10-31-2022

Evaluating/assessing the impacts of invasive species through biofouling in Nigeria: sustainable marine environmental management in profile

Jamila Idris Opadeyi

WORLD MARITIME UNIVERSITY
Malmö, Sweden

EVALUATING/ASSESSING THE IMPACTS OF INVASIVE SPECIES THROUGH BIOFOULING IN NIGERIA: SUSTAINABLE MARINE ENVIRONMENTAL MANAGEMENT IN PROFILE

By
JAMILA IDRIS OPADEYI
Nigeria

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE
in
MARITIME AFFARS

(OCEAN SUSTAINABILITY GOVERNANCE AND MANAGEMENT)

2022

Declaration

I certify that all the material in this dissertation that is not my own work has been identified and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): **...**

(Date): 19-09-2022

Supervised by: Prof. Ronán Long

Supervisor's affiliation**: Professor, Director of Global Ocean Institute**

....

Co-supervised by: **Dr. Tafsir Johansson**
Supervisor's affiliation **Assistant Professor**

Foreword

This dissertation is devised from the research work conducted for a forthcoming peer-review publication titled "Evaluating/assessing the impacts of invasive species through biofouling in Nigeria: sustainable marine environmental management in profile" to be published in Frontiers in Political Science under the article collection "Blue Economy and Ocean Sustainable Development in a Globalized World: Social, Political, Economic and Environmental Issues". The thesis utilized primary data on vessels' traffic in Lagos Ports and marine ecoregions invasive aquatic species (IAS) data to assess the risk of bio-invasion based on vessels residence time and records on IAS of the vessels Ports of departure, which will guide the Maritime Administration of Nigeria in putting in strategic biofouling management systems and inspection regime targeting the high-risk vessels.

Acknowledgments

My profound gratitude to Almighty Allah for seeing me through the completion of my dissertation.

I want to use this opportunity to show my utmost appreciation to the Norwegian Agency for Development Cooperation (NORAD) for awarding me a scholarship to study at the World Maritime University.

My sincere appreciation goes to my employer Nigerian Maritime Administration and Safety Agency (NIMASA) and the Director General Dr Bashir Jamoh for granting me permission to further my studies. My appreciation also goes to the head of training Mrs Simi Daju for all her guidance and support.

My sincere gratitude to my diligent and untiring supervisors Professor Ronan Long and Professor Tafsir Johansson for their utmost guidance every step of the way, their encouragement, and non-stop supervision until completion of my work.

To my loving husband, Mr Opaleke Opadeyi for his love and support, my children, Hezekiah, Michelle, George and my-inlaws for their care and understanding.

My friends Fatima lawal, Fatai Bello, Moshood Taiwo and Saratu Inuwa a big thank you for your love and care during my trying period.

And finally my OSGM colleagues, Professors, the Global ocean institute, members of faculty, WMU for their guidance and support throughout my journey in Sweden.

Abstract

Title of Dissertation: **Evaluating/assessing the impacts of invasive species through biofouling in Nigeria: sustainable marine environmental management in profile.**

Degree: **Master of Science**

The introduction of non-indigenous marine species (NIMS) can be deemed as an explicit threat to achieving a blue economy which is the sustainable use of oceans and their resources. Fouling of ships by marine organisms is a conduit of NIMS-transfer in global waters, conversely, the focus of threats from marine invasive species was mostly on ship's ballast water. These NIMS can out-compete the native ones, thereby threatening their existence, biodiversity, and national food security resulting in huge social and economic impacts.

This article commences with examining the nexus between biofouling and blue economy, and subsequently delves into the Apapa Port of Lagos, which serves as a case study to assess the potential of non-indigenous invasive species transfer from ships biofouling. Carefully embedded into the analysis is first-hand port traffic data from 2017 to 2021. In addition to the above, the research utilizes marine ecoregion information, and marine invasive species database to determine and evaluate the risks from invasive species transfer. Based on preliminary quantitative analysis of the fore-mentioned data and a review of relevant literature, it is deduced that there is a high expectation of bio-invasion in very busy ports, which can be influenced by the vessel's retention time, the marine ecoregion of the last port of call (geographical similarities).

The NIMS transfer risk matrix tabled by the author is projected to assist the Maritime Administration (MARAD) in developing necessary measures to prevent, monitor, and control the threats of invasive species for ensuring a sustainable marine environment, which remains at the heart of the United Nations Convention on the Law of the Sea.

KEYWORDS: Non-indigenous invasive aquatic species, Ships biofouling, Marine ecoregion, Blue economy, Bio-invasion, Residence time, Vessel traffic, Sustainability

Table of Contents

List of Tables

List of Figures

List of Abbreviations

1. INTRODUCTION

Shipping is deemed as the crux of global trade. Axiomatically, more than 80 percent of the world's trade and commerce is facilitated through shipping (UNCTAD, 2021; Xu et al., 2020). Although shipping is an activity common to major maritime nations due to reasons of cost-effectiveness and efficiency, however, this mode of trade and commerce is not entirely free from issues and concerns (Costello et al., 2022). Environmental pollution, both air and water, is a negative externality that has typically dominated discussions on this topic. Recently, scientific literature has turned our attention to a narrower focus on compartmented (niche) sources that contribute directly or indirectly to global environmental change (GEC) (Essl et al., 2015; Hulme, 2021).

In the context of shipping, evidence-based study reveals that the hulls of ships serve as a conduit for transportation of harmful non-indigenous invasive aquatic species (IAS) (Costello et al., 2022; Kacimi, 2021; Luoma et al., 2021). The species attach themselves to the outer surface and niche areas of the ship and are translocated from one ecoregion to the other. The accumulation of marine organisms, e.g., barnacles, algae, seaweed, mussels, and crabs on the outermost surface of ships (hull and its appendages) is known as "biofouling" (IMO, 2019a, IMO, 2019b). The International Maritime Organization (IMO) recognized the role of biofouling as a critical vector for the transfer of non-indigenous IAS in conjunction with ballast water, and notes it as one of the major environmental and economic threats to sustainable shipping (IMO, 2011). Patently, IAS refer to species that are not native to a specific environment, and whose introduction is detrimental to the health and economy of the region (Manchester & Bullock, 2000; Shevalkar et al., 2020).

According to the United Nations (UN) 2021 global population growth projection, Nigeria is touted as the fastest-growing population and could be ranked as the third largest populous country in the world by 2050 (United Nations, 2021). With this booming population and the need for an import-driven economy through oil production coupled with the need to continue, if not, increase seaborne trade would inevitably expose Nigeria to threats of IAS transfer from foreign ships entering into areas within national jurisdiction (Statista, 2021).

What is also noted is that this ship-facilitated species-transfer could result in the introduction of harmful alien species and pathogens into a new environment known as bio-invasion, leading to disruption of the functioning of the marine ecosystem and ill-health (Costello et al., 2022; (Yildirim & Kaplan, 2022). Aside from IAS transportation, biofouling increases the hull resistance of ships, leading to the consumption of more fuel and power, thus altogether resulting in increased emission of greenhouse gasses (GHG), (Demirel et al., 2022; Luoma et al., 2021; UN Climate Change Conference of the Parties - COP 26, 2021;).

Moving forward, Blue Economy as a sustainable strategy for economic development and environmental stewardship is underpinned by the necessity to continuously ensure a marine ecosystem that is healthy to deliver goods and services (Cziesielski et al., 2021). In a sustainable scenario, it is predicted that, if developed strategically, the blue economy could generate about 43 million jobs and a growth in value by $500 Billion (OECD, 2016). Biofouling poses huge threat to the blue economy as it incurs both environmental burdens, such as, low productivity, biodiversity loss, lower resilience to climate change, and economic burdens including, financial loss due to low productivity, huge prevention and control costs, increased operational cost of offshore infrastructure (Cruz et al., 2020). Unfortunately, the study of the nexus between biofouling and blue economy remains, to a great extent, an untraversed area.

The unwanted accumulation of micro and macro marine organisms on the submerged surface of ships (biofouling) on international voyages is considered a major route for global biological invasions, where invasive alien species are transported via the hull of ships from one location (ports, oceans, seas) to the other (Demirel et al., 2022; Hulme, 2021; IMO, 2019a).

The introduction of harmful non-indigenous invasive species is a major threat to marine biodiversity (Alidoost Salimi et al., 2021; Bax et al., 2003; IMO, 2019a). It goes without saying that alien species out-compete the native ones, thereby threatening their existence and food security of the people (Alidoost Salimi et al., 2021). The recognition of the threats to food security and marine biodiversity motivated the current study, which aims to assess the potential of invasive species introduction in Nigerian Ports using Apapa port as a case study. This research proceeds to analyze vessel traffic information and residence time; and develop a first-hand risk-matrix based on statistical analysis of traffic data, last port of calls of vessels, residence time, marine ecoregions, bio-geographical similarities and data on invasive species.

The scope of the research covers all foreign vessels entering the Apapa Port using data extending to the past five years between January 2017 and December 2021. In addition, this study assesses original vessel data from the Nigerian Maritime Administration and Safety Agency (NIMASA) and details scientific literature obtained from the above.

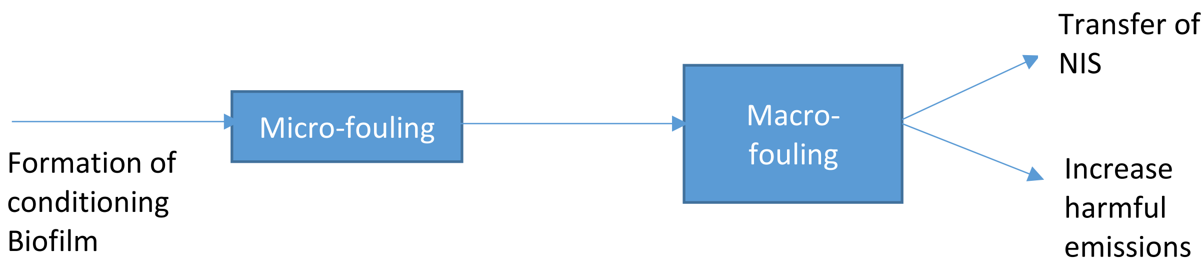
The outcome of this study will assist the Maritime Administration (MARAD) of Nigeria: better appraise the threats of non-indigenous IAS from biofouling; identify the risk status of foreign vessels in accordance with their routes (biogeographical origin) to Nigeria, and table feasible management strategies to prevent and control bio-invasion from these vessels for a productive and sustainable Nigeria's maritime domain. All of this is done respecting Nigeria's commitments to the blue economy movement.

2. BIOFOULING AS A VECTOR FOR TRANSFER OF INVASIVE SPECIES FROM SHIPPING

2.1 Ship Biofouling

Ship Biofouling commonly refers to the attachment of aquatic organisms to the immersed surface, i.e., the hull of a ship. It has been regarded as a medium for transfer of harmful non-indigenous invasive aquatic species (IAS) from one point to another (Chan et al., 2022). The process of biofouling commences immediately after a surface is immersed in natural water with adsorption of proteins, cellulose (polysaccharides) and other soluble organic matter leading to formation of conditioning biofilm that attracts micro-foulers, e.g., such as bacteria, algal spores, fungi, which is followed by attachment of macro-foulers (larger algae and invertebrates) (Georgiades et al., 2021; Kiil et al., 2007). Biofouling occurs at the wetted surface of a ship's hull and the niche areas (the rudders, the propellers, thruster tunnels) (Moser et al., 2017). Understanding the attachment mechanisms is critical to the prevention and control of fouling by these organisms given that the aforementioned processes can be halted at any stage of colonization. For instance, before the micro-fouling, after micro-fouling or after macro-fouling, as illustrated below:

Figure 2.1: Ships biofouling processes (created by author)



Serving as the backbone of the ever-growing global trade (UNCTAD, 2021), ship's submerged surfaces have become a medium for transportation of invasive species from one ecoregion to another. These species once transported to a new environment can become a nuisance to the new environment by disrupting the ecosystem's goods and services. To this end, the IMO Convention on Biological Diversity (CBD) as well as many regional United Nations Environment Programme (UNEP) Conventions recognize ship biofouling as a key medium for the transfer of marine invasive species (Tamburri et al., 2020). Organizations implement measures in line with the United Nations Conventions on the Law of the Sea (UNCLOS) of 1982, forging an alliance with Member States, economic sectors, and Non-Governmental Organizations (NGOs), and putting in place strategies, guidelines for prevention and control of pollution caused by humans through the direct or indirect transfer of invasive alien species to any part of the marine environment (IMO, 2019a). One such strategy is IMO's 2011 Biofouling Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species and technical co-operation programmes to create awareness on bio-invasions from ships.

2.2 Ship Biofouling and the Blue Economy

The blue economy advances knowledge for economic growth, environmental stewardship and sustainable development, and it has been popularly utilized to protect the world's seas and oceans and their resources (Lee et al., 2021). For the blue economy to achieve its goals, it has to be sustainable, reduce negative externalities on the environment and improve the living standards of people.

Adopting the principle of blue economy in marine environment management requires development of a strategic framework that will ensure marine industry development with social, ecological, environmental and economic benefits to the people (Wenhai et al., 2019). A sustainable blue economy is also dependent on sustainable maritime transport where the negative externalities such as harmful emissions, bio-invasions, noise pollution and other forms of marine pollution are reduced to the minimum

(Nikčević & Škurić, 2021). In view of this, bio-invasion resulting from ships biofouling is a big threat to the blue economy as the Non indigenous IAS can adversely impact the economy and ecology of the recipient marine ecosystem via predation, disruption of food webs and competition with native species which could lead to decreased ecosystem productivity and loss of biodiversity with the resultant effect on the people's income (impacting Sustainable Development Goal (SDG 1)) (Bouda et al., 2017).

Understanding that the blue economy encompasses the aforementioned negative externalities resulting from the predatory nature of invasive species would pose serious threats to food security, marine biodiversity, economy (financial stress for response), peoples' income and marine environment, thereby jeopardizing the aims of the blue economy.

2.3 Factors Influencing Ship Biofouling and Transfer of Invasive Aquatic Species

The following entails a cursory overview of factors that influence ship biofouling:

2.3.1 Availability and quality of anti-fouling paints on ships' hulls

There is a natural tendency that marine organisms attach themselves to an immersed object. To achieve efficiency in ships' operations, anti-fouling coatings are adopted to reduce biofouling by delaying the onset but not necessarily preventing it. Nonetheless, the effectiveness reduces with time (Arndt et al., 2021; Demirel et al., 2022). The presence of quality anti-fouling coats on the outer surface of ships inhibits the fouling process for a period of time, as the surface roughness increases, the fouling levels increase, therefore, the quality, age, condition of anti-fouling coatings and maintenance plans (dry-docking/hull cleaning) influence the biofouling process (IMO, 2019a; Kerr et al., 1999). It is essential to highlight that in the process of dry-docking/hull cleaning, there is risk of potential introduction of IAS into the local habitats (Georgiades et al., 2021; Scianni & Georgiades, 2019; Tamburri et al., 2020).

The common view is that there are always some levels of fouling no matter the paints applied, coupled with other influential environmental parameters such as temperature, salinity, illumination, nutrients level and vessel's voyage profile (Arndt et al., 2021; IMO, 2019a; Tamburri et al., 2020; Woods Hole Oceanographic Institution, 1952).

Also, some areas such as the dry-dock support strips and anodes are not effectively painted with anti-fouling coats due to limitations on the practicability, thus making this part a hot-spot for biofouling in terms of abundance and diversity (Georgiades et al., 2021; Schimanski et al., 2016). Arndt et al., 2021 highlighted that anti-fouling (AF) paints effectiveness is dependent on the type of paints, the biocides utilized, vessels operations and environmental circumstances; while the age of AF coatings is a valuable pointer for biofouling risks (implying that there is high likelihood of biofouling in ships with aged coatings).

2.3.2 Ships Characteristics and Voyage Profiles

Biofouling is also influenced by the way the ship is designed, especially the number, location and configuration of the niche areas such as appendages, sea chest, bulbous bow, thrusters, propellers and protrusions (IMO, 2019a). The amount and location of niche areas is determined by the ships design, these exposed areas are difficult to access and paint effectively, thereby considered major hot-spots of bio-fouling (Arndt et al., 2021; Davidson et al., 2016), In addition, the ship type and size also influence biofouling, as the bigger the ship, the larger the surface area available for fouling by marine organisms (Arndt et al., 2021; Davidson et al., 2016).

It is also established that ships' voyage speed influences biofouling, claiming a decrease in the percentage area covered by species with increasing speed especially from 10 to 18 knots (Coutts et al., 2010). The implication of this is that slow moving ships (such as bulk carriers and oil tankers) spend more time in the receiving environment (coastal waters), raising the likelihood of bio-invasion either by attachment of new species or introduction of alien species (Arndt et al., 2021; MAF Biosecurity, 2010).

The voyage route (including the region, shipping routes and ports called) is another critical factor influencing the level of biofouling, as ships trading through the tropical regions are more profoundly fouled than ships that charter the temperate regions (Chan et al., 2022).

The probability for the survival of non-indigenous aquatic species during a voyage is also influenced by the voyage profiles such as the routes, time spent in port, as well as voyage speed and duration (Georgiades et al., 2021; Schimanski et al., 2016). Some regions/ports/harbors are regarded as the hot-spots of IAS transfer or advancing IAS distribution due to their busy status and shipping connectivity (Luoma et al., 2021).
For successful establishment of invasive aquatic species, the species must have survived its uptake from the state of origin, the transportation by ships to a new environment and the environmental conditions (biotic and abiotic) of the new habitats ((Blackburn et al., 2014; Chan et al., 2016; Coutts et al., 2010). Organisms with flexible and hard morphological properties survived better than others even at higher ship speeds (Coutts et al., 2010). Moreover, there are some abiotic factors such as the physico-chemistry of sediments, water quality, available nutrients, and hydrological system that influence the level of invasibility of a particular ecosystem by IAS (Thomaz et al., 2014).

2.4 Non-Indigenous Invasive Aquatic Species

Non-Indigenous Aquatic Species refers to non-native, alien, or exotic found outside its natural environment introduced through direct or indirect, intentional or unintentional anthropogenic activities, which is termed “invasive” if established in the new habitat and threaten the native species, ecosystems goods and services, and human well-being (Alidoost Salimi et al., 2021).

In the event that an invasive aquatic species is introduced into a new environment, it establishes itself via interaction with the prevailing communities and as a result, can modify the habitats, and consequently escalate the predation gravity on indigenous organisms (for example: comb jelly scenario in Asov and Black seas; shore crab of European origin established in North America; Japanese seaweeds in South Africa, Europe and Australia) (Bax et al., 2003).

The main pathways for introduction of these invasive aquatic species are classified as intentional or unintentional introduction in accordance with classification scheme provided by the Convention on Biological Diversity, which explains that an introduction that is facilitated through ships fouling and ballast water is regarded as unintentional or accidental, while the release of organisms into a new environment for intended human use is referred to as intentional (CBD, 2014; Rotter et al., 2020).

2.5 Impacts of Non-Indigenous Invasive Aquatic Species on Blue Economy

Marine ecosystems are valuable locations for biodiversity and economic prowess of a nation through provision of essential goods (foods, water, mineral resources) and services (carbon sink, shipping, tourism, mariculture and others) (Townsend et al., 2018; Buonocore et al., 2021). Evidently, the use of oceans and seas by humans for shipping, mining, fishing, dredging, oil and gas production, and recreation has negative repercussions on the marine ecosystem that in turn, has negative implications on citizens, especially coastal inhabitants' socio-economic benefits (Alidoost Salimi et al., 2021; Thomaz et al., 2014). Globally, bio-invasion is on the rise whereby these non-indigenous invasive aquatic species (IAS) once fully established in the "receiving ecosystem" could altogether have negative impacts on food security, loss of biodiversity and the economy (Kourantidou et al., 2021; Thomaz et al., 2014). For instance, the Mediterranean basin is known to harbor numerous dangerous invasive aquatic species due to its interconnectivity that spans 3 continents, and the economic damage from bio-invasion was put at an approximate value of $25.2billion (Kourantidou et al., 2021). Also, the invasion of the United States' mid-Atlantic coast in the 1950s by *Haplosporidium nelsoni* had severe impacts on *Crassostrea virginica* with 90% mortality in Chesapeake and Delaware Bays (Georgiades et al., 2021).

Invasive aquatic species could: cause extinction of indigenous plants and animals by predation or outcompeting them for food and other essential resources like preys, light, habitat; cause biodiversity and productivity loss resulting from reduction in habitat quality (due to increasing population of the invader in the habitat); introduce pathogens and diseases into the native environment (Alidoost Salimi et al., 2021; NOAA, 2021; Yildirim & Kaplan, 2022).

The invasive aquatic species poses serious threats to the economy --- the study of which is limited with little comprehension compared to the study of terrestrial habitats, nonetheless Cuthbert et al (2021) cited that the economic cost of global bio-invasion is about US$345 billion, which is huge. The economic costs include (but not limited to) those that are concerned with direct impacts on fisheries, recreation, marine infrastructure and other costs associated with control and management of IAS (Cuthbert et al., 2021; Kourantidou et al., 2021).

Acknowledging that the concept of "blue economy" entails economic activities carried out for conservation and sustainable management of marine and coastal resources and towards economic growth (Olatidoye, 2022; Yildirim & Kaplan, 2022), it is posited that any human-induced pressure on these resources will hinder the expected economic growth from the blue economy (Yildirim & Kaplan, 2022).

At this juncture, it is important to note that seafood production is very critical for global food security and provides enormous socio-economic benefits to the people in terms of job creation and source of income, therefore, deemed as essential to achieving a "blue economy". This cannot be truer for countries that are explicitly dependent on marine resources (Yildirim & Kaplan, 2022). It has been recognized that introduction of invasive alien species, coastal and marine environment pollution, global warming, ocean acidification (resulting from climate change) threatens the biological diversity of marine ecosystems. This is said to hinder the long-term goals of the blue economy (Yildirim & Kaplan, 2022).

Apparently, the European Union (EU) also recognizes the role of “blue economy” in achieving the EU Green Deal objectives, and identified the development of offshore renewable energy, decarbonization of the maritime sector (including shipping and ports), and adoption of circularity in the design of fishing gears, ship recycling and other maritime operations as some of the blue development concepts that will protect biodiversity, mitigate climate change impacts and advance the blue economy towards sustainable economic growth (European Commission, 2021b). The European Commission reported that the blue economy sector employed about 4.5million people across the EU and a turnover of about 650billion euros generated. The biotechnology sector was boosted by the algae production subsector with Portugal, Spain and France having a total turnover of 10.7million euros, and the EU boasted 66% of global installed wave energy capacity (a renewable energy source) (European Commission, 2021a).

It seems that the effective operation of blue developments, such as the offshore wind turbines, surveillance systems, could be hampered by biofouling through blocking/damaging of sensors, deterioration of structures, increasing energy consumption (marine renewables and shipping). This could very well impact environmental data accuracy, placing enormous financial burdens from costs associated with labor increment for prevention/management of biofouling; productivity loss; replacement/maintenance of sensors/damaged equipment; hull cleaning and other related costs (Cruz et al., 2020).

The reliability and efficiency of marine renewable energy (MRE) resources is highly dependent on maximization of captured energy and minimization of downtime, which is affected by biofouling, also, the reliability and accuracy of devices such as digital data buoys deployed to monitor the hydrodynamic properties around the devices and the installed devices performance are impacted when fouled by marine organisms (Want & Porter, 2018). These biofouling effects necessitate adequate biofouling management on the MRE resources, the cost of which is very huge, time consuming and challenging to apply in-situ due to the nature of the offshore environment (Vinagre et al., 2020; Want & Porter, 2018).

3. DATA ANALYSIS

Given that Nigeria is a maritime nation with a population of more than 200million people, with an economy that is highly dependent on the importation of goods from foreign countries and the exportation of crude oil and gas, which makes seaborne trade a critical sector of the economy (Lloyd et al., 2020). It is also noted that the ships calling at Nigerian Ports are vessels from different maritime nations bringing in many household commodities, grains and petroleum products to meet the increasing demands of the population.

The hypothesis that follows: there is risk of invasive aquatic species transfer from foreign ships plying Nigeria's waters. In this regard, the research considers using vessel traffic data for Lagos Ports (Apapa and Tincan Island Ports) being the Ports with the highest traffic in Nigeria, and method involves the following (a) determination of foreign vessel traffic and approximate residence time; (b) determination of potential risks of IAS transfer from the vessels using their voyage history (marine ecoregion) and available data on global distribution of IAS; and (c) development of a risk matrix to assess the potential for IAS transfer from marine eco-regions that are regarded as "hot-spots".

For this study, the data/information gathering was carried out as follows:

1. Acquisition of data on vessel traffic in Lagos Ports from NIMASA's C4i Centre for 2017 to 2021;
2. Screening of the data collected to remove irrelevant data;
3. Survey of relevant peer-reviewed and grey literatures and technical reports from International Organizations such as IMO, Supranational Organizations like the European Union (EU) and the shipping industry; and

Review of identified literatures and reports for gathering of data/information on IAS prevalence in marine ecoregions and databases on global distribution of IAS.

(a) Determination of Vessel Traffic and Approximate Residence Time in Lagos Ports

Research studies by Costello et al., (2022); Lim et al., (2017) and Ware et al., (2013) adopted the use of vessel traffic and networks, the time spent in ports as well as previous port calls to identify the potential routes for IAS transfer, while matching it with the global IAS distribution across marine ecoregions.

There currently exists a dearth in evidence-based research from a Nigerian context in relation to the above. Be that as it may, this study intends to fill out some of the vacuum in research through the determination of potential risk of IAS introduced via foreign ships calling at the Nigeria's busiest maritime corridor, Lagos. Using the Nigerian Maritime Administration and Safety Agency's (NIMASA) C4i surveillance systems to gather data on vessels' movement in Lagos Ports between 2017 to 2021 enhanced the possibility of identification of ships calling at the Ports, the time spent in Lagos Ports (residence time) and prospective bio-invasion routes. The two ports under consideration are Apapa Port with coordinates: Latitude 6.4395°N / Longitude 3.3585°E and Tincan Island Port with coordinates Latitude 6.4343° N, Longitude 3.3562° E.

To evaluate the potential pathways for transfer of IAS through biofouling using the available shipping traffic data from NIMASA's C4i (Command, Control, Computer, Communication and Intelligence) system, and taking a cue from (Costello et al., 2022) the following parameters were considered:

- Type of Vessel: to identify the prevailing ship types and use the time spent in ports for residence time;
- Previous Port of Call: to identify the ports with frequent calls from which the identified vessels enter Lagos Ports. This will be used to identify potential

threats of transfer of IAS from these international routes with confirmed data of invasive aquatic species;

- Next Port of Call: to identify the differences in routes visited by prevalent vessels that call in Lagos Port, as that route may be strong hot-spots for invasive species.
- Residence Time: to use the length of stay of the vessels in determining the risk of IAS being introduced.

Noting that there are other factors such as sailing speed, anti-fouling systems, environmental conditions, full records of vessels' previous voyages (ports visited by each vessel), and hull maintenance practices, that can influence the transfer of invasive species from ships' hull fouling (Linley et al., 2014), these factors could not be considered in the study due to time and data limitations.

(b) Determination of potential risks of IAS transfer from the vessels using their voyage history (marine ecoregion)

To determine the prevalence of IAS in the last Ports of calls of vessels that called at Lagos Ports, the earlier study by Molnar et al. 2008 which gave comprehensive data/information on global geographical distribution of non-indigenous IAS; and other online databases such as International Union for Conservation of Nature's (IUCN) Global Invasive Species Database (GISD) and Global Register of Invasive Species (GRIS) were used to provide a linkage between the shipping networks to Lagos and possibility of bio-invasion from the routes.

Using the data on previous Ports of call of vessels calling at Lagos Ports in conjunction with the databases on geographical distributions of IAS helped in the identification of the marine ecoregions (defined as marine zones that contain homogeneous species with quite distinctions from adjacent areas and are represented in global scale (Molnar et al., 2008)) from which the vessels entered and the prevalent IAS in the regions as well as their ecological impacts. The information will assist in determining the possible pathways for transfer of IAS into Lagos Ports and the gravity of threats to native marine biodiversity.

(c) Development of a risk matrix to assess the potential for IAS transfer from marine eco-regions that are regarded as "hot-spots".

Following the identification of the predominant shipping networks of vessels calling at Lagos Ports and the potential IAS that could be introduced via these shipping networks, this phase entails using freely accessible online databases of invasive marine species to identify the routes within the marine ecoregions that contain high-risk species (hot-spots) (such as European Green Crab that is reportedly a resilient and predatory species established in the pacific; *Didemnum vexillum* and other truncates are considered successful invaders with predatory attributes and threats to the marine environment globally (Linley et al., 2014)). The result will be used to develop a risk matrix for identification of potential threats of IAS transfer from vessels coming to Lagos Ports via the hot-spots. Consequently, the risk assessment will assist policymakers and designated regulatory bodies to put in place preventive measures based on the level of risk posed by the vessels calling at the Lagos Ports, as priorities can be set for management or control efforts.

In developing the risk matrix, two essential parameters were used: (a) vessels' residence time in Lagos Ports and (b) biogeographic similarity of the ships' previous ports of call to categorize the vessels based on the risk levels. The choice of the vessel response time is based on the principle that the longer the stay of vessels from high-risk marine ecoregions the higher the likelihood of transfer or uptake invasive species being introduced in receiving Ports (Lim et al., 2017). The risk matrix will rank the vessels based on the risk posed as: low risk vessels, medium risk vessels and high-risk vessels.

3.1 Vessels Residence Time

With Nigeria as the case study, and the Lagos Ports in profile, the marine transport traffic data from NIMASA's C4i for 2017-2021 was obtained and analyzed to identify the number of vessels, vessel types, residence time in Lagos Ports and previous ports of call.

The Ports considered for the study are Apapa Port, Tincan Island Port and Aje Oil Field, Lagos, while the vessel types included: Bulk Carriers; General Cargo Ships; Container Carriers; Oil/Chemical Tankers; Reefers, LPG Tankers; Vehicle Carriers; Heavy Load Carriers, Crude-Oil Tankers and Roro Cargo Vessels. The above constituted the major cargo carriers plying the Lagos Ports. During the analysis, the dominant cargo vessels were determined via cumulative numbering in Microsoft Excel:

Another key data required for the assessment is the time spent (in hours) by these vessels in the Ports, which is provided in the data from the C4i. Understanding that the time spent by the vessels at the Ports varies, which can be due to different factors such as cargo handling efficiency, congestion at the ports, common industrial strike and several other hindering factors (Slack et al, 2018). Based on the ships traffic data provided by the C4i, the average residence time for the vessels were determined using Microsoft Excel and graphically illustrated (see figures (2) to (6).

Table 3.1: Average Residence Time of Cargo Vessels for Lagos Ports from 2017 to 2021

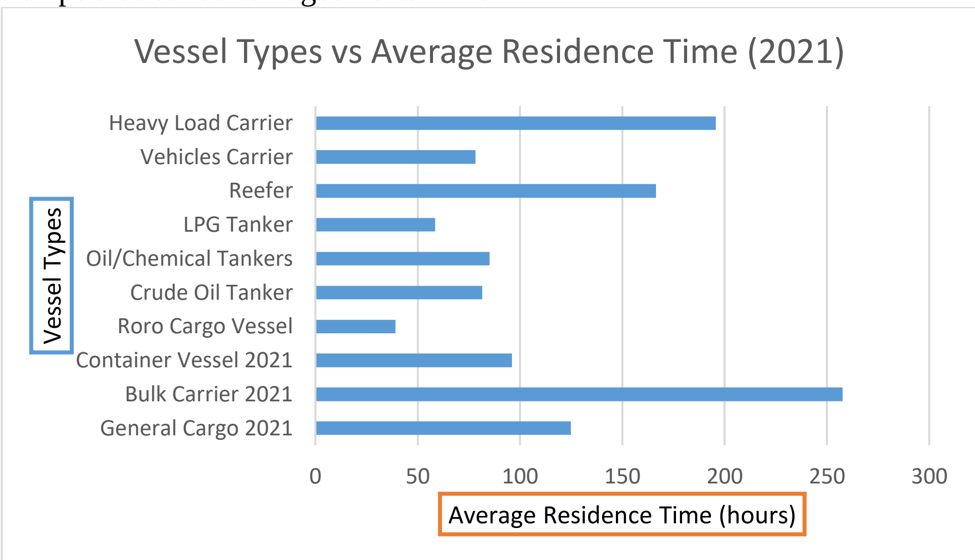
	Year 2021	**Year 2020**	**Year 2019**	**Year 2018**	**Year 2017**
General Cargo Carriers	124.84	162.73	83.936	127.3354	121.6784
Bulk Carriers	257.68	229.79	213.5762	218.0323	227.3042
Container Carriers	96.13	102.24	75.55536	47.50425	40.66319
Roro Cargo Vessels	39.112	47.22	37.82239	20.28086	26.68313
Crude Oil Tanker	81.58	47.94	21.52218	26.87656	87.68635

Oil/Chemical Tanker	85.14	99.63	98.46022	88.0028	85.41085
LPG Tanker	58.59	70.90	69.37263	86.7718	71.7943
Reefers	166.49	162.72	150.7835	159.8806	137.4909
Vehicle Carriers	78.24	85.25	58.17188	36.05989	29.17863
Heavy Load Carriers	195.68	169.29	152.7193	208.5526	48.263

Source: NIMASA C4i Database

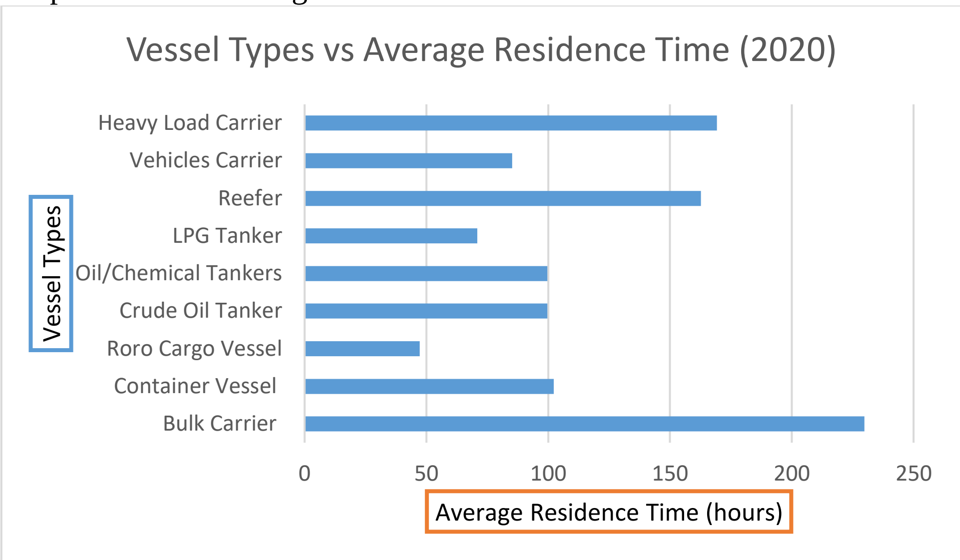
The average residence time data helped determine: the vessels with the longest and shortest residence, and the median residence time for the dominant vessels to identify vessels that pose the highest risk of invasive species transfer due to their length of stay at Ports (which would be linked with the invasive species records of the vessels previous Ports of call).

Figure 3.1: Graphical representation of vessel types vs average residence time for cargo ships that called at Lagos Ports in 2021



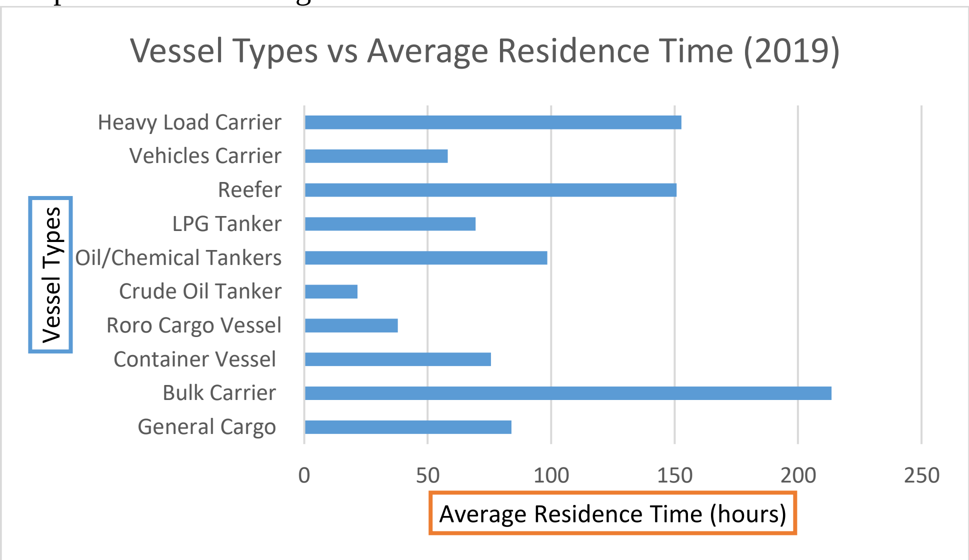
Source: NIMASA C4i Database

Figure 3.2: Graphical representation of vessel types vs average residence time for cargo ships that called at Lagos Ports in 2020



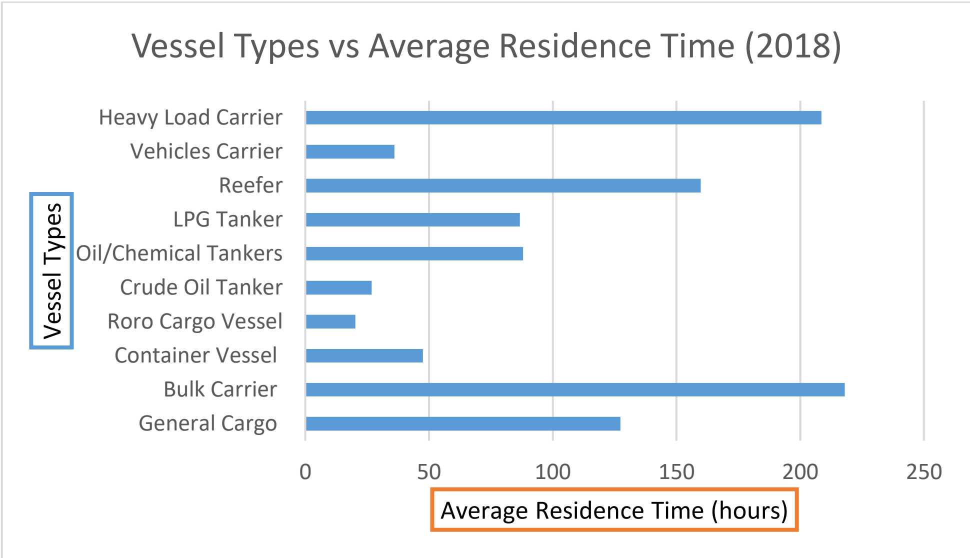
Source: NIMASA C4i Database

Figure 3.3: Graphical representation of vessel types vs average residence time for cargo ships that called at Lagos Ports in 2019



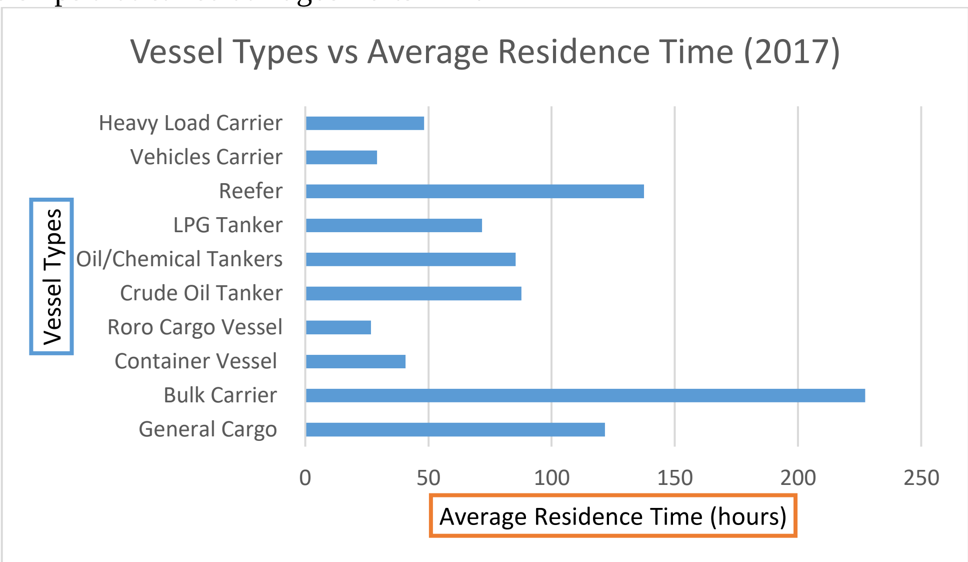
Source: NIMASA C4i Database

Figure 3.4: Graphical representation of vessel types vs average residence time for cargo ships that called at Lagos Ports in 2018



Source: NIMASA C4i Database

Figure 3.5: Graphical representation of vessel types vs average residence time for cargo ships that called at Lagos Ports in 2017



Source: NIMASA C4i Database

3.2 Identification of Invasive Species Hot-Spots Using Marine Ecoregion Data

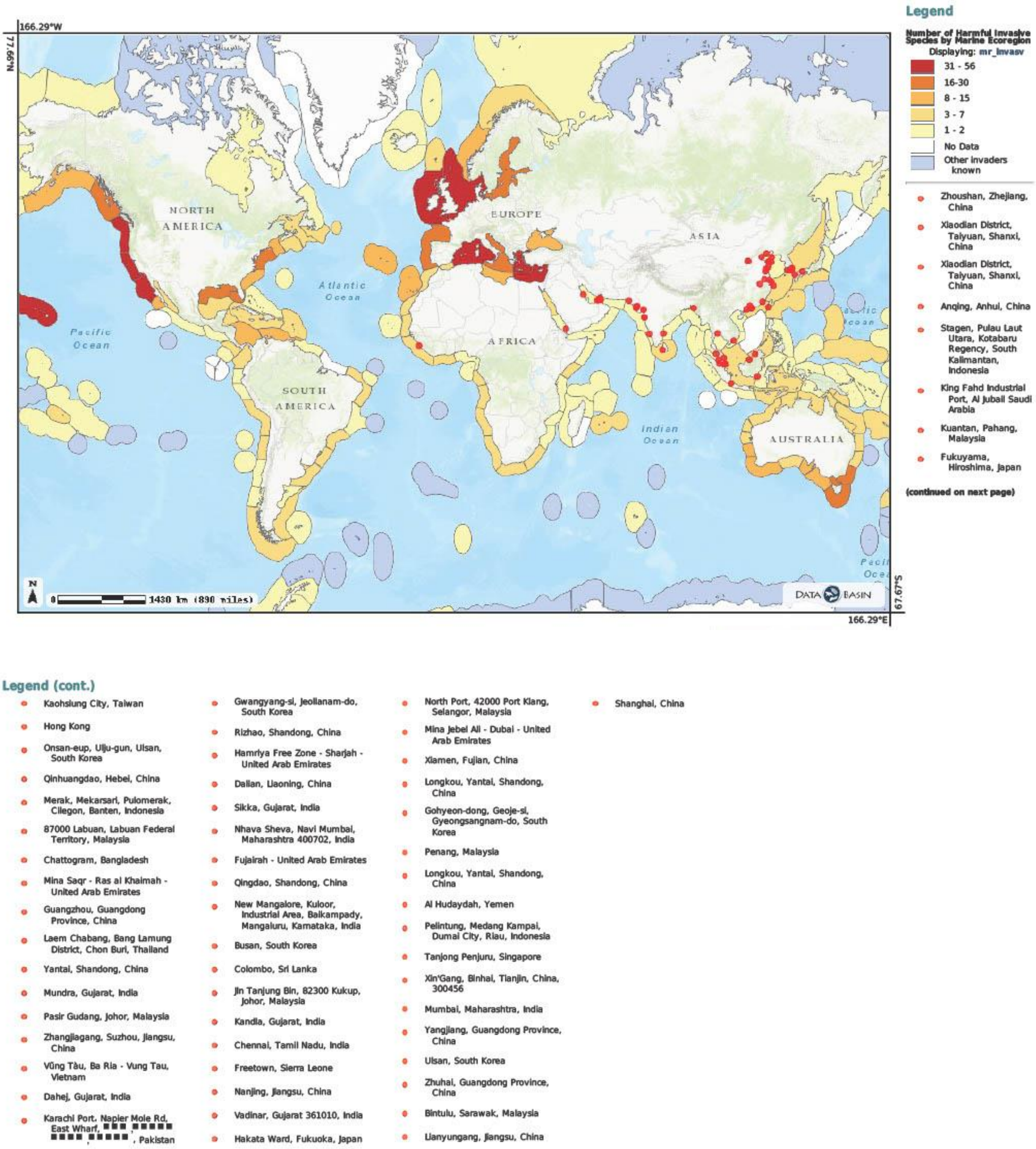
Marine ecoregion regions are regions that are classified based on the biogeographic characteristics of their shelves and oceans (Molnar et al., 2008). For this study, the online global marine invasive species database was used in conjunction with the NIMASA's C4i data on previous Ports of call. Using the previous Ports of call records of the vessels that called at Lagos ports, the originating ports were categorized according to their continents and identified on the ecoregion maps to see the range of invasive species that the ports fall into. Following the identification of the originating Ports on the maps, each continent map was produced as demonstrated below:

The map is used to indicate the number of harmful marine invasive species in the ecoregions of the vessels' originating ports, for instance in figure (7) A, the range of harmful invasive species from the Asian region is majorly within the band 3-7 IAS.

The outcome of the data analysis is used to develop a risk matrix where the risk pose by vessels are identified using the resident time for the ship categories in Lagos port with the harmful invasive species records of the Ports of origin of the vessel. This will enable the determination of the potential pathways of introduction of IAS (vessel categories/ecoregion) and their risk levels.

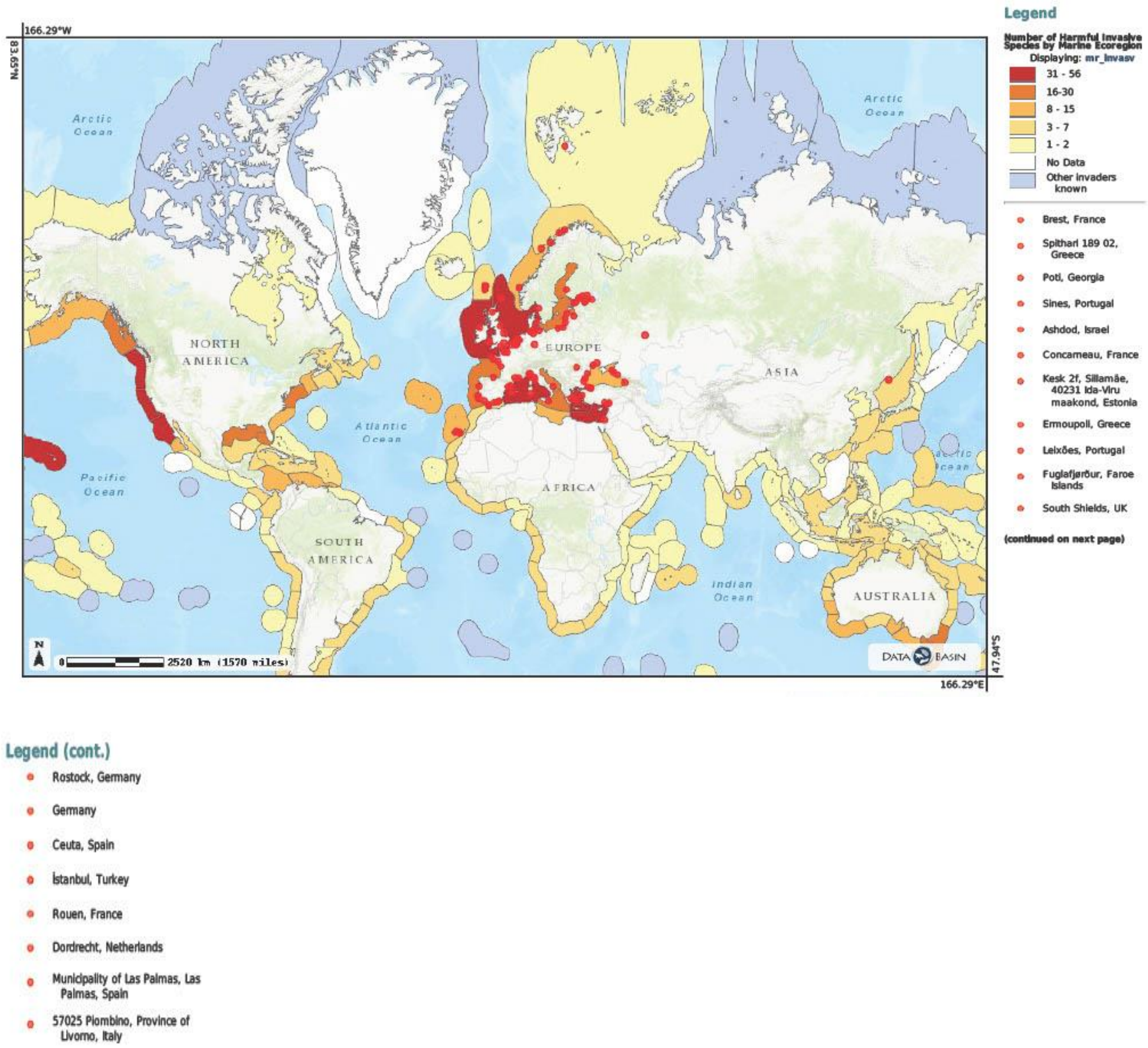
Figure 3.6: Maps of Marine Ecoregions of Vessels that Called at Lagos Ports (2017)

A. Asia



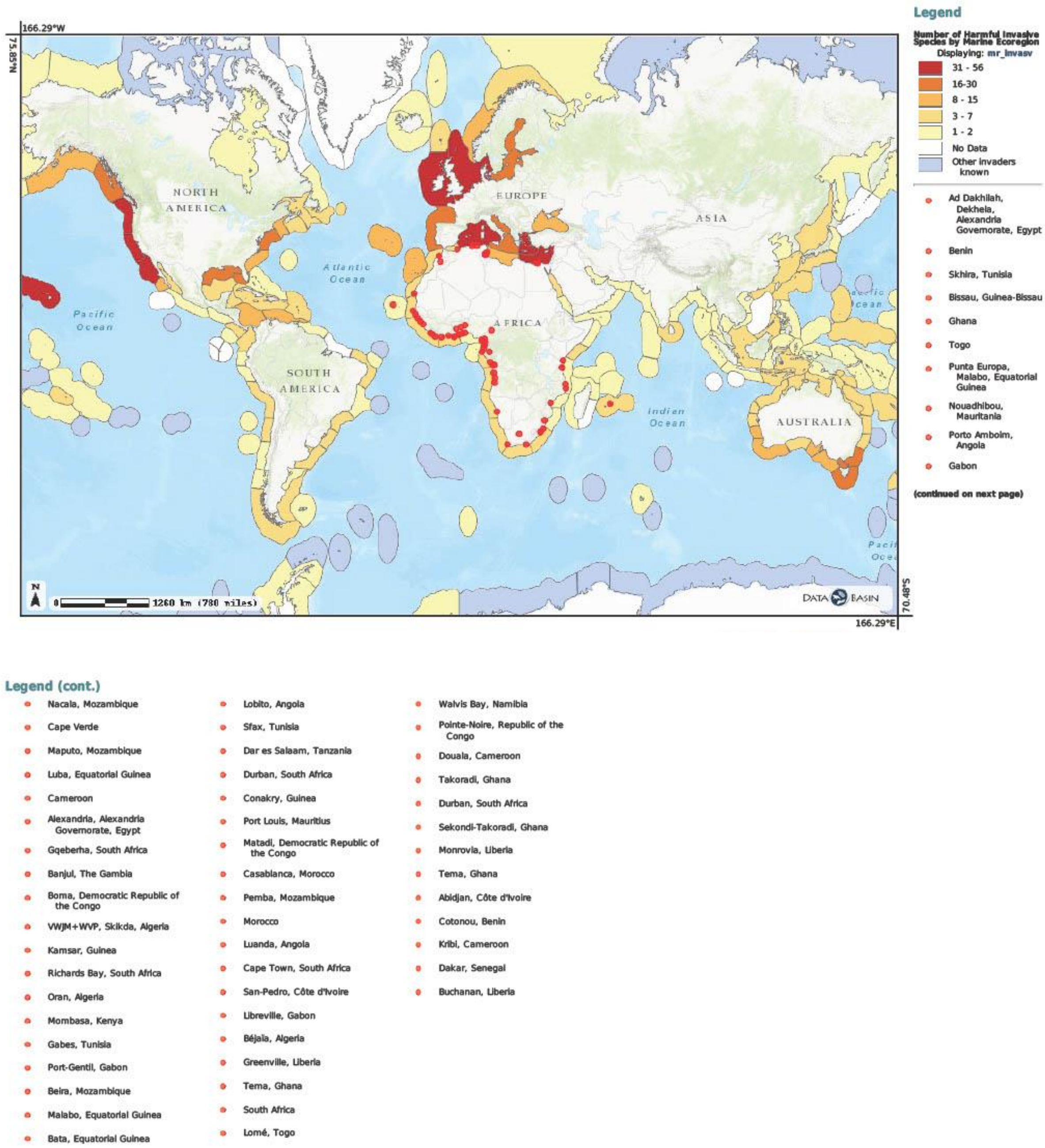
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

B. Europe



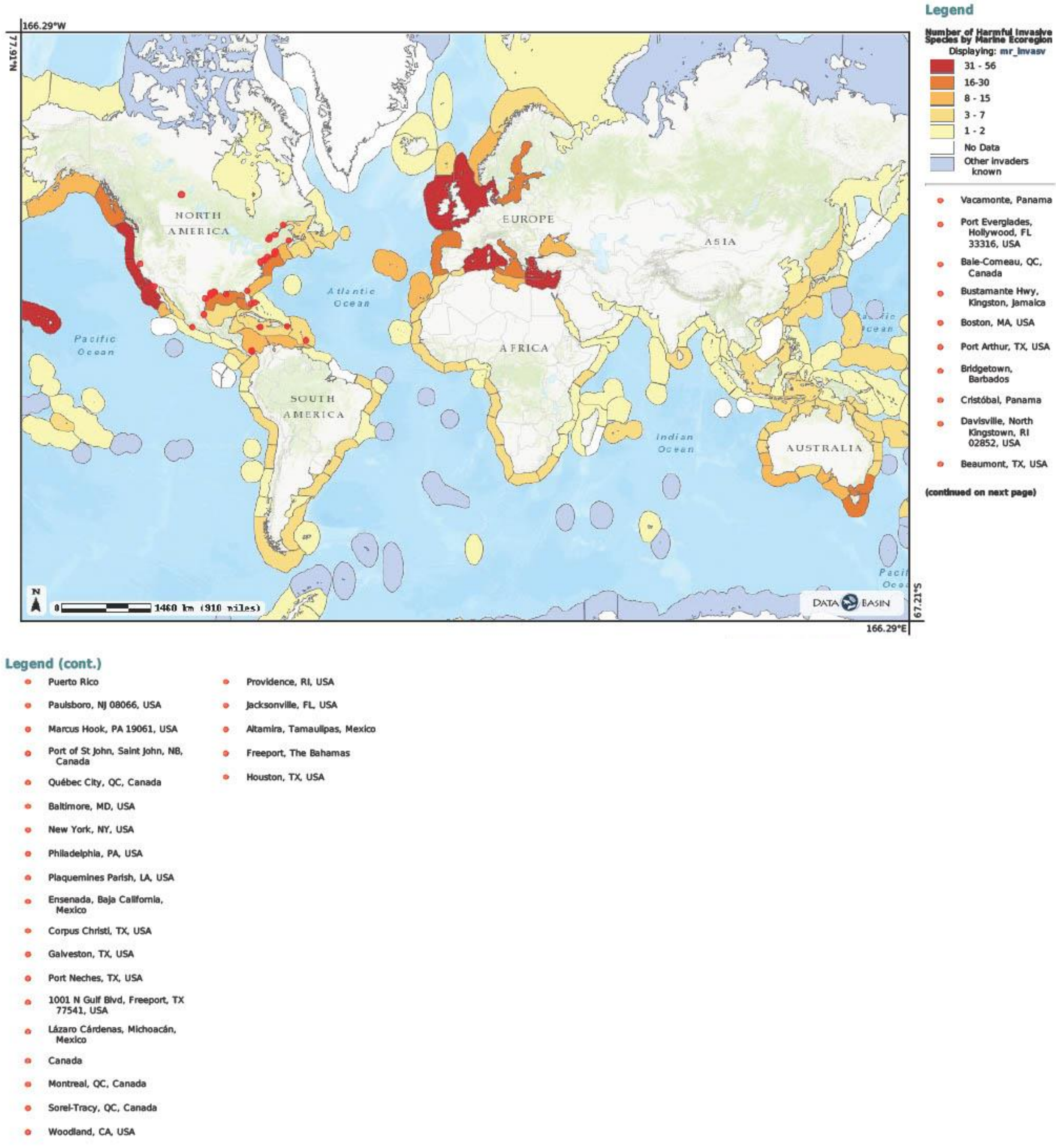
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

C. Africa



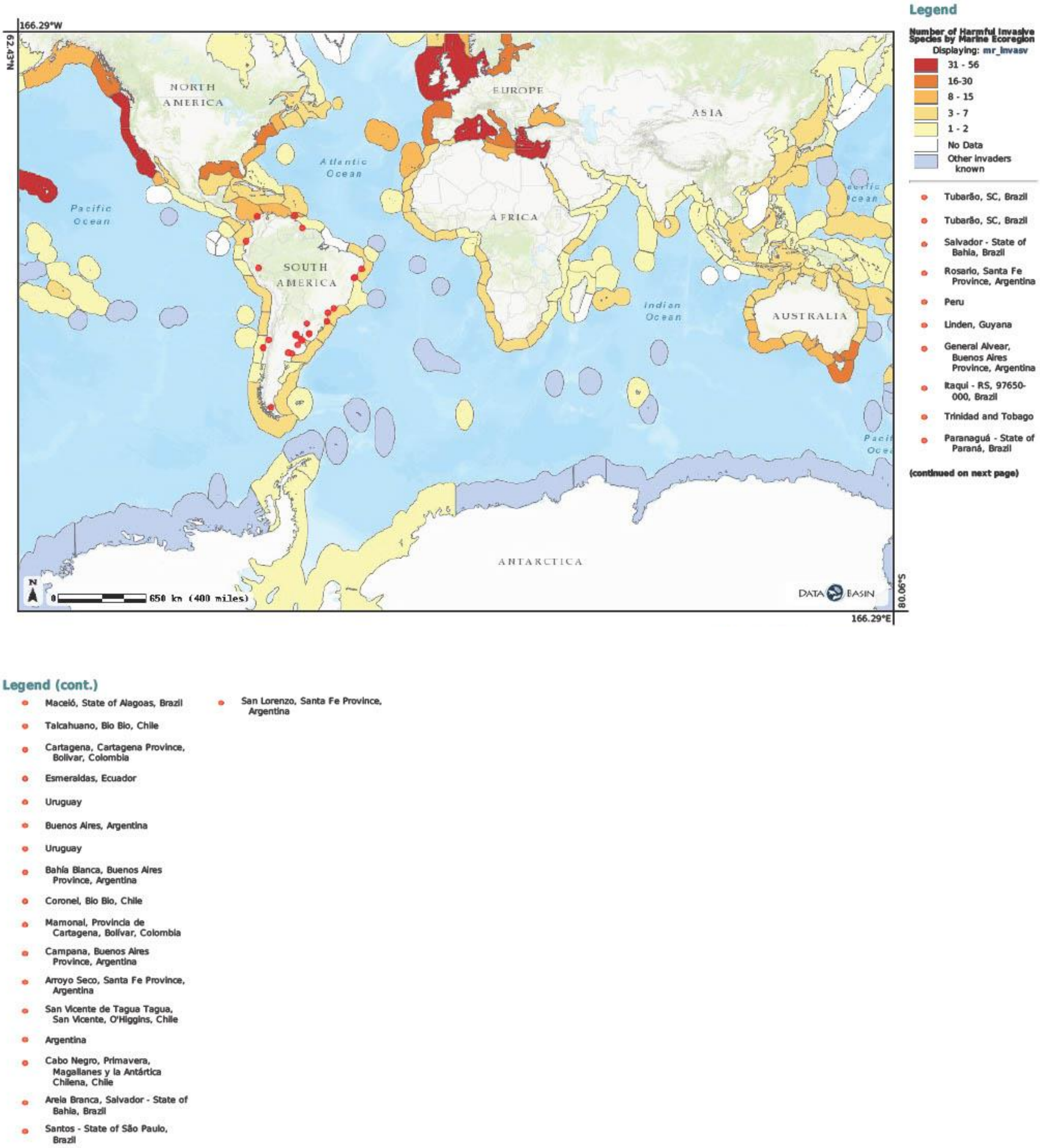
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

D. North America



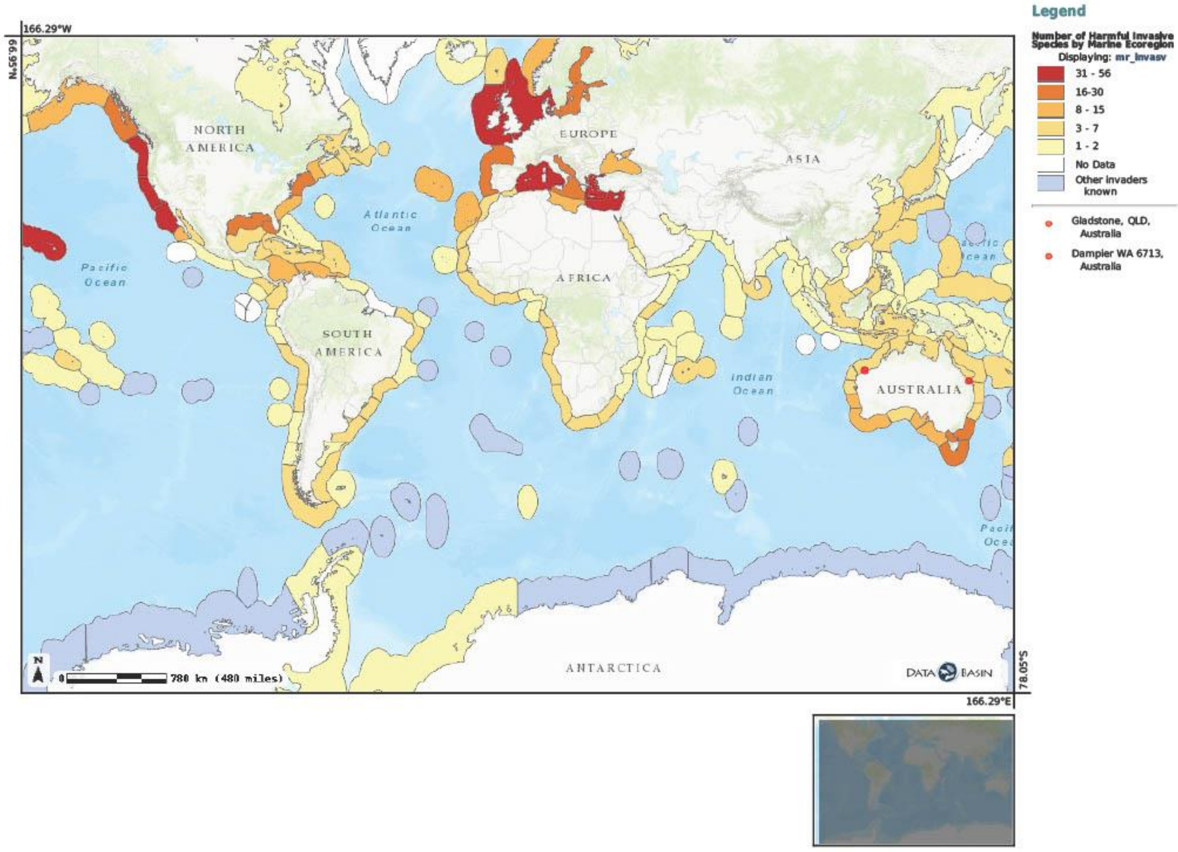
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

E. South America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

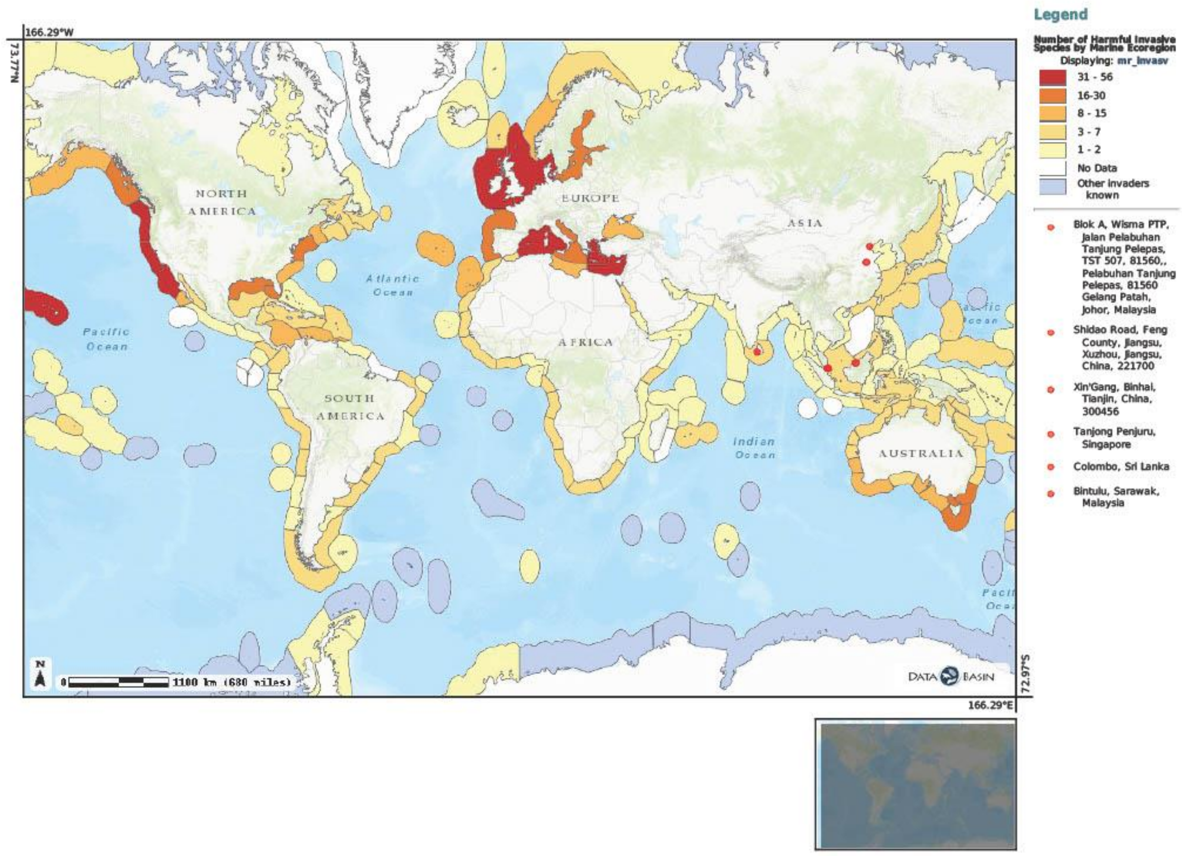
F. Australia



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

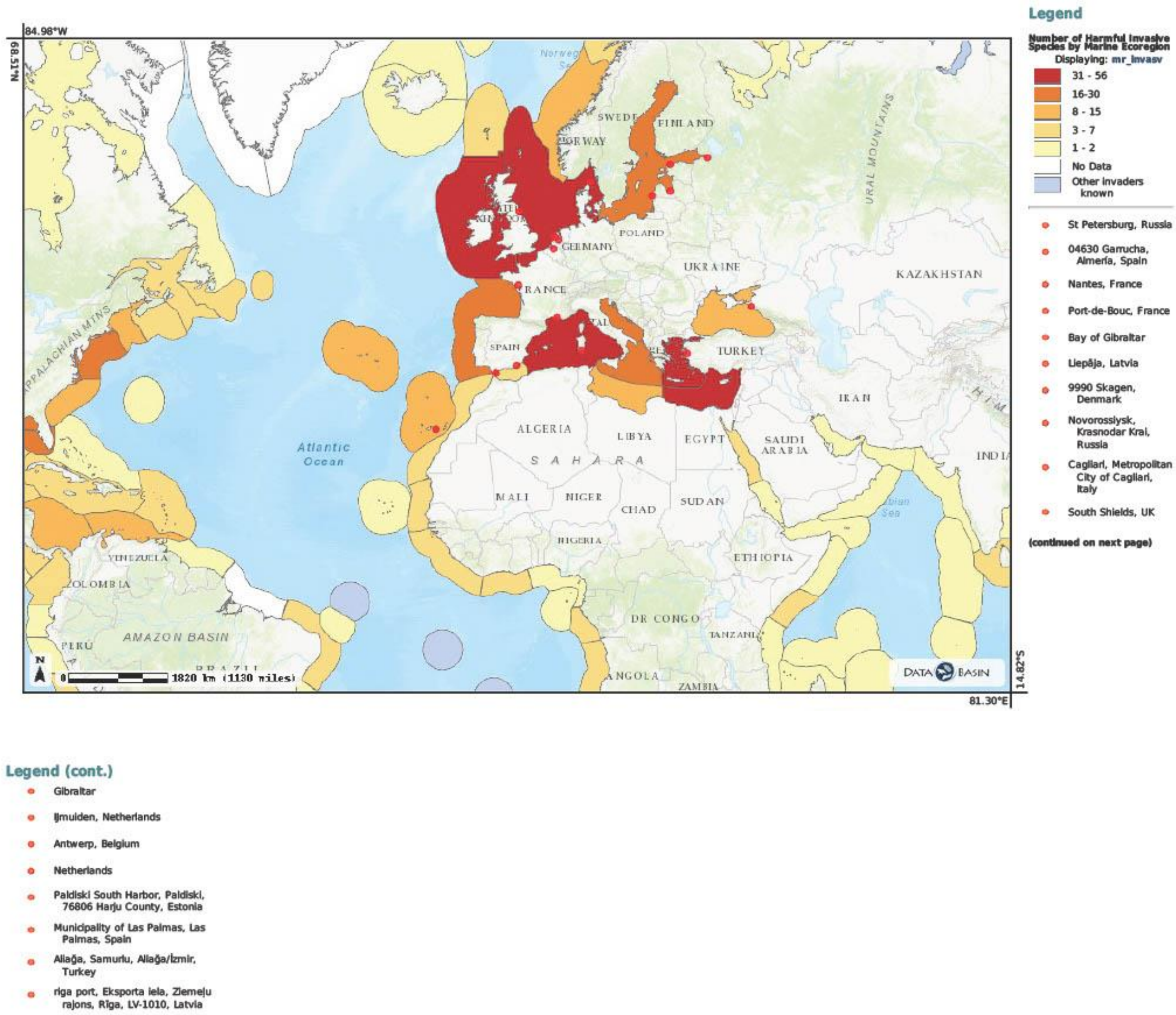
Figure 3.7: Maps of Marine Ecoregions of Vessels that Called at Lagos Ports (2018)

A. Asia



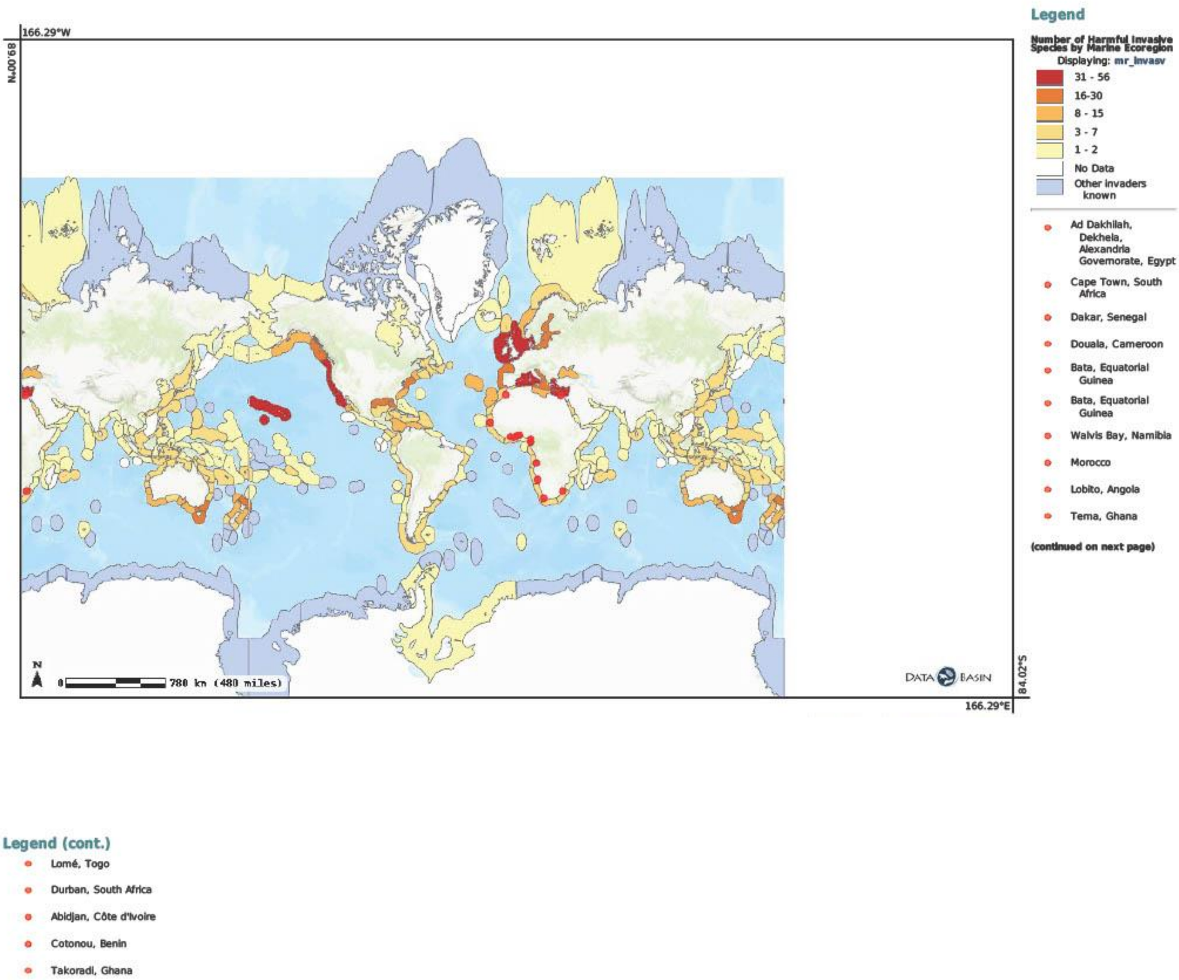
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

B. Europe



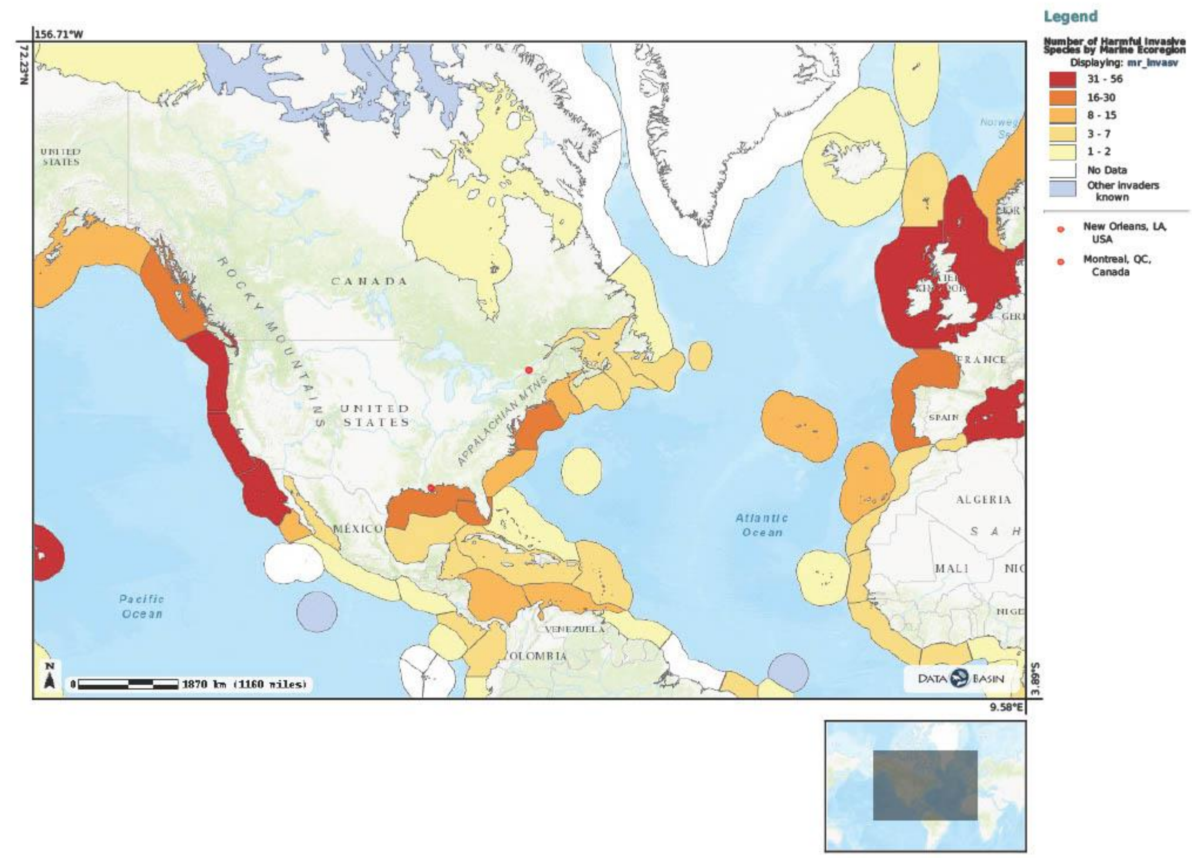
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

C. Africa



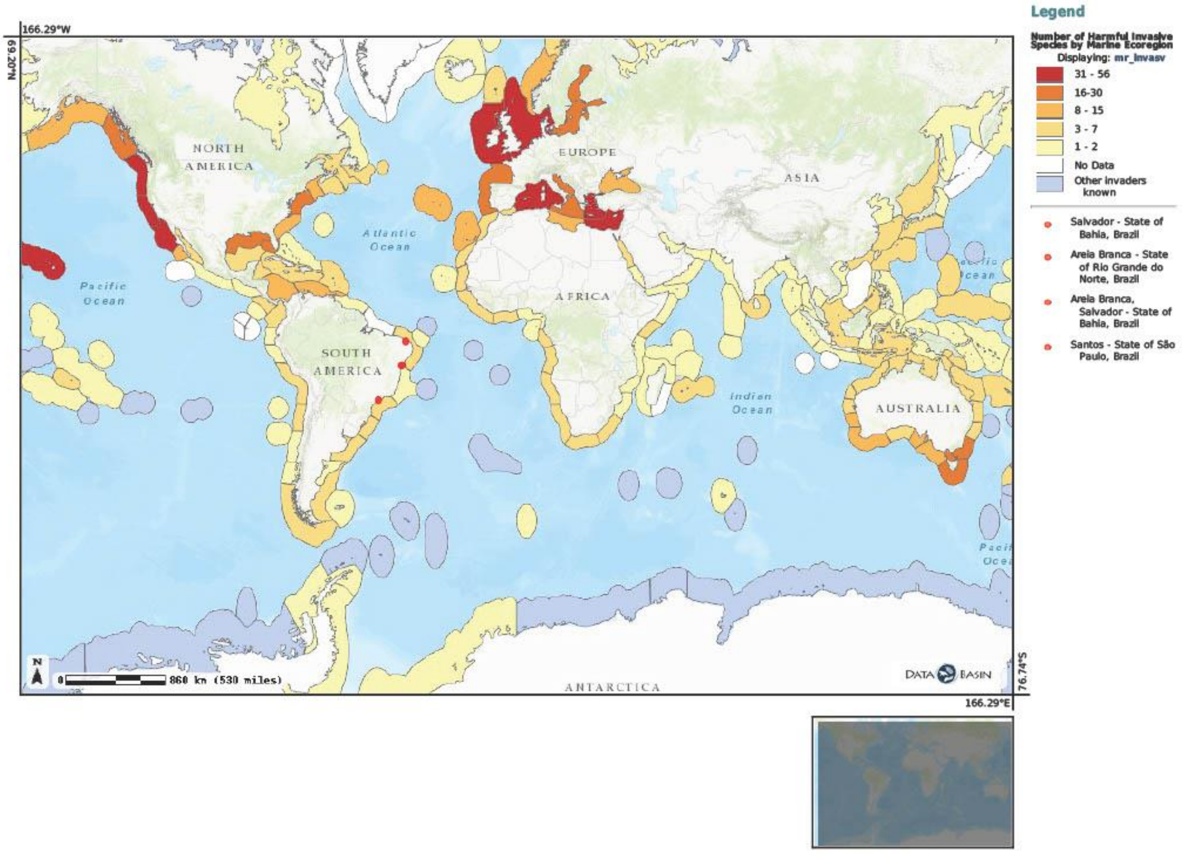
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

D. North America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

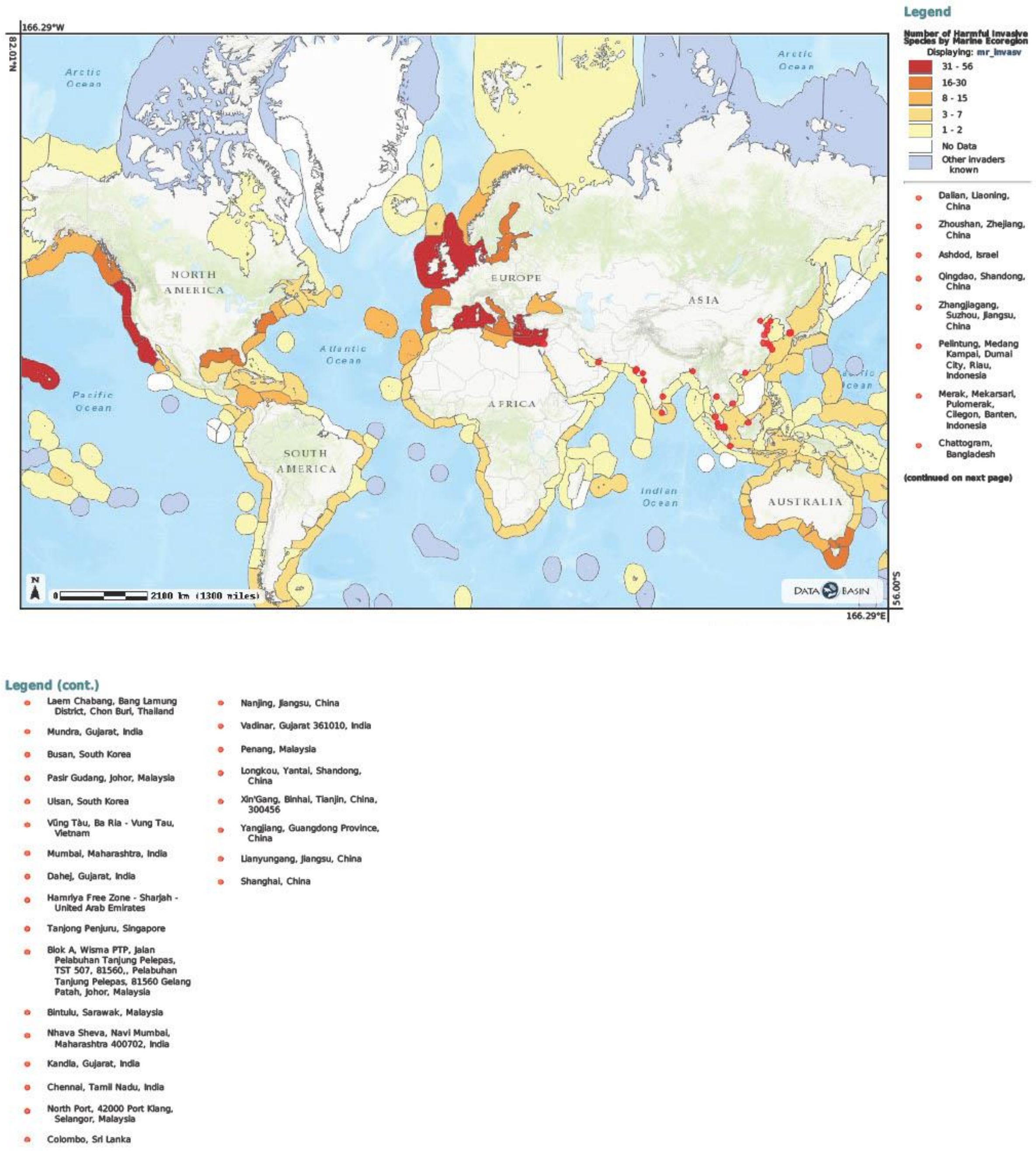
E. South America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

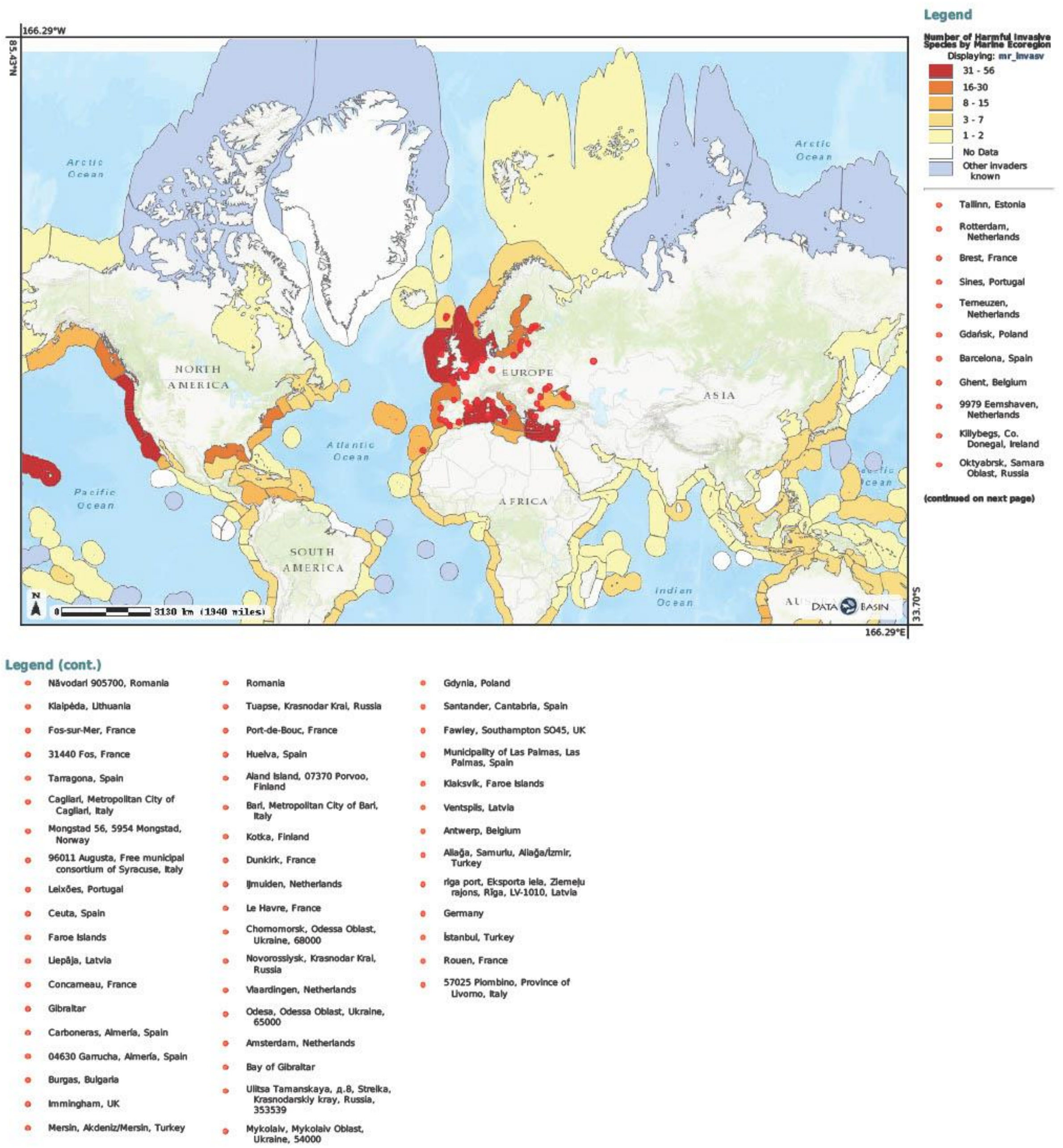
Figure 3.8: Maps of Marine Ecoregions of Vessels that Called at Lagos Ports (2019)

A. Asia



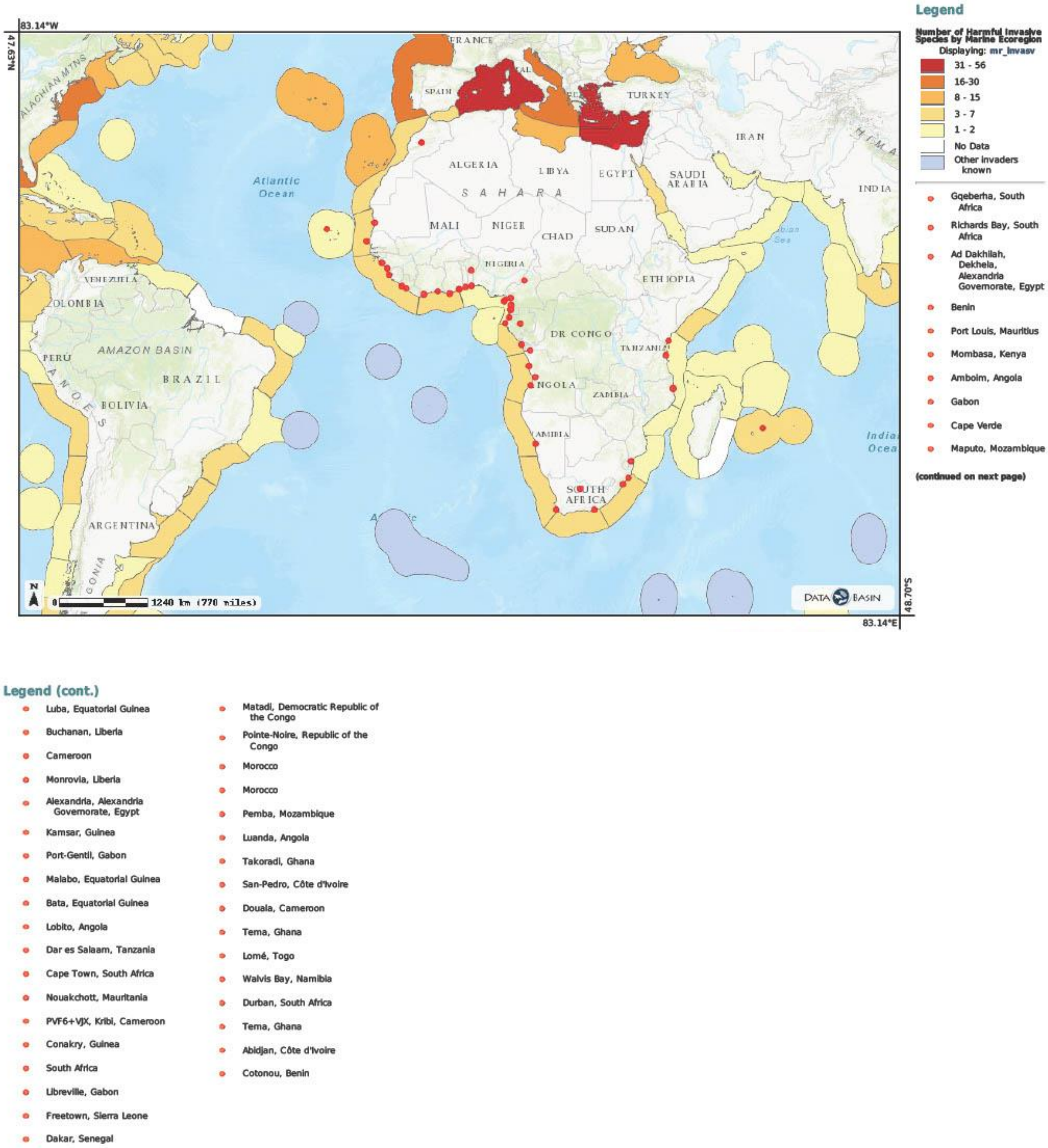
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

B. Europe



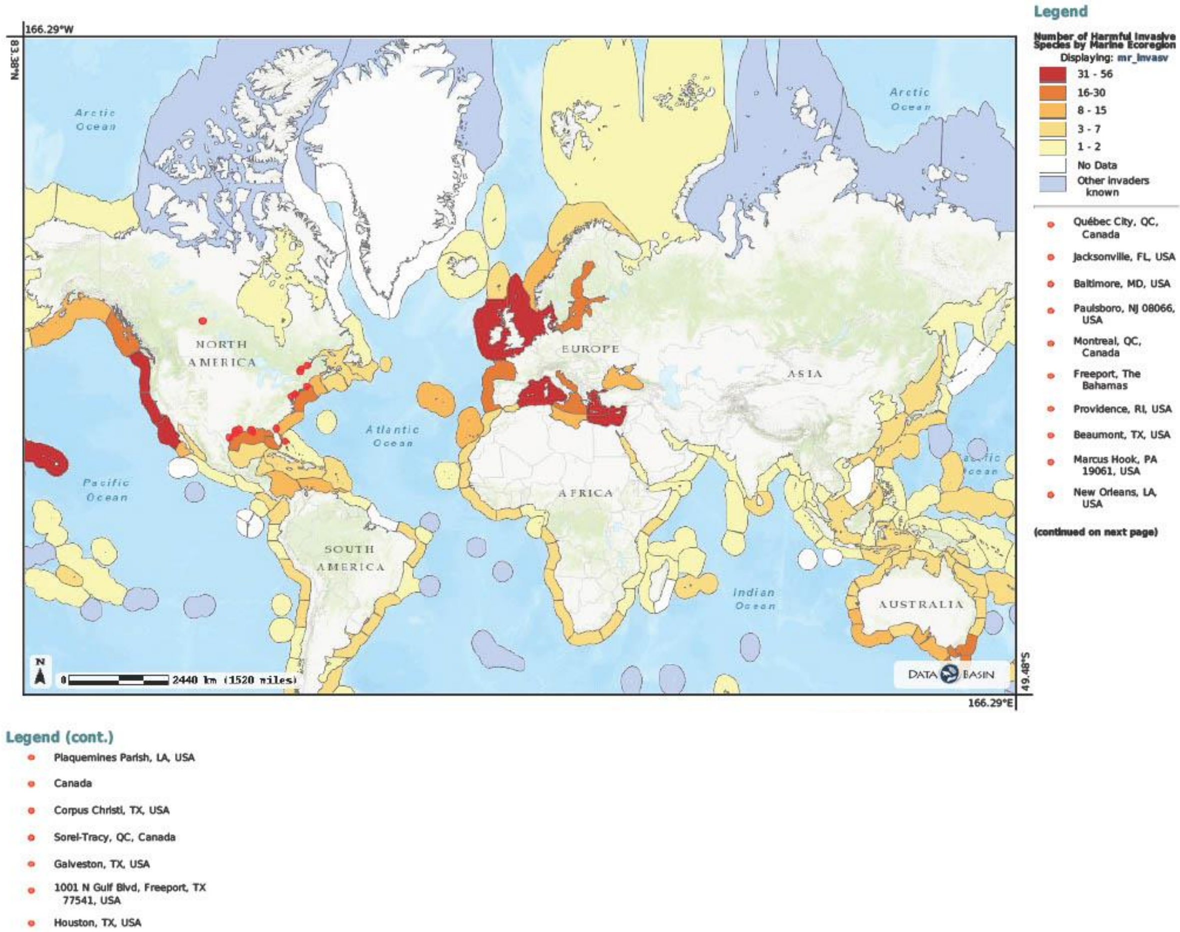
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

C. Africa



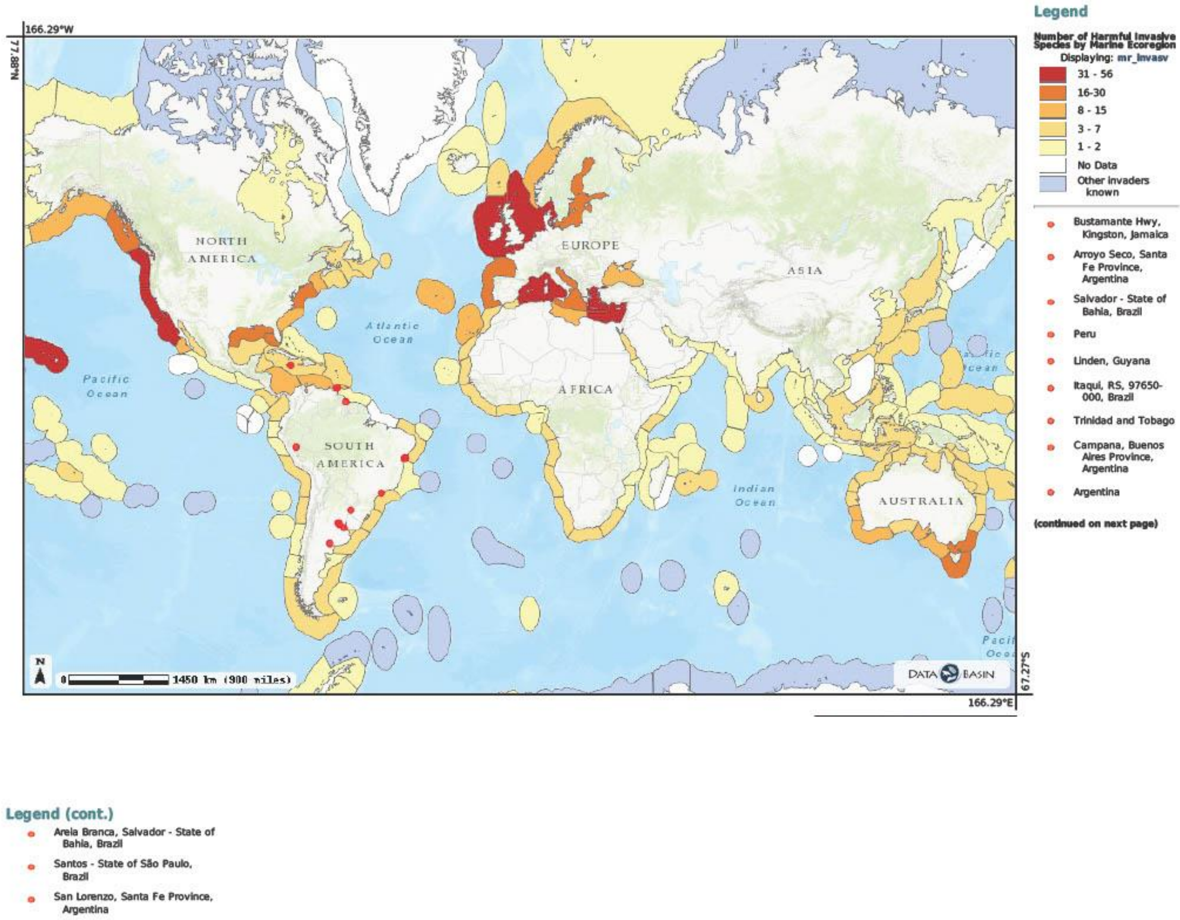
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

D. North America



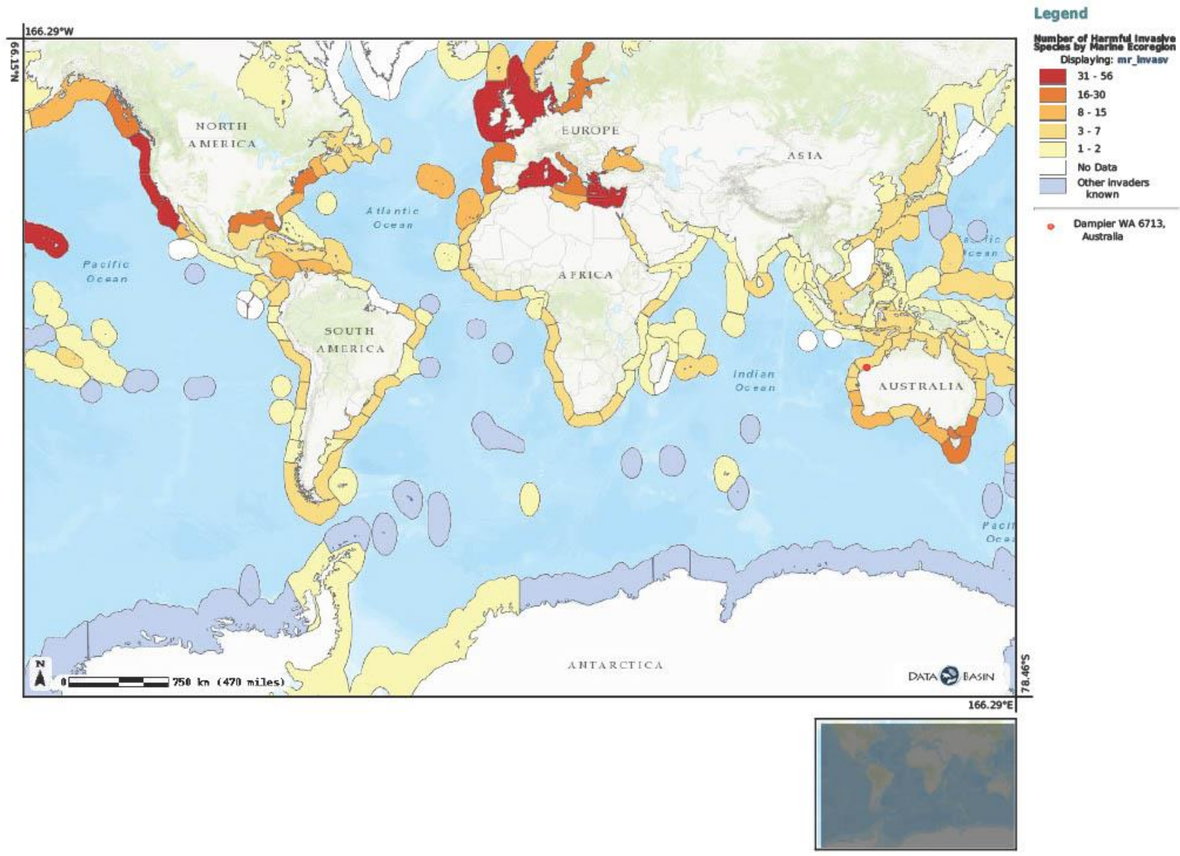
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

E. South America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

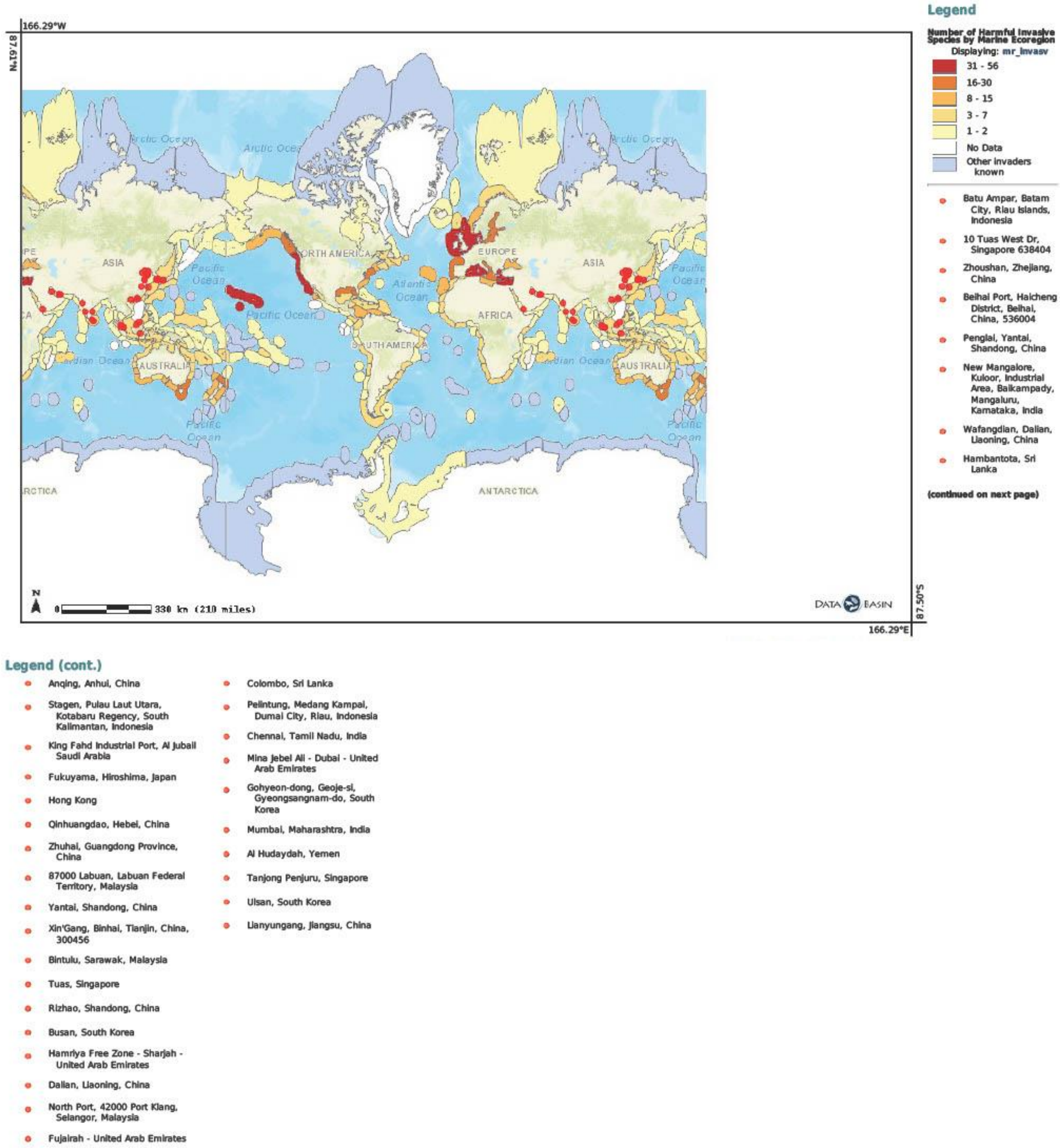
F. Australia



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

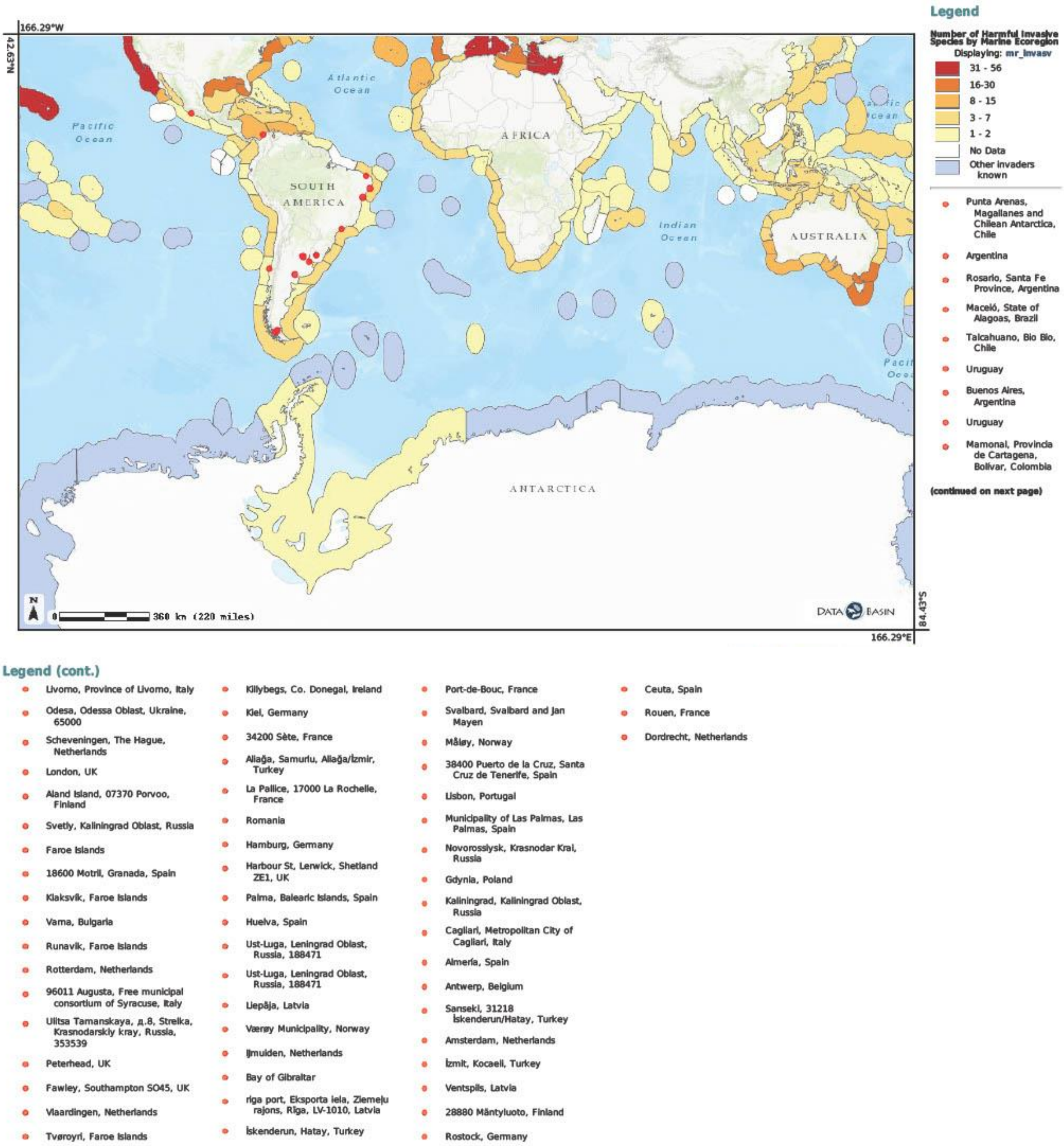
Figure 3.9: Maps of Marine Ecoregions of Vessels that Called at Lagos Ports (2020)

A. Asia



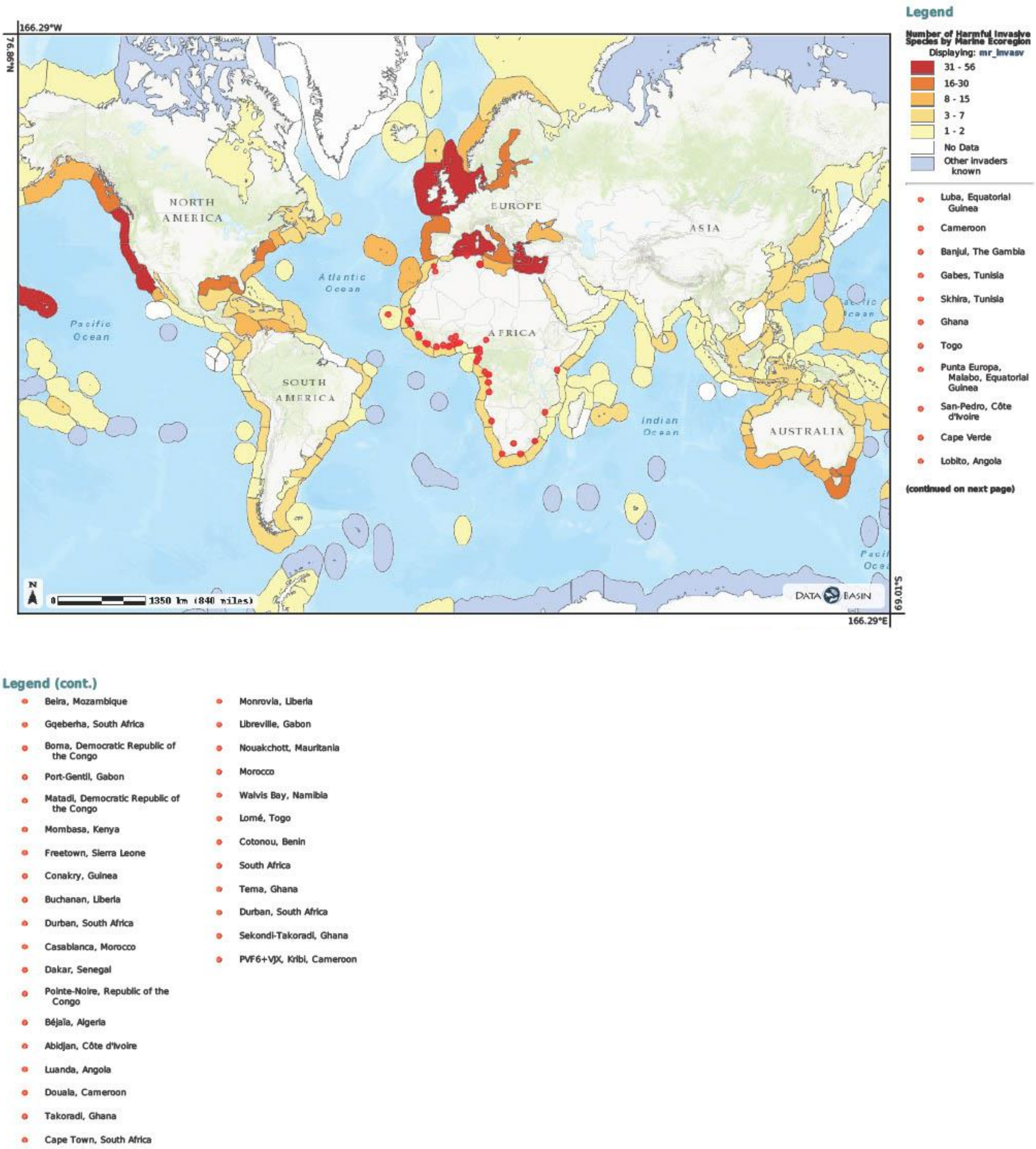
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

B. Europe



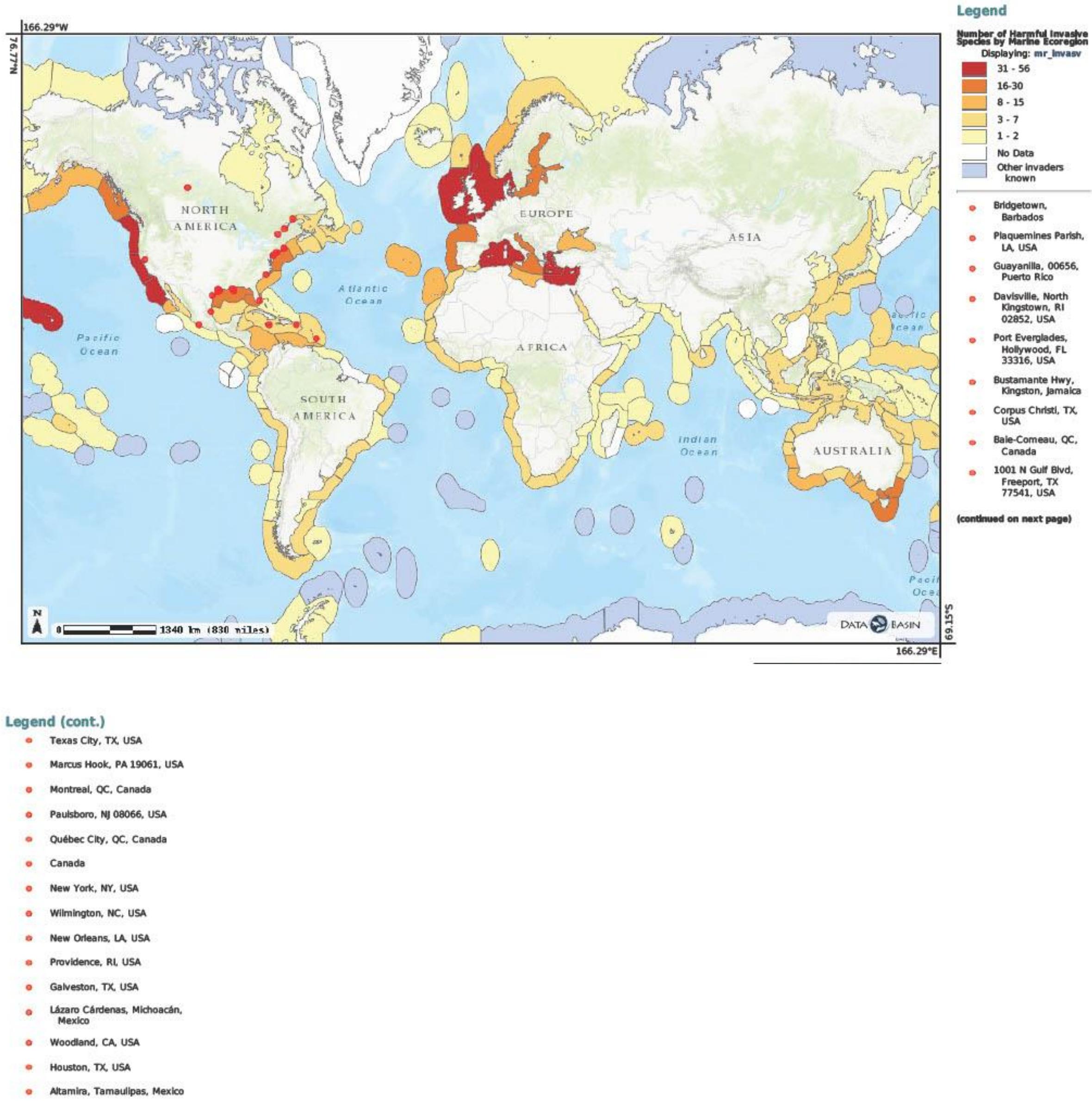
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

C. Africa



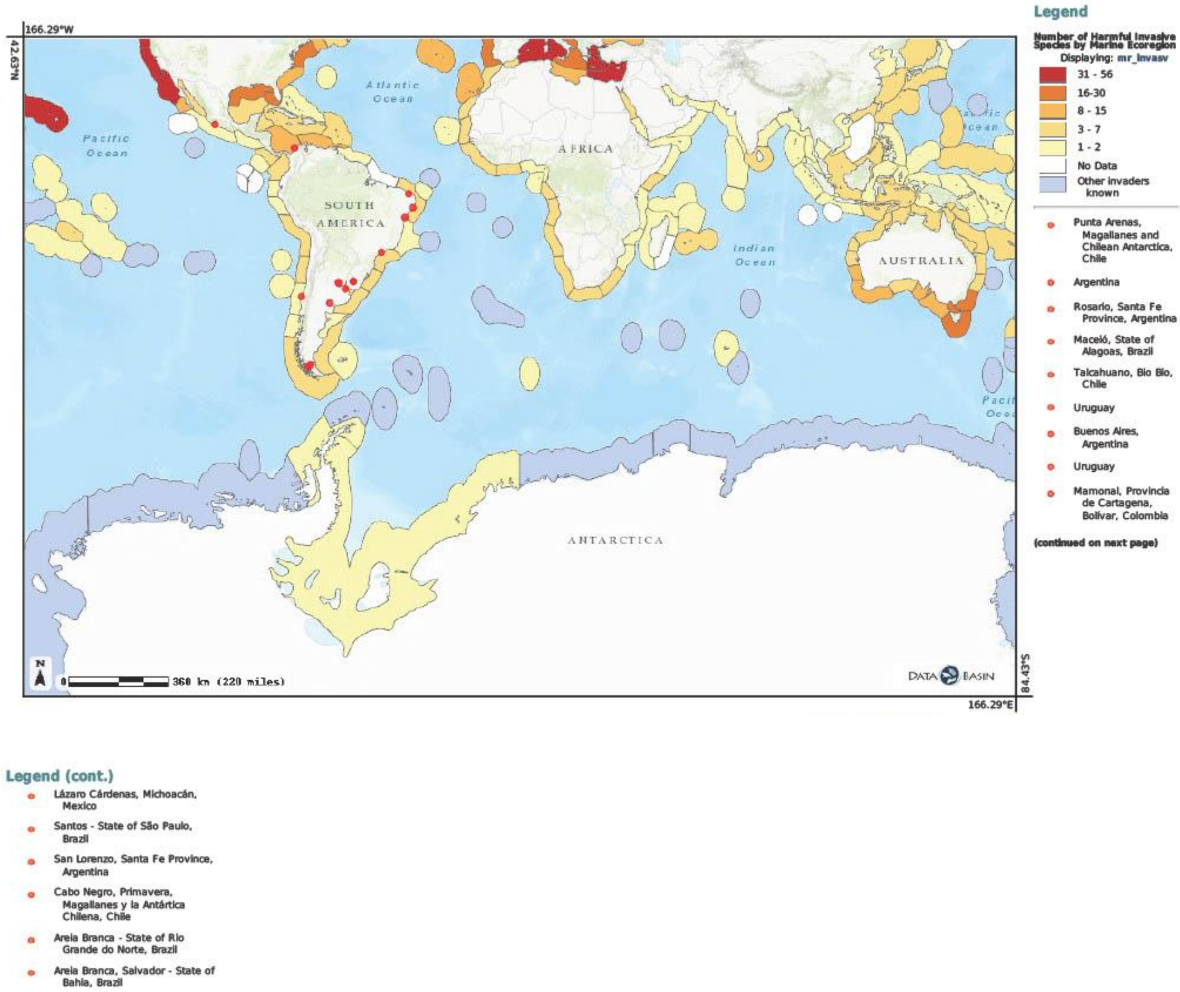
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

D. North America



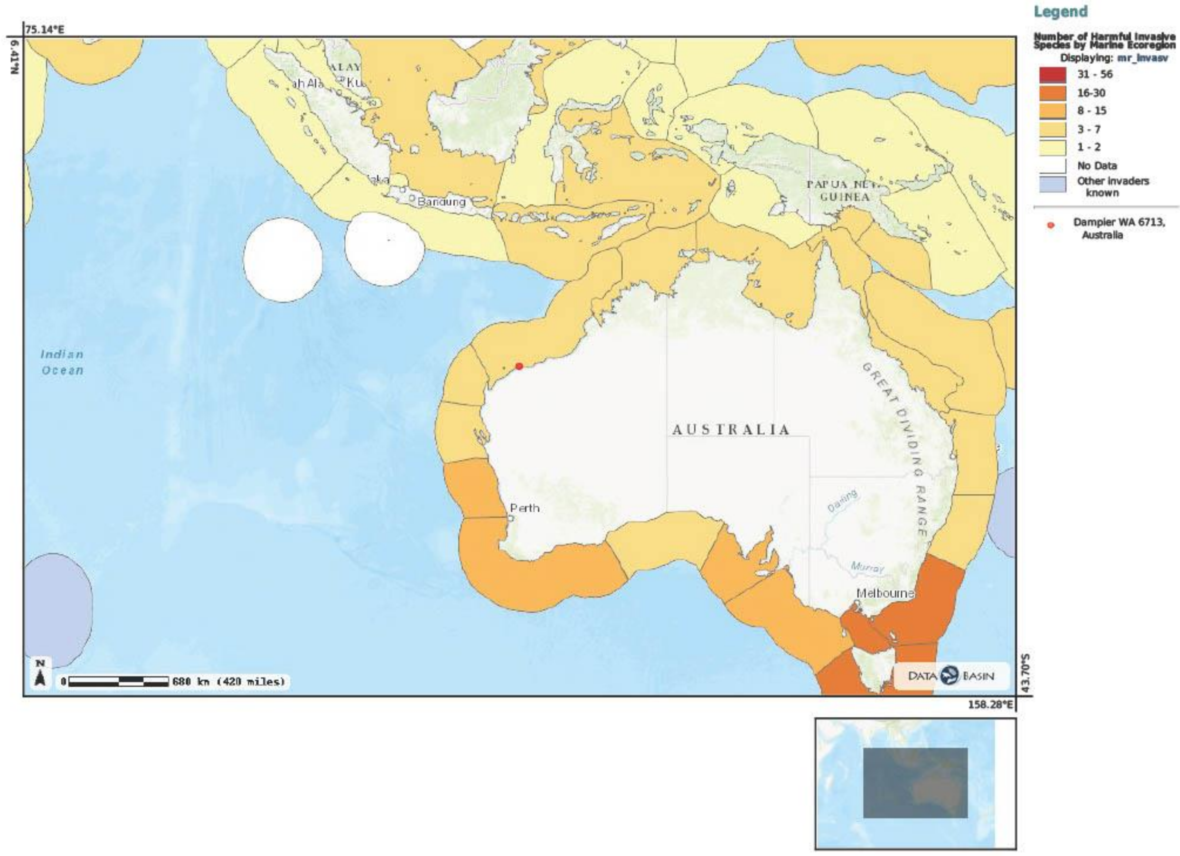
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

E. South America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

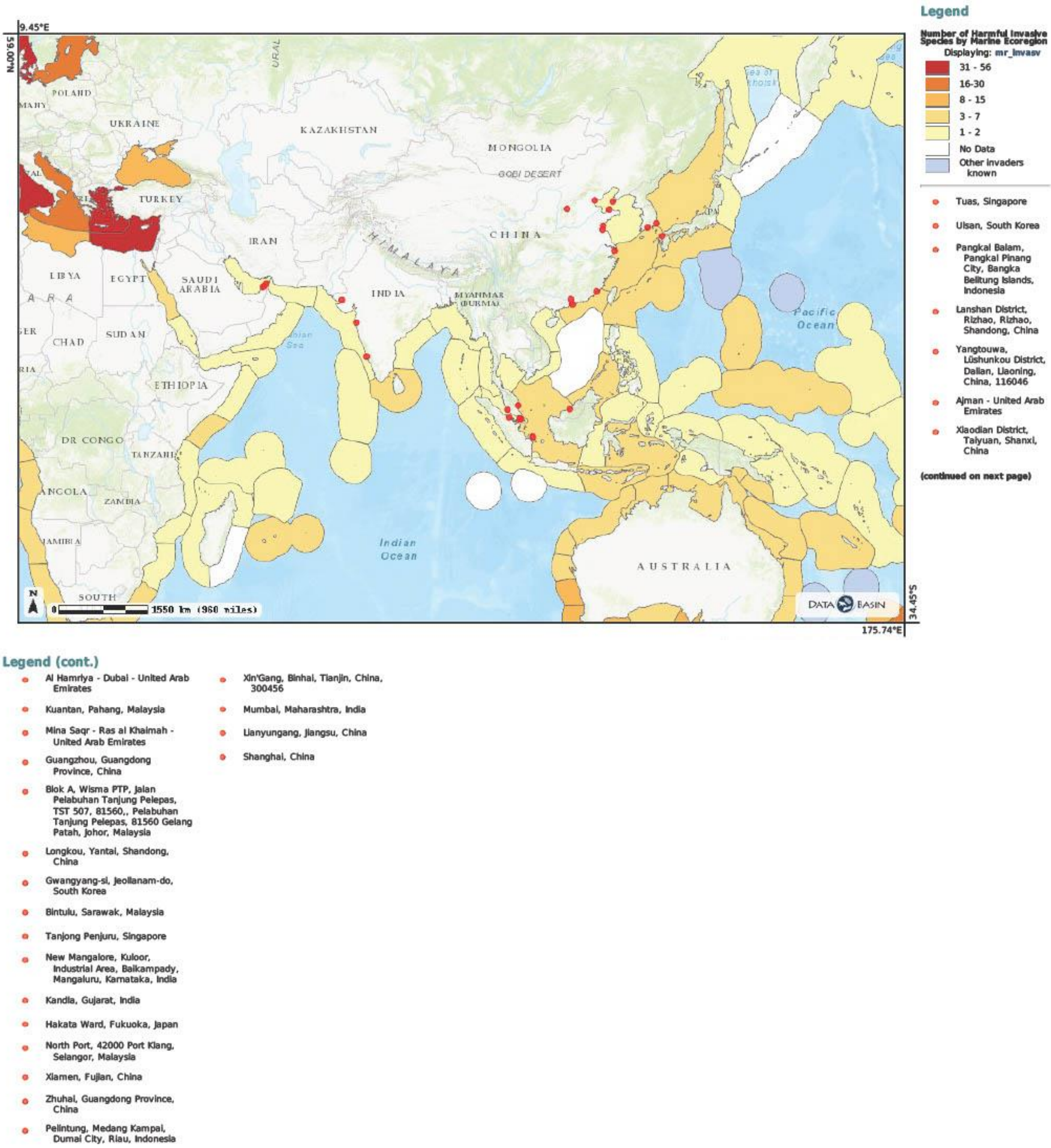
F. Australia



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

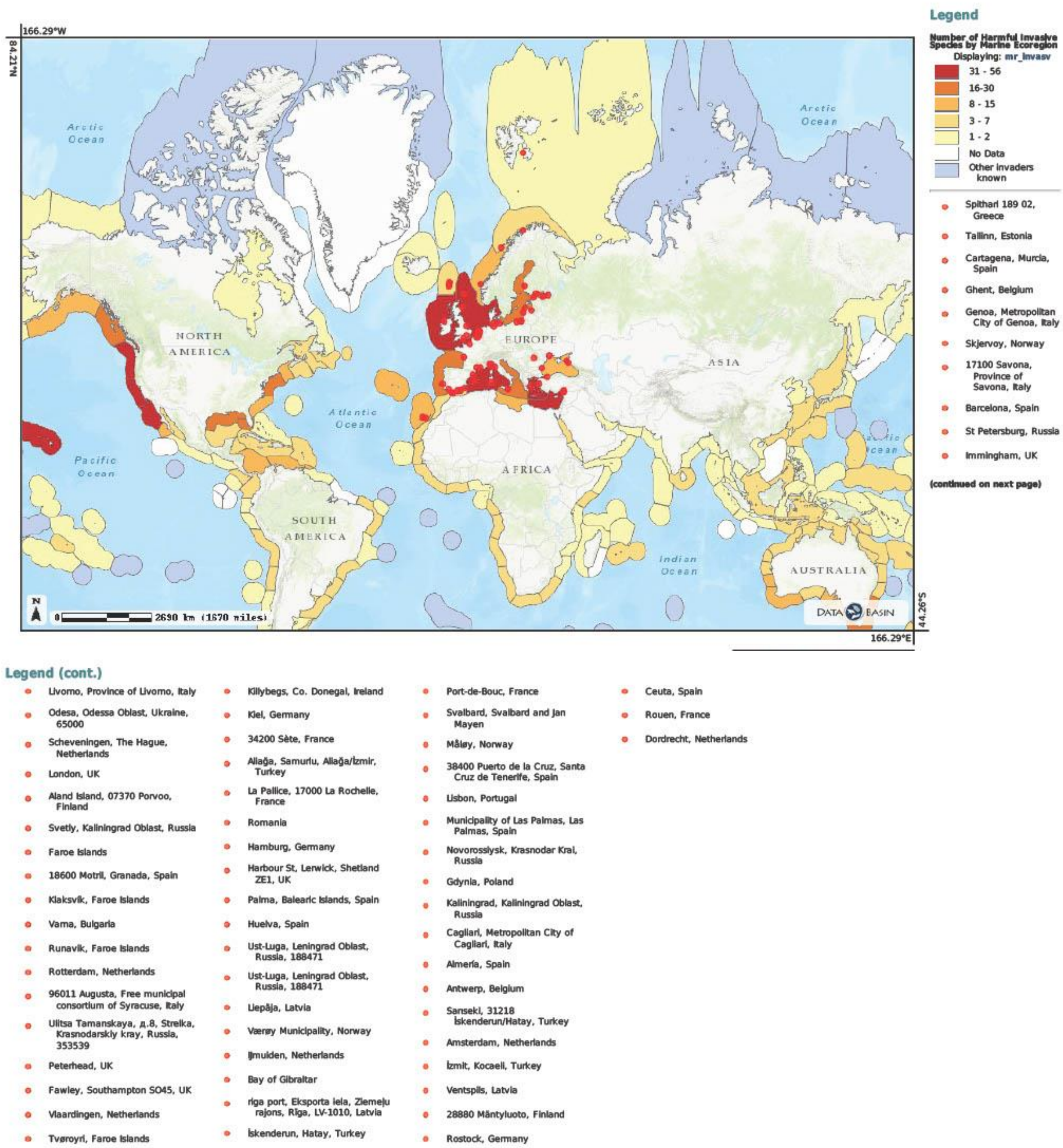
Figure 3.10: Maps of Marine Ecoregions of Vessels that Called at Lagos Ports (2021)

A. Asia



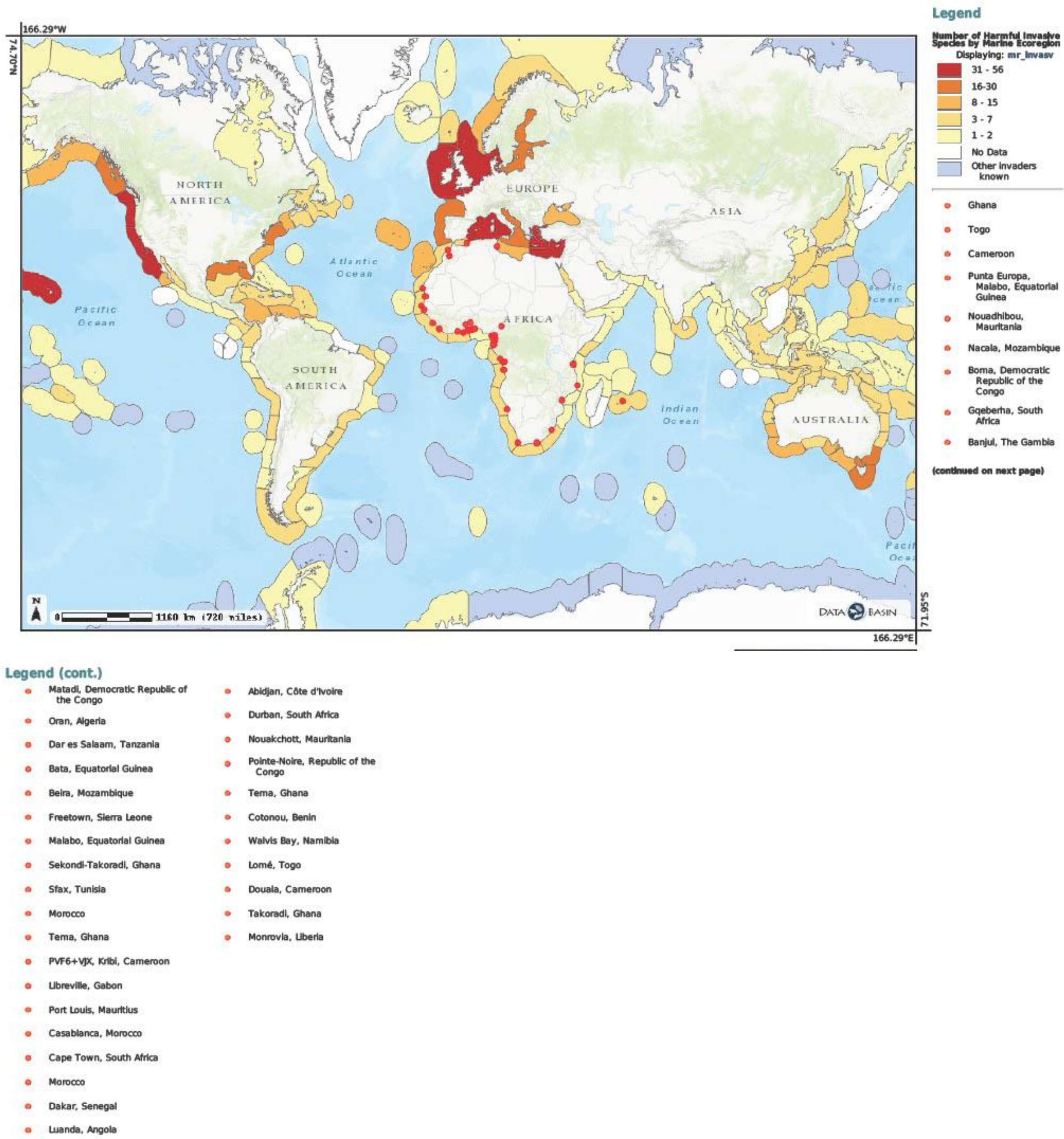
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

B. Europe



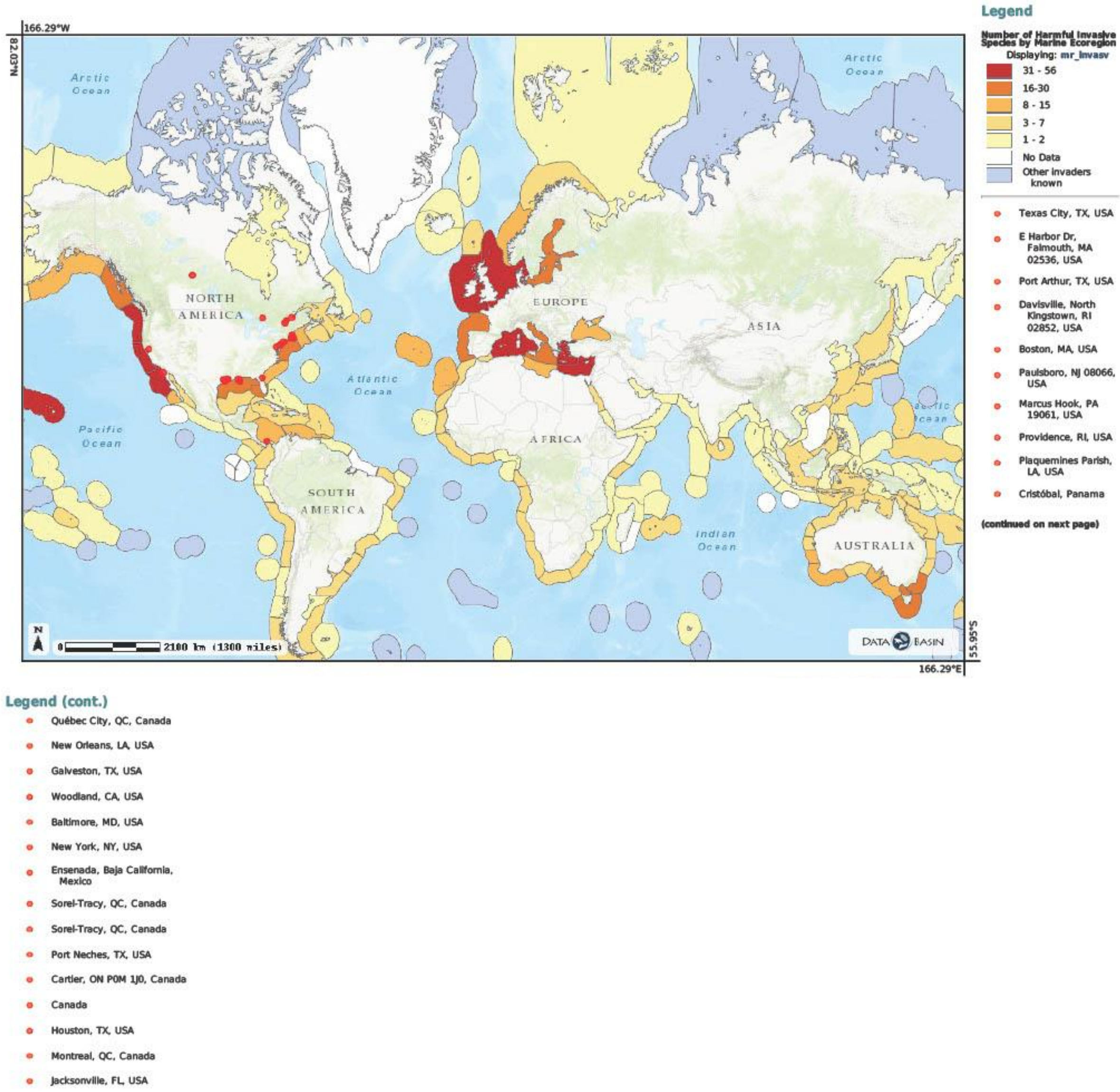
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

C. Africa



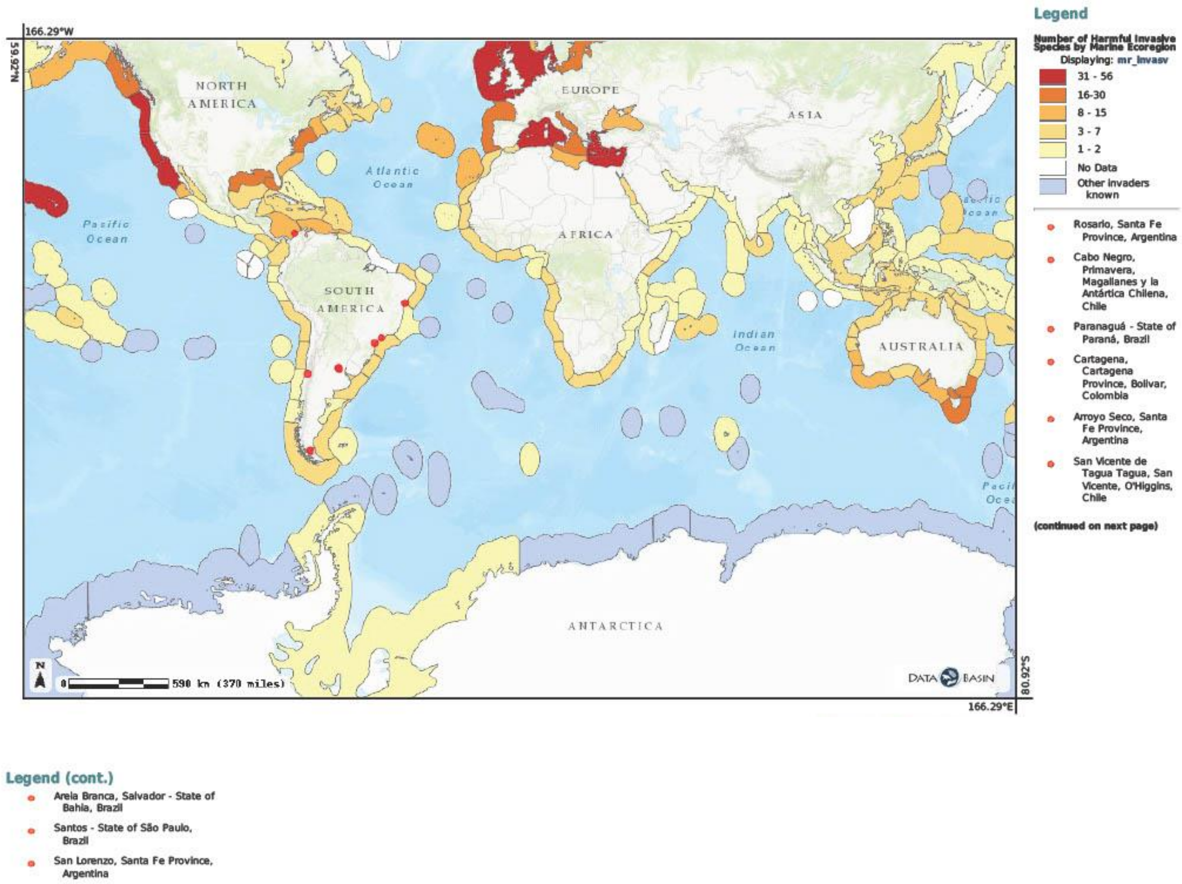
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

D. North America



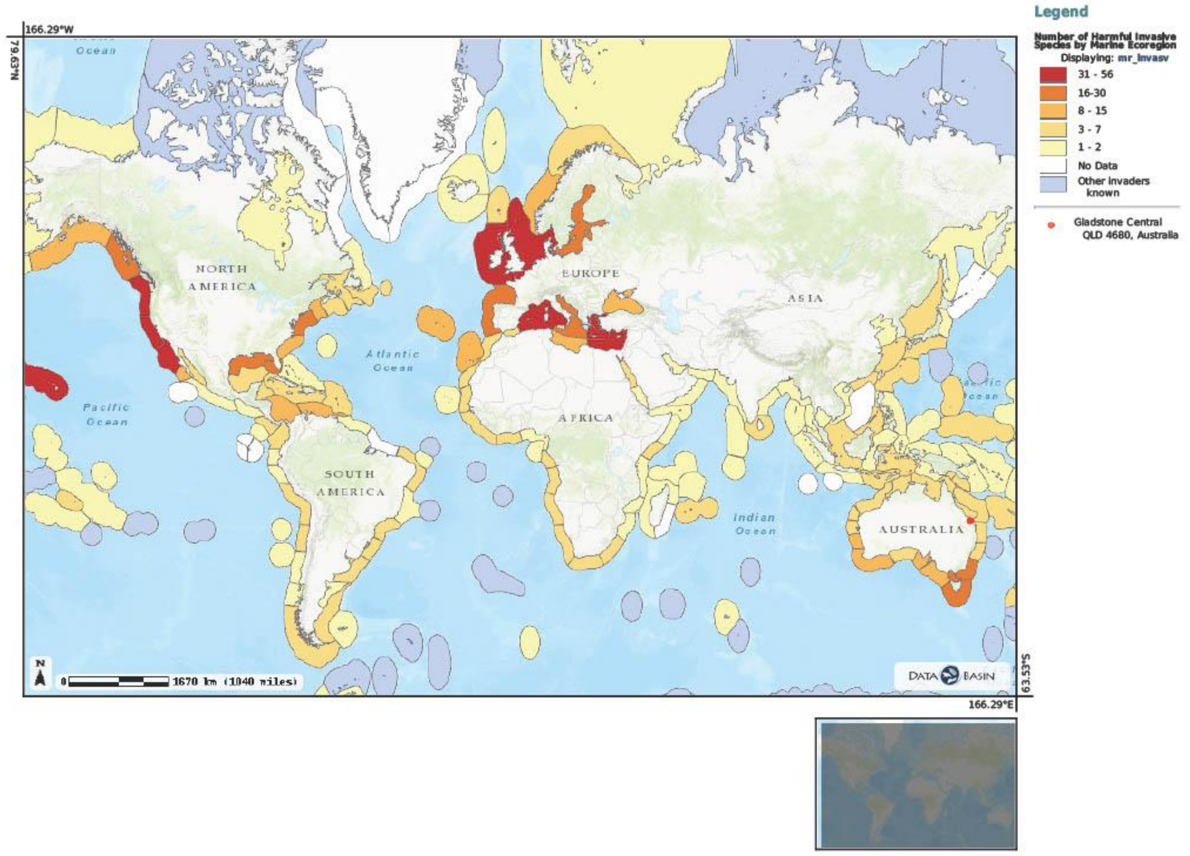
Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

E. South America



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

F. Australia



Source: Conservation Biology Institute (2022), credit to: Molnar et al., 2008. Applied Vessels Traffic Data for Lagos Ports from NIMASA C4i data center.

4. DISCUSSION OF RESULTS

After evidence-based comprehension of the threats posed by harmful invasive species, and once they are established in a new environment, it is important that priorities are set to prevent the introduction via interception or pathway removal (Molnar et al., 2008). Predicting the pathways and level of invasion remain complex. In this scope, this study is designed to predict the risk of introduction of IAS using the vessels traffic, residence time at Lagos Ports and the range of harmful invasive species in the marine ecoregions of the originating Ports of ships calling at Lagos Ports, which will give focus to the monitoring efforts/targets of designated authorities, for instance in Nigeria, NIMASA and the Nigerian Ports Authority have roles to play as the regulator of shipping and the custodian of the Ports respectively.

From the data analysis in section 3, it was observed that the container carriers, oil/chemical tankers and bulk carriers are the dominant types of vessels in terms of voyages to Lagos Ports for all years 2017 to 2021 under consideration.

It is generally highlighted that the bulk carriers have the longest residence time (average residence time 229.28hrs; and median residence time of 227.30hrs□, followed by the heavy load carriers, while the vessel with shortest residence time is roro cargo vessels. It was also observed that the dominant vessels at the ports: container carriers and oil/chemical tankers have average residence time of 72.42hours and 91.33hours respectively; and a median average residence time of 75.56hours and 88hours respectively.

Scholars Bouda et al. (2018) and Costello et al. (2022) are of the opinion that a longer residence time of a vessel in a Port can increase the risk of biofouling and bio-invasion, as there is ample time for IAS to foul hull of ships and to be released into the marine environment. Based on this, considering the dominant calls and residence time in Lagos Ports, the bulk carriers with the longest average residence time of almost 10 days pose the biggest risk of bioinvasion, followed by oil/chemical tankers and container carriers in that order. In addition, due to long residence time, there is also a heightened risk of foreign vessels being fouled by potential native IAS in Lagos ports, which can be translocated to another Port. Noting the non-realistic and difficulty in accurately quantifying the release of marine organisms from a fouled hull into the environment via sampling of all vessels calling at the Ports, it is critical that the potential management strategy prioritized or put more efforts in inspection of vessels that pose the most serious danger.

Based on the data from the NIMASA C4i database, the dominant continental Ports for ships calling at Lagos Ports using the previous ports of call information are, African Ports, European Ports, Asian Ports, North American Ports, South American Ports and Australian Ports in descending order. In addition, using the range of harmful IAS data in the marine ecoregions of vessels calling at Lagos Ports from the Conservation Biology Institute's Invasive Species Database to identify the hot-spots of harmful IAS, the vessels from most European Ports in Netherlands, Germany, Italy, France, Turkey, United Kingdom, Belgium, Greece, Denmark, Faroe Island, Gibraltar and some parts in Spain) pose the most threats of all the regions due to having most Ports falling within the hot-spots (ranges: 31-56 and 16-30) (as shown in figures 7B, 8B, 9B, 10B and 11B). Some vessels that originated from some areas in North America (such as Mexico, and United States) fall within the hot-spots of invasive species range 31-56 and 16-30 (as shown in figure 7D, 8D, 9D, 10D, 11D).

It is important to also highlight that the dominant African region (with the most calls) pose little risk as the Ports in the region fall within the areas with harmful invasive species number range 3-7 and 1-2 (as shown in figure 7C, 8C, 9C, 10C, 11C). The vessels from the Asian region pose the least risk (given its high volume of traffic to Lagos) as most of the Ports fall within the area with range 1-2 of harmful IAS (as shown in figure 7A, 8A, 9A, 10A, 11A).

It is clear from the above that the vessels calling from the European Ports and North American Ports pose the major risk of transferring harmful IAS in accordance with the study by Molnar et al. (2008), however, this study is limited to identification of these hot-spots as a contributing factor to bio-invasion, there are other factors such as ecological properties/similarities, climate change, installed anti-fouling system, quality of hull surfaces, the available wetted surface areas that can influence IAS transfer from one region to the other (Thomaz et al., 2014).

Having identified the vessel types that pose major IAS transfer risk due to the residence time and the potential invasive species hot-spots (ports) linkage to Lagos Ports using the marine ecoregions data continentally. This study tends to come up with a simple risk assessment matrix using these two parameters, which are based on the premise that longer residence time of vessels could increase the risk of uptake or introduction of IAS; and those vessels coming from the ports that falls within ecoregions with highest range on harmful invasive species pose bigger risk of translocating IAS to the destination ports.

Figure 4.1: Proposed Risk Assessment Matrix

		Vessels Residence Time (days)		
		Short Residence Time (<3days)	Medium Residence Time (>3days & <7days)	High Residence Time (>7days)
Originating Ports Marine Ecoregion	Originating Ports within ecoregions with 31-56 IAS range	Low	Medium	High
	Originating Ports within ecoregions with 16-30 IAS range	Low	Medium	Medium
	Originating Ports within ecoregions with (3-7) & (1-2) IAS ranges	Low	Low	Low

This risk matrix as illustrated in figure 4.1 is designed for identification of vessels that are of high risk and to guide biofouling inspections by prioritizing inspection of vessels that fall within the red zone (high risk) and possibly the yellow zone (medium risk). According to the risk matrix, the high-risk zone identifies vessels with longer stays of more than 7days and originated from areas where there is high number of IAS.

It is to serve as support tool for targeted inspections as inspection of all vessels visiting the ports is difficult and not feasible, however, other parameters such as the last dates of dry-docking or hull cleaning or propeller polishing; biogeographic characteristics of the originating ports environment (Lim et al.) in comparison with Lagos ports environmental characteristics; as well as anti-fouling systems used may be considered in conjunction with this risk matrix for a holistic decision on vessels that pose the highest risk of invasive species transfer. Considering the Africa's regional Ports as the dominant traffic to Lagos Ports, from the study, the region falls within the low risk using the IAS presence range, but there is high likelihood of survival of IAS translocated from Ports whose environment share similar biogeographic characteristics with the receiving Ports (for instance Lagos Ports and Cotonou Ports).

Moreover, noting that bio-invasion creates negative externalities and impacts the sustainable provision of ecosystem goods and services by the Large Marine Ecosystems (LMEs) (Haubrock et al., 2021; Pejchar & Mooney, 2009). It is considered a major cause of biodiversity loss, threat to food security and climate change mitigation (as essential productive species are displaced by ones with less productivity, less carbon sink potential, as well as increase in harmful emissions due to resistance from fouling), and loss of aqua-tourism (Pejchar & Mooney, 2009). In the light of these negative externalities of bio-invasion, it is important that nations come up with management strategies that would ensure prevention of translocation of invasive species from one area to another.

5. MANAGEMENT OF SHIPS BIOFOULING

As discussed in the previous sections, ships biofouling has been identified as a major vector for transfer of harmful IAS from one region to another via ships, which needs to be addressed at a global level by putting in place International Conventions/Regulations in the form of the International Convention for the Control and Management of Ship's Ballast Water and Sediments, 2004 (IMO, 2019) adopted to address the transfer of IAS from ballast water; and establishment of management/control mechanisms. Effective implementation of strategic control/management mechanisms for biofouling would reduce the risk of IAS transfer and improve the hydrodynamic performance of ships (reduction of emission).

5.1 Legislation for Regulation of Ship's Biofouling

Continuous benefits from the Large Marine Ecosystems (LMEs) goods (source of food and energy) and services (transportation medium, tourism, carbon sink) require international Regulations to which every stakeholder is committed to its compliance being the UN Agency statutorily empowered to ensure safety of shipping and protection of the marine environment, the IMO is yet to adopt an international convention or binding regulations to tackle IAS transfer through ships biofouling.

Markedly, in this context, it is important to note that part XII of UNCLOS highlights good environmental stewardship, and requests Member States (MS) to undertake "individually or jointly as appropriate, all measures that are necessary to prevent, reduce and control pollution of the marine environment from any source, using the best practicable means at their disposal and in accordance with their capabilities, and they shall endeavour to harmonize their policies in this connection". Pursuant to Article 196, States are under an environmental obligation to take all the essential measures to prevent pollution of the marine environment resulting from the use of technologies or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment (UNCLOS, Part XII, Article 196.1). Here, strong emphasis is placed on mitigating vessel-source pollution by regulating vessel design, construction and equipment. Furthermore, Part XII lays the foundation for a global and regional cooperative regime with reference to "competent international organizations" to establish "international rules, standards and recommended practices and procedures" on vessel-source pollution (UNCLOS, Part XII, Article 197).

Nonetheless, through Rules of Reference, we observe that the IMO adopted "Guidelines for the Control and Management of Ship's Biofouling" (IMO Resolution MEPC.207(62)) to put in place a consistent global biofouling management strategy aimed at minimizing the IAS transfer from ships.

In addition, the IMO adopted an international Convention to control the use of harmful Anti-fouling Systems (AFS Convention) such as organotin compounds and biocide cybutryne on ships in 2001 (IMO, 2001), which is aimed at ensuring the use of coatings that would prevent biofouling of ships hulls while also preserve the marine ecosystem from toxic elements in anti-fouling paints.

The Convention on Biological Diversity (CBD), 1992 also recognized the need to preserve biological diversity by ensuring human activities within each State's jurisdiction do not harm the environment and other States' environments, which is also relevant to control of biofouling from shipping.

5.2 Management Techniques for Ship Biofouling

There are two common methods for management of ships biofouling, namely: coating of hulls; and In-Water-Cleaning (IWC) (Georgiades et al., 2021; Luoma et al., 2021).

The hull coating involves the use of anti-fouling systems to coat the hull of ships, which is intended to prevent fouling of the ship by marine organisms, and there are presently three commonly applied coating technologies, namely: 1) Hard Insoluble Polymers; 2) Mechanical, non-biocidal fouling release technologies; 3) Chemical, Biocidal Anti-Fouling Technology (Luoma et al., 2021).

The IWC entails the removal of the biofouling from the hull of the ship, it involves the use of Remotely Operated Vehicles (ROVs) and divers for hull cleaning which can be reactive (removal of slime layers/soft microfouling) or proactive (removal of macrofouling), this maintenance would increase the operational cost of the ship but there would be environmental benefits in emission saving and improving biodiversity, which in-turn benefit the LMEs (Georgiades et al., 2021; Luoma et al., 2021). In essence, usage of ROVs, also known as Remote Inspection Techniques (RIT) and other emerging technologies is aligned with IMO's strategic directions: (SD 1) aiming at the effective, efficient and consistent implementation and enforcement of the provisions of the IMO instruments; (SD 2) aiming at integrating and advancing technologies in the regulatory framework; (SD 5), aiming at enhancing facilitation and security of international trade; and (SD 6), which aims at ensuring that a universally adopted, efficient, international regulatory framework is in place and consistently implemented, embracing and integrating new and advancing technologies, without causing unnecessary burdens.

Based on the proposed risk assessment matrix and other influencing factors for IAS transfer, the designated Authorities may adopt the Guidelines put in place by the IMO as exemplified by the Panamanian Flag Administration and Australian Maritime Safety Authority (AMSA), in which ships are required to record in details the biofouling management actions and hull inspections carried out on the ship and have biofouling management plan; may request high risk vessels to carry out IWC or other hull maintenance measures before visiting (especially if departing from region with high records of IAS) (Bahamas Maritime Authority, 2022); and may carry out in-situ random biofouling inspections.

6.0 CONCLUSION

The United Nations' Framework Convention on Climate Change (UNFCCC) entered into force in 1994 with the aim to tackle "dangerous" human interference with the climate system and stabilize greenhouse gas concentrations. The Parties to the Convention are requested to: cooperate to promote sustainable economic development, communicate regularly, update national and, where appropriate, regional programs. In this process, niche sources, such as biofouling cannot be overlooked.

Ship's biofouling is considered a major vector for translocation of IAS, which pose serious threat to Large marine ecosystem's biodiversity, food security and other benefits, and there is need for adoption of stand-alone international Convention on the control of ships biofouling by the IMO and effective policies on marine biosecurity, this will give a universal direction to tackling the spread of IAS.

The fore mentioned international Convention would entail Regulations requesting vessels to manage their biofouling using approved management techniques by the IMO (in accordance with the existing Guidelines (possibly revised) and put in place biofouling management plan to be approved by the Flag Administration and possible issuance of International Biofouling Management Certificate to show compliance. Alternatively, it may be adopted as a code under the AFS Convention (just as the ISPS code for SOLAS), which would entail mandatory provisions on management of biofouling and inspection powers of the Flag and Port States.

This study identified the bulk carriers, the container carriers and chemical/oil tankers as the dominant vessel type plying Lagos Ports with the bulk carrier boasting the highest residence time, making it a high-risk ship for IAS transfer subject to consideration of the IAS records of the marine ecoregion where the bulk carrier is departing from. Also, vessels coming from the European Ports are regarded as potential major harmful invasive species carriers to Lagos Ports, with the successful introduction or establishment of IAS still depends on other factors such as biogeographic similarities, voyage speed, and resident time.

Lastly, a biofouling risk matrix is proposed using the residence time and departing ports marine ecoregion IAS data to rank the risk of IAS transfer to receiving Ports, this is a critical tool needing holistic consideration of all influential factor for better prediction of IAS transfer, it is designed to guide inspections of priority vessels (vessels with high risk of IAS transfer) by Maritime Administrations (MARAD) or other designated authorities, noting that inspection of hulls of vessels visiting the ports physically may place resources and administrative burdens on the Regulators.

For effective management of biofouling in Nigeria, it is essential that NIMASA as the designated authority come-up with Ships Biofouling Control Plan and Policy which will be communicated via a marine notice, while also collaborate with the Nigerian Ports Authority on the monitoring of high-risk vessels plying the Lagos Ports.

This research can be furthered by the adoption of in-situ sampling of ships biofouling at Lagos Ports to confirm the IAS; a baseline study is required to identify the current state of Nigerian waters; and development of comprehensive biofouling risk assessment model that considers all the factors influencing biofouling.

Bibliography

Alidoost Salimi, P., Creed, J. C., Esch, M. M., Fenner, D., Jaafar, Z., Levesque, J. C., Montgomery, A. D., Alidoost Salimi, M., Edward, J. K. P., Raj, K. D., & Sweet, M. (2021). A review of the diversity and impact of invasive non-native species in tropical marine ecosystems. *Marine Biodiversity Records*, *14*(1). https://doi.org/10.1186/s41200-021-00206-8

Arndt, E., Robinson, A., Hester, S., Woodham, B., Wilkinson, P., Gorgula, S., & Brooks, B. (2021). *Factors that influence vessel biofouling and its prevention and management Final report for CEBRA Project 190803*. https://cebra.unimelb.edu.au/__data/assets/pdf_file/0010/3822922/Endorsed-CEBRA-190803-Final-Report.pdf

Bahamas Maritime Authority. (2022). INFORMATION NOTICE 08 Control and Management of Ships' Biofouling Notice to ship owners, managers, Masters, Approved Nautical Inspectors, Recognised Organisations and surveyors This Notice supersedes BMA Information Bulletin No.171 IN 08 v 2. 0 CONTROL AND MANAGEMENT OF SHIPS' BIOFOULING. https://www.bahamasmaritime.com/wp-content/uploads/2022/06/IN008-Control-and-Management-of-Ships-Biofouling-v2.0.pdf

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., & Geeves, W. (2003). Marine invasive alien species: a threat to global biodiversity. *Marine Policy*, *27*(4), 313–323. https://doi.org/10.1016/s0308-597x(03)00041-1

Blackburn, T. M., Essl, F., Evans, T., Hulme, P. E., Jeschke, J. M., Kühn, I., Kumschick, S., Marková, Z., Mrugała, A., Nentwig, W., Pergl, J., Pyšek, P., Rabitsch, W., Ricciardi, A., Richardson, D. M., Sendek, A., Vilà, M., Wilson, J. R. U., Winter, M., & Genovesi, P. (2014). A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts. *PLoS Biology*, *12*(5), e1001850. https://doi.org/10.1371/journal.pbio.1001850

Bouda, A., Bachari, N. el I., Nacef, L., & Bensari, B. (2017). Risk Analysis of Invasive Species Introduction in the Port of Arzew, by Calculation of Biofouling Surface on Ships' Hulls. *Environmental Modeling & Assessment*, *23*(2), 185–192. https://doi.org/10.1007/s10666-017-9567-1

Buonocore, E., Grande, U., Franzese, P. P., & Russo, G. F. (2021). Trends and Evolution in the Concept of Marine Ecosystem Services: An Overview. *Water*, *13*(15), 2060. https://doi.org/10.3390/w13152060

CBD. (2014). *Convention on Biological Diversity. Pathways of Introduction of Invasive Species, Their Prioritization and Management. UNEP/CBD/SBSTTA/18/9/Add.1, Subsidiary Body on Scientific, Technical and Technological Advice.* https://www.cbd.int/doc/meetings/sbstta/sbstta-18/official/sbstta-18-09-add1-en.pdf

Chan, F. T., MacIsaac, H. J., & Bailey, S. A. (2016). Survival of ship biofouling assemblages during and after voyages to the Canadian Arctic. *Marine Biology*, *163*(12). https://doi.org/10.1007/s00227-016-3029-1

Chan, F. T., Ogilvie, D., Sylvester, F., & Bailey, S. A. (2022). Ship Biofouling as a Vector for Non-indigenous Aquatic Species to Canadian Arctic Coastal

Ecosystems: A Survey and Modeling-Based Assessment. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.808055

Conservation Biology Institute. (2022). *INVASIVES | Maps | Data Basin*. Databasin.org. https://databasin.org/maps/a89bb5bda2c4492db33089b21d510426/active/

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. https://doi.org/10.1016/j.marpolbul.2022.113496

Coutts, A. D. M., Piola, R. F., Hewitt, C. L., Connell, S. D., & Gardner, J. P. A. (2010). Effect of vessel voyage speed on survival of biofouling organisms: implications for translocation of non-indigenous marine species. *Biofouling*, *26*(1), 1–13. https://doi.org/10.1080/08927010903174599

Cruz et al. (2020). *Biofouling Challenges and Possible Solutions, 1.20.003 – Final Project Report*. Launceston, Australia: Blue Economy Cooperative Research Centre. https://blueeconomycrc.com.au/wp-content/uploads/2021/03/BECRC_Flyer_1.20.003_e160321.pdf

Cuthbert, R. N., Pattison, Z., Taylor, N. G., Verbrugge, L., Diagne, C., Ahmed, D. A., Leroy, B., Angulo, E., Briski, E., Capinha, C., Catford, J. A., Dalu, T., Essl, F., Gozlan, R. E., Haubrock, P. J., Kourantidou, M., Kramer, A. M., Renault, D., Wasserman, R. J., & Courchamp, F. (2021). Global economic costs of aquatic invasive alien species. *Science of the Total Environment*, *775*, 145238. https://doi.org/10.1016/j.scitotenv.2021.145238

Cziesielski, M. J., Duarte, C. M., Aalismail, N., Al-Hafedh, Y., Anton, A., Baalkhuyur, F., Baker, A. C., Balke, T., Baums, I. B., Berumen, M., Chalastani, V. I., Cornwell, B., Daffonchio, D., Diele, K., Farooq, E., Gattuso, J.-P., He, S., Lovelock, C. E., Mcleod, E., & Macreadie, P. I. (2021). Investing in Blue Natural Capital to Secure a Future for the Red Sea Ecosystems. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.603722

Davidson, I., Scianni, C., Hewitt, C., Everett, R., Holm, E., Tamburri, M., & Ruiz, G. (2016). Mini-review: Assessing the drivers of ship biofouling management – aligning industry and biosecurity goals. *Biofouling*, *32*(4), 411–428. https://doi.org/10.1080/08927014.2016.1149572

Demirel, Y. K., Hunsucker, K. Z., Lejars, M., & Georgiades, E. (2022). Editorial: Impact and Management of Marine Biofouling. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.958812

Essl, F., Bacher, S., Blackburn, T. M., Booy, O., Brundu, G., Brunel, S., Cardoso, A.-C., Eschen, R., Gallardo, B., Galil, B., García-Berthou, E., Genovesi, P., Groom, Q., Harrower, C., Hulme, P. E., Katsanevakis, S., Kenis, M., Kühn, I., Kumschick, S., & Martinou, A. F. (2015). Crossing Frontiers in Tackling Pathways of Biological Invasions. *BioScience*, *65*(8), 769–782. https://doi.org/10.1093/biosci/biv082

European Commission. (2021a). *2021 EU Blue Economy report – Emerging sectors prepare blue economy for leading part in EU green transition*. Oceans-And-Fisheries.ec.europa.eu. https://oceans-and-fisheries.ec.europa.eu/news/2021-

eu-blue-economy-report-emerging-sectors-prepare-blue-economy-leading-part-eu-green-transition-2021-05-20_en

European Commission. (2021b). *A new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future - EUR-Lex - 52021DC0240 - EN - EUR-Lex*. Eur-Lex.europa.eu. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:240:FIN

Georgiades, E., Scianni, C., Davidson, I., Tamburri, M. N., First, M. R., Ruiz, G., Ellard, K., Deveney, M., & Kluza, D. (2021). The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.660125

Haubrock, P. J., Turbelin, A. J., Cuthbert, R. N., Novoa, A., Taylor, N. G., Angulo, E., Ballesteros-Mejia, L., Bodey, T. W., Capinha, C., Diagne, C., Essl, F., Golivets, M., Kirichenko, N., Kourantidou, M., Leroy, B., Renault, D., Verbrugge, L., & Courchamp, F. (2021). Economic costs of invasive alien species across Europe. NeoBiota, 67, 153–190. https://doi.org/10.3897/neobiota.67.58196

Hulme, P. E. (2021). Unwelcome exchange: International trade as a direct and indirect driver of biological invasions worldwide. *One Earth*, *4*(5), 666–679. https://doi.org/10.1016/j.oneear.2021.04.015

IMO. (2001). International Convention on the Control of Harmful Anti-fouling Systems on Ships. Www.imo.org. https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-the-Control-of-Harmful-Anti-fouling-Systems-on-Ships-(AFS).aspx

IMO. (2019a). *Biofouling*. Www.imo.org. https://www.imo.org/en/OurWork/Environment/Pages/Biofouling.aspx

IMO. (2019b). *Common Hull Fouling Invasive Species*. Www.imo.org. https://www.imo.org/en/OurWork/Environment/Pages/Common-Hull-Fouling-Invasive-Species.aspx

Kacimi, A. (2021). Modeling the risk of introducing non-indigenous species through ship hull biofouling: case study of Arzew port (Algeria). *Management of Biological Invasions*. https://doi.org/10.3391/mbi.2021.12.4.14

Kerr, A., Beveridge, C. M., Cowling, M. J., Hodgkiess, T., Parr, A. C. S., & Smith, M. J. (1999). Some physical factors affecting the accumulation of biofouling. *Journal of the Marine Biological Association of the United Kingdom*, *79*(2), 357–359. https://doi.org/10.1017/s002531549800040x

Kiil, S., Weinell, C. E., Yebra, D. M., & Kim, D.-J. (2007). Marine biofouling protection: design of controlled release antifouling paints. *Computer Aided Chemical Engineering*, 181–238. https://doi.org/10.1016/s1570-7946(07)80010-1

Kourantidou, M., Cuthbert, R. N., Haubrock, P. J., Novoa, A., Taylor, N. G., Leroy, B., Capinha, C., Renault, D., Angulo, E., Diagne, C., & Courchamp, F. (2021). Economic costs of invasive alien species in the Mediterranean basin. *NeoBiota*, *67*, 427–458. https://doi.org/10.3897/neobiota.67.58926

Lee, K.-H., Noh, J., Lee, J., & Khim, J. S. (2021). Blue economy and the total environment: Mapping the interface. *Environment International*, *157*, 106796. https://doi.org/10.1016/j.envint.2021.106796

Lim, C. S., Leong, Y. L., & Tan, K. S. (2017). Managing the risk of non-indigenous marine species transfer in Singapore using a study of vessel movement. *Marine Pollution Bulletin*, *115*(1-2), 332–344. https://doi.org/10.1016/j.marpolbul.2016.12.009

Linley, R. D., Doolittle, A. G., Chan, F. T., O'Neill, J., Sutherland, T., & Bailey, S. A. (2014). *Relative Risk Assessment for ship-mediated introductions of aquatic nonindigenous species to the Pacific Region of Canada*. https://www.researchgate.net/publication/269707514_Relative_Risk_Assessment_for_ship-mediated_introductions_of_aquatic_nonindigenous_species_to_the_Pacific_Region_of_Canada

Lloyd, C., Onyeabor, E., Nwafor, N., Alozie, O. J., Nwafor, M., Mahakweabba, U., & Adibe, E. (2020). Maritime transportation and the Nigerian economy: matters arising. *Commonwealth Law Bulletin*, 1–21. https://doi.org/10.1080/03050718.2019.1708426

Luoma, E., Nevalainen, L., Altarriba, E., Helle, I., & Lehikoinen, A. (2021). Developing a conceptual influence diagram for socio-eco-technical systems analysis of biofouling management in shipping – A Baltic Sea case study. *Marine Pollution Bulletin*, *170*, 112614. https://doi.org/10.1016/j.marpolbul.2021.112614

MAF Biosecurity. (2010). *Vessel biofouling as a vector for the introduction of non-indigenous marine species to New Zealand: Fishing vessels*. https://www.mpi.govt.nz/dmsdocument/7335-vessel-biofouling-as-a-vector-for-the-introduction-of-non-indigenous-marine-species-to-new-zealand-fishing-vessels

Manchester, S. J., & Bullock, J. M. (2000). The impacts of non-native species on UK biodiversity and the effectiveness of control. *Journal of Applied Ecology*, *37*(5), 845–864. https://doi.org/10.1046/j.1365-2664.2000.00538.x

Molnar, J. L., Gamboa, R. L., Revenga, C., & Spalding, M. D. (2008). Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment*, *6*(9), 485–492. https://doi.org/10.1890/070064

Moser, C. S., Wier, T. P., First, M. R., Grant, J. F., Riley, S. C., Robbins-Wamsley, S. H., Tamburri, M. N., Ruiz, G. M., Miller, A. W., & Drake, L. A. (2017). Quantifying the extent of niche areas in the global fleet of commercial ships: the potential for "super-hot spots" of biofouling. *Biological Invasions*, *19*(6), 1745–1759. https://doi.org/10.1007/s10530-017-1386-4

Nikčević, J., & Škurić, M. (2021). A Contribution to the Sustainable Development of Maritime Transport in the Context of Blue Economy: The Case of Montenegro. *Sustainability*, *13*(6), 3079. https://doi.org/10.3390/su13063079

NOAA. (2021, November 17). *Invasive and Exotic Marine Species | NOAA Fisheries*. NOAA. https://www.fisheries.noaa.gov/insight/invasive-and-exotic-marine-species#:~:text=Invasive%20species%20can%20lead%20to

OECD. (2016). *The Ocean Economy in 2030 | en | OECD*. Www.oecd.org.

https://www.oecd.org/environment/the-ocean-economy-in-2030-9789264251724-en.htm
Olatidoye, O. P. (2022). Blue Economy, Food Security, and Food Sustainability. *Practice, Progress, and Proficiency in Sustainability*, 31–49. https://doi.org/10.4018/978-1-6684-3393-5.ch003
Pejchar, L., & Mooney, H. A. (2009). Invasive species, ecosystem services and human well-being. Trends in Ecology & Evolution, 24(9), 497–504. https://doi.org/10.1016/j.tree.2009.03.016
Rotter, A., Klun, K., Francé, J., Mozetič, P., & Orlando-Bonaca, M. (2020). Non-indigenous Species in the Mediterranean Sea: Turning From Pest to Source by Developing the 8Rs Model, a New Paradigm in Pollution Mitigation. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00178
Schimanski, K. B., Piola, R. F., Goldstien, S. J., Floerl, O., Grandison, C., Atalah, J., & Hopkins, G. A. (2016). Factors influencing the en route survivorship and post-voyage growth of a common ship biofouling organism, Bugula neritina. *Biofouling*, *32*(8), 969–978. https://doi.org/10.1080/08927014.2016.1217407
Scianni, C., & Georgiades, E. (2019). Vessel In-Water Cleaning or Treatment: Identification of Environmental Risks and Science Needs for Evidence-Based Decision Making. *Frontiers in Marine Science*, *6*. https://doi.org/10.3389/fmars.2019.00467
Shevalkar, M., Mishra, A., & Meenambiga, S. S. (2020). A review on invasive species in marine biofouling. *Research Journal of Pharmacy and Technology*, *13*(9), 4517. https://doi.org/10.5958/0974-360x.2020.00796.9
Slack, B., Wiegmans, B., & Witte, P. A. (n.d.). Ships Time in Ports. *International Journal of Shipping and Transport Logistics*. https://doi.org/DOI: 10.1504/IJSTL.2018.10008534
Tamburri, M. N., Davidson, I. C., First, M. R., Scianni, C., Newcomer, K., Inglis, G. J., Georgiades, E. T., Barnes, J. M., & Ruiz, G. M. (2020). In-Water Cleaning and Capture to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00437
Thomaz, S. M., Kovalenko, K. E., Havel, J. E., & Kats, L. B. (2014). Aquatic invasive species: general trends in the literature and introduction to the special issue. *Hydrobiologia*, *746*(1), 1–12. https://doi.org/10.1007/s10750-014-2150-8
Townsend, M., Davies, K., Hanley, N., Hewitt, J. E., Lundquist, C. J., & Lohrer, A. M. (2018). The Challenge of Implementing the Marine Ecosystem Service Concept. *Frontiers in Marine Science*, *5*. https://doi.org/10.3389/fmars.2018.00359
UN Climate Change Conference of the Parties - COP 26. (2021). *COP26 Managing Ships' Biofouling*. Www.bimco.org. https://www.bimco.org/Events/20211104-Managing-Ship-Biofouling---COP26
UNCTAD. (2021). *Review of Maritime Transport*. https://unctad.org/system/files/official-document/rmt2021_en_0.pdf
Vinagre, P. A., Simas, T., Cruz, E., Pinori, E., & Svenson, J. (2020). Marine

Biofouling: A European Database for the Marine Renewable Energy Sector. *Journal of Marine Science and Engineering*, *8*(7), 495. https://doi.org/10.3390/jmse8070495

Want, A., & Porter, J. (2018). BioFREE: An International Study of Biofouling Impacts on the Marine Renewable Energy Industry. *2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO)*. https://doi.org/10.1109/oceanskobe.2018.8559322

Ware, C., Berge, J., Sundet, J. H., Kirkpatrick, J. B., Coutts, A. D. M., Jelmert, A., Olsen, S. M., Floerl, O., Wisz, M. S., & Alsos, I. G. (2013). Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. *Diversity and Distributions*, *20*(1), 10–19. https://doi.org/10.1111/ddi.12117

Wenhai, L., Cusack, C., Baker, M., Tao, W., Mingbao, C., Paige, K., Xiaofan, Z., Levin, L., Escobar, E., Amon, D., Yue, Y., Reitz, A., Neves, A. A. S., O'Rourke, E., Mannarini, G., Pearlman, J., Tinker, J., Horsburgh, K. J., Lehodey, P., & Pouliquen, S. (2019). Successful Blue Economy Examples With an Emphasis on International Perspectives. *Frontiers in Marine Science*, *6*. https://doi.org/10.3389/fmars.2019.00261

Woods Hole Oceanographic Institution. (1952). *Marine fouling and its prevention ; prepared for Bureau of Ships, Navy Dept.* https://doi.org/10.1575/1912/191

Xu, M., Pan, Q., Xia, H., & Masuda, N. (2020). Estimating international trade status of countries from global liner shipping networks. *Royal Society Open Science*, *7*(10), 200386. https://doi.org/10.1098/rsos.200386

Yildirim, S., & Kaplan, M. (2022). The Threat of Invasive Alien Marine Species to the Blue Economy. *Practice, Progress, and Proficiency in Sustainability*, 50–80. https://doi.org/10.4018/978-1-6684-3393-5.ch004