Geographical Analysis of Ballast Water Data and Potential Threats of Invasive Species for the North Eastern United States

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1.0 Introduction

The globalization of consumer goods and natural resources has led to an unintentional increase in exchanges of native biota (Bright 1999, Barbier and Shogren 2004, Perrings et al. 2005). Organisms that were once constrained to niche native environments are increasingly finding means of transporting themselves to new territories where lack of predation and ideal living conditions allow for geographic takeover. Ballast water discharge and hull fouling have been identified as the main vectors for these introductions (Ruiz et al. 1997, Molnar et al. 2008) which end up causing billions of dollars in economic damage (Pimentel et al. 2005) and invaluable ecological harm (Gurevitch and Padilla 2004).

In the United States, several regulatory policies have been enacted in order to prevent new introductions of foreign organisms that could potentially interfere with local economies. The National Invasive Species Act of 1996 amends the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 to specifically regulate ballast water from vessels entering the United States from outside of the Exclusive Economic Zone (EEZ) (US Coast Guard 2004). Vessels entering the Great Lakes or the Hudson River above the George Washington Bridge were required to practice a prescribed ballast water exchange protocol, while every other vessel was urged to voluntarily follow the ballast water management system. On top of this, every entering vessel was required to fill out a Ballast Water Reporting Form (BWRF) that identified details of the ship's route and ballast practices (See Appendix for form). However, it was not until 2004, when the US Coast Guard extended the mandatory ballast water exchange protocol to all foreign vessels (US Coast Guard 2004), that a significant number of entering ships begin to submit these forms (Ye Seul, pers comm. 2008) Currently, a bill has reached the Senate that if passed would mandate that by 2009 all foreign vessels entering the US would be required to have on board ballast water treatment systems that meet international standards, and that by 2012 would exceed the International standard, according to number of organisms per volume of water, by a hundred fold (Kart 2008).

In this paper ballast water data is summarized and analyzed in order to identify regions that pose particularly high risk threats of introducing an invasive species to the Northeastern United States. Certain species have drawn considerable global attention because of their introductions to and subsequent detrimental effects on local economies. These species are representatives of all phyla and lists of the worst offenders number in the hundreds (Zibrowius 1991, Lowe 2001, Zenetos 2005). This is why six particular species have been selected for cross-analysis with the ballast water data. These species were chosen for their known global threat, and with consideration to the region of interest, the North Eastern United States based on expert opinion (J. Pederson, MITSG, 2008; G. Lambert, Friday Harbor, 2007; J. Carlton, Williams-Mystic Maritime Program 2007). The species of greatest concern include: *Corella eumyota*, *Elminius modestus*, *Eriocheir sinensis*, *Rapana venosa*, *Sargassum muticum*, and *Undaria pinnatifida*. One other species not included in this list but that has a potential to invade is *Hemigrapsus takanoi*. This species was previously misidentified in Europe but its location as yet is not well-defined and a decision was made not to include it in the analysis. By superimposing the known locations of establishment for these species with localized ballast water data, we can better understand the risk level that these species pose.

2.0 Methods

Ballast water data were cleaned, compiled, and entered into a Geographic Information System (GIS). This allowed for a geographic analysis of the data based on predetermined bioregions. High risk bioregions were identified, and select species were analyzed for relative risk of introduction based on species establishment in these bioregions.

2.1 Ballast Data

All ballast data for this paper originated from Ballast Water Reporting Forms (BWRF) submitted to the National Ballast Information Clearinghouse (NBIC). Data had been previously queried from the NBIC online database in August of 2007 and assembled into spreadsheets by state. Data in this paper only apply to the Northeastern United States defined here as Connecticut, Massachusetts, Maine, New Hampshire, New Jersey, New York, and Rhode Island, and covers the period of 7/1/1999-8/14/2007.

The spreadsheet data were imported into a relational database on June of 2008. There were 28,995 records total, 973 of which had no last port of call listed; these were excluded from analysis. Because fields in a BWRF are manually filled out, uniformity among names of ports, names of countries, volume units, ship types, and other fields was lacking. Therefore, port names and countries were altered to match official English spellings, and all volume units were converted to cubic meters.

Although BWRFs are not required of vessels traveling within the EEZ of the United States, numerous records were available with last port of calls lying within the Continental US. This can only be assumed to be a small subset of all travels made between the North Eastern region and other US ports, and therefore any analysis of this subset would be misleading. For this reason, only records with last port of calls outside of the continental US are included in any further discussion. This leaves 18,870 records and 686 unique ports. Finally, in order to focus the discussion on significant ports, only ports that had 20 or more vessels arriving within the North Eastern US were included. This left 16,778 records with 130 unique foreign ports.

Statistics based on the records were calculated for each foreign port. This included the total number of vessels from that port, as well as, the total ballast on board and total ballast water capacity for every ship originating from each port.

2.2 GIS

The list of ports and their relevant statistics were moved to a GIS database. This required obtaining latitudes and longitudes for the 130 foreign ports. The port list was cross-referenced with the NGA World Port Index, and any remaining coordinates were found elsewhere (PortWorld, WorldPortSource, GoogleEarth).

Ports were then grouped by coastal bioregions. The Marine EcoRegions of the World (MEOW) map developed by Spalding et al. [2007] was used, and all ports fell within one of the described regions. The MEOW map has three different resolutions: Realms, Provinces, and EcoRegions. The GIS database was set up to allow for easily switching data views between these three groupings. All of the analysis in this paper used the smallest division, EcoRegions, but could easily be done with both Realms and Provinces.

2.3 Risk Assessment

Of the aforementioned data entered into each BWRF, three specific fields were used to estimate a relative overall risk for each bioregion: last port of call, total ballast on board, and total ballast water capacity. Each of the selected parameters has a corresponding risk coefficient that was equally weighted to produce an estimate of relative overall risk. This allowed for geographically displacing bioregions according to risk level and easily identifying any risk patterns. (This can also easily be done with individual ports as opposed to bioregions for a more detailed analysis.) Locations of each of the six high-risk species were then researched in order to identify bioregions that contain established populations. If a species is established in one part of the EcoRegion, it has potential to spread throughout based on the assumed uniformity of a bioregion, and therefore, the entire region is counted. Coefficients from these regions were then used to calculate new risk ratings for the particular species. Regions that contained records of a species, but had no conclusive established population were graphically displayed as so, but were not included in the risk calculation.

Number of Arrivals (C1)

If a ship is a vector for foreign species introduction through hull fouling and ballast water discharge, then the number of ship arrivals in a region corresponds to the number of inoculations. Assuming each ship arrival from a region has some likelihood of carrying and releasing a foreign organism into the local ecosystem then an increase in the number arrivals should correspond to an increase in the probability of a successful inoculation. A region that sends many ships to the North Eastern United States will have a much higher risk of being the source of an introduced invasive species. The total effect of the number of ship arrivals from a region is summarized as coefficient c1 when associated with a bioregion, and C1 when associated with a high-risk species.

Ballast Water on Board (C2)

The total ballast water on board a boat (TBOB) can be used as a relative estimate of the amount of organisms present in a ship, the assumption being that the more water a ship carries from its source port, the more organisms it brings with it. Therefore, a high relative TBOB will result in a higher risk of introducing foreign species to the destination port. The total effect of TBOB will be summarized as coefficient c2 when associated with a bioregion, and C2 when associated with a high-risk species.

Ballast Water Capacity (C3)

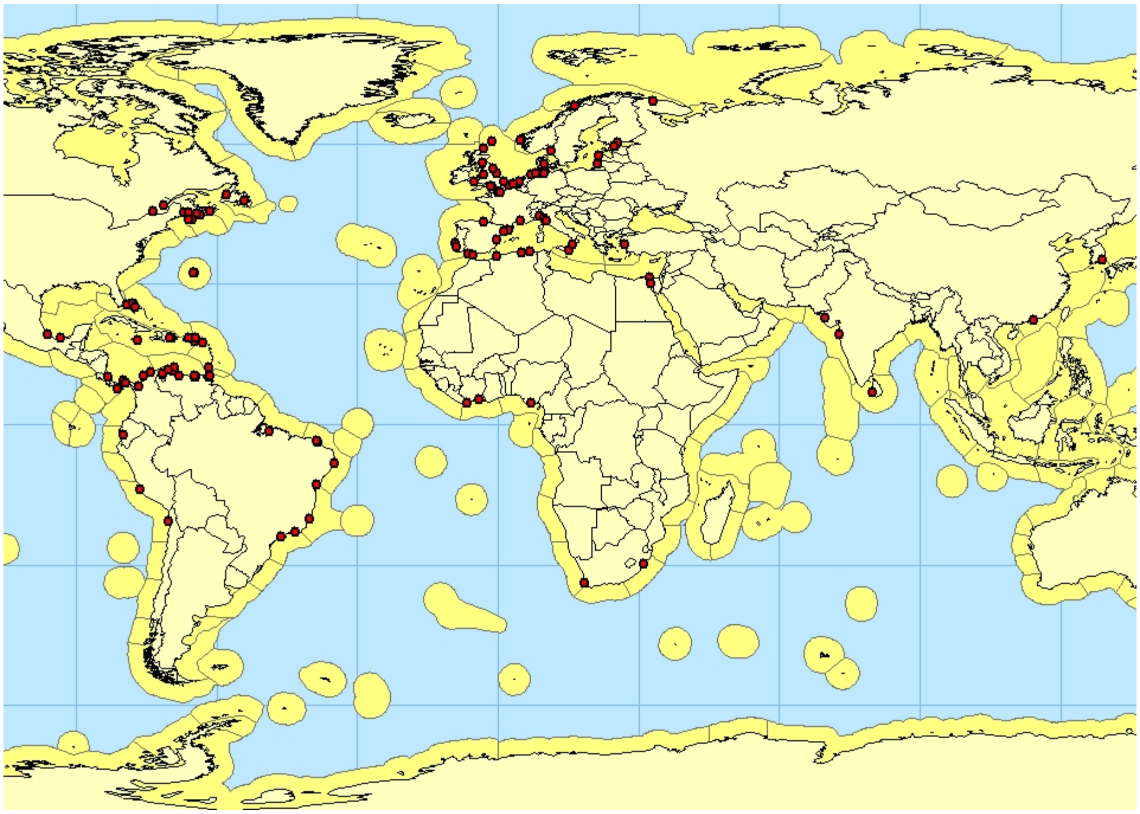
The total ballast water capacity of a boat (TBWC) can be used to estimate relative ship size. A greater TBWC implies a bigger ship (Smith et al. 1999) which in turn, allows for greater surface area availability for potential hull fouling. For this reason, reported TBWC values for ships coming from a specific bioregion have been used to estimate a relative hull fouling risk coefficient for that region. Regions with bigger ships have a higher associated hull fouling risk coefficient. Furthermore, a ship's tank size can determine likelihood of organism survival in ballast water as reported in GloBallast's ballast water risk assessment. A small tank size corresponds to a low likelihood of organism survival (due to lower oxygen levels, greater changes in temperature, and overall worse water quality) confirming that a high TBWC implies a high relative risk of foreign species introduction (Alexandrov et al. 2004). The total effect of TBWC will be summarized as coefficient c3 when associated with a bioregion, and C3 when associated with a high-risk species.

3.0 Results

GIS maps of the foreign ports as well as EcoRegions colored by risk level were made. The resulting database allows for easily viewing by ecoregion, province, or realm, as well as switching between calculated risk level and individual risk coefficients. The latter allows for identifying regions that for example have the greatest amount of ballast water on board (if coefficient C2 is selected) or whose vessels most frequent the North Eastern Untied States (coefficient C1). Additional layers for each species are also available for viewing where populations of the invasive species currently lie according to published literatures. The layers highlight the bioregions on the map with different colors depending on whether a native, "established but introduced", or "recorded but not known to be established" population exists.

3.1 Ports

As to be expected, almost all of the 130 foreign last ports of call are in major areas closest to the North Eastern United States. The Ivory Coast, Nigeria, and South Africa are the only non-Mediterranean African countries with ports represented in this Dataset. Ports in India, China, and South Korea are the only contributing Asian ports, while the Oceanic region has no port at all identified as being the last port of call for ships entering the seven North Eastern coastal states.



Figures 1. All 130 last ports of call. A full list of these ports can be seen in Appendix A2.

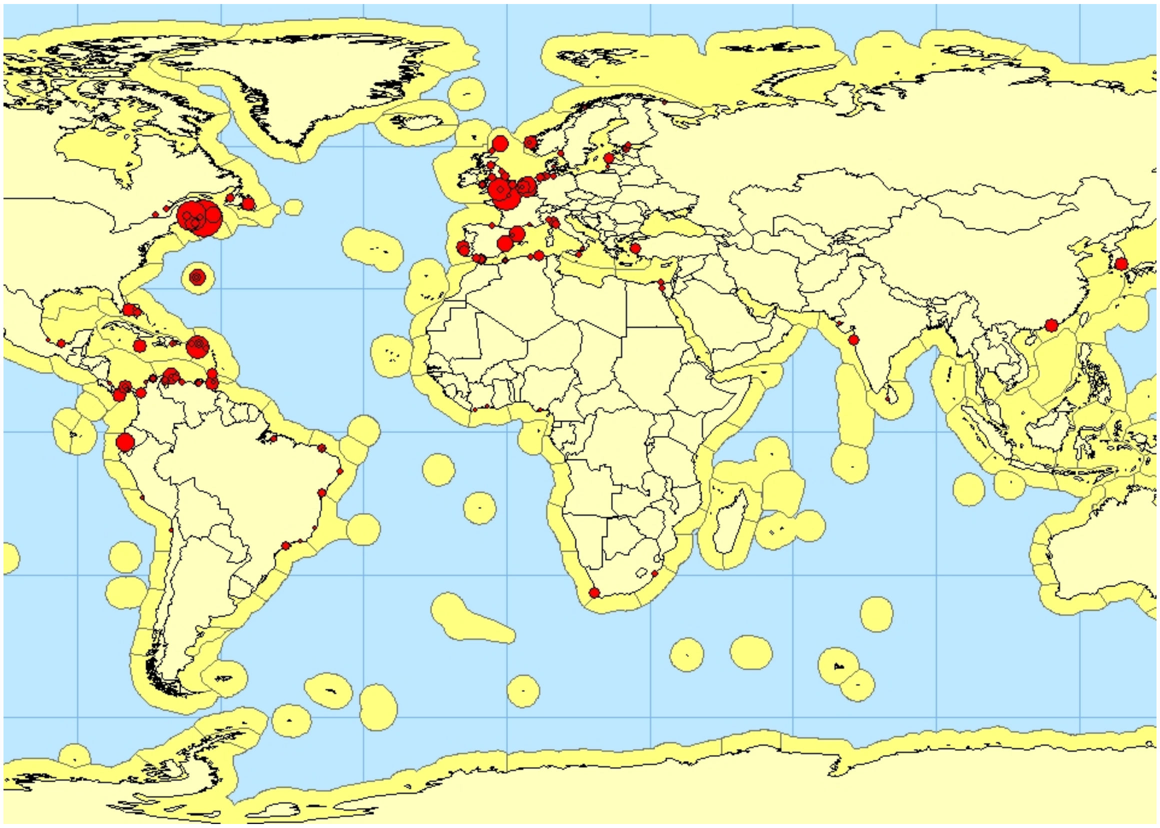


Figure 2. Number of arrivals displayed proportionally by port.

The top ten ports in regard to highest number of arrivals, total ballast on board each vessel, and total ballast water capacity of each vessel are displayed on the next three charts. These graphs correspond to the three risk coefficients used to calculate the ROR. The port of Halifax in Canada is the largest source port for all three categories. The proximity to the Northeastern United States explains why Canadian ports are largely represented.

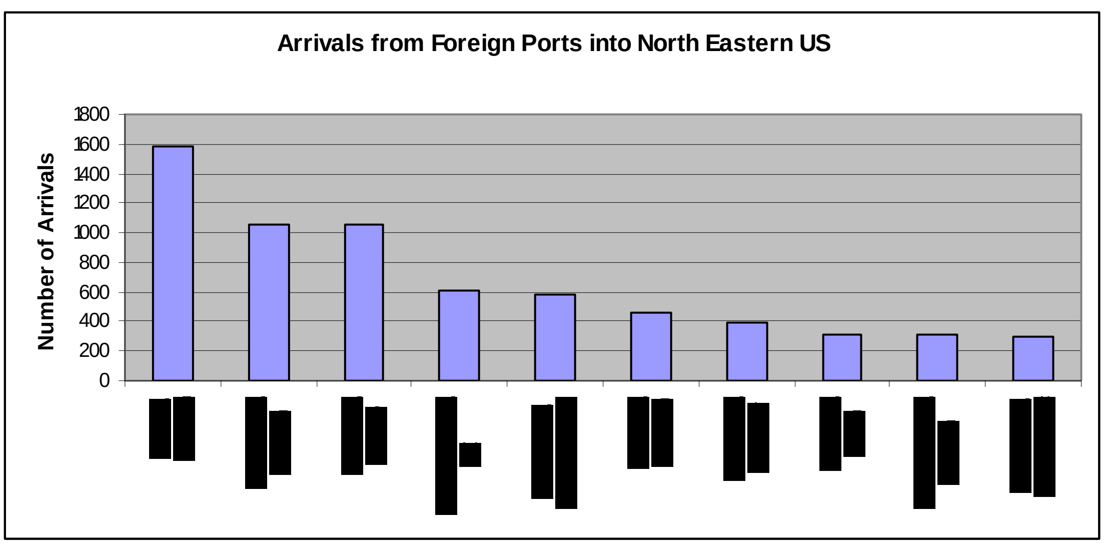


Figure 3. Top 10 foreign ports with greatest risk coefficient c1 (Number of Arrivals).

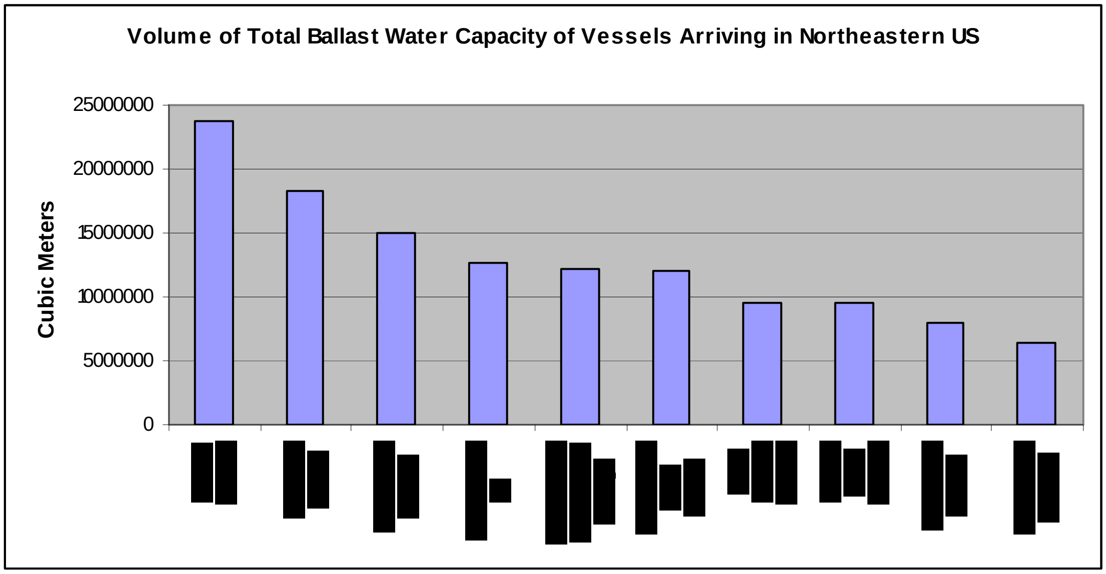


Figure 4. Top 10 foreign ports with greatest risk coefficient c2 (Total Ballast Water on Board).

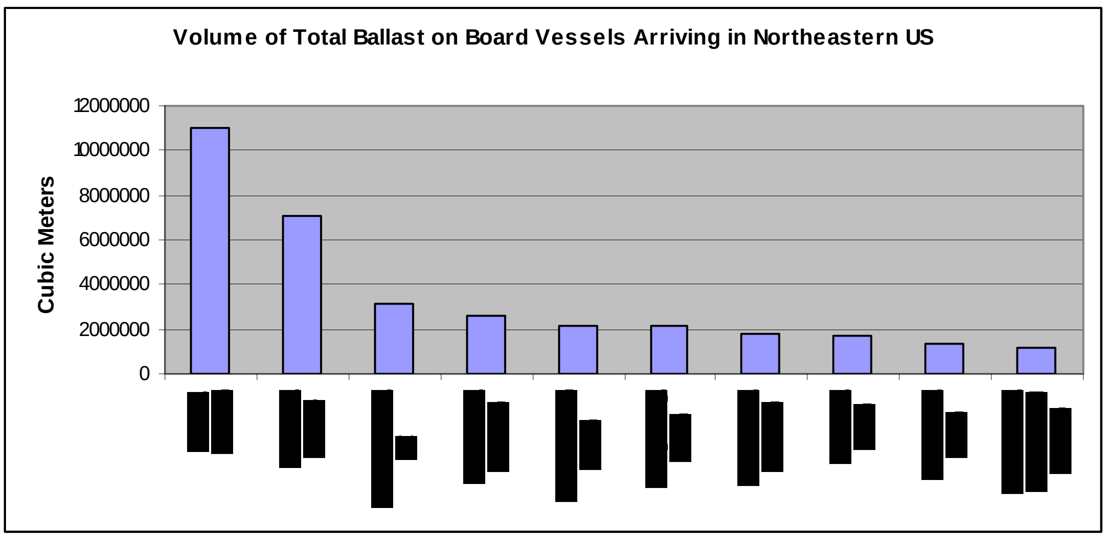


Figure 5. Top 10 foreign ports with risk coefficients c3 (Total Ballast Water Capacity).

3.2 EcoRegions

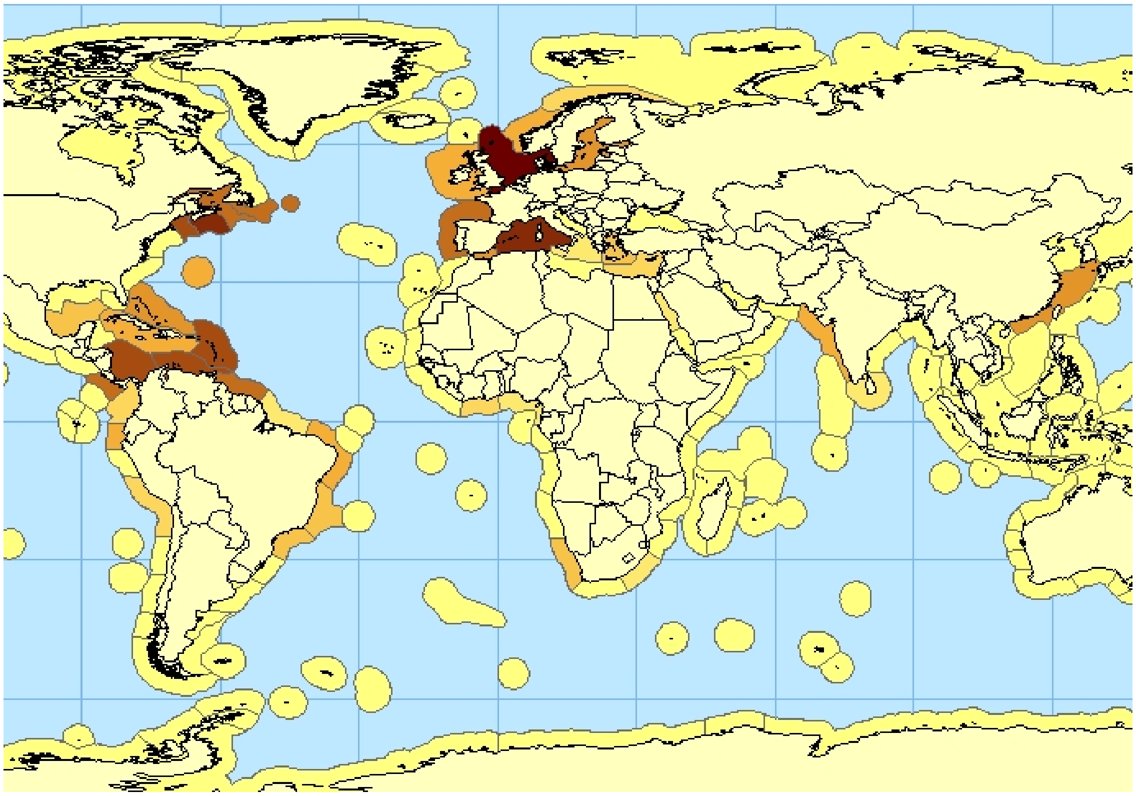


Figure 6. EcoRegions of the world identified by Relative Overall Risk. Darker implies greater risk.

Based on the three parameter risk assessment of ports within each bioregion, three general high risk areas have been identified: the Caribbean Sea, the South East Coast of Canada, and the European seas. The two large ports of Halifax and Saint John as well as the proximity of the region are what make south east Canada such a high risk threat. Whereas the sheer number of source ports in the Caribbean and European waters (33 and 51) are what add to their respective threat levels. The top ten riskiest EcoRegions seen on the next graph are comprised of the bulk of these three regions.

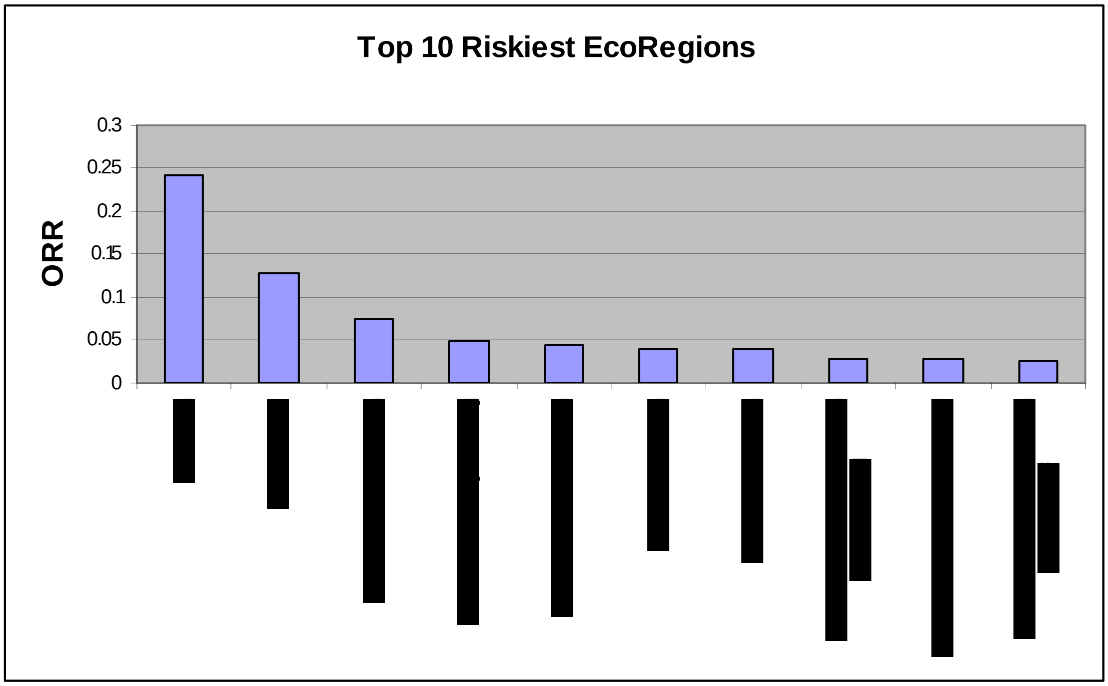


Figure 7. A Full list of the riskiest EcoRegions can be seen in Appendix A3.

The North Sea and the Scotian Shelf (Southeast Canada) ranked first and second respectively when it came to all three risk coefficients, making them have a significantly higher ROR than every other bioregion. The greatest threat level from outside the three major risk areas comes from the ranked 13th and 14th bioregions: Southern China and Eastern China Sea. These two regions each have only one port represented in the data set: Hong Kong and Busan, South Korea respectively.

3.3 Species

None of the predicted high risk species we looked at are located in either the Caribbean or Canadian waters. Therefore, whether or not a species had been established in the North Sea played a very significant role in identifying its risk level. Presence in the North Sea implied a likelihood of high risk of introduction into the North Eastern United States. The second most significant ecoregion for these specific species was the Western Mediterranean. Three species were present in both of these regions, two were only present in the North Sea, and one was not present in the North Sea at all. This determined the three clear categorizations of High, Medium, and Low risk that the species naturally grouped into when calculating the NORR.

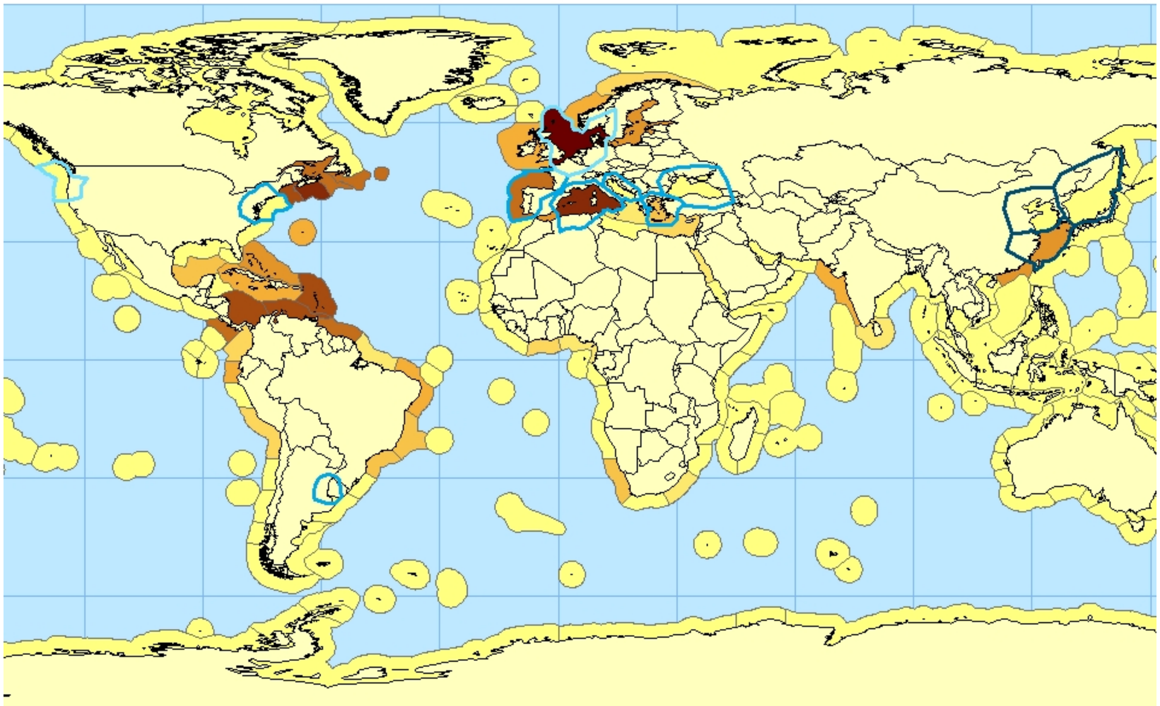


Figure 8. Example of an active species layer in the GIS database. Bioregions containing different types of populations of *Rapana venosa* are highlighted with different colors. A full description of each species' presence in different bioregions can be seen in Appendix A4.

Species	C1 (Arrivals)	C2 (TBOB)	C3 (TBWC)	ROR	NORR	Category
Undaria pinnatifida	0.363	0.465	0.370	0.399	1.000	High
Eriochier sinensis	0.354	0.422	0.373	0.383	0.959	High
Sargassum muticum	0.347	0.428	0.355	0.377	0.943	High
Corella eumyota	0.277	0.307	0.284	0.289	0.725	Medium
Elminius modestus	0.267	0.298	0.278	0.281	0.704	Medium
Rapana venosa	0.117	0.173	0.100	0.130	0.326	Low

Table 1. The six chosen species and their calculated risk values.

According to the analysis *Undaria pinnatifida* has the highest risk of being introduced into the northeastern United States. With established populations in South America, Europe, Asia, Australia, New Zealand, and on the west coast of the US, this species has not been recorded anywhere where it has not become established.

Rapana venosa has been identified as the least threatening of these species because of its lack of establishment in the North Sea, the most influential bioregion according to this analysis. It has been recorded in the bioregion, but established populations have yet to be identified (Kerckhof, 2006, ICES 2004). *Rapana venosa* is in fact likely to be significantly more threatening to the North Eastern United States than this analysis predicts because of its establishment in the Chesapeake Bay. Because BWRFs did not have to be filled out when traveling within the EEZ, local ports in the US were left out of the analysis when looking at last port of calls. This means that presence of *R. venosa* in the Chesapeake Bay area added no additional risk in the analysis even though recreational and commercial boating along the US coast would be a significant vector.

4.0 Conclusion

Often, risk assessment is performed at the local level. However, the threat of invasive species is a global matter. In order to truly focus efforts on preventing the further spread of invasive species, easier means of finding and distributing data must be found. With uniformity in how data is characterized and ease in how it is presented, researchers can both better collaborate with each other, and with the public and policy makers. Setting up databases of information by bioregion allows for a logical and useful analysis of a situation that is taking place at a global level. Molnar et al. (2008) have also used the MEOW regionalization of the world to globally categorize 329 different species according to a four parameter threat level. They too found the North Sea to be of especially high risk, having the third most abundant number of invasive species of any other bioregion. With our current ballast water database, a completely new analysis can be done by cross-referencing our two similarly formatted datasets.

Simple analysis of ballast water data and shipping routes, allows for identifying regions of high interconnectivity. This can considerably narrow down specific species that pose the greatest threat. This form of analysis combined with techniques such as environmental niche modeling can be used as a powerful tool of preventative measure.

A1. Calculating the Coefficients

Coefficients c1, c2, and c3 are calculated in a similar manner to the risk coefficients used in GloBallast's Ballast Water Risk Assessment reports. Each coefficient is the fraction of total Arrivals/TBOB/TBWC reported in the North Eastern United States associated with the source bioregion. The coefficients are calculated so that summing the coefficient from every bioregion will result in unity. Then, for a given species, the coefficient from each bioregion that has been identified as containing an established population (whether native or invaded) is summed to give C1/C2/C3.

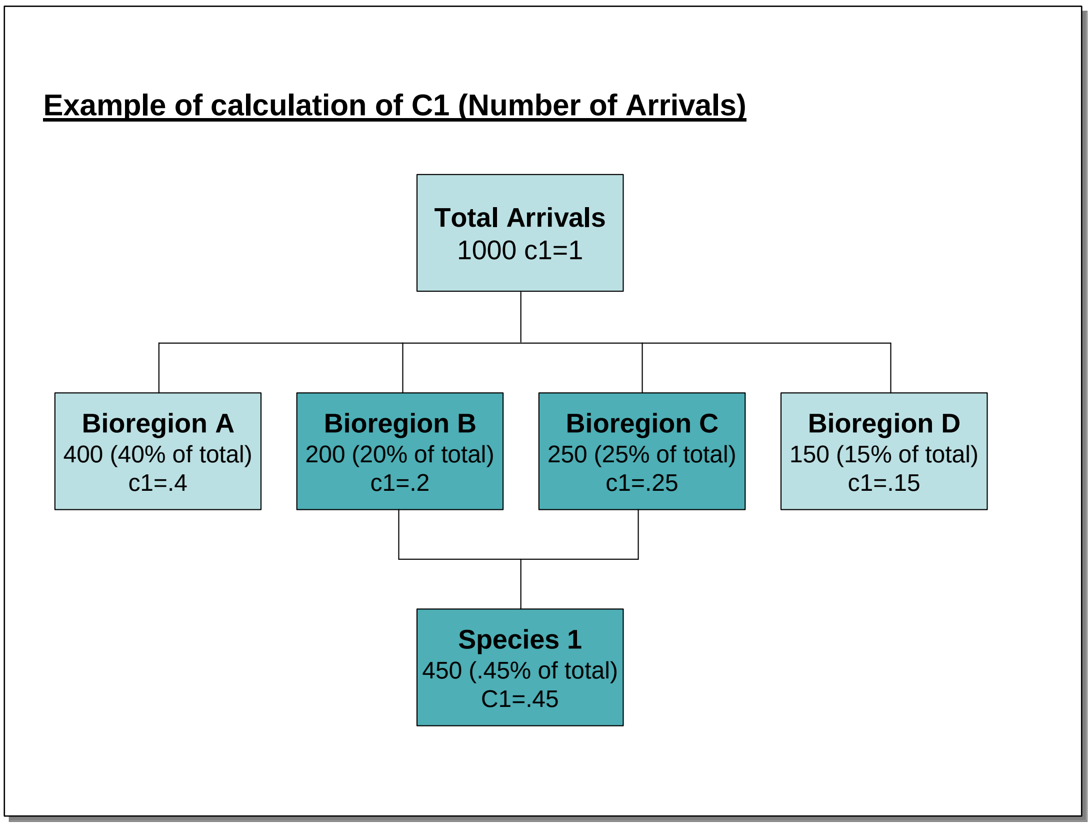


Figure 1. Methodology for calculating the three risk coefficients.

When C1, C2, and C3 are calculated for each species, the coefficients are then averaged (with each coefficient equally weighted) to give an overall risk rating for that species (ROR). For the purposes of comparison, this rating is then normalized (NROR) in order to identify groups of high, medium, and low risk threats.

A2. List of the 130 Foreign Ports (Ordered by number of arrivals)

Port	Country	TBOB (m^3)	TBWC (m^3)	Number of Arrivals
Halifax	Canada	11,046,657	23,788,649	1589
Saint John	Canada	778,245	14,966,607	1061
Le Havre	France	7,119,123	18,351,585	1056
Southampton	United Kingdom	3,131,413	5,941,665	611
Saint Croix	Virgin Islands, USA	473,254	11,967,808	587
Antwerp	Belgium	904,342	4,216,776	458
Guayaquil	Ecuador	624,350	1,394,227	394
Valencia	Spain	1,719,491	4,131,032	309
Point Tupper	Canada	305,622	9,508,089	308
Rotterdam	Netherlands	588,143	4,182,082	296
Sullom Voe	United Kingdom	278,261	12,687,069	288
Barcelona	Spain	1,370,072	2,776,240	283
Amuay Bay	Venezuela	154,824	5,159,840	279
Hamilton	Bermuda	882,609	596,714	273
Whiffen Head	Canada	201,426	9,498,866	233
Manzanillo	Panama	2,564,938	6,404,561	228
Hong Kong	China	2,138,481	3,787,520	224
Point Fortin	Trinidad and Tobago	1,202,615	12,201,779	211
Busan	South Korea	2,184,981	3,724,470	202
Netherland	Netherlands	149,416	4,391,306	201
Come by Chance	Canada	194,209	5,926,018	200
Bahamas	Bahamas	737,621	4,253,691	198
Coco Solo	Panama	1,760,266	5,033,716	197
Lisbon	Portugal	1,062,237	2,259,965	193
Mongstad	Norway	95,303	7,902,978	191
Yarmouth	Canada	47,293	73,678	191
Kingston	Jamaica	899,776	1,729,498	183
Izmir	Turkey	560,082	828,518	169
Saint Georges	Bermuda	33,599	304,365	163
Ventspils	Latvia	178,210	4,667,465	158
La Spezia	Italy	805,398	1,855,494	155
Nhava Sheva	India	709,415	1,472,193	154
Gibraltar	Gibraltar	245,699	3,002,964	141
Cape Town	South Africa	472,278	1,372,721	127
Turbo	Colombia	168,183	237,369	127
Sines	Portugal	483,914	2,013,789	123
Skikda	Algeria	215,308	5,046,426	123
Bayside	Canada	21,187	1,836,734	119
Maracaibo	Venezuela	59,913	2,366,430	119
Pecem	Brazil	622,890	1,633,844	118
Livorno	Italy	819,984	1,595,424	115
Cumarebo	Venezuela	20,583	1,109,320	113
Nassau	Bahamas	183,684	474,566	112
Tortola	British Virgin Islands	137,831	450,275	110
Algeciras	Spain	377,684	2,065,647	109
Dos Bocas	Mexico	52,815	4,259,732	106

Puerto Drummond	Colombia	54,320	3,188,404	104
Wilhelmshaven	Germany	52,646	2,764,344	103
Immingham	United Kingdom	148,574	2,606,856	102
Liverpool	United Kingdom	543,021	1,276,547	99
Hound Point	United Kingdom	48,620	4,007,392	97
Felixstowe	United Kingdom	910,252	1,674,689	93
Shelburne	Canada	130,700	200,538	92
Corner Brook	Canada	123,727	325,426	82
Kings Wharf	Bermuda	53,471	210,399	79
Emden	Germany	351,587	548,175	76
Pembroke	United Kingdom	76,291	1,655,604	76
Salvador	Brazil	185,652	1,221,492	76
Santos	Brazil	234,280	783,427	76
Cadiz	Spain	336,415	769,217	73
Muuga	Estonia	85,837	2,062,847	71
Flotta	United Kingdom	94,584	2,885,976	70
Puerto Prodeco	Colombia	12,556	2,000,273	70
Fawley	United Kingdom	48,250	1,526,492	69
Suape	Brazil	468,649	994,210	69
Puerto La Cruz	Venezuela	24,717	2,326,220	68
Arzew	Algeria	30,208	2,582,548	64
Colon	Panama	585,318	1,306,668	63
Puerto Jose	Venezuela	103,086	1,744,581	63
Montreal	Canada	187,015	447,917	61
Puerto Cabello	Venezuela	238,163	611,871	60
Bilbao	Spain	64,542	1,129,395	56
Saint Eustatius	Netherlands Antilles	175,794	1,427,554	56
Bejaia	Algeria	69,353	2,208,465	55
Tees	United Kingdom	53,131	2,161,006	55
Quebec City	Canada	79,953	917,013	49
SAN Juan	Puerto Rico, USA	170,004	345,380	49
Hamburg	Germany	238,094	703,330	46
Hantsport	Canada	0	312,536	45
Puerto Miranda	Venezuela	21,127	1,866,526	45
Bremerhaven	Germany	257,924	474,093	44
Brofjorden	Sweden	16,939	983,997	44
Milford Haven	United Kingdom	32,116	896,047	39
Cristobal	Panama	96,828	418,258	38
Suez	Egypt	34,928	496,960	38
Vila do Conde	Brazil	26,804	247,840	38
Durban	South Africa	38,144	386,014	37
Porvoo	Finland	55,006	1,014,232	36
Santa Marta	Colombia	15,112	793,973	36
Port Said	Egypt	210,028	581,169	35
Rio Haina	Dominican Republic	53,987	80,595	35
Augusta	Italy	21,106	658,422	34
Genoa	Italy	84,466	339,165	34
Pertigalete	Venezuela	3,103	284,396	34
Bonny	Nigeria	37,247	690,537	33
Caleta Patillos	Chile	2,724	589,926	33

Pisco	Peru	20,033	381,731	33
Pointe a Pierre	Trinidad and Tobago	24,510	753,596	33
Zeebrugge	Belgium	160,820	357,675	33
Panama	Panama	192,759	505,680	32
Tallinn	Estonia	10,697	830,736	32
West End	Bermuda	16,552	30,772	30
Mamonal	Colombia	60,974	711,465	28
Puerto Moin	Costa Rica	48,483	72,593	28
Bethioua	Algeria	40,291	451,749	27
Port Jerome	France	8,477	569,744	27
Rio de Janeiro	Brazil	87,287	519,996	27
San Pedro	Ivory Coast	116,862	121,152	27
West End	British Virgin Islands	9,114	11,493	27
Fredericia	Denmark	58,000	1,040,969	26
Mundra	India	168,321	364,285	26
Murmansk	Russia	29,624	714,948	26
Abidjan	Ivory Coast	96,533	276,210	25
Fortaleza	Brazil	73,101	176,519	25
Fos	France	37,268	405,543	25
Gioia Tauro	Italy	140,823	289,846	25
Tarragona	Spain	30,331	318,307	25
Caucedo	Dominican Republic	85,887	163,569	24
Dunkirk	France	46,834	406,816	24
Sture	Norway	21,194	970,174	24
Balboa	Panama	20,224	351,213	23
Klaipeda	Lithuania	6,438	556,045	23
Veracruz	Mexico	115,038	184,268	23
Punta Cardon	Venezuela	10,812	386,826	22
Great Stirrup Cay	Bahamas	39,184	96,413	21
Saint Thomas	Virgin Islands, USA	57,425	144,253	21
Vitoria	Brazil	86,468	179,935	21
Colombo	Sri Lanka	137,009	280,943	20
Curacao	Netherlands Antilles	34,662	358,313	20
Kjopsvik	Norway	2,458	249,056	20

A3. List of the 42 Riskiest Bioregions (Other regions had no risk at all)

CIP=Central Indo-Pacific, TA=Tropical Atlantic, TEP=Tropical East Pacific, TNA=Temperate Northern Atlantic, TNP=Temperate Northern Pacific, TSAF=Temperate Southern Africa, TSAM=Temperate South America, WIP= Western Indo-Pacific

EcoRegion	Province	Realm	ORR	NORR
North Sea	Northern European Seas	TNA	0.2419	1.0000
Scotian Shelf	Cold Temperate Northwest Atlantic	TNA	0.1289	0.5330
Western Mediterranean	Mediterranean Sea	TNA	0.0746	0.3086
Gulf of Maine/Bay of Fundy	Cold Temperate Northwest Atlantic	TNA	0.0482	0.1992
Southwestern Caribbean	Tropical Northwestern Atlantic	TA	0.0453	0.1875
Eastern Caribbean	Tropical Northwestern Atlantic	TA	0.0403	0.1668
Southern Caribbean	Tropical Northwestern Atlantic	TA	0.0385	0.1590
Southern Grand Banks - South Newfoundland	Cold Temperate Northwest Atlantic	TNA	0.0282	0.1167
South European Atlantic Shelf	Lusitanian	TNA	0.0270	0.1116
Gulf of St. Lawrence - Eastern Scotian Shelf	Cold Temperate Northwest Atlantic	TNA	0.0265	0.1097
Nicoya	Tropical East Pacific	TEP	0.0265	0.1096
Guianan	North Brazil Shelf	TA	0.0265	0.1095
Southern China	South China Sea	CIP	0.0210	0.0869
East China Sea	Warm Temperate Northwest Pacific	TNP	0.0208	0.0860
Alboran Sea	Mediterranean Sea	TNA	0.0199	0.0822
Baltic Sea	Northern European Seas	TNA	0.0186	0.0767
Bahamian	Tropical Northwestern Atlantic	TA	0.0175	0.0725
Greater Antilles	Tropical Northwestern Atlantic	TA	0.0154	0.0635
Southern Norway	Northern European Seas	TNA	0.0149	0.0617
Northeastern Brazil	Tropical Southwestern Atlantic	TA	0.0141	0.0582
Bermuda	Tropical Northwestern Atlantic	TA	0.0140	0.0580
Guayaquil	Tropical East Pacific	TEP	0.0130	0.0537
Celtic Seas	Northern European Seas	TNA	0.0123	0.0509
Western India	West and South Indian Shelf	WIP	0.0107	0.0442
Southern Gulf of Mexico	Tropical Northwestern Atlantic	TA	0.0085	0.0353
Aegean Sea	Mediterranean Sea	TNA	0.0075	0.0311
Namaqua	Benguela	TSAF	0.0068	0.0281
Southeastern Brazil	Warm Temperate Southwestern Atlantic	TSAM	0.0054	0.0222
Eastern Brazil	Tropical Southwestern Atlantic	TA	0.0051	0.0210
Panama Bight	Tropical East Pacific	TEP	0.0033	0.0136
Gulf of Guinea Upwelling	Gulf of Guinea	TA	0.0027	0.0112
Levantine Sea	Mediterranean Sea	TNA	0.0026	0.0106
Humboldtian	Warm Temperate Southeastern Pacific	TSAM	0.0025	0.0105
Northern Norway and Finnmark	Northern European Seas	TNA	0.0022	0.0090
Gulf of Guinea Central	Gulf of Guinea	TA	0.0016	0.0068
Ionian Sea	Mediterranean Sea	TNA	0.0015	0.0064
Northern and Central Red Sea	Red Sea and Gulf of Aden	WIP	0.0015	0.0063
South India and Sri Lanka	West and South Indian Shelf	WIP	0.0015	0.0062
Natal	Agulhas	TSAF	0.0014	0.0057
Amazonia	North Brazil Shelf	TA	0.0012	0.0049

A4. Table of Species Presence

Species	Native	Introduced- Established	Recorded - Not established	Sources
Undaria pinnatifida	Central Kuroshio Current, East China Sea, Northeastern Honshu, Sea of Japan, Yellow Sea	Bassian, Bounty and Antipodes Islands, Celtic Seas, Central New Zealand, Chatham Island, North Patagonian Gulfs, Northeastern New Zealand, Northern California, South European Atlantic Shelf, Southern California Bight, Southern China, Southern New Zealand, North Sea, Adriatic Sea, Ionian Sea, Western Mediterranean		ICES 2007, Russell 2007, Streftaris 2005, Wallentius 1999, Zhang 1984
Eriochier sinensis	East China Sea, Yellow Sea	Baltic Sea, Black Sea, Northern California, South European Atlantic Shelf, North Sea, Western Mediterranean	Hawaii, Northern Gulf of Mexico	Herborg 2007, Rudnick 2000, Gilbey 2008, Streftaris 2005, Clark 1998, Ojaveer 2007, Gomoiu 2002, Gollasch 1999, Zaitsev 2001,
Sargassum muticum	Central Kuroshio Current, East China Sea, Northeastern Honshu, Sea of Japan, Yellow Sea	Celtic Seas, Gulf of Alaska, North American Pacific Fijordland, Northern California, Oregon Washington Vancouver Coast and Shelf, South European Atlantic Shelf, Southern California Bight, North Sea, Adriatic Sea, Western Mediterranean		Britton-Simmons 2004, Karlsson 1999, Staehr 2000, Streftaris 2005, Ices 2006, Wallentius 1999
Corella eumyota	Agulhas Bank, Amsterdam-St Paul, Antarctic Peninsula, Araucanian, Auckland Island, Bassian, Bounty and Antipodes Islands, Campbell Island, Central Chile, Central New Zealand, Channels and Fjords of Southern Chile, Chatham Island, Chiloense, East Antarctic Wilkes Land, Macquarie Island, Malvinas/Falklands, Namaqua, Natal, North Patagonian Gulfs, Patagonian SHelf, Snares Island, South Georgia, South Orkney Islands, South Shetland Islands, Southern New Zealand, Tristan Gough, Weddell Sea	Celtic Seas, South European Atlantic Shelf, North Sea		Lambert 2004, Varela 2007, Minchin 2007, Primo 2004, Dupont 2007, Arenas 2006,

Elminius modestus	Bassian, Cape Howe, Central New Zealand, Manning-Hawkesbury, Northeastern New Zealand, Southern New Zealand, Three Kings-North Cape, Tweed-Moreton, Western Bassian	Celtic Seas, South European Atlantic Shelf, North Sea		Crisp 1958, O'Riordan 1999, Luckens 1974, Foster 1986, Streftaris 2005
Rapana venosa	East China Sea, Sea of Japan, Yellow Sea	Black Sea, Rio de la Plata, South European Atlantic Shelf, Virginian, Adriatic Sea, Aegean Sea, Western Mediterranean	Oregon, Washington, Vancouver Coast and Shelf	Streftaris 2005, Mann and Harding 2003, Kerckhof 2006, Harding and Mann 2005, Mann Harding 2000, ICES 2004

A5. Ballast Water Reporting Form (BWRF)

BALLAST WATER REPORTING FORM

IS THIS AN AMENDED BALLAST REPORTING FORM? YES ☐ NO ☐

1. VESSEL INFORMATION	2. VOYAGE INFORMATION		3. BALLAST WATER USAGE AND CAPACITY		
Vessel Name:	Arrival Port:		*Specify Units Below (m^3, MT, LT, ST)*		
IMO Number:	Arrival Date:		Total Ballast Water on Board:		
Owner:	Agent:		Volume	Units	No. of Tanks in Ballast
Type:	Last Port:	Country of Last Port:			
GT:			Total Ballast Water Capacity:		
Call Sign:	Next Port:	Country of Next Port:	Volume	Units	Total No. of Tanks on Ship
Flag:					

4. BALLAST WATER MANAGEMENT Total No. Ballast Water Tanks to be discharged: ☐

Of tanks to be discharged, how many: Underwent Exchange: ☐ Underwent Alternative Management: ☐

Please specify alternative method(s) used, if any: ____________________

If no ballast treatment conducted, state reason why not: ____________________

Ballast management plan on board? YES ☐ NO ☐ Management plan implemented? YES ☐ NO ☐

IMO ballast water guidelines on board [res. A.868(20)]? YES ☐ NO ☐

5. BALLAST WATER HISTORY: Record all tanks to be deballasted in port state of arrival; IF NONE, GO TO #6 *(Use additional sheets as needed)*

Tanks/ Holds	BW SOURCE				BW MANAGEMENT PRACTICES						BW DISCHARGE			
List multiple sources/tanks separately	DATE D/M/YYYY	PORT or LAT. LONG.	VOLUME (units)	TEMP (units)	DATE D/M/YYYY	ENDPOINT LAT. LONG.	VOLUME (units)	% Exch	METHOD (ER/FT/ ALT)	SEA HT. (m)	DATE D/M/YYYY	PORT or LAT. LONG.	VOLUME (units)	SALINITY (units)
				C										sg
				C										sg
				C										sg
				C										sg
				C										sg
				C										sg
				C										sg

Ballast Water Tank Codes: Forepeak = FP, Aftpeak = AP, Double Bottom = DB, Wing = WT, Topside = TS, Cargo Hold = CH, Other = O

6. RESPONSIBLE OFFICER'S NAME AND TITLE, PRINTED AND SIGNATURE: ____________________

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