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Identify monitoring needs and emerging technology to support ecosystem based management (EBM) and sustainable blue growth in Nigerian ports: case study : Lagos Ports (Lagos Pport Complex and Tin Can Island Port Complex)

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IDENTIFYING MONITORING NEEDS AND EMERGING TECHNOLOGY TO SUPPORT ECOSYSTEM BASED MANAGEMENT (EBM) AND SUSTAINABLE BLUE GROWTH IN NIGERIAN PORTS

CASE STUDY: LAGOS PORTS (LAGOS PORT COMPLEX AND TINCAN ISLAND PORT COMPLEX)

BY

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DECLARATION

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

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

Signature: **Roland Oladipo Ijabiyi**

Date: **24th September, 2019**

Supervised by: …….

Supervisor's Affiliation: …….

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ABSTRACT

Title of Dissertation: **Identifying Monitoring Needs and Emerging Technology to Support Ecosystem Based Management (EBM) and Sustainable Blue Growth in Nigerian Ports**

Case Study: Lagos Ports (Lagos Port Complex & Tin Can Island Port Complex)

Degree: **Master of Science**

This research takes a critical look at two salient aspects of monitoring in a marine environment: monitoring needs and emerging monitoring technologies, within the scope of seaports and coastal waters.

As a precursor to understanding environmental monitoring from these two aspects, a review of impact of shipping and port activities on the marine environment was carried out. This complements the research by revealing the sources of threats introduced into the environment which ultimately informed the monitoring needs and technological approaches required.

Reviews, assessments and analysis done for this research were carried out from a global perspective, but information gathering was limited to Nigeria and parts of Europe, due to limited resources and time constraints. Though the recommendations and conclusions reached can be applied globally, there is a bias for solutions which can address the challenges of monitoring in Nigerian maritime environment, using the Lagos ports of LPC and TCIPC as case studies.

The methodology of choice for this research is qualitative analysis, using 15 semi-structured interviews. The interviewees were selected from the academia, maritime institutions and commercial entities spanning, 5 countries in Europe, China and Nigeria. The interview questions centered around future and present monitoring technologies, environmental parameters, environmental regulations, monitoring data, threats to marine environment, EBM and Blue Growth.

The interviews were transcribed and coded, and the results were presented in charts and tables. These results were subsequently analyzed and inferences were drawn to identify monitoring needs and emerging technology from the interview data.

The research concludes by proffering solutions to threats introduced from shipping and port activities to the marine environment, and a comparative review of environmental regulatory frameworks between some countries in Europe and Nigeria, with a view to improving the latter. It also streamlined the key environmental parameters and affordable state-of-the-art monitoring technologies best suited for developing regions with emphasis on Nigeria.

Keywords: monitoring, emerging technology, marine environment, seaports, threats, Nigeria, regulations

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
BWM	Ballast Water Management Convention
COD	Chemical Oxygen Demand
CTD	Conductivity Temperature and Depth
DAISIE	Delivering Alien Invasive Species Inventories for Europe
DPR	Department of Petroleum Resources
EBM	Ecosystem Based management
ECA	Emission Control Area
eDNA	Environmental Deoxyribonucleic Acid
EGASPIN	Environmental Guidelines and Standards for the Petroleum Industry in Nig.
EIA	Environmental Impact Assessment
EU	European Union
FMEnv	Federal Ministry of Environment
FMoT	Federal Ministry of Transport
GESAMP	Group of Experts on Scientific Aspects of Marine Environmental Protection
GOOS	Global Ocean Observation System
HOAP	Harmful Organisms and Pathogens
ICZM	Integrated Coastal Zone Management
IEA	Integrated Environmental Assessment
IMO	International Maritime Organization
IOPC	International Oil Pollution Compensation Fund
IoT	Internet of Things
ISI	Institute for Scientific Information

ITOPF	International Tanker Owners Pollution Federation
LPC	Lagos Port Complex
LASEPA	Lagos State Environmental Protection Agency
LAWMA	Lagos Waste Management Authority
MARPOL	Marine Pollution Convention
MSP	Marine Spatial Planning
NBS	National Bureau of Statistics
NESREA	National Environmental Standards and Regulations Enforcement Agency
NIHSA	Nigerian Hydrological Services Agency
NIMASA	Nigerian Administration and Safety Agency
NIWA	National Inland Waterways
NOSDRA	National Oil Spill Detection and Response Agency
NPA	Nigerian Ports Authority
PM	Particulate Matter
Q&A	Question and Answer
ROV	Remotely operated Vehicle
SIA	Social Impact Assessment
SSI	Semi Structured Interview
TEU	Twenty-foot Equivalent Unit
TCIPC	Tin Can Island Port Complex
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change

1.0 INTRODUCTION

Marine ecosystems are under threat from Blue Growth activities leading to climate change and unsustainable anthropogenic pressures worldwide. Considering that half of the world's population live close to the coast, these threats are most pronounced in the coastal waters due to the concentration of human activities and conflicting uses of coastal resources (Creel, 2003). Marine science recognizes a great diversity of ecosystem impacts on coastal areas, and these vary according to region and type of activities (Halpern, 2015). Examples include: climate change, seafloor dredging, oil spill, effluent discharge causing eutrophication and hypoxia, habitat loss from activities such as land reclamation and unsustainable fishing practices (Yuan et at. 2016). The impacted coastal areas cover 10% of the world's surface area with goods and services worth $10.6 trillion per year (Duda and Sherman, 2002). Examples of coastal challenges include: coastal zone management and challenges of regulating deep sea mining in parts of Europe, pollution, waste recycling issues and overfishing in Africa and Asia, and loss of biodiversity and climate change in the Americas and other parts of the world (Global Environment Outlook 6 Regional Assessments, 2019).

To promote the sustainable use of coastal waters and reduce the impact of ports and shipping activities on the ecosystem, decisions-makers may need to establish a regime of Ecosystem Based Management (EBM) and integrated Ecosystem Assessment (IEA) (Long et al. 2015). IEA is tool to support EBM by integrating all components of the ecosystem, including humans (Mollmann et al. 2013). These approaches to the sustainable management of marine resources require environmental monitoring data on the state of the ecosystem, this data will also inform on the severity of the impact and also as an indicator of future threats to the ecosystem (Hunsaker and Carpenter, 1990).

Ports and shipping are two of the world's fastest growing blue growth sectors. They are part of the global trade value chain with a high volume and intensity of shipping activities, which has increased significantly in the last couple of decades. 90% of global trade is done by the international shipping (International Chamber of Shipping, 2017), with an estimated 50,000 ships in the global fleet and 8,292 major seaports in 222 countries (ports.com, 2018). Additionally, the global container throughput is 732 million Twenty-foot Equivalent Unit (TEU), which increased by 6% in 2017 up from 2.1% the previous year, representing 42.3 million TEU (UNCTAD 2018). The threats introduced from the coastal and ports ecosystems are diverse, understanding the resultant impacts from these threats require monitoring data, ranging from physical, biological and chemical

parameters (Corbett & Winebrake, 2007). To support blue Growth and EBM, emphasis is placed on indicators of threats from port activities, therefore, what needs to be monitored and the technologies best adapted to the monitoring of port environments are important research questions which this study seeks to answer (Lovett et at. 2007).

To understand the state of an ecosystem and the impact of human activities, environmental monitoring is needed to collect the relevant data for analysis. The types of parameters being monitored depends largely on the nature of threats introduced and components of the ecosystem (Jahan and Strezov, 2017). Monitoring technologies are advancing fast, with new innovations being released to the market frequently. A look at the different types of monitoring technologies being used currently includes; eDNA, remotely operated vehicles, robotics, fixed point marine observation systems and in situ monitoring devices (Danovaro et al. 2016).

The objectives of this research are to review the impact of shipping on ports environment, also to identify appropriate monitoring needs and monitoring technologies which are fit-for-purpose in the seaports to support EBM and Blue Growth. Additionally, the application of environmental data to achieve better policies and regulatory regimes is also an important aspect of this research.

Nigerian seaports environment was used as a case study for this research because environmental monitoring in Nigeria is in its early developmental stages and there is no sufficient data on the state of the ecosystem. Additionally, Nigerian ports and shipping industry is one of the largest in Africa, with a ship traffic of 2,461 in 2017 (NPA Handbook, 2018).

The methods I will use are literature review and semi-structured interviews. I will identify impacts on the marine environment that may be detectable in ports using literature review, I will also identify monitoring needs and emerging technologies with literature review and interviews.

2.0 METHODS

I applied literature review and semi-structured interview (SSI) methodologies. Literature review focused on identifying impact of shipping on the environment. I used SSI to study monitoring parameters and available technologies.

2.1 Description of the Study Area: Nigerian Seaports Environment (Lagos Ports)

The port marine environment in Nigeria is exposed to different types of anthropogenic pressures from shipping and port activities, this has impacted the components of the ecosystem over the years (Abowei et al. 2011). The efforts to protect the fragile ecosystem components from abuse by port users is plagued by lack of adequate resources, lack of sufficient capacity and weak regulatory framework. Recent changes in the administration of the ports has improved the level of awareness, enforcement capacity and compliance to environmental regulations (Akinyemi, 2016).

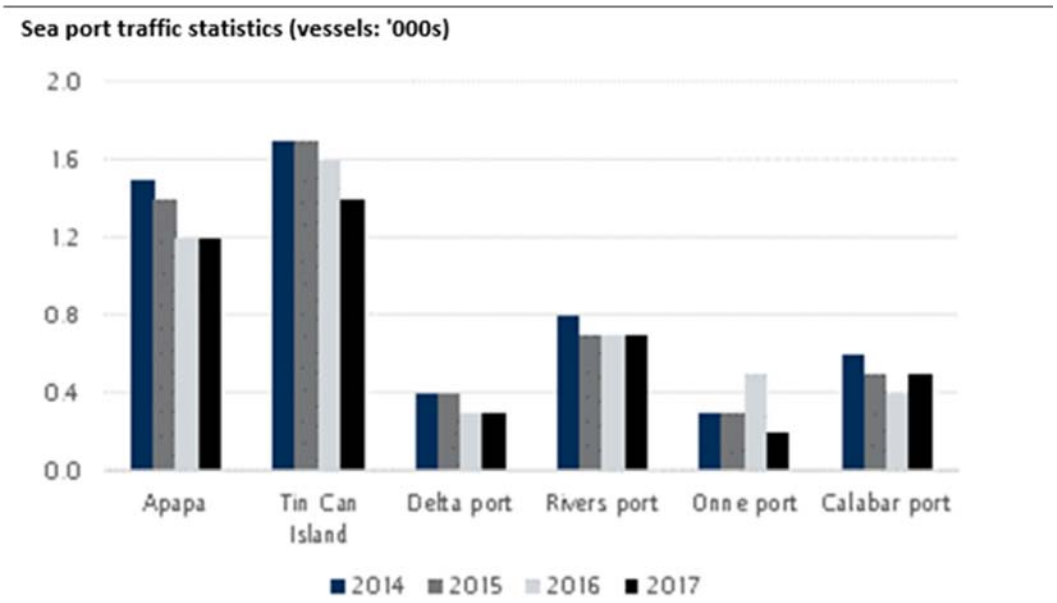

Fig. 1: *Shipping traffic for Nigerian Ports Authority from 2014 to 2017*
Source: *National Bureau of Statistics (NBS) Nigeria; FBNQuest Research*

The six major seaports which are spread across the western and eastern parts of the country are inland ports (Figure 1). Nigerian coastline overlooks the Atlantic Ocean but the seaports are located further inland at different distances from the coast. The marine environment of Inland ports introduces more threats to the environment because there is a higher concentration of

anthropogenic activities inland than along the coasts. For the purpose of this research, I used Lagos ports of LPC (Apapa) and TCIPC as case study.

2.1.1 Lagos Port Complex (LPC)

This is the largest port in Nigeria and one of the largest in Africa, it is also known as the Premier Port. It is located at 2.7 nautical miles from the fairway buoy. It has an overall quay length of 2,537 meters with 21 berths (Figure 2). Its navigational approach has a depth of 13.5 meters and its developed land area is 200 hectares (NPA Handbook, 2018). These dimensions describe the size of the port marine environment.

Fig. 2: *A profile of Lagos Port Complex (LPC)*
Source: *NPA Handbook, 2018*

2.1.2 Tin Can Island Port Complex (TCIPC)

Tin Can Island Port is the second largest port in the country (Figure 3) with a length of 3,393 meters and access channel depth of 13.5 meters. It is located further inland at a distance of 5.9 nautical miles (11km). The total land area developed is 157 hectares, with 13 berths (NPA Handbook, 2018).

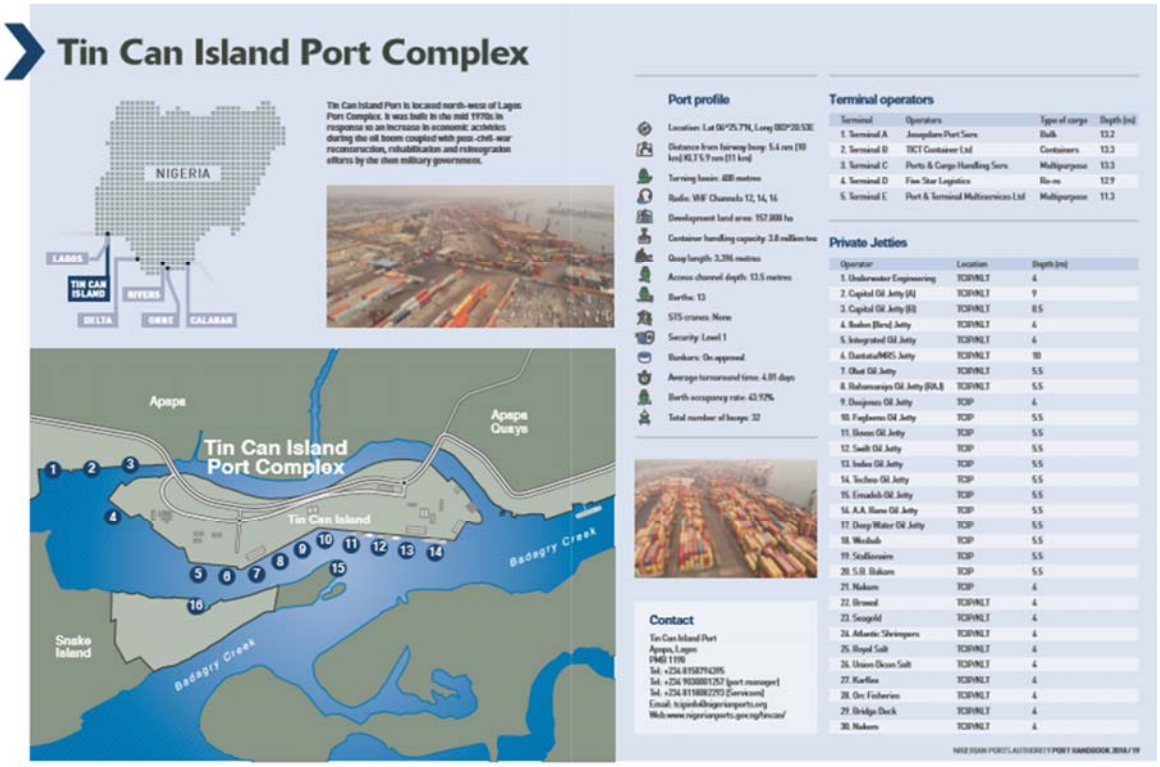

Fig. 3: *A profile of Tin Can Island Port Complex (TCIPC)*
Source: *NPA Handbook, 2018*

2.2 Literature Review

In the literature review, I identified the potential environmental risks and the regulatory framework of port activities. I also reviewed the impact of shipping activities on the port and coastal environment.

2.2.1 Oil Spill and Ship Operational Pollution

Nature of Activity

Oil Spill and ship operational pollution are sources of threats introduced to the environment from shipping. Oil spill occurs either through intentional oil discharge into the marine environment or by accident (Adolf & Song, 2010). The latter is the most common cause. Examples of accidental oil spill include fire incident on board a ship, rupture of hose during bunkering, sunken vessel or collision at sea. (Fingas, 2012). Ship operational waste refers to the waste categories described in MAPROL 73/79 Convention. These are Category 1-6: Oily waste, Noxious liquid, Packed harmful substances, Sewage, Garbage and Air Pollution. (Szepes, 2013)

Impact

The effect of oil spill and ship operational pollution on the environment is immense. Some of these impacts include: death of species, destruction of fragile ecosystems, marine litter, eutrophication and ocean acidification (Lamendella et al. 2014). Major oil spill incidents have received far more attention due to its size and significant impact on the ecosystem in a single instant. The cost of clean-up, remediation and compensation for economic loss and environmental damage, the extensive media coverage and public outcry, are other reasons why there has been a lot of emphasis on big oil spills (Anderson, 2014). For this reasons, there is no shortage of research into impacts of major oil spills, examples are: Medelssohn et al. (2012), Al-Majed, Adebayo and Hossain (2012) and Prince (2015). Ship operational waste, which is less in volume compared to oil spills, occurs more frequently and thus causes more impact than oil spills (Adolf & Song, 2010).

Monitoring Oil Spill and Ship Operational Pollution

Modern technology provides different ways of monitoring ship waste in the marine ecosystem. Monitoring the water for the presence of ship waste shows short, medium to long term effects on the ecosystem components. Monitoring can be done by satellite remote sensing (Breke & Solberg, 2005), collecting water samples for laboratory analysis, camera monitoring, use of ROVs and drones and genomic methods such as eDNA (Danovaro et al. 2016).

2.2.2 Ship Emissions: Ocean Acidification and Climate Change

Nature of Activity

The contribution of international shipping to ocean acidification is a well-researched subject by a number of scientists; Hassellov et al. (2013), Turner et al. (2018), Omstedt et al. (2015) and many others, all drawing conclusions that international shipping is indeed a major contributor to global ocean acidification. Hassellov et al. (2013), after studying heavily trafficked shipping routes, established that SOx and NOx make more contributions than COx, because COx forms a weaker carbonic acid compared to sulfuric and nitric acids. Hunter et al. (2011) from their research, added that the input of NOx and SOx would lead to the reduced uptake of COx in water, this makes it available as a contributor to global warming.

Impact on the Environment

NOx and COx emissions are released into the atmosphere as the ship burns fuel through its combustion engines. NOx on the other hand is produced from the high temperature generated during the combustion process from nitrogen in the air (Hassellov et al. 2013). The overall impact

of these gases on pH is not very significant in the oceans, this is due to the high salt content of ocean water which has a neutralizing effect of acids, thus acting as a buffer. On the contrary, other water bodies with little or no salt content, such as inland fresh waters and some coastal waters, where most seaports are located, the impact of NOx, SOx and COx from ships increases the pH significantly over time (Doney et al. 2007).

Monitoring and Control

The negative impacts of ship emission on the coastal environment and human health necessitated the introduction of legislation through the instrument of MARPOL Annex VI by the IMO in 2005, which has further led to other regulations such as the creation of four ECAs (Emission Control Areas) to limit the impact SOx, NOx and PM (particulate matter) emissions by ships (Figure 4) on both human health and plants health, but also on the marine ecosystem. Time series data of pH monitoring in the affected marine ecosystem shows the level of ocean acidification.

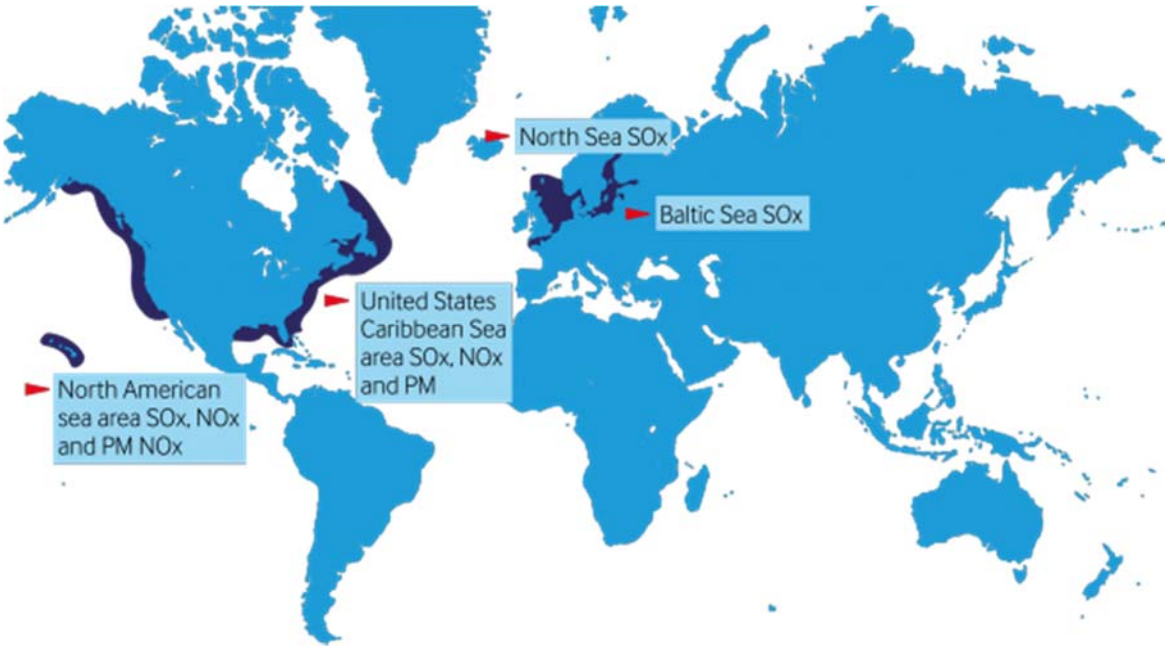

Fig. 4: *Four Emission Control Areas (ECA) in the world*
Source: *Sulfur Requirements in the IMO Emission Control Areas (imo.org)*

2.2.3 Underwater Noise

Nature of Activity and Background

Growth and development of the global economy and urbanization is increasingly filling our oceans with noise (McDonald et al. 2008 & Moore et al. 2012). Payne and Webb (1971) noted that substantial research work on marine noise pollution only started recently with work on long range

communication among baleen whales. Before that, most research has been focused on military applications like in World War II when it was discovered that ship noise interferes with signal processing of active sonar or even earlier than that during the first world war, when hydrophones were developed for listening to submarine sounds (Lenon, 2004).

In recent times, underwater noise has constituted a threat to the marine ecosystem as it interferes with animal behavior in terms of hunting, communication, mating and navigation. The sources of such noise includes ship engines, cranes for loading and offloading ship cargo, heavy duty plants in the ports, dredging, pile driving and other shipping and ports related activities in the marine environment (Slabbekoorn, 2016).

Impact

The threat of underwater noise impacts animal life in spatial and temporal scales, though the full biophysical impact of the impact requires more studies. (Slabbekoorn, 2016). Response to underwater noise was studied by Neo et al. 2014 who established different factors as responsible for the type of animal reactions observed. These reactions ranged from a startled response to increased swimming speed, increased group cohesion and bottom diving. The researcher also concluded that the duration of exposure was an important factor as fishes have a short recovery time when exposed to short sounds, but stand a risk of a permanent behavioral change when exposed for longer periods (Neo et at. 2014). Continuous and high noise level conceals important biological cues leading to increased psychological stress, developmental deficiencies, hearing loss, change in feeding habit and migration (Merchant et al. 2016).

Monitoring Underwater Noise

Passive acoustic Monitoring Device (PAM) is a category of underwater monitoring devices which measures acoustics. For ship source underwater noise, the combination of vessel Automatic Identification System (AIS), ship traffic video recording and analysis can be used to estimate the level of noise produced by ships in port. Noise monitoring stations can also be set up in at locations where anthropogenic noise is prevalent (Merchant et al. 2016).

2.2.4 Invasive Species

Nature of Activity

The use of ballast water by ships to improve stability, balance for a safe voyage across the ocean has been in operation since the late 1870s, a few decades later in the 1890s, this method, along

with ship hull biofouling was recognized as a vector for introducing foreign planktons across regions (Sarah, 2015).

Impact

Invasive species have been classified as Harmful Organisms and Aquatic Pathogens (HOAPs) which have negative impact on biodiversity and changes to ecosystem. The International Union for the Conservation of Nature published in its Red List database that invasive species are responsible for 54% of cases of species extinction (Clavero & Garcia-Berthou, 2005). Under favorable conditions, some invasive species compete for survival and overwhelm the indigenous species, multiplying at alarming rates over a short period and the process is virtually irreversible (Vila et al. 2010). They also pose health threats to humans, examples are some toxin releasing algae (Doblin et al. 2004) and pathogenic bacteria (Ruiz et al. 2000).

Monitoring Invasive Species

Monitoring the presence of foreign invasive species in the marine environment is targeted at identifying the species and estimating their population growth rate (Delaney et al. 2008). The methods of catch-per-unit-effort over time by fishermen and Citizen Science can provide data on invasive species in an ecosystem. Additionally, eDNA is a modern monitoring method with better reliablity in identifying species using DNA analysis of the species biological remains (Darling & Blum, 2005). Delaney et al. (2008) also noted that the data from Citizen Science method has limited applications due to unreliability of its sources.

2.3 Semi-Structured Interviews

Most of the data for this study was gathered using semi-structured interview methodology, which allows for discussions outside the scope of a predetermined set of questions but within the same research topic (Kallio et. al., 2016). This method was chosen considering that the science of environmental monitoring and the related technologies are constantly evolving, and so a lot of new and emerging information are frequently being released (beyond state-of-the-art). A flexible interview approach encourages the interviewee the freedom to cover diverse but related issues, revealing valuable new information in the process. The answers provided usually dictates the direction of the interview (Wilson, 2013).

A total of 12 interviews and 3 questionnaires were conducted, this was regarded as the saturation point for this research as additional interviews did not yield any new information (Hennink et al. 2017). Questionnaires were included to complement the interviews because of some logistical challenges encountered in reaching some of the participants. Table 1 is a summary of the interviews

conducted and questionnaires returned, including the interviewees areas of specialty, their position, location, date and duration of the interview.

(In keeping with the anonymity terms agreed for the interviews, the participants will be represented by serial numbers from "P1 – P15".)

INTERVIEWS					
Interviewees	**Area of Specialty**	**Position**	**Location**	**Date**	**Duration**
P1	Environmental Regulatory Standards	Chief Geologist	Nigeria	4th July	33 mins
P2	Ship Waste Management	Supervisor	Nigeria	5th July	37 mins
P3	Observation Technology (Oceanography)	Senior Researcher	Denmark	8th July	40 mins
P4	Environmental Law	Associate Research Officer	Sweden	8th July	1hr 13 mins
P5	Port Environmental Protection	Principal Manager	Nigeria	8th July	45 mins
P6	Monitoring Equipment Production	Engineer	China	9th July	21 mins
P7	Marine Environmental Protection	Senior Researcher	Sweden	11th July	48 mins
P8	Oceanography	Director of Research	Italy	11th July	1hr 7 mins
P9	Maritime Safety and Administration	Chief Marine Officer	Nigeria	11th July	25 min
P10	Ecosystem	Senior Researcher	Denmark	17th July	1hr 5 mins
P11	Port Environmental Protection	Senior Manager	Nigeria	17th July	1hr 4 mins
P12	Marine Observation	General Secretary	Belgium	24th July	46 mins

QUESTIONNAIRES					
P13	Port Environmental protection	Senior Manager	Nigeria	16th July	-
P14	Oil Spill Response Agency	Manager	Nigeria	16th July	-
P15	Health Safety & Environment	Supervisor	Nigeria	22nd July	-

Table 1: *List of interviews conducted showing interview dates, area of specialty and location*

2.3.1 Sample Selection

The sample size chosen for the semi-structured interview was 15, and they cut across government agencies, the academia and the business community. A balanced stakeholder representation is critical to the integrity of the data and results, as it might lead to marginalization of important stakeholders and affect the demographic balance (Reybold et al. 2013).

The following criteria for sample selection were adhered to in this research:

1. **Relevance of Participant's Qualifications:** Purposive sampling method was used as the participants' qualifications were considered before selection (McIntosh et al. 2015). The areas of expertise range from Marine Observation Technology, Marine Biology, Environmental Management and related fields.
2. **Geographical Spread:** Considering the scope of the research is Nigeria, there was a bias towards participants from Nigeria, as evident in table 1, particularly with regards to the monitoring needs. Other participants who provided the technology needs were concentrated in Europe. This is because a lot of the state-of-the-art technologies researched were found in Europe, and also to take advantage of proximity and logistics. (Al-Shaggaf and Williamson, 2004)
3. **Snowball Technique:** This is a common method adopted in research interviews where participants with particular qualifications were sought and asked to recommend other participants within similar fields of expertise (Woodley and Lockhard, 2016). This was used in this research to select participants who are experts in monitoring technology.
4. **Participation of Relevant Stakeholders:** Participants were selected from three important sectors which were the key stakeholders to this research. These are: academic institutions, government agencies and business communities. (Reed M.S., 2008).

2.3.2 Interview Process

The participants were carefully selected from academic institutions, government agencies and the business community. Their consent was sought through a Consent Form which contains detailed terms of the interview, informing the participants of their rights and seeking their approval to participate in the interview. Predetermined questions were used as a guide for the interview, but other questions were introduced as the interviewee provided answers requiring further clarity.

The recorded interviews were played back and transcribed. From the transcribed materials, a coding system was developed using keywords, in order to establish a trend to help understand the most relevant issues and areas of emphasis by the participants, and also to compare similar themes in the answers provided during each interview (DeLyser et al. 2013).

Interviews took place both over the phone, via skype and face-to-face, with the average duration of 45 minutes per interview. Parts of the interviews were quoted verbatim in this research to reinforce the argument and preserve the integrity of the data (Vaughn and Turner, 2016).

The interview questions were about gathering information from the participants on the use of environmental monitoring data, the environmental parameters, their views on present and emerging monitoring technologies and environmental regulations.

3.0 RESULTS

The results for this research includes data on port activities in Nigeria, interview results on monitoring needs and technology, and literature review on impact of shipping on marine environment. These are presented in tables and charts.

3.1 Research Location

The research area are the ports of Lagos, Nigeria; TCIPC and LPC.

3.1.1 A Description of Port Activities in Lagos Ports

A variety of port activities are carried out in Nigeria, these range from e.g. terminal operations to bunkering, oil tank farms, cargo handling, channel management and others (Table 2).

No.	Types of Companies	Number of Companies/Agencies		Description of Activities
		LPC	TCIPC	
1	Terminal operators	7	5	Loading/unloading of cargo on ships (wheat, clinker, container, oil, chemicals and general cargoes) and storage.
2	Logistics bases	2	-	Warehousing, fabrication & assembly, helicopter base, sewage and 6waste water treatment.
3	Jetties	15	30	Local transshipment of different types of cargo
4	Oil tank farms	4	2	Storage and transportation of petroleum products
5	Pilotage	1	1	Navigation of visiting ships through the port channel for berthing
6	Towage	1	1	Towing of ships using tug boats within the harbor

7	Berthing and Mooring	1	1	Berthing and securing of ships at the quays in the port
8	Cargo handling	4	4	Movement of cargo from ships, to storage facilities and trucks for removal from the port by stevedores
9	Channel management	1	1	Dredging, wreck removal, provision of navigational aids, monitoring of siltation.
10	Bunkering	5	5	Supply of fuel to ship tanks by bunkering facilities in the port
11	Salvage and rescue	3	3	Emergency response in the port or navigational area in the event of an accident, oil spill or fire incident.
12	Mid-stream operations	3	3	Loading and unloading of cargo midstream from ship to ship or barges or rigs
13	Anchorage	1	1	When ship anchors at the port while waiting to berth
14	Waste management	2	2	Collection, recycling and disposal of ship waste by port reception facility
15	Ballast water management	1	1	Onshore ballast water treatment services
16	Liquefied Natural Gas operations	1	1	Berthing and discharge of liquefies natural gas
17	Handling of hazardous cargo	3	3	Accompanying of hazardous cargo from ships to destination
18	Construction projects	2	2	Construction of port infrastructure and expansion of existing
19	Fumigation and pest control	1	1	Sanitation of port using chemicals to control pests and germs
20	Sand winning/filling	1	1	Extraction of port sand or filling of port land with sand
21	Pipe laying	1	1	Laying of pipes on port land or in water

22	Onshore/offshore Drilling	1	1	Drilling operations for construction, exploration of resources or for other purposes in the port
23	Factory	-	5	Production of Flour and cement in the port.
24	Warehousing	5	6	Warehouses for storage of different categories of cargoes
25	Container stacking area	12	11	Storage of containers in outdoor stacking areas using cranes
26	Silo storage	-	2	Silos for storage of what, chemicals and other products
27	Offices, workshops & stores	7	10	Offices and shops for the personnel of companies in the port
28	Fishery operations	-	2	Fish cold storage and maintenance of fishing equipment.

Table 2: *Overview of port activities by different companies and agencies in LPC and TCIPC*
Source: *Culled from nigerianports.gov.ng (LPC and TCIPC Terminal operators, logistics bases, jetties, tank farms, other leases)*

As described in Table 2, port activities in Nigeria, particularly, LPC and TCIPC are vast, with each having different levels of impact on the marine environment. These activities and their corresponding impacts are summarized in Table 3 below:

No	**Category of Port Activity**	**Threats Introduced to the Marine Environment** (Acciaro et al. 2014; Hiranandani, 2014; Anne et al. 2015)
1	Ship navigational & berthing operations	Ship noise, oil pollution, COx, SOx, NOx emissions, plastics, ballast water, bilge water, anti-fouling agents
2	Loading and unloading of cargoes	Nutrient over-enrichment, algae bloom, oil pollution, marine debris, heavy equipment noise
3	Storage and transportation	-
4	Factory production and manufacturing	Effluent discharge, chemicals discharge, marine debris, noise pollution, air pollution, nutrient over-enrichment
5	Channel management (dredging)	Destruction of marine habitats, noise pollution, emission, water turbidity increase
6	Construction and exploration activities	Destruction of marine habitats, noise pollution, emission, oil leakages, water turbidity

7	Waste and ballast water management	Oil pollution, effluent discharge, marine litter, invasive species
8	Fisheries	Overfishing, marine debris, ecological disruption
9	Office buildings, workshops and warehouses	Power generator noise, oil leakages, garbage and sewage

Table 3: *Categories of port operations in NPA and the corresponding threats introduced to the port environment*
Source: *Monthly Reports of port activities (Environment Department of NPA)*

3.1.2 Regulatory Framework of Port Environment: LPC and TCIPC

The regulatory regime for the protection of Nigeria's port environment includes international conventions and local laws, enforcement by a number of government agencies and departments (Barnes-Dabban et al. 2017). Though different agencies address different aspects of port environmental protection, the overall approach can be described under four categories: *environmental monitoring, site inspection, waste disposal* and *emergency response.*

A list of the major agencies and departments involved in regulation and enforcement of port environmental laws, as culled from the Annual Report of NPA (2017) are:

1. **Federal Ministry of Environment (FMEnv):** A ministry of government responsible for overseeing all agencies and departments involved in environmental protection, and setting the policy direction of government in this regard. This included the port environment.
2. **Federal Ministry of Transport (FMoT):** This federal ministry is responsible for setting the policy direction of the transport sector, which includes the seaport. It oversees all agencies and department within the transport sector.
3. **Federal Ministry of Water Resources:** Management of Nigeria's water resources, provision of access to clean water and protection of the marine ecosystem from unsustainable use of water resources.
4. **Nigerian Maritime Administration and Safety Agency (NIMASA):** The apex maritime administration body for Nigeria. Its main responsibility is to oversee and administer the country's maritime industry, this includes prevention and control of marine pollution.
5. **Nigerian Ports Authority (NPA):** The NPA through its environment department, is the main agency who's primary responsibility is to ensure protection of the ports marine environment.
6. **National Environmental Standards and Regulations Enforcement Agency (NESREA):** Sets the standards for exploitation of environmental resources, enforces environmental regulations in the country, both terrestrial and marine environments.

7. **National Oil Spill Detection and Response Agency (NOSDRA):** Prevents and controls oil spill incidences in Nigeria. It also enforces related regulations and coordinates all other stakeholders in an oil spill emergency response.
8. **National Inland Waterways Authority (NIWA):** The administrative authority of the inland water ways. Maintains, protects and regulates all activities related to the Nigerian Inland Waterways.
9. **Nigeria Hydrological Services Agency (NIHSA):** Administration and management of Nigeria's surface and ground water to ensure the sustainable use of water resources in the country.
10. **Lagos State Environmental Protection Agency (LASEPA):** A state environmental protection agency, monitors, regulates and enforces the use of the environment in the state of Lagos, this includes the marine environment.
11. **Lagos Waste Management Authority (LAWMA):** Collection and disposal of all waste generated in the state. Oversees the recycling of waste and manages the dump site. Enforces waste disposal regulations in the state.
12. **Department of Petroleum Resources (DPR):** In addition to regulating Nigeria's oil resources and its exploitation processes, DPR is also involved with ensuring Health, Safety and Environmental regulations at all locations where oil operations are carried out, including the ports.

The ministries, agencies and departments listed above carry out the duties described using various local and international legal instruments. Nigeria is signatory to a number of international conventions related to environmental protection, Table 4 shows the list of such laws.

No.	Local Laws
1	Nigerian Ports Authority Act(Port Act), 2004
2	Nigerian Ports Authority Concession Agreement, 2006
3	Petroleum Act, 1969
4	Environmental Impact Assessment (EIA) Act, 1992
5	Oil in Navigable Water Act, 1968
6	Oil Pipeline Act, 1965
7	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), 2002

8	Endangered Species Act, 2004
9	National Inland Waterways Act, 1987
10	National Oil Spill Detection Regulations Agency Act, 2006
11	National Environmental Standards and Regulations Agency Act, 2006
12	National Environmental Sanitation and Wastes Control Regulations, 2009
13	Federal Emergency Protection Agency Act, 1992
14	International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM), 2004
15	Convention on Biological Diversity, 1992
	International Conventions
1	International Convention for the Prevention of Pollution From Ships (MARPOL) 73/78
2	International Oil Pollution Compensation (IOPC) Fund, 1992
3	Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, 1972
4	International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC), 1990
5	Basel Convention on the Trans Boundary Movement of Hazardous Wastes and Disposal, 1988
6	International Convention for the Control and Management of Ship's Ballast Water and Sediments (BMW), 2004
7	Convention on Biological Diversity, 1992
8	Vienna Convention for the Protection of Ozone Layer, 1985
9	Montreal Protocol on Substances that Depletes the Ozone Layer, 1987

Table 4: *A list of local and international environmental laws regulating Nigerian ports and coastal waters*
Source: *Health Safety and Environment Report, NPA, 2017*

3.2 Interview Results

I collated the results using the themes which emerged from the interviews. These are: environmental Monitoring data and its applications, threats to ports and coastal environment, environmental parameters, EBM and Blue Growth, review of present and future monitoring technologies and environmental regulatory framework (Tables 5 – 10).

3.2.1 Results from the Interview Themes

Participants	Questions on monitoring data	Answers
Data for policy-making purposes		
P2	Do you use all the environmental data you collect?	*"Yes, this is used by the 3rd parties that carries out our environment monitoring to ensure the effluents discharged into water are within the permissible limits."*
P4	Do you think there are some data which are not necessary to collect?	*"No. It is important we collect data and how we collect it, but if we don't use it then it's useless. As long as it is part of the objective of understanding the state of our marine environment, I don't think it's useless. Data should be Smartly used and smartly translated. The data we collect is only as good as its use for policy."*
P5	What is the monitoring data used for? Are all of them used?	*"They are used for decision-making for the type of approach to environmental issues within the port. Also to advice the government."*
P7	Concerning the relationship between data and policy making, do u think this a problematic relationship?	*"Depends on what the data is being collected for. If it's for confirming whether any thresholds are being exceeded or whether an ecosystem is collapsing, these are different objectives i.e. whether we don't do anything until something happens. Sometimes, there might be pollution but as long as the threshold is not exceeded, the policy makers might not do anything."*
P13	For the purpose of monitoring marine pollution, how is environmental data collected and what is it used for?	*"MARPOL Compliant Inspection Forms are issued to visiting vessels, to monitor their level of compliance with various IMO instrument during their voyage to the country. The information provided is used for strategic policy formulation and enforcement."*
Data sharing with other organizations		
P5	What is the monitoring data used for? Are all of them used?	*"Some data is shared with other government agencies and ministries."*
Data for academic uses and other purposes		

P10	What is the use of the data you collect from your fish monitoring?	*"At the moment we use the data to understand influence of benthic habitat on fish abundance, we use a lot of benthic video recording using cameras positioned on the bottom, we use the data to understand where these fishes occur in different habitats, the goal is to protect or even restore the habitat in the most beneficial way. For example we have been testing with different kinds of reef such as stone reef, to see how the fish behave."*
P12	What is the primary use of the data you collect in your monitoring?	*"From the European context, we collect for the quality of water, good environmental standards and monitoring of fishes."*
P15	For the purpose of monitoring marine pollution, how is environmental data collected and what are they used for?	*"Environmental Data are collected by Satellite Remote Sensing. The data collected are used to suggest what can be done to reduce pollutant flow into oceans and also to map and monitor marine pollutants to ensure a sustainable marine ecosystem."*
P10	Do u have an interface with policy makers by sharing with them or its for purely academic purposes?	*"A combination of both. I'm not involved in inspection of fisheries as such. The research I have been describing here is currently not being used by policy makers but eventually I think it will."*

Table 5: *Excerpts of interview Q&A on environmental monitoring data and its applications*

Participants	**Questions on environmental threats**	**Answers**
Current threats in port environment		
P2	What are the threats you think you should be worried about in the port marine environment?	*"…one threat is oil spill from illegal bunkering activities. Also, damage from dredging by destabilizing the ecosystem. Also shipwrecks are a lot in the port waters because as they rust, they release chemicals into the water. Also there is debris all along the shoreline dumped by villages along the coastlines. Also many port companies do not have waste treatment systems so they release their waste directly into the water."*
P5	What are the major pollutants in the seaport and what are their sources?	*"Municipal waste, waste from vessels which is currently being well managed by applying MARPOL annexes, blocked drainages, waste oil from mechanic and industrial workshops."*
Future threats in port environment		
P1	What new threats are you worried about?	*"Persistent floaters like plastic bottles."*
P1	Are there new threats in the future?	*"We keep monitoring until we discover new threats."*

		"…chemical pollution"
P4	What new threats do you think are coming up?	*"Nano particles and impact of certain medical chemicals. There is not enough monitoring for noise, invasive species, impact of genetically modified fish bait created in the lab."*
P4	Impact of new developments/construction in the ports or coastlines, are there new threats we should be worried about as a result?	*"…if you have a big construction there might be some impacts missed by the SIA and the EIA, like in the north of Germany where I come from, we have the Kiel Canal which connects the north sea to the Baltic sea, we are creating a new lock there, it's the fifth lock, which is the biggest waterway construction in the EU, they didn't know that the light and the sound and sedimentation will have a lot of impact on marine life."*
P4	In the long term, what should we be worried about in the marine environment?	*"For me, we should be concerned with iron that is dumped into the water in marine engineering, the chemicals generally that we do not know their full impact yet, chemicals introduced through the sewage system, nutrient recycling in the Baltic sea which is very prone to eutrophication."*
P7	What are the new threats coming into the environment in the future particularly in shipping and port environment?	*"…the effects of climate change might change in the future. Impact of shipping particularly from automation which is new might bring new threats in the future since there's not sufficient data on the impact yet. Also, if you shift source of fuel, there could be new threats from that for instance leakages in battery cells."*
P8	What are the new threats expected in the future?	*"One of them is micro plastics and nano plastics because their effects are not yet fully understood. Another one is pharmaceuticals, antibiotics and other new chemical compounds disposed into the ocean. Also traditional pollutants like nutrients can also be a problem. Also coastal erosion like in the Gulf of Guinea is a real problem… Others are change in the marine habitats due to fishing, climate change etc."*
P10	What threats do think we should be worried about in the ports and coastal environments in the near future, possibly in a developing country like Nigeria?	*"The situation in Denmark and Nigeria are different… The anthropogenic effects are limited in Danish waters but one of the challenges they have is the release of nutrients into the water and u have algae blooms and that causes oxygen depletion from now till winter. Another threat is climate change… Also, overfishing depleting the population of fishes."*
P12	What threats specifically are the main concern for you that prompts your monitoring?	*"A lot of what we do is operational oceanography is around safety of people at sea. In a climate change context where there are changes in ocean temp, change in sea level, changes in carbon, as these affects distribution of living resources."*

Table 6: *Excerpts of interview Q&A on threats to ports and coastal marine environments*

Participants	Environmental Parameters Questions	Answers
P3	Can you list the kinds of parameters that you check for when you do your monitoring?	*"Conductivity, Temperature and Depth (CTD), underwater visibility such as turbidity, these are the standard parameters used in Oceanography, also different types of chemical compounds using different types of fluorescent sensors…."* *"Also atmospheric properties such as radiation and light available under water and wave motion. This will give a lot of information with regards the physical environment. For biology, depends on what you want to observe, if you want to observe fish, you go with acoustics, if you want to observe plankton you can go with lab-on-chip, but if u want to observe zooplanktons u will have a hard time there, because u will need to collect images and analyze with systems like Zooscan to make real-time analysis."*
P5	What might be useful to monitor in the short, medium and long terms?	*"Effluent limitation standards by the Ministry of the Environment which contains all the parameters such as: BOD, nitrogen, COD, magnesium and other parameters, which are online. Also air quality."*
P8	Can you give a list of parameters you think are important to check?	*"…depends on what u are looking for. Looking at scientific approach, GOOS reports has a lot of such data. But to look at economic and social priorities from my experience, these are: temp, partial salinity, turbidity, chlorophyll, dissolved oxygen, PH, alkalinity, sea level, harmful algae blooms, waves, surface current. These are the physical, now chemicals could include antibiotics and so on, which samples are collected and taken to the lab for analysis. But the physical list above you can set up automatically routinely."* *"You can have satellite images which can sometimes give you chlorophyll, surface temp, salinity, current… Such data can be accessed via an online resource such as Copernicus…"*
P12	What are the key parameters that could be monitored in a seaport environment to give indicators of the state of the ecosystem health?	*"In the vicinity of ports, some of the important things to measure are nutrients particularly nitrates, nitrites, sulfates, because they can cause algae bloom which affects living resources and also affects vessels water intake, leaks of hydrocarbon are also important to measure. Also, the agitation levels of the seaports are important to ships, also invasive species."*
P11	What are the parameters you believe should be monitored in the port marine ecosystem?	*"…HAOPs introduced by ballast water are a threat to local species and so I think they need to be monitored to understand the extent of damage to they have caused."*

Table 7: *Excerpts of interview Q&A on key environmental parameters to monitor*

Participants	Questions on EBM and Blue Growth	Answers
P3	What in your experience are the major challenges in establishing a robust EBM?	*EBM is very complex due to human involvement and because it involves many components which are non-linear. Also, there are aspects of EBM which we have sufficient data while others not so much.*
P4	How much do you know about environmental management and EBM in Africa?	*"…I interfaced with some reps of countries from Africa, where one of the reps from Nigeria, NPA talked about the seaweed infestation in the country. Apart from this, I think the sense I have is there is challenge of capacity development."*
P7	What do you understand by EBM and how does it apply to monitoring?	*"…it is a reaction to how we traditionally try to protect the environment, we try to identify specific impacts on a specific component of the environment, without understanding the health of that ecosystem as a whole and the interconnections between the components."*
P8	What in your sense is the relationship between blue growth and monitoring?	*"…there some emerging new sectors like blue biotech, deep sea exploration, energy from the sea etc. To see the connection between different components of the blue economy such as tourism and ports, or aquaculture and fishing, u need good data, so monitoring plan is essential to provide this connection."*
	How do you think environmental monitoring can help improve EBM?	*EBM is highly dependent on monitoring and very good understanding of the connections within the ecosystem. Researchers and policy makers need to understand the different links btw different parts of the ecosystem and they have to be able to predict what will happen in the ecosystem.*
P12	What are the Challenges to the implementation of EBM in Europe?	*"One of the major challenges is getting different disciplines to work together."*
P9	What is the main challenge of EBM in Nigeria?	*"Lack of baseline studies to determine the true state of the environment."*
P11	Are you familiar with blue growth? How can environmental monitoring improve this concept?	*"…it encompasses sustainable economy, jobs and environmental protection. Monitoring the ecosystem provides information needed to protect the environment in a blue economy program."*

Table 8: *Excerpts of interview Q&A on EBM and Blue Growth*

Participants	Questions on Monitoring Technology	Answers

State-of-the-art Monitoring Technology and Beyond		
P3	How is monitoring of the environment changing with regards to technology available and those coming?	*"Automation is a major change in recent times… another one is satellite data… information on plankton tide or algae bloom from autonomous vessels… improvements in camera technology… and acoustics. Autonomous species Identification."* *"Lab-on-chip is a new technology which is a small laboratory deployed into the ocean. Also in this category, there is the genomic activities. This is the analysis of genes and their prices are going down quickly."*
P3	What is your area of specialty and how does modern monitoring tools connect to this?	*"…marine observation technology…. We have been developing laser camera for better image quality... and cognitive robotics which can adapt to different conditions in water."*
P8	How do you think monitoring technology will change in the future?	*"…IoT is one of the technologies coming to monitoring in the future… the second part is communication technology that is more cheap. Citizens Science is the last point."*
P10	Can you give a summary of the monitoring and observation technology you are familiar with?	*"…we have increasingly moved to video monitoring where we deploy different kinds of camera to the seabed… we have mono cameras which is one camera… but stereo camera can give us size of fish… We also use eDNA by surveying DNA of other species. We do fish telemetry where we tag fish with different kinds of transmitters…"*
P10	What do u think the future of monitoring technology looks like?	*"I think video analysis will eventually become automated… Also, ROVs that can do real time identification… eDNA might eventually become automated… Also, transmitters for e-tagging will become smaller…"*
P12	What is your sense of how monitoring technology will change in the future?	*"Power… new battery technology will come in the future… Also, miniaturization will be a big issue in the future because some technologies are very large makes them not so efficient to use. Also eDNA will improve and used more frequently… satellite technology will improve and will be used in places with high biomass events like Nigeria. Also, image resolution will improve and will be supported with autonomous drones..."*
P13	What types of monitoring technologies are you familiar with?	*"Oceanographic and hydrographic research vessels, smart buoys sensors, semi-autonomous drones."*
P15	What types of monitoring technologies are you familiar with?	*"Remote sensing technology…"*
Monitoring technology for Nigerian waters		
P3	What type of monitoring technology might work in	*"…an integrated system involving many systems. An example is a mooring system like fixed on a*

	Nigeria Considering challenges of funding and technical expertise?	*buoy, they are cheaper than many other systems. But they might require maintenance and physical collection of data."* *"Another one is called IoT which could work for Nigeria which includes long range Wi-Fi transmission because it is cheaper, maintenance requirements is low and easy to configure."*
P4	What type of monitoring technology might work in Nigeria Considering challenges of funding and technical expertise?	*"Citizens Science could help where people upload pictures of sightings…"*
P10	What type of monitoring technology might work in Nigeria Considering challenges of funding and technical expertise?	*"It depends on what issue you want to address. If it is fish, you can use catch-per-unit-effort…"*
P12	What type of monitoring technology might work in Nigeria Considering challenges of funding and technical expertise?	*"Miniaturization is one thing that could work because it brings down the cost."*

Table 9: *Excerpts of interview Q&A on present and future monitoring technologies*

Participants	**Questions on Environmental Regulations**	**Answers**
Environmental Regulations in Europe		
P4	Do you think the current environmental laws in the EU are sufficient?	*"In the EU, the laws are largely effective enough but in some parts of Europe, I have seen a lot of slacking countries, like in Malta, I have lived in Malta and where there are illegal aquaculture and discarding of household waste openly in nature and the municipal refuses the enforce the laws. Also there is no agreed threshold for noise pollution across Europe. And monitoring can help with that."*
P10	What's your sense of the marine regulatory regime for Denmark or Scandinavian or even the whole of Europe?	*"I think EU is going slow but they are going in the right direction, and there are increasing number of parameters that have to be met, for instance laws in terms of eelgrass, micro algae growing at the bottom, in terms of benthic health, water transparency, oxygen etc."*
P12	Are the current regulatory frameworks in Europe Sufficient?	*"Let me use Marine Strategy Framework Directive (MSFD) as an example. Within that directive, there are eleven descriptors, which are descriptors of the state of the marine environment across ecosystems, it's a well written directive and countries take it seriously*

		and they turn it into legal basis in respective countries."
Environmental Regulations in Nigeria		
P2	The current system of monitoring the port environment, do u think the laws and regulations being operated in Nigeria right now are effective?	*"No they seem to be doing some work but they are not sufficient."*
P12	What is your sense of the regulatory framework for the marine environment in Africa?	*"I think it is not well developed looking at this from the European context. There are some very good programs such as the LME programs that has been done under the UN system like the Gulf of Guinea LME…."* *"There are possibly some countries with good programs but the networking is not good enough. Africa needs to adopt international best practices and build upon the existing frameworks instead of starting from the scratch. Also, its important to share data among African countries."*
P13	Do you think the current seaport and coastal environmental regulatory regimes are effective? If they are not, what are your recommendations for improvement?	*"The regulatory regimes are not yet effective. The deployment of technology in monitoring and control will help improve on the present state."*

Table 10: *Excerpts of interview Q&A on environmental regulations*

3.2.2 Data Relating to the Themes of the Interviews in Order of Significance

The participants provided different information on some interview themes, these are ranked in order of significance in Table 11.

No.	Monitoring Data Uses	Environmental Threats	Environmental Parameters	Monitoring Technology
1	State of Ecosystem	Micro & Nano Plastics	Radiation & Light	eDNA[1]
2	Policy-Making	Nutrient Pollution	Temperature[2]	ROVs[1] (water)
3	Sharing with the Public	Noise Pollution	PH[2]	Drones[2]

4	Academic Research	Oil Pollution[4]	Pressure[4]	Satellite[2] Data
5	Commercial Purposes	Over-Fishing[4]	Partial Salinity[4]	Autonomous Monitoring Vessels[3]
6	-	Invasive Species[6]	Turbidity[4]	Citizen Science[3]
7	-	Pharmaceutical Waste[6]	Dissolved Oxygen[4]	Acoustic Device[4]
8	-	Industrial Effluents	Toxic Algae Bloom[4]	Lab-on-chip[4]
9	-	Erosion[9]	Invasive Species[4]	Cognitive Robotics[4]
10	-	Genetically Modified Fish Bait[9]	Noise[10]	Agro Floats[4]
11	-	-	Chlorophyll[10]	Video Monitoring[4]
12	-	-	Wave Motion[12]	Fish Telemetry[4]
13	-	-	Sea Level[12]	Telepresence[4]
14	-	-	Pharmaceuticals[12]	Smart Buoys[4]
15	-	-	Water Agitation[15]	Mobile Laboratory[4]
16	-	-	Plankton[15]	-
17	-	-	Eel Grass[15]	-

Table 11: *Data on interview themes in order of significance*
(Numbers in superscript indicate items that are tied in the ranking.)

3.2.3 Results of Environmental Parameters Deduced from the Interviews

Participants discussed different environmental parameters for monitoring the impact of environmental threats introduced to the ecosystem. These parameters are listed here, highlighting number of participants who mentioned them, category and indication (Table 12).

Environmental Parameters (Variables)	**Category**	**Indication**	**Participants**
Temperature	Physical	Indication of sea surface temperature changes	P3, P8, P9, P11, P15
Pressure	Physical	Depth of the water	P3, P8, P10, P15
Partial Salinity (Conductivity)	Physical	Electrical conductivity of water	P3, P8, P10, P15
Turbidity	Physical	Water visibility	P3, P8, P10, P15
PH	Chemical	Water alkalinity/acidity	P5, P8, P9, P11, P15

Radiation and Light	Physical	Radiation and light available under water	P3, P4, P8, P11, P12, P15
Noise	Physical	Level of noise in the ecosystem	P4, P13, P15
Wave motion	Physical	Measurement of waves	P3, P8
Chlorophyll	Chemical	Monitors ecosystem productivity	P8, P10, P15
Dissolved Oxygen	Chemical	Oxygen content of water	P5, P8, P10, P15
Sea Level	Physical	Changes in sea level	P8, P10
Toxic algae bloom	Biological	Presence of toxic algae in water	P3, P8, P10, P12
Water agitation	Physical	Level of water agitation	P12
Pharmaceuticals	Chemicals	Monitoring levels of pharmaceutical wastes	P4, P8
Plankton	Chemical/ Biological	Measurement of plankton in water	P8
Eel grass	Biological	Indication of water transparency	P10
Invasive species	Biological	Spread of foreign species introduced by ballast water	P4, P10, P11, P12

Table 12: *Information on environmental parameters deduced from the interviews*

3.2.4 Overview of Monitoring Technologies

1. ***Argo floats*** – A system of programmed floats which can dive as deep as 200 meters. It measures temperature, salinity, currents and bio-optical properties of the ocean. (P3)
2. ***Satellite data*** – Ecosystem data collected via satellite and accessible through different databases and websites. (P3, P8, P10, P12)
3. ***Acoustic device (EK80 Simrad)*** – A high precision echo sounder with wide band acoustic observation which can monitor individual species. (P3)
4. ***Autonomous monitoring vessels (Ocean Alpha ESM30)*** – Autonomous water sampling and monitoring boat, fitted with a probe capable of monitoring PH, oxidation-reduction potential

(ORP), dissolved oxygen (OD), temperature, turbidity, plankton tide, alae bloom and many physical and biological parameters. (P3, P6)

5. ***Lab-on-chip*** – Miniature laboratories with small integrated circuits which can handle multiple laboratory chemical analysis on site and autonomously. (P3)
6. ***Environmental DNA (eDNA)*** **–** Collection and analysis of DNA materials in water to identify species, its abundance and other information. (P3, P4, P8, P10, P12)
7. ***Cognitive Robotics*** – Robotic technology which can adapt to different conditions in water. (P3)
8. ***Citizen Science*** – Collection and reporting of sightings and environmental incidences through an online platform by volunteers. (P3, P4)
9. ***Video monitoring*** – Different types of cameras; aided and unaided cameras, mono and stereo cameras for monitoring fishes. (P10)
10. ***Fish telemetry –*** Tagging of fishes with different kinds of transmitters, such as acoustic transmitters in marine environment. It tracks fish migration pattern and body temperatures at different locations. (P10)
11. ***Remotely Operated Vehicles (ROVs)*** – Underwater vehicles remotely controlled, used for different types of monitoring. (P3, P6, P8, P10, P12,)
12. ***Drones*** – Unmanned aerial vehicles, used for monitoring water surface. (P11, P13, P14, P15)
13. ***Telepresence*** – High bandwidth internet connectivity between ship/ROVs in the ocean and locations ashore for real time video streaming. (P12)
14. ***Smart buoys*** – Marine observations buoys fitted with different monitoring tools. (P13)
15. ***Mobile laboratory*** – Mobile laboratory for running chemical analysis (P14)

3.2.5 Summary of Interview results

The information volunteered by the participants covers a wider range of subjects relating to the research area, but the scope and size stipulated for this research paper made it necessary to present only the most relevant results as presented in the tables above. The following figures (Table 13 & Figure 5) are summaries of all the topics discussed as derived from interview themes, and the corresponding participants who provided the information. This reveals the areas with most emphasis and in the interviews.

Interview Themes & Total Discussions	**Number of times Participants explored interview themes**														
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**
Monitoring data & its uses (51 times)	3	1	6	3	4	-	4	5	2	4	3	8	1	2	5

Threats to marine environment (30)	2	2	-	5	3	-	3	1	2	1	3	2	3	1	2
Environmental (16) variables to monitor	-	-	1	-	1	1	-	2	-	5	2	1	1	-	2
Blue Growth (15)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EBM (8)	-	-	1	1	-	-	2	1	-	1	-	1	-	-	1
Review of monitoring technology (33)	-	-	5	2	1	2	3	1	1	4	2	3	5	1	3
Future of monitoring technology (10)	-	-	2	-	-	2	1	1	-	1	1	1	-	-	1
Environmental regulations effect (22)	1	2	-	4	3	-	2	1	1	1	1	2	2	1	1
Decade for Ocean (6) Science & monitoring	-	-	1	1	-	-	1	1	-	1	-	1	-	-	-

Table 13: *Summary results of all interviews and questionnaires*

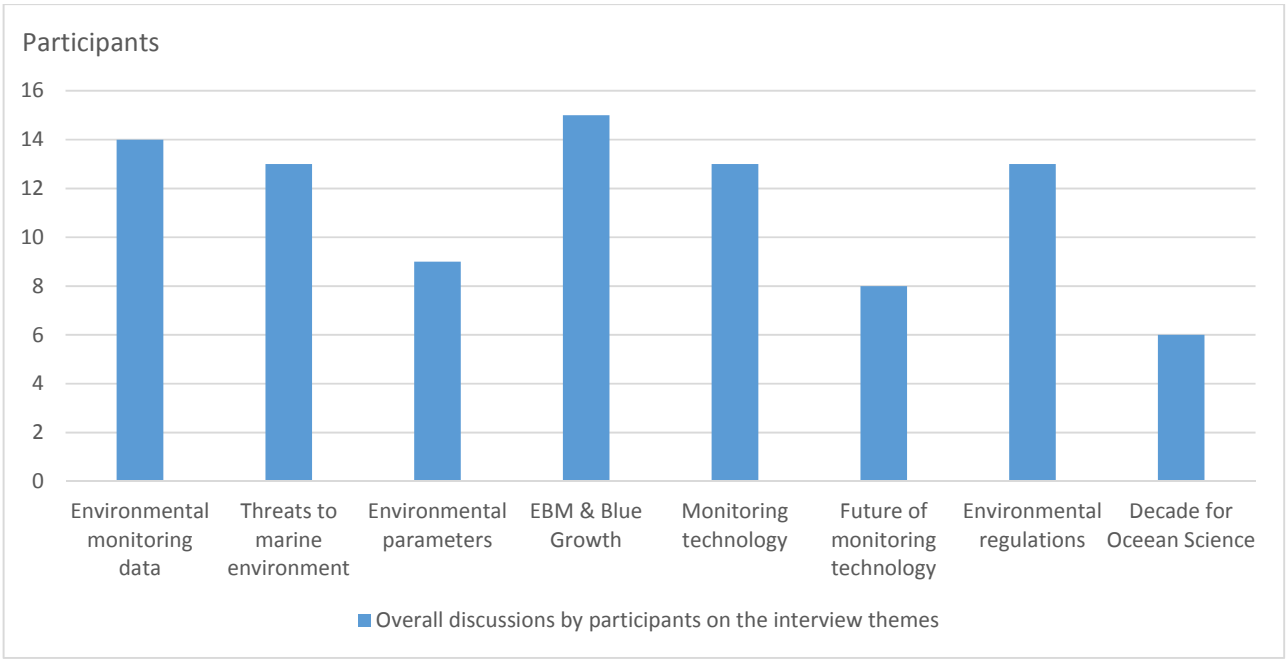

Fig. 5: *Chart of variations in interview discussion topics by participants*

3.3 Results of Literature Review on Impact of Shipping on Marine Environment

The results are based on my review of impact of shipping in four areas: 1. Ship operational pollution & oil spill, 2. Ship emission, ocean acidification and climate change 3. Underwater noise pollution and 4. Invasive species.

3.3.1 Ship Operational Pollution and Oil Spill

Table 14 describes the six annexes of IMO's MARPOL 73/78 Regulations, which are ship operational waste. Figure is a chart of reducing incidences of ship oil spills over time.

Convention	Pollution	Main requirements	Category
MARPOL – 1	Oil	Discharge oil < 1/15,000 of cargo (1/30,000 for new tankers), max 60 litres/mile > 50 miles to shore; Double-hull for C-1:tankers by 2005, C-2 & C-3 tankers by 2010, engine room oil, segregated ballast tank	*Pollution and Technical*
MARPOL – 2	Noxious liquid	Discharge x substances to reception facilities only No discharge of noxious substance within 12 miles to shore	*Pollution and Procedure*
MARPOL – 3	Packed harmful substances	Standards on packing, marking, labelling, documentation, stowage, quantity limitation, exceptions and notifications of harmful substances	*Procedure*
MARPOL – 4	Sewage	Discharge only with on board sewage treatment plant or comminuting disinfecting system or sewage tank > 3 miles, or > 12 miles without disinfecting system to land	*Pollution and Procedure*
MARPOL – 5	Garbage	Port reception facilities, no disposal of plastics Garbage record book on board	*Procedure and Technical*
MARPOL – 6	Air pollution	Standards for particulate matters and SOx, NOx technical Code	*Pollution*

Table 14: *MARPOL 73/78 Regulations and its 6 Annexes describing categories of ship operational waste*
Source: *IMO Conventions (imo.org)*

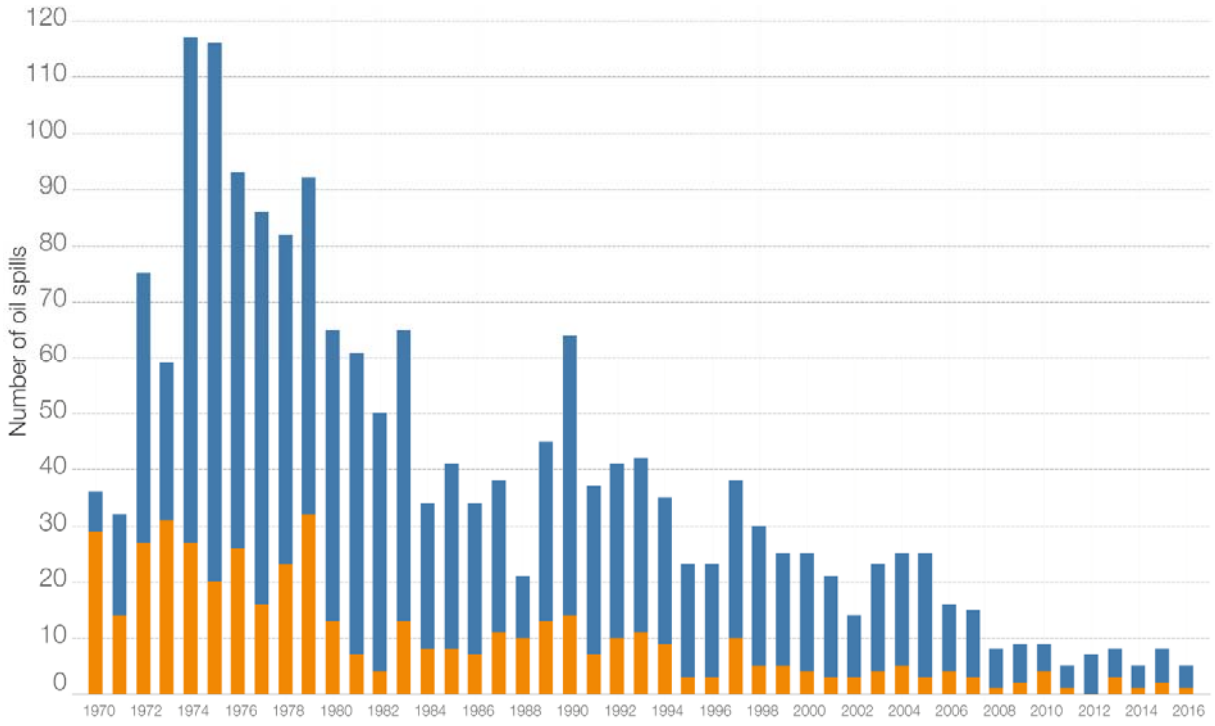

Fig. 6: *The reducing numbers of major tanker oil pollution incidents from 1970 to 2016 (7-700 tonnes in blue, >700 tonnes in orange)*
Source: *International Tanker Owners Pollution Federation (ITOPF) for the number of oil spills, UNCTAD for data*

Oil Spill Incident	**Volume (metric tonnes)**	**Cost Implication (dollars)**	**Year**
Prestige	60,000	1.8 billion	2002
Exxon Valdez	37,000	7 billion	1989
Deepwater Horizon	627,000	65 billion	2010

Table 15: *Three major oil spill incidents in recent history and their statistics*
Source: *International Tanker Owners Pollution Federation (ITOPF, 2019)*

3.3.2 Ship Emissions: Ocean Acidification and Climate Change

Results of my findings on ship emission, ocean acidification and climate change are represented in Figures 7 and 8. This highlights the different emission figures from selected regions and current Sulphur limits and future targets.

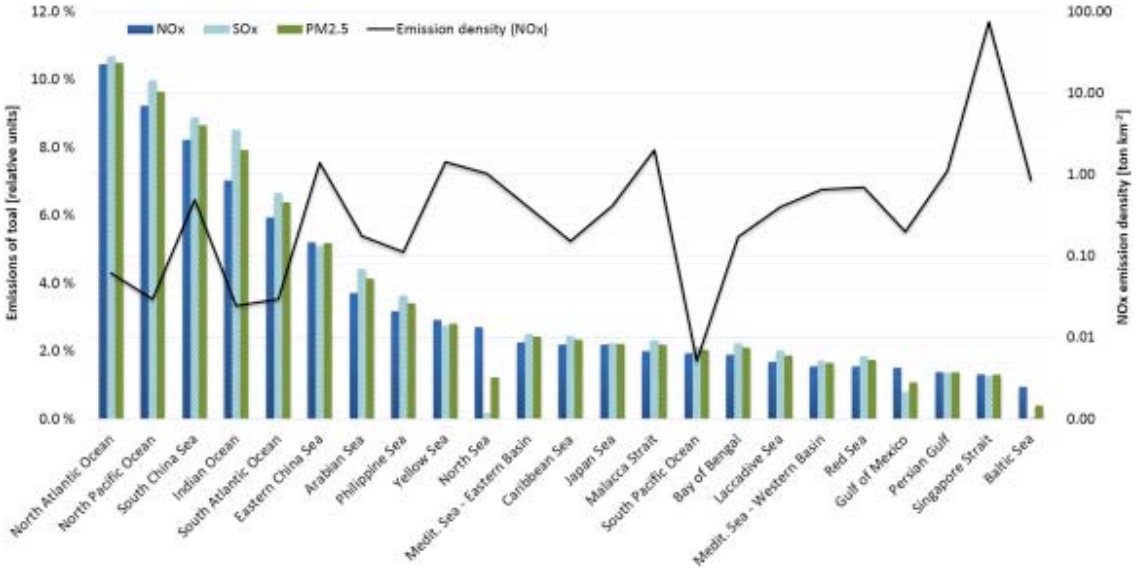

Fig. 7: *Ship emission figures according to regions*
Source: *Global Assessment of Shipping Emissions in 2015 on a High Spatial and Temporal Resolution*

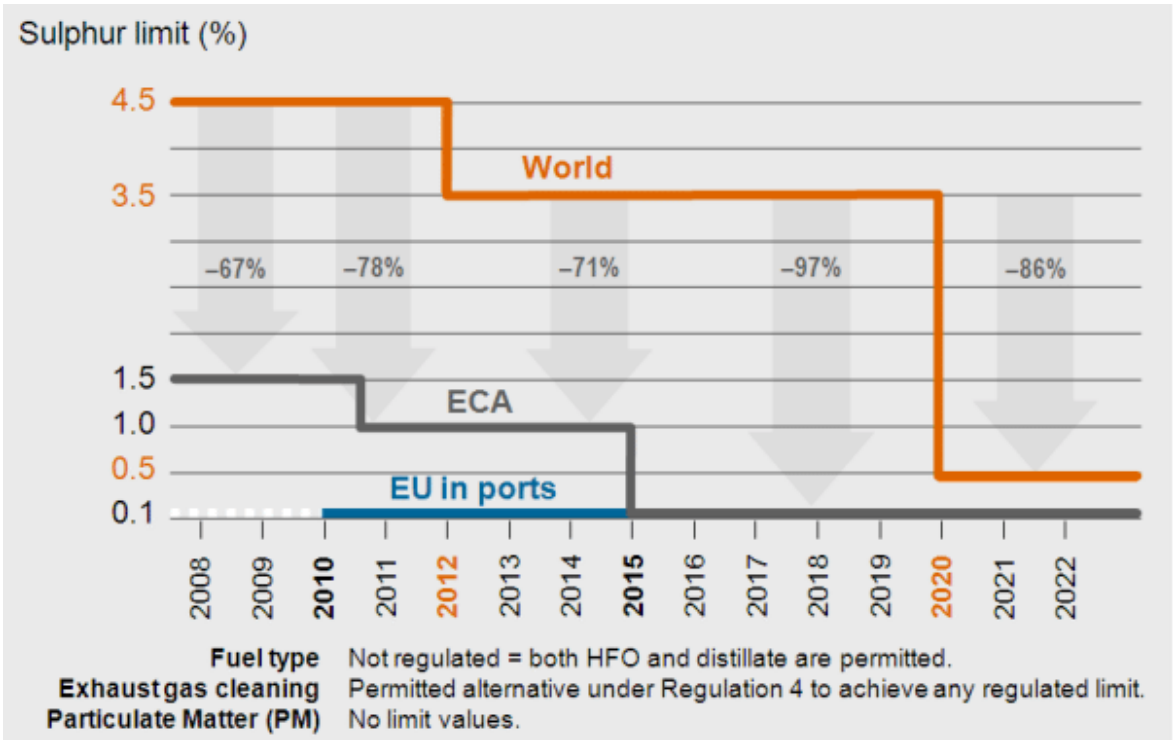

Fig. 8: *IMO Sulfur limits for years 2008 to 2020 (% mass)*
Source: *imo.org*

The emission limits from ships started at 4.5% in 2008, currently, it is at 3.5% globally, 1.5% in the ECAs and 0.1% in the EU ports (fig. 9). The target is a global reduction to 0.5% by 2020 (IMO, 2019). Currently, there are only two effective options for ships to meet these emission limits;

switching to the more expensive low sulfur content fuels or use of abatement technology which removes sulfur from the exhaust scrubber systems which is sometimes disposed into sea water due to its high buffering capacity (Lindstad et al. 2017, Ammar & Sheddiek, 2017, Yang et al. 2018)

3.3.3 Underwater Noise

Results from the research carried out on underwater noise pollution and its effects on marine life focuses on the sources of underwater noise (Figure 9), the reaction of different classes of marine animals based on noise frequency and their hearing range (Figure 10) and evaluation of the impact of anthropogenic noise on marine ecosystem.

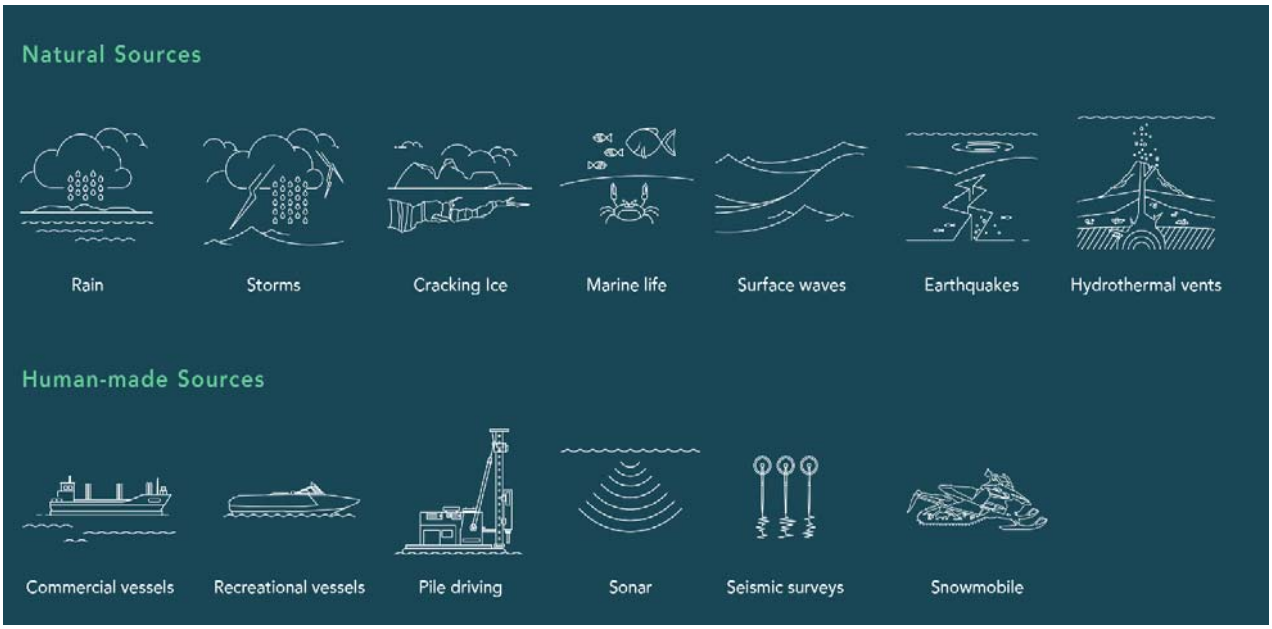

Figure 9: *Primary sources of underwater noise (man-made and natural)*
Source: https://clearseas.org/en/underwater-noise/

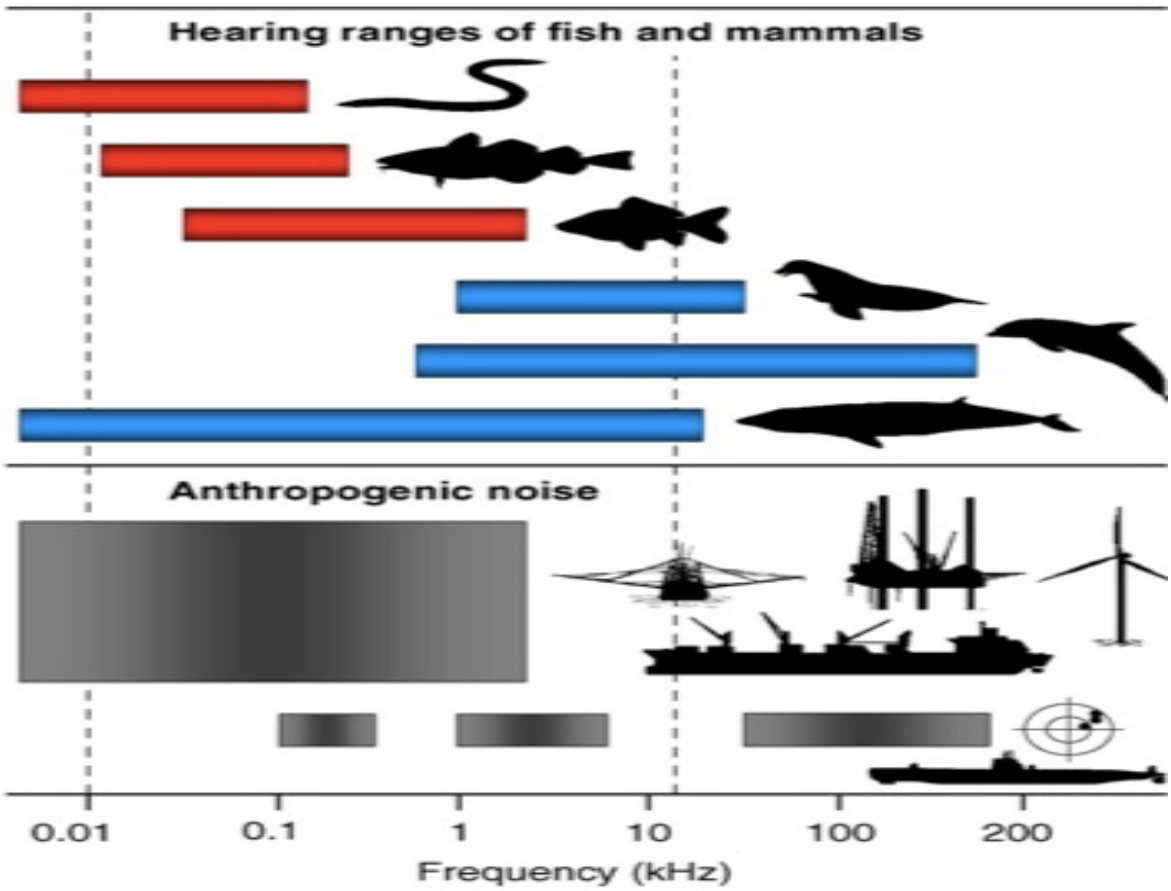

Table 10: *Hearing ranges of marine animals and frequency of some anthropogenic noise*
Source: https://www.wired.com/2010/06/fish-and-noise/

Williams et al. (2014) described six metrics for evaluating the impact of anthropogenic noise on marine life:

1. The duration of recovery by marine animals after exposure using European eel *(Anguilla anguilla)*.

2. Effect of ship noise on behavior and physiology using shore crab (*Carcinus maenas*).

3. Noise exposure from shipping in the strait of Georgia, British Columbia, Canada.

4. Analysis of vessel movement and spatiotemporal data analysis.

5. Critical whale habitats and chronic ocean noise and

6. Promoting management solutions to underwater noise by engaging diverse audiences.

This was complemented with bibliometric analysis of noise pollution literature using ISI Web of Science database, where 685 records and 576 papers returned from the search of 11 keywords,

within a search period spanning 1900 to 2010. Journal records matching the keywords did not begin to appear until the 1940s.

3.3.4 Invasive Species

Database: A database of about 1000 invasive species have been documented in European Seas alone, out of this, a project called DAISIE (Delivering Alien Invasive Species Inventories For Europe) listed the top 100 most impacting species, two examples are the Chinese mitten crab *(Eriocheir Sinensis)* and the box jellyfish *(Mnemiopsis Leidyi).*

Economic Losses: An IMO's corporative initiative, The Globallast programme (2004), established that the economic losses incurred from the impact of invasive species traverses different industries such as impact on recreational areas and tourism, physical impact on coastal infrastructure, reduction of fisheries and loss of income to the shipping industry, as evident in their dispersal method (Figure 11). The monetary cost has been estimated at over $100 billion annually, this excludes cost of response, monitoring, enforcement and treatment technologies.

Regulation: The UN in addressing this challenge, adopted the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM) in 2004, which entered into force in 2017, with the aim of establishing standards and procedures for the management and control of ship's ballast water and sediments (IMO, 2017).

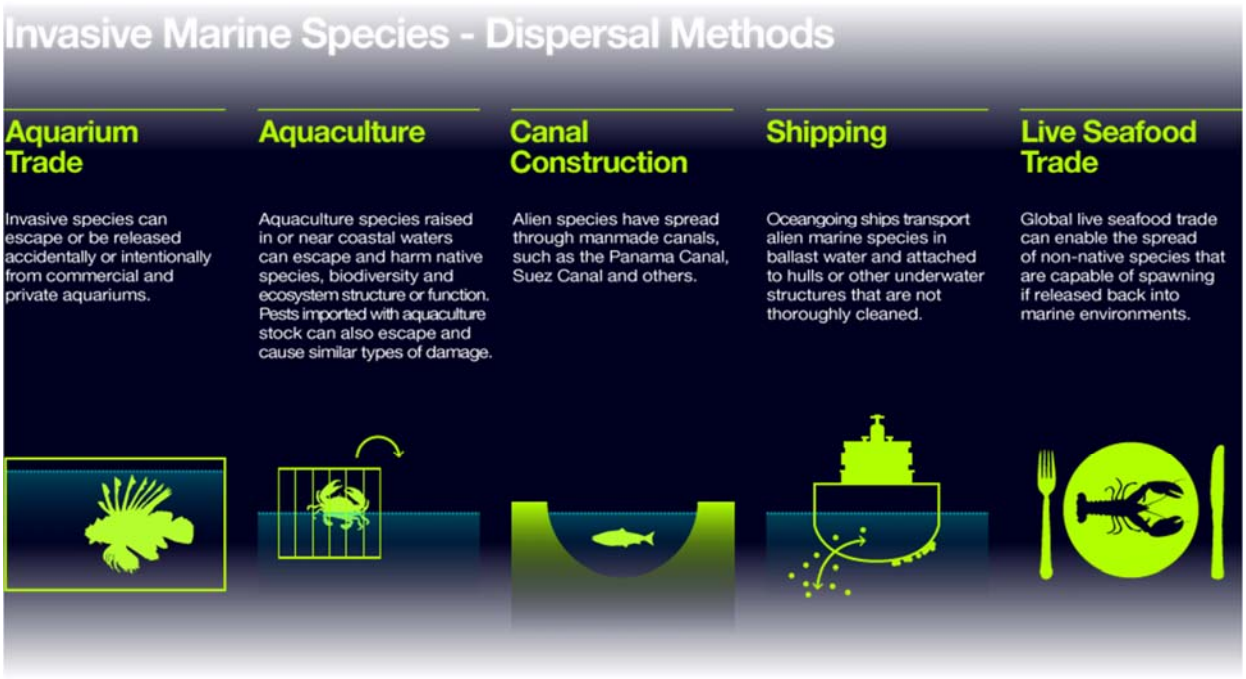

Fig. 11: *Invasive Species Dispersal Methods*
Source: *Ocean Health Index: Alien Species (oceanhealthindex.org)*

4.0 DISCUSSION

4.1 Discussion and analysis of interview themes on environmental monitoring

4.1.1 Use of Environmental Monitoring Data

The participants placed a lot of emphasis on the use of data as evident from the results presented in Table 13 and Figure 5, where it shows that a total of 14 out of 15 participants discussed monitoring data 51 times. A review of the information provided on environmental monitoring data highlights a number of primary uses which includes:

- Policy making
- Academic research
- Fish stock management
- Biodiversity monitoring
- Commercial purposes
- Sharing with other organizations

Referring to the results presented in Table 5, it is evident from the discussions with the participants that, regardless what the primary application of the data is, the final objective is to improve the quality of decision-making for the preservation and protection of the marine environment and ecosystem resources from unsustainable exploitation through anthropogenic activities (Nilssen et al. 2015). This is eventually achieved through any of the uses of data listed above.

Additionally, repeated emphasis by the participants on investments of vast amounts of resources, technologies and manpower in the collection of data indicates its importance in policy formulation, predicting environmental trends, environmental management and planning, also in academic research and embarking on business projects, in and around the seaport and the coasts.

4.1.2 Environmental Threats in Ports and Coastal Environments

The questions relating to threats introduced into the marine environment in the seaport and coastal areas were presented as current threats and future threats. Analyzing this diverse list of environmental threats provided by the participants, a few threats appeared to be of more concern to them as shown in the ranking list presented in the results in Table 11, where micro and nano plastics and genetically modified fish bait were at the top and bottom of the list respectively.

From a regional perspective, many of the threats listed by the European participants appear to be of less concern to some Nigerian based participants (P2, P5, P10, P13, P15) as the latter group focused more on oil pollution, industrial effluents, plastics and noise. This can be attributed to the different nature of port activities in the two regions.

The participants also placed a lot of emphasis on future threats, where most of them admitted that there is no sufficient data to understand the impact of some new threats on the marine environment in the future (Table 6). Examples are: nano & micro particles and pharmaceutical waste (Da Costa, 2016), hence the need for continuous monitoring.

4.1.3 Environmental Monitoring Parameters

Considering the varied nature port and coastal activities in different locations, and the diverse areas of expertise of the participants, their views on the key environmental parameters to be measured in as the best indicators of the health of the ecosystem differ slightly. As shown is Figure 5, 9 out of 15 participants had any idea of the parameters. These are divided into three categories: physical, biological and chemical variables.

The participants cumulatively provided a list of variables in these three categories, while trying to identify those parameters which are relevant to this research and those that best indicate the impact of port and costal activities on the marine ecosystem in Nigeria. As described in the results presented in Table 7, an experienced oceanographer (P3), suggested starting with the basic parameters of CTD (Conductivity – *salinity,* Temperature – *photoresistor* & Depth – *pressure)* which are standard parameters in many monitoring activities due to the simplicity, their generic nature regardless of the type of ecosystem and low cost of measurement (Srbinvoska et al. 2015)

Other parameters are broad and they cover a wide range of ecosystems, some of them are also complex and monitoring them is expensive. Considering the Nigerian ports marine environment, the participants advised that simple and cost effective parameters are sufficient to monitor the effect of threats introduced from port activities. Participant P8 added that environmental data from free satellite monitoring services around Europe such as *Corpenicus* can also be utilized to complement port and costal environment monitoring needs (*Table 7*).

4.1.4 Current and future monitoring technologies

There was a consensus among the participants about the importance of technology in environmental monitoring as it was discussed 43 times as recorded in the results in *Table 13*, but

only 8 of them (P3, P6, P8, P10, P12 and P13) provided substantial information because their areas of specialty and experience is closely related to monitoring technology (*Table 1*). This is an indication of the significance of technology in monitoring.

The interview questions focused on achieving three objectives:

- Overview of current state-of-the-art monitoring technologies.
- Gaps in monitoring technology and improvements expected in the near future.
- Fit-for-purpose monitoring technologies for Nigerian marine environments and other developing regions.

An analysis of the overview of technologies available highlights 15 different technology categories which were discussed by the participants as described in the results in *Section 3.2.4,* covering areas such as:

- Automation and autonomy
- Camera sensing
- Satellite data
- Acoustics
- Miniaturization
- Data processing
- Genomic activities

This shows the level of advancement which already exists in monitoring technology. The participants also noted that these modern technologies have gaps and limitations, these were highlighted in the results in *Table 9.* Examples of such gaps are; automatic species identification from captured images is not yet possible and the manual process is time consuming and expensive (P8), need for cheap and more advanced power technology, high cost of advanced technologies and challenges of fully autonomous monitoring systems (*Table 9*). This is an indication of future trends of monitoring technology.

Considering the technologies fit-for-purpose in Nigeria, four participants; P3, P4, P10 and P12, recommended technological concepts such as IoT (Shah & Mishra, 2016), Integrated monitoring, Citizen Science, marine observation buoys, satellite and miniaturization technologies. An assessment of these suggestions appears to be influenced by factors such as affordability, low cost of maintenance, little or no training required to operate and ease of access to such technology. Additionally, there are limitations to cheaper and less advanced monitoring technologies such as reduced level of autonomy, higher margin of error and overall effectiveness. An example is Citizen

Science in which its application for decision making is limited due to the unreliability of its sources (Martin et al. 2016).

4.1.5 Marine Environmental Regulations

The aim of this study is to establish the existing gaps in implementation of regulations and areas of improvement. Results from the interview shows that environmental monitoring was discussed 22 times by 13 out of 15 participants (*Table 13 & Figure 5*). Though 13 participants out of 15 discussed environmental regulations, there was less emphasis on this subject compared to other subjects. This might be an indication that regulations have less impact on environmental monitoring (Ren, 2018).

Table 10 describes the positions of the participants both on the state of environmental regulations in Nigeria and Europe. For Europe, the regulations appear to be effective but participants P4 and P10 pointed out that some countries in the EU are not as effective as others. P4 cited the example of Malta as a country that appear to have lax enforcement of marine environmental regulations. P10 also noted the slow speed of the implementation of environmental regulations by the EU.

Reviewing the state of environmental regulations in Nigeria, participants remarked that, though there are improvements in recent years, they are not sufficiently effective (*Table 10*). This suggests that there is need for improvement in Nigeria's marine environmental regulations regime. P12 (*Table 10*) suggested better data sharing among African nations, improvement of regional networking and adoption of international best practices as solutions to some the challenges. P13 (*Table 10*) proposed that an improvement in the current state of environmental monitoring will solve some of the challenges of regulations and enforcement in Nigeria.

4.2 Impact of Shipping and Port Activities on Marine Environment

4.2.1 Ship Operational Pollution and Oil Spill

Regardless of the size and staggering cost of large scale accidental oil spills, the cumulative impact of operational oil spill has been found to be larger with even greater impact on the ecosystem according to the International Maritime Organization (IMO, 2019). To support this claim, IFAW (2007) reported that annual total operational oil pollution in the EU, is seven times the total *Exxon Valdez* oil spill in tonnes (Table 15). Environmental monitoring, new regulatory frameworks affecting ship operations, upgraded construction and technology has made major oil spills a rarity, according to Oldham (1998). This is further verified with data from International Tanker Owners Pollution

Federation (ITOPF, 2019) in *Figure 6*. Between 1970 and 2008, major oil spills greater than 700 tonnes have reduced drastically from 25.2 to 3.4 incidents per year.

GESAMP (2001), Etkin (1999) and Etkin et al. (1999) all agreed that operational ship pollution sources should be of greater concern and should be given more monitoring attention than major oil spills. Button (1999) identified anti-fouling agents, ballast water, garbage, grey water, persistent floaters as some of the key sources of ship operational pollution which can be controlled through environmental monitoring. These operational ship pollutants fall under the six annexes of MARPOL 73/78 Convention (IMO, 2019) in Table 14.

4.2.2 Ship Emissions: Ocean Acidification and Climate Change

Emissions from ship exhaust consists of NOx (oxides of Nitrogen), SOx (oxides of Sulfur) and PM (particulate matter), these are contributors to ocean acidifications and climate change as indicated in the results I presented in *Figures 7 & 8,* culled from the literature review.

Considering the impacts of climate change and ocean acidification, ship emission poses a significant threat to the marine ecosystem. Monitoring the oceans and high seas is not practicable due to its vast size. The coasts and seaports which are less challenging to monitor, are the most impacted because the salt content of the waters in these areas are low, since salt has a buffering effect on ship emission (Doney et al. 2007). The vulnerability of coastal areas and seaport environments necessitated the establishment of the ECAs (*Figure 4*) and the emission limits set by the IMO and the EU (*Figure 8*).

Figure 7 is a chart of ship emission per shipping routes, it shows the data of NOx, SOx and PM from the North Atlantic Ocean to the Baltic Sea (high to low). The disparities in the emission levels can be attributed to factors such as use of alternative fuels, installation of exhaust scrubber systems, ECAs and Sulphur limits in force within the region and effectiveness of environmental monitoring. This view is corroborated by Lindstad et al. 2017, Ammar & Sheddiek, 2017 and Yang et al. 2018.

4.2.3 Underwater Noise Pollution

Figure 9 is a result of literature review showing natural and anthropogenic sources of underwater noise. I inferred from this list that natural noise does not constitute pollution as marine animals have acclimatized to natural environmental sounds, but anthropogenic noise interferes with biophysical activities of marine life, though the full impact is an ongoing research (Hawkins & Popper, 2017).

From the results of different noise frequencies depicted in *Figure 10,* I established that the impact on marine life is determined by factors such as the intensity of sound, duration of exposure to noise and the hearing range of the animal (William et al. 2014). For monitoring of anthropogenic noise in the ports, considering these factors will help achieve better outcomes (William et al. 2014).

4.2.4 Invasive Species

Section 3.3.4 summarized the state of invasive species in the European seas through the DAISIE (Delivering Alien Invasive Species Inventories for Europe) project, where it documented 1000 species. Also, I summarized the results of the economic losses by Globallast, an IMO cooperative organization, where invasive species cause about 100 million dollar in annual losses, and the introduction of the Ballast Water Management Convention, adopted in 2004.

Considering the huge economic losses caused by invasive species worldwide and high record reported DIAISE database for Europe alone, this indicates a threat capable of disrupting the natural order of biodiversity of the ecosystem. The impact of invasive species extends beyond the marine environment into other areas as indicated in *Figure 11.*

Monitoring of the invasive species can be done by environmental DNA, but this poses a challenge in some developing countries such as in the ports and coastal environment of Nigeria due to the cost implication.

5.0 RECOMMENDATIONS AND CONCLUSION

5.1 Recommendations

To improve the process of environmental monitoring and marine observation in seaports and coastal environments, I put forward the following recommendations from this research:

1. In designing an environmental monitoring program for the seaport environment and coastal areas, four impacts of shipping and related activities may be considered: i) Oil spill and ship operational pollution, ii) Ship emission: ocean acidification and climate change, iii) Underwater noise and iv) Invasive species.

2. The appropriate environmental parameters to monitored in the marine environment should be determined first, by the three standard parameters for every marine ecosystem (*Section 4.1.3*), the type of threats prevalent in that environment, the cost of monitoring and the availability of technology required.

3. In order to overcome the challenges of manual environmental monitoring, modern technology should be introduced to eliminate human errors, reduce cost of manpower and logistics, increase speed and efficiency of data collection and analysis, and capacity to monitor a wider area.

4. Selection of fit-for-purpose technology should be based on the parameters to be measured, affordability, level of autonomy, accuracy of measurement and cost of maintenance.

5. The approach to EBM and Blue Growth implementation should be preventive rather than curative. Data from environmental monitoring should form the basis for the implementation of these environmental resources management approaches.

5.2 Conclusion

The global impact of international shipping and port activities on the marine environment is a concern to all stakeholders. The growing number of seaports and international shipping fleet and their resultant operations, introduce threats to the ecosystem. These threats range from oil pollution, invasive species, underwater noise, marine litter, toxic emissions and many others (Williams, 2015). The full scope of the effects of these threats on marine ecosystems is an ongoing study (Hawkins

& Popper, 2017). This research attempts to understand this situation by studying the monitoring of marine ecosystems through the review of state-of-the-art technologies and the environmental parameters to be monitored (Gray & Shimshack, 2011), also the review of impact of shipping on the marine environment (Yuan et at. 2016). Data and expert views on these subjects were gathered and discussed to proffer recommendations towards better environmental management.

The methods adopted for this research are: literature review and semi-structured interviews (SSI). The literature review focused on the impact of shipping on ports and costal ecosystems in four areas; 1. Oil pollution & ship operational pollution, 2. Ship emission: ocean acidification & climate change, 3. Noise pollution and 4. Invasive species. For the SSI, 15 interviews (13 interviews & 3 questionnaires) were conducted, these focused on understanding the parameters to be measured and the monitoring technologies adopted for port and coastal ecosystems.

The scope of this research is global but materials and data were gathered from Europe (Denmark, Sweden, Italy and Belgium) and Nigeria. For Nigeria, two ports were used as case study; Lagos Port Complex and Tin Can Island Port Complex. The recommendations and conclusions from this research can be applied globally but primarily focused on solving the environmental monitoring challenges experienced in the Nigerian maritime industry (Chete, 2014).

The following conclusions can be drawn from the discussions and analysis of data gathered from this research:

- The impacts of shipping and port operations on the marine environment is dependent on the nature of activities in the port, the volume of shipping traffic and the effectiveness of environmental regulations.
- Long term effects of some anthropogenic threats introduced into the marine ecosystem is not yet fully understood, continuous monitoring is required to understand these threats.
- The right environmental parameters to be monitored depends on the type of port and costal activities and the nature of threats introduced.
- The use of modern technology for monitoring the marine environment is needed for an effective monitoring process and reliable data.
- Access to state-of-the-art modern monitoring technology is expensive, thus, cost implication is an important factor to consider in identifying the right monitoring technologies fit-for-purpose in a developing country such as Nigeria.

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