantic salmon are particularly susceptible to the disease. Infection takes place at the base of the fins. The virus is spread in faeces, urine, and mucus and with direct contact.

Expected: With increased bio-security of fish movements the spread of the virus might be controlled. The virus occurs in water and may be spread with transmitted water or with infested migrating salmon.

Monitoring localities: Possibly at the 'border', more likely to be post-border. Freshwater salmonid hatcheries, freshwater pens and marine cage rearing sites.

Monitoring method: Specialist veterinarian knowledge.

Field characteristics: Infected fish are normally lethargic with highly active bouts of activity, the skin and gills may be darker than normal. Fish may have protruding eyes and a swollen abdomen. The liver, spleen and kidney are pale in colour.

References:

Anderson ED, Engelking HM, Emmenegger EJ, Kurath G (2000). Molecular epidemiology reveals emergence of a virulent IHN Virus strain in wild salmon and transmission to hatchery fish. *Journal of Aquatic Animal Health,* 12, 85–99.

Armstrong R, Robinson JR, Rymes C, Needham T (1993) Infectious hematopoietic necrosis virus in Atlantic salmon in British Columbia. *Canadian Veterinarian Journal,* 34:312–313.

Baudin-Laurencin F (1987) IHN in France. *Bulletin of the European Association of Fish Pathologists,* 7:104.

Bovo G, Giorgetti G, Jorgensen PEV, Olesen NJ (1987) Infectious haematopoietic necrosis. *Bulletin of the European Association of Fish Pathologists,* 7(5): 124.

Enzmann PJ, Dangschat H, Feneis B, Schmitt D, Wizigmann G, Schlotfeldt HJ (1992) Demonstration of IHN virus in Germany. *Bulletin of the European Association of Fish Pathologists,* 12:185–188.

Enzmann P-J, Kurath G, Fichtner D, Bergmann SM (2005) Infectious hematopoietic necrosis virus: monophyletic origin of European isolates from North American geno-group M. *Diseases of Aquatic Organisms,* 66:187-195.

Kocan R, Bradley M, Elder N, Meyers T, Bratts W, Winton J (1997) North American strain of viral haemorrhagic septicaemia virus is highly pathogenic for laboratory-reared Pacific herring. *Journal of Aquatic Animal Health,* 9: 279–290.

Sano T, Nishimura T, Okamoto N, Yamazaki T, Hanada H, Watanabe Y (1977). Studies on viral diseases of Japanese fish. VI. Infectious hematopoietic necrosis (IHN) of salmonids in the mainland of Japan. *Journal of the Tokyo University of Fisheries,* 63: 81–85.

St-Hilaire S, Ribble CS, LaPatra SE, Chartrand S, Kent ML (2001) Infectious hematopoietic necrosis virus antibody profiles in naturally and experimentally infected Atlantic salmon *Salmo salar*. *Diseases of Aquatic Organisms,* 46:7–14.

St-Hilaire S, Ribble CS, Stephen C, Anderson E, Kurath G, Kent ML (2002) Epidemiological investigation of infectious hematopoietic necrosis virus in salt water net-pen reared Atlantic salmon in British Columbia Canada. *Aquaculture,* 212: 49–67.

Traxler GS, Roome JR, Kent ML (1993) Transmission of infectious hematopoietic necrosis virus in seawater. *Diseases of Aquatic Organisms,* 16:111–114.

21: Infectious salmon anaemia (ISA) virus

Orthmyoxoviridae

Current status: Cryptogen, once present in Ireland.
Native range: unknown.
Established in Ireland: Only known to occur in farmed salmonids and Ireland was declared free of ISA in 2009.
First record: 2002, west coast of Ireland in rainbow trout.
Pathway: transmission of the virus is not known.
Level of certainty of pathway: no clear evidence for transmission.
Further spread: Not all of the pathways for the spread of the virus are known and other forms of transmission may take place. Improved bio-security measures will reduce the risk of further events.
Level of confidence: Possible.
Probability of further spread to Ireland: High.
Known occurrence: Recorded in Norway in 1984 and has spread to Scotland and then Ireland and the Faroe Islands. It is also known in Canada, USA and Chile.
Not known in: Continental Atlantic Europe
Impact: The virus affects the circulatory system and cause internal haemorrhaging that can result in high mortalities with the loss of the majority of the cultivated salmon. The virus is shed in the mucus, faeces and urine and via the skin and enters other salmonids via the gills or broken skin and transmission may be with crustacean ecto-parasites.
Expected: It is possible that further infestations may occur in the future.
Monitoring localities: Most probably post-border. Atlantic salmon farms in the sea where smolts from infected might become introduced. Trout and other salmonids can act as carriers for the disease. A surveillance program already exists, managed by the Marine Institute.
Monitoring method: Specialist veterinarian knowledge
Field characteristics: fish behave lethargically and swim near the surface, often vertically when gasping, and are reluctant to feed. Symptoms include a distended abdomen, protruding bloodshot eyes and pale swollen gills. Symptoms normally develop slowly.
References:

Cunningham CO, Snow M (2000) Genetic analysis of infectious salmon anaemia virus (ISAV) from Scotland. *Diseases of Aquatic Organisms,* 41:1–8.

Cunningham CO, Gregory A, Black J, Simpson I, Raynard, RS (2002) A novel variant of the infectious salmon anaemia virus (ISAV) haemagglutinin gene suggests mechanisms for virus diversity. *Bulletin of the European Association of Fish Pathologists,* 22:366–374.

Devold M, Krossøy B, Aspehaug V, Nylund A (2000) Use of RT–PCR for diagnosis of infectious salmon anaemia virus (ISAV) in carrier sea trout *Salmo trutta* after experimental infection. *Diseases of Aquatic Organisms,* 40: 9–18.

Hovland T, Nylund A, Watanabe K, Endresen C (1994) Observation of infectious salmon anaemia virus (ISAV) in Atlantic salmon *(Salmo salar* L.). *Journal of Fish Diseases,* 17: 291–296.

Inglis JA, Bruce J, Cunningham CO (2000) Nucleotide sequence variation in isolates of infectious salmon anaemia virus (ISAV) from Atlantic salmon *Salmo salar* in Scotland and Norway. *Diseases of Aquatic Organisms,* 43: 71–76.

Jones SRM, Groman DB (2001) Cohabitation transmission of infectious salmon anaemia virus among freshwater-reared Atlantic salmon. *Journal of Aquatic Animal Health*, 13: 340–346.

Jones SRM, MacKinnon AM, Salonius K (1999) Vaccination of freshwater-reared Atlantic salmon reduces mortality associated with infectious salmon anaemia virus. *Bulletin of the European Association of Fish Pathologists,* 19: 98–101.

Krossøy B, Nilsen F, Falk K, Endresen C, Nylund A (2001) Phylogenetic analysis of infectious salmon anaemia virus isolates from Norway, Canada and Scotland. *Diseases of Aquatic Organisms,* 44: 1–6.

Melville KJ, Griffiths SG (1999) Absence of vertical transmission of infectious salmon anaemia virus (ISAV) from individually infected Atlantic salmon *Salmo salar*. *Diseases of Aquatic Organisms,* 38: 231–234.

Nylund A, Wallace C, Hovland T (1993) The possible role of *Lepeophtheirus salmonis* in the transmission of infectious salmon anaemia. In: Boxshall G (ed) *Pathogens of wild and farmed fish: sea lice*. Ellis Horwood, Chichester, p 367–373.

Nylund A, Kvenseth AM, Krossøy B (1995) Suceptibility of wild salmon *(Salmo salar* L.) to infectious salmon anaemia (ISA). *Bulletin of the European Association of Fish Pathologists,* 15 (5): 152–156.

Nylund A, Kvenseth AM, Krossøy B, Hodneland, K (1997) Rainbow trout *(Onchorhynchus mykiss*, Walbaum, 1792): a carrier of infectious salmon anaemia (ISAV). *Journal of Fish Diseases,* 20: 275–279.

Plarre, H, Devold, M, Snow, M, Nylund, A (2005) Prevalence of infectious salmon anaemia virus (ISAV) in wild salmonids in western Norway. *Diseases of Aquatic Organisms,* 66: 71-79.

Raynard RS, Murray AG, Gregory A (2001) Infectious salmon anaemia virus in wild fish from Scotland. *Diseases of Aquatic Organisms,* 46: 93–100.

Rodger HD, Turnbull T, Muir F, Millar S, Richards RH (1998) Infectious salmon anaemia (ISA) in the United Kingdom. *Bulletin of the European Association of Fish Pathologists,* 18: 115–116.

Rolland JB, Nylund A (1998) Sea running trout: carrier and transmitter of the infectious salmon anaemia virus (ISAV). *Bulletin of the European Association of Fish Pathologists,* 18: 50–55.

Totland GK, Hjeltnes BK, Flood PR (1996) transmission of infectious salmon anaemia (ISA) through natural secretions and excretions from infected smolts of Atlantic salmon *Salmo salar* during their pre-symptomatic phase. *Diseases of Aquatic Organisms,* 26: 25–31.

22: *Marenzellaria viridis* (Verrill, 1873). Red-gilled mud-worm

Spionidae, Polychaeta, Annelida

Current status: NIS, might be present in Ireland.

Native range: eastern coast of North America.

Established in Ireland: unknown, but might be present in the Shannon Estuary.

First record: An immature worm was found in the Shannon Estuary; but identification to species was not possible. The first record in Europe was from the Firth of Forth Estuary, Scotland in 1982. Elsewhere it was first found in northern Europe the Szczecin Lagoon (German side) in 1985. Distinction between species of *Marenzellaria* is difficult. In the Baltic Sea three species of *Marenzellaria* are known.

Pathway: most probably with shipping in ballast water.

Level of certainty of pathway: Very likely.

Further spread: Should the species be established it may be expected to occur over a wide area.

Probability of spread to Ireland: High, might already be present.

Known occurrence: The species occurs in the Baltic Sea and the North Sea in Germany, Sweden, Norway, Denmark, The Netherlands, Belgium and in Britain.

Not known in: the Irish Sea

Impact: The depth of bioturbation is greater than many other

Expected: The species may already be present in Ireland in the Shannon Estuary. Specimens would need to be distinguished from *M. wireni*.

Monitoring localities: Post-border. Muddy estuaries with mud flats in Ireland; but known elsewhere to also occur in shallow sandy bays.

Monitoring method: cores are needed to obtain adults as these may exist 40cm below the mud surface with immature specimens occurring closer to the mud surface and these may be captured in grabs. Worms have a small pore on the mud surface indicating their presence. Worms are fragile and easily break into sections. Plankton nets could be used for collecting specimens at night when they may leave their burrows.

Field characteristics: Differentiating between species requires expert knowledge. Specimens may be up to 115mm with a long slender body with >200 segments.

References:

Atkins SM, Jones AM, Garwood PR (1987) The ecology and reproductive cycle of a population of *Marenzelleria viridis* (Annelida: Polychaeta: Spionidae) in the Tay Estuary. *Proceedings of the Royal Society of Edinburgh,* 92B: 311-322.

Bick A (2005) A new Spionidae (Polychaeta) from North Carolina, and a redescription of *Marenzelleria wireni* Augener, 1913, from Spitsbergen, with a key for all species of *Marenzelleria*. *Helgoland Marine Research,* 59(4): 265-272.

Blank M, Bastrop R, Röhner M, Jürss K (2004) Effect of salinity on spatial distribution and cell volume regulation in two sibling species of *Marenzelleria* (Polychaeta: Spionidae). *Marine Ecology Progress Series,* 271: 193-205.

Bochert R (1997) *Marenzelleria viridis* (Polychaeta: Spionidae): a review of its reproduction. *Aquatic Ecology,* 31: 163-175.

Bochert R Fritzsche D, Burckhardt R (1996) Influence of salinity and temperature on growth and survival of the planktonic larvae of *Marenzelleria viridis* (Polychaeta, Spionidae). *Journal of Plankton Research,* 18(7): 1239-1251.

Bochert R, Zettler ML, Bochert A (1996) Variation in the reproductive status, larval occurrence and recruitment in an estuarine population of *Marenzelleria viridis* (Polychaeta: Spionidae). *Ophelia,* 45: 127–142.

Dauer DM, Ewing RM, Tourtellotte GH, Baker HR Jr (1980) Nocturnal swimming of *Scolecolepides viridis* (Polychaeta: Spionidae). *Estuaries,* 3: 148–149.

Essink K, Kleef HL (1993) Distribution and life cycle of the North American spionid polychaete *Marenzelleria viridis* (Verrill, 1873) in the Ems estuary. *Netherlands Journal of Aquatic Ecology,* 27(2-4): 237-246.

Hietanen S, Laine AO, Lukkari K (2007) The complex effects of the invasive polychaetes *Marenzelleria* spp. on benthic nutrient dynamics. *Journal of Experimental Marine Biology and Ecology,* 353: 89-102.

McLusky DS, Hull SC, Elliott M (1993) Variations in the intertidal and subtidal macrofauna and sediments along a salinity gradient in the upper Forth Estuary. *Netherlands Journal of Aquatic Ecology,* 27: 101–109

Norkko A, Bonsdorff E, Boström C (1993) Observations of the polychaete *Marenzelleria viridis* (Verill) on a shallow sandy bottom on the South coast of Finland. *Memoirs of the Society Fauna Flora Fennica,* 69: 112–113.

Zettler M. 1997. Bibliography on the genus *Marenzelleria* and its geographical distribution, principal topics and nomenclature. *Aquatic Ecology,* 31: 233-258.

23: *Marteilia refringens* Grizel, Bonami, Cousserans, Duthoit & Le Pennec, 1974. Aber disease

Marteiliidae, Ascetosporea, Cercozoa

Current status: NIS, not known in Ireland.

Native range: Not known but may be Mediterranean Sea.

Established in Ireland: not known in Ireland.

First record: not recorded in Ireland.

Pathway: The infestations most probably arose from stock movements of shellfish. Its occurrence in mussels could enable spread with hull fouling on vessels. Mussels are one of the most abundant fouling organisms on ship, barges and recreational craft hulls.

Level of certainty of pathway: stock movement transmissions are very likely.

Further spread: With climate warming sea temperatures may be expected to rise about the coast and such conditions may trigger an event when combined with an inoculation. Direct transmission between oysters is not known to take place and it is speculated that this species has a complex life history. Studies in ponds indicated that a copepod *Paracartia grani* may be a potential intermediate host for the parasite which occurs in the spring and summer and is commonly found in estuaries with transmissions taking place in summertime.

Probability of spread to Ireland: Moderate risk.

Known occurrence: marteiliosis is known to occur in *Ostrea edulis*, *Mytilus edulis* and *M. galloprovincialis*. It is known in Europe from north-west Brittany and the Bay of Biscay in France, the Atlantic coast of Spain and in the Adriatic Sea in Italy and Croatia and in Morocco in North Africa. It has been reported on one occasion from the Netherlands from near Yeseke where the oysters were either harvested or otherwise destroyed.

Not known in: Britain.

Impact: Has caused mass mortalities in the native oyster in Europe since it first became recognised in the 1960s. It is of concern for molluscan aquaculture as outbreaks significantly affect production.

Expected: The distribution of the copepod *Paracartia grani*, which in Mediterranean waters can be locally very abundant, would appear to be one of the pre-requirements for the disease to become present in Irish waters. With changes in its abundance, perhaps pole-wards in the future, may place Ireland at risk. *P. grani* is known to occur from the Mediterranean Sea to the Norwegian coast.

Monitoring localities: Possibly pre-border and at the border, otherwise post-border. In areas where the native oyster and mussels are present with events most likely to take place once the sea-water temperatures exceed 17º C.

Monitoring method: Specialist veterinarian knowledge and plankton studies for *Paracartia grani* which may herald the potential for an infection.

Field characteristics: Infections are associated with a poor condition index with discolouration of the digestive gland with lesions appearing on the gills, the mantle surface and the digestive gland.

References:

Alderman DJ (1979) Epizootiology of *Marteilia refringens* in Europe. *Marine Fisheries Review*, 41: 67-69.

Balouet G (1979) *Marteilia refringens* - Considerations of the life cycle and development of Aber disease in *Ostrea edulis*. *Marine Fisheries Review*, 41: 64-66.

Baseiro P, Montes A, Ceschia G, Gestal C, Novoa B, Figueras A (2007) Molecular epizootiology of the European *Marteilia* spp., infecting mussels (*Mytilus galloprovincialis* and *M. edulis*) and oysters (*Ostrea edulis*): and update. *Bulletin of the European Association of Fish Pathologists*, 27(4): 148-156.

Berthe FCJ, Le Roux F, Adlard RD, Figueras A (2004) Marteiliosis in molluscs: a review. *Aquatic Living Resources,* 17: 433-448.

Comps M (1970) Observations sur les causes d'une mortalité anormale des huîtres plates (*Ostrea edulis* L.) dans le bassin de Marennes. *Revue des Travaux de 'Institut Pêches Maritimes*, 34: 317-326.

Comps M, Joly JP (1980). Contamination expérimentale de *Mytilus galloprovincialis* Lamark par *Marteilia refringens*. *Science et Pêche,* 301: 19-21.

Fuentes J, Villalba A, Zapata C, Alvarez G (1995) Effects of stock and culture environment on infections by *Marteilia refringens* and *Myticola intestinalis* in the mussel *Mytilus galloprovincialis* cultured in Galicia (NW Spain). *Diseases of Aquatic Organisms*, 21: 221-226.

Le Roux F, Lorenzo G, Peyret P, Audemard C, Figueras A, Vivares C, Gouy M & Berthe F (2001). Molecular evidence for yhe existence of two species of *Marteilia* in Europe. *The Journal of Eukaryotic Microbiology,* 48: 449-454.

Longshaw M, Feist SW, Matthews RA & Figueras A (2001). Ultrastructural characterisation of *Marteilia* species (Paramyxea) from *Ostrea edulis*, *Mytilus edulis* and *Mytilus galloprovincialis* in Europe. *Diseases of Aquatic Organisms,* 44: 137-142.

López-Flores I, de la Herrán R, Garrido- Ramos MA, Navas JI, Ruiz-Rejón C, Ruiz-Rejón M (2004). The molecular diagnosis of *Marteilia refringens* and differentiation between *Marteilia* strains infecting oysters and mussels based on the rDNA IGS sequence. *Parasitology,* 129: 411-419.

Robledo JAF, Caceres-Martinez J, Figueras A (1994) *Marteilia refringens* in mussel (*Mytilus galloprovincialis* Lamark) beds in Spain. *Bulletin of the European Association of Fish Pathologists*, 14: 61-63.

Robledo JA, Figueras A (1995). The effects of culture-site, depth, season, and stock source on the prevalence of *Marteilia refringens* in cultured mussels (*Mytilus galloprovincialis* Lamark) from Galicia, Spain. *The Journal of Parasitology,* 81: 354-363.

Villalba A, Mourelle SG, Carballal MJ, Lopez MC (1993) Effects of infection by the protistan parasite *Marteilia refringens* on the reproduction of cultured mussels *Mytilus galloprovincialis* in Galicia (NW Spain). *Diseases of Aquatic Organisms*, 17: 205-213.

24: *Mnemiopsis leidyi* A. Agassiz, 1865. American comb jelly

Bolinopsidae, Tentaculata, Ctenophora

Current status: NIS, not known in Ireland**.**

Native range: eastern coasts of North and South America.

Established in Ireland: not known in Ireland.

First record: Appeared in the Black Sea in the early 1980s and from there to the Caspian Sea. Genetic evidence suggests an origin from the Gulf of Mexico. The populations in the western Baltic Sea in 2005, then found the German part of the North Sea in the autumn of 2006, was probably derived from the New England coast of North America.

Pathway: It has an entirely pelagic life history and as a result its dispersal by ballast water seems a rational mode of transmission and could explain the large distances that have been involved in its spread and its occurrence in the Caspian Sea following the opening up of a common canal.

Level of certainty of pathway: Very likely.

Further spread: Its continued spread to the Celtic seas can be expected as a result of natural dispersal or arising from a ballast water transmission.

Probability of spread to Ireland: High.

Known occurrence: known close inshore along the French coast in the English Channel as far west as the Cotentin Peninsula in 2011 and is the nearest site known to Ireland.

Not known in: Britain.

Impact: It is a zooplankton predator that has been responsible for serious declines in fisheries by feeding on fish eggs and larvae and other zooplankton species.

Expected: in Ireland as a result of natural drift or from ballast water discharges.

Monitoring localities: Post-border. Offshore to estuaries on all coasts and near ports. The species can tolerate salinities of 2 to 39 psu, with optimal salinities at 25+ psu.

Monitoring method: direct observation and plankton sampling. Specimens are fragile and may break-up on collection. Oblique tows using a cone-net with a 200µm mesh have been successfully used. Specimens can be preserved in Lugol's iodine solution. Ctenophores are not easily determined to species and this will have already caused some confusion as specimens of *M. leidyi* in the Baltic were later found to be that of an Arctic ctenophore *Mertensia ovum*.

Field characteristics: Can attain 100mm in overall length and has a laterally compressed body with large lobes arising from the stomodeum with four deep furrows typical of this genus. It has four bands of ciliated combs producing iridescent colours and a transparent or milky-grey body.

References:

Boersma M, Malzahn AM, Greve W, Javidpour J (2007) The first occurrence of the ctenophore *Mnemiopsis leidyi* in the North Sea. *Helgoland Marine Research,* 61: 153–155.

Bolte S, Fuentes V, Haslob H, Huwer B, Thibault-Botha D, Angel D, Galil B, Javidpour J, Moss AG, Reusch TBH (2013) Population genetics of the invasive ctenophore *Mnemiopsis leidyi* in Europe reveal source-sink dynamics and secondary dispersal to the Mediterranean Sea. *Marine Ecology Progress Series,* 485: 25–36.

Engell-Sørensen K, Andersen P, Holmstrup M (2009) Preservation of the invasive ctenophore *Mnemiopsis leidyi* using acidic Lugol's solution. *Journal of Plankton Research,* 31: 917–920.

Faasse MA, Bayha KM (2006) The ctenophore *Mnemiopsis leidyi* A. Agassiz 1865 in coastal waters of the Netherlands: an unrecognized invasion? *Aquatic Invasions,* 1: 270–277.

Fuentes VL, Angel DL, Bayha KM, Atienza D, Edelist D, Bordehore C, Gili JM, Purcell JE (2010) Blooms of the invasive ctenophore, *Mnemiopsis leidyi*, span the Mediterranean Sea in 2009. *Hydrobiologia,* 645: 23–37.

Ghabooli S, Shiganova TA, Zhan A, Cristescu MC, Eghtesadi- Araghi P, MacIsaac HJ (2011) Multiple introductions and invasion pathways for the invasive ctenophore *Mnemiopsis leidyi* in Eurasia. *Biological Invasions,* 13: 679–690.

Hamer HH, Malzahn AM, Boersma M (2011) The invasive ctenophore *Mnemiopsis leidyi*: a threat to fish recruitment in the North Sea? *Journal of Plankton Research,* 33: 137.

Hosia A, Titelman J, Hansson LJ, Haraldsson M (2011) Interactions between native and alien ctenophores: *Beroe gracilis* and *Mnemiopsis leidyi* in Gullmarsfjorden. *Marine Ecology Progress Series,* 422: 129–138.

GESAMP, 1997. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Opportunistic settlers and the problem of the ctenophore *Mnemiopsis leidyi* invasion in the Black Sea. *Reports of Studies GESAMP*, 58: 84pp.

Lehmann A, Javidpour J (2010) Potential pathways of invasion and dispersal of *Mnemiopsis leidyi* A. Agassiz 1865 in the Baltic Sea. *Hydrobiologia,* 649: 107–114.

Reusch TBH, Bolte S, Sparwel M, Moss AG, Javidpour J (2010) Microsatellites reveal origin and genetic diversity of Eurasian invasions by one of the world's most notorious marine invader, *Mnemiopsis leidyi* (Ctenophora). *Molecular Ecology,* 19: 2690–2699.

Roohi A, Kideys AE, Sajjadi A, Hashemian A, Pourgholam R, Fazli H, Khanari AG, Eker-Develi E (2010) Changes in biodiversity of phytoplankton, zooplankton, fishes and macrobenthos in the Southern Caspian Sea after the invasion of the ctenophore *Mnemiopsis leidyi. Biological Invasions,* 12: 2343–2361.

Schaber M, Haslob H, Huwer B, Harjes A, Hinrichsen HH, Koster FW, Storr-Paulsen M, Schmidt JO, Voss R (2011) The invasive ctenophore *Mnemiopsis leidyi* in the central Baltic Sea: seasonal phenology and hydrographic influence on spatio-temporal distribution patterns. *Journal of Plankton Research,* 33: 1053–1065.

Van Ginderdeuren K, Hostens K, Hoffman S, Vansteenbrugge L, Soenen K, De Blauwe H, Robbens J, Vincx M (2012) Distribution of the invasive ctenophore *Mnemiopsis leidyi* in the Belgian part of the North Sea. *Aquatic Invasions,* 7: 163– 169.

25: *Neogobius melanostomus* (Pallas, 1814). Round goby

Gobiidae, Pisces, Chordata

Current status: NIS, not known in Ireland

Native range: This is a Ponto-caspian species that occurs in the shallows of the Black, Caspian seas and the Marmara Sea and the Sea of Azov.

Established in Ireland: not known in Ireland.

First record: The first record in northern European seas was from the Gulf of Gdansk in 1990 and this spread then to the Vistula Lagoon in 1999. Since then the species has spread within the Baltic Sea to Estonia and to the North Sea to The Netherlands and Belgium.

Pathway: Considered to have arrived in Belgium in ballast water.

Level of certainty of pathway: Possible, but might also have been a transmission on the hulls of vessels as laid eggs which adhere to the hull of a vessel. Since fish lay eggs in cryptic habitats the sea-chest might provide a site for their nesting behaviour.

Further spread: This fish has spread to Eastern Europe via the Danube River and its connections via canals to the Baltic Sea; and thereafter as a result of natural spread and most probably shipping to account for the isolated populations that will have arisen. Its occurrence in North America in the Great lakes is thought to be due to an introduction via ballast water. It has recently spread to the Croatian coast in the Mediterranean Sea.

Probability of spread to Ireland: Moderate risk.

Known occurrence: Baltic States in the southern Baltic Sea and to Germany, Belgium and the The Netherlands in Northern Europe.

Not known in: Britain.

Impact: Native fishes have declined in abundance where this goby species occurs and it is known to feed on trout eggs and fry of trout and other fishes. Adults aggressively defend their own sites and so may exclude other species. It will feed upon zebra mussels but also on native blue mussels. The abundance of zebra mussels in Irish lake ecosystems is likely to result in a rapid expansion of the round goby following an arrival.

Expected: in Ireland as a result of shipping to a brackish or freshwater port.

Monitoring localities: At border in aquarium consignments is possible, otherwise post border. Gobies occur in salinities <20 psu, as a result it will be the estuaries and rivers that are likely to be colonised. The species is then likely to progress through the river catchments linked by canals. It has a preference to feed on mussels and so might be expected near where these can be found.

Monitoring method: Traps and intertidal surveys. Fish may be collected on rotating screens or eel nets. Capture in estuarine areas in young fish surveys may also reveal the species.

Field characteristics: Attains 9 to 25cm in males depending on the locality. There is a large black spot on the posterior part of the dorsal fin often surrounded by a white ‘ring’ with yellow-grey bodies but males are black when breeding with white to whitish-blue edge to the caudal fin. The number of fin rays and scale counts are needed for confirmation.

References:

Charlebois PM, Marsden JE, Goettel RG, Wolfe RK, Jude DJ, S. Rudnicka S (1997) The round goby, *Neogobius melanostomus* (Pallas), a review of European and North American literature. *Illinois-Indiana Sea Grant Program and Illinois Natural History Survey. INHS Special Publication* No. 20. 76 pp.

Corkum LD, Sapota MR, Skóra KE (2004) The round goby, *Neogobius melanostomus*, a fish invader on both sides of the Atlantic Ocean, *Biological Invasions,* 6: 173-181.

Kalchhauser I, Mutzner P, Hirsch PE, Burkhardt-Holm P (2013) Arrival of round goby *Neogobius melanostomus* (Pallas,1814) and bighead goby *Ponticola kessleri* (Günther, 1861) in the high Rhine (Switzerland). *BioInvasions Records,* 2:79–83.

Miller PJ (1986) Gobiidae in: Whitehead P.J.P, Bauchot M.L., Hureau J.C., Nielsen J. & E. Tortonese (eds.), *Fishes of the northeast Atlantic and Mediterranean*. UNESCO, Paris: 1019-1095.

Mombaerts M, Verreycken H, Volckaert FAM, Huyse T (2014) The invasive round goby *Neogobus melanostomus* and tubenose goby *Proterorhinus semilunaris*: two introduction routes to Belgium. *Aquatic Invasions,* 9(1): 305-314.

Moskalkova KI (1996) Ecological and morphophysiological prerequisites to range extension in the round goby *Neogobius melanostomus* under conditions of anthropogenic pollution. *Journal of Ichthyology*, 36: 584-590.

Sapota MR, Skóra KE (2005) Spreading of alien (non-indigenous) fish species *Neogobius melanostomus* in the Gulf of Gdańsk (South Baltic), *Biological Invasions*, 7:157-164.

Skóra KE, Rzeźnik J (2001) Observations on food composition of *Neogobius melanostomus* Pallas 1811 (Gobiidae, Pisces) within the area of the Gulf of Gdansk (Baltic Sea). *Journal of Great Lakes Research*, 27: 290-299.

van Beek GCW (2006) The round goby *Neogobius melanostomus* first recorded in the Netherlands. *Aquatic Invasions,* 1: 42–43.

Verreycken H, Breine JJ, Snoeks J, Belpaire C (2011) First record of the round goby, *Neogobius melanostomus* (Actinopterygii: Perciformes: Gobiidae) in Belgium. *Acta Ichthyologica et Picatoria,* 41: 137–140.

26: *Ocenebra inornata* (Récluz, 1851). Japanese oyster drill

Muricidae, Gastropoda, Mollusca

Current status: NIS, not known in Ireland.

Native range: NW Pacific, Japan, northern China, Korea to the Sakhalin and Kurile islands.

Established in Ireland: No known records in Ireland.

First record: No records for Ireland.

Pathway: Potentially may be spread with shellfish consignments such as half-grown Pacific oyster imports. The arrival in the Netherlands and Denmark is almost certainly arising from contaminated imported consignments. Genetic evidence suggest the origin of the French snails is from the NE Pacific and may have arrived with known consignments of Pacific oysters from British Columbia in 1971-1975.

Level of certainty of pathway: Very likely.

Further spread: Recently will have appeared on the south-west coast of Portugal with movements of shellfish consignments.

Probability of spread to Ireland: High.

Known occurrence: Was first recorded in Europe in 1995 in the Marrenes-Oleron region of the Atlantic coast of France and then spread to Brittany and Normandy and more recently has been found in The Netherlands in the Oosterschelde and in the south-west region of Portugal.

Not known in: Britain

Impact: This predatory snail bores perfectly circular holes in the shells of oysters and mussels and can result in significant losses, particularly of small oysters. In British Columbia and Washington State the snail is considered to be one of the most serious predators of layings of the imported and now feral Pacific oyster with up to 25% of losses.

Expected: to arrive at sites of oyster cultivation where imports of consignments originate from areas where the snail is present.

Monitoring localities: Examinations pre-border and at the border may reveal egg clusters, juveniles or adults associated with oyster consignments. Otherwise post border. Oyster on-growing sites where there is either trestle and bag cultivation or where there are layings.

Monitoring method: inspections of consignments and intertidal surveys. Since early recruitment is likely to be slow following an arrival and early detection may enable an eradication. Snails predominate between the tidal levels.

Field characteristics: Specimens can attain 50-60mm in shell height. The shell has a flat upper projecting shelf with a deep suture between whorls extending to the spire apex. There may be four to seven flared vertical ridges (costae) occurring irregularly but spaced on the whorls. Although there is great variation in the sculpture of the shell ornament these features may aid in distinguishing it from smaller the native oyster drill *Ocenebra erinacea* which has eight to nine ridges which are generally not as raised. The yellow egg-capsules are flattened and occur in a cluster of 20 to 40 and attach to shells and stones and are easily transported with consignments of oysters. Young crawlers hatch directly from these egg-capsules and so all life history stages should be searched for. Snails prefer to lay the egg capsules on Pacific oyster shells their removal in the late spring and summer is considered the best means of controlling a population.

References:

Alfonso CML (2011) Non-indigenous Japanese oyster drill *Pteropurpura (Ocinebrellus) inornata* (Reclúz, 1851) (Gastropoda: Muricidae) on the south-west coast of Portugal. *Aquatic Invasions,* 6 (Suppl. 1): S85-S88.

Faasse MA, Ligthart AHM (2009) American (*Urosalpinx cinerea*) and Japanese oyster drill (*Ocinebrellus inornatus*) (Gastropoda: Muricidae) flourish near shellfish culture plots in The Netherlands. *Aquatic Invasions,* 4: 321–326.

Lützen J, Faasse M, Gittenberger A, Glenner H, Hoffmann E (2012) The Japanese oyster drill *Ocinebrellus inornatus* (Récluz, 1851) (Mollusca, Gastropoda, Muricidae), introduced to the Limfjord. *Aquatic Invasions,* 7(2): 181-191.

Martel C, Viard F, Bourguet D, Garcia-Meunier P (2004) Invasion by the marine gastropod *Ocinebrellus inornatus* in France. I. Scenario for the source of introduction. *Journal of Experimental Marine Biology and Ecology,* 305(2): 155–170.

Martel C, Viard F, Bourguet D, Garcia-Meunier P (2004) Invasion by the marine gastropod *Ocinebrellus inornatus* in France. II. Expansion along the Atlantic coast. *Marine Ecology Progress Series,* 273: 163–172.

Martel C, Guarini JM, Blanchard G, Sauriau PG, Trichet C, Robert S, Garcia-Meunier P (2004) Invasion by the marine gastropod *Ocinebrellus inornatus* in France. III. Comparison of biological traits with the resident species *Ocenebra erinacea*. *Marine Biology,* 146: 93–102.

Pigeot J, Miramand P, Garcia-Meunier P, Guyot T, Séguignes M (2000) Présence d'un nouveau prédateur de l'huître creuse, *Ocinebrellus inornatus* (Récluz, 1851), dans lebassin conchylicole de Marennes-Oléron. *Comptes Rendus de l'Académie des Sciences de Paris (Ser. 3) Sciences de la Vie/Life Sciences,* 323: 697–703.

27: Ostreid herpesvirus 1-microvariant (OsHV-1 µvar), causing summer mortality syndrome in Pacific oysters

Current status: NIS.

Native range: NW Pacific.

Established in Ireland: in Dungarvan and Bannow bays.

First record: 1993 in Dungarvan Bay and further records in Ireland in 1995, 2003 and 2004.

Pathway: With introduced oysters from France in early 1993.

Level of certainty of pathway: Very likely.

Further spread: with stock movements.

Probability of further spread in Ireland: High.

Known occurrence: Ostreid herpesvirus 1 has been reported from Pacific and native oysters and the manila clam *Ruditapes philippinarum* as well as the native clam *R. decussatus* and the scallop *Pecten maximus*. The microvariant occurs in the Pacific oyster. The virus is spread between oysters and may also affect larvae. The microvariant DNA has been found in the mussel *Mytilus edulis* and in the surf clam *Donax trunculus* but it remains unclear whether these species can act as carriers.

Not known in: Scotland, Northern Ireland or the west coast of Ireland.

Impact: Mass mortalities have been attributed to the OsHV-1 virus in Europe, North Africa, the NW Pacific, Australia and New Zealand. Spat and juveniles may rapidly succumb and die following infection, taking place soon after the warmest part of the year.

Expected: With projected increases in sea-temperatures, in concert with climate warming, further outbreaks in new areas might be expected. However, there is evidence that resistance to the virus may be developing.

Monitoring localities: Post-border. Sites where Pacific oysters are on-grown in mid to late summer following the warmest part of the year once sea-temperatures exceed 18º C. In affected areas in 2003 sea temperatures ranged between 22º and 28º C in the shallows of bays. Handling may increase the levels of mortality at this time.

Monitoring method: Specialist veterinarian knowledge.

Field characteristics: Mortalities that can be extensive in the summer, at a time when in reproductive condition. All ages are affected and mortality events may be associated with neap tides

References:

Arzul I, Renault T, Lipart C, Davison AJ (2001) Evidence for interspecies transmission of oyster herpesvirus in marine bivalves. *Journal of General Virology,* 82: 865-870.

Batista FM, Arzul I, Pepin JF, Ruano F, Freidman C, Boudry P, Renault T (2007) Detection of ostreid herpesvirus-1 DNA in bivalve molluscs: a critical review. *Journal of Virology Methods*, 139 (1), 1–11.

Degremont L (2011) Evidence of herpesvirus (OsHV-1) resistance in juvenile *Crassostrea gigas* selected for high resistance to the summer mortality phenomenon. *Aquaculture*, 317 (1–4): 94–98.

Lynch SA, Carlson J, Reilly AO, Cotter E, Culloty SC (2012) A previously undescribed ostreid herpes virus 1 (OsHV-1) genotype detected in the Pacific oyster, *Crassostrea gigas*, in Ireland. *Parasitology*, 139: 1526- 1532.

Lynch SA, Dillane E, Carlsson J, Culloty SC (2013) Development and Assessment of a Sensitive and Cost-Effective Polymerase Chain Reaction to Detect Ostreid Herpes virus 1 and Variants. *Journal of Shellfish Research*, 32(3): 657-664.

Malham SK, Cotter E, O'Keeffe S, Lynch S, Culloty SC, Latchford JW, Beaumont AR (2009). Summer mortality of the Pacific oyster *Crassostrea gigas* in the Irish Sea: The influence of temperature and nutrients on health and survival. *Aquaculture*, 287: 128-139.

Peeler JE, Reese RA, Cheslett D, Geoghan F, Power A, Trush MA (2012) Investigation of mortality in Pacific oysters associated with Ostreid herpesvirus-1 μVar in the Republic of Ireland in 2009. *Preventive Veterinary Medicine*, 105: 136-143.

Schikorski D, Renault T, Saulnier D, Faury N, Moreau P, Pepin JF (2011) Experimental infection of Pacific oyster *Crassostrea gigas* spat by ostreid herpesvirus 1: demonstration of oyster spat susceptibility. *Veterinary Research,* 42: 1–13.

Segarra A, Pépin J F, Arzul I, Morga B, Faury N, Renault T (2010) Detection and description of a particular ostreid herpesvirus 1 genotype associated with massive mortality outbreaks of Pacific oysters, *Crassostrea gigas*, in France in 2008. *Virus Research,* 153: 92–99.

Vigneron V, Solliec G, Montanie H, Renault T (2004) Detection of ostreid herpes virus 1 (OsHV-1) DNA in seawater by PCR: influence of water parameters in bioassays. *Diseases of Aquatic Organisms*, 62: 35–44.

28: *Pseudorasbora parva* (Temmick & Schlegel, 1846). Top-mouthed gudgeon, stone morocco, false harlequin

Actinopterygii, Cypiniformes Cyprinidae,

Current status: NIS, no records for Ireland.

Native range: the eastern Asian region in the catchments of the Amur, Yang-tze, Huang-ho, and on Japan, the Korean Peninsula and Taiwan.

Established in Ireland: not known in Ireland.

First record: First recorded in southern Romania in 1961 and subsequently spread via the Danube River and spread to many countries in Eastern Europe to fish ponds where carp were in cultivation and spread to the wild. It appeared in the Rhine via the Main-Danube Canal and then spread in Western Europe and known in Belgium and The Netherlands since 1992. In Western Europe it has been sold as a baitfish and also as an ornamental. It was probably introduced to southern Britain with ornamental fishes from Europe in the mid-1980s but not recognised until 1990 in Hampshire. Since then it has spread to several ponds, reservoirs and river catchments.

Pathway: It spread, was associated with cyprinid fry, such as carp cultivated in ponds

Level of certainty of pathway: Very likely.

Further spread: This species spawns at temperatures that exceed 21°C, such conditions occur in the shallows of Irish lakes in summer. It is likely to be spread by a transfer of eggs on fishing equipment from an infested site in Britain or from release of pond reared fishes into the wild.

Probability of spread to Ireland: High.

Known occurrence: There are several areas where this species is present in Britain and in some confined water bodies it has been eliminated by using rotenone treatments.

Not known in: Scotland.

Impact: A competitive fish species, its eradication has resulted in an increased growth of native fish species.

Expected: in Ireland with imports of ornamental fishes. Might also be imported as a bait fish in the wells of angling craft arriving from abroad, perhaps for fishing competitions. Fish may release eggs which attach to leisure craft hulls or to anglers fishing equipment which then become transported to Ireland.

Monitoring localities: Pre-border and at the border examination of aquarium and pond-fish consignments, otherwise post border. Areas where there is submerged vegetation about the periphery of water bodies and for attached eggs on leisure craft hulls and on fishing gear arriving from Britain or the European continent. Ornamental fish stores. Post-border sampling in canals, ponds, lakes and reservoirs using nets.

Monitoring method: Specimens grow to 11cm total length and can be captured in nets.

Field characteristics: This cyprinid lacks barbels, has less than 15 rays in the dorsal fin and less than 14 rays on the pectoral fin and an anal fin with six branched rays, the eyes lie above the midline of the body and with an eye diameter 40% of the distance between the snout and front of the eye. A dark stripe of equal width runs along each flank but this can disappear with age. There are less than 39 scales along a normal lateral line. The mouth is slightly superior.

References:

Arkush KD, Frasca S, Hedrick RP (1998) Pathology associated with the rosette agent, a systemic protist infecting salmonid fishes. *Journal of Aquatic Animal Health*, 10: 1-11.

Beyer K. (2004). Escapees of potentially invasive fishes from an ornamental aquaculture facility: the case of topmouth gudgeon *Pseudorasbora parva*. *Journal of Fish Biology*, 65 (Suppl.): 326-327.

Caiola N, de Sostoa A (2002) First record of the Asiatic cyprinid *Pseudorasbora parva* in the Iberian Peninsula. *Journal of Fish Biology*, 61: 1058-1060.

Gozlan R E, Andreau D, Asaeda T, Beyer K, Bouhadad R, Bernard D, Caiola N, Cakic P, Esmaeili HR, Falka I, Golicher D, Harka A, Jeney G, Kovac V, Musil J, Povz M, Virbickas T, Wolter Ch, Tarkan AS, Tricarico E, Trichkova T, Verreycken H, Witkowski A, Zweimueller I, Britton JR (2010) The great escape: A review of topmouth gudgeon *Pseudorasbora parva* invasion in Europe and beyond. *Fish and Fisheries*, 14: 315-340.

Gozlan RE, Pinder A C, Shelley J (2002) Occurrence of the Asiatic cyprinid *Pseudorasbora parva* in England. *Journal of Fish Biology*, 61: 298-300.

Pollux BJA, Korosi A (2006) On the occurrence of the Asiatic cyprinid *Pseudorasbora parva* in the Netherlands. *Journal of Fish Biology*, 69: 1575-1580.

29: ***Sphaerothecum destruens*** **Arkush, Mendoza, Adkison, & Hedrick, 2003. Rosette agent**

Dermocystida, Opisthokonta incertae sedis

Current status: NIS, not thought to be established.

Native range: North America.

Established in Ireland: May be already be present, cyprinids from an infected farm are thought to have been imported to Northern Ireland. No report of its existence.

First record: No reports for Ireland.

Pathway: Stock movements of fishes to inland freshwater bodies, ornamental fish releases.

Level of certainty of pathway: Very likely.

Further spread: to be expected by same pathways.

Probability of spread to Ireland: High, might already be present.

Known occurrence: Britain, Europe and North America.

Impact: This is an intracellular protozoan parasite of fishes, in particular of salmonids, such as the Atlantic salmon *Salmo salar*. It has been associated with the topmouth gudgeon *Pseudorasbora parva*, that acts as a carrier of this disease organism. Some other cyprinid species act as carriers but may also suffer mortalities, such as the sunbleak *Leucaspius delineates* and the orfe *L. idus*. The bream *Abrama abrama* is also susceptible to this parasite. The parasite is probably more widely distributed than is currently known. Mortalities of bream in Lough Derg during April 1996 were not explained.

Expected: In freshwater, migrating salmon may carry the parasite to sea.

Monitoring localities: Pre-border and at the border and post border. Aquarium outlets.

Monitoring method: Specialised veterinarian.

Field characteristics: Not always possible, but the carrier *P. parva* if present should be sampled. Mortality in the bream should be examined pathologically.

References:

Andreou D, Gozlan RE, Paley R (2009) Temperature influence on production and longevity of *Sphaerothecum destruens* zoospores. *Journal of Parasitology*, 95: 1539–1541.

Andreou D, Gozlan RE, Stone D, Martin P, Bateman K, Feist SW (2011) *Sphaerothecum destruens* pathology in cyprinids. *Diseases of Aquatic Organisms,* 95: 145-151.

Gozlan RE, St-Hilaire S, Feist SW, Martin P, Kent ML (2005) Biodiversity, disease threat to European fish. *Nature,* 435:1046.

Gozlan RE, Andreou D, Asaeda T, Beyer K and others (2010) Pan-continental invasion of *Pseudorasbora parva*: towards a better understanding of freshwater fish invasions. *Fish and Fisheries,* 11:315–340.

Mendonca HL, Arkush KD (2004) Development of PCR-based methods for detection of *Sphaerothecum destruens* in fish tissues. *Diseases of Aquatic Organisms*, 61:187–197.

30: *Styela clava* Herdman, 1881. Club tunicate, leathery tunicate
Styelidae, Acidiacea, Tunicata
Current status: NIS, widespread.
Native range: NW Pacific.
Established in Ireland: Yes and expanding possibly in relation to climate change.
First record: Cork Harbour in 1971.
Pathway: hull fouling.
Level of certainty of pathway: Very likely
Further spread: hull fouling on ships and leisure craft, transmissions with stocks of oysters and with imported consignments of oysters from France.
Probability of further spread in Ireland: High.
Known occurrence: Dun Laoghaire Marina; North Channel, Cork Harbour; Marloge Marina, Cork Harbour; Crosshaven Pier, Cork harbour; Roaring Water Bay longlines; Whiddy Island, Bantry Bay; Dingle Marina; Fenit Marina; Mulroy Bay; Glenarm Marina; Larne Lough; Carrickfergus Marina, Belfast Lough.
Impact: Dense occurrence on longlines in Roaring Water Bay.
Expected: Sheletered bays and inlets where vessels and culture activities take place.
Not known in: Strangford Lough; Carlingford Lough; Waterford Estuary; Shannon Estuary; Malahide Estuary; Lough Foyle; Kinsale Harbour; Kilmore Quay; Kenmare Bay; Galway Bay; Donegal Bay; Lough Swilly; Bannow Bay; Dungarvan Bay; Dunmanus Bay; Kilkieran Bay; Bertraghboy Bay; Killary harbour; Clew Bay.
Monitoring localities: Post-border**.** Sheltered estuaries and bays and at aquaculture sites.
Monitoring method: shore surveys, oyster consignment inspections, marina pontoons, rotating screens, navigation bouys, drag sampling.
Field characteristics: a brown club shaped individual with a firm warty tunic attached by means of a narrow stalk and attaining 18cm in length, clusters of individuals may occur in areas where they are abundant. Found on boat hulls, marina pontoons, oysters, oyster bags trestles and occasionally on the carapace of the green crab. Specimens can be found throughout the year.
References:
Clarke CL, Therriault TW (2007) Biological synopsis of the invasive tunicate *Styela clava* (Herdman 1881). *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2807, 23 pp.

Davis MH, Lützen J, Davis ME (2007) The spread of *Styela clava* Herdman, 1882 (Tunicata, Ascidiacea) in European waters. *Aquatic Invasions,* 2(4): 378-390.

Dupont L, Viard F, Dowell MJ, Wood C, Bishop JDD (2009) Fine- and regional-scale genetic structure of the exotic ascidian *Styela clava* (Tunicata) in southwest England, 50 years after its introduction. *Molecular Ecology,* 18: 442-453.

Karney RC, Rhee WY (2009) Market potential for *Styela clava*, a non-indigenous pest invading New England coastal waters. *Aquatic Invasions,* 4(1): 295-297.

Guiry GM, Guiry MD (1973) Spread of an introduced ascidian to Ireland. *Marine Pollution Bulletin*, 4:127.

Minchin D, Duggan CB (1986) The distribution of the exotic ascidian, *Styela clava* Herdman, in Cork Harbour. *Irish Naturalists' Journal,* 22(9): 388-392.

Minchin D, Davis MM, Davis ME (2006) Spread of the Asian tunicate *Styela clava* Herdman, 1882 to the east and south-west coasts of Ireland. *Aquatic Invasions,* 1(2): 91-96.

Minchin D (2007) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions,* 2(1): 63-70.

Minchin D, Nunn, JD (2013) *Rapid assessment of marinas for invasive alien species in Northern Ireland*. Northern Ireland Environment Agency Research and Development Series No. 13/06.

Nunn JD, Minchin D (2009) Further expansions of the Asian tunicate *Styela clava* Herdman 1882 in Ireland. *Aquatic Invasions,* 4(4): 591-596.

Parker LE, Culloty S, O'Riordan RM, Kelleher B, Steele S, Van der Velde G (1999) Preliminary study on the gonad development of the exotic ascidian *Styela clava* in Cork Harbour, Ireland. *Journal of the Marine Biological Association of the United Kingdom,* 79: 1141-1142.

31: *Undaria pinnatifida* (Harvey) Suringar, 1873. Japanese kelp, wakame

Alariaceae, Laminariales, Ochrophyta

Current status: NIS, Locally established.

Native range: NW Pacific, southeast Russia, China, Japan, Korea.

Established in Ireland: Established, present at Carrickfergus Marina over three years.

First record: In 2012.

Pathway: Recreational craft.

Level of certainty of pathway: Very likely, found attached to marina pontoons and to boat hulls.

Further spread: Almost certain but may already be present elsewhere in Ireland.

Probability of further spread in Ireland: High.

Known occurrence: Carrickfergus Marina, Belfast Lough; Carlingford Marina, Carlingford Lough. Elsewhere known in The Isle of Man, south and east coasts of Britain, Belgium, The Netherlands, France, Spain and Portugal.

Not known in: Scotland.

Impact: Forms dense growths on floating structures and may appear to depths of >8m.

Expected: at marine sites to regions where there are no abrupt changes to salinity below 23-27psu

Monitoring localities: Post-border. Coastal areas with fully marine semi-sheltered conditions are preferred and the sporophyte stage may appear on the floats of shellfish longlines, boat moorings, navigation bouys.

Monitoring method: Marinas and intertidal surveys. Drift plants may be taken in young-fish surveys, rotating screens and drag sampling. Although may be seen directly from a marina boardwalk plants need to be plucked to confirm their identity as they may superficially look like other kelp species.

Field characteristics: The gametophyte stage is small and inconspicuous and can tolerate aerial exposure and so is unlikely to be recognised. The sporophyte stage is obvious. It is a kelp with a midrib and a corrugated sporophyll. Plants can vary in size to 3m in overall length but small plants may occur on pontoons in the sheltered areas of marina enclosures. Senescent plants lose their lamina and the sporophyll may persist.

References:

Farrell P, Fletcher RL (2006) An investigation of dispersal of the introduced brown alga *Undaria pinnatifida* (Harvey) Suringar and its competition with some species on the manmade structures of Torquay Marina (Devon, UK). *Journal of Experimental Marine Biology and Ecology,* 334: 236–243.

Fletcher RL, Farrell P (1999) Introduced brown algae in the north east Atlantic, with particular respect to *Undaria pinnatifida* (Harvey) Suringar. *Helgoländer Meeresuntersuchungen,* 52: 259–275.

Fletcher RL, Manfredi C (1995) The occurrence of *Undaria pinnatifida* (Phaeophyceae, Laminariales) on the south coast of England. *Botanica Marina,* 38: 355–358.

Floc'h JY, Pajot R, Wallentinus I (1991) The Japanese brown alga *Undaria pinnatifida* on the coast of France and its possible establishment in European waters. *ICES Journal of Marine Science,* 47: 379–390.

Forrest BM, Brown SN, Taylor MD, Hurd CL, Hay CH (2000) The role of natural dispersal mechanisms in the spread of *Undaria pinnatifida* (Laminariales, Phaeophyceae). *Phycologia,* 39:547–553.

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.

Hewitt CL, Campbell ML, McEnnulty F, Moore KM, Murfet NB, Robertson B, Schaffelke B (2005) Efficacy of physical removal of a marine pest: the introduced kelp *Undaria pinnatifida* in a Tasmanian Marine Reserve. *Biological Invasions*, 7: 251–263.

Minchin D, Nunn J (2014) The invasive brown alga *Undaria pinnatifida* (Harvey) Suringar, 1873 (Laminariales: Alariaceae), spreads northwards in Europe. *BioInvasions Records,* 3(2): 57-63.

Minchin D, Nunn JD (2013) *Rapid assessment of marinas for invasive alien species in Northern Ireland*. Northern Ireland Environment Agency Research and Development Series No. 13/06.

Mineur F, Johnson MP, Maggs CA (2008) Macroalgae introductions by hull fouling on recreational vessels: seaweeds and sailors. *Environmental Management,* 42: 667–676.

Wallentinus I (2007) Alien species alert: *Undaria pinnatifida* (wakame or Japanese kelp). *ICES Co-operative Research Report* No 283,36pp.

32: *Vibrio cholerae* Pacini, 1854, including *serogroups 001 and 0139 and biotype 'El Tor'*

Gram negative bacterium, Vibrionaceae, Vibrionales, Gammaproteobacteria

Current status: NIS, not established.

Native range: Probably Asia.

Established in Ireland: Will have caused epidemics in Belfast in 1832 and 1848/9. Epidemics also occurred in Dublin and Cork causing high levels of mortality killing many famine survivors. Rare cases known since.

First record: Its arrival in Ireland formed the second world pandemic of the disease occurring in 1832 and having a second wave some years later.

Pathway: Introduced with ships, either from contaminated bilges or crew members infested with the disease.

Level of certainty of pathway: Very likely.

Further spread: Isolated cases occur from time to time. Shipping may release contaminated water in port regions to take on cargo. The possibility of infectious strains becoming concentrated by filter feeding shellfish might cause a health risk to those that eat raw molluscan shellfish that have not been depurated, or from imported contaminated cultured prawns. Cessation of harvesting of oysters in Mobile Bay, United States, took place as a result of this bacterium being found in the American oyster *Crassostrea virginica*. Since then infectious strains have been recovered in ships' ballast water. Non-001 and non-0139 strains of *V. cholerae* have been found in Baltic waters and have resulted in human mortalities.

Probability of further spread in Ireland: Moderate to low. Further isolated cases may be expected.

Known occurrence: Outbreaks have taken place in many third world countries where there is poor hygiene where there are high population levels and where there are inadequate sanitary conditions.

Not known in: cold climates.

Impact: This bacteria infests the intestine of humans and is transmitted with contaminated food and water. In severe cases there is rapid loss of body fluids leading to dehydration and shock. Without treatment death occurs. Not every person will respond in the same way. And inoculum of $>10^6$ bacteria are required to produce a significant illness.

Expected: Discharges of this bacterium from ships' ballast water are probably taking place.

Monitoring localities: Specialist microbiologist sampling areas of cultivation and fishing of suspension feeders within and close to ports.

Monitoring method: Pre-border, if ballast water is treated**.** Post-border, sampling molluscan shellfish. Plating of swabs and PCR assay methods.

Field characteristics: No field characteristics known.

References:

Baker-Austin C, Trinanes JA, Taylor NGH, Hartnell R, Siitonen A, Martinez-Urtaza J (2013) Emerging *Vibrio* risk at high latitutes in response to ocean warming. *Nature Climate Change,* 3: 73-77.

Blackstone GM, Nordstrom JL, Bowen MD, Meyer RF, Imbro P, DePaola A (2007) Use of real time PCR assay for detection of the ctxA gene of *Vibrio cholerae* in an environmental survey of Mobile Bay. *Journal of Microbal Methods,* 68(2): 254-259.

Cohen NJ, Slaten DD, Marano N, Tappero JW, Wellman M, Albert RJ, et al. (2012) Preventing maritime transfer of toxigenic *Vibrio cholerae*. *Emerging Infectious Diseases*, 18 (10): 1680-1682.

Fenning H (2003) The cholera epidemic in Ireland, 1932-3: priests, ministers, doctors *Archivium Hibernicum,* 57: 77-125.

Lukinmaa S, Mattila K, Lehtinen M, Koskela M, Siitonen A (2006) Territorial waters of the Baltic Sea as a source of infections caused by *Vibrio cholerae* non-01, non 0139: report of 3 hospital cases. *Diagnostic Microbiology and Infectious Disease,* 54(1): 1-6.

McCarthy SA, Khambaty FM (1994) International dissemination of epidemic *Vibrio cholerae* by cargo ship ballast and other nonpotable waters. *Applied and Environmental Microbiology,* 60(7): 2597-2601.

Motes M, DePaola A, Ginkel S (1994) Occurrence of toxigenic *Vibrio cholerae* 01 in oysters in Mobile Bay, Alabama: an ecological investigation. *Journal of Food Protection,* 11: 952-1037.

Peters JC (1867) Conveyance of cholera from Ireland to Canada and the United States Indian territories, in 1832. 1-3pp Leavenworth, Kansas.

Ruiz GM, Rawlings TK, Dobbs FC, Drake LA, Mullady T, Huq A, Colwell RR (2000) Global spread of microorganisms by ships. *Nature,* 408: 49-50.

APPENDIX 2

Evaluation of the principal pathways to Ireland

EVALUATION OF THE PRINCIPAL PATHWAYS TO IRELAND

A2.1 THE PATHWAYS OF TRANSMISSION

A primary introduction from a distant biogeographical region involves a single pathway. Following introduction and establishment more than one pathway process can be involved in the secondary spread. As a NIS increases its range more opportunities for the subsequent enlargement of its range evolve and this makes effective management more difficult. This level of difficulty usually increases over time. Pathways are made up of intentional and inadvertent transmissions (**Table A2.1**). There may be an overlap between vectors within the different pathways, or between different pathways, whereby an NIS may be exchanged and spread further. Such exchanges may depend upon different NIS life-history stages.

Table A2.1 - Main pathways and vectors of biological introductions in estuarine and coastal environments (Modified from: Olenin *et al.* 2010). In Ireland the principal pathways are items 1 and 4. [Likely and possible examples of NIS introduced by such pathways for Ireland are in brackets].

Pathway Primary and secondary spread	**Vectors**
1. Ships, leisure craft, floating structures (all vessels, buoys *etc.*)	Water, sediments, solid and sedimentary ballast; the hull and hull projections; intakes and crevices; bored wood; bilges; anchor, anchor chains, fenders, portable moorings, overland transport, snagged materials; dredge spoil. [*Didemnum vexillum*, *Corella eumyota, Styela clava, Elminius modestus*]
2. Canals (channels, drainage cuts to lagoons, marina basins, *etc.*)	The Suez Canal is recognized as the main source of NIS in the Mediterranean Sea, including its coastal and estuarine areas. European inland canal systems. [Secondary spread. [*Dreissena polymorpha, Gammarus tigrinus, Crangonyx pseudogracilus*]
3. Wild fisheries	Stock movements; population re-establishment; discharges of by-catch, disease agents from processing live, fresh and frozen foods; live bait releases and discharges of live packaging material; movement of retrieved fishing equipment; releases of transported water [*Anguillicoloides crassus, Calyptraea chinensis, Crepidula fornicata*].
4. Culture activities	Intentional releases and movement of stock associated water; unintended or unauthorized releases; movement of nets, cages, lines, pumping equipment, etc.; broadcasting of live, fresh, frozen feed; release of genetically modified species [*Mytilicola orientalis Crassostrea gigas*].
5. Aquarium and live food trade	Intentional and accidental releases from aquaria and impoundments; organisms associated with rock, gravels and sediments ('living rock'); untreated waste discharges; unauthorised releases of imported living foods, discharged live packing materials; releases of transported water [*Homarus americanus, Carassius auratus, Hottonia palustris*]

Pathway Primary and secondary spread	Vectors
6. Leisure activities	Live bait movements and discharge of packaging materials; accidental/ intentional transport and release of angling catch; water sport equipment (diving, angling gear); live souvenirs; stocking for angling [*Rutilus rutilus, Aphamomyces astaci, Leuciscus cephalus, Oncorhychus mykiss*]
7. Research and education (including pilot projects)	Intentional releases, field experiments, including translocations; accidental release; waste water and biological waste discharges; discarded samples and demonstration materials; living food releases from cultures; field and experimental gear movement; releases/ escapes of caged organisms used for monitoring [not known in Ireland]
8. Biological control	Deliberate and inadvertent releases that reduce invasive pests [*Stenopelmus rufinasus*].
9. Habitat management	Soil stabilization/reclamation using rock barriers, sediments and plantings; use of filter-feeding invertebrates for managing water quality [*Spartina anglica*]
10. Natural spread	Rafting, floatation, water and wind currents, exceptional meteorological or seismic events, wildlife (birds, turtles *etc*.). [*Karenia mikimotoi, Cordylophora caspia*]

Human activities have different relative strengths in the transmission of NIS into, and within, Europe. There will be some similarities in the way these pathways act and so management actions may be effective for those that tend to have common dispersal characteristics. In the European marine environment there are generally ten main pathways of NIS (**Table A2.1**).

In Ireland, most introductions are due to vessel transport and stock movements of NIS used in aquaculture. The transmissions of aquatic biota ferried in ballast water to different world regions has been of special concern. Ballast water will have been operating as a vector since the c.1880s. There is good evidence that this is an important vector, most clearly illustrated with the transmission of European freshwater biota to the Great Lakes of North America since the opening of the St. Lawrence Seaway in 1959 (Holeck *et al.* 2004). Introductions by vessels are most usually attributed to ballast water, and associated sediments, and also fouling of the hull (Hewitt *et al.* 2009). However, NIS may also be spread from entanglement or by adhering to anchors and chain, from dredge-spoil or with the incremental dispersal of by-catch from fishing vessels. A recently-emerging consensus is that hull fouling is probably more important for transmissions of NIS than ballast water. Hull fouling will have spread species over millennia and leisure craft have now achieved a level of significance to warrant consideration as a separate pathway. In British Columbia leisure craft have been identified as the principal component for species spread (Murray *et al.* 2014) and a similar situation may apply in Ireland.

Canals are important for the spread of Erythrean and Ponto-Caspian species. The majority of NIS arriving in the Mediterranean Sea have passed through the Suez Canal (Galil *et al.* 2014). In Ireland canals have also been used as a conduit by NIS and several have spread to different catchments including those originally from the Ponto-Caspian region, and more can be expected. The highly ambulatory Chinese mitten crab *Eriocheir sinensis* is of special concern because it is able to tolerate estuarine conditions and use canal and river corridors to extend its range.

Aquaculture practices have been responsible for the introduction of competitors, predators, parasites, pests, diseases and disease agents causing issues that can compromise production and impact upon wild fisheries (Minchin 1996). Introductions as well as transfers of half-grown oysters and mussel seed, have spread several harmful NIS, with some entering Ireland (Lynch *et al.* 2012; McNeill *et al.* 2010). The introduction of cultured species, themselves, have seldom resulted in production difficulties. The Pacific oyster, *Crassostrea gigas*, was introduced to Ireland in 1969 following quarantine in Conwy, Wales and produced a vibrant industry, based on hatchery produced spat. In January 1993, following a European Commission decision on trade in shellfish in Europe (EC Directive 91/67/EEC), the quarantine process was eroded with the introductions of half-grown Pacific oysters to Ireland directly from France, despite concerns from Irish biologists (ICES 1993). This stock had originally been introduced to France without full quarantine precautions following the demise of the native oyster *Ostrea edulis* due to bonamiosis. Half-grown Pacific oysters were imported as air-freight from Japan by in the mid-1970s resulting in several unwanted biota arriving to Europe (Gruet *et al.* 1976) including a disease causing oyster summer mortality now known to be the *ostreid herpes virus 1* (Lynch *et al.* 2012).

A quarantine process, for new culture products, considerably reduces risks of introducing unwanted NIS, yet enables the development of the desired product intended for cultivation. In Ireland, an attempt to import the scallop *Patinopecten yessoensis* from Japan closely followed the ICES Code of Practice and contributed to modifications to the code (ICES 2005, Appendix F). While the code was improved, the project failed due to poor advice originating outside of Ireland.

Inadvertent introductions have been utilised, as in the case of the red alga *Asparagopsis armata* on the west coast of Ireland (Kraan and Barrington 2005). Further cultivation to produce useful products from NIS will almost certainly take place in the future. Some may be managed by developing a fishery as in the case the predatory snail *Rapana venosa* in the Black Sea using traps (Saglam *et al.* 2007) and dredging for the American razor clam *Ensis directus* in the southern North Sea (Wolff 2005). Some NIS produce 'bryostatins' considered to be of value in the management of certain cancers and found with the associates of *Bugula neritina* and *B. simplex* (Lim and Haygood 2004) both occur in Ireland.

The imports of baitworms such as the American bloodworm *Glycera dibranchiata* to Europe, may pose a risk of becoming introduced in northern Europe (Costa *et al.* 2006). *Perinereis linea*, *P. aibuhitensis* from eastern Asia are also imported for bait and *P. linea* has become established in a lagoon in the Mediterranean Sea along with non-native ciliates which may act as carriers of diseases (Arias *et al.* 2013).

A2.2 ASSESSING PORTS IN IRELAND

A2.2.1. INTRODUCTION

Cork Harbour was assessed for NIS in 1993 and this study revealed twenty-four species (Minchin and Sheehan 1998). Since then a further four are known (Minchin 2007a), although more probably exist. These were introduced with Pacific oysters (McArdle *et al.* 1991; Holmes and Minchin 1995), for habitat restoration (Cummins 1930) and almost certainly with ship and leisure craft movements. The list includes an oyster ecto-parasite new to science (Holmes and Minchin 1991) which may have been introduced with oysters. Cork Harbour is a sheltered harbour with a wide range of habitats ranging from lagoons, estuaries to fully marine conditions to provide a wide range of niches for an NIS, according to its preferences, to become established.

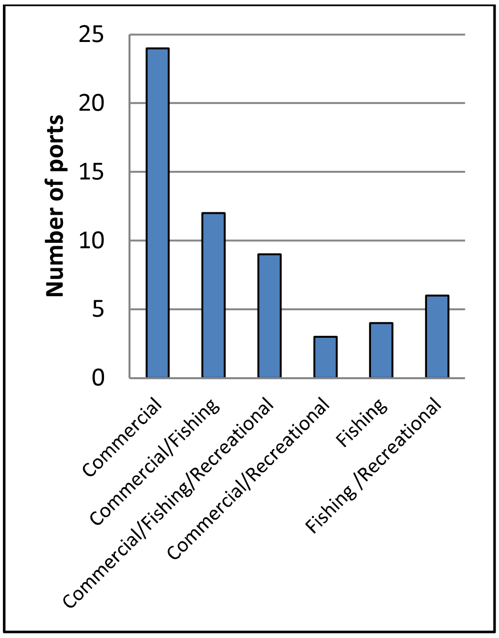
Here we examine Irish ports according to trade, and vessel NIS imports, that may have arrived with ballast water and on hulls (Hewitt *et al.* 2009). In theory the arrival of a vessel entering a warm water port could stimulate a spawning event for hull fouling biota. Increases of water temperature are known to stimulate spawning in a wide range of invertebrates once in reproductive condition. A container vessel, with a rapid port turn-around of half-a-day, could leave behind zygotes to form a founder population (Minchin and Gollasch 2003). As a result all trading vessels may have the capability of inoculating a port region. On occasion, the propagule size is insufficient to form a colony and a transitory, or casual, appearance of a species may take place, as in the case of the Chinese mitten crab found in Waterford Harbour (Minchin 2006). Such transitory occurrences may herald an establishment at a future time.

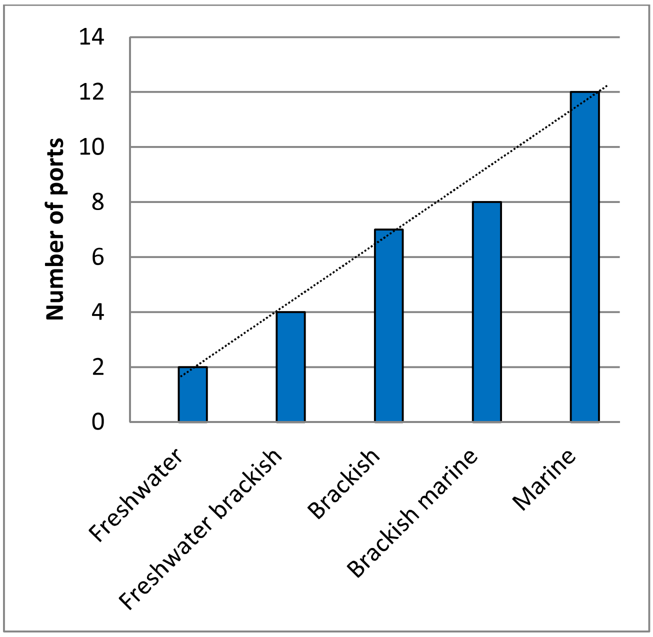
A2.2.2. METHODS

According to *World Port Source* there are no large ports in Irish waters (http://www.worldportsource.com/ports/IRL.php). Statistics for shipping and trade were based on those of the Irish Marine Development Office datasets from their most recent annual account (IMDO 2014) for trade by shipping for the year 2013. The list of Irish ports includes commercial and fishing harbours. Some also have recreational craft berths. Combinations of these are shown in **Figures A2.1** and **A2.2**. Each of the ports were assigned salinity classes according to the geography of each region.

A2.2.3. RESULTS

The majority of trade is with the European Union, with ports in the Baltic, North and Celtic seas and in the Mediterranean Sea (IMDO 2014). Some trade takes place with the eastern coast of North America and Pacific Rim countries of China and Japan. There has been a long-established trading activity with Britain and a regular ro-ro and ferry service with Britain and France. The trading figures (IMDO 2014) indicate that imported products arrive from these regions but the products may have been transferred from intercontinental to coastal shipping in Europe and subsequently redistributed.





Figures A2.1 and A2.2 - Showing the different shipping ports and different levels of potential interaction and levels of salinity and port numbers Based on IMDO (2014).

Some vessels, such as car-carriers, arrive directly from the Pacific Rim. In the case of the Aughinish Alumina Ltd site in the Shannon Estuary, the largest alumina site in Europe, approximately70% of imported bauxite originates from Guinea, West Africa. (http://www.epa.ie/licences/lic_eDMS/090151b280355c49.pdf). While the vessels arriving to Aughinish, will be loaded with ore the risk of NIS from ballast water discharge from this region is most probably low; and in any case African fouling organisms may be compromised by the low salinities at the Aughinish berth. Whereas the Leahill Quarry, in fully marine conditions in Bantry Bay, exports aggregates and as a result imports of ballast water which is discharged before taking on cargo. The volumes released are large.

Not all ports have the same vessel traffic. Ferries and ro-ro have regular patterns between specific ports, as do some coastal container vessels. Bulk containers, however, have varied shipping patterns but operate according to whether the cargo is liquid bulk or general bulk. The difference in the volume of the imports against the exports provides an indication of the amount of imported ballast water. However, the value of the products do not relate directly to the volumes imported (**Figure A2.3**).

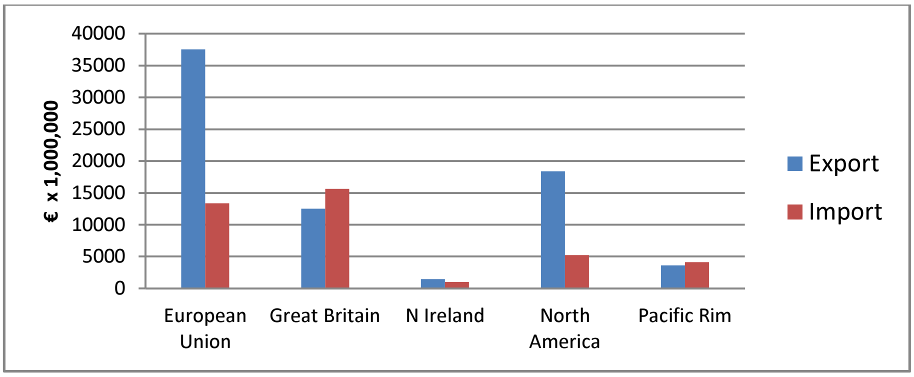
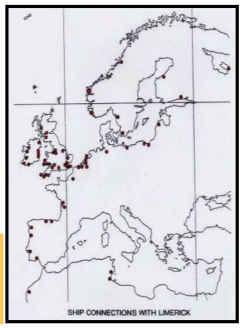


Figure A2.3 - The value of imports and exports to the Republic of Ireland from the principal trading regions (based on IMDO 2014).

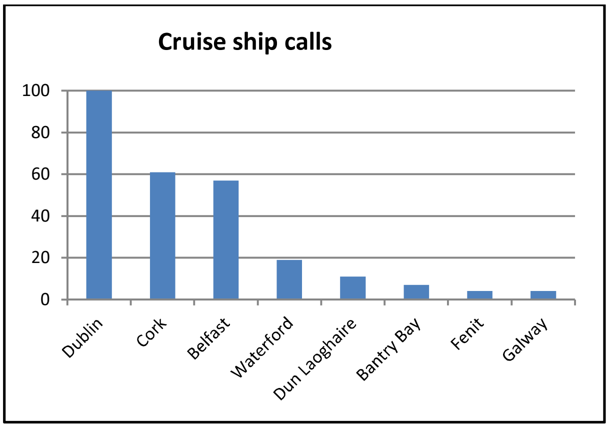
Ferries on standard routes (**Table A2.2** and **Figure A2.4**) operate either seasonally or throughout the year. Even small ports have connections over a wide geographical area (**Figure A2.5**). General freight with ro-ro vessels passes through six port regions, the greatest volume passing *via* Warrenpoint, Belfast and Larne in Northern Ireland and to the south at Rosslare. (**Figure A2.6**)



Irish port	Destinations
Dun Laoghaire	Holyhead
Dublin	Holyhead, Douglas, Liverpool
Rosslare	Pembroke, Fishguard, Cherborg, Rosscoff,
Belfast	Cairnryan, Douglas, Liverpool, Stranraer
Larne	Troon, Cairnryan
Cork	Swansea, Rosscoff

Figure A2.4 - (left) Ferry routes to Ireland. Figure A2.5 - (right) General routes of ships trading with Limerick in the 1990s

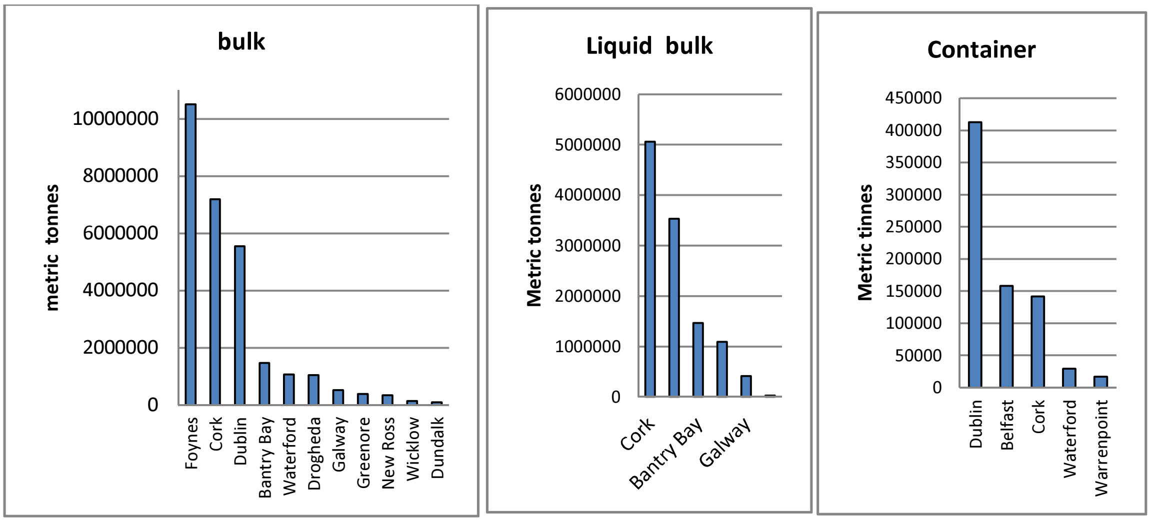
Table A2.2 - Irish current ferry routes.



Figures A2.6 - The ro-ro freight units exported from Irish ports including accompanied and accompanied trailers (left) and Figure A2.7 - The number of cruise ship calls to Irish ports during 2013. Some additional very occasional ports or sites are also visited by cruise ships and are not included here. Data based on IMDO (2014).

Ferries enable the transport of trailered goods vehicles, cars and caravans, but also vivier (live transport) trucks suspected as being responsible for importation of the eel parasite *Anguillicoloides crassus* by having collected living eels in Britain and Ireland, refreshing the water in tanks, then returning to northern Europe. Such exchanges could have released the parasite to the wild to then infest wild eels. Imports of live fish, such as carp *Cyprinus carpio* fingerlings have been apprehended and the chub *Leuciscus cephalus* probably entered by this same route (Caffrey *et al.* 2008).

Cruise ships have seasonal passages and may seasonally operate in the southern hemisphere during northern winters. The greater number of cruise ship visits to Irish ports is to Dublin (**Figure A2.7**). During summer periods invertebrates are at their most active reproductive and recruiting period and this could lead to southern hemisphere species gaining access to northern regions. Some from this region are expanding their ranges rapidly in northern Europe including the cold circum-Antarctic tunicates *Corella eumyota* and *Asterocarpa humilis*.



Figures A2.8 to A2.10 - The main trade of bulk, including petroleum and container traffic.

Ballast discharges take place in most Irish port regions, sometimes at holding areas (roads), away from the berthing site. Should the export of goods exceed the imports there is a general surplus that is made up of ballast water which is discharged at the destination port. The trade by shipping depends on the port facilities and this determines the nature of the goods imported and clearly varies between ports (**Figures A2.8** to **A2.10**). Under the IMO Ballast Water Management Convention (IMO 2004), when in operation the regulation of ballast water is subject to controls on the numbers of organisms discharged, being less than ten living organisms, of >50µm, per cubic meter of ballast water. The convention is likely to enter into force once 35% of the world shipping fleet, controlled by signatory states, agree to operate the Convention rules. Nevertheless, it is unknown whether this regulation could still, under certain circumstances, give rise to some NIS becoming established. Estuarine ports and estuarine regions of Irish ports may acquire NIS that are invasive in the Baltic Sea.

The only assessment of ballast water in Ireland was undertaken in 1994/5 with Cork Harbour and Foynes having the greater apparent discharges (**Figure A2.11**).

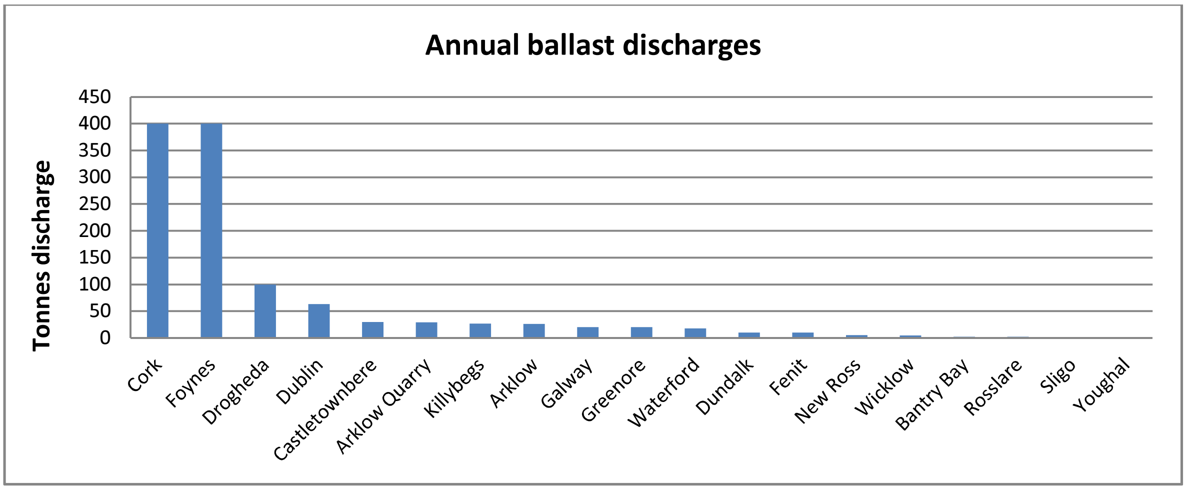


Figure A2.11 - Ballast discharges, by port in the Republic of Ireland, following results from a questionnaire for either 1994 or 1995 received from port managers (Minchin 1996).

A2.3 ASSESSING MARINAS AND AQUACULTURE SITES IN IRELAND

A2.3.1. INTRODUCTION

Murray *et al.* (2014) in a study in the temperate region of western Canada, in British Columbia, has shown the majority of NIS records are most probably due to leisure craft movements. They found salinity, human population density, port arrivals and marina 'propulsiveness' (the probability of travel from a home marina) were the principal drivers. Their study involved eighty-one sites using questionnaires and deployment of settlement plates for collecting NIS. This region has similarities to Ireland having relatively isolated inlets and high leisure craft activity. This study provides a good basis for separating ship activities with those from leisure craft. In Ireland NIS surveys have only been conducted at marina sites because of the ease of access, enabling rapid sampling at any tidal stage and access to a habitat that yields several NIS species. Here we examine the numbers of NIS at marinas sites and some of the associated variables.

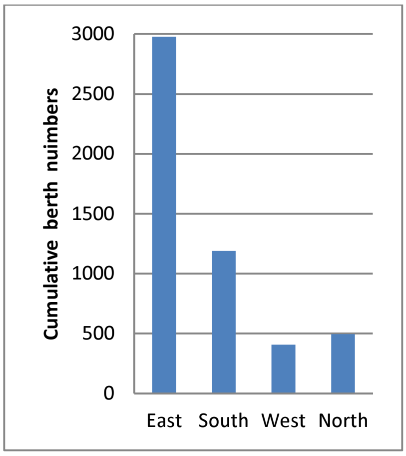
The Irish coastline has a caged salmon industry extending from the rias on the southwest coast to the north Irish coast, situated mainly within sheltered bays; but with new engineered structures are venturing into more exposed conditions. The shellfish industry mainly consists of an intensive cultivation of Pacific oysters confined within bags on trestles, Manila clams cultivated in the sediment beneath netting, rope grown culture of mussels and broadcast management of mussels within sheltered bays.

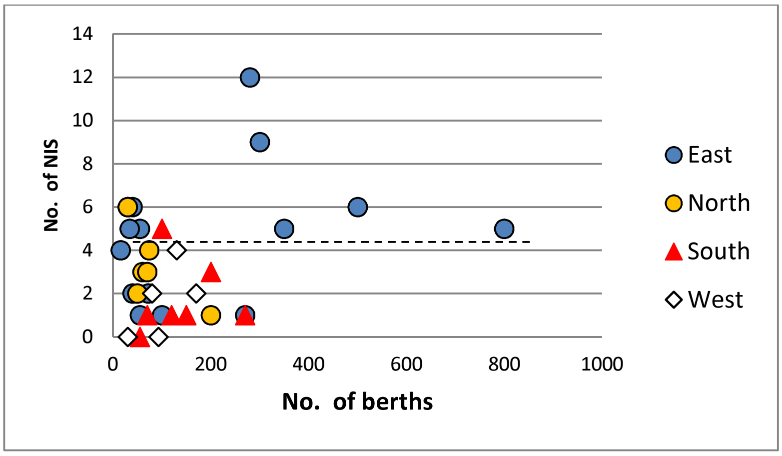
A2.3.2. METHODS

Previous surveys in Ireland were undertaken at coastal sites using a predetermined list of target NIS. Additional target species were included as further impacting species became recognised. Marinas sampled were sourced from (http://afloat.ie/resources/irish-coastal-marinas) and information on aquaculture activities obtained from the Irish Aquaculture Directory and Guide 4th Edition. Distances to the nearest port, marina, oyster growing area and salmonid farm were estimated using the most direct routes by sea using Google Earth. A broad classification of the salinity to five broad levels, ranging from freshwater to marine (<1; 1-10; 10-20; 20-30; 30+psu) were based on personal experience and geographic features according to the location of each marina site. The high risk NIS appear in Appendix 1. The numbers of NIS found provide a trend, and while these have arrived within the last decade (Minchin 2007; Minchin and Nunn 2013), several further NIS have appeared in Irish waters and during this time further marinas have been constructed. As a result, the current situation may not be accurately represented. Nevertheless the dataset provides the best information available at this time.

A2.3.3. RESULTS

The greatest number of marina berths, ~3000, are on the east coast of Ireland and the least on the west coast (**Figure A2.12**) and the greater numbers of previously reported NIS generally appeared at large marinas on the east coast (**Figure A2.13**). There are plans for the development of further marinas on the east coast at Courtown, Bray and Skerries. Other marinas are planned on the south coast at Dungarvan, Baltimore, Cobh, Schull and Union Hall. Elsewhere there are also plans for developments at Sligo, Killybegs and Portrush.





Figures A2.12 and A2.13 - The cumulative numbers of marina berths according to coastal region.

Ireland's marinas are located in areas where salinities range from freshwater to fully marine conditions. The numbers of NIS found at these sites follow a salinity-dependent trend whereby more NIS have been found on marinas exposed to fully marine conditions with least numbers for freshwater-brackish conditions (**Figure A2.14**). Freshwater port regions were not sampled.

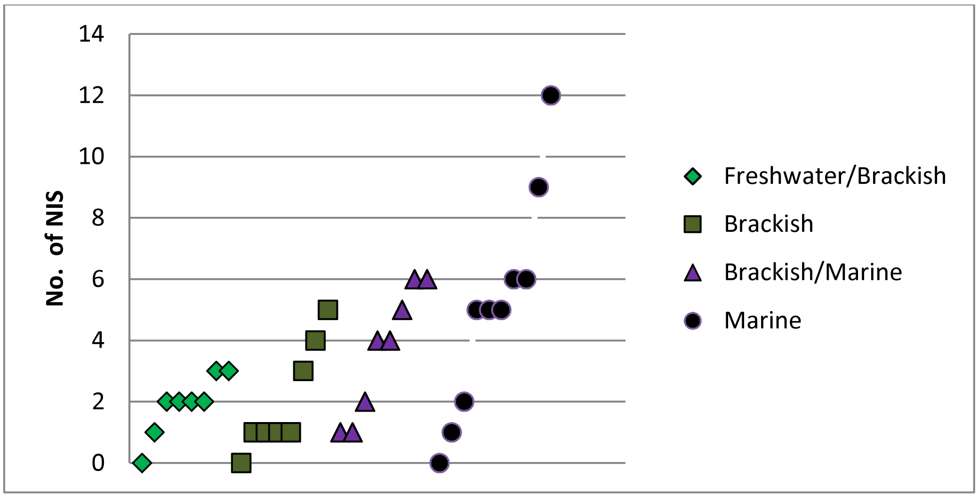
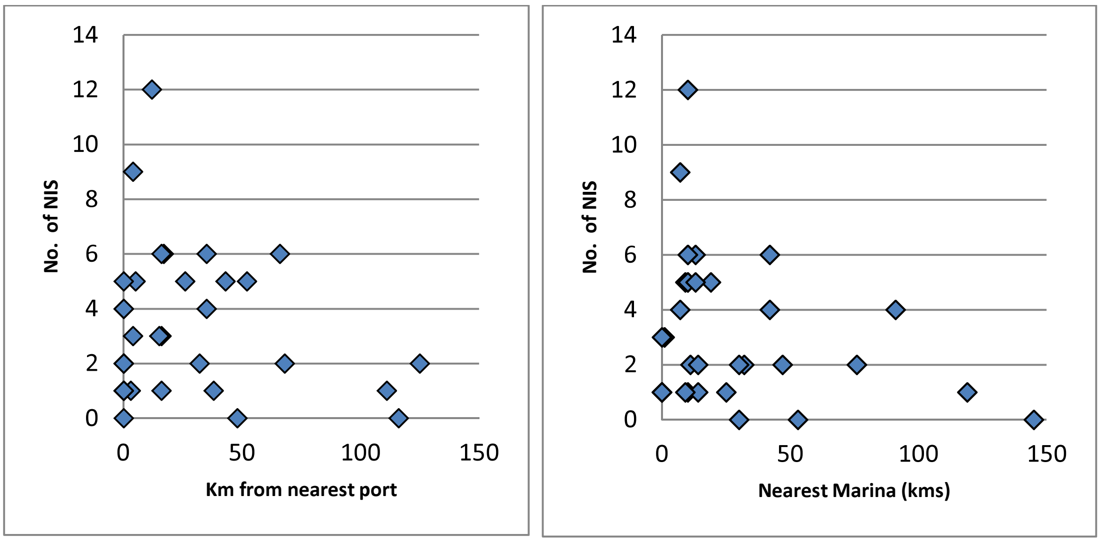


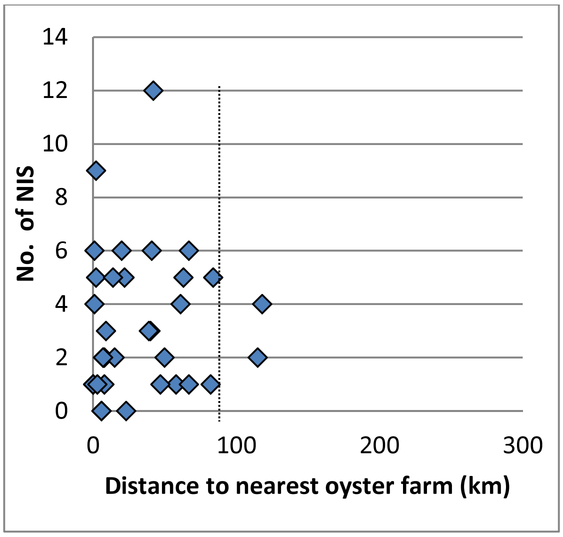
Figure A2.14 - Range of NIS found for four different classes of salinity ranging from<10 psu to >30 psu.

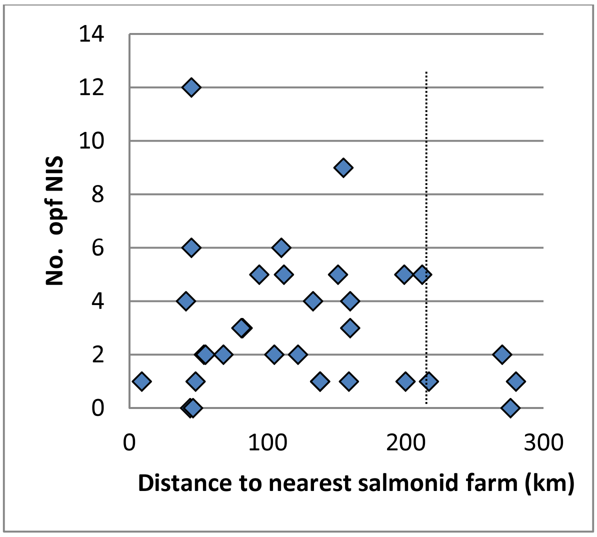
The distances to the nearest port or marina are shown in (**Figures A2.15** and **A2.16**). These plots indicate that there may be some correlation between the number of NIS present at a particular marina and the proximity to ports or other marinas, with potentially greater numbers of NIS present with closer proximity.

When the same exercise is plotted to the nearest Pacific oyster farm, or salmonid farm, there is an indication that oyster farms in closer proximity to each other have greater numbers of NIS present (Figures **A2.17** and **A2.18**).



Figures A2.15 and A2.16 - Plots of the number of NIS and distance of a marina to the nearest port (left) and to the next nearest marina (right).





Figures A2.17 and A2.18 - Plots of the number of NIS and distance of a marina to the nearest Pacific oyster farm (left) and to the nearest salmonid farm (right). Vertical lines indicate the relative distances between NIS numbers for oyster and salmonid farms.

A3 DISCUSSION

Shipping and other mobile floating structures, such as barges, dredgers, jack-up structures, oil platforms, are of particular concern as these can accumulate large fouling burdens and the maintenance procedures for some of these craft does not specifically include removal or reduction of hull fouling. The distances over which such vessels range are not always predictable. Dredgers that operate within northern Europe may have the capability of inadvertently spreading infaunal biota should they be engaged in Ireland. The harbours of particular susceptibility based on maintenance and the varied services present are Cork Harbour and Belfast Lough and port surveys for these particular sites as indicated by Awad *et al.* (2014) are recommended.

Studies have shown that the greatest numbers of known NIS occur in marinas with fully marine conditions; but there is much variation between different marina sites. More marinas occur on the east coast of Ireland and this is the coast where the greatest range for NIS will have been found. This may be due to the levels of activity associated with the greater number of berths present.

There would also seem to be some relationship with the nearest port, or nearest other marina, possibly as a result of oceanographic, local geographic features or increased interactivity between these sites. Such proximity poses future risk. Similarly, there are different patterns for oyster and salmonid farm sites. Their distribution about the coast depends on available sites where culture can take place. The relative proximity of oyster farms, with many being < 20km from each other, might pose a NIS propagation risk, especially in areas where cultivated stock may be moved or stored. Salmonid farms are spread over greater distances and are not so dependent upon being situated within the more sheltered sites. It would seem that risk evaluation based on the distance between cultivated sites needs to be undertaken according to the life-history stages and levels of recognition of the target NIS of concern and with an added need to examine for the presence of parasites, diseases and disease agents which may need epidemiological investigation.

Pacific oyster movements from France have been of particular concern. Half-grown and adult oysters have the greatest risk of introducing NIS, so also does the equipment (usually plastic mesh bags) used to transport them (Cook *et al.* 2008). Some direct imports from France have introduced small male *C. fornicata*. These did not survive due to being crushed by oyster movements and bag turning; however, on-bottom layings pose a risk for their establishment. In addition, there are associated species, such as crabs that may also become transported within oyster bags or within the cavities of dead molluscs. Accumulated living wastes on van floors involved in such transport, might also enter the sea (Minchin 2000 a,b,c). Oyster inspections on arrival, and subsequently while in culture, should be undertaken regularly for the overall health of the stock, as some unexpected events may occasionally take place (Minchin 2001). Locally based co-operative measures that are employed in the management of species such as the Co-ordinated Local Aquaculture Management System (CLAMS) involved in single bay management where co-operative approaches may greatly reduce risks from importations of stock (http://www.bim.ie/media/bim/content/BIM_CLAMS_Explanatory_Handbook.pdf). CLAMS involves a single bay management approach based on Integrated Coastal Zone management and County Development plans. Bannow Bay, Castlemaine Harbour, Clew Bay, Dungarvan Harbour, Killary Harbour, North Shannon Estuary, Kilkerrin Bay, Lough Swilly and Roaring Water Bay are included in this scheme.

The current knowledge of NIS in Irish coastal areas has been dependent upon occasional monitoring of specific sites, or has relied on special taxonomic investigations. Many of the finds have been reported by members of the public or by those involved in specific industries. With more frequent monitoring within a wide range of habitats it is certain that previously unknown occurrences of NIS will be found. While the majority of NIS will not be of specific concern to human activities, there are those that may have ecological consequences which can only be revealed with specialist studies. Some of the species that will arrive will be of value for food, biotechnological services or perhaps for biomass energy and an open mind on the management of these species will be needed as our environmental conditions change.

A4 REFERENCES

Arias A, Richter A, Anodón N, Glasby J (2013) Revealing polychaetes invasion patterns: identification, reproduction and potential risks of the Korean ragworm, *Perinereis linea* (Treadwell), in the Western Mediterranean. *Estuarine, Coastal and Shelf Science,* 131: 117-128.

Awad A, Haag F, Anil AC, Abdulla A (2014) GEF-UNDP-IMO GloBallast Partnerships Programme, IOI, CSIR-NIO and IUCN. Guidance on Port Biological Baseline Surveys. GEF-UNDP-IMO GloBallast Partnerships, London, UK. GloBallast Monograph No. 22.

Caffrey JM, Acevedo S, Gallagher K, Britton (2008) Chub (*Leuciscus cephalus*): a new potentially invasive fish species in Ireland. *Aquatic Invasions,* 3(2): 201-209.

Cook EJ, Ashton G, Campbell M, Coutts A, Gollasch S, Hewitt C, Liu H, Minchin, D, Ruiz G, Shucksmith R (2008) Non-native Aquaculture Species Releases: Implications for Aquatic Ecosystems, pp 155-184. In: Holmer M, Black K, Duarte CM, Marbà N, Karakassis I (eds) *Aquaculture in the Ecosystem*. Springer, The Netherlands.

Costa PDE, Gil J, Passos AM, Pereira P, Melo P, Batista F, Da Fonseca LC (2006) The market features of imported non-indigenous polychaetes in Portugal and consequent ecological concerns. Scientific Advances in Polychaete Research. *Scientia Marina,* (2006): 287-292.

Cummins HA (1930) Experiments on the establishment of rice grass (*Spartina townsendii*) in the estuary of the Lee. *The Economic Proceedings of the Royal Dublin Society,* 2. No 26, 419-421.

Galil BS, Marchini A, Occhipinti_Ambrogi A, Minchin D, Narščius A, Ojaveer H, Olenin S (2014) International arrivals: widespread bioinvasions in European seas. *Ethology Ecology and Evolution,* 26(2-3): 152-171.

Gruet Y, Heral M, Robert J-C (1976) Premiéres observations sur l'introduction de la fauna associée au naissain d'hûitres Japonaises *Crassostrea gigas* (Thunberg), importe sur la côte Atlantique Française, *Cahiers de Biologie Marine*, 17: 173-184.

Hewitt C, Gollasch S, Minchin D (2009) The vessel as a vector – biofouling, ballast water and sediments, pp 117-129. In: *G. Rilov and J. Crooks (eds) Biological Invasions in Marine Ecosystems: Ecological, Management and Geographic Perspectives. Ecological Studies 204.* Springer, Heidelberg, Germany.

Holeck KT, Mills EL, MacIsaac HJ, Dochoda MR, Colautti RI, Ricciardi A (2004) Bridging troubled waters: biological invasions, transoceanic shipping and the Laurentian Great lakes. *Bioscience,* 54 (10): 919-929.

Holmes JMC, Minchin D (1995) Two exotic copepods imported into Ireland with the Pacific oyster *Crassostrea gigas* (Thunberg). *The Irish Naturalists' Journal,* 25: 17-20.

Holmes JMC and Minchin D (1991) A new species of *Herrmannella* (Copepoda, Poecilostomatoida, Sabelliphilidae) associated with the oyster *Ostrea edulis* L. *Crustaceana,* 60: 258-269.

ICES (1993) Report of the Working Group on the Introductions and Transfers of Marine Organisms, Aberdeen, Scotland CM 1994/ENV:7 :F 65pp.

ICES (2005) ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005, 30 pp.

IMDO (2014) http://www.imdo.ie/IMDO/newsroom/press releases/IrishShippingvolumesupQ22014.htm (accessed 22 October 2014) 36pp.

IMO (2004) International convention for the control and management of ships' ballast water and sediments 2004. BWM/CONF/36 16 February 2004.

Kraan S, Barrington KA (2005) Commercial farming of *Asparagopsis armata* (Bonnemaisoniaceae, Rhodophyta) in Ireland, maintenance of an introduced species? *Journal of Applied Phycology,* 17: 103-110.

Lim GE, Haygood MG (2004) "*Candidatus Endobugula glebosa*" a specific bacterial symbiont of the marine bryozoan *Bugula simplex*. *Applied and Environmental Microbiology* , 70(8): 4921-4929.

Lynch SA, Carlson J, Reilly AO, Cotter E, Culloty SC (2012). A previously undescribed ostreid herpes virus 1 (OsHV-1) genotype detected in the Pacific oyster, *Crassostrea gigas*, in Ireland. *Parasitology*, 139: 1526- 1532.

McArdle JF, McKiernan F, Foley Hand D, Jones DH (1991) The current status of *Bonamia* disease in Ireland. *Aquaculture,* 93: 273-278.

McNeill G, Nunn J, Minchin D (2010) The slipper limpet *Crepidula fornicata* Linnaeus, 1758 becomes established in Ireland. *Aquatic Invasions,* 5 *Supplement* 1: S21-25.

Minchin D (1996) Management of the introduction and transfer of marine molluscs. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 6: 229-244.

Minchin D (1996) Desk assessment of discharges of shipping ballast water in Ireland. *ICES CM 1996/E:11.* 13pp.

Minchin D (2000a) Examination of Pacific oyster wild seed arriving at Crooke, Waterford from Arcachon, France, 29 April 2000. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 2/2000, 8pp.

Minchin D (2000b) Examination of native and Pacific oysters in the North Channel of Cork Harbour. A review of some organisms associated with oyster cultivation. 25-26 October 2000. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 10/2000, 9pp.

Minchin D (2000c) Examination of Pacific oysters from Woodstown Strand, Waterford, originating from Arcachon France. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 8/2000, 4pp.

Minchin D (2001) Examination of an oyster gill condition in three coast inlets: Oysterhaven, Cork Harbour and Waterford Harbour with notes on some exotic species, 16-18 October 2001. A Report for the Marine Institute. *Marine Organism Investigations*, Killaloe, Co Clare, Report 19/2001, 13pp.

Minchin D (2006) First Irish record of the Chinese-mitten crab *Eriocheir sinensis* (Milne-Edwards, 1854) (Decapoda: Crustacea). *Irish Naturalists' Journal*, 28(7): 303-304.

Minchin D (2007a) Rapid coastal survey for targeted alien species associated with floating pontoons in Ireland. *Aquatic Invasions,* 2: 63–70

Minchin D (2007b) A checklist of alien and cryptogenic aquatic species in Ireland. *Aquatic Invasions,* 2(4): 341-366.

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 (Supplement) 111-122.

Minchin D, Nunn JD (2013) *Rapid assessment of marinas for invasive alien species in Northern Ireland*. Northern Ireland Environment Agency Research and Development Series No. 13/06.

Minchin D, Sheehan J (1998) The significance of ballast water in the introduction of exotic marine organisms to Cork Harbour, Ireland. In: Ballast Water: Ecological and Fisheries Implications. J.T. Carlton (ed.) *ICES Co-operative Research Report, No.* 224, pp 12-23.

Murray CC, Gartner H, Gregr EJ, Chan K, Pakhomov E, Therriault TW (2014) Spatial distribution of marine invasive species: environmental, demographic and vectors driven. *Diversity and Distributions*, doi: 10.1111/ddi.12215

Olenin S, Alemany F, Cardoso AC, Gollasch S, Goulletquer P, Lehtiniemi M, McCollin T, Minchin D, Miossec L, Occhipinti Ambrogi A, Ojaveer H, Rose Jensen K, Stankiewicz M, Wallentinus I, Aleksandrov B (2010) Marine Strategy Framework Directive, Task Group 2 Report – non-indigenous species (April 2010). *Joint Report ICES and JRC European Commission,* EUR 24342 –EN 2010.

Saglam H. Kutlu S, Bascinar S, Dagtekin M, Duzgunes E, Sahin A (2007) Pot fishery of *Rapana venosa* Valenciennes 1846 in the south-eastern Black Sea. *Rapport Commission Internationale pour Mer Méditerranée,* 38: 585.

Wolff WJ (2005) The exploitation of living resources in the Dutch Wadden Sea: a historical overview. *Helgoland Marine Research,* 59: 31-38.