

An Invasive Species Surveillance and Monitoring Framework for the Island of Ireland

Dr Hannah Tidbury, Cameron Bullen, Lucinda Lintott, Jo-Hannah
Rees, Sarah Atkinson & Dr Paul Stebbing

Chapter 4. Data and Mapping



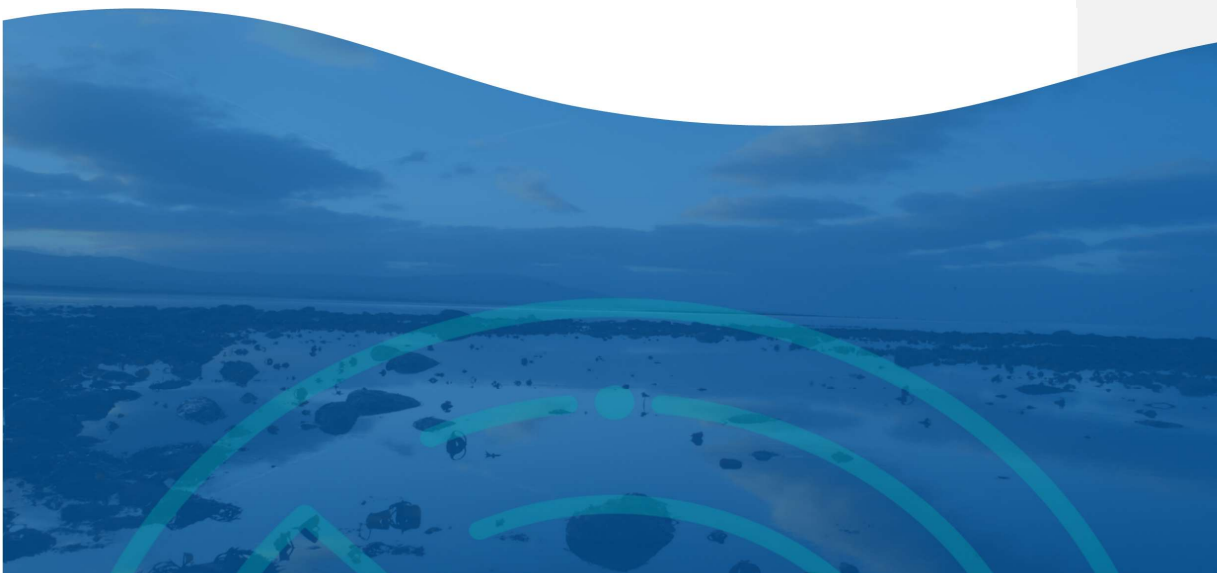
An tIonad Náisiúnta
Sonraí Bithéagsúlachta
National Biodiversity
Data Centre



NPWS
An tSeirbhís Náisiúnta
Náisiúnta agus Fíadhuirí
National Parks and Wildlife
Service



Shared Island
Initiative



Client: National Biodiversity Data Centre

Address: Beechfield House
SETU West Campus
Carriganore
Waterford
Ireland
X91PE03

Project reference: 16528

Date of issue: March 2026

Project Director: Dr Paul Stebbing

Project Manager: Dr Hannah Tidbury

Other: Cameron Bullen, Lucinda Lintott, Jo-Hannah Rees, Sarah Atkinson.

APEM Ltd

Riverview

A17 Embankment Business Park

Heaton Mersey

Stockport

SK4 3GN

Tel: 0161 442 8938

Fax: 0161 432 6083

Registered in England No. 02530851

Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
1.0	17/10/2025	All	All	Review and approval for submission to client	Dr Paul Stebbing, APEM
2.0	19/12/2025	All	All	Revisions following client review	Dr Paul Stebbing, APEM
Final	24/03/2026	4	23-43	Update to commercial port risk analysis and citation added	Dr Paul Stebbing, APEM

Acknowledgements

Funding for this project was provided under the Shared Island Biosecurity and Invasive Species Initiative which is funded by the Government of Ireland's Shared Island fund, the National Parks and Wildlife Service and the Northern Ireland Environment Agency. Additional support was provided by The Heritage Council through the National Biodiversity Data Centre.

Citation: Tidbury, H., Bullen, C., Lintott, L., Rees, J., Atkinson, S., & Stebbing, P. (2026). Chapter 4. Data and mapping. In A non-native and invasive species surveillance and monitoring framework for the island of Ireland. A report commissioned by the National Biodiversity Data Centre and completed by APEM Ltd.

Contents

1	Overview	1
2	Improved invasive species surveillance and monitoring coverage with focus on the freshwater and terrestrial environments.	1
2.1	Spatial analysis	1
2.2	Future directions	5
3	Enhancement of Existing Invasive Species-Specific Monitoring Programmes in the Marine Environment to Optimise Spatial, Temporal and Species Coverage	6
3.1	Invasive species rapid assessment surveys in Marinas	6
3.2	Monitoring at marine aquaculture sites	15
4	Development and implementation of additional bespoke invasive species monitoring programmes to address shortfalls with respect to priority site-specific legislative requirements – commercial ports	23
4.1	Risk Scoring	23
4.2	Future Directions.....	30
5	Appendix - Data Analysis Notes	31
5.1	Software used	31
5.2	Hotspot Risk Score Normalisation Equation	31
5.3	Data Sources	31
5.4	Specific notes	36
6	References	38

1 Overview

This chapter provides data-driven outputs and maps to facilitate the implementation of more comprehensive invasive species monitoring across the island of Ireland. Based on the recommendations proposed in Tidbury et al., (2025), it covers three main elements:

Improved spatial, temporal and priority species coverage through standardised integration of invasive species into existing broader environmental monitoring programmes, with focus on the freshwater and terrestrial environments.

Enhancement of existing invasive species-specific programmes to optimise spatial, temporal and species coverage.

Development and implementation of additional bespoke invasive species monitoring programmes to address shortfalls with respect to legislative requirements.

There is a strong emphasis on risk-based site prioritisation, building on the concepts and framework outlined in Chapter 1.

2 Improved invasive species surveillance and monitoring coverage with focus on the freshwater and terrestrial environments.

A number of hotspot locations exist in the freshwater and terrestrial environments which are not covered by existing invasive species-specific monitoring programmes (Tidbury et al., 2025). To facilitate improved invasive species surveillance and monitoring, data on hotspots linked to pathways commonly associated with the identified priority species (see Chapter 1) were sought and mapped. Further, these sites were evaluated in the context of existing monitoring and site sensitivity to impacts from invasive species, to identify candidates for pilot testing (and scaling-up) the integration of more comprehensive invasive species monitoring into existing broader environmental monitoring programmes.

2.1 Spatial analysis

Data were sought on zoos and wildlife parks, botanical gardens, aquaria, fisheries and finfish aquaculture sites (see below for prioritisation of shellfish/marine aquaculture sites). A total of 263 hotspot locations were identified (Figure 1, also see appendix Table 9 for information on data sources). It is recommended that invasive species monitoring is undertaken at these sites. Unfortunately, data to inform activity associated with these hotspots was not available (see the appendix for information on data limitations) to facilitate prioritisation of sites.

Grid cells (10km²) covering the extent of Ireland (IE) and Northern Ireland (NI) were categorised according to whether they fulfilled the following criteria: 1) sensitive to invasive species impact (i.e.

Grid cells meeting the three criteria are shown in Figure 4. Further, grid cells which contained more than two protected site types and greater than 15 WFD monitoring stations (relevant to IE only) were identified to provide greater resolution on the grid cells (i.e. locations) which provide good candidates for pilot testing (and scaling up) of integrated standardised invasive species monitoring into broader environmental monitoring programmes.

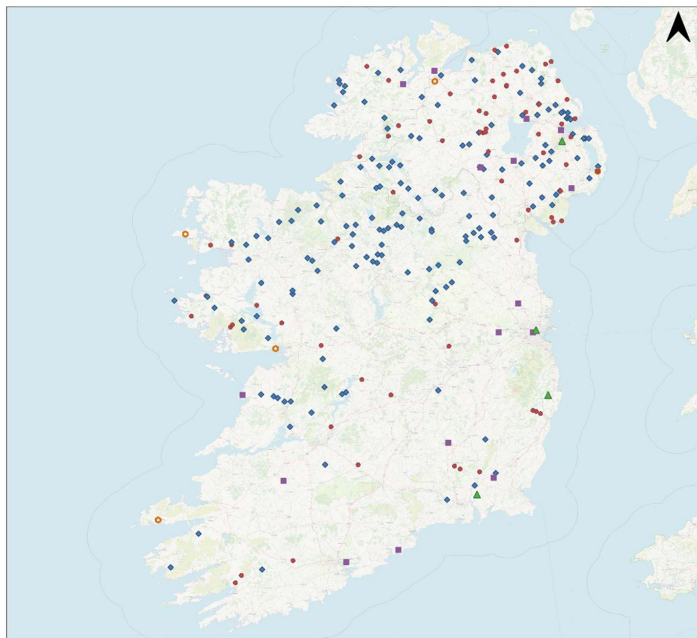


Figure 1. The location of hotspot sites representing zoos and wildlife parks, aquaria, botanical gardens, fisheries and finfish aquaculture sites. Note that the centroid of finfish aquaculture authorisation area polygons was calculated and is displayed in this map. Information on the sources of these data are provided in the appendix.

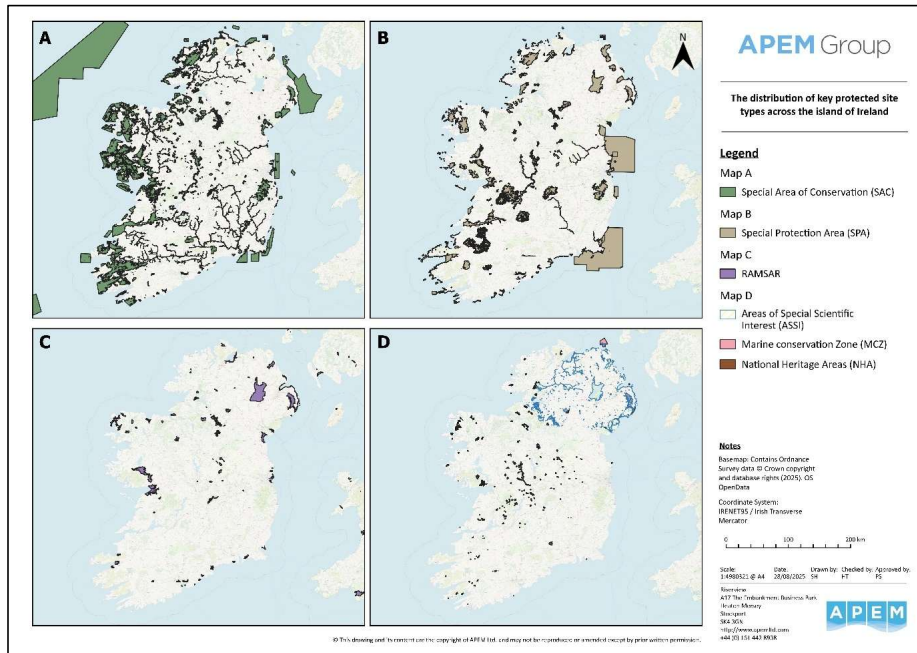


Figure 2. The distribution of key protected site types across the island of Ireland, namely Special Areas of Conservation (A), Special Protection Areas (B), RAMSAR sites (C) and Areas of Special Scientific Interest, Marine Conservation Zones and Natural Heritage Areas (D).



Figure 3. WFD monitoring stations in IE and NI. For information on data sources see the appendix.

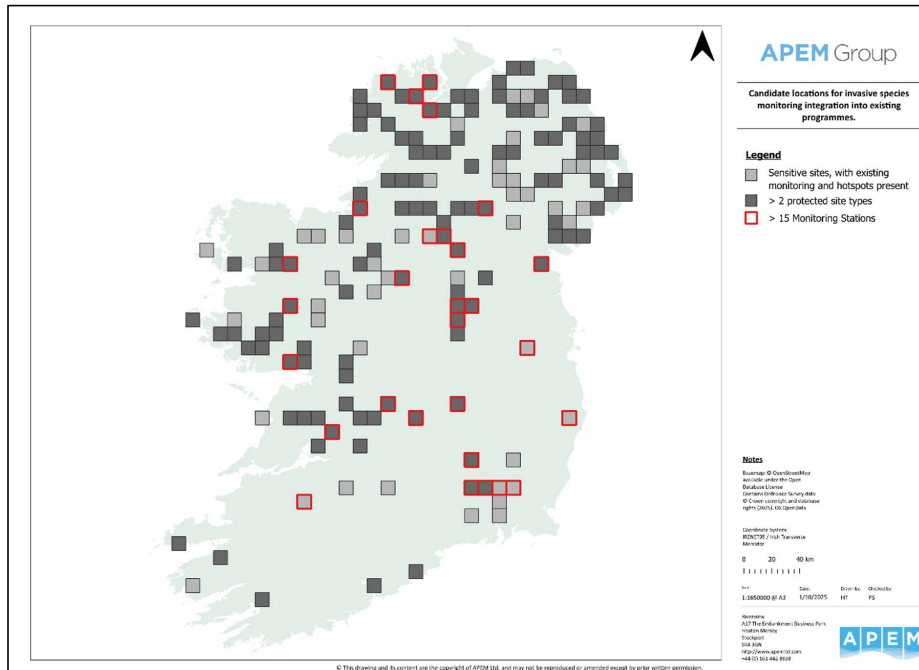


Figure 4. 10km² grid cells which comprise at least one protected site type, are subject to existing environmental monitoring, and contain a hotspot location (zoo and wildlife park, aquaria, botanical garden, fishery and finfish aquaculture site) (pale grey). The most sensitive sites, i.e. those that contain more than two protected site types (dark grey), and the most comprehensively monitored (i.e. those that contain more than 15 monitoring stations, relevant to IE only) (red outline) are also identified.

2.2 Future directions

Note that the sensitivity of hotspot sites to impact may also be considered in future analysis. For example, here we use the presence of fisheries and aquaculture sites to reflect the risk of introduction or spread. However, these sites are also vulnerable to the impacts of invasive species, in particular with respect to loss of production and revenue.

More advanced analysis may also include higher resolution evaluation to capture the types of protected sites and their relevance to the hotspot sites (i.e. the associated pathway and the priority species of relevance), whose distribution can be compared to the site priority outputs following collation of invasive data as covered in the roadmap (summary report, section 6.6.2).

The ability to prioritise hotspot locations across the freshwater and terrestrial environment was severely impeded by the lack of data to inform pathway activity levels at these hotspot locations.

While also somewhat limited in the marine environment, more data seemed to be available for the marine environment, with access facilitated by key marine data and mapping platforms – this is perhaps driven by marine legislation and policy which requires data on human activities in the marine environment (see the appendix for further information). Future site prioritisation should include pathway activity data as it becomes available. For example, data evidencing the level of fishing activity and biosecurity awareness at fishery sites could be used to inform the relative risk of invasive species introduction and spread at each fishery site.

3 Enhancement of Existing Invasive Species-Specific Monitoring Programmes in the Marine Environment to Optimise Spatial, Temporal and Species Coverage

3.1 Invasive species rapid assessment surveys in Marinas

Marinas are considered hotspots for invasive species introduction and spread, given their association with recreational boating activity and the transfer of invasive species attached to vessel hulls and niche areas. A selection of marinas across the island of Ireland are currently monitored using the established Rapid Assessment Survey method (Tidbury et al., 2025). This monitoring contributes to several key drivers, including the Invasive Alien Species Regulations (1143/2014), Habitats Directive (92/43/EEC) and the Marine Strategy Framework Directive (MSFD) (2008/56/EC), as well as their associated national implementing legislation. However, review of this monitoring programme against key monitoring programme components, highlighted some opportunities for its enhancement including an increase in the frequency of site surveys, in particular at the highest risk sites. To facilitate the selection of higher risk sites for more frequent monitoring, risk assessment and site prioritisation was undertaken. Recommendations for deployment of additional methods and future risk analysis was also provided.

3.1.1 Risk scoring

A simple assessment to identify marinas at relatively higher risk of invasive species introduction and spread across the island of Ireland was conducted. Outputs can be used to identify marinas not currently monitored for invasive species and underpin the selection of candidate marinas for more frequent invasive species surveys according to their risk.

Marina data, including location and number of berths, was collated from Ireland's Marine Atlas, NI Marine Mapviewer, through direct discussion with The Department of Agriculture, Environment and Rural Affairs (DAERA) (June-August 2025), and from reports detailing marina surveys by National Parks and Wildlife Services (O'Shaughnessy et al., 2023). Where data on the number of berths was not available via these sources, marina and boating websites were consulted or the number of berths estimated from Google Maps satellite view. The source of berth data is recorded for clarity in Table 1 (also see the appendix for data information).

The number of berths serves as a proxy for invasive species risk, as it reflects the size of the marina and the potential scale of recreational boating movements in and out of the marina.

The number of berths was normalised across all marinas to create a risk score between 0-100 (see appendix for the normalisation equation used). Based on their normalised risk score, marinas were assigned to five risk score categories (see Table 2). Marinas were mapped by risk category to facilitate visualisation of risk associated with marinas across the island of Ireland. For notes on data analysis and mapping software used see the appendix. Results are presented in and Figure 5.

The majority of the highest risk marinas are located in close proximity to Belfast, Dublin, Waterford and Cork. All marinas categorised as 'Very High' risk are currently monitored via an existing programme. However, three marinas categorised as 'High' are not currently monitored under an existing programme (Poolbeg, New Ross, Killibegs). The locations of the highest risk marinas are also locations which are covered by designations including Special Protected Areas (SPAs) under the EU Birds Directive (2009/147/EC) and associated national implementing legislation, and Special Areas of Conservation (SACs) under the EU Habitats Directive and associated national implementing legislation (Figure 2a and b). Therefore, in addition to a high risk of invasive species introduction into these locations, there is also a high risk of impact from any introduced invasive species, further highlighting the need for frequent monitoring.

Table 1. The number of berths and risk scores for marinas across the island of Ireland.

ID	Name	Region	Latitude	Longitude	Berths	Source of Berth Data	Current Monitoring Frequency (years)	Lead Organisation	Risk Score	Risk Category
1	Dun Laoghaire Marina	IE	53.29788	-6.13697	820	Marine Atlas	4	NPWS	100	Very High
2	Bangor Marina	NI	54.66435	-5.66925	560	NI Marine Map Viewer	1	DAERA	68.29268	Very High
3	Malahide Marina	IE	53.45494	-6.15272	350	Marine Atlas	4	NPWS	42.68293	Very High
4	Carrickfergus Marina	NI	54.71084	-5.81353	325	NI Marine Map Viewer	1	DAERA	39.63415	Very High
5	Howth Marina	IE	53.38898	-6.06723	250	Marine Atlas	4	NPWS	30.4878	Very High
6	Kinsale Yacht Club Marina	IE	51.70281	-8.51814	220	Marine Atlas	4	NPWS	26.82927	Very High
7	Carlingford	IE	54.05172	-6.19142	200	Marine Atlas	4	NPWS	24.39024	Very High
8	Royal Cork Yacht Club Marina	IE	51.80496	-8.30118	200	Marine Atlas	4	NPWS	24.39024	Very High
9	Carlingford Marina	NI	54.05169	-6.19155	180	NI Marine Map Viewer	3	DAERA	21.95122	Very High
10	Kilrush Creek Marina	IE	52.63448	-9.49441	170	Marine Atlas	4	NPWS	20.73171	Very High
11	Castlepark Marina	IE	51.69645	-8.51656	130	Marine Atlas	4	NPWS	15.85366	High
12	Crosshaven Boat Yard	IE	51.80511	-8.29567	120	Marine Atlas	4	NPWS	14.63415	High
13	Fenit Harbour Marina	IE	52.27174	-9.86279	120	Marine Atlas	4	NPWS	14.63415	High
14	Dublin City Moorings	IE	53.34765	-6.24637	100	Marine Atlas	4	NPWS	12.19512	High
15	Waterford Marina	IE	52.26179	-7.10732	100	Marine Atlas	4	NPWS	12.19512	High
16	East Ferry Marina	IE	51.86629	-8.21363	100	Marine Atlas	4	NPWS	12.19512	High
17	Poolbeg Marina	IE	53.34382	-6.21739	100	Marine Atlas	NA	NA	12.19512	High
18	Portrush Harbour	NI	55.2069	-6.65856	100	NI Marine Map Viewer	3	DAERA	12.19512	High
19	Glenarm Marina	NI	54.96932	-5.95223	98	NI Marine Map Viewer	1	DAERA	11.95122	High

20	Copelands	NI	54.64032	-5.52961	90	NI Marine Map Viewer	3	DAERA	10.97561	High
21	Cahersiveen Marina	IE	51.94757	-10.2332	80	Marine Atlas	4	NPWS	9.756098	High
22	Dingle Marina	IE	52.13792	-10.2775	80	Marine Atlas	4	NPWS	9.756098	High
23	Cork Harbour Marina	IE	51.84584	-8.33332	80	Marine Atlas	4	NPWS	9.756098	High
24	Ballycastle	NI	55.20687	-6.23939	74	NI Marine Map Viewer	1	DAERA	9.02439	High
25	New Ross Marina	IE	52.39137	-6.95157	66	Marine Atlas	NA	NA	8.04878	High
26	Killibegs Marina	IE	54.6342	-8.44447	63	Marine Atlas	NA	NA	7.682927	High
27	Foyle Marina	NI	55.00639	-7.31826	60	Practical boat owner, https://www.pbo.co.uk/marina-guide/visitor-berth-guide-2017/foyle-port-marina-4	3	DAERA	7.317073	High
28	Kilmore Quay Marina	IE	52.1728	-6.58831	55	Marine Atlas	4	NPWS	6.707317	High
29	Ardglass Marine	NI	54.26173	-5.60654	55	NI Marine Map Viewer	3	DAERA	6.707317	High
30	Coleraine	NI	55.14441	-6.67607	55	NI Marine Map Viewer	3	DAERA	6.707317	High
31	Seatons Marina	NI	55.15385	-6.69538	50	https://seatonsmarina.co.uk/	3	DAERA	6.097561	High
32	Arklow Marina	IE	52.79255	-6.14569	42	Marine Atlas	4	NPWS	5.121951	High
33	Lawrence Cove Marina	IE	51.63416	-9.82625	40	Marine Atlas	4	NPWS	4.878049	Moderate
34	Bantry Marina	IE	51.67997	-9.46088	40	Marine Atlas	NA	NA	4.878049	Moderate
35	Belfast Harbour Marina	NI	54.60502	-5.91403	40	Practical Boat Owner, https://www.pbo.co.uk/marina-guide/annual-berth-guide-2017/belfast-harbour-marina-2	1	DAERA	4.878049	Moderate
36	Galway Marina	IE	53.26928	-9.0501	31	Marine Atlas	NA	NA	3.780488	Moderate
37	Portaferry	NI	54.37958	-5.54873	30	NI Marine Map Viewer	3	DAERA	3.658537	Moderate
38	Sea Horse Marina	IE	51.93996	-9.39962	25	Google Maps	4	NPWS	3.04878	Moderate

39	Rossaveal Marina	IE	53.26838	-9.55788	24	Marine Atlas	NA	NA	2.926829	Moderate
40	Baltimore Pontoon	IE	51.48255	-9.37527	20	Atlantic Boating Services	4	NPWS	2.439024	Moderate
41	Ballydorn Lightship	NI	54.49098	-5.64927	20	Estimated from google maps	3	DAERA	2.439024	Moderate
42	Town dock Marina	NI	54.10044	-6.25563	20	Estimated from google maps	3	DAERA	2.439024	Moderate
43	White harbour	NI	54.74194	-5.71978	15	http://www.whiteharbour.org/home-.html	3	DAERA	1.829268	Low
44	Whiterock Pontoon	NI	54.48306	-5.64786	15	https://eoceanic.com/sailing/harbours/202/white-rock_bay , google maps	3	DAERA	1.829268	Low
45	East Down Yacht club	NI	54.41465	-5.64455	12	Estimated from google maps	3	DAERA	1.463415	Low
46	Rathlin Marina	NI	55.29246	-6.19369	12	NI Marine Map Viewer	1	DAERA	1.463415	Low
47	Carlingford Lough Yacht Club	NI	54.07543	-6.18299	10	Estimated from google maps	3	DAERA	1.219512	Low
48	Killyleagh Yacht Club	NI	54.39305	-5.64724	10	Estimated from google maps	3	DAERA	1.219512	Low
49	Quoile Yacht Club	NI	54.36733	-5.67939	10	Estimated from google maps	3	DAERA	1.219512	Low
50	Sketrick Island Pontoon	NI	54.48918	-5.64683	10	Estimated from google maps	3	DAERA	1.219512	Low
51	Strangford Yacht Haven	NI	54.37258	-5.55494	6	Practical Boat Owner, https://www.pbo.co.uk/marina-guide/visitor-berth-guide-2017/strangford-yacht-haven	3	DAERA	0.731707	Low
52	Tident Marina	IE	51.70095	-8.51797	4	Marine Atlas	NA	NA	0.487805	Low
53	Wicklow Harbour	IE	52.98211	-6.03368	3	NI Marine Map Viewer	NA	NA	0.365854	Low

54	Youghal	IE	51.95336	-7.84235	2	https://www.noforeignland.com/place/6582711063937024	NA	NA	0.243902	Low
55	Adrigole Harbour	IE	51.67937	-9.71741	0	Marine Atlas	NA	NA	0	Very Low
56	Rosmoney	IE	53.82776	-9.62214	0	Marine Atlas	NA	NA	0	Very Low
57	Sligo Harbour	IE	54.27695	-8.48093	0	Marine Atlas	NA	NA	0	Very Low
58	Star Marina	IE	51.84638	-9.65286	0	Marine Atlas	NA	NA	0	Very Low
59	Heir Island	IE	51.494	-9.42799	0	Marine Atlas	NA	NA	0	Very Low
60	Bray Harbour	IE	53.20901	-6.09973	0	Marine Atlas	NA	NA	0	Very Low
61	Glandore Harbour	IE	51.56384	-9.12037	0	Marine Atlas	NA	NA	0	Very Low
62	Foynes Yacht Club	IE	52.61277	-9.10573	0	Marine Atlas	4	NPWS	0	Very Low
63	Rossbrin Cove	IE	51.52973	-9.47176	0	Marine Atlas	NA	NA	0	Very Low
64	The Royal St. George Yacht Club	IE	53.29544	-6.13136	0	Marine Atlas	NA	NA	0	Very Low
65	Knightstown	IE	51.92651	-10.2866	0	Marine Atlas	NA	NA	0	Very Low
66	Schull	IE	51.52647	-9.53811	0	Marine Atlas	NA	NA	0	Very Low
67	Port of Cork	IE	51.89866	-8.46323	0	Marine Atlas	NA	NA	0	Very Low
68	Belmullet	IE	54.21988	-9.96323	0	Marine Atlas	NA	NA	0	Very Low
69	Dunmore East	IE	52.14808	-6.99082	0	Marine Atlas	NA	NA	0	Very Low
70	Rathmullan	IE	55.09549	-7.52941	0	Marine Atlas	4	NPWS	0	Very Low
71	Oysterhaven	IE	51.70081	-8.4454	0	Marine Atlas	NA	NA	0	Very Low
72	Derrynane Harbour	IE	51.76083	-10.117	0	Marine Atlas	NA	NA	0	Very Low
73	Clifden Bay	IE	53.48539	-10.0432	0	Marine Atlas	NA	NA	0	Very Low
74	Courtmacsherry Harbour	IE	51.63336	-8.70585	0	Marine Atlas	4	NPWS	0	Very Low
75	Greystones Harbour Marina	IE	53.15239	-6.06684	0	Marine Atlas	NA	NA	0	Very Low
76	Dungarvan Marina	IE	52.09013	-7.61866	0	Marine Atlas	NA	NA	0	Very Low
77	Fahan Marina	IE	55.08763	-7.4795	0	Marine Atlas	4	NPWS	0	Very Low

Table 2. Risk category thresholds. Note that the risk scores are included to allow risk category thresholds to be adjusted as required (for example, if a fixed proportion of hotspot locations is required within each risk category).

Risk Category	Risk Score
Very High	20-100
High	5-20
Moderate	2-5
Low	<2
Very Low	0

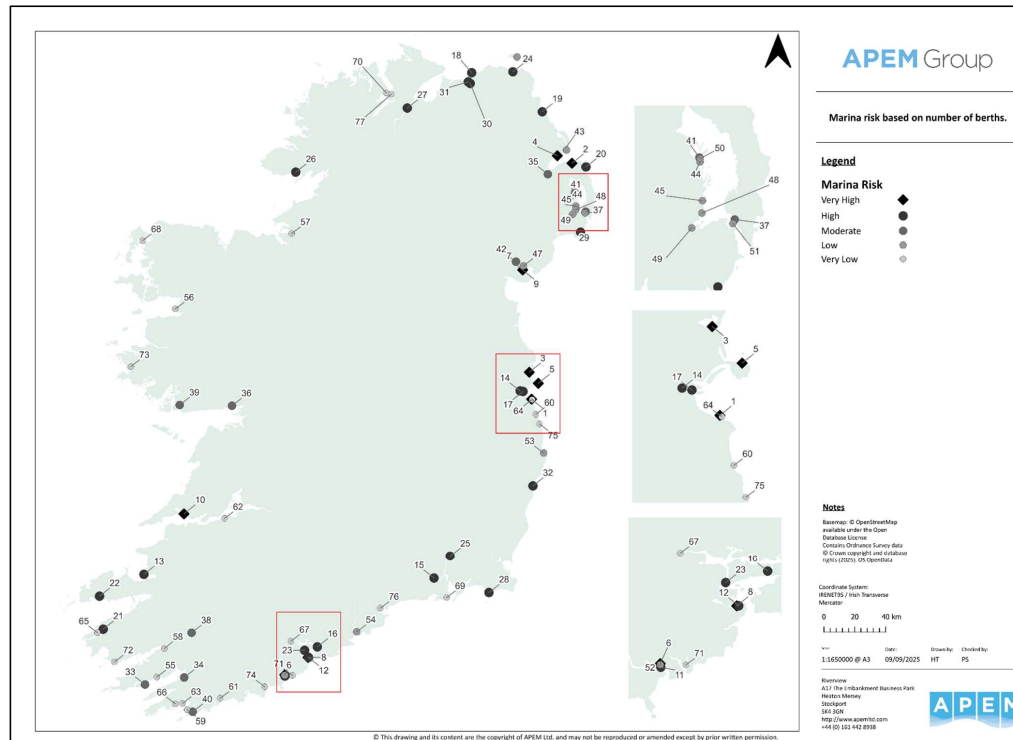


Figure 5. Marinas across the island of Ireland, by invasive species risk estimated using the number of berths. Please see Table 1 for details of marinas according to the ID number shown.

3.1.2 Marina-specific monitoring programme design considerations

Marina risk, based on number of berths, follows an exponential-like distribution (Figure 6), suggesting that a sampling approach which prioritises high-risk sites (though still includes low risk sites) may be suitable (see Chapter 2 for information on sampling design output from a theoretical simulation).

The frequency of surveys at marina sites may need to be increased in order to capture new invasive species introductions. Annual or biennial survey of the highest risk sites is recommended.

Three high-risk marinas not currently surveyed should be included in regular surveys.

RASs focus on the detection of fouling organisms attached to artificial hard substrate around marinas, including pontoons, buoys and ropes. However, supplementation of the RAS method with additional methods such as baited traps will enhance capacity to detect mobile pelagic and mobile benthic species and can be deployed for the duration of the RAS (see Chapter 3 for detailed information on invasive species monitoring methods, including seasonal considerations).

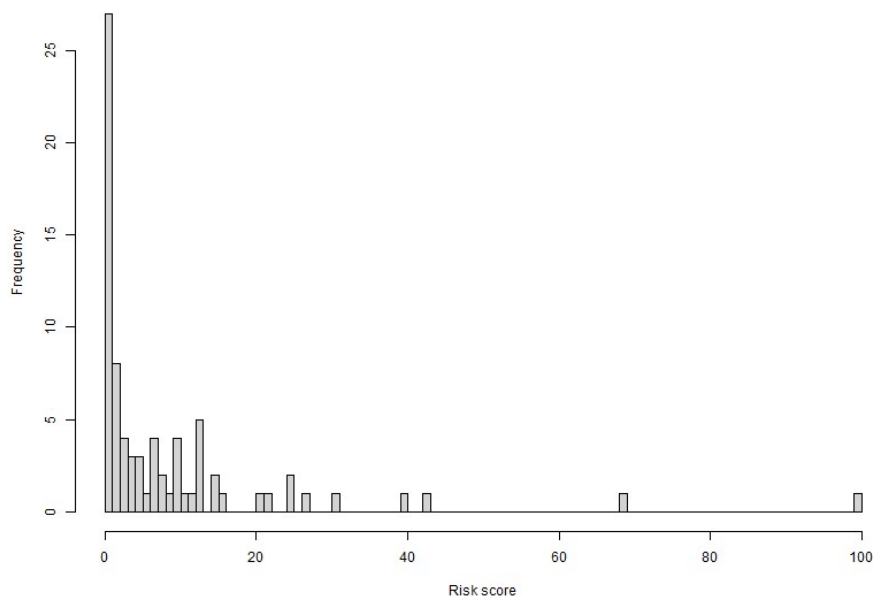


Figure 6. The frequency distribution of marina risk scores based on number of berths.

3.1.3 Future directions

While the number of berths provides insight into the size of a marina and the scale of associated recreational boating activity, more in-depth analysis of risks associated with recreational vessels will be useful to enhance risk assessment of marinas into the future. In particular, studies to examine the level of biofouling on recreational vessels, recreational vessel movement patterns (spatial and temporal) and biosecurity uptake by boaters, will be key to more accurate prediction of invasive species risk at marinas across the island of Ireland. Outputs from research conducted throughout 2025 and 2026, assessing the role of marine recreational vessels as a pathway for the introduction and spread of marine invasive species in the UK, commissioned by Natural England, may serve as a useful starting point for such data.

3.2 Monitoring at marine aquaculture sites

Aquaculture sites are considered hotspots for invasive species introduction and spread given the movement of stock and equipment on and between sites. Aquaculture sites are also vulnerable to the impacts of invasive species, which may lead to significant reduction in yield and associated economic losses. Marine aquaculture (i.e. shellfish) site monitoring is well established in IE and is undertaken at varying frequencies from annual to every three years. In NI, marine aquaculture site monitoring for invasive species commenced in 2025 and is expected to be repeated at least every three years (Tidbury et al., 2025). This monitoring contributes to a number of drivers including shellfish import monitoring requirements and the MSFD. However, review of this monitoring programme against key monitoring programme components, highlighted some opportunities for its enhancement including an increase in the frequency of site surveys, in particular at the highest risk sites. To facilitate the selection of higher risk sites for more frequent monitoring, risk assessment and site prioritisation was undertaken. Recommendations for deployment of additional methods and future risk analysis was also provided.

3.2.1 Risk scoring

A simple assessment to identify areas associated with marine aquaculture production at high risk of introduction and/ or impact of invasive species across the island of Ireland was conducted. Outputs can be used to inform a risk focussed invasive species monitoring programme in the marine environment, in particular with respect to aquaculture production.

In contrast to marinas and ports, information relating to invasive species risk for individual licensed aquaculture sites (e.g., stock movements, scale of production) was not available for use in this analysis due to potential commercial sensitivities (pers comms, Marine Institute & DAERA, 2025). Risk scoring was therefore undertaken for broader geographical areas (as opposed to specific site locations), according to a predefined 10km² grid (see the appendix for data analysis notes).

Licensed aquaculture production area data was sourced from DAERA Open Data and Ireland's Marine Atlas, for NI and IE, respectively (see the appendix). The total area within each cell occupied by licensed aquaculture production areas was calculated. This was used to determine the proportion of the cell's area occupied by aquaculture production. Assuming that the licensed areas are utilised for production, the proportion of each grid cell occupied by licensed aquaculture production areas provides a proxy for the scale of aquaculture production activity within the grid cell - and therefore the potential risk of invasive species introduction and spread, and also the potential impact of invasive species establishment.

The proportions (the proportion of the cell's area occupied by aquaculture production) were normalised across all cells within which licensed aquaculture sites were located to create a risk score between 0-100 (see appendix for the normalisation equation used). Based on their normalised risk score, cells were assigned to five risk score categories (see Table 3). Grid cells were mapped by risk category to facilitate visualisation of risk associated with aquaculture production across the island of Ireland. For notes on data analysis and mapping see the appendix. Outputs are presented in Table 4. and Figure 7.

While invasive species monitoring is conducted at aquaculture sites within many of the grid cells identified as highest risk, there are a few notable gaps. In particular, in NI, monitoring is not conducted at aquaculture sites located within Belfast Harbour which is a hotspot of activity for multiple marine invasive species pathways and the location of other high-risk sites (e.g., ports and marinas). Further, in IE, current aquaculture site monitoring does not cover Bertraghboy Bay which has been identified through this analysis as a potential hotspot.

Considering potential broader impacts associated with invasive species introduction into aquaculture sites, sites in the Belfast and Strangford Lough area, as well as the Waterford area should also be prioritised given that these areas are designated as SACs and SPAs (Figure 2).

Table 3. Risk category thresholds for grid cells associated with aquaculture production. Note that the risk scored are included to allow risk category thresholds to be adjusted as required (for example, if a fixed proportion of cells is needed within each risk category).

Risk Category	Risk Score
Very High	50-100
High	20-50
Moderate	5-20
Low	2-5
Very Low	<2

Table 4. Total area and proportion of grid cell occupied by aquaculture production across the island of Ireland, and associated risk scores and risk categories.

Grid Cell ID	Total Aquaculture Production Area (m ²)	Prop ⁿ Cell Occupied	Risk Score	Risk Category
1639	86739425	0.867394	100	Very High
1470	85567935	0.855679	98.64941	Very High
1532	78662493	0.786625	90.68824	Very High
1583	50608095	0.506081	58.34479	Very High
1531	49326458	0.493265	56.86722	Very High
1577	46218470	0.462185	53.28407	Very High
1520	35618860	0.356189	41.06396	High
1469	27924754	0.279248	32.19355	High
1653	27562956	0.27563	31.77644	High
1644	25012858	0.250129	28.83647	High
1645	22704597	0.227046	26.17532	High
1408	22334926	0.223349	25.74913	High
1777	21878602	0.218786	25.22304	High
1533	20889343	0.208893	24.08254	High
1638	20048383	0.200484	23.11301	High
1521	18157797	0.181578	20.93339	High
1715	17058387	0.170584	19.6659	Moderate
1582	14077590	0.140776	16.22939	Moderate
1576	13860548	0.138605	15.97916	Moderate
1839	13400438	0.134004	15.44871	Moderate
1534	12438350	0.124384	14.33953	Moderate
1511	11852562	0.118526	13.66419	Moderate
2219	10696031	0.10696	12.33084	Moderate
1584	8680560	0.086806	10.00724	Moderate
3020	7533446	0.075334	8.684751	Moderate
3180	6631585	0.066316	7.645011	Moderate
1409	6463737	0.064637	7.451502	Moderate
1594	6219503	0.062195	7.169929	Moderate
1471	5131379	0.051314	5.915448	Moderate
1640	4869603	0.048696	5.613651	Moderate
1727	4817656	0.048177	5.553763	Moderate
3062	4663798	0.046638	5.376382	Moderate
1449	4375213	0.043752	5.043678	Moderate
1578	4208663	0.042087	4.851664	Low
3179	3979937	0.039799	4.58797	Low
3063	3847771	0.038478	4.435598	Low
2430	3542538	0.035425	4.0837	Low
1595	3446000	0.03446	3.972404	Low
2773	3357611	0.033576	3.870501	Low

1894	3290844	0.032908	3.793526	Low
2493	2838333	0.028383	3.271834	Low
1956	2737445	0.027374	3.155523	Low
2188	2724386	0.027244	3.140466	Low
1714	2560471	0.025605	2.951492	Low
1701	2548841	0.025488	2.938084	Low
3000	2506391	0.025064	2.889144	Low
2527	2432239	0.024322	2.803655	Low
2069	2365245	0.023652	2.726419	Low
3118	2032580	0.020326	2.342895	Low
1725	2012818	0.020128	2.320112	Low
2068	1992047	0.01992	2.296165	Low
1518	1781084	0.017811	2.05295	Low
2494	1771958	0.01772	2.042428	Low
1601	1665989	0.01666	1.920259	Very Low
1538	1643463	0.016435	1.894289	Very Low
1652	1473400	0.014734	1.698225	Very Low
2958	1332071	0.013321	1.535291	Very Low
2123	1229159	0.012292	1.416645	Very Low
2126	1155676	0.011557	1.331927	Very Low
1700	1073633	0.010736	1.237341	Very Low
1663	1050280	0.010503	1.210418	Very Low
2250	1029906	0.010299	1.186929	Very Low
1539	1012923	0.010129	1.16735	Very Low
1895	920511	0.009205	1.060809	Very Low
2127	919846.3	0.009198	1.060043	Very Low
2125	917641	0.009176	1.057501	Very Low
2097	866390	0.008664	0.998414	Very Low
3114	845980.8	0.00846	0.974885	Very Low
1580	796821	0.007968	0.918209	Very Low
1581	777629.9	0.007776	0.896084	Very Low
3019	769388.3	0.007694	0.886582	Very Low
1579	736527.3	0.007365	0.848698	Very Low
2185	677712.6	0.006777	0.780891	Very Low
3077	659658.9	0.006597	0.760077	Very Low
2281	645482.3	0.006455	0.743733	Very Low
3184	636089.1	0.006361	0.732904	Very Low
3178	596219.1	0.005962	0.686939	Very Low
1456	591337.4	0.005913	0.681311	Very Low
2553	582342.1	0.005823	0.67094	Very Low
1513	550070	0.005501	0.633734	Very Low
3243	543831.4	0.005438	0.626542	Very Low
1519	535660.9	0.005357	0.617122	Very Low
1457	532344.4	0.005323	0.613299	Very Low

1515	529751.6	0.005298	0.610309	Very Low
2835	515025.5	0.00515	0.593332	Very Low
1514	453737.2	0.004537	0.522674	Very Low
1957	438762.3	0.004388	0.505409	Very Low
1477	422480.8	0.004225	0.486639	Very Low
1662	399175.3	0.003992	0.45977	Very Low
2368	380768.8	0.003808	0.43855	Very Low
1665	370702.6	0.003707	0.426944	Very Low
1602	359068.3	0.003591	0.413532	Very Low
2067	355081.7	0.003551	0.408935	Very Low
2492	341564.9	0.003416	0.393352	Very Low
2405	326802.8	0.003268	0.376333	Very Low
3113	304910	0.003049	0.351093	Very Low
2957	298670.4	0.002987	0.3439	Very Low
2189	289606	0.002896	0.333449	Very Low
2774	289104.9	0.002891	0.332872	Very Low
1664	286970	0.00287	0.330411	Very Low
1517	262556.2	0.002626	0.302264	Very Low
1476	262183.8	0.002622	0.301835	Very Low
1603	251020	0.00251	0.288964	Very Low
1350	248813.7	0.002488	0.286421	Very Low
1599	234632.9	0.002346	0.270072	Very Low
2064	200301.2	0.002003	0.230492	Very Low
1706	197533.7	0.001975	0.227301	Very Low
2431	193665.2	0.001937	0.222841	Very Low
3306	187623	0.001876	0.215875	Very Low
1348	180697.1	0.001807	0.20789	Very Low
1591	177525.9	0.001775	0.204234	Very Low
1473	153119.2	0.001531	0.176096	Very Low
1537	150218.1	0.001502	0.172751	Very Low
1414	146828.3	0.001468	0.168843	Very Low
2159	119029.8	0.00119	0.136795	Very Low
1575	111590.5	0.001116	0.128218	Very Low
1821	108492.3	0.001085	0.124647	Very Low
3305	106777.9	0.001068	0.12267	Very Low
3076	105405.2	0.001054	0.121087	Very Low
1512	99952.81	0.001	0.114802	Very Low
1912	90027.88	0.0009	0.103359	Very Low
2184	84382.51	0.000844	0.096851	Very Low
1724	64587.53	0.000646	0.07403	Very Low
3245	64178.96	0.000642	0.073558	Very Low
3246	56821.17	0.000568	0.065076	Very Low
1900	55889.44	0.000559	0.064002	Very Low
1766	55597.06	0.000556	0.063665	Very Low

2124	45928.46	0.000459	0.052518	Very Low
2183	45577.37	0.000456	0.052113	Very Low
1572	42348.12	0.000423	0.04839	Very Low
2772	32974.24	0.00033	0.037583	Very Low
2245	24394.67	0.000244	0.027692	Very Low
1661	22502.17	0.000225	0.02551	Very Low
3244	19948.01	0.000199	0.022565	Very Low
1726	17310.78	0.000173	0.019525	Very Low
1412	15572.69	0.000156	0.017521	Very Low
3014	15435.79	0.000154	0.017363	Very Low
2130	11848.91	0.000118	0.013228	Very Low
1478	10628.61	0.000106	0.011821	Very Low
1833	10397.86	0.000104	0.011555	Very Low
1892	9731.598	9.73E-05	0.010785	Very Low
1472	8148.635	8.15E-05	0.008964	Very Low
3051	7842.905	7.84E-05	0.008606	Very Low
2186	6813.727	6.81E-05	0.007419	Very Low
1707	5314.853	5.31E-05	0.005689	Very Low
1708	5110.755	5.11E-05	0.005459	Very Low
2370	3731.393	3.73E-05	0.003868	Very Low
1641	2682.405	2.68E-05	0.002657	Very Low
1646	1812.595	1.81E-05	0.001654	Very Low
3124	1221.679	1.22E-05	0.000974	Very Low
2940	937.619	9.38E-06	0.000649	Very Low
1413	499.687	0.000005	0.000144	Very Low

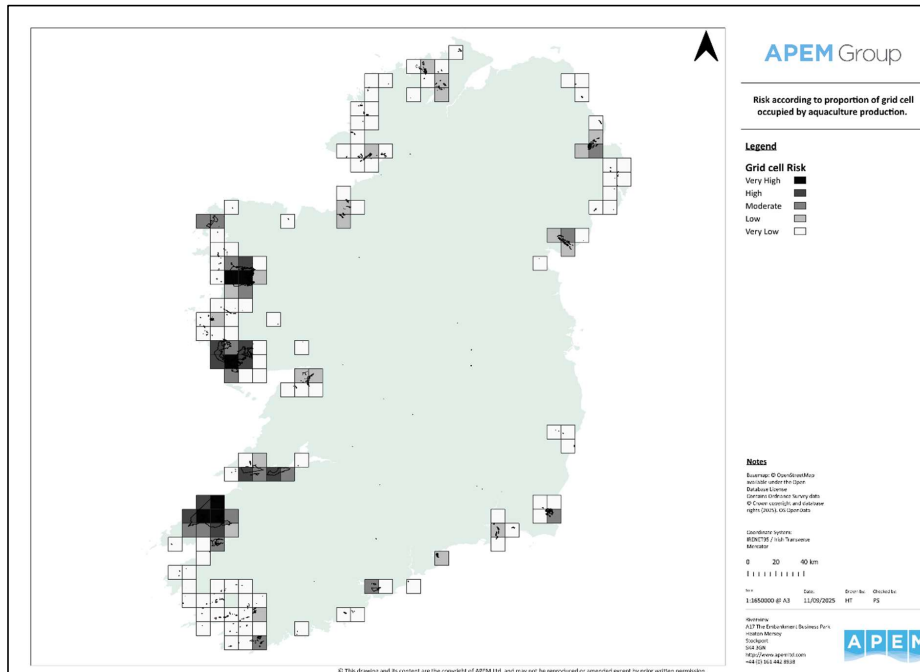


Figure 7. 10km² grid cells across the island of Ireland by invasive species risk associated with aquaculture production, estimated using the proportion of the cell occupied by licensed aquaculture production sites. Note that inland sites have been excluded as this section focuses on marine invasive species monitoring.

3.2.2 Marine aquaculture site invasive species-specific monitoring programme design considerations

The frequency of surveys at marine aquaculture sites may need to be increased in order to capture new invasive species introductions. Annual or biennial survey of highest risk sites is recommended.

High risk areas not covered by existing monitoring – Belfast Harbour and Bertraghboy Bay – should also be considered for inclusion in future surveys. Sites in Belfast, Strangford Lough and Waterford should also be prioritised given that these areas have protection designations.

The methods deployed at aquaculture sites as part of the existing invasive species monitoring programme focus on the detection of fouling organisms attached to aquaculture stock as well as artificial hard substrate such as cages and ropes located around the sites. The deployment of additional methods such as baited traps should be considered to enhance capacity to detect mobile

pelagic and mobile benthic species (see Chapter 3 for detailed information on invasive species monitoring methods, including seasonal considerations).

The risk of aquaculture sites should also be considered in light of stock movement restrictions and biosecurity practices, driven by aquaculture animal health legislation.

3.2.3 Future Directions

A more robust assessment of risk with respect to aquaculture sites, to inform the enhancement of an invasive species-specific monitoring programme into the future, requires access to data which better reflects the scale of activity, in particular production and stock movements, at each site. While the sensitivity of such data is acknowledged, opportunities to receive and use this data at an acceptable resolution should be explored. For example, production and movement data could be classified into broader categories, or manipulated into risk categories by the relevant regulatory authority and passed on as a data product, such that no raw data is shared. This more robust assessment of risk will facilitate the optimisation of sampling design (according to outputs from Chapter 2 on sampling design).

While bespoke invasive species monitoring at marine aquaculture sites is conducted via existing programmes, there is perhaps opportunity to supplement this by incorporating more standardised invasive species detection and reporting into existing industry surveys and monitoring requirements. This will be facilitated by awareness raising within the industry, in particular in relation to key invasive species risks associated with the marine aquaculture pathway (i.e., *Didemnum vexillum* whose spread may be attributed to movement of contaminated oyster stock (e.g., Cottier-Cook et al., (2019)).

4 Development and implementation of additional bespoke invasive species monitoring programmes to address shortfalls with respect to priority site-specific legislative requirements – commercial ports

Commercial ports are considered hotspots for invasive species introduction and spread, given their association with commercial shipping and the transfer of invasive species via ballast water and hull fouling pathways biofouling (Seebens et al., 2013; Sardain et al., 2019; Costello et al., 2022). Monitoring of ports across the island of Ireland is specifically required to fulfil the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004, as well being relevant to the Invasive Alien Species Regulations, the MSFD, and their respective national implementing legislation (see Legislation Summary in Supplementary Material). The 'ship/boat ballast water' and 'hitchhikers on ship/boat' pathways are also assigned to a high proportion of identified priority invasive species across the island of Ireland ranking as 6th and 8th most common pathways for all priority species types, respectively (see Chapter 1, Table 4), further highlighting the importance of monitoring at ports.

4.1 Risk Scoring

A simple assessment of invasive species risk for ports across the island of Ireland, to contribute evidence to underpin the development of a risk-based port monitoring programme, was undertaken. Port risk was also considered in the context of potential impacts informed by the location of protected sites. Further, specific considerations with respect to port monitoring programme design and future work to inform port risk assessment are highlighted.

Commercial ports in operation across the island of Ireland were identified from NI Marine Mapviewer (Table 5). Data on the number of vessels arriving into main ports in IE and NI were downloaded from the Central Statistics Office (CSO) and the UK Government Department for Transport, respectively. In addition, data on tonnage received into each main port in IE and NI were downloaded from CSO and the Northern Ireland Statistics and Research Agency, respectively (see appendix for information on data sources). Note that the data used were available for main ports only.

Analysis was based on data from 2021 to 2023 inclusive, given that these are the most recent years for which data were available for all ports. Kilroot Power Station Jetty was not listed on NI Marine Mapviewer but was included in the analysis as it is considered a Major Port in NI. Greenore port is currently considered a main port in IE, meeting the definition of main port from Q1 2025 (Central Statistics Office, 2025), but is excluded from the analysis given it covers 2021-2023 only.

The mean number of vessels into each port for years 2021 to 2023 was calculated (Figure 8). The tonnage received per port was categorised by origin category as detailed in Table 6 and the mean arrival tonnage from each origin port category was calculated (Figure 9). Note that for ports in NI,

category 'Ireland and UK' excludes tonnage from IE as this is grouped in with EU and therefore incorporated into category 'Europe'.

The risk score was based on the mean number of vessels into port, a proxy for invasive species propagule pressure, weighted by the proportion of arrival tonnage from outside Ireland and UK, a proxy for the risk of introduction of an invasive species not yet reported in Ireland (see Table 7). This weighted mean number of vessels into port was normalised to create a risk score between 0 and 100 (see appendix for the normalisation equation). Based on these normalised scores, ports were ranked and assigned to five risk score categories as defined in Table 8 to facilitate comparison of relative risk between ports.

Data were mapped to facilitate visualisation of risk associated with main ports across the island of Ireland. For notes on data analysis and mapping see the appendix. Outputs are presented in Figure 10 and Table 7.

Risk scores indicate that Dublin is the highest risk port. This concurs with previous studies by Tidbury et al., (2016), and Costello et al., (2022) which examined invasive species risk for selected ports in Ireland using Automatic Identification System (AIS) data. Shannon Foynes and Cork rank 2nd and 3rd, and along with Dublin, are categorised at 'Very High' risk. Belfast and Waterford have the 4th and 5th highest risk scores, and are categorised as 'High' risk. Risk categories indicate relative risk between ports, though as main ports experiencing high volume of incoming traffic, all ports analysed are considered at high risk of introduction of invasive species.

It is worth noting that weighting vessel count by proportion of tonnage from outside Ireland and UK does change port ranking and risk category for some ports. This highlights the importance of using the most accurate data to inform such risk assessment. In this assessment, delineation of tonnage between origin countries was not possible and groupings by origin category was not straightforward. More specifically, for tonnage into IE, delineation between NI (i.e., domestic at an island of Ireland level) and GB origin was not possible. Further, for NI, delineation of tonnage between origin ports in IE and the rest of European Union (EU) was not possible (as tonnage from IE is combined with tonnage from the rest of the EU). This highlights the need for port data at individual origin port or origin port country resolution (see future directions section or further information).

Providing further weight to the need to monitor the ports identified as 'Very High' and 'High' risk, is their location within or in close proximity to sensitive sites, specifically SACs and SPAs (Figure 2), and the potential impact that the introduction of invasive species into these ports could have on protected features.

Table 5. Commercial ports across NI and IE identified from NI Marine Mapviewer. Main Ports refers to ports meeting specific criteria¹ between 2021 and 2023.

Name	Region	Latitude	Longitude	URL	Main Port
Arklow	IE	52.79	-6.14	http://www.worldportsource.com/ports/IRL_Port_of_Arklow_3201.php	N
Bantry Bay	IE	51.68	-9.46	http://www.bantrybayport.com	Y
Belfast	NI	54.63	-5.89	http://www.belfast-harbour.co.uk	Y
Castletownbere	IE	51.65	-9.91	http://www.worldportsource.com/ports/IRL_Castletownbere_Harbor_4405.php	N
Coleraine	NI	55.13	-6.67	http://www.coleraineharbour.com/	N
Cork	IE	51.9	-8.42	http://www.portofcork.ie	Y
Drogheda	IE	53.72	-6.31	http://www.droghedaport.ie	Y
Dublin	IE	53.35	-6.22	http://www.dublinport.ie	Y
Dun Laoghaire	IE	53.29	-6.11	http://www.dlharbour.ie	N
Dundalk	IE	54.01	-6.35	http://www.worldportsource.com/ports/portCall/IRL_Port_of_Dundalk_3208.php	N
Foyle	NI	55.04	-7.27	https://www.foyleport.com/	Y
Galway	IE	53.27	-9.05	http://www.galwayharbour.com	N
Greenore	IE	54.03	-6.14	http://www.worldportsource.com/ports/IRL_Port_of_Greenore_3210.php	N
Killybegs	IE	54.64	-8.44	http://www.killybegsharbour.ie	N
Kilroot Power Station Jetty*	NI	54.72	-5.76		Y
Kilrush	IE	52.63	-9.5	http://www.kilrushcreekmarina.ie/	N
Kinsale	IE	51.7	-8.52	http://www.irelandwide.com/port/kharbour/index.htm	N
Larne	NI	54.86	-5.81	http://www.portoflarne.co.uk	Y
New Ross	IE	52.4	-6.95	http://www.worldportsource.com/ports/IRL_Port_of_New_Ross_3216.php	N
Rosslare	IE	52.26	-6.34	http://www.rosslare-europort.ie	Y
Shannon Foynes	IE	52.59	-9.36	http://www.sfpc.ie	Y
Sligo	IE	54.28	-8.49	http://www.sligococo.ie/Services/SligoHarbour	N
Tralee Fenit	IE	52.27	-9.86	http://www.fenitharbour.com	N
Warrenpoint	NI	54.1	-6.25	http://www.warrenpointharbour.co.uk/	Y
Waterford	IE	52.26	-7.1	http://www.portofwaterford.com	Y
Wicklow	IE	52.98	-6.04	http://www.wicklowport.ie	N
Youghal	IE	51.94	-7.84	http://www.worldportsource.com/ports/IRL_Port_of_Youghal_3228.php	N

*Kilroot Power Station Jetty was not listed on NI Marine Map Viewer but is included for completeness as it is considered a main port in the port risk analysis.

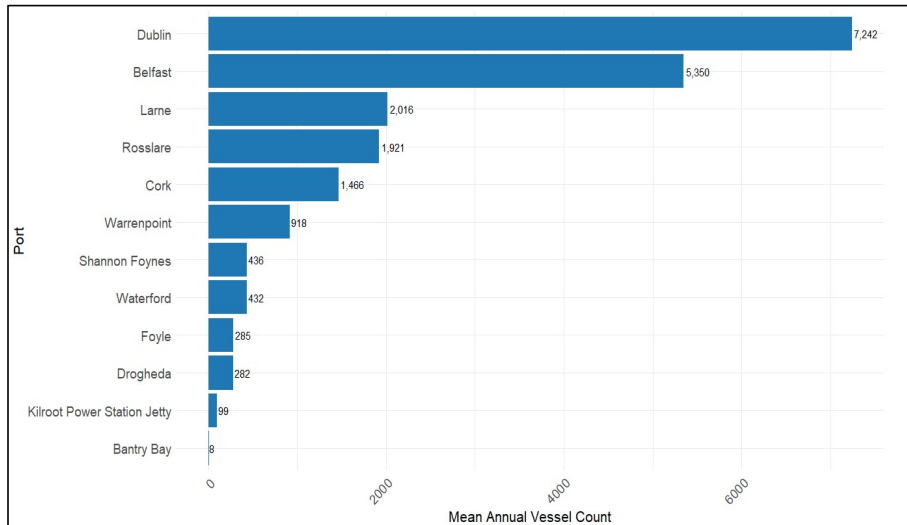


Figure 8. Mean annual inward vessel counts for 2021 to 2023, for main ports across the island of Ireland.

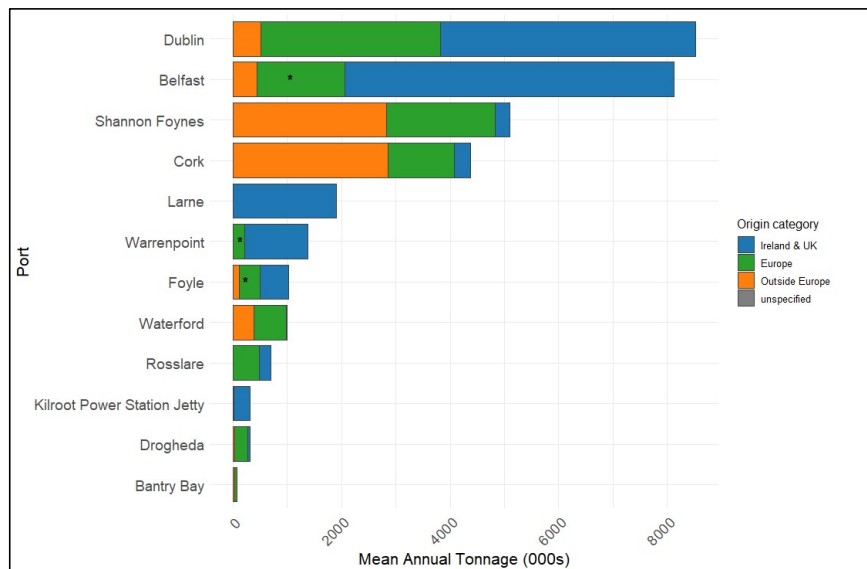


Figure 9. Mean annual tonnage (000s) arriving in 2021 to 2024 into main ports across the island of Ireland.

Table 6. Origin port categories referenced in tonnage arrival data used for NI (middle column) and IE (right hand column) and their grouping into origin port categories used in the analysis to inform port risk scoring (left hand column).

Origin port categories for analysis	NI origin categories referenced in downloaded data	IE origin categories referenced in downloaded data
Ireland and UK (for NI this excludes tonnage from IE as this is grouped in with EU)	United Kingdom (inc. CHI & IOM)	Foreign trade: Great Britain and Northern Ireland
		Coastal: Irish ports, excl. Northern Ireland
Europe	European Union (excl. United Kingdom)	Foreign trade: EU excl. Ireland
	Other Europe (excl. European Union) & Mediterranean	Foreign trade: Non-EU European countries, excl. Great Britain and Northern Ireland
Outside Europe	Africa (excl. Mediterranean)	Foreign trade: Outside Europe
	America	
	Asia (excl. Mediterranean)	
	Australasia	

Table 7. Relative port risk scores and categories, and their components.

Name	Prop ⁿ Tonnage from Outside Ireland & UK	Mean Annual Vessel Count	Weighted Mean Annual Vessel Count	Risk Score	Risk Category
Dublin	0.448023	7242	3244.579	100	Very High
Shannon					
Foynes	0.946084	2016	1907.305	58.71856	Very High
Cork	0.934526	1921	1795.225	55.25868	Very High
Belfast	0.253806	5350	1357.862	41.75735	High
Waterford	0.987789	432	426.7247	13.01329	High
Foyle	0.482455	436	210.3502	6.333847	Moderate
Rosslare	0.693868	285	197.7523	5.944953	Moderate
Warrenpoint	0.157564	918	144.6442	4.305513	Moderate
Drogheda	0.877005	99	86.82353	2.5206	Moderate
Kilroot Power Station Jetty	0.054361	282	15.32992	0.313604	Low
Bantry Bay	1	8	8	0.08733	Low
Larne	0.003527	1466	5.171017	0	Low

Table 8. Risk category thresholds for ports. Note that the risk scores are included to allow risk category thresholds to be adjusted as required (for example, if a fixed proportion of ports is needed within each risk category).

Risk Category	Risk Score
Very High	50-100
High	20-50
Moderate	5-20
Low	2-5
Very Low	<2

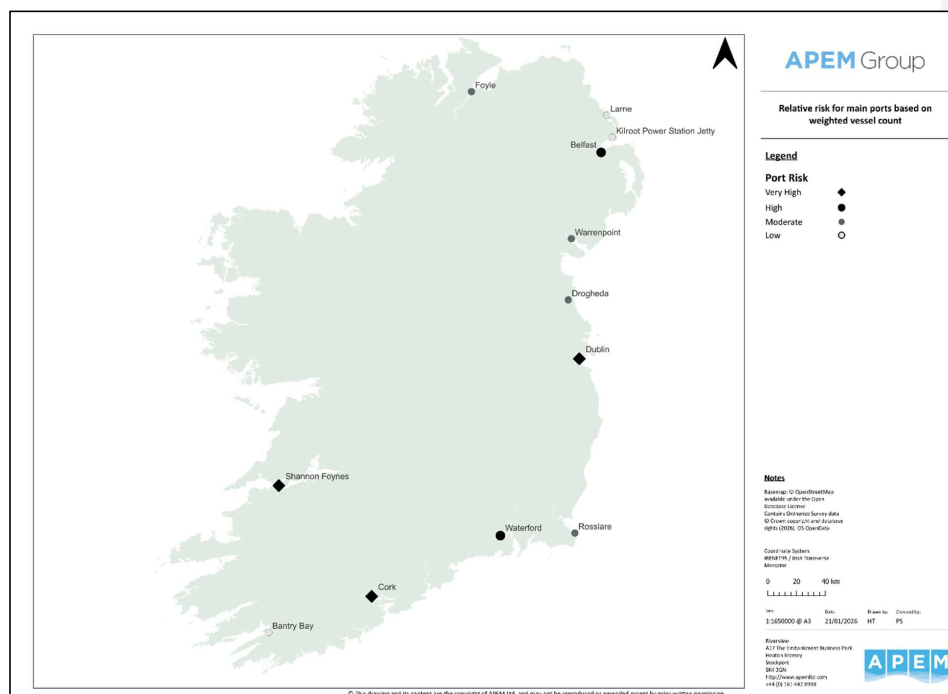


Figure 10. Main commercial ports across the island of Ireland, presented to reflect their relative invasive species risk estimated using inward vessel counts weighted by the proportion of tonnage from outside Ireland and UK.

4.1.1 Port-Specific Monitoring programme design considerations

Comprehensive guidance regarding the implementation of port surveys exists (e.g., Awad et al., 2014; Kraus et al., 2023) and should be consulted alongside this report.

Relative port risk for main ports across the island of Ireland, based on weighted inward vessel counts, follows a positive skewed distribution (Figure 11), suggesting that a sampling approach which prioritises high-risk sites while still incorporating low risk sites but at a lower monitoring frequency may enhance monitoring success (see simulation outputs within Chapter 2).

Ports are hotspots for species associated with the shipping pathway, including both ballast water and biofouling transfer mechanisms. Artificial hard substrate is common within port environments. Appropriate monitoring methods are therefore those suited to species with pelagic life stages (including larvae and juveniles), as well as fragmenting or fouling species, including zooplankton trawls, settlement panels; RASs; baited traps; and eDNA (see Chapter 3 for detailed information on invasive species monitoring methods, including seasonal considerations).

Note that the focus here is on the detection of priority invasive species. However, to fulfil the requirements of Ballast Water Management Legislation, deployment of methods to detect pathogens, and indicator organisms at very low prevalence, will also be required.

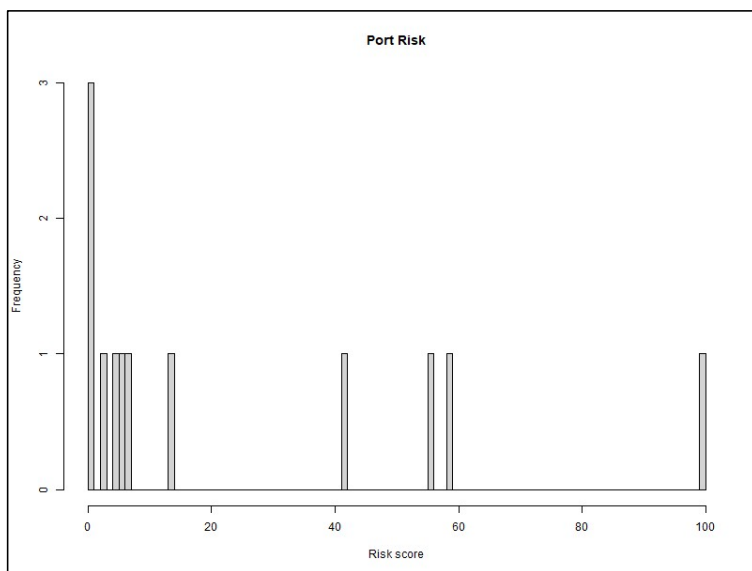


Figure 11. The frequency distribution of port risk scores based on tonnage received.

4.2 Future Directions

Readily accessible port data do not allow for high resolution analysis, with data detailing inward vessel counts per origin port not available. Weighting vessels counts according to tonnage into ports from different origin regions goes some way to account for the differential risks posed by vessel traffic coming from other ports across the island of Ireland and the UK compared to further afield, but due to the origin port categories has limitations.

A more robust port risk assessment, including all ports across the island of Ireland is needed, and should incorporate:

- Shipping data such as vessel numbers, vessel size, origin port, vessel type, and within- and between-year seasonality in traffic, expanding the analysis conducted by Costello et al., (2022) and Tidbury et al., (2016).
- Environmental data (e.g., temperature, salinity, habitat in origin and receptor ports) and invasive species data (e.g., number of marine invasive species recorded in origin port but not in receptor port), to facilitate the identification of high-risk origin ports, in terms of priority invasive species presence and climatic matching.
- Other relevant marine invasive species pathway data / information to inform understanding of proximity of port to other pathway hotspots such as marinas and aquaculture sites.
- Sensitive site data to inform understanding of potential impact of introduction of invasive species via ballast water.
- Consideration of ballast water compliance testing outputs and high-risk activity/events (decommissioning of infrastructure, construction, dredging) and the need for reactive / ad-hoc monitoring programme refinement.

5 Appendix - Data Analysis Notes

5.1 Software used

Data analysis was performed in R Studio (v2024.04.02), primarily using package dplyr.

Mapping and spatial analysis was conducted in QGIS (v 3.40.10-Bratislava).

5.2 Hotspot Risk Score Normalisation Equation

$$z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)} * 100$$

Where,

z_i : Normalised risk score for the i^{th} hotspot site

x_i : Risk score for the i^{th} hotspot site

$\min(x)$: Minimum risk score across all hotspot sites

$\max(x)$: Maximum risk score across all hotspot sites

5.3 Data Sources

A variety of data sources were interrogated. The sources of data used in the data analysis and mapping presented above are outlined in Table 9.

Table 9. Summary of data used for the data analysis and mapping.

Data	Source	Data note
Marina locations	Agriculture, Environment and Rural Affairs (DAERA), O'Shaughnessy, et al., (2023), Ireland's Marine Atlas	Data file combined from all sources.
Finish Aquaculture NI	DAERA: https://www.daera-ni.gov.uk/publications/public-register-approved-aquaculture-establishments	Spatial reference information was not available and had to be manually sought using the site addresses provided. For some sites, the address information was not specific, and the site name did not yield location data, such that the confidence in the spatial reference is low.
Shellfish Aquaculture NI	DAERA open data: https://opendata-daerani.hub.arcgis.com/datasets/DAERANI::aquaculture-licences-open-data/explore?location=54.494063%2C-5.974678%2C9.36	Licensed shellfish production areas for Northern Ireland (NI)
Aquaculture sites IE	Ireland's Marine Atlas	Details via Ireland's Marine Atlas: Aquaculture data has been provided via special request, by the Department of Agriculture, Food and the Marine (DAFM) for reporting on aquaculture activities under Ireland's Marine Strategy Framework Directive (MSFD) article reporting. Aquaculture sites include shellfish, finfish and seaweed as monitored for licensing purposes. Aquaculture sites are updated periodically.

Data	Source	Data note
		Note that finfish sites were included.
Ports locations IE & NI	NI Marine Mapviewer	Checked by Department of Transport, Ireland (IE).
Port vessel arrivals, IE	Central Statistics Office (CSO), Ireland https://data.cso.ie/table/TBQ01DoT	
Port vessel arrivals, NI	Department for Transport, UK Government port0602.ods	
Tonnage into port, IE	CSO, Ireland CSO https://data.cso.ie/table/TBQ07	
Tonnage into port, NI	Northern Ireland Statistics and Research Agency https://ws-data.nisra.gov.uk/public/api.restful/PxStat.Data.Cube_API.ReadDataset/PORT01/XLSX/2007/en	
Botanical gardens	Google searches, yielding information from: https://assets.gov.ie/static/documents/historic-garden-visitor-guide.pdf https://www.botanicgardens.ie/kilmacurragh/ https://www.botanicgardens.ie/glasnevin/	Manually extracted names and locations.

Data	Source	Data note
	https://en.wikipedia.org/wiki/List_of_botanical_gardens_in_Ireland	
Zoos and wildlife parks	Google searches, yielding information from: https://en.wikipedia.org/wiki/List_of_zoos_and_aquariums_in_Ireland (for IE) https://discovernorthernireland.com/things-to-do/outdoors-nature-and-wildlife/wildlife-and-zoos (for NI)	Manually extracted names and locations.
Aquaria	Google searches, yielding information from: https://www.go-to-ireland.com/type-of-place/irish-aquariums/ https://en.wikipedia.org/wiki/List_of_zoos_and_aquariums_in_Ireland	Manually extracted names and locations.
Fisheries	Fishery Guide Website: https://www.fisheryguide.co.uk/northern-ireland/ (for NI) https://www.fisheryguide.co.uk/ireland/ (for IE)	Manually extracted names and locations of fisheries listed in NI and IE from this site. For some fisheries specific location information was not available so location spatial reference confidence is low.
Protected Sites	NPWS website: Protected Sites in Ireland National Parks & Wildlife Service (for IE) Open Data NI https://www.opendatani.gov.uk/search (for NI)	

Data	Source	Data note
WFD monitoring locations	EPA website: https://gis.epa.ie/GetData/Download, Mon_QStations_1802202 shapefile (for IE) DAERA open data: https://opendata-daerani.hub.arcgis.com/search, WFD_River_and_Lake_Monitoring_Sites.shp (for NI).	

Field Code Changed

5.4 Specific notes

5.4.1 Finfish Aquaculture sites in Northern Ireland

Data were downloaded from the Northern Ireland Executive website (see Table 9). Explicit spatial references were not provided in the downloaded dataset. Addresses provided were therefore manually converted into longitudes and latitudes. Confidence in the assignment of spatial reference was low for some establishments whose name was not recognised and whose address did not include a house number or street name. Further, it was not clear whether the addresses listed were for the fish farms/fisheries themselves or the registered business, which may have been located elsewhere. It is recommended that data on aquaculture site locations are checked with the regulator in more detail.

5.4.2 Fisheries data

State fishery lists were found for both IE and NI. For NI this was in the form of a shapefile (DAERA open data: <https://opendata-daerani.hub.arcgis.com/datasets/DAERANI::inland-fisheries-public-angling-estate/about>). However, the list for IE was in pdf format (Inland Fisheries Ireland: <https://www.fisheriesireland.ie/media/state-fisheries-list-2025>) and contained descriptive spatial information only, limiting scope to translate into a shapefile without significant time, effort and uncertainty.

Given the importance of angling/fishing equipment as a pathway of invasive species introduction, and the potential impact of invasive species on the angling industry, alternative data to allow these hotspots to be incorporated into analysis were sought. Google searches were performed to determine potential sources of fishing location data. The best source of data was deemed to be <https://www.fisheryguide.co.uk/>, which lists all key fishing locations (including fisheries, lakes, loughs, reservoirs) for both IE and NI. This information was extracted, and each identified site was assigned a longitude and latitude.

5.4.3 Data Observations and Limitations

- The number of data and information portals available, when considering the three habitats (marine, freshwater, and terrestrial) across the two jurisdictions, was difficult to manage, particularly where the data were inconsistent and download functions were different.
- More data seemed to be available / easily accessible for the marine environment, facilitated by key marine data and mapping platforms Ireland's Marine Atlas and NI Marine Mapviewer. This is perhaps driven by marine legislation and policy which requires data on human activities in the marine environment.
- Data which is available for IE is not always available (or open access) for NI and vice versa. For example, sailing route data was available via Ireland's Marine atlas for IE, but similar data for NI needs to be purchased from the Royal Yachting Association.

- Some data portals link to external data sources for download but it is not always easy to match the data to download with the data presented on the portal (the portal links to data homepage rather than page for specific data).
- Some seemingly obvious data (e.g., the WFD waterbody shapefiles) is not available in an easy-to-access location/format across both jurisdictions.
- Site lists and distribution maps (images) for the sites of interest for the project (indicating locations of pathway activity) exist but require time-consuming digitisation (see below for examples).
- Some data could not be obtained/used due to sensitivities. For example, aquaculture import data could not be provided by the relevant authorities for the purpose of this project due to the sensitive nature of these data.
- Organisations contacted regarding data often did not respond, despite the purpose and value of the project and data requested being outlined. Lack of response could have been exaggerated because it was a consultancy who contacted them rather than a government agency.

Table 10. Examples of useful data which is available but requires digitisation for use in analysis.
Greyed out entries are those manually digitised for analysis in Chapter 4.

Environment	Data	Link
Freshwater / Marine	Sailing clubs in IE & NI	https://www.sailing.ie/Training/Find-a-club-or-centre
Freshwater / Marine	Waterski and wakeboard clubs in IE & NI	https://www.irishwwf.ie/clubs
Freshwater / Marine	Swimming locations in Ireland	https://swimcoach.ie/ireland-swimming-map
Freshwater / Marine	Canoeing / kayak clubs in IE & NI	https://www.canoe.ie/find-a-club/
Marine	Coastal rowing clubs in IE & NI	https://www.coastalrowing.ie/clubs-drafting/
Freshwater / Marine	Rowing in Ireland	https://www.rowingireland.ie/rowing-for-all/find-a-club-in-your-area/
Freshwater / Marine	Irish Aquariums	https://www.go-to-ireland.com/type-of-place/irish-aquariums/
Freshwater	Coarse fishing clubs Ireland	https://www.ncffi.ie/find-a-club/

Freshwater	State Fisheries list (2025) for Ireland	https://www.fisheriesireland.ie/media/state-fisheries-list-2025
Freshwater	Navigable waterways	https://www.waterwaysireland.org/boat-owners/boat-owner-information
Marine	Blue Flag Beach locations	https://beachawards.ie/blue-flag/
Marine	Coastal rowing clubs in IE & NI	https://www.coastalrowing.ie/clubs-drafting/
Terrestrial	National parks in IE	https://www.go-to-ireland.com/type-of-place/national-parks/
Terrestrial	Zoos and wildlife parks (and aquariums) in Ireland	https://en.wikipedia.org/wiki/List_of_zoos_and_aquariums_in_Ireland
Terrestrial	Garden centres in IE	https://www.gardencentreguide.ie/garden-centres
Terrestrial	Garden centres and nurseries in NI	https://www.4ni.co.uk/sub/428x1/northern-ireland-garden-centres-and-nurseries
Terrestrial	Wildlife parks and zoos in NI	https://discovernorthernireland.com/things-to-do/outdoors-nature-and-wildlife/wildlife-and-zoos
Terrestrial	Gardens of Ireland	https://www.gardensofireland.org/directory/?q=0&gid=1
Terrestrial	Open gardens in Northern Ireland	https://en.wikipedia.org/wiki/Gardens_in_Northern_Ireland
Terrestrial	Ireland's trails (walking, cycling)	https://www.sportireland.ie/outdoors/find-your-trails

6 References

Awad, A., Haag, F., Anil, A.C. and Abdulla, A., 2014. Guidance on Port Biological Baseline Surveys (PBBS).

Central Statistics Office, 2025. Statistics of Port Traffic Quarter 1 2025.

<https://www.cso.ie/en/releasesandpublications/ep/p-spt/statisticsofporttrafficquarter12025/>

- Costello, K. E., Lynch, S. A., McAllen, R., O'Riordan, R. M., & Culloty, S. C. (2022). Assessing the potential for invasive species introductions and secondary spread using vessel movements in maritime ports. *Marine Pollution Bulletin*, 177, 113496-113496. <https://doi.org/10.1016/J.MARPOLBUL.2022.113496>
- Cottier-Cook, E. J., Minchin, D., Giesler, R., Graham, J., Mogg, A. O. M., Sayer, M. D. J., & Matejusova, I. (2019). Biosecurity implications of the highly invasive carpet sea-squirt, *Didemnum vexillum* kott, 2002 for a protected area of global significance. *Management of Biological Invasions*, 10(2): 311-323. <https://doi.org/https://doi.org/10.3391/mbi.2019.10.2.07>
- Kraus, R., 2023. Ballast water management in ports: Monitoring, early warning and response measures to prevent biodiversity loss and risks to human health. *Journal of marine science and engineering*, 11(11), p.2144.
- O'Shaughnessy, K., Lyons, D., Ashelby, C., Counihan, R., Pears, S., Taylor, E.,...Stebbing, P. (2023). Rapid assessment of marine non-native species in Irish marinas. *Management of Biological Invasions* 14(2), 245-267.
- Sardain, A., Sardain, E., Leung, B., Sardain, A., Sardain, E., & Leung, B. 2019. Global forecasts of shipping traffic and biological invasions to 2050. *Nature Sustainability* 2019 2:4, 2(4). <https://doi.org/10.1038/s41893-019-0245-y>
- Seebens, H., Gastner, M.T. and Blasius, B., 2013. The risk of marine bioinvasion caused by global shipping. *Ecology letters*, 16(6), pp.782-790.
- Tidbury, H., Houghton, R., Lintott, L., Rees, J., & Stebbing, P. (2026). Invasive Species Surveillance and Monitoring: A Comprehensive Review of Existing Programmes and Initiatives. A report commissioned by the National Biodiversity Data Centre and completed by APEM Ltd.
- Tidbury, H. J., Taylor, N. G. H., Copp, G. H., Garnacho, E., & Stebbing, P. D. (2016). Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biological Invasions*, 18(11), 3277-3292. <https://doi.org/10.1007/S10530-016-1219-X>