UNIVERSITY OF CAPE COAST

ASSESSING THE EFFECTS OF CLIMATIC VARIABILITY AND ANTHROPOGENIC ACTIVITIES ON THE FLAT SARDINELLA (*SARDINELLA MADERENSIS*) FISHERY OF IBEJU-LEKKI, LAGOS

TEMITOPE ADEJOKE ADEWALE

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BY

TEMITOPE ADEJOKE ADEWALE

Thesis Submitted to the Department of Fisheries and Aquatic Sciences of the School of Biological Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy Degree in Fisheries Science

DECEMBER 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree at this University or anywhere else.

Candidate's Signature………………. Date…………..

Name: Temitope Adejoke Adewale

Supervisor's Declaration

We hereby declare that the preparation of this thesis was supervised in accordance with the guidelines on supervision of theses laid down by the University of Cape Coast.

Principal Supervisor's Signature…………………..…… Date………………..

Name: Prof. Denis W. Aheto

Co-Supervisor's Signature…………………………….. Date……………..

Name: Dr Isaac Okyere

ABSTRACT

This study assessed the effects of climatic variability and anthropogenic activities on the *Sardinella maderensis* fishery of Ibeju-Lekki, Lagos, Southwest Nigeria. Fish and water samples were collected from six sampling stations, while primary data were obtained from 360 fishers across 30 fishing stations from October 2020 to August 2022. Genetic analysis of the fish samples revealed that the species had 89.38 - 100% similarity to *Sardinella maderensis* in NCBI. Multiple linear regression shows that variability in climatic indicators such as rainfall, chlorophyll-a, mean sea level, sea surface salinity, and sea surface temperature explained approximately 21.90% of the variance in catch per unit effort ($p < .001$, $R^2 = .22$). Similarly, anthropogenic variables as land use, social amenities, and fishing effort explained approximately 4.62% of the variance in the fish catch ($p < .001$, $R^2 = .05$). Although the condition factor indicated fish is still in relatively good condition, the result revealed a decrease in the average size (SL) of *Sardinella maderensis* (from 32cm to 23.2cm). Water samples indicated heavy metals' levels were above international limits, presence of high total petroleum hydrocarbon (TPH) pollution in all stations (27.56 mg/L- 3985.40 mg/L), TDS levels were higher than acceptable limits (Mean = 24971.1 mg/L) and inadequate chlorophyll-a level (Mean = 0.01 µg/L). The ARIMA model corroborated the results with fluctuating trends in rainfall, temperature, and rising sea levels. It also has a declining chlorophyll-a and fish catch trend. Hence the need for urgent management intervention through coastal management policies and Marine Spatial Planning (MSP) of the *Sardinella maderensis* fishery.

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MSP

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DEDICATION

To my loving Father.

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ACECoR	Africa Centre of Excellence in Coastal Resilience
ADB	African Development Bank
ARIMA	Autoregressive Integrated Moving Average
CECAF	Committee on the East and Central Atlantic Fisheries
CHL_A	Chlorophyll-a
CPUE	Catch per Unit Effort
ECOWAS	Economic Community of West African States
ESA-CCI	European Space Agency - Climate Change Initiative
FAO	Food and Agriculture Organisation
FEPA	Federal Environmental Protection Agency
FGD	Focus Group Discussion
IDI	In-depth Interview
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LFTZ	Lekki Free Trade Zone
LSADA	Lagos State Agricultural Development Authority
RFL	Rainfall
MSL	Mean Sea Level
SDG	Sustainable Development Goal
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
UCC	University of Cape Coast
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency

CHAPTER ONE

INTRODUCTION

The 2030 Agenda for the attainment of Sustainable Development Goal (SDG)14 emphasises the importance of oceans and the sustainable use of marine resources (Lucks et al., 2019; UN, 2022). Achieving the goal however remains challenging as climatic variability and anthropogenic activities impact oceans and areas around the coast (Gissi et al., 2021; Hawkins et al., 2017), invariably affecting fisheries, especially in Nigeria.

Historical climate trends in Nigeria indicate an average of 0.8°C increase in temperature, with a steep rise since 1980 (Abubakar, 2019; Obubu et al., 2021; USAID, 2018). There is also significant precipitation variability, with extreme rainfall events across the country, which may lead to a 0.4–1.0 m sea level rise by 2100 (Shiru et al., 2021; USAID, 2018). In addition, due to population growth, anthropogenic activities have increased along the coastline, resulting in a significant increase in pressures on marine ecosystems and pollution of aquatic habitats, threatening ecosystem services and livelihoods (Bali et al., 2021; Farella et al., 2021; Hiralal et al., 2022; Jones & Rowe, 2017).

Climatic variability and anthropogenic impacts result in functional and structural responses of the water ecosystems and their biota. Marine fish populations are threatened, especially the Sardinella maderensis, which is endemic to coastal areas. Hence, assessing these impacts is crucial for managing the coastal zone's ecology and biodiversity. This study, therefore, applied the ecosystem approach by considering biotic, abiotic, and human components to assess the effects of climatic variability and anthropogenic activities on the *Sardinella maderensis* fishery in Ibeju-Lekki, Lagos.

Background to the Study

Climate change impacts harm natural and human systems, including infrastructure, eroding natural resources, disturbing fish stocks, and endangering species and ecological processes (Kalikoski et al., 2018). African countries, particularly coastal fishing communities, are among the most susceptible to climate change impacts. These impacts include increase in sea surface temperatures, storm surges, changes in salinity conditions, and sea-level rise, aggravated by the over-reliance on natural resources and working mainly in the fisheries and agriculture sectors, which are both impacted by climate (Yanda et al., 2019).

Nigeria's climate has changed, evident in variable rainfall, temperature increase, sea-level rise, flooding, and biodiversity loss (Ebele & Emodi, 2016; Elisha et al., 2017; Olaniyi et al., 2019). In addition, climate change's impact on coastal regions has often resulted in a high frequency of the loss of yields for artisanal fishers due to exceptional dry seasons or upsurge in ocean level (Mohammed et al., 2017).

Similarly, anthropogenic activities have constituted grave impediments to the sustainability of natural resources. For example, the fast development of infrastructures and population increases around the Lagos coastline present many challenges (Omenai & Ayodele, 2014). There is an interrelationship between the rapid population growth in Nigeria's coastal settlements and industrialisation, which has resulted in environmental crises, and its effects have raised significant concern for people's welfare (Bukola et al., 2015; Hiralal et al., 2022). Moreover, as a vital source of livelihood, fisheries resource declines can impact fishers and other shore-based businesses such as wholesales seafood distributors, restaurants, and markets (Gledhill et al., 2015).

As a global resource, fisheries support about 600 million people's livelihoods and supply 214 million tons of fish and 17% of animal protein consumption for the world's population (Blasiak & Wabnitz, 2018; FAO, 2022). Products made from fish and seafood have a high nutritional value due to the healthy protein levels, fats, and vital micronutrients they contain (Sarvenaz & Sabine, 2018). They are high demand products, with a production value of USD 424 billion globally, substantially contributing to Gross Domestic Product (GDP), poverty alleviation and nutritional security (FAO, 2022). In Nigeria, fish is a vital source of protein, and fisheries is a significant sector of the economy, contributing approximately 5.40% of the country's GDP (Adebesin, 2011; Olaoye & Ojebiyi, 2018).

According to USAID (2013), Nigeria's coastal resources, agricultural systems, freshwater ecosystems, and biodiversity are all susceptible to climate change effects. The report shows that Nigeria's high vulnerability to climate change events is due to several factors: its geographical characteristics, limited capacity to adapt, dependence on climate-sensitive resources, teeming population, and high levels of poverty. Moreover, for the artisanal fishers, they have limited capacity to adapt due to low awareness, financial resources, and institutional and technological capability (Olayide et al., 2016).

A country report by FAO (2017a) states that artisanal fisheries dominate fish production in Nigeria, contributing to over 80% of Nigeria's total domestic fish production. This submission corroborates previous reports by the Nigerian National Bureau of Statistics (NBS), which confirms that artisanal fisheries dominated fisheries production in Nigeria between 2005 and 2011 (Table 1), (NBS, 2010, 2012).

Table 1: ***Nigerian Fish Production Per Sector 2005 - 2011 (Metric-tonnes)***

Sector	**2005***	**2006***	**2007**	**2008**	**2009**	**2010**	**2011**
Artisanal							
Sub-Total	490,594	518,537	589,314	654,589	751,006	817,516	859,614
Coastal & Brackish	259,831	269,878	260,099	264,988	288,229	328,332	346,381
Inland	230,768	248,659	244,128	246,394	309,981	288,649	292,105
Fish Farm	56,355	84,533	85,087	143,207	152,796	200,535	221,128
Industrial: Commercial Trawlers							
Sub-Total	32,595	33,778	26,193	29,986	29,698	31,510	33,485
Fish	19,724	19,129	18,040	18,585	18,820	19,261	19,736
Shrimps	10,946	13,767	5,995	9,881	10,878	12,249	13,749
EEZ	1,925	882	2,158	1,520	-	-	-
Distant (Imports)	611,520	646,484	739,666	937,428	946,851	-	-
Total	**1,191,065**	**1,283,332**	**1,355,173**	**1,622,003**	**1,727,555**	**849,026**	**893,099**

Source: (NBS, 2010, 2012).

Although Nigeria has abundant fisheries resources, the country is still mostly protein deficient. As a result, total protein consumption is below the UN/FAO's estimated minimum of 75 gm of daily per capita consumption (Oladimeji, 2017). Moreover, the country can only produce 1.123 million metric-tonnes (Mt.) out of its annual total fish demand of 3.32 million Metric-tonnes (FCWC, 2016).

The Ibeju-Lekki coastline is about 75km of the total 180km of the Lagos State coastline, and contributes the highest percentage of fish caught among other coastal sections. It is a multi-species fishery with a dominance of *Sardinella spp* and *Caranx spp* (Anetekhai et al., 2018; Jim-Saiki et al., 2014; Omenai & Ayodele, 2014).

Sardinella maderensis (Lowe, 1838) is commonly known as Madeiran or flat Sardinella and locally as *Sawa*. It has an elongated body with variable depth, black or blue/green colour and silvery flanks. Size is usually 20-25cm and inhabits the near-surface of coastal waters, shoaling at the surface or bottom down to 50m. It feeds on various small planktonic invertebrates, fish larvae, and phytoplankton. According to Tous et al. (2015), *S. maderensis* is presently found in 43 countries, with Africa dominating the global fish catch. Moreover, using a 10-year average reported in the FAO 2017 Yearbook of Fisheries and Aquaculture (2008-2017), Nigeria is the third-highest contributor with approximately 9% (Table 2) of the total global catches of Madeiran *sardinella* species (FAO, 2019).

In the Ibeju-Lekki community, it is regarded as the most abundant and economically valuable fish species. Jim-Saiki et al. 2014 reported that it accounts for 69% of the fish catch by artisanal fishers in the locality. Despite its significance, "there is a paucity of information on its population parameters and biology in Nigerian water bodies" (Olopade et al., 2019). In addition, knowledge about climatic and anthropogenic impacts on the species in Nigeria is limited. Given the above, there is a need to research what can be done to sustain the *Sardinella* fishery despite climatic and anthropogenic effects.

Table 2: *Global capture of Sardinella maderensis by Country (2008-2017)*

Fishing Area	2008	2009	2010	2011	2012	2013	2014	20l5	2016	2017	10 Year Average	% of Total	Rank
	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)		
Congo	3,946	4,723	4,780	10,552	4,827	3,105	5,108	5,612	875	2,547	4,608	2.66	*5*
Côte D'lvoire	1,000	721	865	500	400	588	3,804	2,000	209	209	1,030	0.6	*8*
Germany	-	-	-	206	-	-	56	56	98	-	42	0.02	*11*
Ghana	15,772	6,269	11,311	10,719	9,287	6,617	4,896	6,031	2,256	4,145	7,730	4.47	*4*
Liberia	-	-	-	-	-	-	-	-	-	30	3	0	*13*
Lithuania	-	-	981	1,946	101	-	81	-	82	51	324	0.19	*9*
Morocco	-	-	45,498	75,643	93,460	81,227	50,872	35,311	8,551	24,319	41,488	23.99	*2*
Netherlands	2,215	3,000	1,813	2,426	267	24	1,144	31	118	-	1,104	0.64	*7*
Nigeria	**14,809**	**14,439**	**14,078**	**13,278**	**13,969**	**14,002**	**13,973**	**15,115**	**5,264**	**24,126**	**15,305**	**8.85**	***3***
Portugal	4	4	1	2	1	2	2	1	-	1	2	0	*14*
Senegal	85,976	93,481	82,951	99,569	128,894	124,516	97,220	93,220	101,026	103,037	100,989	58.4	*1*
Spain	91	127	157	196	93	99	110	39	77	65	105	0.06	*10*
Togo	100	20	3	16	37	49	63	7	20	5	32	0.02	*12*
UK	132	504	713	175	6	-	-	-	-	-	153	0.09	*6*
Total	***124,045***	***123,288***	***163,151***	***215,228***	***251,342***	***230,229***	***177,329***	***157,423***	***128,576***	***158,535***	***172.915***	***100***	

Source: (FAO, 2019)

Statement of the Problem

In Nigeria, the effects of climate change and anthropogenic factors are manifesting themselves more and more often. The ongoing unsustainable management of natural resources has led to a scramble for water, minerals, and other resources. Fish as a natural resource is not left out of the impact, which has been a challenge to quantify adequately. Fish is essential within Nigeria's agriculture sector for its potential contribution to poverty alleviation and improving nutrition and food security (WorldFish, 2018).

However, despite Nigeria's abundant fisheries resources, the country is still essentially a protein-deficient nation. As a result, the total protein consumption is below the UN/FAO'S estimated minimum of 75 gm of daily per capita intake. The Federal Department of Fisheries (FDF) and Food and Agriculture Organisation (FAO) records also show that Nigeria's self-sufficiency ratio in fish production was as high as 98.8% in 1983 but dwindled between 40% and 19.2% in 2005 and 2014 (Oladimeji, 2017). Nigeria presently produces a little above 1 million tons of fish, while over 800,000 metric tons deficit is imported annually (Okeowo et al., 2015; WorldFish, 2018).

Nigeria is particularly susceptible to climate change impacts, which affects the country's natural resource base. In a report by Ashley et al. (2018), it was noted that Nigeria's compound fragility-climate risks of 58 ranks among the highest. The report stated further that fragility scores across countries worldwide in 2014 ranged from 0 to 69. The highest fragility category ranged from 53 to 69, and West African countries ranged from 18 to 58, with Nigeria's score of 58 at the top.

Climate change impacts have ravaged most northern states, gradually turning the entire region into an arid zone or desert. The southern part of the country has to deal with severe coastal and soil erosion. In the coastal areas, sea-level rise due to climate change and rainfall is expected to increase (Haider, 2019). Human settlements and livelihoods are affected by rising unemployment, widespread poverty, overpopulation, and over-dependence on natural resources vulnerable to climate change. Inhabitants of Lagos state coastal communities mainly live in a low-lying coastal environment with a fragile coastal ecosystem vulnerable to a changing climate (Ashley et al., 2018; Omenai & Ayodele, 2014).

The climate change scenario, primarily through carbon dioxide and temperature increase, will continuously warm the earth with consequential effects on aquaculture and fisheries, heightening the vulnerability of Nigeria (Anyanwu et al., 2015; Idowu et al., 2011; Ipinjolu et al., 2013; Mohammed & Uraguchi, 2013; Oluowo, 2017). Furthermore, Sayne (2011) observed that Nigeria could experience severe resource shortages if there is an inadequate response to climatic shift issues. These changes could endanger people's access to essential fisheries-based food supplies and means of subsistence even more, particularly in areas where overfishing is present (Cisneros-Mata et al., 2019).

In addition to climatic effects, anthropogenic activities have also constituted grave impediments to natural resources' sustainability, especially in developing nations like Nigeria. These activities puts both humans and animals in an ecosystem at risk. Rural areas are fast becoming urban and are causes of concern to development experts (Dekolo & Oduwaye, 2011). Marine fish populations are already threatened and pressured by human activities arising from overfishing and pollution, resulting in a decline in fish quantity and quality. Further, due to inefficient and inadequate fishing rules, illegal, unreported and unregulated fishing has negatively impacted fisheries sustainability, leading to major changes in species composition, catch decreases, and depletion (Abiodun, 2021; Chikelu, 2021).

Presently at Ibeju-Lekki, there is an ongoing project for a multi-billion-dollar refinery. When completed, it will be the largest single-line refinery in the world, having a daily processing capacity of 650,000 oil barrels (Edozien, 2018). Significant development of this magnitude covering 2,500 hectares of land and others put artisanal fisheries of *Sardinella maderensis* endemic to coastal areas at risk (Adeshokan, 2019). Furthermore, according to Sossoukpe et al. (2016), most African fisheries "are overexploited and lack management strategies."

Furthermore, existing literature on spatiotemporal dynamics, demographic parameters, and abundance indices of *S. maderensis* have focused on other West African coasts, excluding Nigeria. These include Ivory Coast (Mendelssohn & Philippe, 1989), Cameroon (Gabche & Hockey, 1995), Benin (Sossoukpe et al., 2016), Liberia (Wehye et al., 2017), Ghana (Amponsah et al., 2019). Despite the scientific advice by FAO (2009) on the need for specie-specific research on the estimate of growth, mortality, abundance indices, and environmental interactions of the *Sardinella* species in Nigeria, there is a paucity of research outputs. The need for an in-depth understanding of Nigeria's climate future on better country-specific and local-level analysis is now imperative.

Given the above, there is a need to assess the effects of climate change and anthropogenic factors on artisanal fisheries of *S. maderensis* and propose appropriate management strategies to build resilience and ensure sustainability.

Purpose of the Study

Despite high landings of *S. maderensis* species that have attracted artisanal fishers from local ethnic groups and foreign nationals, there is limited knowledge of the effect of climatic variabilities and anthropogenic factors on the growth, mortality, and abundance indices of the *Sardinella* species on the Lagos coastline. Therefore, the primary goal of the study was to investigate the climatic and anthropogenic effects on the fish species to build the fisheries' resilience and suggest recommendations for sustainable fishing and enhanced livelihoods.

Research Objectives

The objectives of the study were to:

1. identify the *Sardinella species* in the Ibeju-Lekki coastal waters.
2. examine the effects of climatic variabilities on *Sardinella maderensis* abundance.
3. assess the effects of anthropogenic activities on the *Sardinella maderensis* abundance.
4. evaluate the length-weight relationship and condition of *Sardinella maderensis* in the fishery.
5. assess the vulnerabilities of small-scale fishers and explore their strategies for resilience.

Hypotheses

i. H_0: Climatic variabilities do not have significant effect on the abundance of *Sardinella maderensis*.

H_A: Climatic variabilities have significant effect on the abundance of *Sardinella maderensis.*

ii. H_0: Anthropogenic activities do not have significant effect on the abundance of *Sardinella maderensis*.

H_A: Anthropogenic activities have significant effect on the abundance of *Sardinella maderensis.*

Significance of the Study

The results of this study will provide information on the genetics of Sardinella spp in the Ibeju-Lekki stretch of Nigerian coastal waters. It will also contribute to SDG 13 in terms of generating policies for climate action. The study will provide an in-depth understanding of Nigeria's climate from a local-level analysis perspective and contribute to the literature on modelling the effects of climate change and anthropogenic activities on the fishery. The water quality analysis will provide baseline data for the state of water quality of the Ibeju-Lekki coastal water before the commencement of the full operation of the refinery located there.

The species of focus in the study is among the IUCN list of threatened species, and urgent attention needs to be given to avoid stock overexploitation, the results of the study will therefore provide information on its conservation and sustainable use in line with SDG 14. It will also proffer strategies for resilient and sustainable fisheries of the vulnerable species. The holistic approach used in the study would provide robust data for coastal management policies and necessary management interventions for the conservation of *S. maderensis* and ensuring sustainable livelihoods for small-scale fishers in Ibeju-Lekki.

In addition, “the approach undertaken in this study furthers the course of the international agenda, relating to implementing the fourth guiding principle of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries” (FAO, 2015).

Delimitations

This study covered the Ibeju-Lekki community in Lagos, South Western Nigeria. The research focuses on the fishery of the coastal environment, which are locations around a 2km buffer along the coast. The locations selected around the coast included the fishing communities where *Sardinella maderensis* was being caught. Lagoons and landlocked communities in the same geographical area were excluded. In examining the fishery, the fish was taken into consideration. Even though a multi-species fishery could be identified in the study area, the focus was on *Sardinella maderensis* because it has become vulnerable since the coastal region it inhabits is being encroached upon through anthropogenic activities. More so, it is the primary fish caught in the fishery. The environment was also considered in terms of water and land cover. The fishers in the fishing business in the communities are also involved in the study. The fishers involved in fishing *S. maderensis* were the population of the study, fishers whose catch did not include the species were excluded.

Limitations

The research was carried out during the COVID pandemic, and some precautions were taken in the research investigation. Hence, the COVID protocols were observed. During the pilot survey, security unrest in the locality delayed the task for some time. Getting responses from the fishers was challenging because of their uncooperative attitude. Some complained that other researchers had been coming to interview them and that no benefit had come to them through research. Some of the fishers insisted on getting incentives before they could answer questions due to research fatigue. Accessibility was a peculiar challenge in some locations, and vehicles could not reach some communities because there were no access roads. Accessing local satellite data from the bulk world data was difficult. In addition, getting local catch data was arduous due to the non-availability of data. The irregularity in data collection and the crude methods used in storing historical data made some data unavailable, while the available ones were not easily accessible.

Definition of Terms

Climate Change: refers to variations in average weather that persist for extended periods, typically decades or more.

Climatic variability: are climatic fluctuations that persist longer than specific weather events.

Anthropogenic: originating from human activity

Anthropogenic activities: activities of people, especially those that cause pollution of the environment.

Fishery: a place or area where people go fishing or engage in the business of catching fish.

Fishers: Individuals involved in fishing or whose work is catching fish as a source of livelihood

Sardinella maderensis: is a fish species of the genus Sardinella in the family Clupeidae found in the Atlantic, Indian and Pacific Oceans. They are abundant in warmer tropical waters.

Vulnerability: Vulnerability is being susceptible to the impacts of hazards or disasters.

Livelihoods: This is a means of support or subsistence. Livelihood is the job or source of income that gives the money to buy the things needed.

Organisation of the Study

This thesis contains six chapters. Chapter One comprises the introduction, the study's background, a problem statement, and the study's objectives. The chapter also presents the significance of the study, delimitation, limitations, and definition of some terminologies. Chapter Two discusses a review of literature relevant to the study. Chapter Three describes the methods used in the study, ranging from the research design, description of the study area, sampling procedure used, the research instrument applied to the data collection and analytical techniques. Chapter Four elaborates on the results derived from data analysis. Chapter Five discusses the results from the findings, and Chapter Six provides some conclusions based on the research, areas for further study and recommendations.

CHAPTER TWO

LITERATURE REVIEW

This literature review focuses on the world fisheries, the background of fisheries in Nigeria and the study area, the climatic phenomenon and its effect on fisheries. The various anthropogenic issues in the study area are discussed. The combined impacts of the above variables on fish regarding the relationship between length and weight and condition factor of the fish are evaluated and strategies for small-scale fisheries described.

Global Fisheries

Aquatic foods comprise roughly 17% of all animal protein consumed worldwide, with some Asian and African nations seeing percentages as high as 50%, further, in the primary sector alone about 58.5 million folks are reportedly employed, with females making up about 21% of the workforce (FAO, 2022). Moreover, in recent decades, the demand for seafood has significantly increased globally, putting further pressure on the oceans (Jouffray et al., 2020). The need for more exploitation has led to overfishing, pollution, and other issues, making fishery resources to decline. This decline has therefore brought the need for management interventions. However, fishery management is inherently complex because they are influenced by the ecological, economic, and social environments in which they are located (Farella et al., 2021). As these issues occur at the global scale, it extends to the national and local levels, exhibiting higher effects and more complexity especially in developing nations like Nigeria.

Nigerian Fisheries

Fish and fish products are essential sources of nourishment for the teeming 200 million population in the nation. Those who depend on coastal fishing for sustenance and livelihoods will continue to increase as the population grows. Fish intake in Nigerian households is low, with 13.3 kilograms per person per year, compared to the global average of 20.3 kg (FAO, 2018). Increased fish supply may alleviate the nation's food and nutrition insecurity (Bradley et al., 2020).

Although Nigeria is one of the countries most reliant on coastal ecosystems for fish production (Selig et al., 2018), harnessing the resource through the artisanal and industrial sectors, yet the nation's domestic demand for fish has not been met. According to the FCWC (2021) , Nigeria is said to be the largest fish producer in the ECOWAS region, but still imports fish primarily to meet up with the deficit. Notably, Nigeria's main source of fish is small-scale capture fishing (Igoni-Egweke, 2018), accounting for over 90% of fish caught between 1971-1984 (FAO, 1986). The fishing industry provides not only food and nutrition but also a means of livelihood for many Nigerians in the coastal, lake, and riverine areas; people make their living from fish processing, marketing, and fisheries research (Soyinka & Kusemiju, 2007).

Ibeju-Lekki Fishery

Ibeju-Lekki, a municipality in Lagos State is made up of a group of about 80 communities that are coastal, lagoon, and landlocked. The name Ibeju-Lekki is a merge of two autonomous settlements, Ibeju and Lekki. The local government was created in 1990, with the capital being Igando Oloja. Eti-Osa and Epe local governments form its western and eastern borders, respectively, Ogun state frames it in the north while the Atlantic Ocean bounds its southern end. It covers about 75km in length and about 25km at its widest point (Adeosun, 2017; Omenai & Ayodele, 2014).

The fishers engage in the small-scale fishery using Ghanaian dugout canoes, paddled canoes, and motorised planked boats. The outboard engines have various capacities, ranging from 20 to 55Hp but the most frequently used is the 40hp of either Yamaha or Suzuki brand. They use different fishing gears specific to the fish they catch. The gears include bottom or surface gill nets, encircling or drifting nets, beach seine nets and cast nets (Udolisa & Solarin, 1979).

The fisheries resource makes up a significant source of livelihood for a large number of community residents. Mostly caught species include bonga, sardines, shad, barracuda, and mackerel, while the most commercially important species are sardines, bonga, croakers, shad, catfish, and sole. Clupeids (sardines, shads, herrings, hilsa and menhadens) are the most abundant species, followed by mullets, tilapias, and croakers (Adeosun, 2017).

Males dominate the fish capturing (Figure 1) and do not allow the women to go fishing with them. Women and children however are not entirely left out as they are involved immediately after the fish is landed (Figure 2) and through various postharvest processes of sorting, grading, processing, and marketing. Therefore, Okeowo et al. (2015) reported that women's contribution should not be undermined.

Figure 1: Fishers at Ibeju Lekki Coastal Water (Source: Field Survey, 2021)

Figure 2: Women and Children Sorting fish at Ibeju Lekki Coastal Water (Source: Field Survey, 2021)

Fishers are involved in fishing activities throughout the year except specific periods when the sea level is high and the water turbulent. Although fishing activities are done all through the year, the availability of fish is seasonal, with a peak in the dry season when the sea is warm and calm (Jim-Saiki & Ogunbadejo, 2004). Along the beaches of Ibeju-Lekki coastal communities are regions made up of mainly mangrove and coconut trees.

Climate Change Effect on Fisheries

Climate change is impacting ecosystems worldwide (Störmer, 2011), and coastal regions show peculiar sensitivity to environmental changes (Schernewski et al., 2008; Störmer, 2011) and the agitations about the consequences of climate change impact on fisheries are escalating (Brander, 2010). Tropical climatic regions are mainly characterised by seasonal climatic variations, significantly affecting living organisms (Azongo et al., 2012). Around 3 billion people cannot afford good food, and despite efforts to combat malnutrition and hunger in all of its forms, 811 million people still go hungry due to changing climate and its consequences which have been recently aggravated by the COVID-19 epidemic (FAO, 2022). The weather pattern has been changing, making predicting or forecasting future atmospheric events gdifficult. Changes in major environmental elements as a result of climate change could result in further challenges for the coastal ecosystem (Störmer, 2011).

Climate change, directly and indirectly, impacts fish stocks, coastal regions and ecosystems worldwide, showing peculiar sensitivity to environmental changes (Schernewski et al., 2008; Störmer, 2011), leading to heightened concerns over the consequences of climate change on fisheries

(Brander, 2010). Tropical climatic regions are mainly characterised by seasonal climatic variations (Azongo et al., 2012), which significantly affect living. The changing weather pattern has made it difficult to predict or forecast future atmospheric events. Furthermore, changes in major environmental indicators due to climate change have resulted in further challenges for the coastal ecosystem (Störmer, 2011). In addition, due to the combined influence of physical-chemical processes in the atmosphere adjacent to the land and coastal seas, coastal waterbodies are among those most impacted by the continuing changes in climate (IPCC, 2014b; Melet et al., 2016; Pesce et al., 2018; Poloczanska et al., 2016).

Furthermore, there are growing concerns about climate extremes (Michalak, 2016) because of the rising greenhouse gas emissions to the atmosphere, which has led to substantial global warming. Despite significant efforts to reduce the emissions, the likelihood that the climate will continue to change over the next several hundred years is high (IPCC, 2014a), and species' responses will typically have unanticipated effects (Pecl et al., 2017). The responses will be to adapt to the condition or migrate to other places with better conditions (Berg et al., 2010). However, because all species have limits to their capacity for adaptive response to changing environmental conditions (Williams et al., 2008), some might not cope and finally go into extinction (Drinkwater et al., 2010). This issue of extinction has been discussed and debated with a predicted increase in the 21st century (Maclean & Wilson, 2011; Malcolm et al., 2006; Pereira, 2013; Urban, 2015).

Additionally, the IPCC's Fifth Assessment Report (AR5) (IPCC, 2014b) predicts that global sea level rises will be between 75 and 98 cm above current levels by 2100 (Church et al., 2013). The average warming since 1880 has been 0.85^{o}C. However, there are predictions from the Paris Conference of Parties 21 that we will have more than double this amount in the future (IPCC, 2014a). As a result, a global atmospheric temperature increase of 2^{o}C is predicted to reduce precipitation (Cramer et al., 2018).

Due to the combined consequences of changing land use, poor water quality, and decreased biodiversity, there are now more environmental difficulties as a consequence of climate change (Cramer et al., 2018). Climatic variabilities affect the natural and societal systems in Sub-Saharan in different forms. The region is expected to warm, according to climate change forecasts, and by 2050, summer temperatures will rise by roughly 1.5 ^{o}C, though the warming is less pronounced than it is globally. Under a 4 ^{o}C warming scenario and a 30-70% increase in precipitation, the region might also suffer up to one meter of sea-level rise by the end of this century (Serdeczny et al., 2016). They further stated that the projection of local sea level rise in Sub-Saharan coastlines is expected to be 10% higher than the worldwide average. For example, in their forecasts for 2081 - 2100, sea level rise in Lagos, Nigeria, would be between 0,4m and 1.15m with an average rise of 0.65m when it is 4 ^{o}C global and 0.2 - 0.7m with a median rise of 0.4m when it is 2 ^{o}C.

Globally, aquatic ecosystems respond sensitively to climate change effects change (Cheung et al., 2018). In addition, coastal regions are susceptible to environmental changes (Störmer, 2011). As a result, there is agreement on the need to approach environmental issues from various angles, especially in light of the consequences of climate change on coastal regions, which are characterised by the dynamics and interconnections of socio-economic and biogeophysical phenoms (Iyalomhe et al., 2013).

Resulting risks due to environmental changes include a decrease in catches leading to a reduction in livelihood outcomes for the fishing populations and a decline in prominent protein sources (Badjeck et al., 2010). Forecasts suggest negative changes in the maximum capture potential for the western African coast, where fish can make up as much as 50% of the animal protein ingested (Lam et al., 2012). Hinkel et al. (2011) reported that Nigeria and Mozambique are projected to be the most affected in Sub-Saharan Africa regarding the absolute population impacted by rising sea-level. In Nigeria, about a 2.5million more people would be flooded annually than in a scenario without sea-level rise.

Concern over how global warming may affect the livelihoods and food security of the 36 million fishers worldwide, and the approximately 1.5 billion people who consume fish as more than 20% of their animal protein is growing (Badjeck et al., 2009). Freshwater and marine habitats, as well as their resident fish stocks, may experience significant biological and ecological changes as a result of changes in water temperature, precipitation, wave action, and sea level rise (Brander, 2010; Cheung et al., 2009; Drinkwater et al., 2010). A direct result of this is that it affects people who depend on those ecosystems for their livelihoods. According to Poloczanska et al. (2016), it is vital to understand how climatic variability interacts with other stresses to influence how organisms and the ecosystem react to long-term climate variability. This understanding will help to be able to predict climate change's ecological, social, and economic consequences at regional scales

Sardinella Fishery

In Africa, Sardinella species are some of the most numerous small pelagic species, with catches of more than 2 million tonnes per year. They are coastal small pelagic fishes tolerant to low salinities and move in schools (AU-IBAR, 2019; Brainerd, 1991). They prefer clear waters with temperatures below 24^{o}C and dwelling habitat near the surface or down to 50m depth. They are highly migratory and feed on various planktonic invertebrates, phytoplankton and fish larvae. The taxonomy of *S. maderensis* is illustrated in Figure 3, its size reaches up to 30cm standard length, but the usual size is 25cm. Its common name is madeiran or flat sardinella while its local name in Ibeju-Lekki is 'Sawa'. It is a small ray-finned fish with an elongated body with variable depth; black, blue/green flanks silvery with a faint golden mid-lateral line. They are hard to differentiate from *S. aurita*; however, they can be distinguished by having grey caudal fins with black tips and seven rays on their pelvic fins (8 in *S. aurita*).

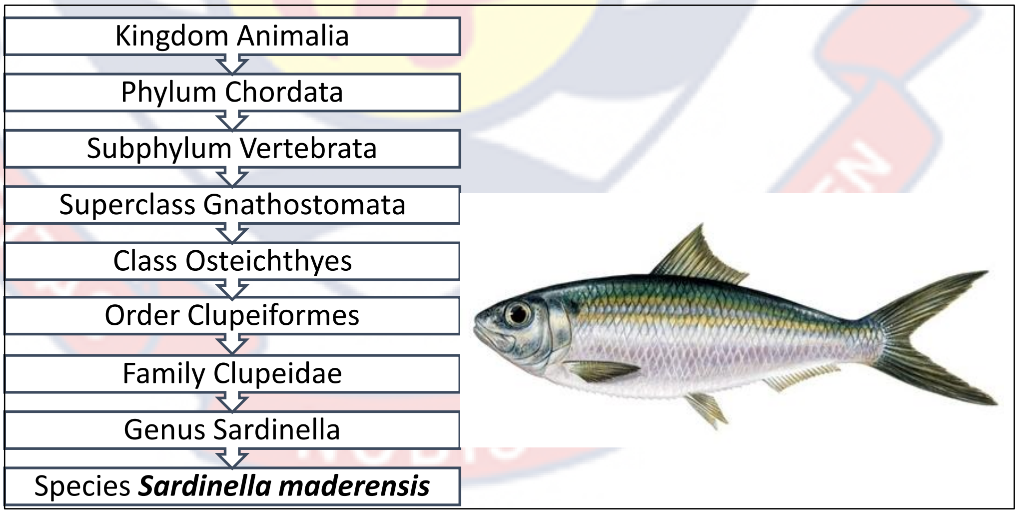

Figure 3: Taxonomy of *Sardinella maderensis* (Adapted from Froese & Pauly, 2022)

According to FAO (1985), *S. maderensis* has an elongated body with varying depth, a fairly strongly keeled abdomen, total scutes of 31 to 34, and lower gill rakers of 70 to 166 (in fishes, 6 cm standard length or more). The membrane between the upper pectoral fin rays is black, while the outer side is white. It is similar to *S. aurita*, but lacks the black patch on the back of the gill cover (pale gold or black area just behind the gill opening) and with pelvic fin rays that are seven as opposed to eight in *S. aurita*.

It differs from *S. rouxi* by having more lower gill rakers (compared to just 30 to 40 in *S. rouxi*) and a grey caudal fin (FAO, 1985), with tips that are nearly black (yellow in *S. rouxi*). It inhabits coastal surface waters and can tolerate estuaries' low salinities, shoaling at the surface or bottom to 50m. It is distinctly elongated, with varying protruding bellies. It is abundant in areas with upwelling. Its conservation status has been rated as vulnerable by the IUCN (Tous et al., 2015).

According to Brainerd (1991), it continuously reproduces throughout the year, however, the hot season in Cote d'Ivoire (November to March), Senegal (around October), and the cold season in the Congo are periods it reproduces the most. The juveniles are frequently congregated in coastal waters, but as they get older, they move. Although their movements according to age are not as clear cut as in the situation with *S.aurita*. The shallow portion of the continental shelf continues to be home to the vast majority of adult *S. maderensis*. Compared to the *S.aurita*, the adult *S. maderensis* are more sedentary and remains restricted over the continental shelf's shallow half. The *S. maderensis* is most prevalent in the two locations north and south of the Gulf of Guinea, from Cote d'Ivoire to Nigeria, where several small populations are very important, particularly to small-scale fisheries. *S. maderensis* is typically caught in Nigeria by small-scale fishermen using monofilament gillnets, cast nets and beach seine nets, similar to what obtains in Ghana (Arizi et al., 2022; Jim-Saiki & Ogunbadejo, 2004).

A significant challenge for the Sardinella fishery is that a reliable regional assessment of the level of its exploitation is scarce. The CECAF region is home to two distinct Sardinella species, *Sardinella maderensis*, the flat sardinella and *Sardinella aurita*, the round sardinella (Brainerd, 1991). However, it has been challenging to estimate the overall biomass for the two Sardinella species accurately, due to the species mix in the CECAF region and the difficulty of collecting small pelagic species like Sardinella with the equipment employed for trawl surveys. It is mainly caught by small-scale fishermen who do not usually take records of their catches and are secretive about declaring the actual output of their catch.

Sardinella is among the world's most used fish in the canning industry (Froese & Pauly, 2022). It is present in thirty-nine (39) countries of the world (Figure 4), with dominance in twenty-nine (29) African countries' salt and brackish water (Froese & Pauly, 2022). Moreover, its exploitation provides many jobs in African countries through operations such as capture fisheries, fish processing and trade activities. For instance, in Senegal, more than 100,000 jobs are dominated by the female workforce, especially in smoking and marketing, and are provided by the small pelagic fisheries subsector (AU-IBAR, 2019).

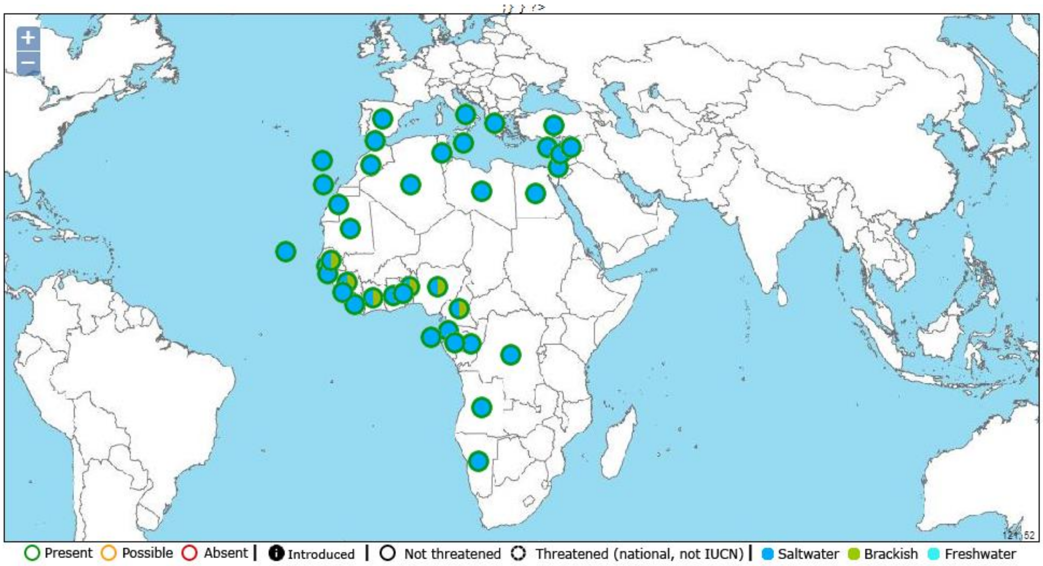

Figure 4: Distribution of *Sardinella maderensis* (Froese & Pauly, 2022)

Furthermore, small pelagic contribute 86% (FAO, 2012) of the landings with *Sardinella maderensis* and *Sardinella aurita* being the two most targeted species (Diankha et al., 2017). No coastal state can assert dominance over any stock because sardinella stocks migrate across international borders. As a result, nobody is interested in preserving the sustainability of this common property resource in the absence of any legally binding regulatory measures amongst the states that share these assets. Moreover, there are noticeable annual variations in the quantity of the stocks due to environmental and biological factors (Brainerd, 1991).

Climate Variability Impact on Sardinella Fishery

Climate and weather dynamics significantly affect fisheries activities and fish population variability. Climate variability affects the distribution, migration and abundance of fish, and fishing is directly affected by the prevailing weather conditions (Lehodey et al., 2006). Variations in climatic factors such as rainfall, temperature, sea level and primary productivity cause fluctuations in fish stocks. Abdellaoui et al. (2017) also stated that environmental conditions play an essential role in marine fishes, especially small pelagics. Some authors have also written on the specific impact on fishing abundance (Macias et al., 2013; Puspasari et al., 2019), while some have talked about how it affects species' spread by regulation the maturation, spawning conditions and eggs/larvae dispersal (Falcini et al., 2015; Palatella et al., 2014; Sabatés et al., 2007; Xu et al., 2015).

Climatic variables also depend on one another; for instance, chlorophyll-a biomass, sea salinity, and mean sea level depend on rainfall. Inadequate rainfall can reduce chlorophyll-a biomass; high rain can increase the sea level and reduce the sea salinity. The changes cause substantial fluctuations in sardine abundance. From their studies on sardine fisheries in Bali, Indonesia, Puspasari et al. (2019) reported that the sardine fishery is influenced by fishing effort and environmental factors such as temperature and chlorophyll. An increase in sea surface temperatures leads to more water vapour in the atmosphere over the oceans, which produces precipitation, increasing the risk of heavy rain and rising sea water levels. Fluctuations in oil sardine (*Sardinella longiceps)* were also reported to be influenced by sea level, rainfall and solar periodicity by Jayaprakash (2002). His findings showed that rain positively affected the fish abundance and that the abundance was also down when rainfall was low.

Compared with *S. aurita*, *S. maderensis* is less sensitive to climatic fluctuations because it can tolerate more environmental changes (Ba et al., 2016). Its lesser sensitivity does not mean that it is not affected by the variability, but the *S. maderensis* can persist when there are unfavourable conditions. There have been various studies on the effect of environmental conditions and climatic variability on the small pelagics in Senegal and Ghana (Asiedu et al., 2021; Diankha et al., 2017; Neokye et al., 2021; Thiaw et al.,

2017) and sardine in South Alboran (Abdellaoui et al., 2017) but there's paucity of research on the effects of climatic variability on *S. maderensis* in Nigeria.

In this study therefore, the effect of the following five climatic variables classified as essential climate variables by the Global Climate Observing System (https://gcos.wmo.int/en/essential-climate-variables/table) and cited by the following authors - Chune et al. (2020); Lamouroux et al. (2019); Perruche et al. (2019) and Varona et al. (2022) were examined.

Sea surface temperature (SST)

Sea Surface Temperature (SST) is an essential climate variable and is the most prolonged and most measured variable in the ocean (Emery, 2015). SST can be refered to as the water temperature close to the sea surface. It varies with latitude, usually coldest in the Arctic and Antarctic regions and warmest near the equator. Sea temperature affects fish productivity, species migration, and the biodiversity of coastal areas. It is a strong indicator of productivity, pollution and climate change (Fingas, 2018). Its traditional mode of measurement is by putting a mercury-in-glass thermometer in water. However, thermal infrared bands from optical satellite data are also used for global measurements (Fingas, 2018). These data were obtained for the study area.

Sea level rise (SLR)

Sea Level Rise (SLR) is also a crucial climate change indicator measured due to its high sensitivity and variability. Sea-level rises due to global warming, leading to coastal erosion, flooding, and loss of breeding habitat, invariably resulting in a lower fish yield and a threat to livelihoods (Daw et al., 2009). The ESA-CCI's portal provides Altimetry-based data for the entire globe from January 1993. The Global Mean Sea Level (GMSL) has provided data continuously for sea-level studies. This data was obtained for this study.

Rainfall (R)

Rainfall data is an essential climate variable affecting fish abundance's seasonal variation. It is referred to as liquid precipitation falling from the sky, usually measured by the depth in inches. Rainfall can increase the productivity of coastal fisheries through nutrient exportation, generating new production in coastal waters (Hoguane et al., 2012).

Primary productivity (PP)

Phytoplankton plays a vital role in understanding the effect of climatic change on the availability of marine food (Dutkiewicz et al., 2019). It is measured in terms of chlorophyll-a concentration, a good indicator of food availability (Lanz et al., 2009). Chl-a, the main kind of chlorophyll used in photosynthesis, has generated much interest in environmental research thanks to satellite measurements of its concentrations (Fingas, 2018). Chl-a is a concentration that depicts the available stock of phytoplanktons. Therefore, the higher the concentration, the more productive the feeding would be for a plantivorous fish like Sardinella. As a primary food source that begins a food chain, its availability also determines the zooplankton abundance, a secondary food source for Sardinella. According to Kulk et al. (2020), primary phytoplankton production can be estimated at high spatial and temporal scales by in-situ measurements obtained from satellite-based calculations.

Sea surface salinity (SSS)

Sea Surface Salinity (SSS) is a vital climate change variable. Ocean salinity could be determined by surface freshwater flux, rainwater, evaporation, and river runoff. Salinity has been found to influence the growth and development of most fish species in previous studies. According to Boeuf and Payan (2001), the reproduction and growth rates of most fish species in brackish water are better in intermediate salinity. Satellite color photography is used to measure salinity, and algorithms are used to transform the data (Fingas, 2018). Salinity data for the study area was obtained from the Marine Copernicus portal.

Effects of Anthropogenic Activities on Fisheries

Ecosystems are significantly impacted by anthropogenic activities like pollution, overfishing, and noise (Störmer, 2011). ADB (2011) stated that coastal areas are densely populated and often the most developed stretches of land in many parts of the world. Coastal waters experience numerous human disruptions especially through the business context. These activities affect the ecosystem and living organisms domiciled there in different ways. Urban coastal areas that host the main harbours and account for 60–80% of industrial production have been overrun by industrial activity. In the outskirts of the coastal settlements that already existed at the time, industrial development began in the 1950s. Still, due to a lack of urban planning, it eventually blended in with the growing residential districts. Currently, industry makes up 21.5% of GDP in the area, but notably more so in Nigeria, where oil-related sectors form the backbone of the nation's economy (FEPA, 1988).

Anthropogenic factors frequently cause water pollution. These factors include actions that increase the use of water resources in urban, agricultural, and industrial settings (Irfan & Shakil, 2012). Presently, urbanization, industrialization and population growth have resulted in multiple environmental problems. Still, they have heightened the complexity due to their unpredictability and scale diversities (Iyalomhe et al., 2013). Therefore, monitoring the condition of the biota is essential due to the detrimental consequences of human activity on the ecosystem as this will indicate the temporal and spatial variation in morphological, physiological and ecological diversity in aquatic habitats (Aderinola et al., 2020).

A lot of such activities are ongoing at Ibeju-Lekki, the study area. The government apportioned part of the land under the Ibeju-Lekki local government as a Free Trade Zone (FTZ – Figure 5) in April 2006 as a partnership between Lekki Worldwide Investments and the Lagos State Government Limited and covers an area of 17,500 hectares (Adeosun, 2017). It is located in the Southeastern part of Lagos State and a multifunctional special economic zone with many production and financial activities, supported by the development of modern residential facilities. The communities mostly affected which are coastal within the Ibeju-Lekki Local Government are Tiye, Ilege, Imobido, Idasho, Lekure, Magbon Segun, Itoke, Idotun, Alasia, Okunraye and Olomowewe.

Free trade zone: This is an economic development model that employs generous incentives such as land contributions, tax breaks, import and export duty waivers, profits, reparation, etc., to attract foreign investment. Usually, the incentives in the designated free trade zones do not apply to the rest of the economy. FTZs are considered special economic zones in some other countries and are testing grounds for implementing liberal market economy principles. The benefits include creating more business and manufacturing options, job opportunities, increased foreign exchange earnings, and a higher rate of cross-border trading. As good as the potential benefits sound, these should not be allowed to hinder the environmental health of the natural environment and result in a total collapse of the livelihoods of the local populace who depend on the natural resources in that locality. Among the developments springing up at the free trade zone are:

***Petrochemical complex**:* This complex comprises the world's largest single-train crude oil refinery, Africa's largest granulated Urea fertiliser plant, and the world's second-largest refinery plant. The refinery is hoped to process 650,000 barrels of crude oil per day when completed. It is a welcomed development because presently, Nigeria exports its crude oil and subsequently imports petroleum products that have been refined for domestic usage. It is anticipated that the $12 billion refinery will remove Nigeria's reliance on imported petroleum products. The fertiliser plant is proposed to utilise by-products from the refinery as raw materials, and the outputs will benefit the local market. However, this development is having some consequential impact on the local ecosystem.

Figure 5: Lekki Free Trade Zone(Source: http://3invest.org/2017/08/27/impact-free-trade-zones-nigeria-property-sector/)

The refinery complex (Figure 6) lies on roughly 2,500 hectares of swamp land that had to be sand filled through sand dredged from the coast. As a result of this development and others in the FTZ, inhabitants of some of the coastal communities have been evicted. According to Tagliarino et al. (2018), in their survey of nine different communities affected by land expropriation indicated there had not been adequate compensation for the inhabitants.

In addition, the Guardian newspaper, in 2019, reported that over 30,000 people had been displaced, while some are about to lose their homes. Furthermore, the reduction in the fishing population has caused a decline in fishing activities, and those that are available sometimes have to travel far to other communities farther away from the free trade zone to get fish.

Figure 6: Dangote Refinery Complex and Fertilizer Plant (Source: The Guardian, 2019)

The Guardian added that although there are guidelines to protect Nigeria's waters and environment, enforcement has been a problem. Nigeria's Department of Petroleum Resources released environmental guidelines for the petroleum industry in 1991. Nigeria is also a signatory to the Abidjan

Convention on International Waters Governance. However, the country has not dealt with oil spills properly. There are complaints of oil spills in other parts of the country where oil exploration has been done. The fishers are, therefore, anxious and fearful for the nearest future. They have questions begging for answers regarding their situation when the refinery is fully operational. "What if there are spills?", "what if there is a leakage somewhere" "what will be left for us."

Lekki deep sea port: This deep sea port (Figure 7) is estimated to worth about \$1.5 billion. Its purpose is to utilise modern port infrastructure to ease traffic congestion in other parts of Lagos, and serve other ports in Nigeria more efficiently. In addition, it can relieve the Apapa seaport of cargo ships by more than 50%. The port is projected to handle 8,000 Twenty-foot equivalent units (TEU) and 160,000 Deadweight Tons (DWT) of liquid bulk carriers. As stated by Adeosun (2017), the port covers 90 hectares (ha) of land in the Lagos Free Trade Zone (LFTZ).

The construction activities include the removal of most of the existing vegetation and general site clearing at the beach. The Lekki Port and Harbor site are located within the Ibeju Lekki Local Government Area of Lagos State, Nigeria. The area of influence (AOI) covers about a 5-km radius of the project location and includes communities such as Lekuru, Oke Segun, Lujagba, and Idotun (Tagliarino et al., 2018).

Figure 7: An Artist's Impression of Lekki Deep Sea Port (https://areteafrica.com/2022/03/11/lekki-seaport-construction-nears-completion)

The seaport activities possess great potential to make life much more difficult for fishermen and their households, as many more will be rendered homeless and jobless with little or no compensation. In situations where there is provision for payment or resettlement of displaced communities, it is a common occurrence for such to be badly implemented in a way that the affected communities engage lawyers and take the government to court. In other instances, their case may be taken over by Social Crusaders and Non-Governmental Organisation that have to battle with the government on their behalf. Apart from the above significant developments, the Lekki Free Trade Zone is projected to accommodate more than 48 companies. Some companies have started operations, while others are still either in the construction phase or yet to start activities. Aside establishment of industries in Ibeju-Lekki, recreational centres have also been on the increase.

Assessing anthropogenic impacts on the artisanal fishing of *S. maderensis* on Lagos coastlines will help to proffer adaptation and mitigation strategies for sustainable fishery of the vulnerable species. Further, there has been studies on the effect of anthropogenic activities on fisheries (Amosu et al., 2012; Ansari & Matondkar, 2014; Bukola et al., 2015; Duque et al., 2020; Paul, 2017; Teixeira-Neves et al., 2015) but species-specific research of anthropogenic effects on *S. maderensis* in Nigeria is lacking.

The indicators for anthropogenic activities in this study include land use change, water quality parameters, heavy metal presence and fishing effort. These were measured and correlated with the fish abundance of the *Sardinella maderensis.*

Land use and land cover changes

Up to 50% of the population in Africa is anticipated to live in urban settings by 2030, making it the continent with the highest pace of urbanisation in the world (UN-HABITAT, 2010). The rate of various forms of land use change and degradation in several regions of Sub-saharan Africa continues at an alarming proportion (Merem, Twumasi, Wesley, Alsarari, Fageir, Crisler, Romorno, Olagbegi, Hines, Mwakimi, et al., 2019a).

Mushore et al. (2022) stated that changes in land use and land cover affect an environment's near-surface features. Moreover, nutrient loads in the catchment areas will be primarily affected by changes in agricultural management and land use trends. In addition, Störmer (2011) noted concerning the southern Baltic Sea area that sociocultural changes, such as the growing popularity of tourists and migrants to coastal regions will influence the local ecosystem of coastal waters. According to Merem et al. (2019a), copious agricultural land degradation has resulted in output drops of around 30% to 90% and a 5% deficit in farm GDP. They emphasised the urgent need for regular use of geospatial technology in undertaking change detection analysis of land cover.

According to IUCN (2016), there is evidence indicating a degrading human-land interrelationship in which negative changes in landscape quality keep diminishing both the natural environment's productivity and aesthetic quality. The land is used for a wide range of human needs and countless various reasons. As the land's users choose to use its resources for diverse purposes, land use changes, having both good and harmful effects.

Water quality

Water quality is crucial for the survival and wellness of aquatic life in the ecosystem (Odulate et al., 2017). Factors that affect of water quality includes daily human activity, industry and the natural environment. As stated by the National Research Council (1993) in the report requested by the US Environmental Protection Agency, many coastal areas still suffer from persistent environmental issues, inspite of advancements made in improving water quality over the past 20 years. The coastal environment is a highly productive part of marine waters.

Despite this development, anthropogenic activities such as siting of industries, mining, agriculture, fisheries and recreational activities such as tourism are usually concentrated on the coast. These activities often produce waste pollutants that destroy fish habitats and harm aquatic life (Spanton & Saputra, 2017). The resultant effect is usually reflected by declining fish stocks and overexploitation of certain fish species (Jisr et al., 2018).

Despite efforts to preserve fish species by maintaining a healthy marine environment, certain areas' fisheries are disappearing (Tsikliras et al., 2015). To remedy such situations, water testing results can provide current values and aid in determining the best course of action for a specific water body (Harris et al., 2015)). He added that "sampling and testing allow managers and owners to establish baseline values, ultimately increasing the knowledge and understanding surrounding the specific issues of a water body”. Water's physical and chemical parameters are crucial for fish growth, reproduction, and continual existence. In addition, the Canadian Council of Ministers of the Environment (CCME) stated that the conventional method of monitoring water quality has been to create reports indicating trends and compliance with statutory norms or other objectives on an individual variable-by-variable basis (Odulate et al., 2017). Therefore, these fundamental water quality indicators were considered in this study, which includes water temperature, dissolved oxygen, pH, Biological Oxygen Demand, and total dissolved solids. Other parameters considered in this study are metals and total petroleum hydrocarbon.

Water temperature: usually expressed in degrees Celsius (C), this gauges the kinetic energy of water (Christ & Wernli Sr., 2013).

pH**:** This is a measure of acidity or alkalinity of water. Measurements are on a scale of 1-14, with 1-6 being acidic, pH 7 being neutral, and 8-14 being alkaline or basic. The acceptable range for fish is between 6.5 - 9.0.

Salinity: Salinity measures dissolved salt content in a water body, which is measured in parts per thousand (g/L).

Total dissolved solids (TDS): includes total dissolved salts but also non-ionised salts.

Dissolved Oxygen (DO)*:* It is a crucial indicator of a water body's quality, ecological status, productivity, and health. It is usually measured in milligrams per litre, and the amount of DO for fish species survival in a water body is 6.5-8.5mg/l (USEPA, 1985).

Biological oxygen demand (BOD): BOD is a commonly used index in the assessment of water quality and shows how much oxygen is used up by bacteria and other microbes as they break down organic matter in an aerobic environment at a specific temperature (Chukwu, 2008; Ngah et al., 2017). It is the quantity of oxygen needed for bacteria to digest organic matter (Bajpai, 2018).

Nitrate (NO_3): Nitrate is considered a high-priority parameter in water quality. It is a kind of nitrogen essential for aquatic species' growth and survival (Adeosun et al., 2016). Therefore, it is usually high in water bodies impacted by anthropogenic activities such as waste and fertilising runoff.

Phosphate (PO_4): In aquatic settings, phosphorus can be found in three states: dissolved inorganic (orthophosphate), condensed or polyphosphate, and organically bound phosphate (Worsfold et al., 2016). It is a crucial nutrient for biological productivity and can degrade water when present in relatively small amounts. It is crucial to conduct monitoring studies that use continuous sampling to record water ecosystem dynamics and lower the danger of eutrophication (Kalkhajeh et al., 2019).

Chlorophyll-a: Its concentration can indicate abundance and biomass of phytoplankton in coastal seas as one of the best indicators of phytoplankton density (Jamshidi & Bin Abu Bakar, 2011). Therefore, Chl-a concentration or phytoplankton biomass are essential parameters (Tas et al., 2011).

Planktons: The abundance and diversity of planktons are governed by environmental factors that determine an aquatic ecosystem's health status (Odulate et al., 2017).

Plankton diversity indices:A diversity index is a numerical indicator of the number of distinct types present in a dataset or sample collection while also accounting for phylogenetic relationships between the individuals distributed among those types, such as richness, divergence, and evenness. The indices serve as statistical depictions of biodiversity in various contexts (dominance, evenness, and richness) (Tucker et al., 2017). Diversity indices for this study were measured as the number of species in existence and their relative abundances, and various indices were used to define the plankton diversity.

Taxa (s): Taxon refers to the particular level of hierarchy in the plankton classification. The taxa at different hierarchical levels are kingdom, phylum, class, order, family, genus and species.

Individuals (N)*:* An individual refers to a distinct plankton or organism within a sample collection, and it is the abundance or number of occurrences per species.

Margalef Index (d): This is a measure of species richness. It depends largely on richness of species and does not account for dominating diversity; the more species there are in a sample, the larger the diversity (Margalef, 1968; Ogbeibu, 2005).

Shannon-Weaver Information Index (H): The Shannon-Weaver Information Index (H) is an index sensitive to the number of species present, and it is sensitive to both species and dominance diversity (Ogbeibu, 2005; Shannon & Weaver, 1963).

Equitability or Evenness (j): It measures how evenly distributed the species' individuals are within a sample. Maximum values fall between 0 and 1, indicating an environment where individuals are dispersed equally among the species (Ogbeibu, 2005).

Heavy metals

The metals considered in this study are Lead (Pb), Cadmium (Cd), Iron (Fe), Manganese (Mn), Nickel (Ni), and Chromium (Cr). The term "heavy metals" refers to a class of metals with an average atomic density greater than 4g/cm3, or five times that of water (Hawkes, 1997). Elevated concentrations of metals can generally be toxic to aquatic life and are regarded as an intermediate priority. They are used as an indicator of pollution because of their high toxicity to marine and human lives (Ayobahan et al., 2014).

Lead (Pb): It comes as a pollutant through paint, pesticides, batteries, and automobile emission (Paul, 2017). Unlike Fe, Mn, Ni, and Cr, lead has no biological function, and there a little elevation of its concentration is toxic (Ghannam et al., 2015).

Cadmium (Cd): Its source is usually from industrial works like welding, electroplating, pesticides, fertiliser, and batteries (Paul, 2017). Like lead, cadmium also has no biological function, and a little concentration in water can be toxic. Cadmium can cause reduced embryo and larval survivability in fish (Garriz & Miranda, 2020).

Iron (Fe): Iron is one of the metals required as trace nutrients for biological processes in living organisms. It, however, becomes toxic at higher concentrations (Paul, 2017). The source of iron pollution could be from

Manganese (Mn): It is also required in minute quantities as trace elements in life processes (Taslima et al., 2022). The source of manganese are welding, fuel addition, and ferromanganese production.

Nickel (Ni): Also required in trace amounts biologically (Taslima et al., 2022). Its source is from electroplating, zinc base casting, battery and industries.

Chromium (Cr): Its source is mining, electroplating, textile, tannery and industries. It is also required in minute quantities for biological processes (Akter et al., 2021). It was reported by Nguyen & Janssen (2002) that high chromium concentration (11 - 114mg/L) caused decreased growth and survival of larvae and altered the body axis of catfish.

Total Petroleum Hydrocarbon (TPH)

Oil spill impacts on coastal ecosystems can be devastating and are regarded as an intermediate priority. However, this study is a high priority because the refinery is being constructed and almost completed. Therefore, baseline studies will be necessary to assess the state of the coastal waters before the full commencement of the refinery operation. In addition, there are already speculations from some of the fishers that they sometimes notice oil film on the water.

Catch Per Unit Effort (CPUE)

In reaction to fishing pressure, populations of small pelagic species can quickly decrease. Such abrupt reductions in production usually demand quick interventions by fisheries managers to maintain sustainability (Lazar et al., 2018). According to Akintola and Fakoya (2017), the availability of the Clupeids family, where Sardinella belongs, has diminished over the last decade due to habitat destruction and overfishing. In addition, fish resources are being negatively impacted by illegal, unreported, and unregulated (IUU) fishing issues. Fish supplies in Nigeria are declining due to IUU, threatening the nation's food, economic, and environmental security (Chikelu, 2021).

There is no adequate data on the number of fishermen and how many fishers and their fishing crafts are licensed. Also, catches are not usually recorded and regulated. In some cases, data taking are funded by international organisations like the FAO, and when such funds are not forthcoming, the process is stalled. Monitoring for compliance with standard mesh size regulation concerning the fishing gears they use, are usually absent or inadequate.

Fishing effort refers to the quantity of a particular type of fishing gear utilized on the fishing grounds over a specified period. For instance, hauls of a beach seine each day, the number of hooks set per day or hours spent trawling (FAO, 1997). For example, in their study, Coulibaly et al. (2018) considered fishing effort as the daily fishing trip for all the gear used in the coastal lagoon of Cote d'Ivoire, West Africa.

While Catch Per Unit Effort (CPUE) can be defined as a quantitative approach used to describe a fishery and serves as a good indicator of their exploitation status (Saberin et al., 2013), CPUE may be expressed as the quantity of fish per unit of fishing time or as any other unit of effort that most accurately reflects the fishery (Appelman, 2015). Also, it serves as an index to calculate the population and relative abundance of fish stocks (Lynch et al., 2012; Maunder et al., 2006). These indices are used in stock evaluations to help fisheries managers decide how best to manage a fishery or a particular stock (Appelman, 2015).

According to Harley et al. (2001) and Maunder et al. (2006), the use of CPUE as an abundance index is based on a fundamental correlation between catch, abundance, and effort that is frequently utilized in quantitative fisheries analysis and can be expressed as:

$$C_t = qE_tN_t \qquad (1)$$

Where C_t is catch at *time t*, q is the portion of the stock captured by one unit of effort (catchability coefficient), E_t is the effort used at time t, *and* N_t is abundance at time t. The equation can be rearranged thus:

$$C_t / E_t = qN_t \qquad (2)$$

CPUE being a function of abundance (provided q is constant over time).

$$CPUE_t \propto N_t \qquad (3)$$

However, q varies and is not usually constant over an entire exploitation history. The efficiency of the fleet, species targeting, the environment, and the population or fishing fleet dynamics are some of the factors that frequently cause q to fluctuate over time. Although CPUE has limitations because it cannot provide all the information needed to manage ecosystems, and most of the time, the species' relative catchability is unknown (Hampton et al., 2005). However, when catch time series are unavailable and full stock assessments are not attainable, CPUE-based studies will be crucial for management (Maunder et al., 2006). Therefore, for this research, CPUE was used as a measure of abundance despite its limitations because full stock assessment cannot be done due to the unavailability of adequate data. It was estimated as the number of fish per amount of fishing time.

$$CPUE\ (KG/H) = \frac{CATCH\ PER\ TRIP}{TRIP\ HOURS} \qquad (4)$$

Implications of Length-Weight Relationship (LWR) and Condition Factor (CF) in Fish

The length-weight relationship of these fish species captured is a crucial way of managing and assessing the fish stocks. The management of fisheries depends on biometric studies that provide data on fish species for an estimated biomass assessment (Zargar et al., 2012). The growth characteristics and condition of the well-being of fish provide information about the growth pattern, health, habitat conditions, life history, fish condition and morphological characteristics of the fish (Jisr et al., 2018). The absence of information on population dynamics, particularly length at first capture (Lc50) within the Sardinella fishery, hinders sustainable management (Ofori-Danson et al., 2018).

In fishery assessment studies, length-weight relationships (LWRs) and relative condition factors are of utmost importance since they reveal information on fish growth and overall health in marine settings (Cheung et al., 2021). Due to a number of ecological and physiological characteristics that are more size-dependent than age-dependent in fish, size is typically more biologically important than age (Aderinola et al., 2020). Typically, LWRs are expressed as a formula that enables the estimation of weight (W) based on a total, standard, or fork length.

When describing the state of a fish population and assessing the potential of fisheries, such as understanding recruitment patterns, selective exploitation, effective conservation, and management of fish species in a waterbody, length-weight relationship and condition factor are crucial tools (Ogunola et al., 2018). As a result, knowledge of the length-weight connection is critical for fishery biology (Dar et al., 2012), and is a key tool for fishery management (Ndiaye et al., 2015; Ogunola et al., 2018).

Thus, this subject has received a lot of attention in recent years. Generally, "the study of the length-weight relationship of fish aims to determine the variation of weight and length of fish in individuals or groups of fish as an indicator of obesity, health, productivity and physiological conditions, including gonadal development" (Blackweel et al., 2000; Saygin et al., 2016). In addition, the condition factor of the fish population is estimated using the LWR analysis (Everhart & Youngs, 1981). Planning a better management strategy for fisheries resources, such as establishing the selectivity of fishing gear, requires this information (Merta, 1993) in (Muchlisin et al., 2017).

Fish biomass is calculated using the length-weight-relation (LWR) method, which has become a common measurement in studies on fisheries and conservation (Froese, 2006). Behavioral or predictive population models at the population and community levels can also be constructed using the LWR (McCallum, 2008). Fulton's condition factor (K), which offers a proxy relating to fish health, is an example of how the condition factor is described. Also, it is used to compare the health of fish under the premise that fish with higher weights at specific lengths are in better shape than fish with lower weights at the same lengths (Anzueto-Calvo et al., 2017).

Fish length and weight relationships were first utilized to convey information about the health of the fish. (Le Cren, 1951). It was later used by Ricker (1975) to assess if somatic growth was isometric or allometric. The Length-weight relationship helps to understand the understanding fish biology, physiology, ecology, population dynamics, fisheries evaluation and the fish's general conditions (Jaiswar et al., 2004). Length-weight relationships (LWRs) and condition factors are essential to the fishery industry as they help predict the ideal length and time for harvesting and rational exploitation of particular fish species(Dulčić & Kraljević, 1996).

LWRs are also used in other fields, including fish biology, physiology, ecology, and fisheries evaluation. LWR makes it possible to track seasonal variation in fish growth and to calculate condition indices in biological studies. For example, Flura et al. (2015) estimated the length-weight relationships of *T. illisha* to know the hilsa fishery status in Bangladesh for managing the fishery. In addition, LWR enables morphological comparisons and provides the life history of fish species or fish populations from different habitats (Abobi, 2015).

Condition Factor (CF)

The condition factor (CF) is an additional biometric tool derived from the length-weight relationship by Le Cren (1951). CF measures the deviation of an organism from the average weight in a given sample to assess the suitability of a specific water environment for the growth of fish (Abobi, 2015).

The condition factor is a popular index in fish biology studies (Panicker & Katchi, 2021). Based on the idea that fish of a certain length and weight are in better condition than those of a different length, it provides essential information on the physiological health of fish (Lima Junior et al., 2002). According to Panicker and Kachi (2021), it is investigated using a technique known as Fulton's condition factor or the coefficient of the condition, sometimes referred to as the Ponderal Index. Anderson and Neumann (1983) reported that the condition factor was a relative indication of fish health and the extent of sustainable settings. Changes in the relative condition factor are related to sexual maturity and the amount of environmental nutrition supply. Condition factor can be expressed as:

$$CF = (W/L^3) \times 100 \qquad (5)$$

Where W = weight of fish body (g)

L = length of fish (cm)

The condition factor is an index that depicts the interaction of biotic and abiotic elements in fish physiological states. As a result, fish species in various habitats may differ in the condition factor. In general, the condition factor is a useful metric for evaluating fish age, feeding frequency, growth rate, and general health (Aderinola et al., 2020).

Allometry

Fish with a b value of less than 3.0 get leaner as they grow longer, and their growth will be negatively allometric. On the other hand, when b is more than 3.0, fish grow larger with length as they exhibit positive allometric growth and the ideal growing environment. Fish grow allometrically in both situations; when $b<3$ or $b>3$, the fish's weight increases faster than its length does, and the opposite is true. Fish growth is isometric, when $b=3.0$.

Genetic Analysis of *Sardinella maderensis*

There are increasing concerns about the loss of global biological diversity. Biological diversity, usually shortened as biodiversity, is a term used to describe the variety, variability and number of living organisms in a given assemblage (Rogers et al., 1995). Almost half of all vertebrate species are fish, comprised of nearly 15,700 marine and 13700 freshwater species (FishBase: www.fishbase.org). Fishes are a diverse, conspicuous and increasingly threatened species (Zemlak et al., 2009). The Sardinellas belong to the

Clupeidae family. The clupeids are of prime importance to fisheries as they represent the largest suborder of non-domesticated vertebrates harvested by man (Abdullah, 2013). The population of *Sardinella maderensis* is reportedly decreasing because of overfishing, and its average size is reducing as a result (Olopade et al., 2019). In addition, “the International Union for Conservation of Nature (IUCN) has rated its status as vulnerable” (Tous et al., 2015). The genus *Sardinella* has different species reported on the West African coast. They are also said to be migratory; therefore, there are speculations that there could have been a mix in the species population. The question is, are the *Sardinella* in the Nigerian coastal waters mainly maderensis or a blend of *Sardinella* species?

Unambiguous identification of fish and fish products is essential in many areas, such as detecting retail substitution of fishes, managing fisheries for long-term sustainability and improving ecosystem and conservation (Ward et al., 2005). It also helps to know the state of the stocks to detect extraneous species before they ultimately infiltrate the indigenous ones. Genetic analysis also helps identify fish that may be difficult to recognise through phenotypic features because they are at the immature stages or in a situation where only body fragments are available (Ivanova et al., 2007). In addition, limited morphological characteristics because of damage, poor specimen condition and ambiguous morphological features can lead to misidentification (Ward et al., 2009). Compared to other methods of fish species identification, DNA-based techniques can be used when proteins have been highly denatured, especially in canning (Bossier, 1999; Lockley & Bardsley, 2000). Isoelectric focusing (IEF) of proteins) was used for only raw fish (Durand et al., 1985; Lundstrom, 1980; Rehbein et al., 1995). While electrophoretic methods such as urea isoelectric focusing (Etienne et al., 2000; Mackie et al., 2000; Pineiro et al., 1999; Rehbein et al., 1999), which were used for processed fish (cooked, pre-fried or smoked).

In addition, due to the genetic code's degeneracy and the abundance of non-coding areas with functional polymorphism for studies on species evolution, DNA can supply more information than protein. (Jérôme et al., 2003). The *S. aurita* and the *S. maderensis* are the two most common species in the CECAF region, which includes all of West Africa from Morocco to Angola. They are among the most numerous and economically significant migratory small pelagic species in West Africa, making up the majority of the captures in the CECAF region (Takyi, 2019). The two species frequently coexist in schools and are classified as the *Sardinella species* in statistics. This is because they have very similar physical features regarding their morphology. The southern zone of the CECAF region within the Gulf of Guinea constituted four zones, namely Western zone (Cote d'Ivoire); Northern zone (Guinea-Bissau, Guinea, Sierra Leone, and Liberia). Togo, Ghana, and Benin; Nigeria and Cameroon; the Central Zone; and the Southern Zone (Gabon, the Democratic Republic of Congo, the Congo and Angola

Understanding stock limits and having knowledge of the genetic makeup of specific species groupings are essential for developing effective fisheries management techniques. According to Durand et al. (2013), there are a variety of complementary ways for defining stocks, however it is now known that in delineating stock structure for sustainable management, genetic analysis is expedient. Compared to their counterparts in the North, they said that West African ecosystems had not received adequate genetic study, preventing the advancement of stock delineation and progress of fishery management.

The molecular marker is an excellent method to obtain the result that the morphological analyses cannot achieve. Besides that, with this approach, genetic studies of DNA variation in marine species have revealed the existence of multiple species in many cases where only one was previously recognised, as well as the presence of numerous and reproductively isolated stocks in many fish and shellfish species (Abdullah, 2013).

DNA sequencing has long been recognised as means used to discriminate species through protein analysis. Although different sequences have been employed for various taxonomic groupings and laboratories, DNA sequencing has been utilized for 30 years to help identify species (Ward et al., 2005). For instance, Hebert et al. (2003) suggested using the mitochondrial DNA gene cytochrome oxidase subunit I (COI) as a universal animal bio identification system, claiming that a single gene sequence would be adequate to distinguish all or the vast majority of animal species (Ward et al., 2005).

However, Ward et al. (2005) stated that within-species DNA sequences must be more similar than sequences in distinct species for a barcoding method to species identification to be successful. Therefore, their study employed two forward and two reverse primers.

FishF1-5'TCAACCAACCACAAAGACATTGGCAC3'

FishR1-5'TAGACTTCTGGGTGGCCAAAGAATCA3'

FishF2-5'TCGACTAATCATAAAGATATCGGCAC3'

FishR2-5'ACTTCAGGGTGACCGAAGAATCAGAA3'

However, Ivanova et al. (2007) believe four PCR amplification needs are undesirably complex and suggest a single set of primers comprising the forward and the reverse. This study used the universal primer, the animal ID

COI, and compared the results with the fish-specific primer by Ward et al. (2005).

Effective Management of Fishing Stock through Forecasting

Time series data forecasting has emerged as the most pertinent and useful method for assessing fisheries stocks. Forecasting is essential in fisheries management to help make informed decisions at present to help save possible future difficulties and challenges. Information through forecasting would help in the effective management of fish stocks. Various Management approaches have been introduced but have faced some inadequacies. For example, quotas and regulations like the implementation of the closed season, mesh size regulation, regulation of fishing effort, gear licensing and regulation have met with resistance in their execution. It was seen as a command control management approach. Hence with the system, governments were still finding it challenging to manage capture fisheries and, thus, the continuation of overexploitation.

The co-management approach was introduced in the 1980s and considered more holistic. It aimed so that the biological sustainability and sustained use of the fishery resource and had primary stakeholders as the users and the state (Hara & Nielsen, 2003). The main goal was to involve the users in managing the resource. However, it was later faulted that it lacked incorporation of numerous details on the institutional, social, and cultural aspects (Hara, 2011) and that a top-down approach was used.

The government involved users in the process without ceding control over administration or decision-making. According to Makwinja et al. (2021), the Malawian government adopted the ecosystem-based management method as a result of the failure of the co-management model, which includes forecasting of catch per unit effort and total annual biomass landings as a fundamental element for effective management of stocks. This approach uses time series historical data on catch and CPUE to predict future outcomes.

Some researchers have used this time series approach to efficiently forecast fishery landings (Georgakarakos, Koutsoubas & Valavanis, 2006; Koutroumanidis et al., 2006; Lloret et al., 2000; Park, 1998; Prista et al., 2011; Raman, Sathianandan, Sharma & Mohanty, 2017; Selvaraj et al., 2020; Stergiou, 1990) to understand the dynamics of the fisheries and forecast of fish landings in areas lacking sufficient data.

The general trend for fish landings has frequently been predicted with greater accuracy and dependability using the Autoregressive Integrated Moving Average (ARIMA) modelling (Makwinja et al., 2021). This model was developed by Selvaraj et al. (2020) to forecast fish landings in the Colombian Pacific Ocean. The use of time series analysis has been described as the best approach because it helps assess catch trends and makes possible forecasts of catches. Previous models only show the current status of a fishery and are prediction deficient. The approach works with fewer assumptions and simple mathematical models. They stated that it helps significantly in data-poor fishing, which is the situation in the small-scale fisheries in Nigeria. It can help support potential evaluations and make informed management decisions.

According to Makwinja et al. (2021), ARIMA(0,1,1) and ARIMA (0,1,0) are the best forecasting models for fish landings and catch per unit effort. The values for the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Mean Absolute Error (MAE), Standard Error of Prediction

(SEP), and Average Relative Variance (ARV) are lowest for the two models. They also displayed the highest values of the Gaussian Maximum Likelihood Estimation Algorithm (GMLE), Persistent Index (PI), Coefficient of Determination (R^{2}) and Efficiency of Coefficient (E_2).

Fisheries Management Approaches

The impacts of climatic variabilities and anthropogenic activities on fisheries call for urgent management attention. In addition, the ever-growing exploitation pressures, which mostly result from socio-economic forces, including high population growth, market growth, and rural poverty, continue to provide problems to natural resource managers that necessitate quick but flexible responses (Kosamu, 2017). Therefore, for effective fisheries management, it is essential to know the fish and its dynamics, where the fish lives, the environmental conditions, and how these parameters affect the fish stock.

A fishery is made up of three parts: fish, people and the environment (Figure 8). Therefore, fishery management should focus on the three aspects to be effective in the system. The aim or goal of management is to achieve the sustainable use of a resource to make it available in the present and the future.

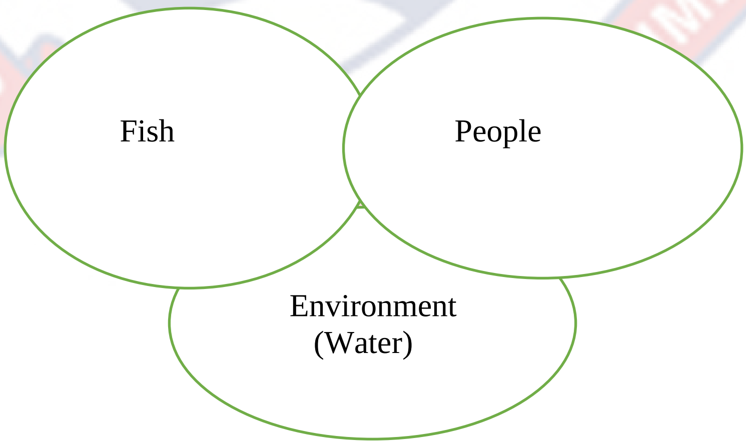

Figure 8: Components of a Fishery

Management is also interested in equitable resource use by all interested parties. Management has three main focuses: maintaining biodiversity, high catch, and high employment. Why is there a need to manage the artisanal fishery of Sardinella in Nigeria? Statistics have shown that there is a general fluctuation tending towards a decline. There are concerns by the Fisheries Committee for the West Central Gulf of Guinea (FCWC) that despite its imposing maritime space (2,633 km of coastline from Liberia to Nigeria), enough fishes are not produced to feed the population in the FCWC area (FCWC, 2016). Nigeria and the other four counties still import more than 70% of fish products needed in their nation. Only Ghana is relatively 'self-sufficient' in fish production, with less than 10% fish importation.

Fisheries management is multi-sectoral and includes livelihoods, and it is also multidimensional with various parameters. The basic unit for fisheries management is stock. A stock is a population or collection of individuals who are members of the same species and exist within a specific geographic area and time frame. It is a distinct group of people sharing the same gene pool, self-replicating, and distant from neighbouring populations of the same species.

There are various methods used for stock identification. Firstly, studying distribution and abundance, which involves using tags. Secondly, there are life history studies, which use growth rate, birth rate and fecundity. Third are meristic studies, which involve countings of spines and gill rakers, and the fourth, morphometric measurements, which use length-weight relationships. Lastly, genetic studies, which involve DNA extraction. This study used meristic, genomic and morphometric investigations combined.

There are two main fisheries management categories: single-species and multi-species management. This study is based on single-species management of the *S. maderensis* which involves description of the spatial-temporal limits of the stock, tracing of trend quantities and dynamics, making long predictions and intervention.

The management process starts with scoping, which involves trying to understand everything about the fishery in terms of the describing the status of the fishery and the difficulties facing it. The scoping is followed by stating the objectives to be attained at the end of the process and followed by identifying and implementing strategies/actions that are time bound. Various approaches have been used in fisheries management which include the Precautionary approach, Comprehensive rational planning approach and Adaptive management approach. However due to the shortcomings in these previous approaches, the Ecosystem-based management approach was proposed.

The Precautionary Approach: can be used when there is not much research on the fishery. It relies on traditional ecological knowledge and use the best available scientific information on catch trends, effort trends, and catch-per-unit effort trends. Valuable in a data-poor fishery.

Comprehensive Rational Planning (CRP) *Approach:* It is research-oriented and comprehensive but fails to achieve a sufficient understanding of the fishery. CRP does not address uncertainty; therefore, it is suited for no or low uncertainty conditions. It is not possible anywhere, but it is the ideal situation.

Adaptive Management Approach: It involves active learning by doing. The challenges in adaptive management are that it is trial and error, which may backfire, and there is difficulty in finding the correct balance between gaining knowledge to improve governance in the future and obtaining the finest short-term results.

Ecosystem-Based Management (EBM) Approach: Considers every aspect of the fishery, balancing the societal objective with biotic, abiotic and human factors (Lockerbie et al., 2018; Patrick & Link, 2015). The aim is to have a healthy environment and optimum fish output that will provide sustainable livelihoods to people. EBM effectively manages fish population and their ecosystem and considers that fish do not exist in isolation. It recognises and considers physical, biological and ecological factors and teases out driving forces to work at its management measures. Therefore, the EBM approach was adapted for this study.

Strategies for Resilient Small-Scale Fisheries

In line with SDG Target 14.2, which is to "sustainably protect and manage marine and coastal ecosystems to avoid significant adverse impacts, including strengthening their resilience and taking action for their restoration to achieve healthy and productive oceans" (UN, 2022). It is imperative to have a resilient fishery to sustain the ocean resources; therefore, management that considers every aspect of the ecosystem is vital. Since humans are the primary drivers, the best strategies towards achieving the above goals should start with and have enough focus on the fishers.

According to Badjeck (2010), around 90% of fishers and seafood traders worldwide are small-scale fisherfolks. For example, in Nigeria, artisanal fisheries represent 89% of local fish production (Ogunsola & Adeyeni, 2018), with fishing activities as their primary source of livelihood.

Sustainable livelihood strategies and livelihood outcomes

A livelihood may be described as “the capabilities, assets and activities required for means of living” (Chambers & Conway, 1991; DFID, 1999). Oxford dictionary defines livelihood as means of earning or providing enough food, among others, to sustain life. However, livelihoods are not only food, but social and human developments are also essential to a sustainable livelihood. Capital assets such as stable family life, equitable access to community institutions and education, however necessary, are also needed to make a livelihood sustainable, likewise access to medical facilities, comfortable housing and a clean water supply.

“A livelihood can be called sustainable when it copes with and recover from stress and shocks, maintain or enhance capabilities and assets and provide opportunities for the next generation” (DFID, 1999). Livelihoods are diverse and multifaceted, consisting of a variety of resources or capital that people use to counter risks to their wellbeing (Chambers & Conway, 1991; White & Ellison, 2007). Five capital assets: natural, physical, human, economic/financial, and social, can be accessed by people following the framework for sustainable livelihoods (DFID, 1999).

Following on from the above, potential capital assets concerning small-scale fisheries in this study are: Natural assets (marine plankton/fish food, fishing ground, breeding ground, landing sites, water quality, fish catch); physical assets (housing, basic infrastructure, boats, canoes, fishing gear); human assets (good life, health status, skilled fishers/labour); financial assets (income/profits, savings, credit system, insurance) and social assets (social relationships, affiliations/associations, diversity (cultural/ethnic), security/safety).

Livelihood Strategies: Livelihood strategies are the range of activities and choices people engage in, to achieve their livelihood (Satia, 2016). Fish workers may pursue a diversity of livelihood strategies. In the case of fish farmers, integrating crop or animal husbandry with fish farming is a livelihood strategy (Adewale, 2003). In addition, small-scale fishermen migrate from one location to another to get good catches.

Livelihood Outcomes: Livelihood outcomes can be defined in terms of what people achieve from their livelihoods and what they hope to achieve in the future (livelihood goals). It can be assessed multi-dimensionally for more income, increased well-being, improved food security, reduced vulnerability, and sustained natural resource use (Hussein, 2001).

Vulnerability Context

The vulnerability context is the set of external environmental elements that influence people's susceptibility to poverty (Allison & Horemans, 2006). The vulnerability context significantly affects the livelihood strategies people choose and the outcomes they hope to attain for their livelihoods. The causes of vulnerability are shocks and seasonality, declining fish stocks, lack of basic infrastructures, non-availability of good schools and prevalence of HIV/AIDS. Furthermore, Cutter et al. (2009) defined vulnerability as "the susceptibility of a given population, system, or place to harm from exposure to the hazard and directly affects the ability to prepare for, respond to, and recover from hazards and disasters."

The United Nations Office for Disaster Risk Reduction (UNDRR, 2020) defines "vulnerability as the conditions determined by physical, economic, social, and environmental factors or processes, which increases the individual, community, assets or systems' susceptibility to the impacts of hazards". They opine that people's vulnerability is the most significant factor in determining their risk.

Causes and sources of vulnerability include scarcity of resources, bad governance, limited capacity and climate change (Schuhbauer & Sumaila, 2016; TBTI, 2020; Utete et al., 2018). Small-scale fishermen's capacity to maintain their livelihoods and adapt to changing conditions is directly impacted by these problems (Saldaña, 2019). Understanding the sources of vulnerability at the individual and community levels is necessary for small-scale fishing to benefit society as much as possible (Adger, 1999; Andrew et al., 2007; Salas et al., 2019).

Fishers that rely on the ocean for their livelihoods face difficulties due to the ocean's poor condition, which causes them to alter their behaviour by moving to other fishing grounds or going farther offshore (Naranjo-Madrigal & Bystrom, 2019; Saldaña et al., 2017). In these conditions, coping with threats to meet basic needs become difficult for fisherfolks, making them vulnerable. In many instances, it is difficult for them to diversify to other livelihood activities. Sometimes, people use migration to reduce their vulnerability by moving within or outside of their country (Islam et al., 2014; Kheang, 2013).

To address the problem, we need to assess the fishers' perception regarding their vulnerabilities and adaptation. According to Adeleke et al. (2018), perception is the bedrock for apprehending the consistent claim and interpretations of the fishers, who are the primary receptors of climatic variability effects. Individual perceptions and knowledge on climate change vary according to the entity's geographic area, vocation, political, socio-economics, ecological, and cultural background. Therefore, the fishers in this study were interviewed to assess their perception of vulnerability and adaptation to the effects of climatic variabilities and anthropogenic activities.

The Resilience Concept

The resilience concept argues that it is possible for there to be resource management that addresses the needs of the resource users, the resource itself, and proper development practices to meet these goals (Russell, 2017) despite vulnerabilities. A system's resilience is its capacity to withstand a shock, disturbance, or change while mostly preserving its structure and function. It connects and dynamically integrates human and environmental factors in socio-ecological systems. (IPCC, 2014a). It could also be referred to as a substance or object's ability to spring back into shape.

Cutter et al. (2008) defined resilience as ‘the capacity of a system to absorb effects, deal with an event, and make post-event adjustments that aid the system in changing and learning.” Walker and Salt (2012) also described resilience as coping with shocks and functioning similarly. Small-scale fisheries are connected to natural, social and political processes that occur beyond the fishing domain but remarkably impact the system (USAID, 2019). Therefore, adaptability and resilience will be essential characteristics in future fishery management and the science that informs management (Farady & Bigford, 2019).

Climate resilience is the ability of social, ecological, technical, or infrastructural systems to respond to opportunities and handle challenges while maintaining their current function, structure, and overall identity (IPCC, 2007). One of the crucial measures and solutions for climate resilience, according to

Poulain et al. (2018) is that adaptation to climate change should begin with a precise assessment of current climatic variability and take future climate change into account as a prerequisite for deciding on adaptation interventions. The resilience of local communities and people is being challenged by climate change and small-scale fishers are particularly vulnerable. Fishers are vulnerable because of where they live and how poor they are (Kalikoski et al., 2018).

The following equation describes how vulnerability (V) can be defined as a function of exposure to climate change (E), sensitivity to climate change (S), and adaptive capacity (AC):

$$V = f\,(E, S) - AC \qquad (6)$$

Where adaptive capacity (resilience) can lessen the negative consequences of exposure and sensitivity. Adaptive capacity is the capability of ecosystems to be resilient. A community (human or ecological) that can adapt is more likely to be resilient or able to overcome severe situations and occurrences. Resilience-building programs would help to prevent vulnerable people from descending into poverty (FAO, 2017b), and weak systems would be saved from total collapse. There has to be either an anticipated or existing problem to build resilience. The situation in this study's context has to do with climatic variabilities andhuman activities. Hence variables that include rainfall, sea-level rise, sea surface temperature, land-use changes, and catch effort data were assessed to identify those that expose the fishery to vulnerability. Having identified factors leading to high exposure, interventions would then focus on increasing the adaptability and resilience of the communities and the ecosystems they depend on (Soto et al., 2018).

Conceptual Framework

The current climate change is projected to affect individual organisms, consequently, the population of species, communities, and ecosystems' functioning (Pörtner & Peck, 2010). The challenge is to improve small-scale fisheries governance to build fishery-dependent communities' resilience and ensure ecological sustainability. Therefore, resilience-based analyses and multi-stakeholder interventions are needed to support improved natural resource management, especially where alternative uses of water, land, and aquatic resources threaten production (CGIAR, 2016).

In this study, the Ecosystem Approach (EA) in Fisheries Management was adopted to consider every aspect of the fishery to balance the societal objectives with physical, biological, and environmental factors (FAO, 2003; Garcia, 2006). The Ecosystem Approach was described by Staples et al. (2014) as a tactic for the equitable promotion of conservation and the sustainable management of living resources, land, and water. The ecosystem consists the biotic, abiotic, and human components and their interconnections; when the abiotic (environment) is healthy, it will provide the right conditions for the biotic (fish) to thrive and help humans to have good livelihoods. Managing fisheries in isolation from what they affect and are affected by has proven to be relatively ineffective and unsustainable. According to Staples et al. (2014), fisheries governance should guarantee the equity and well-being of both people and ecosystems. Therefore, this study adopted the Ecosystem-Based Management (EBM) Approach to assess *Sardinella maderensis* fishery and offer recommendations for building resilience and enhancing its sustainability. This was done by setting broad objectives to include the various aspects of the ecosystem. Indicators used in the study are related to fish catch and other parts of the aquatic ecosystem (Lockerbie et al., 2018).

The impacts of climate change were assessed by measuring indicators such as sea surface temperature, sea-level rise, rainfall, primary productivity, and salinity. Anthropogenic activities were measured by assessing water quality, land use/land cover changes, and fishing effort (Figure 9). The effects of the above factors could result in either a decline or an abundance of fish. In the event of a decline, mitigation and preparedness strategies would have to be introduced to help the fishery to be resilient, sustainable and enhance the community's livelihoods.

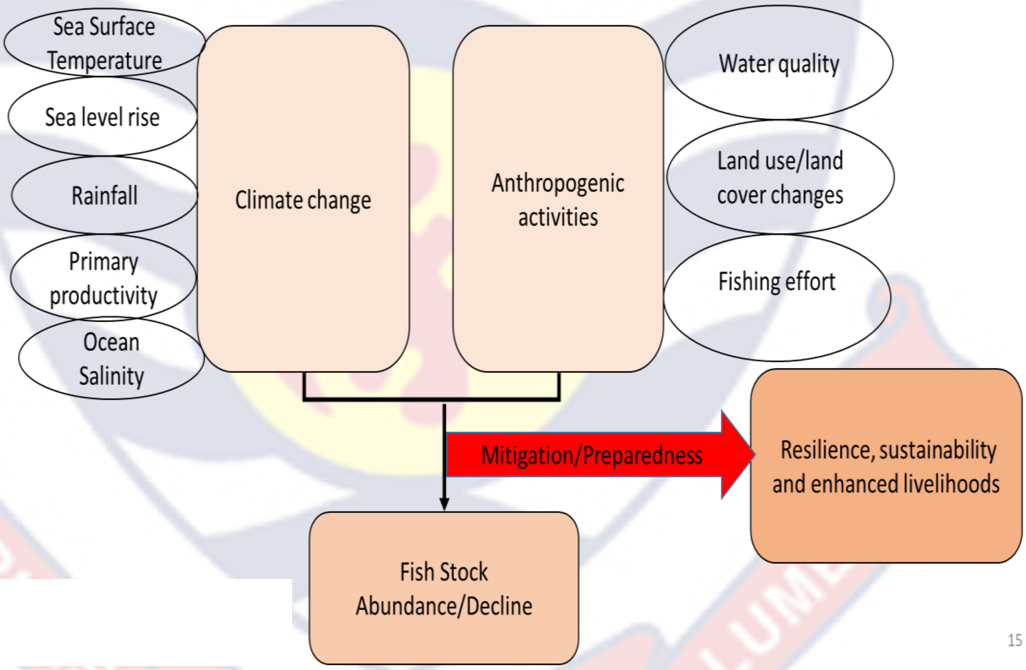

Figure 9: Conceptual Framework: The Ecosystem Approach (Adapted from Cutter, 2008)

CHAPTER THREE

MATERIALS AND METHODS

This study assessed the effects of climatic variability and anthropogenic activities on the *Sardinella maderensis* fishery of Ibeju-Lekki, Lagos, Nigeria. This chapter is designed to show the research paradigms or philosophical worldview that guides the research. It further describes the study area, the population involved, the sampling procedure and the type of instruments used for data collection. In addition, the ethical consideration and clearance process, the pilot testing, and the data entry and analysis process are explained. The limitations encountered during the fieldwork are included as well.

Research Design

A philosophical worldview guided this study to propel the research process. Philosophical worldview is the fundamental beliefs that drive action, paradigms or epistemologies, and ontologies (Creswell, 2013a; Lincoln et al., 2011; Crotty, 1998). It could also be broadly conceived as a research methodology (Neuman, 2000). According to Plano Clark and Ivankova (2017), the collection of assumptions and values about the nature of reality and knowledge provides the foundation for research. This study is based on the Pragmatic philosophical worldview in that all approaches available were used to understand the problem. Pragmatism is "a philosophical underpinning for mixed methods" (Morgan, 2007) and uses a pluralistic approach to derive knowledge about the issue (Creswell, 2013b).

The study used quantitative and qualitative assumptions, methods, and approaches to comprehend the research problem effectively. It was essential to use mixed methods because a holistic approach is required to understand and solve an ecosystem's problems. The approach was adopted because the ecosystem consists of various components comprising living and non-living interacting together. The process of conducting mixed methods research involves combining quantitative and qualitative data collection techniques (Plano Clark & Ivankova, 2017). It is ideal and beneficial for a complete understanding of a phenomenon by enhancing validity through triangulation. Triangulation “involves corroboration or verification through multiple data points or types of data about the same phenomenon” (Creamer, 2019; Doyle et al., 2020).

Qualitative research explores and understands individuals or groups' meaning ascribed to a social or human problem and helps to derive individual opinions and perceptions on issues. The quantitative method, on the other hand tests the validity of theoretical hypotheses by analysing the relationship between variables. These variables are measured using instruments, and the resulting numerical data is then subjected to statistical analysis (Creswell, 2013b). The mixed-method approach effectively integrates the quantitative and qualitative data, employing unique designs that might involve theoretical frameworks and philosophical assumptions. In addition, this method ensures that each method's shortcomings are reduced (Creswell, 2015), and data from the quantitative method can also be used to get more illumination on qualitative findings (Doyle et al., 2020).

Survey research design was used to examine a sample of the population and provide a quantitative or numerical assessment of its trends, attitudes, or opinions. It includes cross-sectional and longitudinal studies that use structured interviews as the data collection method to extrapolate findings from a sample to the entire population (Creswell, 2015). In addition, the researcher used the phenomenological study design to describe the people's actual experiences about climate change and anthropogenic effects phenomena by unstructured interviews through focus group discussions. The grounded theory design or form of inquiry was also used to develop a broad, abstract theory of the process, activity or interaction from the perspectives of participants. Collecting both forms of data helped to neutralise the weakness of each, and this led to triangulating data sources to seek convergence across qualitative and quantitative methods.

Regarding the research approach, the study also used the case study research design. The use of a case study as the research design for this study is based on the nature of the research questions, which require different data sources to understand better. The case study allows us to explore a program, event, or activity (Creswell, 2013). Despite its major limitation of not allowing the results to be generalised, it enables the researcher to spend more time interacting with the participants on the field to have an in-depth account of the situation. The convergent parallel mixed method design is thus used, which involves converging or merging quantitative and qualitative data to analyse the research problem comprehensively.

The case study in this research comprises the coastal communities of Ibeju-Lekki, Lagos, Nigeria. The fishery bio-statistical data for the analyses were obtained through field visits and fishery data available in the repositories of the Food and Agriculture Organisation (FAO) and the Federal Department of Fisheries. Time-series climatic data, fish catch data, remote sensing, and GIS data of fishing communities were used for the study. In addition, there was a selection of fishing villages and fish landings sites, examining coastal survey maps and some remote sensing data to obtain information on coastal topography.

Primary data was collected through interviews, focus group discussions and observations. Also, a mobile application was used to input responses by clicking on the tablets provided to enumerators. The enumerators selected were those who understand the local language and could interpret for respondents. Statistical, text, and image analysis was done using spatial, descriptive and inferential statistics to derive statistical interpretation, themes, and patterns. The study used a structured interview guide (Appendix A) for the in-depth interviews (IDIs), a focus group discussion (FGD) guide (Appendix B) for the group discussions, and the observational checklist (Appendix C) to collect observational data.

The IDIs aimed to have a face-to-face interview with one respondent at a time to acquire information. The FGDs are a group of interviews where a small group of people, often between 6-10 people, are interviewed simultaneously at a particular time. Secondary data on registered fishers and their communities was compiled from the Lagos State Agricultural Development Agency (LSADA) of the Ministry of Agriculture & Cooperatives.

Study Area

The study area is Ibeju-Lekki, a local government area (municipality) in Lagos State, Nigeria, West Africa (Figure 10 a). Spatially, Lagos State lies between latitude 6°20' North to 6°40' North and long 2°45' East to 4°20' East. Its coastline stretches 180 km across the Atlantic Ocean, 22.5% of the 853 km coastline in Nigeria. Although Lagos is the smallest state in Nigeria (Figure

10b), it is the most densely populated, occupying a 3,577 sq. km. landmass, with about 786.94 sq. km. (22%) of it being lagoons and creeks (Dekolo & Oduwaye, 2011; Jinadu, 2000). The state's lagoons, inland waters, creeks, and coasts make fishing activities very prominent.

As a local government area in Lagos State (Figure 11), Ibeju Lekki is regarded as one of Nigeria's ten wealthiest local governments in natural resources. Ibeju-Lekki is bounded southwards by the Atlantic Ocean (Gulf of Guinea), on the west by Eti-Osa Local Government, and by Lagos Lagoon and Epe Local Government in the north and the east. There are about thirty -seven coastal fishing communities in the study area. Fishers in Ibeju-Lekki constitute different ethnic groups and foreign nationals predominantly from Ghana. Fish species commonly caught in the fishery include *Sardinella maderensis*, *Caranx senegallus*, *Ethmalosa fimbriata*, *Drepane africana*, *Cynoglossus spp*, and *Pseudotolithus senegalensis* (George et al., 2014).

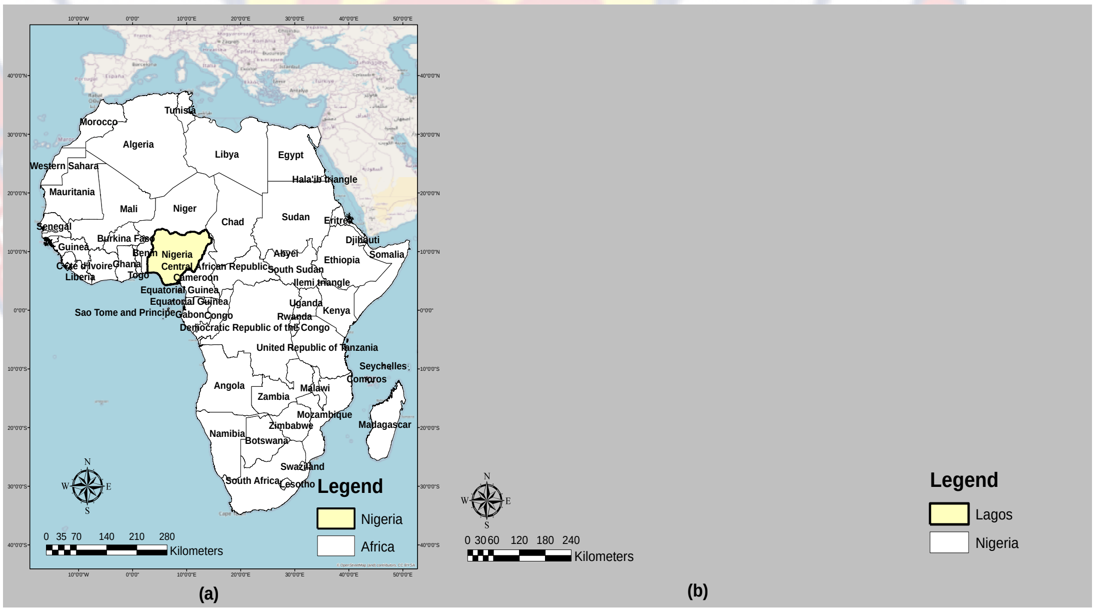

Figure 10: (a) Map of Africa Showing Nigeria and (b) Map of Nigeria Showing Lagos State (Credit: Centre for Coastal Management, UCC)

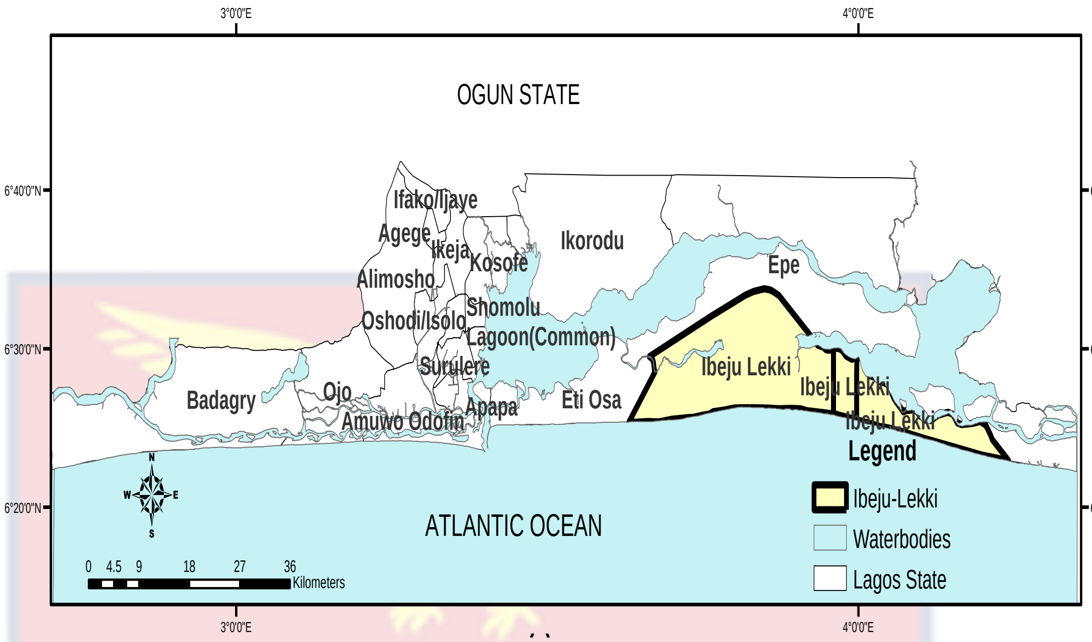

Figure 11: Map of Lagos State Showing Ibeju-Lekki (Credit: Centre for Coastal Management, UCC)

In addition, artisanal fisherfolks operate from small, scattered coastal communities using the Ghana plank boats, traditional half-dugout canoes, and traditional small plank canoes (Anetekhai et al., 2018). Due to the study area's location on Lagos State's low-lying coastline, it is vulnerable to flooding and coastal erosion. (Adedire & Adegbile, 2018). The most significant commercially relevant species include *Sardinella maderensis* (Flat sardine, *Ethmalosa fimbriata* (Bonga), *Ilisha africana* (West African shad) and some Carangids (Nwafili & Gao, 2007). These are exploited by the small-scale fisheries.

Population

The study's target population comprises Sardinella fishers in the coastal fishing communities of Ibeju-Lekki, Lagos State. There are 37 out of the 80 communities in the study area, Ibeju Lekki, which can be classified as coastal communities. These are communities within a land coverage distance of 2 km from the coast. A standard setback of 2 km was used to create buffers around the coastline to identify the communities using ArcGIS 10.3 software. Through the reconnaissance survey and pilot study, only 30 out of 37 coastal communities have *Sardinella spp* fishery activities, the species' focus in this study. Therefore, this population was chosen to understand better climate variability impacts and anthropogenic effects at the local level. The 2006 National Census showed that Ibeju-Lekki had a total population of 117,793, with 57,064 women and 60,729 men working in natural resource-based industries such as fishing, agriculture, timber/sawmilling, mat/raffia weaving, oil palm processing, and developing ecotourism (Omenai & Ayodele, 2014).

Sampling Procedure

The total number of 1879 fishers in the 30 coastal communities (Figure 12) was the sample frame of this study. A sample size of 330 fishers was derived from the sample frame of 1879 fishers by calculating using the Yamane (1973) formula with a 95% confidence level (i.e. the margin of error = 0.05). The formula is presented as follows:

$$n = \frac{N}{1+N(e)^2} \quad (7)$$

Where : n = sample size required

N = number of people in the population

e = allowable error (%)

However, by adding the non-response estimate of 10%, it is estimated that 363 of the survey instruments should be administered to participants. Therefore, the survey instrument was assigned proportionally according to the fishers' size in each community (Table 3). A random sampling technique was used for data collection, and there was a 99% response rate (360).

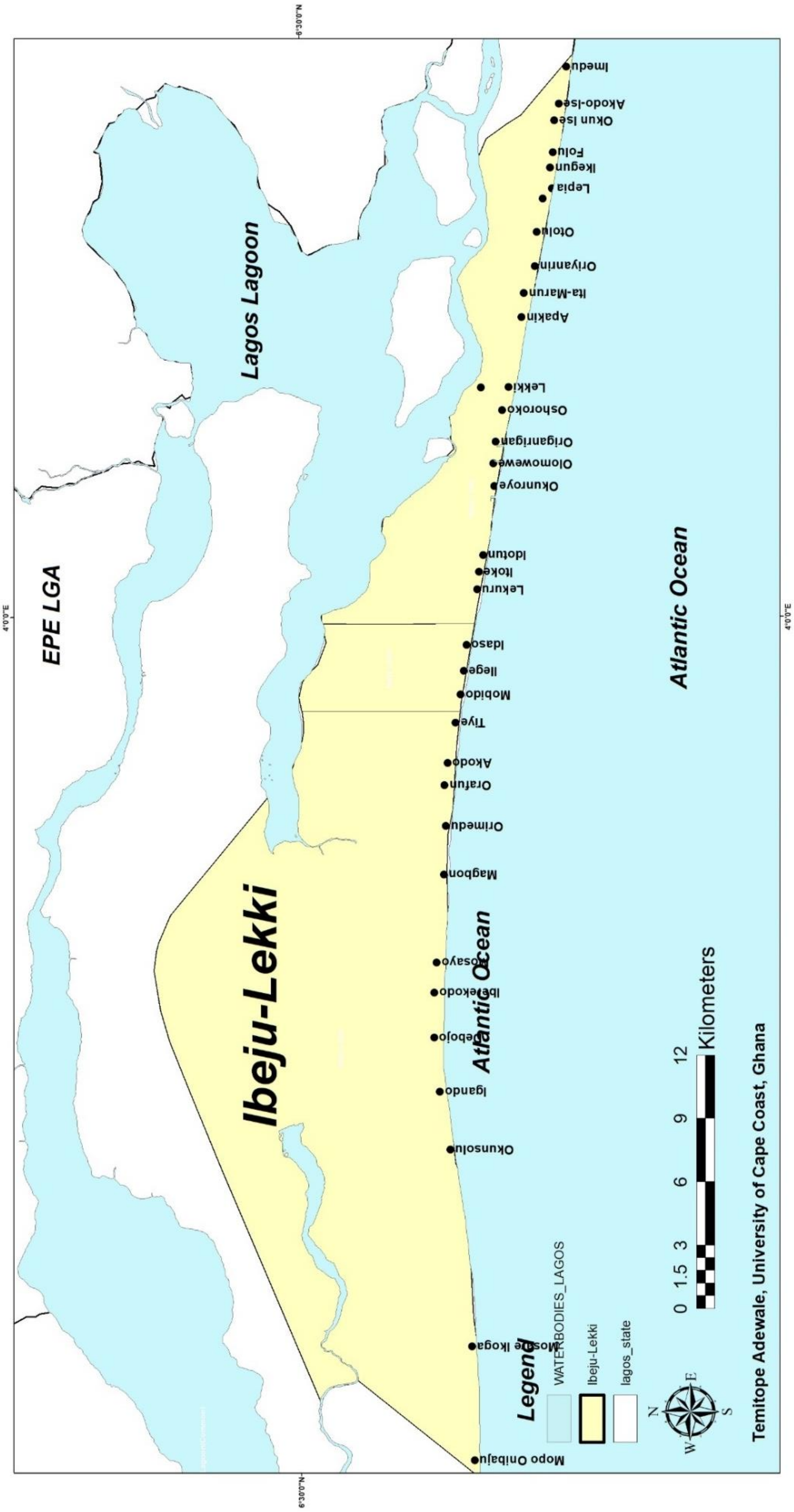

Figure 12: Map of Ibeju-Lekki Showing Fishing Communities (Credit: Centre for Coastal Management, UCC)

Table 3: ***List of Fishing Communities, Sardinella Fishers' Population and Number of Respondents Sampled***

O_ID	Name of Community	X_Coord	Y_Coord	No of Fishers	Respondents Sampled
1	Mopo Onibeju	570649.904	710203.215	26	7
2	Mosare-ikoga	576039.373	710332.186	20	2
3	Iwerekun	580971.087	710695.66	22	5
4	Igando Orudu	588118.119	711854.276	20	4
5	Debojo/Idado	590680.321	712122.65	10	2
6	Badore/Eleko	592815.844	711999.131	6	1
7	Magbon Alade	598409.745	711667.942	290	52
8	Orimedu	600708.216	711570.328	315	57
9	Orofun	602640.31	711634.803	40	9
10	Akodo	603698.202	711494.404	185	34
11	Tiye	605610.807	711111.619	32	6
12	Mobido	606933.329	710870.107	12	1
13	Idaso	609293.271	710589.953	40	6
14	Idotun/Magbon segun	613545.895	709805.322	40	8
15	Okunraye	616821.825	709262.975	20	5
16	Olomowewe	617879.415	709326.165	30	6
17	Origanrigan	618917.048	709206.33	15	3
18	Oshoroko	620422.918	708904.5	15	2
19	Lekki	621501.646	708601.792	60	7
20	Apakin	624818.66	707978.634	40	7
21	Ita-Marun	625958.063	707859.144	100	19
22	Oriyanrin	627240.777	707333.312	74	15
23	Otolu	628868.325	707255.64	80	15
24	Okegelu	630435.325	706974.531	40	14
25	Lepiya	630924.571	706528.296	60	13
26	Ikegun	631900.825	706611.888	20	4
27	Folu	632633.442	706491.583	200	40
28	Okun Ise	634138.993	706413.772	42	10
29	Akodo Ise	634932.844	706212.301	15	6
30	Imedu	636683.217	705850.448	10	0
	Total			1879	360

The selection of communities for focused group discussion was made purposively based on dominant anthropogenic features. Communities close to industrial land use (e.g. refinery), residential land use (a housing estate) and recreational land use (Eleko Beach) were selected. Two FGDs each were held in communities with the above-stated features to total six (6) FGDs. An additional FGD was held, making seven (7). The number of FGDs chosen was based on the principle of *saturation*, which is commonly used to assess data adequacy in purposive sampling and determine sample sizes in qualitative research (Hennink et al., 2019). According to a study by Guest et al. (2016), saturation can be reached in three to six focus groups with a homogeneous study population when groups are not stratified.

Moreover, Coenen et al. (2012) claimed that five focus groups could attain saturation even with a more diversified study sample. From these concepts of saturation, it has been observed that the third group discussion would have identified 84% of most themes from the data, and 90% of themes would have emerged by the sixth (Hennink et al., 2019). Therefore, six focus groups were organised for the study and fishers were assembled into a group of 8-10 persons for each FGD.

The focus group discussion participants were randomly selected among the fishers in each community where the discussions were done. Therefore, fishers who were available, willing and knowledgeable to provide the needed information were invited to participate.

Data Collection Instruments

The research instruments used for gathering data in this study include an interview schedule (Appendix A), a focus group discussion guide (Appendix B) and an observational checklist (Appendix C). The researcher developed the survey instruments, which were structured to capture variables to be measured and ensure that the questions respond to the variables. Section A is structured to elicit responses on respondents' socio-demographic data, which was used as part of the data to assess the fishers' livelihoods. Section B deals with fishers' perception, vulnerability, and adaptation to the effects of climatic variabilities for evaluating the impact of climatic variabilities on fishing and the fishers' livelihoods in the study area. Section *C* focused on anthropogenic activities to assess the effect of anthropogenic activities on fisheries and the livelihood of fishers. Section *D* was based on artisanal fishing of *Sardinella spp*. The focus group discussion guide was used to get qualitative responses that enabled the fishers to express themselves more clearly and give more detailed answers to questions. The observational checklist was used to note structures peculiar to each community in the study area. It helped to obtain evaluative information through direct observation of the characteristics of each community objectively and allowed for inter-individual comparison among communities.

Ethical Consideration and Pilot Survey

Ethical clearance was requested from the University of Cape Coast Institutional Review Board (UCCIRB), Ghana (Appendix D). The Collaborative Institutional Training Initiative (CITI) online training and examination were taken in Nigeria. The training certificate was submitted with other documents to the College of Medicine, University of Lagos Health Research Ethics Committee (CMULHREC), Nigeria (Appendix E), to obtain clearance. This was done to ensure that the research project meets relevant ethical standards (Beckmann, 2017). Research participants were provided adequate information to make a knowledgeable decision as to whether to take part in the research. An informed consent form was given to each respondent to sign or thumbprint to indicate their willingness to participate in the study. No community member was coerced or forced to provide information against their wish. A confidentiality statement was also included in the instrument to assure participants that the study's data would be handled with the utmost confidentiality and used solely for academic purposes.

COVID-19 safety and health protocols were observed using the social distancing measures during interviews. Participants were attended to with their nose masks on, although some were not convenient with the nose masks and could not be forced to use them. In addition to nose masks, handwashing materials, and hand sanitisers were procured and used by the researcher and research assistants.

Fieldwork activities commenced in 2020 with a pilot survey between October and November 2020. The pilot study was conducted prior to the actual data collection and it involved individuals that were not included in the main study. The survey was done to measure the validity and reliability of the study (Devesh et al., 2020). Experts in the field assessed the validity of the interview schedule and suggested changes that were incorporated into the study. The reliability of the collected data was tested using Cronbach's alpha test in SPSS and $\alpha = 0.823$. The alpha value shows that the instrument can be reliably used for the main study. The pilot survey also helped to discover ambiguous and repetitive questions avoided in the research.

Data Collection Procedures for the Study

Sample Collection for Identification of Fish Species

Sample collection for phenotypic identification

Fish samples were collected from landing sites and kept in ice boxes to preserve them from physical and bacterial degradation. The collection was done monthly between January 2021 and March 2022, except when the fish species were unavailable. The samples were then transported to the Marine Sciences

Laboratory at the University of Lagos, Nigeria, for observation and identification. Phenotypic features were examined using the FAO (1990) fish identification guide to verify the species. Samples were subsequently taken for morphometric analysis.

Sample collection for genetic identification

Samples were collected from two primary landing sites, namely the Lekki and Orimedu communities of Ibeju-Lekki. Twelve (12) fish samples were proposed for the analysis based on standards used by Ward et al. (2005), Ivanova et al. (2007) and Kim et al. (2021). However, duplicate samples were collected as a backup for each specimen. Following the method used by Takyi (2019), the dorsal fin of each specimen was cut from the base and was put in a 2ml polypropylene vial. The fin tissues were then preserved in 70% ethanol and kept at -20^{o}C till it was taken to Inqaba Laboratory for extraction. At the Inqaba Laboratory, the description of the samples was entered into a computer before the analysis commenced.

Data Collection on Climatic Variables and Fish Catch Data

Secondary data on climatic variables for Ibeju-Lekki were accessed from Copernicus Marine Services and the Nigerian Meteorological Station (NIMET). The climatic data included rainfall (RFL), sea surface temperature (SST), salinity (SSS), mean sea level (MSL) and ocean colour index (Chl-A) from 1993 to 2019. Monthly averages of the daily data were derived to form climatic variables analysed with the monthly fish catch data available for the same period.

Monthly artisanal landing records for Ibeju-Lekki between 2003 and 2019 were collected from the Lagos State Agricultural Development Agency and Federal Department of Fisheries (FDF), Nigeria repositories. The landing records, consistent for two landing locations in Ibeju-Lekki (Orimedu and Badore), indicated the weather records and total catch in kilogrammes (Kg) for fifteen types of fish, including Sardinella.

Fishing effort and catch per unit effort

Data on fishing efforts were estimated from the observed variables of the primary data by calculating the fishermen's number of trips per hour. According to Arizi et al. (2022) and Stobart et al. (2012), Catch Per Unit Effort (CPUE) measures species abundance in fisheries. CPUE can be estimated by the number of fish caught (often weight) per unit effort expended (often time), which is proportional to the stock size (Thompson et al., 1998). Therefore, to estimate the CPUE, monthly fish catch data were compiled from the LSADA, Federal Department of Fisheries (FDF) Nigeria, and Food & Agriculture Organisation Repositories from 2003 to 2019. In addition, fishing effort data expressed as hours of fishing trips was derived from fishers' responses during the interviews.

Data Collection on Anthropogenic Activities

Anthropogenic indicators used in this research that is perceived to predict *S.maderensis* abundance are fishing effort, water quality and land use/land cover changes. Also, the fishers' perception of land use change, amenities and how it affects their estimated fishing effort was derived from the interviews of fishers and FGDs held in the 30 study area communities classified as coastal communities.

Sampling for measurement of water quality parameters

The water quality monitoring was done by collecting water samples at fishing sites on a two-month basis for 12 months (Feb. 2021- Jan. 2022) to allow for an observational study of seasonal variations in a year. In addition, samples for physicochemical analysis were collected 0.50 m below the water surface in 1dm^3 water samplers and stored in one-litre water bottles, properly labelled and stored in ice chests in the field.

Samples were collected during low tide from the six sampling stations (Figure 13). Water temperature and pH were taken, and salinity and TDS were measured using the Horiba U50. For the dissolved oxygen estimate, separate water samples were taken in 250ml bottles at each station. First, oxygen was fixed following the modified Winkler's technique using prepared Manganus Sulphate (Winkler A) and alkaline potassium iodide (Winkler B). Then, 2ml each of Winkler A & B was added into a carefully filled 250ml amber bottle.

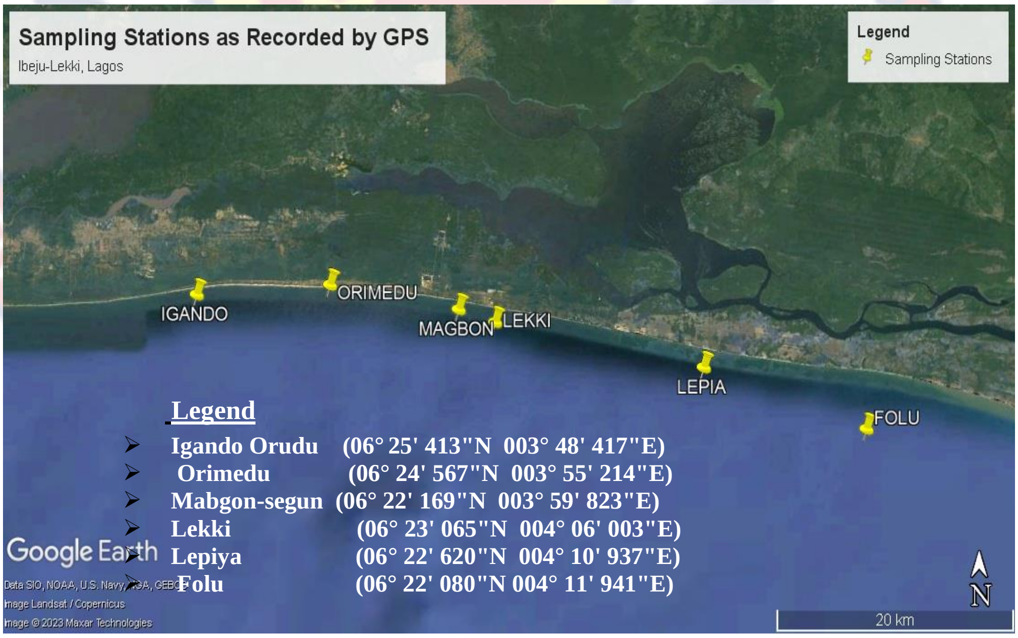

Figure 13: Sample Stations for the Assessment of Water Quality of the Ibeju-Lekki Coastal Waters (Source: Field Survey, 2021)

Water samples for biochemical oxygen demand (BOD), nitrate, phosphate, total petroleum hydrocarbon (TPH) and heavy metals were collected in 250ml & 500 ml amber bottles from the six sampling stations, stored in the ice chest and taken to the laboratory for analysis. Nitrate and phosphate levels were examined using a Spectrophotometer. Water samples for nutrients and heavy metals were collected into 500ml polyethene bottles (HM-preserved with 2ml of conc. HNO_3). Chlorophyll-a water samples were collected in 500ml amber glass bottles fixed with 0.5ml Nitric acid. A typical plankton net with a mesh size of 55 m was used to collect plankton water samples while being held up against the current for 10mins on a moving boat at a slow speed according to the method used by Nkwoji et al. (2010). Then the net was pulled in and the water sample was poured into a 250ml screw-top plastic container that was clearly labelled, fixed with 4% unbuffered formalin, and kept in the lab until microscopic examination.

Data collection on land use/land cover changes

Landsat imageries were accessed at the United States Geological Surveys/Earth Resources and Observation Science (USGS/EROS) website to collect data on land use and land cover changes for the study area for nearly 40 years. As seen in Table 4, imageries used in this research include **Landsat TM** (Thematic Mapper) for 1984, which is the base year, **Landsat ETM+** (Enhanced Thematic Mapper plus) for 2002 and **Landsat OLI_TIRS** (Operational Land Imager and Thermal Infrared Sensors) for 2020. In addition, multispectral and multitemporal analyses were carried out to determine the study area's land use changes. All Landsat images used had a 30m resolution.

Table 4: ***The Data Source of Spatial data***

Acquisition Date	Satellite Number	Sensor Type	WRS Path/Row	UTM Zone	Datum	Spatial Resolution (M)	Sources/ Year
4/1/2020	Landsat 8	OLI_TIRS	191/55	31 N	WGS84	30	USGS, 2020
28/12/2002	Landsat 7	ETM+	191/55	31 N	WGS84	30	USGS, 2006
18/12/1984	Landsat 5	TM	191/55	31 N	WGS84	30	USGS, 1984

Spatio-temporal and land-water changes in the area was conducted using GIS, remote sensing, and image analysis of LANDSAT imagery spanning 36 years. Spatial analysis techniques included land use and land cover changes with the help of ArcGIS Software and Idrisi TerrSet. This research adopted three (3) temporal periods based on Landsat imageries available to conduct a 36-year multi-temporal land use change analysis from multi-spectral remote sense data for available periods (1984, 2002, 2020). In addition, false Colour RGB composite raster imageries (Bands 4,5,1 for Landsat 7 and 5,6,1 for Landsat 8) were also created using ArcGIS Software (Figure 14).

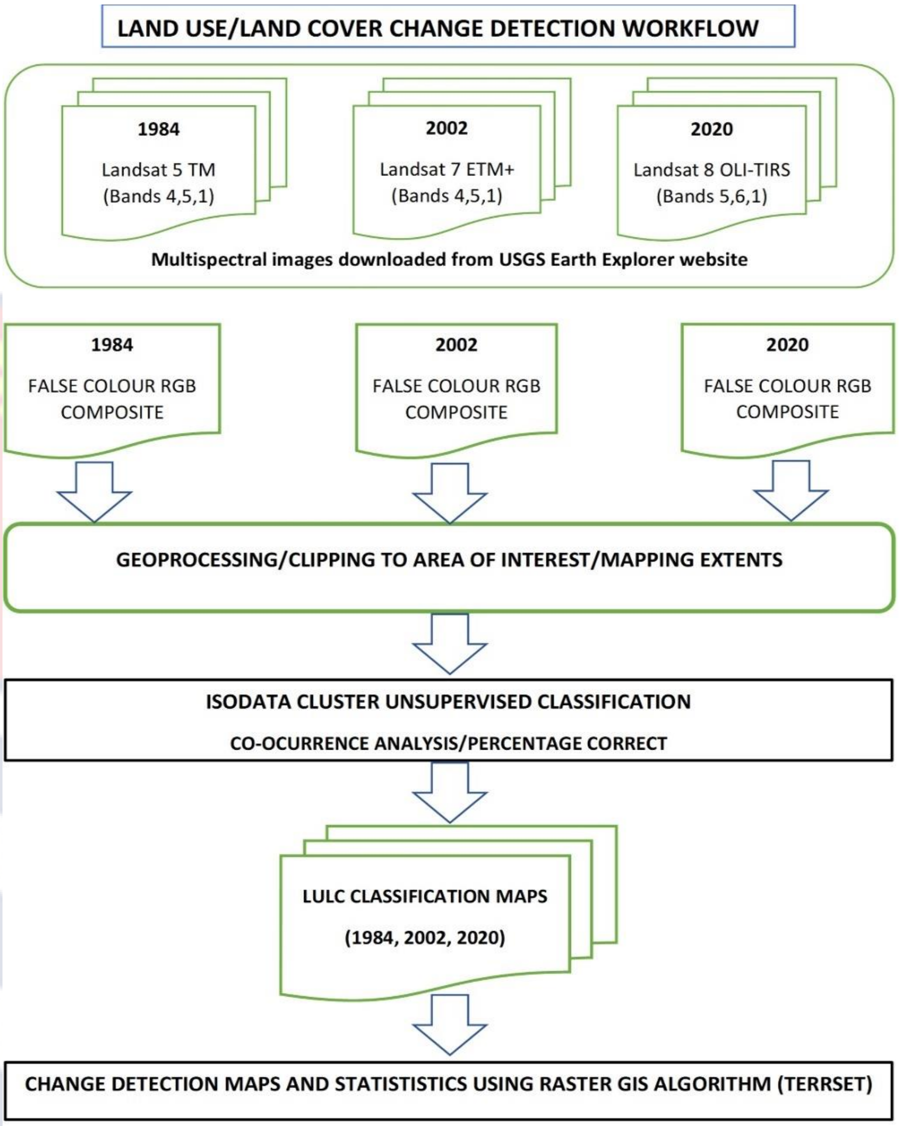

Figure 14: Land Use/Land Cover Change Analysis Workflow (Source: Field Survey, 2021)

Data Collection for Length-Weight Relationship and Condition Factor

A total of 1497 fish samples were collected from sampling stations, namely Orimedu, Magbon Segun, Lekki, Lepiya and Folu (Table 5). These five communities are the major fish landing sites in the study area. The sampling stations were between 06^o 24' 567"N 003^o 55' 214"E and 06^o 22' 080" N 004^o 11' 941"E.

Table 5: ***Sampling Stations with the Coordinates along the Nigerian Coast***

Month	Station	Coordinate	Number of Specimens
January	Lekki	06° 23' 065"N 004° 06' 003"E	111
February	Orimedu	06° 24' 567"N 003° 55' 214"E	72
March	Magbon Segun	06° 22' 169"N 003° 59' 823"E	118
April	Folu	06° 22' 080"N 004° 11' 941"E	120
June	Lepiya	06° 22' 620"N 004° 10' 937"E	120
July	Lekki	06° 23' 065"N 004° 06' 003"E	125
August	Folu	06° 22' 080"N 004° 11' 941"E	153
September	Orimedu	06° 24' 567"N 003° 55' 214"E	127
December	Folu	06° 22' 080"N 004° 11' 941"E	149
March	Lekki Magbon Segun	06° 23' 065"N 004° 06' 003"E	162 140
Total			1492

The collection was done for 15 months, from January 2021 to March 2022. Samples were collected from landing sites with a target of 120 pieces per month; however, the quantity varied by availability. The fish samples were put in an ice chest at the landing site and conveyed to the Marine Research Department, University of Lagos. They were then stored in a deep freezer at a temperature of –20°C. Morphometric characteristics determined included lengths (Total Length, Fork Length, Standard Length) and weight. Length-weight measurements were taken, and the fish samples were dissected to identify the sex and the stomach content/fullness/weight. The gonadal stage was assessed using Fontana's (1969) maturity stages. The stomach contents were removed and observed to ascertain the fullness of the stomach and were subsequently categorized as full (1), three-quarter full (3/4), half full (1/2) or quarter full (1/4). The contents were then crushed and dissolved in 2 ml of water. 3-4 drops were mounted on a slide and examined using the Olympus® binocular light microscope (mag x400) to identify the organisms in the fish stomach.

Field Data Collection (Interviews, FGDs and Observations)

The data collection procedure began with the recruitment and training of field assistants. Three field assistants were trained as enumerators to collect primary data from the fishers. In addition, the field assistants were instructed to use the survey application on their mobile devices. The training also covered maintaining ethical conduct during fieldwork that will assure the respondents of their confidentiality and anonymity. The researcher facilitated the training, and it took place for a day.

Primary data collection commenced after the community entry procedures were met and consent was sought from the respondents. The survey was administered to the participants by asking them questions in the interview guide and entering responses using a survey application, the KoBo Toolbox (Figure 15). This application was installed on Android mobile devices.

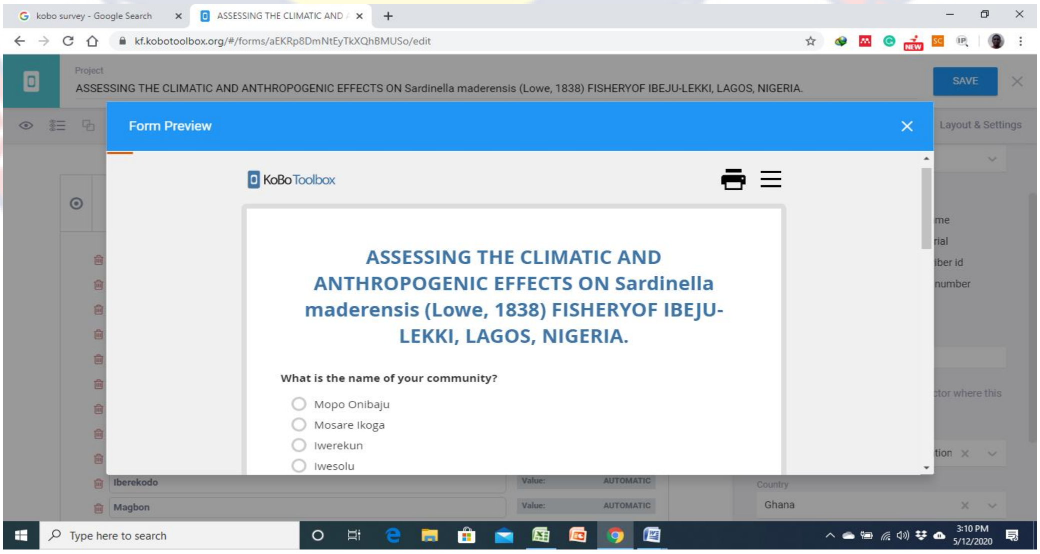

Figure 15: KoBo Toolbox application form used for entering fishers' responses

The application allowed offline data collection and uploading or synchronizing when online. The mobile survey application helped reduce paper-based survey data entry and retrieval errors. It also saved time for data entry into the computer since data is synchronised and downloaded into a statistical package in a spreadsheet format. Another advantage of the mobile application is geocoding the respondents' location, which checks the precision of the field enumerators' tasks.

Primary data was collected through interviews, observations, field notes, key informant interviews and FGDs. The data collected through in-depth interviews (Figure 16) and FGDs (Figure 17) took place for two (2) months between October and November 2021. There was no need to differentiate the fishers into groups of a different gender for the FGD since they were all males. In-depth interviews were conducted in all the communities selected for sampling, and the FGDs were conducted in six communities with dominant anthropogenic features.

Figure 16: Primary data collection through interview of fishers at Ibeju-Lekki

Figure 17: Focus Group Discussion with Fishers at Ibeju-Lekki

Data Analysis Procedures

Phenotypic and Genetic Analysis of Fish Samples

Phenotypic analysis/ species identification procedure: The fish samples were cleaned and sorted into batches for proper labelling. Biometric features include the fin count, ray count, tailfin shape, spine count and position, and count of gill rakers. Other special features, like the black area around the operculum, were also examined on the fish species. Species identification was completed using guides by (FAO, 1990; Froese & Pauly, 2017). Key morphometric and meristic characteristics were examined to identify which species of Sardinella the fish samples belonged.

DNA Extraction: Genomic DNA was extracted from the ethanol-preserved samples using Quick-DNA^{TM} Miniprep Plus kit (Zymo Research Catalogue No. D4068). The process of DNA extraction includes Digestion, Purification and Transfer. Eppendorf tubes/microcentrifuge tubes were labelled in line with the sample specifications. A spatula was used to remove each sample from the ethanol and placed on a foil on the Mettle Toledo weighing balance. 25mg of the sample was weighed and placed into its respective tube. The tissues were removed from the tubes and grinded using the mortar and pestle individually, making sure not to mix the samples by washing and cleaning after every grinding. Afterwards, the crushed sample was transferred into the Eppendorf tube, and 95µl of water (Nuclease-free water), 95µl of solid Tissue Buffer (Blue) and 10µl of Proteinase K were added.

The resulting mixture was mixed by vortexing using the IKA Vortex 2 for 10-15 seconds before incubating at 55°C for 1-3 hours or until the tissue solubilizes and mixes thoroughly before proceeding to the next step. After removing from the incubator, to remove insoluble debris, it was centrifuged at 12,000rpm for 2 minutes to get enough supernatant. After that, the aqueous supernatant was transferred into a clean microcentrifuge tube. Next, 100 µl supernatant was drawn using a pipette and put in another Eppendorf tube.

To the supernatant, two volumes (200µl) of Genomic Binding Buffer were added and mixed thoroughly by vortexing for 10- 15 seconds. The mixture was transferred into the Zymo-Spin IIC- XLR Column in a collection tube and centrifuged at 12,000rpm for 1 minute. Next, 400 µl of the DNA Pre-wash Buffer was added to the spin column, then centrifuged at ≥12,000rpm for 1 minute. Next, the collection tube and 700µl of the gDNA (Genomic DNA) were emptied, and Wash Buffer was added to the spin column. The collection tube was again emptied after centrifuging at ≥12,000rpm for 1 minute. This was followed by adding 200µl of the genomic-DNA Wash Buffer and centrifuge at ≥12,000rpm for 1 minute.

The collection tube was discarded with the flow through, and the spin column was allowed to dry to remove all the reagents for 6mins at 6000rpm and afterwards transferred into a clean microcentrifuge tube. The DNA Elusion buffer was added to improve the total yield by eluting the DNA with a 60- 70°C DNA Elution Buffer. 70 µl of the DNA Elution Buffer pre-heated at 60°C was added directly to the matrix. Incubation for 3 minutes was done at room temperature. Nanodrop spectrophotometry (RNA) was used to check the quality & concentration of the DNA. Storage of the eluted DNA was at ≤ -20°C for future use.

PCR amplification: The target region was amplified using OneTaq® Quick-load®2X Master Mix. This technique is used in making multiple copies of the gene of interest. The PCR process has three steps: denaturation, annealing and extension. The 12.5-µL PCR mixes included 4.75µL of Nuclease-free water, 6.25µL of Master mix ($MgCl_2$, dNTP, Taq polymerase, and water), 0.25 µL each of the forward and reverse primer (Table 6 and 7) and one (1) µL of Template DNA. The first primer used is the universal cocktail primer, a global bio-identification sequence for animals by Hebert et al. (2003), prepared for forward and backward reactions according to Ivanova et al. (2007).

Table 6: *1st Primer Sequences*

Name of Primer	Target	Sequence (5’ to 3’)
FISH F1	COI	TCAACCAACCACAAAGACATTGGCAC
FISH R2	COI	ACTTCAGGGTGACCGAAGAATCAGAA

Table 7: *2nd Primer Sequences*

Name of Primer	Target	Sequence (5’ to 3’)
FISH F1	COI	TCGCCGCATACACTATTCTCAGAATGA
FISH R2	COI	TAGACTTCTGGGTGGCCAAAGAATCA

The second primer proposed by Ward et al. (2005) was also synthesized for both on and backward reverse reactions.

*Gel Electrophoresis***:** First, 100ml of 1xTAE Buffer was measured, and 1g of Agal Powder was added, and this was used to prepare a 1% gel for the electrophoresis. It was mixed thoroughly and microwaved for 1min for about 3x until the agarose perfectly dissolved and allowed to cool down. The DNA Stain – Safe-view fire red was added to aid in visualization under UV light. Next, 5µl for the ladder was loaded into the first well and 2µl for the samples into each of the wells, and the gel run at 100 volts for 40 minutes.

PCR Clean-Up and Sequencing: After the PCR products were run on the gel, they were cleaned up enzymatically using the EXOSAP method. Clean-up was done with the Exo-sap mixture from Exo-nuclease 1, Shrimp Alkalinase-Phosphatase (Shrimp A1). Exo-nuclease 1 removes the excess primer, and Shrimp A1 removes the nucleotides in the PCR. The excess primers and nucleotides were removed so as not to cause any difficulties in the sequencing. 2.5µl of the Exo-sap was added to the 10µl PCR Amplicon, then placed in a microcentrifuge to mix for 1 minute. Then was taken to the Thermocyler at 37°C for 15mins & 80°C for 15mins, and four (4) °C for hold. It was then kept in an ice pack and put in the fridge pending sequencing in the Genetic Analyser or Sequencer. Using Nimagen, BrilliantDye^{TM} Terminator Cycle Sequencing Kit V3.1 sequencing of the extracted fragments was done in the forward and reverse direction, and then purified. The ABI350xl Genetic Analyser was used to analyse the purified fragments. The ab1 files generated were edited using BioEditSequence Alignment Editor version 7.2.5, and a BLAST search in NCBI was conducted to obtain the results.

Description of Analysis/ Testing of the Study's Hypotheses

The second and third research objectives adopted a quantitative approach to understand the effects of climatic variables and anthropogenic activities on the abundance of *Sardinella* species. The following are null Hypotheses tested in this study:

$H_{01:}$ Climatic variabilities do not have significant effect on the abundance of *Sardinella maderensis*.

H_{02}: Anthropogenic activities do not have significant effect on the abundance of *Sardinella maderensis*.

Fish Abundance (FA) was estimated as a measure of Catch per Unit Effort which was used as the dependent variable. At the same time, the five fundamental climate change indicators (rainfall, mean sea level, sea surface salinity, sea surface temperature, and primary production) are the independent variables used to test the first Null Hypothesis. Similarly, the second hypothesis was tested using Catch per Unit Effort as the dependent variable, while fishers' perception of land use, amenities and fishing effort were the independent variables.

According to Harley et al.(2001) & Maunder et al. (2006), the use of CPUE as a measure of abundance depends on a key connection frequently employed in quantitative fisheries analysis, which connects catch to abundance and effort:

$$C_t = qE_tN_t \tag{8}$$

Where C_t = catch (*time t*), q = the quantity of the stock captured by one unit of effort (catchability coefficient), E_t = effort (time t), *and* N_t = abundance (time *t*). The link between CPUE and abundance can be formed by rearranging the equation as follows:

$$C_t / E_t = qN_t \quad (9)$$

Adjusting CPUE to reflect abundance (provided q is constant).

$$CPUE_t \propto N_t \quad (10)$$

Therefore, for this study, catch per unit effort was used as a measure of abundance despite its limitations because full stock assessment cannot be done due to the unavailability of adequate data; and was estimated as the number of fish per amount of fishing time.

$$CPUE(KG/H) = \frac{CATCH\ PER\ TRIP}{TRIP\ (HOURS)} \quad (11)$$

Analysis of the Effects of Climatic Variabilities on *S. maderensis* Abundance

Linear regression models were used to determine if climatic variabilities predict Sardinella fish abundance, while the ARIMA model was used to predict the future trends of fish catch. The method was applied by several authors (Kripa et al., 2018; Puspasari et al., 2019; Sabatés et al., 2006; Zeeberg et al., 2008) for *Sardinella aurita* and *Sardinella longiceps*. The model is as follows:

$$\gamma = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots \beta_n X_n + \varepsilon \quad (12)$$

In the above model, the dependent variable (γ) is Catch per Unit Effort, while the explanatory variables X_1, X_2, $X_3 \ldots X_n$ is monthly data composites on RFL, SST, SSS, SLR and Chlorophyll-*a*. The regression coefficient is β, while the residual or random error term is ε. Therefore, the model was adapted for this research as follows:

$$y_i = \beta_0 + \beta_1 RFL_{} + \beta_2 SST_{} + \beta_3 SSS_{} + \beta_4 SLR_{} + \beta_5 CHL_{} + \varepsilon_i \qquad (13)$$

Where y = CPUE_KG_H (Catch Per Unit Effort Hourly (Kg)

,β= coefficient of regression of the variable X predicting y, RFL_1= Total Monthly Rainfall, SST_2= Sea Surface Temperature, SSS_3= Sea Surface Salinity, SLR_4= Sea Level Rise, and CHL_5 = Chlorophyll_a.

Trend analysis was carried out and the Arima model was used to forecast/predict the future trend of *Sardinella maderensis* abundance.

Analysis of the Effects of Anthropogenic Activities on *S. maderensis* Abundance

Land use change and water quality are primary anthropogenic indicators that are presumed to affect fisheries. Extensive investigations were done to determine the extent of land use change and water quality; however, the fishers' perception of how anthropogenic activities affect Sardinella fisheries forms the basis of testing the second hypothesis. The second hypothesis was tested using the volume of fish catch as the dependent variable, while observed fishers' perception of land use change, amenities and fishing effort were the independent variables. A linear regression analysis was conducted to assess whether land use, social amenities, and fishing effort significantly predicted fish catch.

$$\gamma = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \ldots\ldots\ldots \beta_n Z_n + \varepsilon \qquad (14)$$

For the above model, the dependent variable (γ) is the Volume of Fish Catch, with the explanatory variables Z_1, Z_2, $Z_3 \ldots Z_n$ is V_LANDUSE, V_AMENITY and V_FISHG_EFFORT. The regression coefficient is β, while the residual or random error term is ε. Therefore, the model was adapted for this research as follows:

$$y_i = \beta_0 + \beta_1 V\_LANDUSE + \beta_2 V\_AMENITY +$$
$$\beta_3 V\_FISHG\_EFFORTS + \varepsilon_i \qquad (15)$$

Where *y* = V_FISHCATCH (Volume of Catch (Kg))

,*β*= coefficient of regression of the variable *X* predicting *y*, V_LANDUSE= Land use change effect, $V\_AMENITY_2$= Access to Social Amenity and V_FISHG_EFFORT

Analysis of water quality parameters

TDS, Salinity: At the laboratory, each water sample was carefully poured into the cup to measure the Total Dissolved Solids (TDS) and salinity using the Horiba U50 series water quality instrument. The instrument was inserted into the water to get stable values of readings for further statistical analysis.

Dissolved Oxygen (DO): In the laboratory, 2ml of sulphuric acid was added to dissolve the gelatinous precipitate till a clear golden colour appeared. Then, a measuring cylinder was used to measure 50 ml of the sample into a conical flask. Finally, it was titrated against Prepared Sodium thiosulphate using starch as an indicator till the blue-black colour changed to the clear solution.

Biological Oxygen Demand (BOD): A dissolved oxygen test was used to calculate the five-day BOD following the procedure outlined in APHA (2005). The BOD level was calculated by comparing the DO levels of two water samples: one collected on the first day and the other incubated for five days at 20 °C in darkness. The difference between the two DO levels, which indicates the quantity of oxygen necessary for the decomposition of any organic material in the sample, provided a reliable estimate of the BOD level.

Nitrate: Before analysis, 250 ml of the sample was filtered through a Whatman GF/F filter (0.7 µm pore size). 10ml of the sample was taken and put in a labelled centrifuge tube, add 0.2 ml concentrated buffer (NR_1) was added and shaken. After 5 mins, 0.2ml NR_2 was added and shaken again. The reading was taken in the Spectrophotometer after 30mins (Nitrite LR) with the untreated sample used as blank.

Phosphate: Before analysis, 250 ml of the sample was filtered through a Whatman GF/F filter (0.7 µm pore size). Water was collected from the sampling bottle, 10 ml of the sample was added into a labelled centrifuge tube with 0.2 ml of the composite reagent. The colour was allowed to develop, and reading of the OD was taken at 885 nm after 10 to 20 minutes. The instrument used was the Smart Spectrophotometer (UV).

Chlorophyll-a: In the laboratory, the water was mixed, and 200ml of the water sample was measured and filtered through 0.45 µm pore GF/F filters immediately upon arrival. Each filter paper was introduced into a centrifuge tube and 10 ml of extraction solvent; methanol was added, the filter paper was disintegrated using a glass rod, and the centrifuge tube corked and shook. This was allowed to stand in methanol for an hour at room temperature, centrifuged for a minute at 3000 - 4000 rpm and the supernatant collected in a measuring tube, for analysis. The optical density (OD) of the extract was read at 730, 630, 645 and 663 nm, and the chlorophyll concentration was then calculated using the equation below:

$$[\text{Chl a}](\mu g/l) = (11.43 \times OD663 - 2.16 \times OD645 - 0.11 \times OD630) \times F \quad (16)$$

Where $F = v/(1 \times V)$

V = volume of water sample filtered (ml)

Planktons: In the laboratory, five drops of the concentrated sample (10ml) were placed on a slide and inspected using a Wild II binocular microscope with a calibrated eyepiece at various magnifications (50X, 100X, and 400X). The average was then taken and recorded. For the plankton estimate, the drop count method of microscope examination, as published by Onyema (2007), was applied. Organisms were examined to identify the phytoplankton and zooplankton species (adults and juveniles). Paleontological Statistics (PAST) software version 3.18 was used to calculate the plankton diversity indices.

Total Petroleum Hydrocarbon (TPH) Extraction: The solid phase extraction (SPE) column separation method was employed to remove interfering organic and polar species. SPE (pre-packed column) was pre-rinsed with 20 ml of n-hexane before the sample was loaded, and the sample was eluted with 50 ml of 1:1 Diclomethane + N-Pentane for TPHs. The eluted fraction was evaporated to dryness, and the dried extract was reconstituted with 2ml Iso-octane, and this was transferred into a GC vial. The sample was analysed for TPHs using a Gas Chromatograph fortified with a Flame ionisation detector (GC/FID)

Heavy Metal: Ten (10) ml of Nitric acid was added to 25 ml of the water samples. The samples in the flasks were heated at a temperature not more than 120 ^{o}C for 1hr on the hot plate until the content was about 5 mL; the sample was removed and allowed to cool for 30 min. These were filtered (using Whatman filter Paper 1) into a standard flask (50 m**l**), made up to mark, and stored in a plastic dispensing bottle. The PG 990 Atomic Absorption Spectrophotometer (AAS) was used to determine the metal contents in all extracts.

Land Use/Land Cover Change Analyses: False Colour RGB composite raster imageries (Bands 4,5,1 for Landsat 7 and Bands 5,6,1 for Landsat 8) were derived using ArcGIS Software (Figures 18, 19 and 20). A subset of the composite imageries limited to the AOI was extracted using a clip geoprocessing tool in ArcGIS.

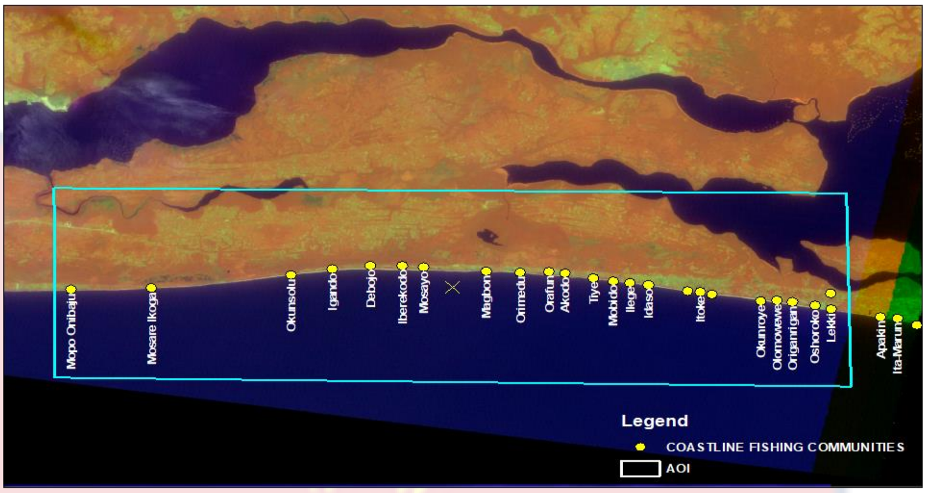

Figure 18: 1984 False Colour RGB Composites for Ibeju-Lekki

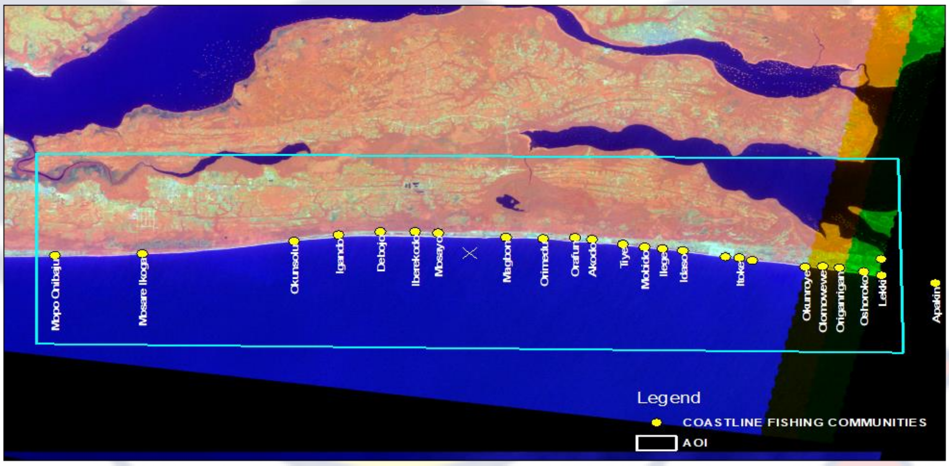

Figure 19: 2002 False Colour RGB Composites for Ibeju-Lekki

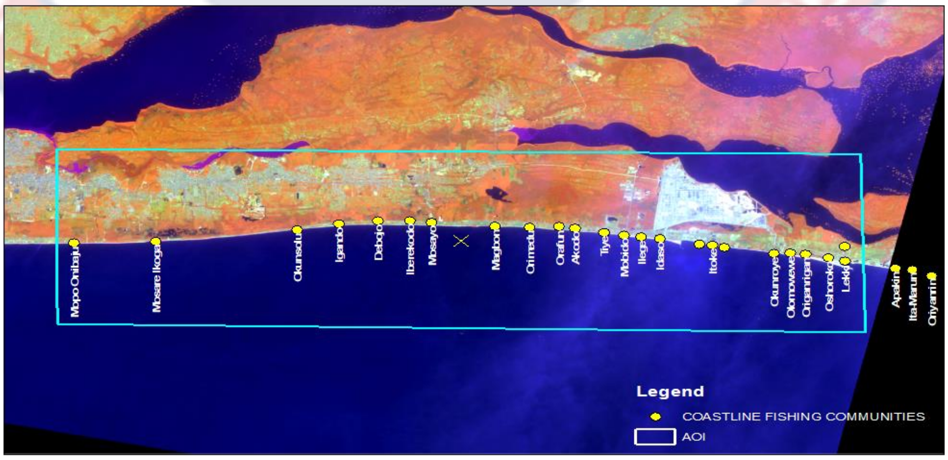

Figure 20: 2020 False Colour RGB Composites for Ibeju-Lekki

The RGB composite imageries were classified utilising ISODATA unsupervised algorithm in Microimages TNTGIS. Imageries were then synchronised with Google Earth and ground truthing to validate the classification. Change detection and change statistics were generated from land use/land cover change maps in TERRSET.

Analyses on Length-Weight Relationship and Condition Factor

Fish samples (Figure 21 a) were cleaned, excess moisture was removed after thawing and biometric measurements were done as described in Soyinka & Ebigbo (2012) and Amponsah et al. (2019). A digital weighing scale was used to measure the weight to the nearest 0.01g (Figure 21 b). The lengths, total length (TL), fork length (FL), and standard length (SL)) were measured for each specimen to the nearest 0.1 cm using a 100 cm measuring board (Figure 21 c). The distance from the closed mouth of the snout to the tip of the caudal fin was used to determine total length; the distance from the snout to the caudal fin's forked tip was used to determine fork length; while the standard length was the distance from the snout to the caudal peduncle.

The samples were also dissected for stomach content observation (Figure 21 d). The fish's length-weight relationship (LWR) was determined using linear regression (Pauly, 1983) as incorporated by the FAO ICLARM Stock Assessment Tool (FISAT) (Gayanilo & Pauly, 1997).

Length-weight relationship: The equation used to determine the growth pattern using the length-weight relationship was by Pauly (1983):

$$W = aL^b \qquad (17)$$

The logarithmic transformation gives:

$$\text{Log } W = \log a + b \log L \qquad (18)$$

Where W= weight in grams(g), L = standard length of fish in centimetres (cm), a = Intercept, b = Slope (weight at unit length)

The correlation (r), was calculated from the regression equation information (r^2) (Ogbeibu, 2005) as stated in equation:

$$r = \sqrt{R^2} \tag{19}$$

Figure 21: (a) Fish samples, (b) length measurement, (c) weight measurement and (d) stomach content observation of *S. maderensis* from Ibeju-Lekki coastal waters

Condition Factor: The condition factor to assess a fish's general health in proportion to size was computed using the equation (Ricker, 1975):

$$K = 100\ W/L^{\wedge b} \tag{20}$$

Where:

K = condition factor

W = weight of the fish in grams (g)

L = length in centimetres (cm)

b = value from the length-weight relationship.

The exponent b value, equal to 3, was not used to calculate the K value because, according to Bolger & Connolly (1989), it is not a true representation of the length-weight relationship for the great majority of fish species. This led to the usage of the b-value calculated from the length-weight relationship ($W = aL^b$) as suggested by Lima-Junior (2002).

The data obtained were analyzed using Descriptive and Regression Analysis in terms of means and standard deviations. Regression and one-way analysis of variance (ANOVA) tests at 0.05 significance level were carried out with standard length and weight as sources of variation (Appendix F).

Analysis of Fishers' Perception of Climate Variability and Anthropogenic Activities Effects

Fishers' perceptions were entered using the KoBo toolbox application. An MS Excel spreadsheet was used to numerically code and record the interview schedule responses. Then, the data was cleaned before being imported and analyzed using the SPSS version 25 platform. Each respondent's normalized scores were then ranked. The analysis included quantitative and qualitative methods. The quantitative aspect employed descriptive statistical methods comprising fundamental frequencies, tables, and charts. In contrast, qualitative methods used to analyse the focus group discussion included Thematic analysis and Crowdsourcing.

Analysis of fishers' vulnerabilities

The responses on vulnerability were considered under the five livelihood dimensions, i.e., natural, physical, human, economic and social (Allison & Ellis, 2001; DFID, 2001). Twenty-one (21) forms of vulnerability to small-scale fisheries-based livelihoods were categorized under the five dimensions. The fishers' responses based on their agreement (5- point Likert scale- Strongly Agree, Agree, Undecided, Disagree and Strongly disagree) to being susceptible to the forms of vulnerability was then scored. The mean of the weighted score was subsequently calculated, and the ranking of the vulnerabilities was based on the mean of the weighted score. The rank (ordinal ranking) is the level of how much they agree to being susceptible to a loss, risk or harm, and it was put at 1 (Highest form of vulnerability) – 21(Least form of Vulnerability). In addition, participants' responses on their perceptions of the severity of the loss of assets were also analysed. The scores for the level of severity were calculated by assigning values 1- 5 to each level of severity, from a range of 'None severe', 'Mildly severe', 'Moderately severe', 'Severe' and 'Extremely severe'. The mean of the weighted score was also calculated and ranked from one(1) - six(6).

Table 8: ***Task Summary***

Objective	Unit of Analysis/ Target Population	Types of Data Required	Source of Data	Analytical Technique
To identify the *Sardinella species* in the Ibeju-Lekki coastal waters	Fish samples from Ibeju-Lekki	Phenotypic features and genetic sequence data	-Marine Science Laboratory of the University of Lagos, Nigeria. - Inqaba Lab, Ibadan, Nigeria.	Physical identification and genetic analysis
To examine the effects of climatic variabilities on *S. maderensis* abundance	-Fishing communities in Ibeju-Lekki	- Climatic data on rainfall, sea surface temperature, salinity, sea-level rise, and chlorophyll-a from 19993 to 2019 -Monthly catch data from 2003 to 2019.	-Copernicus Marine Services and Nigerian Meteorological Station (NIMET) -Monthly fish catch data from LSADA, FDF Nigeria, FAO Repositories	-Trend Analysis -Regression Analysis
To assess the effects of anthropogenic activities on *S. maderensis* abundance	-Water samples -Fish catch in Ibeju-Lekki	- Data on land use, amenities, and fishing effort - Water sampling for nutrient load, plankton, heavy metals and TPH -Land-use change/cover imagery data	-Responses from in-depth interviews -Field sampling January and December 2021 -Landsat and High-resolution satellite image	-Descriptive -Regression analysis -Analysis of Variance -Paleontological Statistics (PAST) -Spatial Analysis
To evaluate the length-weight relationship and condition of *S. maderensis* in the fishery	Fish samples	-Fish samples from landing sites with a target quantity of 120 pieces per month (varied by availability). -Morphometric characteristics, lengths (TL, FL, SL) and weight.	Field sampling	Descriptive Analysis Regression Analysis
To assess the vulnerabilities of small-scale fishers and explore their strategies for resilience	-Fishers in the community	Information on fishers' perception of climatic and anthropogenic risks, effects on their livelihoods	Primary data obtained through a structured questionnaire, FGD, Observations & key informant's interview	Thematic analysis and Crowd Sourcing.

Chapter Summary

This Chapter presented information on the research methods used, the study area, sampling sites, study structure and target population. Procedures for data collection and how data was analysed were described. Statistical analysis, software used to make inferences and the study's limitations have also been indicated.

CHAPTER FOUR

RESULTS

This chapter discusses findings from the field survey. The results of the fish species identification using the morphological characteristics and genetic analysis are presented. The chapter also presents results, the trend of climatic variables and fish catch data, and a forecast of future fish abundance. It further shows the effects of climatic variables and anthropogenic activities on Sardinella species in the study area. The length-weight relationship and the condition of *Sardinella maderensis* in the fishery are presented. The results of fisher responses on their perception of climate change and anthropogenic effects, their vulnerability to these effects and strategies for a resilient small-scale fishery in the study area are also presented.

Fish Species Identification

The morphometrics-based identification system involving external and phenotypic features to identify the fish species revealed that the species are mainly *Sardinella maderensis*. The fish samples (Figure 22) had flat bodies with a black area just behind the gill opening, and the caudal fins were grey, with tips almost black.

Figure 22: Fish Specimen (Source: Field Survey, 2021)

In addition, they have elongated bodies with fairly sharply keeled bellies, 18-23 dorsal soft rays and, 17-23 anal soft rays and 70-166 lower gill rakers. The upper pectoral fin rays are white on the outer side, and the membrane is black with one unbranched and seven branched pelvic fins. A prominent distinguishing feature is that S. *maderensis* has a black spot at the base of the dorsal fin.

Genetic identification

The BLAST (Basic Local Alignment Search Tool from National Centre for Biotechnology Information www.ncbi.nlm.nih.gov) results reflect similarities between the sequence searched and the biological sequences in the NCBI database. The result of the first analysis using the Animal ID COI is presented in Table 9.

Table 9: ***Species Identification with Percentage Similarity and BLAST Prediction (1st Primer)***

S/N	Name of Sample	Percentage ID (%)	GenBank Accession No.	BLAST Prediction
1.	OR1	92.42	CP080036.1	*Brevundimonas nasdae*
2.	OR2	96.18	KY176606.1	*Sardinella maderensis*
3.	OR3	83.88	CP080036.1	*Brevundimonas nasdae*
4	OR4	99.07	KY176606.1	*Sardinella maderensis*
5.	OR5	99.27	AP009143.1	*Sardinella maderensis*
6.	OR6	99.53	KY176606.1	*Sardinella maderensis*
7.	LE1	99.28	MT272817.1	*Sardinella maderensis*
8.	LE2	99.56	AP009143.1	*Sardinella maderensis*
9.	LE3	98.91	KY176606.1	*Sardinella maderensis*
10.	LE4	99.69	KY176606.1	*Sardinella maderensis*
11.	LE5	99.69	KY176606.1	*Sardinella maderensis*
12.	LE6	99.69	KY176606.1	*Sardinella maderensis*

Source: Field Survey 2022

Ten of the twelve samples were identified as *Sardinella maderensis* using the first primer, with percentage identification ranging from 83.88% to 99.69%. The remaining two samples came out as entirely different species, namely *Brevundimonas nasdae.* This species is not fish but a bacterium that has been reported to have been isolated from condensation water. *Brevundimonas* species are referred to as emerging global pathogens (Ryan & Pembroke, 2018).

However, the result derived from the second batch of analysis using the fish primer, according to Ward et al. (2005), indicated that all the samples are *Sardinella maderensis* with a percentage identification of 89.38% - 100% (Table 10). In summary, the results of the genetic identification showed that *Sardinella maderensis* is the species found in the study area.

Table 10: *Species Identification with Percentage Similarity and BLAST Prediction*

S/N	Name of Sample	Percentage ID	GenBank Accession No.	BLAST Prediction
1.	OR1	99.84	MT272815.1	*Sardinella maderensis*
2.	OR2	99.69	MT272814.1	*Sardinella maderensis*
3.	OR3	93.91	MT272807.1	*Sardinella maderensis*
4	OR4	98.89	AP009143.1	*Sardinella maderensis*
5.	OR5	99.21	AP009143.1	*Sardinella maderensis*
6.	OR6	99.01	AP009143.1	*Sardinella maderensis*
7.	LE1	89.38	MT272815.1	*Sardinella maderensis*
8.	LE2	100	MT272815.1	*Sardinella maderensis*
9.	LE3	99.31	MT272816.1	*Sardinella maderensis*
10.	LE4	99.62	MT272816.1	*Sardinella maderensis*
11.	LE5	99.83	MT272811.1	*Sardinella maderensis*
12.	LE6	99.83	MT272816.1	*Sardinella maderensis*

Source: Field Survey 2022

Effects of Climatic Variabilities on *Sardinella maderensis* Abundance

Climatic variabilities were examined using Time Series Analysis. This study created time plots for rainfall, Ocean Colour (Chlorophyll a), Mean Sea Level, Surface Sea Salinity and Surface Sea Temperature between 1993 and 2019. Time plots make visualization of time series data easier to understand, which pattern could be stationary, seasonal, upward/downward, or heteroscedastic. Moreover, ARIMA Time Series Analysis was conducted for the combined fish catch data of Orimedu and Badore communities which were available from 2003 to 2019.

Rainfall (RFL)

The time series analysis conducted for Rainfall (RFL) indicates a lack of seasonality with stationarity. Furthermore, the trend is not increasing or decreasing, but fluctuating, as shown in Figure 23.

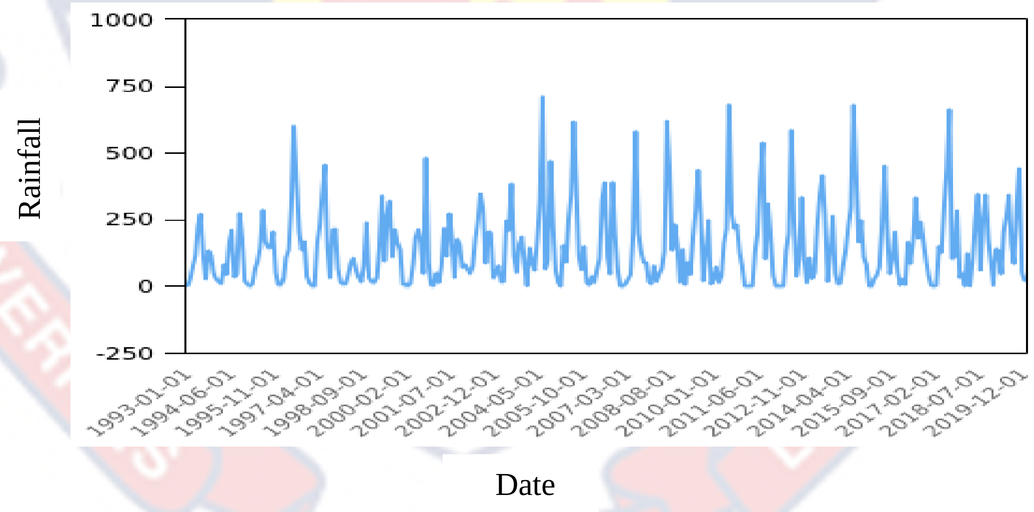

Figure 23: Line plot of Annual Rainfall (RFL) for Ibeju-Lekki from 1993 to 2019

Chlorophyll-a (Chl_A)

The Time Series analysis conducted for Chlorophyll A (Chl_A) also shows a lack of seasonality. In addition, the stationarity condition was not met since there is a downward trend by decreasing Chlorophyll-a (Hyndman & Athanasopoulos, 2018) (Figure 24).

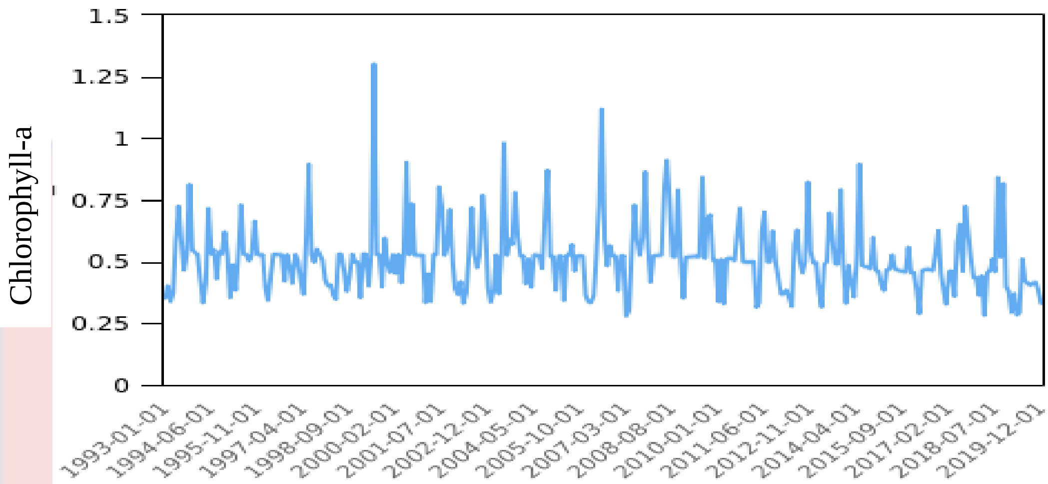

Figure 24: Line plot of Annual Chlorophyll-a (Chl_A) for Ibeju-Lekki from 1993 to 2019

Mean sea level (MSL)

The line plot for mean sea level indicates a lack of seasonality and stationarity. Stationarity can only be met if there is no increase or decrease trend (Hyndman & Athanasopoulos, 2018). The Mean Sea Level shows an upward trend (Figure 25).

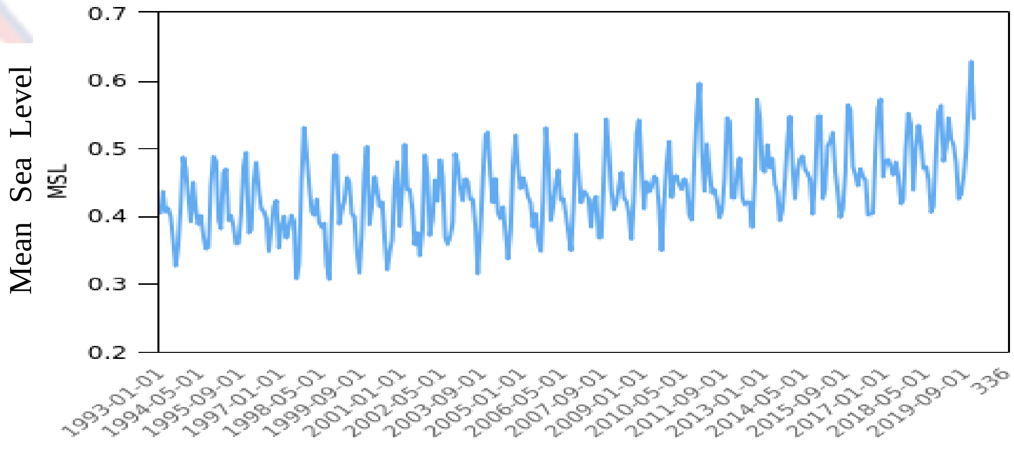

Figure 25: Line plot of Annual Mean Seal Level (MSL) for Ibeju-Lekki, from 1993 to 2019

Sea surface salinity (SSS)

The line plot for Sea Surface Salinity (SSS) in Figure 26 indicates that the data is not seasonal or stationary and there is a decreasing trend.

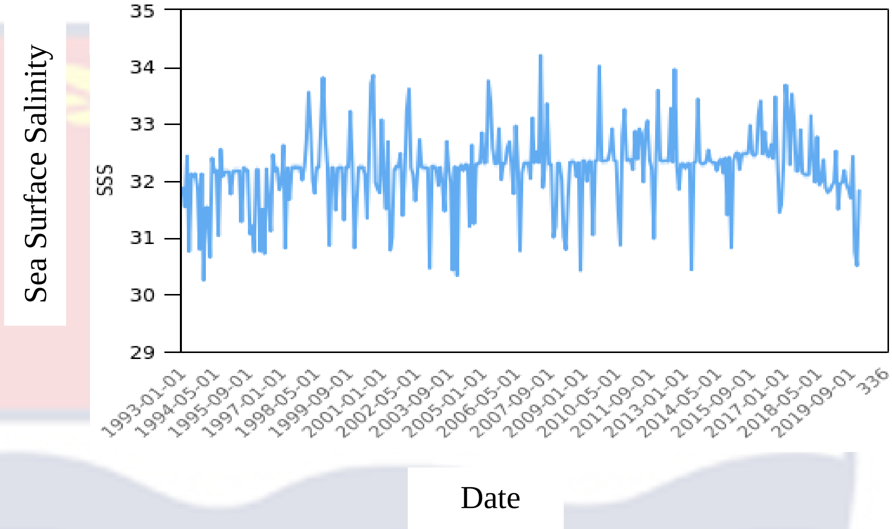

Figure 26: Line plot of Annual Sea Surface Salinity (SSS) for Ibeju-Lekki from 1993 to 2019

Sea surface temperature (SST)

Time Series Analysis for SST (Figure 27), indicates no trends or seasonality in the data. However, the data shows stationarity. There is no decreasing trend in the Sea Surface Temperature.

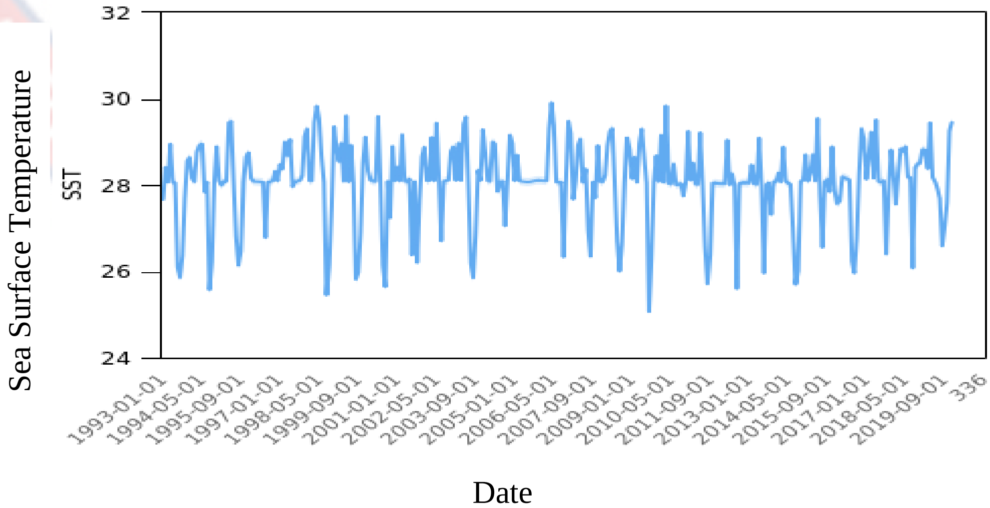

Figure 27: Line plot of Annual Sea Surface Temperature (SST) for Ibeju-Lekki, from 1993 to 2019

In summary, the rainfall and temperature trends are similar, showing a fluctuating pattern. Also, the line plot chart for chlorophyll-a and salinity shows a downward trend towards 2019, while the mean sea level shows a rising trend. The trend analysis results corroborated the fishers' observations (Figure 28) about the climatic indicators in the past ten years. Out of the 360 fishers that participated in the survey, 93.3% observed an increased rainfall, and 91.1% observed a rise in sea level. Also, 63.6% observed some change in the saltiness of the seawater, while 65.8% observed a decline in fish food (Chlorophyll a). In addition, 95.6% noticed an increase in the temperature of the sea.

The fishers' observations, though not scientific, could be said to be first-hand experience in understanding the effect of climatic variabilities in the *Sardinella maderensis* fishery.

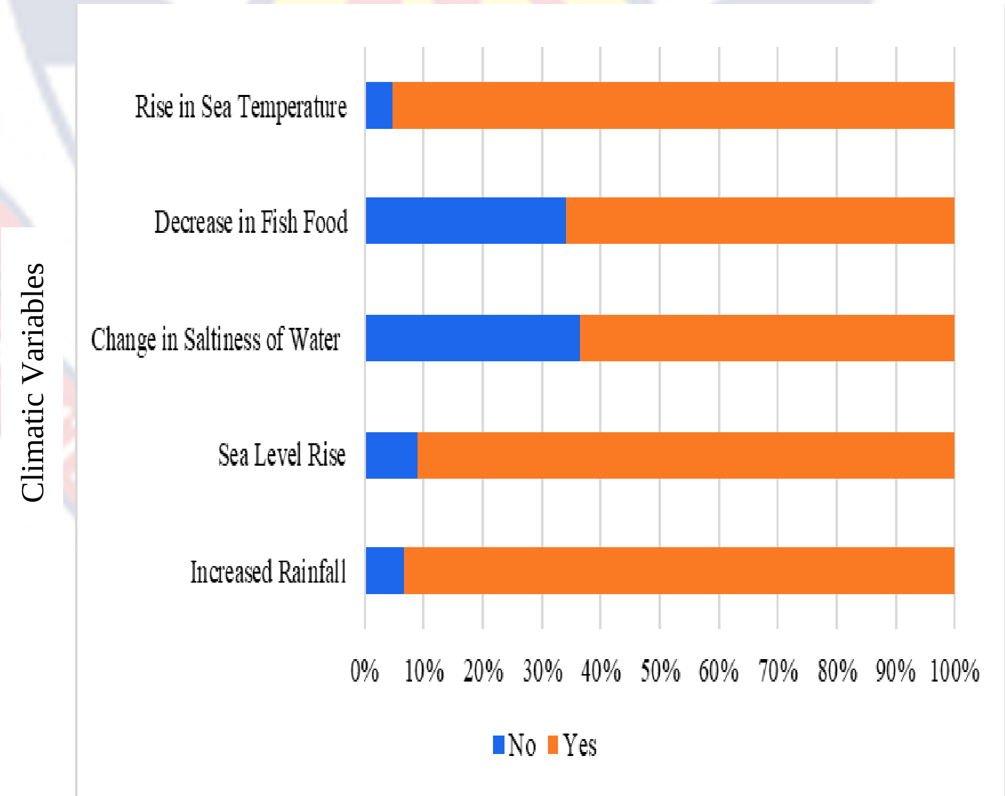

Figure 28: Fishers' Observation of Climate Change in Ibeju-Lekki

ARIMA Time Series Analysis to Forecast Fish Catch Trend

The line plot in Figure 29 shows that the data was not seasonal. Also, using a LOESS curve to determine outliers, twenty-nine (29) data points were outside the upper and lower bounds of the residuals as outliers. Outliers may make the model unreliable. A time plot was also made for the scale variable combined fish catch after differencing to evaluate the assumption of stationarity. There was no stationarity since there was a declining trend in the catch (Hyndman & Athanasopoulos, 2018).

Forecasting future fish catch

The results were based on ARIMA (1, 1, 0), the best model identified by the Hyndman-Khandakar algorithm. Since the lag of 1 for the autoregressive term fits the data well, the AR (1) coefficient was significant, with a p-value of .020. Table 11 presents the coefficients for the ARIMA model. To determine whether the ARIMA model was accurate, its forecast was compared to the observed data beginning on 2019-01-01. Table 12 displays the results of comparing the predictions to the data that was collected and Figure 30 displays the 95% confidence interval for the ARIMA model predictions.

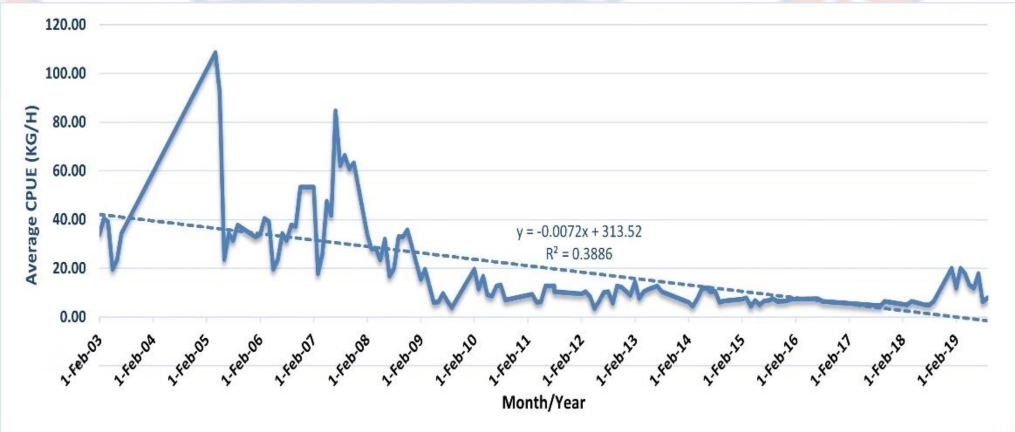

Figure 29: Line plot of Combined Fish Catch at Ibeju-Lekki from 2003 to 2019

Table 11: ***The ARIMA Model's Coefficient Table***

Variable	*B*	*SE*	*t*	*P*
ar1	0.17	0.07	2.34	.020

Note: df = 191; σ^2 = 15,007.988.

Table 12: ***Comparing Observed and Forecasted Values***

ME	RMSE	MAE	MPE	MAPE
-46.18	94.45	71.70	-59.07	68.44

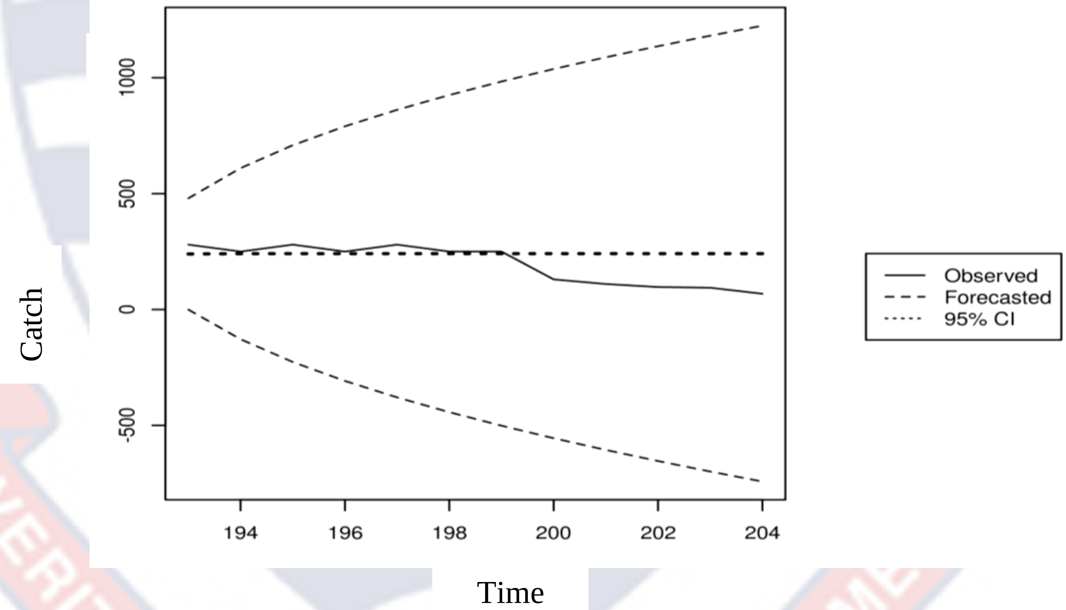

Figure 30: Forecast plot for predicted future values for CATCH at Ibeju-Lekki with a 95% CI

The ARIMA model indicated that the catch trend would continue to decline. Furthermore, the model result is corroborated by complaints from fishers who have noticed a decline in their catches in recent years. Most (77.5%) of the fishers observed a reduction (less catch) in *Sardinella maderensis* in Ibeju-Lekki in the last ten years (Table 13).

Table 13: ***Observed Trend in Sardinella maderensis Catch in Ibeju-Lekki***

Responses	Frequency	Per cent	Valid Percent	Cumulative Percent
Cannot Tell/None	21	5.8	5.8	5.8
Less Catch	279	77.5	77.5	83.3
Same Catch as Before	6	1.7	1.7	85.0
More Catch	54	15.0	15.0	100.0
Total	**360**	**100.0**	**100.0**	

Linear Regression to Determine the Effect of Climatic Variabilities on *S. maderensis* Abundance

In order to assess whether climatic variability indices such as Rainfall (RFL), Cholorophyll_a (Chl_A), Mean Sea Level (MSL), Sea Surface Salinity (SSS), and Sea Surface Temperature (SST) significantly predicted *Sardinella maderensis* abundance (CPUE_KG_H), linear regression analysis was conducted.

Research Question: Do the Independent Variables (RFL, Chl_A, MSL, SSS, and SST) significantly predict the Dependent Variable (CPUE)?

Null Hypothesis (H_0): The Independent Variables (RFL, Chl_A, MSL, SSS, and SST) do not significantly predict the Dependent Variable (CPUE).

Alternative Hypothesis (H_1): The Independent Variables (RFL, Chl_A, MSL, SSS, and SST) significantly predict the Dependent Variable (CPUE_KG_H).

Assumptions: For the model's reliability, some assumptions were made on normality, homoscedasticity, multicollinearity and outliers.

Normality: A Q-Q scatterplot, often known as a test for normality, was used to compare the quantiles of the model residuals to those of the Chi-square distribution (DeCarlo, 1997). The normality condition was met as shown in Q-Q scatterplot of the model residuals (Figure 31). Unreliable parameter estimates are indicated by a strong divergence.

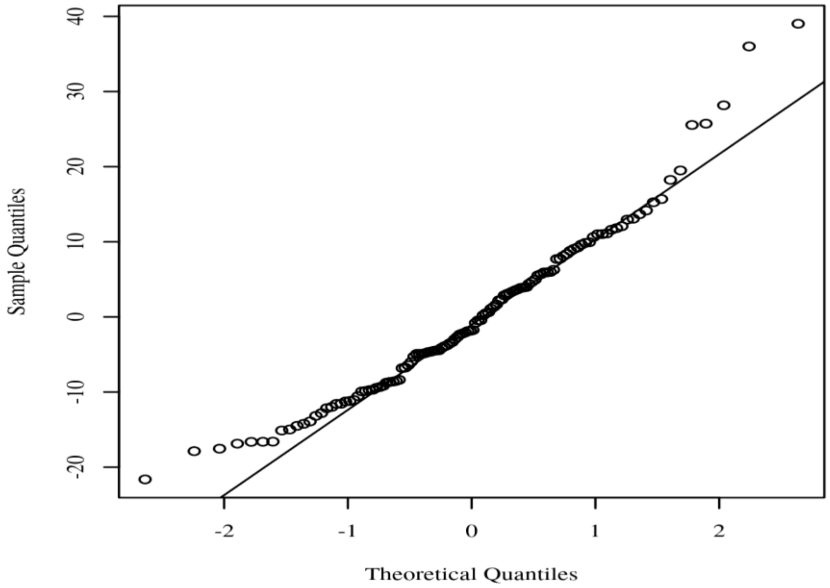

Figure 31: The regression model Q-Q scatterplot for residuals

Homoscedasticity: Plotting the predicted values against the residuals allowed assessment of homoscedasticity (Bates et al., 2014; Field, 2017). The points appear to be randomly distributed, have a mean of zero, and appear devoid of any apparent curvature, which all support the homoscedasticity assumption. Figure 32 shows a scatterplot of model residuals and predicted values.

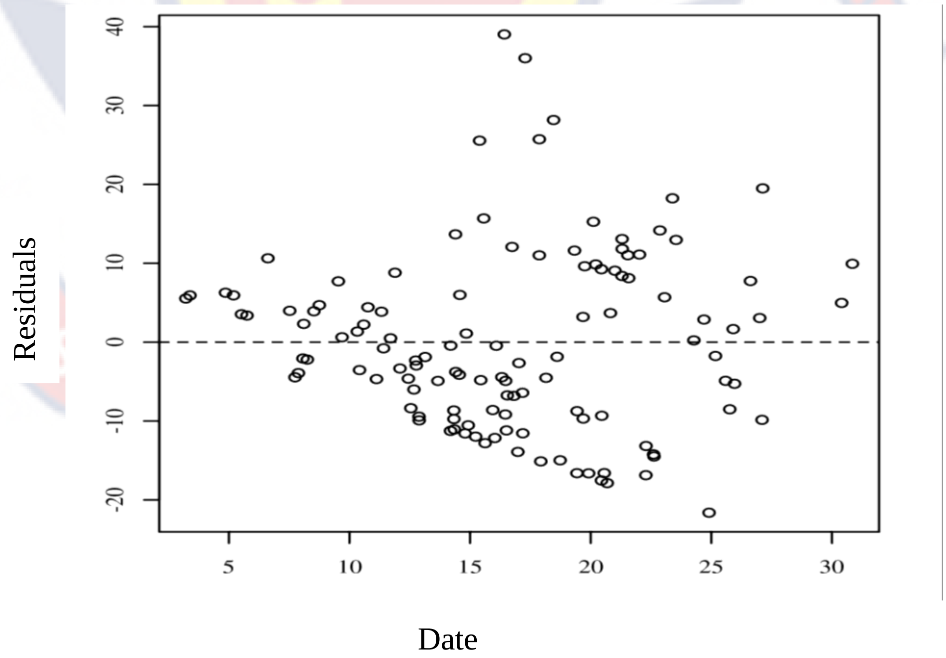

Figure 32: Homoscedasticity test using residuals scatterplots

Multicollinearity**:** Calculating the Variance Inflation Factors (VIFs) allowed for the detection of multicollinearity between predictors. High VIFs show higher multicollinearity effects in the model. VIFs over 5 should raise concerns, while 10 is the absolute upper limit (Menard, 2009). The VIFs for the variables are all below 5. Table 14 displays the VIF for each predictor in the model.

Table 14: ***Variance Inflation Factors for Rainfall, Chlorophyl_a, Mean Sea Level, Sea Surface Salinity, and Sea Surface Temperature in Ibeju-Lekki***

Variable	VIF
RFL	1.24
Chl_A	1.34
MSL	1.30
SSS	1.33
SST	1.21

Outliers: It was necessary to identify outliers that can influence the outcome of any analysis. Identifying such points requires calculating studentised residuals and plotting the same against the observation number (Field, 2017; Pituch & Stevens, 2015). The studentised residuals are calculated by dividing the model residuals by the estimated residual standard deviation. For example, the 0.999 quantiles of a *t* distribution with 119 degrees of freedom significantly influenced the model's outcomes if an observation had a studentised residual bigger than 3.16 in absolute value. Figure 33 displays the observations' studentised residuals plot. Each point with a studentised residual greater than 3.16 has an observation number next to it.

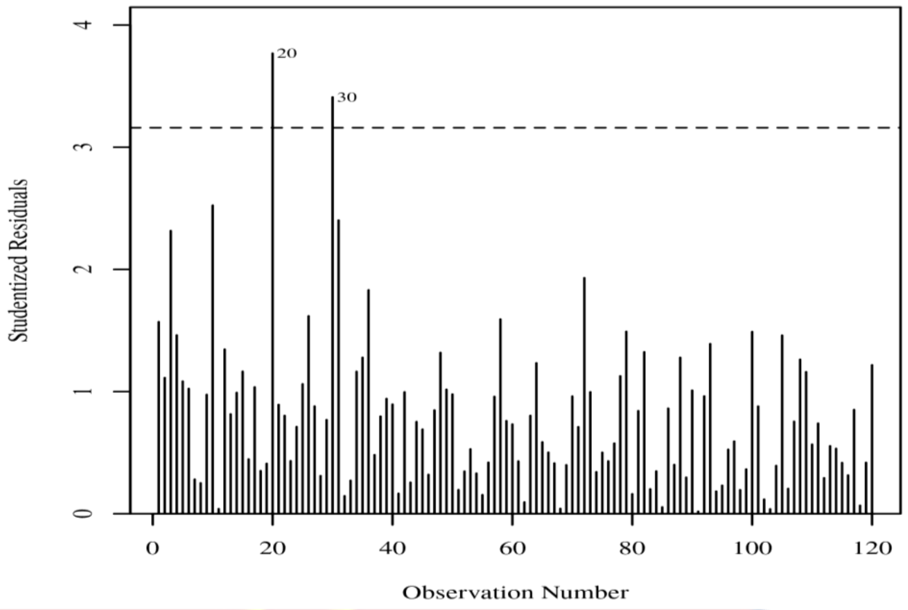

Figure 33: Outlier detection with studentised residuals plot

Regression model results

The results of the linear regression model were significant, $F(5,114) = 6.39$, $p < .001$, $R^2 = .22$, indicating that approximately 21.90% of the variance in *Sardinella Spp* abundance (CPUE_KG_H) is explainable by Rainfall (RFL), Chlorophyll_a (Chl_A), Mean Seal Level (MSL), Sea Surface Salinity (SSS), and Sea Surface Temperature (SST).

Rainfall (RFL) significantly predicted Catch-Per-Unit-Effort (CPUE_KG_H), $B = -0.02$, $t(114) = -2.77$, $p = .007$. Indicating that with a one-unit increase in Rainfall (RFL) the value of CPUE_KG_H will decrease by 0.02 units. Chlorophyll_a (Chl_A) also significantly predicted CPUE_KG_H, $B = 19.61$, $t(114) = 2.42$, $p = .017$. This shows that with one-unit increase of Chlorophyll_a (Chl_A) value of CPUE_KG_H will increase by 19.61 units. Mean Sea Level (MSL) significantly predicted CPUE_KG_H, $B = -79.91$, $t(114) = -3.30$, $p = .001$. Indicating that with one-unit increase in Mean Sea Level (MSL) the value of CPUE_KG_H) will decrease by 79.91 units.

Sea Surface Salinity (SSS) did not significantly predict CPUE_KG_H, *B* = 0.80, *t*(114) = 0.42, *p* = .676. Therefore, on the basis of this sample, a one-unit increase in SSS does not significantly affect CPUE_KG_H. However, Sea Surface Temperature (SST) significantly predicted CPUE_KG_H, *B* = 4.97, *t*(114) = 4.24, *p* < .001. This result reveals that, with one-unit increase in Sea Surface Temperature (SST) the value of CPUE_KG_H will increase by 4.97 units. The results of the regression model are shown in Table 15.

Table 15: ***Linear Regression Results on Climatic Variabilities Effects on Sardinella maderensis Abundance in Ibeju-Lekki***

Variable	***B***	***SE***	**95.00% CI**	**β**	***t***	***p***
(Intercept)	-119.08	80.1	[-277.75, 39.59]	0	-1.49	0.14
Rainfall	-0.02	0.007	[-0.03, -0.006]	-0.26	-2.77	0.007
Chorophyll_a	19.61	8.1	[3.57, 35.66]	0.23	2.42	0.017
Mean Sea Level	-79.91	24.19	[-127.84, -31.98]	-0.31	-3.3	0.001
Sea Surface Salinity	0.8	1.91	[-2.98, 4.59]	0.04	0.42	0.676
Sea Surface Temperature	4.97	1.17	[2.65, 7.29]	0.39	4.24	< .001

Note. Results: $F(5,114) = 6.39$, $p < .001$, $R^2 = .22$

The Unstandardized Regression Equation is as follows:

CPUE_KG_H = -119.08 - 0.02*RFL + 19.61*Chl_A - 79.91*MSL + 0.80*SSS + 4.97*SST

The linear regression model shows that independent variables RFL, Chl_A, MSL, SSS, and SST predict the dependent variable CPUE_KG/H based on the regression model. Therefore the Null Hypothesis (H_0): The Independent Variables (RFL, Chl_A, MSL, SSS, and SST) do not have significant effect the Dependent Variable (CPUE_KG_H) is rejected**.** The Alternative Hypothesis (H_1): The Independent Variables (RFL, Chl_A, MSL, SSS, and SST) have significant effect on the Dependent Variable (CPUE_KG_H) is thereby accepted.

Effects of Anthropogenic Activities on *Sardinella maderensis* Abundance

In examining the effect of anthropogenic activities on *Sardinella maderensis* abundance, land use and land cover change, Ibeju-Lekki, the study area, was analysed to identify the extent of change.

Land Use Change Analysis (1984 - 2020)

Image classification was done on the False Colour RGB composite raster imageries using TERRSET image analysis Software. From the analysis, the coastal area of Ibeju-Lekki had more healthy vegetation and less urban development in 1984. As we move to 2002, urban development became prominent as patches of white and cyan are visible in the imagery. Moreover, viewing the 2020 composite imageries shows the map's increased white and cyan patches. A very close look reveals a section of the map with a white patch, and that is the area with significant development in the study area where we have the free trade zone and refinery. Table 16 shows the land use change statistics for Ibeju-Lekki coastal area from 1984 to 2020.

Table 16: ***Land Use Change Statistics in Ibeju-Lekki (1984-2020)***

Categories	1984 (Sq.Km)	%	2002 (Sq.Km)	%	2020 (Sq.km)	%	1984-2020 change (Sq.km)	%
Water Bodies	268.379	45.07	268.740	45.13	267.046	44.84	-1.333	-0.5
Forested Areas	136.713	22.96	187.481	31.48	118.089	19.83	-18.624	-13.62
Cultivated Lands	102.222	17.6	35.267	5.92	38.913	6.53	-63.309	-61.93
Minor Urban	56.355	9.46	54.482	9.15	83.903	14.09	27.549	48.88
Major Urban	31.868	5.35	49.568	8.32	87.585	14.71	55.717	174.84
Total	**595.538**	**100**	**595.538**	**100**	**595.538**	**100**		

The result indicates a 0.50% loss of water body. The available forested lands were reduced by approximately 14%, while cultivated lands lost 62%. Although minor urban development increased by 48%, land used for major urban development has tremendously increased by 175%. This analysis implies dynamic urban growth at the Ibeju-Lekki coastline, which has displaced artisanal fishers. Urban land uses such as residential, commercial, recreational, institutional and industrial are major anthropogenic activities that have taken over the fishing fields and disrupted artisanal fishing in the study area, as seen in the 1984 to 2020 land cover change maps (Figures 34, 35 and 36).

According to the survey results, most fishers complained that industrial land use activities like the Dangote Refinery and transportation land use activities like the Lekki Deep Sea Port are the major anthropogenic activities affecting Sardinella fishery in Ibeju-Lekki. The Lekki Masterplan (Figure 37) proposal supports the development of the existing refinery, Free Trade Zone, seaport and other industrial complexes. More measures must be implemented to ensure the fishers are not ripped off their livelihoods by these massive urban land use developments. As shown in Figure 38, 342 (95%) of the fishers claimed the development of the Dangote Refinery and industrial complex affects their livelihoods and *S. maderensis* fishery.

At the same time, 207 (57.5%) of the fishers claimed that the Lekki Deep Sea Port's development has led to a decline in the fishery. On the other hand, other land use activities like residential, commercial and recreational developments have a shallow effect on the Sardinella fishery as less than 3% of the fishers are affected by these activities.

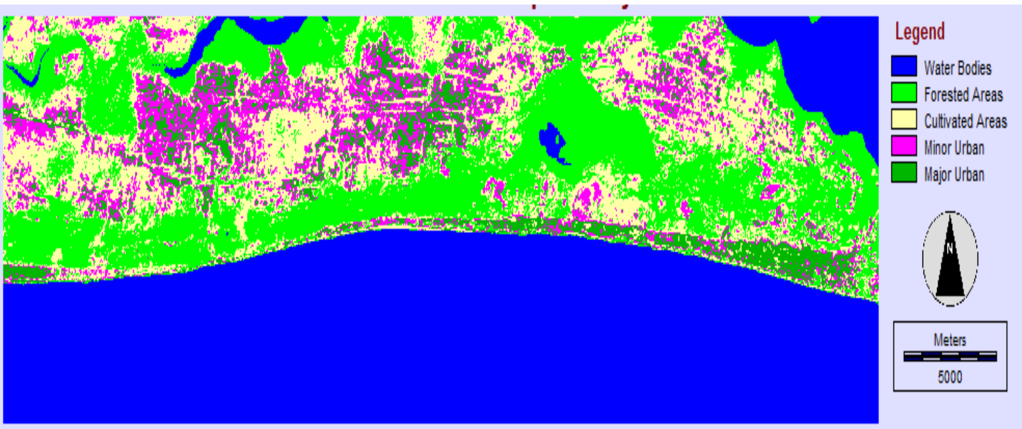

Figure 34: 1984 Land Use/Land Cover Classification Map for Ibeju-Lekki

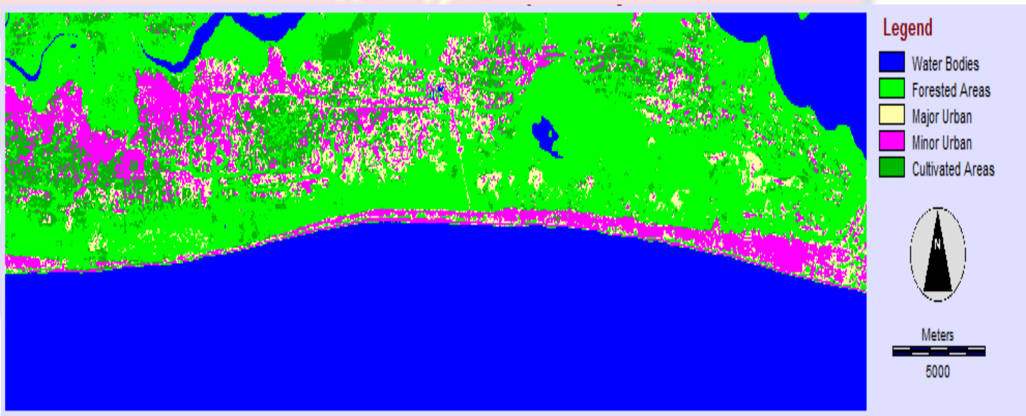

Figure 35: 2002 Land Use/Land Cover Classification Map for Ibeju-Lekki

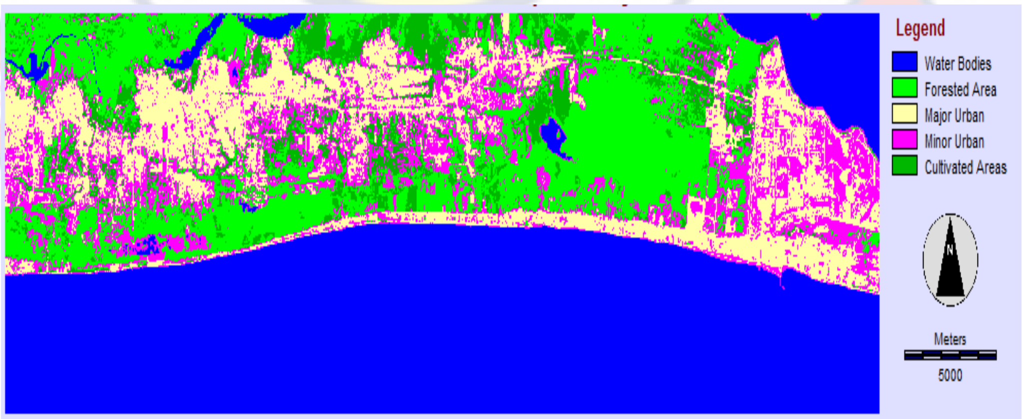

Figure 36: 2020 Land Use/Land Cover Classification Map for Ibeju-Lekki

Figure 37: Lekki Masterplan
Source: Lekki Free Zone Development Company (https://lfzdc.org/lfz-master-plan/)

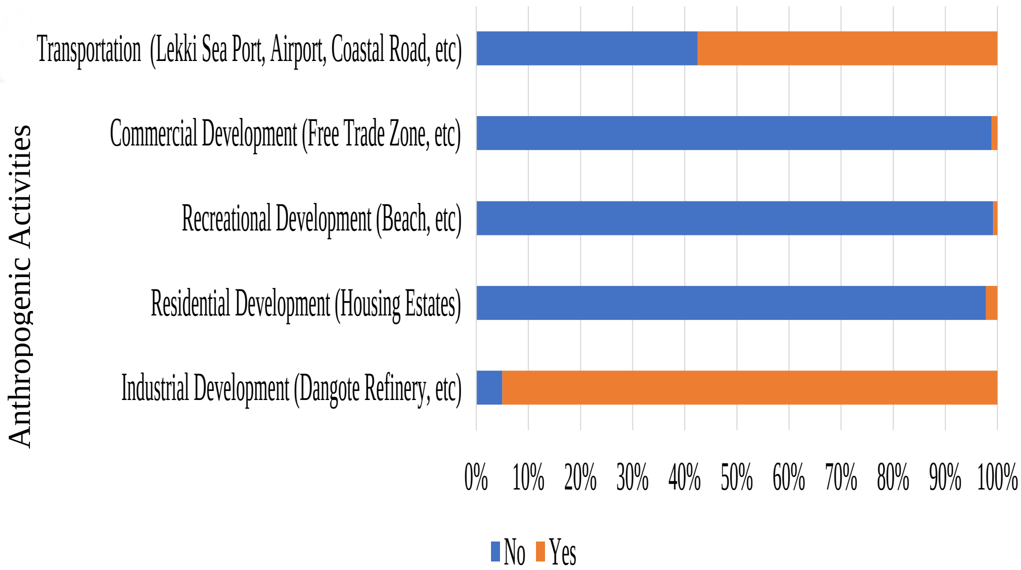

Figure 38: Fishers' Responses on Anthropogenic Activities (Urban Land Use) Affecting Sardinella maderensis in Ibeju-Lekki

Anthropogenic Factors Affecting *Sardinella maderensis* Abundance

A regression analysis was conducted to determine if anthropogenic factors predict *Sardinella maderensis* abundance. Land use change is an essential anthropogenic indicator presumed to affect fisheries. The land use change analysis has indicated an extensive change to urban land use; however, the test was done based on the record of the 360 fishers' perceptions and experiences. The hypothesis was tested using the Volume of Fish Catch (V_FISHCATCH) as the dependent variable. However, the observed fishers' perceptions and experiences of the land use change effect (V_LANDUSE), access to social amenities (V_AMENITY) and fishing effort (V_FISHG_EFFORT) were the independent variables.

The variable V_LANDUSE was derived from the sum of five (5) variables V_62a to V_62e (Industrial, residential, recreational, commercial and transportation), which explains the scale of the effect of various land use categories on artisanal *S. maderensis* fishery. V_AMENITY is the sum of nine (9) variables V66a to V66i (good roads, hospitals, cybercafé, electricity, internet, pipeborne water, primary school, secondary school and tertiary school), explaining the fishers' access to various social amenities enumerated. Finally, the variable V_FISHG_EFFORT was derived by the number of hours of fishing per trip.

Hypothesis and regression model

Research Question: Do Land use, Amenity and Fishing effort have significant effect on Fish catch?

Null Hypothesis (H_0): Land use, Amenity and Fishing effort do not have significant effect on Fish catch.

Alternative Hypothesis (H_1): Land use, Amenity and Fishing effort have significant effect on Fish catch.

Assumptions: For the model's reliability, some assumptions were made on normality, homoscedasticity, multicollinearity and outliers.

Results: The regression model's outcomes were significant, $F(3,356) = 5.75$, $p < .001$, $R^2 = .05$, reveals that about 4.62% of the variance in V_FISHCATCH is explainable by V_LANDUSE, V_AMENITY, and V_FISHG_EFFORT.

V_LANDUSE significantly predicted V_FISHCATCH, $B = -0.13$, $t(356) = -2.10$, $p = .037$. The result shows that, with one-unit increase in V_LANDUSE the value of V_FISHCATCH will decrease by 0.13 units. This means urban land use change in coastal communities, on average, significantly reduces fish abundance.

V_AMENITY significantly predicted V_FISHCATCH, $B = 0.05$, $t(356) = 2.64$, $p = .009$. It implies that with one-unit increase of V_AMENITY the value of V_FISHCATCH will increase by 0.05 units. Access to good roads, schools, telecommunications and other social amenities improves the fishers' livelihood and increases *Sardinella maderensis* fish abundance.

V_FISHG_EFFORT significantly predicted V_FISHCATCH, $B = -0.004$, $t(356) = -2.57$, $p = .011$. It reveals that, with one-unit increase of V_FISHG_EFFORT the value of V_FISHCATCH will decrease by 0.004 units. Excessive fishing effort can have negative effect on *Sardinella maderensis* fishery leading to low yield. The regression model's results are summarized in Table 17.

Table 17: ***Linear Regression Results for Landuse, Amenity, and Fishing Effort Predicting Fishcatch in Ibeju-Lekki***

Variable	*B*	*SE*	95.00% CI	β	*t*	*p*
(Intercept)	2.57	0.13	[2.30, 2.83]	0	19.2	< .001
V_LANDUSE	-0.13	0.06	[-0.26, -0.008]	-0.11	-2.1	0.037
V_AMENITY	0.05	0.02	[0.01, 0.09]	0.14	2.64	0.009
V_FISHG_EFFORT	-0.004	0.002	[-0.007, -0.0010]	-0.13	-2.57	0.011

Note. Results: F(3,356) = 5.75, p < .001, R2 = .05

The Unstandardized Regression Equation is as follows:

V_FISHCATCH = 2.57 - 0.13*V_LANDUSE + 0.05*V_AMENITY - 0.004*V_FISHG_EFFORT

The linear regression shows that the independent variables Land use, Amenity, and Fishing effort significantly predict Fish catch. Therefore, the Null Hypothesis (H_0): Landuse, Amenity and Fishing effort do not have significant effect on Fish catch is rejected**.** In Contrast, the Alternative Hypothesis - Landuse, Amenity and Fishing effort have significant effect on Fish catch is accepted.

Water quality/Physicochemical Parameters Analyses Results

The results for the study period revealed that water temperature ranged between 23°C – 27°C with a mean of 25.39°C. The pH values were between 7.32 – 8.06, with a mean of 7.88. The salinity ranged between 24.86ppt – 32.17ppt, with a mean value of 29.37ppt. Total dissolved solids (TDS) ranged between 11500mg/L – 30000mg/L with a mean of 24971.11mg/L. The dissolved oxygen values range from 4.80mg/L – 15.80mg/L with a mean of 4.80mg/L. While the biological oxygen demand was 0.40 – 11.00 and had a mean value of 3.37mg/L. The nutrients, nitrates (NO_3) and phosphates(PO_4) had the values 0.01mg/L – 2.11mg/L, 0.01mg/L - 0.70 mg/L and average values of 0.31mg/L and 0.15mg/L respectively. The Chlorophyll-a was between 0.00µg/L – 0.04 µg/L and had a mean of 0.01µg/L. The results are presented in Table 18.

The physicochemical parameter analysis result shows that the temperature, pH, salinity, dissolved oxygen (DO), nitrate (NO_3) and phosphate (PO_4) are within the ranges required for the survival of the fish species. The total dissolved solids (TDS) are, however, higher than the acceptable level, which may affect gill and kidney functions that impact the survival and size of the fish. The Biological Oxygen Demand (BOD) values occasionally fall within an acceptable range but sometimes get above the lethal limit, having as high as 11mg/L as the maximum level which is above the 8mg/L lethal limit and chlorophll-a is at an inadequate level in the water body.

Tables 19 and 20 show the mean ± standard error of the physicochemical parameters at all the sampled stations. The means of the temperature, pH, salinity, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), nitrate ($N0_3$), phosphates(PO_4) and Chlorophyll, in all the sampling stations are not significantly different from each other ($p > 0.05$).

Table 18: ***Physicochemical Parameters in Ibeju-Lekki Coastal Waters***

Physicochemical Parameters	Min	Max	Mean	Permissible limits	Remark
Water Temp. (°C)	23	27	25.39	24°C (FAO, 2021)	Within required range
pH	7.32	8.06	7.88	6.5-8.5 (USEPA, 1985); 9.0 (FEPA, 2003)	Within required range
Salinity (ppt)	24.86	32.17	29.37	Tolerates low salinities (Tous et al., 2015; Whitehead, 1985)	Within required range
TDS (mg/L)	11500	30000	24971.1	2000mg/L (FEPA, 2003)	Higher than acceptable level
DO (mg/L)	4.8	15.8	7.97	4.8mg/L (USEPA, 2000)	Within acceptable limit
BOD (mg/L)	0.4	11	3.37	3-6mg/L-Tolerable; 8mg/L-Lethal (Hynes, 1960)	Within range / sometime above the lethal limit
NO_3 (mg/L)	0.01	2.11	0.31	20mg/L (Camargo et al., 2005; FEPA, 2003) 10mg/L (APHA, 1992; USEPA, 2000)	Within acceptable limit
PO_4 (mg/L)	0.01	0.7	0.15	5mg/L (FEPA, 2003)	Within acceptable limit
Chlorophylla (µg/L)	0	0.04	0.01	0.1-8µg/L (Antoine et al., 1996)	Not up to the required level

Table 19: ***Mean ± Standard Error of the Physicochemical Parameters (Water temperature, pH, salinity, TDS and DO) at Ibeju- Lekki Coastal Waters***

Stations/ Parameters	Water Temp. (°C)	pH	Salinity (ppt)	TDS (g/L)	DO (mg/L)
A	25.83 ± 0.41[a]	7.88 ± 0.07[a]	30.83 ± 0.89[a]	20.60± 12.20[a]	8.48 ± 1.76[a]
B	25.67 ± 0.82[a]	7.84 ± 0.26[a]	30.36 ± 0.96[a]	20.50 ± 12.12[a]	7.25 ± 1.85[a]
C	25.67 ± 1.21[a]	7.91 ± 0.08[a]	29.84 ± 1.57[a]	20.15± 11.82[a]	8.17 ± 2.76[a]
D	24.83 ± 1.33[a]	7.85 ± 0.08[a]	29.57 ± 1.37[a]	20.09 ± 11.80[a]	7.72 ± 4.17[a]
E	25.67 ± 1.37[a]	7.88 ± 0.10[a]	30.11 ± 0.84[a]	20.29 ± 11.90[a]	7.62 ± 1.52[a]
F	25.00 ± 1.26[a]	7.92 ± 0.11[a]	29.99 ± 1.86[a]	20.45 ± 12.03[a]	8.33 ± 1.74[a]
F-Statistics (p)	0.832 (0.537)	0.296 (0.911)	0.674 (0.646)	0.002 (1.000)	0.221 (0.951)

Table 20: ***Mean ± Standard Error of the Physicochemical Parameters (BOD, NO3, PO4 and Chlorophyll-a at Ibeju- Lekki Coastal Waters***

Stations/ Parameters	BOD (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	Chlorophyll (µg/L)
A	2.58 ± 1.94[a]	0.23 ± 0.16[a]	0.17 ± 0.13[a]	0.01 ± 0.01[a]
B	2.28 ± 1.76[a]	0.17 ± 0.16[a]	0.10 ± 0.11[a]	0.01 ± 0.01[a]
C	3.30 ± 2.17[a]	0.19 ± 0.17[a]	0.21 ± 0.26[a]	0.01 ± 0.01[a]
D	3.05 ± 4.11[a]	0.32 ± 0.30[a]	0.15 ± 0.12[a]	0.04 ± 0.09[a]
E	2.65 ± 1.72[a]	0.43 ± 0.53[a]	0.18 ± 0.17[a]	0.01 ± 0.01[a]
F	2.83 ± 2.27[a]	0.50 ± 0.80[a]	0.13 ± 0.10[a]	0.01 ± 0.01[a]
F-Statistics (p)	0.128 (0.985)	0.607 (0.695)	0.414 (0.835)	0.854 (0.517)

The heavy metals analysis results are presented in Table 21, which reveals that minimum values for lead and cadmium were 0.00 mg/L, and their maximum values were 0.93 mg/L and 0.20 mg/L, respectively. Iron levels ranged between 0.31 mg/L – 3.16 mg/L, with manganese between 0.07 mg/L – 0.38 mg/L. The values for nickel were between 0.21 mg/L – 0.93 while that of chromium ranged between 0.00 mg/L – 7.00 mg.

Table 21: ***Heavy Metal Concentration Ibeju-LekkiCoastal Water***

Heavy Metals	**Min**	**Max**	**Mean ±Stdev**	**Permissible Limits (USEPA)**	**Permissible Limits (FEPA, 2003)**	**Remark**
Lead	0.00	0.93	0.20±0.17	0.14 (1985)	<1.00	Within acceptable limits nationally but above international limit
Cadmium	0.00	0.20	0.06±0.06	0.03 (2016)	<1.00	
Iron	0.31	3.16	2.62±0.51	1.00 (1988)	-	
Manganese	0.07	0.38	0.19±0.11	0.10 (2010)	5.00	
Nickel	0.21	0.93	0.64±0.19	0.07 (1995)	<1.00	
Chromium	0.00	7.00	1.73±2.09	0.18 (1980)	<1.00	Above acceptable limits

Source: Field Survey (2021) (All values are in mg/L)

The results of the heavy metal analysis reveal that the level of lead, cadmium, iron, manganese and nickel were within the national limit set by the Federal Environmental Protection Agency in Nigeria (FEPA, 2003). However, the values were above the international standard limits by the USEPA (1980-2016). In addition, results for chromium shows that the current level of chromium in the water body is above both the national and the International standard limit. Table 22 shows the mean ± standard error of the heavy metals at the sample stations in Ibeju-Lekki. The means of lead, cadmium, iron, manganese, nickel and chromium in all the stations are not significantly different from each other ($p > 0.05$).

Table 22: ***Mean ± Standard Error of Heavy metals at Sample Stations in Ibeju-Lekki***

Stations	Pb	Cd	Fe	Mn	Ni	Cr
A	0.23 ± 0.13[a]	0.08 ± 0.05[a]	2.70 ± 0.12[a]	0.22 ± 0.12[a]	0.69 ± 0.22[a]	1.82 ± 2.45[a]
B	0.24 ± 0.07[a]	0.08 ± 0.05[a]	2.74 ± 0.25[a]	0.18 ± 0.11[a]	0.62 ± 0.16[a]	1.82 ± 2.07[a]
C	0.17 ± 0.10[a]	0.10 ± 0.05[a]	2.89 ± 0.24[a]	0.18 ± 0.09[a]	0.66 ± 0.16[a]	1.54 ± 1.83[a]
D	0.21 ± 0.10[a]	0.06 ± 0.05[a]	2.56 ± 0.31[a]	0.18 ± 0.12[a]	0.66 ± 0.17[a]	2.09 ± 2.91[a]
E	0.31 ± 0.35[a]	0.05 ± 0.04[a]	2.09 ± 1.05[a]	0.18 ± 0.11[a]	0.61 ± 0.26[a]	1.95 ± 2.92[a]
F	0.14 ± 0.08[a]	0.06 ± 0.08[a]	2.74 ± 0.29[a]	0.19 ± 0.13[a]	0.60 ± 0.23[a]	1.15 ± 1.65[a]
F-Statistics (p)	0.578 (0.716)	0.358 (0.871)	1.649 (0.185)	0.107 (0.990)	0.147 (0.979)	0.102 (0.991)

The least total petroleum hydrocarbon (TPH) level (27.56 mg/L) was measured in February, while the highest (3985.40 mg/L) was measured in August (Table 23). The TPH levels were generally high across the stations in August, which points to the fact that there was a likelihood of an oil spill.

Table 23: ***Total Petroleum Hydrocarbon in Ibeju-Lekki Coastal Water***

SAMPLING STATIONS	Feb'21	Apr'21	Jun'21	Aug'21	Oct'21	Dec'21
Station A (Igando-Orudu)	31.82	58.69	75.59	3455.8	47.02	27.7
Station B (Orimedu)	32.24	55.68	128.23	3292.75	53.65	35.23
Station C (Magbon Segun)	27.56	52.01	59.05	174.76	42.01	40.25
Station D (Lekki)	35.37	44.34	50.12	3590.39	41.51	35.77
Station E (Lepiya)	34.89	46.11	50.78	3823.22	42.5	39.94
Station F (Folu)	36.5	58.51	103.24	3985.4	35.79	40.79
Minimum	*27.56*	*44.34*	*50.12*	*174.76*	*35.79*	*27.7*
Maximum	*36.5*	*58.69*	*128.23*	*3985.4*	*53.65*	*40.79*
Mean	*33.06*	*52.56*	*77.83*	*3053.72*	*43.75*	*36.61*
STDEV	*3.25*	*6.199*	*31.76*	*1432.16*	*6.03*	*4.98*

Source: Field Survey (2021) *(All values are in mg/L)*

The permissible limit for TPH for coastal waters in Nigeria is 10mg/l; consequently, the result indicates that the water in all the sample stations throughout the year is polluted with hydrocarbon.

The mean ± standard error of TPH (Figure 39) reveals that Folu has the highest mean TPH of 710.04 (se = 1604.80), Magbon Segun has the least mean of 65.94 (se = 54.38) and the means of all the stations are not significantly different from each other ($p > 0.05$).

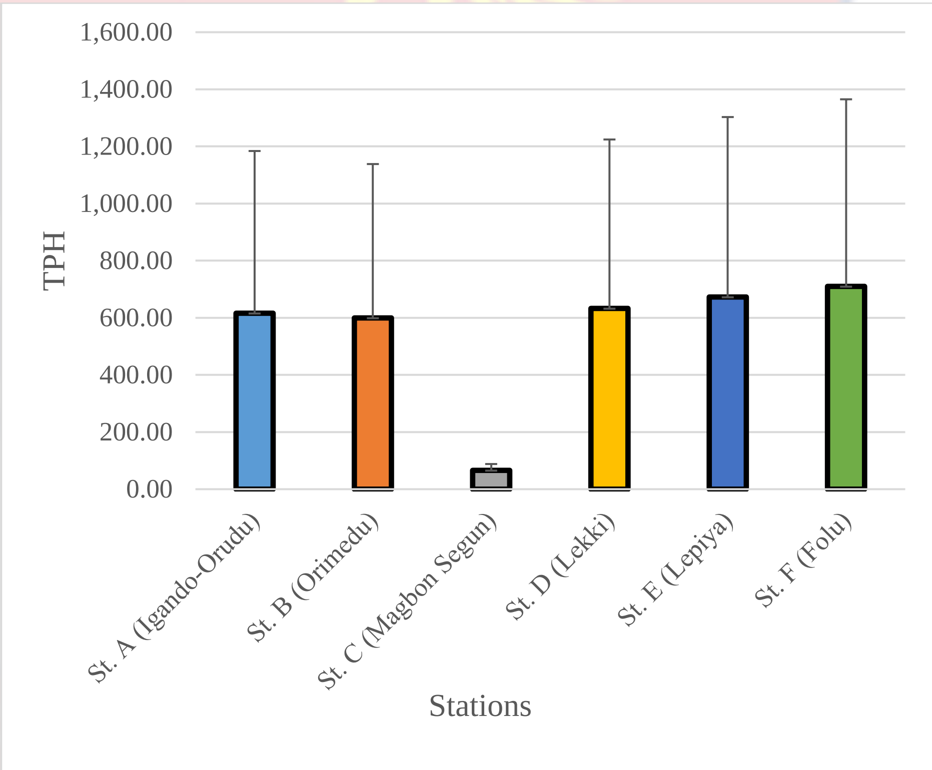

Figure 39: Mean ± standard error of TPH in Ibeju-Lekki Coastal Water

Plankton Analysis Results from Ibeju-Lekki Coastal Water

The water was analyzed to estimate the study area's plankton biomass, abundance, and diversity. The plankton analysis was necessary because *Sardinella maderensis* is a plankton feeder. The plankton comprised plant and animal forms, namely, Phytoplankton and Zooplankton.

Phytoplankton analysis results from Ibeju-Lekki coastal water

The average species diversity (Shannon_H), species richness (Margalef), equitability, taxa and the number of individual species of Phytoplankton recorded in the water samples collected in Ibeju-Lekki (February – December 2021) across the six stations is presented in Table 24. While the percentage composition of plankton individuals is illustrated in Figure 40.

Table 24: ***Diversity Indices of Phytoplankton in Ibeju-Lekki Coastal Water***

Indices	Feb.'21	Apr.'21	Jun.'21	Aug.'21	Oct.'21	Dec.'21
Taxa_S	2	8	7	11	12	12
Individuals	78	338	290	300	175	203
Shannon_H	0.325	0.872	0.619	0.960	1.338	1.225
Margalef	0.192	1.243	0.993	1.779	1.989	1.997
Equitability_J	0.469	0.426	0.345	0.411	0.567	0.460
%Composition (Across the Months)	6	24	21	22	13	15

Source: Field Survey (2021)

Regarding Phytoplankton diversity, species richness was highest (1.997) in December but lowest (0.192) in February. On the other hand, species diversity was highest (1.338) in October but lowest (0.325) in February, while equitability was highest (0.567) in October but lowest (0.345) in June. The highest Phytoplankton composition (24%) was recorded in April, while the lowest (6%) was recorded in February (Figure 40).

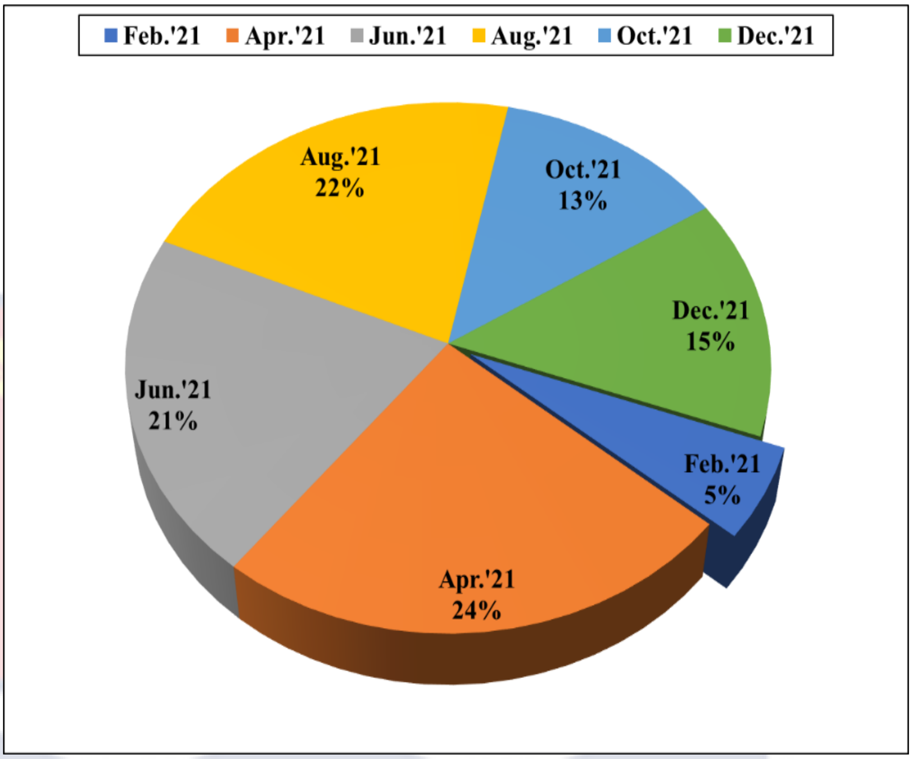

Figure 40: Percentage composition of phytoplankton individuals recorded in the water samples collected across Ibeju-Lekki (February – December 2021)

Zooplankton average results from February to December across the sampling stations

The average species diversity, richness, equitability, taxa and the number of individual zooplankton species were recorded in the samples collected in Ibeju-Lekki (February – December 2021) across the six stations and are presented in Table 25. While the percentage composition of plankton individuals is illustrated in Figure 41.

Table 25: ***Diversity Indices of Zooplankton in Ibeju-Lekki Coastal Water***

Indices	Feb.'21	Apr.'21	Jun.'21	Aug.'21	Oct.'21	Dec.'21
Taxa_S	2	1	0	0	3	3
Individuals	10	6	0	2	13	17
Shannon_H	0.693	0.231	0	0	0.713	0.785
Margalef	0.434	0.167	0	0	0.590	0.630
Equitability_J	1	0.167	0	0	0.500	0.488
%Composition	21.0	13.0	0.0	4.0	27.0	35.0

Source: Field Survey (2021)

Regarding Zooplankton diversity, species richness was highest (0.630) in December but lowest (0) in August. On the other hand, species diversity was highest (0.785) in December but lowest (0) in August, while equitability was highest (1) in February but lowest (0) in August. The highest Zooplankton composition (35%) was recorded in December, while the lowest (4%) was recorded in August.

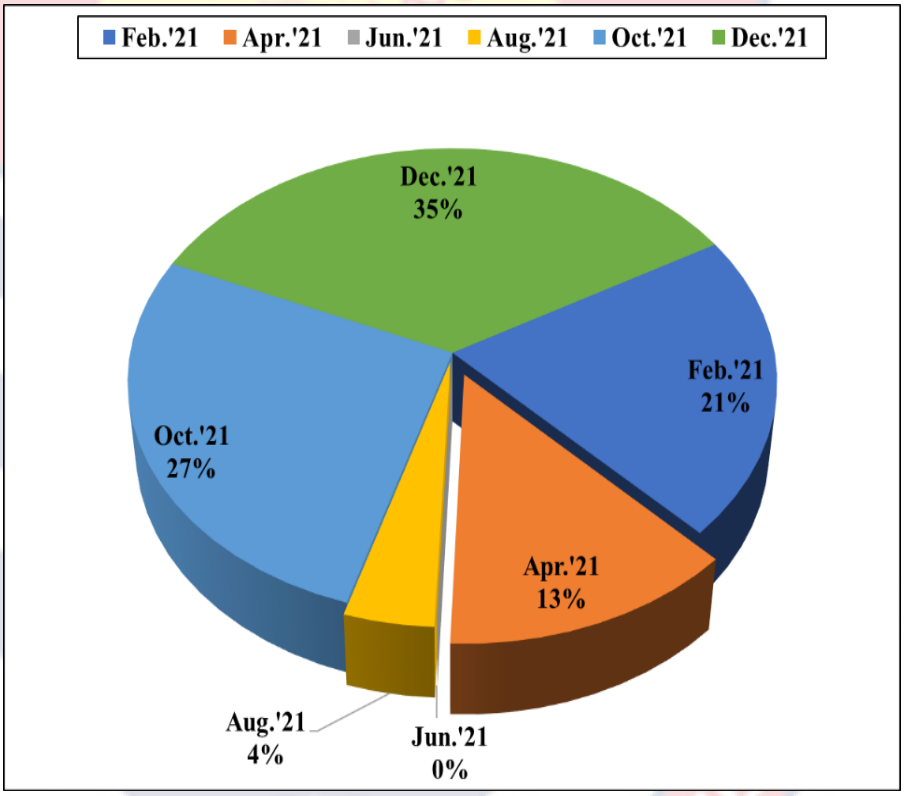

Figure 41: Percentage composition of zooplankton individuals recorded in the water samples collected across Ibeju-Lekki (February - December 2021)

Fish Morphometrics, Length-Weight Relationship and Condition Factor

The length-weight measurements obtained in this study are presented in Table 26. A total of 1492 fish samples were analysed, and the results revealed that among the combined sexes (1492), 767 (51%) were males, 535(36%) were females, and 190 (13%) were the samples that their sexes could not be determined. The results of the morphometric measurement of the fish samples showed that the maximum total length (TL), minimum and mean±SD of the combined sexes (1492) were 31.9 cm, 7.1 cm and 23.6 (±4.80) cm respectively. The values for the standard length were 23.2 cm, 5.5 cm and 17.4 (±3.45)cm, while that of the fork length (FL) is 25.4 cm, 6.2 cm and 18.8 (±3.74)cm respectively. The maximum weight, minimum weight and mean±SD were 300g, 3.0g and 121.1 (±49.36)g respectively. Therefore, the average standard length and weight are 17.40 (±3.45) cm and 121.10 (49.36)g, respectively. The standard length (SL) was correlated with the weights of the fish specimens to determine the allometry (Figure 42a, b). From the data on sizes of *S. maderensis* obtained during the study period, juvenile and adult fish predominate the fishery.

Table 26: ***Measured Parameters of Length-Weight Relationships and Condition Factor of Sardinella maderensis collected from Ibeju-Lekki between January 2021 – March 2022***

Parameter (Mean±SD)	**Male** (n=767)	**Female** (n=535)	**Undetermined** (n=190)	**Combined** (n=1492)
Length, SL(cm)	18.2±1.34	18.9±1.57	9.4±2.35	17.4±3.45
Length, TL(cm)	24.9±1.81	25.7±2.01	12.7±6.94	23.6±4.80
Length, FL(cm)	19.7±1.60	20.4±1.74	10.2±2.37	18.8±3.74
Weight, W(g)	129.5±28.43	145.1±34.77	19.4±14.84	121.1±49.36
Condition Factor(K)	1.0050	1.0054	1.0099	1.0068
Coefficient determination(R^2)	0.7633	0.7972	0.9679	0.9799
Coefficient correlation(r)	0.8737	0.8929	0.9838	0.9899

The length-weight relationship (Appendix F) of the fish specimens is illustrated in Figure 42.

Combined (n=1492)

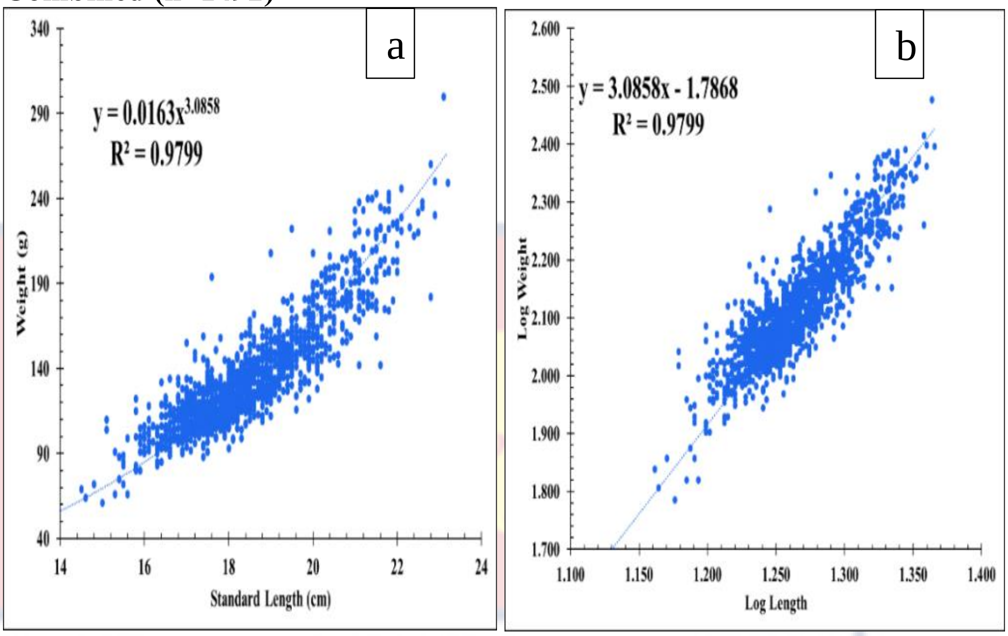

Figure 42: (a) Length-weight and (b) Log length – Log weight relationship in *Sardinella maderensis* specimens (combined sexes) collected from Ibeju-Lekki

From Scatter plot**:**

Intercept (a) = 0.0163

Regression (r) = 0.9898

Slope (b) = 3.0858

The b-value was significantly different from 3 using T-test statistical methods

$$t_S = \frac{(b-3)}{S_b}$$

Tcal = 7.49, Ttab = 6.31

Therefore, $T_{cal} > T_{tab}$

Hence, the fish are positively allometric; fish grows faster in weight than in length, and they put on weight nearly as fast as they get longer.

The r value of *Sardinella maderensis* from Ibeju-Lekki were 0.9899, 0.8435, 0.8842 and 0.9839 in the combined sexes, male, female and undetermined sexes specimens, respectively. The findings suggest a strong link between length and weight, further indicating that as fish grow longer, their weight increases proportionally. However, a higher correlation was observed between the length and weight of the undetermined sexes compared to the males and females. The coefficient of determination was also high (R^2 = 0.9799 (97.99%), 0.7633 (76.33%), 0.7973 (79.73%) and 0.9680 (96.80%) in combined sexes, male, female and undetermined sexes specimens respectively.

The analyses also showed that condition factors (K) were either greater than or equal to 1. The values ranged between 1.0 - 2.8, with a mean of 1.6 ± 0.19**.** As presented in Table 26, the average condition factor in combined sexes, male, female and undetermined sexes specimens were 1.0068, 1.0050, 1.0054 and 1.0099, respectively, which implied that the fish were in good physiological condition.

Additionally, as part of the measures taken to evaluate the fish species' condition, the stomach fullness was examined to assess how well they were feeding in the water body. Consequently, the stomach fullness of the combined sexes, males, females and undetermined sexes, are presented in Figures 43 - 46.

Stomach fullness of *Sardinella maderensis* (combined sexes) collected from Ibeju-Lekki, Lagos

The stomach fullness values for the combined sexes specimens are presented in Figure 43. Of the 1,492 stomachs examined, 46 stomachs (3%) were empty, 466 stomachs (31%) were 1/4 full, 529 stomachs (36%) were 1/2 full, 312 stomachs (21%) were 3/4 full, while 139 stomachs (9%) were full.

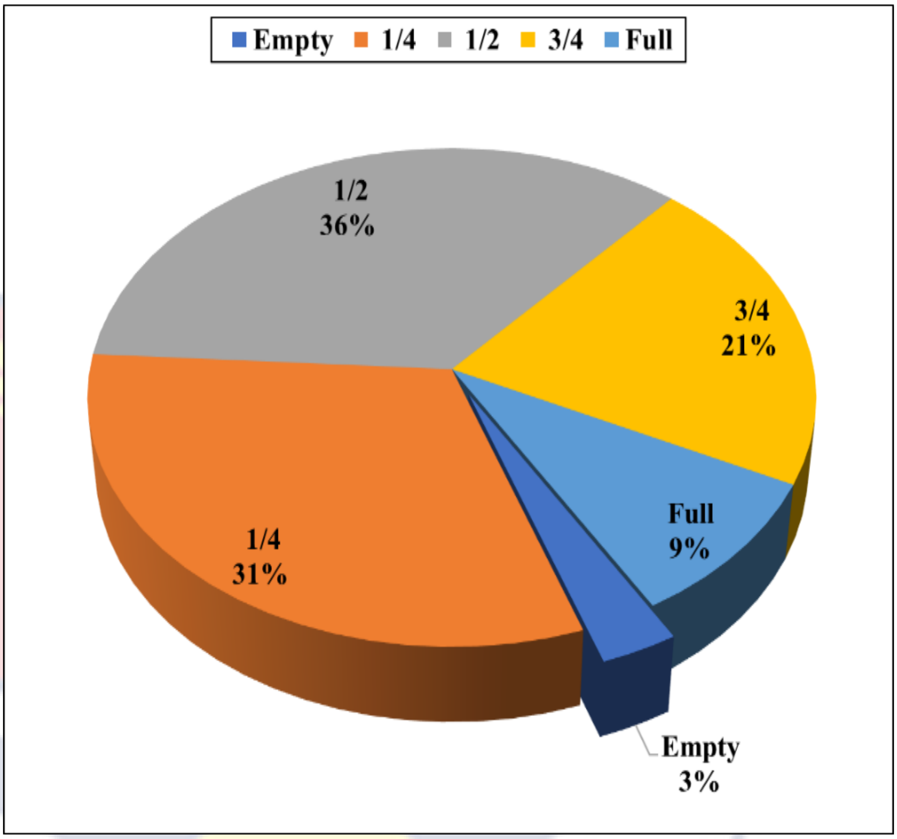

Figure 43: Percentage of stomach fullness of *Sardinella maderensis* (combined sexes) collected from Ibeju-Lekki

Stomach fullness of *Sardinella maderensis* (males) collected from Ibeju-Lekki, Lagos

The stomach fullness values for the male specimens (Figure 44) reveals that out of the 767 stomachs examined, 18 stomachs (2%) were empty, 281 stomachs (37%) were 1/4 full, 278 stomachs (36%) were 1/2 full, 137 stomachs (18%) were 3/4 full, while 53 stomachs (7%) were full.

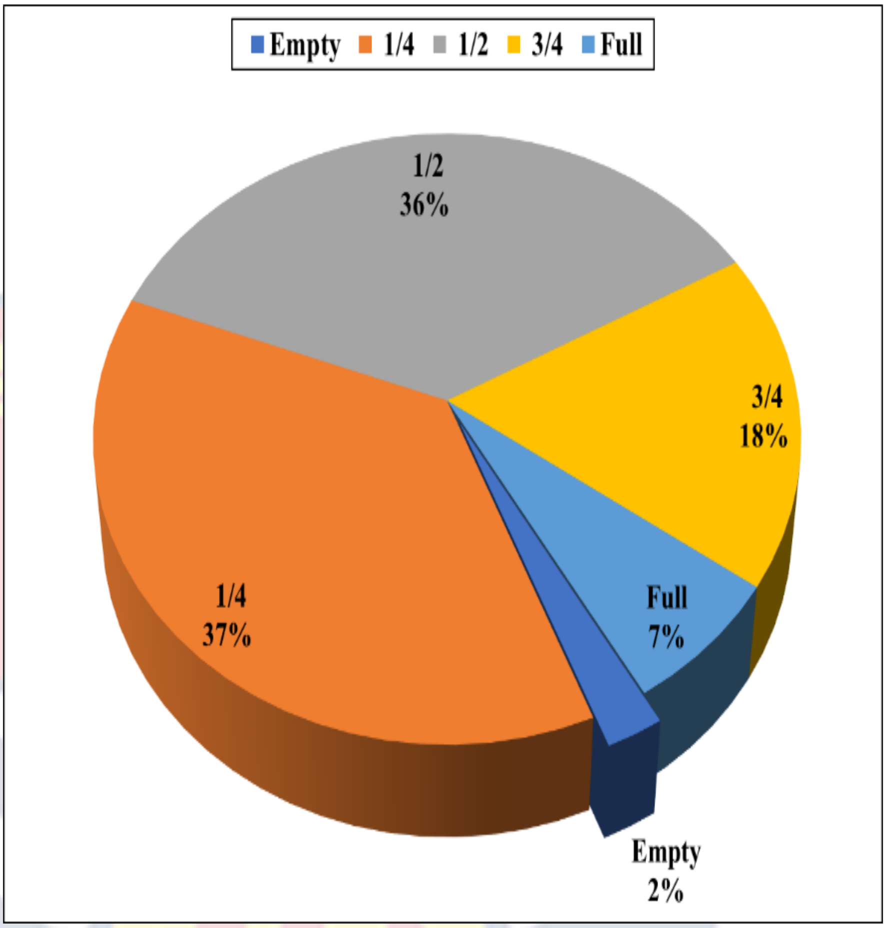

Figure 44: Percentage of stomach fullness of *Sardinella maderensis* (males) collected from Ibeju-Lekki

Stomach fullness of *Sardinella maderensis* (females) collected from Ibeju-Lekki, Lagos, Nigeria

The stomach fullness values for the female specimens are presented in Figure 45. Of the 535 stomachs examined, 28 (5%) were empty, 156 stomachs (29%) were 1/4 full, 172 stomachs (32%) were 1/2 full, 129 stomachs (24%) were 3/4 full, while 50 stomachs (10%) were full.

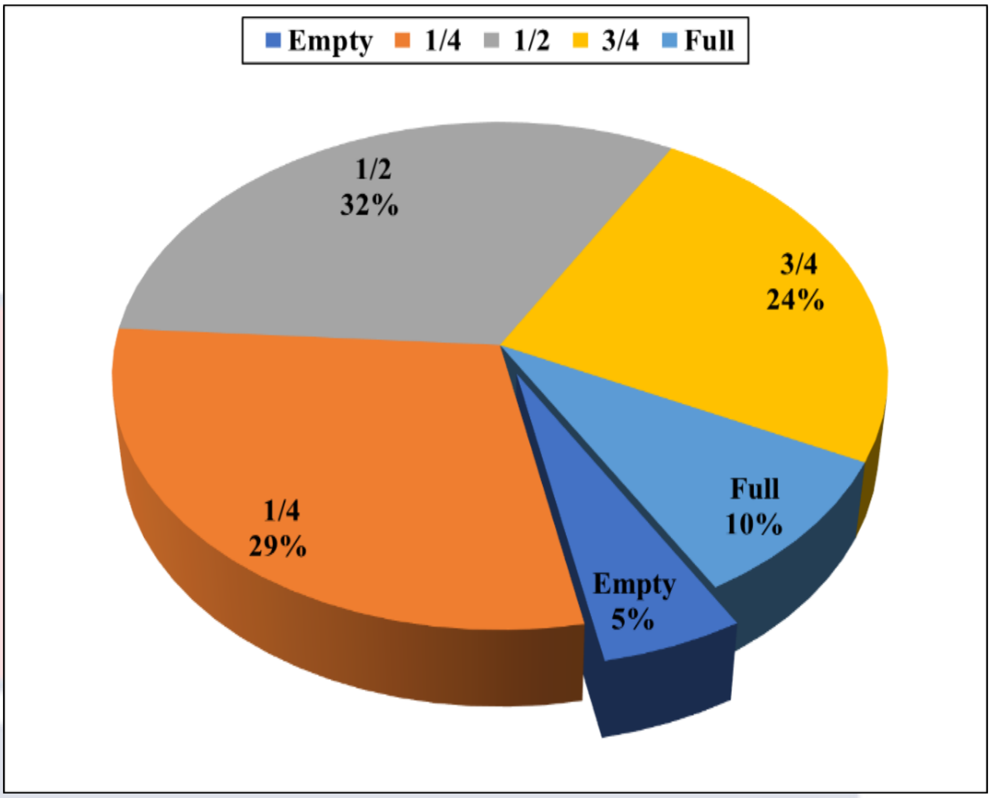

Figure 45: Percentage of stomach fullness of *Sardinella maderensis* (females) collected from Ibeju-Lekki

Stomach fullness of *Sardinella maderensis* (undetermined sexes) collected from Ibeju-Lekki, Lagos

The stomach fullness values for the undetermined specimens are presented in Figure 46. Of the 190 stomachs examined, no stomach (0%) was empty, 29 stomachs (15%) were 1/4 full, 79 stomachs (42%) were 1/2 full, 46 stomachs (24%) were 3/4 full, while 36 stomachs (19%) were full.

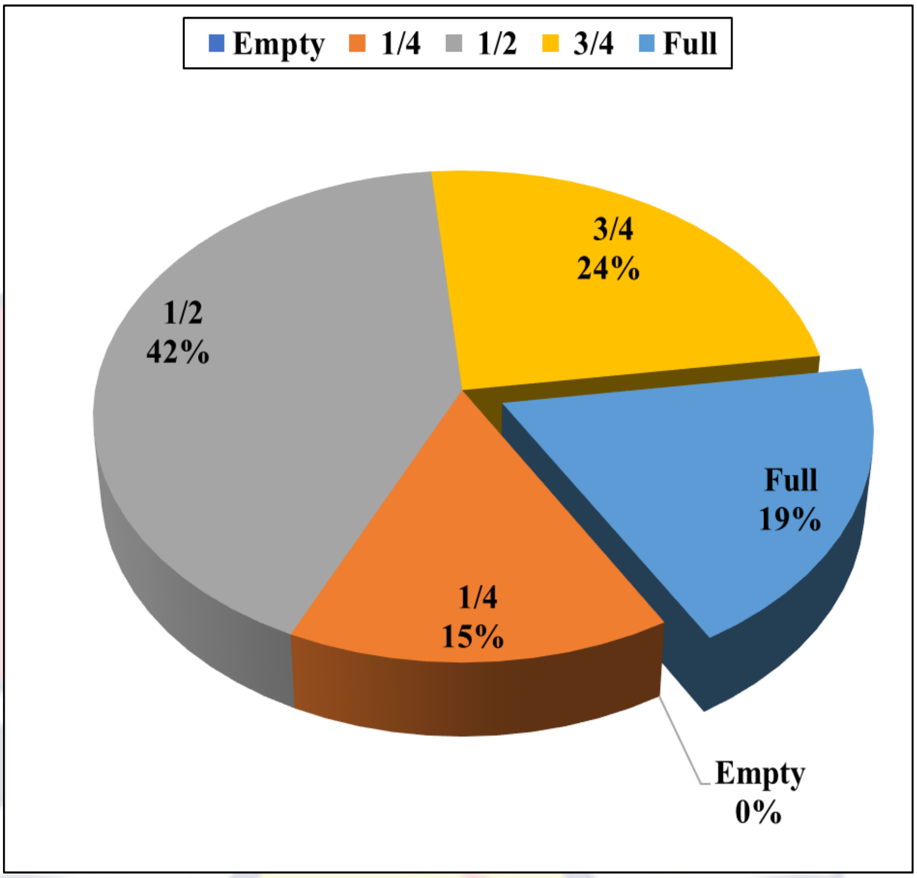

Figure 46: Percentage of stomach fullness of *Sardinella maderensis* (undetermined sexes) collected from Ibeju-Lekki

Vulnerabilities of Small-scale Fishers and Strategies for Resilient Fishery of *S. maderensis* in Ibeju-Lekki

Socio demographics

The analysis of fishers' responses to the in-depth interviews revealed that all the respondents are male. They have a mean age of 38 years, while the most frequently occurring age was 40. Among them 84% were Nigerians, 15% were Ghanaians, and the remaining 1% were Togolese. Nighty-one percent were married, 8% were single, and 1% were divorced/separated. The mean household size and mean number of children was eight and five respectively, and the number of spouses and other dependants both had a mean value of one. Their main physical assets are the boat (84.44%), Outboard Engine (40.56%) and Land (40.56%) (Figure 47).

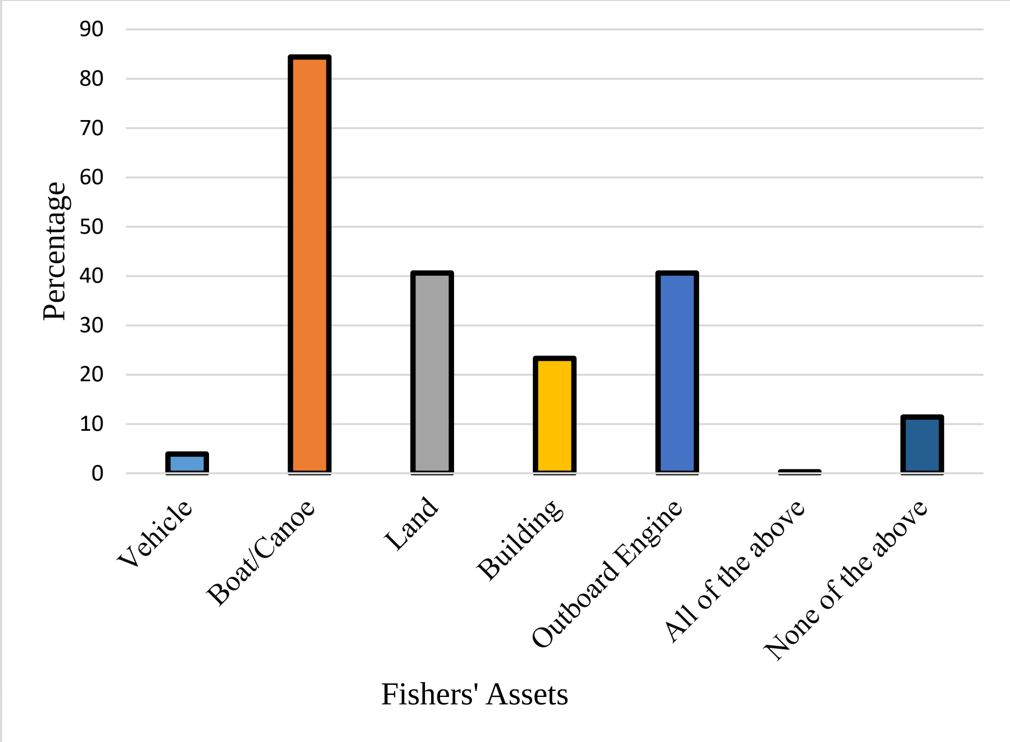

Figure 47: Physical Assets of Fishers in Ibeju-Lekki

Fishers education

Over 48.89% of the respondents stopped schooling at the secondary level, while 32.78% had primary education, 13.06% had no education, 3.33% had ND/NCE, and 0.28% had a university degree. The children's education was like that of the fishers, as 49.44% had secondary education, 24.72% had primary education, 10.56% had no education, and 5% had ND/NCE.

Fishers' occupation and livelihood

Fishing was the major occupation of more than 96.94% of the respondents, who had been doing so for an average of 20 years, mainly on a full-time basis. Eighty-five percent of the fishers do not have any secondary occupation, which means that fishing is their only source of livelihood. This is confirmed by the fact that about the same percentage (84.5%) affirmed that their household income is only from fishing. The average number of household members involved in fishing is two, while the most frequently occurring number is one. It implies that the fishers go fishing alone and does not want their children to be involved in fishing.

About 63.06% of the respondents do not have access to credit facilities. Most of those who can access credit do so from fishmongers. Another common source is the moneylending scheme under a non-governmental organization called LAPO. Over 66.94% of the respondents have not taken credit in the past 1 to 5 years. Out of the 33.06% that took credits recently, 22.78% from were taken from fishmongers, 7.5% from LAPO, 1.39% from cooperatives, 0.83 from relatives, 0.28% from commercial/agricultural banks and 0.28% Non-Government Organizations. The average amount collected was N217,538.37 ($369). The payback period is usually six months. Most respondents who had taken loans before indicated that the loan was inadequate.

Fishers' perception of climate change and vulnerability to its effects

Over half of the fishers (58.33%) have not heard about climate change. However, 97.5% affirmed that they had observed changes in temperature, rainfall, sea-level rise, and the saltiness of the water, fish food and seaweeds in the past ten years. Figure 48 illustrates the responses on their perception of variation in climatic parameters.

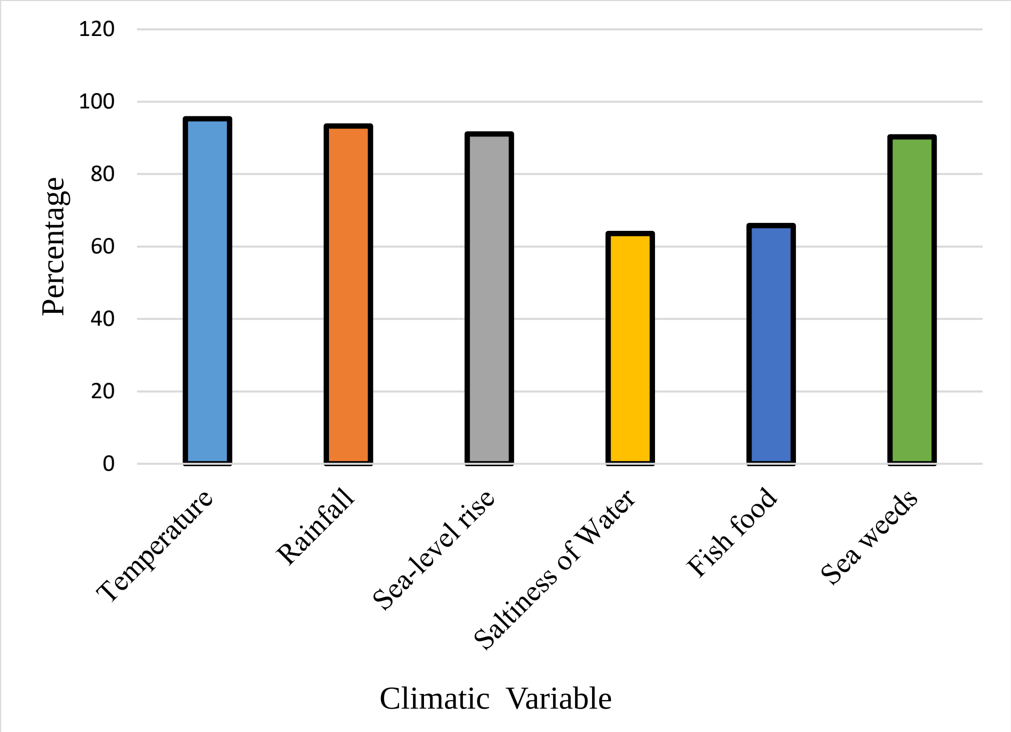

Figure 48: Fishers Perception of Variation in Climatic Factors at Ibeju-Lekki

Most (95%) of the fishers have lost one asset or another, and fishing tools (nets, engines and boats) are the main asset that is usually lost to bad climate. Despite the challenges they face, 90.28% of the fishers have not changed their location of fishing. In addition, the correlation of fishers' socio-demographics shows that gender and marital status household size were not statistically significant meaning that they do not affect the fishers' perception. However, age, nationality, level of education, and period of years in fishing were statistically significant and thus had effect on fishers' perception.

Furthermore, the vulnerabilities of the fishers according to loss of assets and the risks they are exposed to in line with the DFID (2001) guidelines are presented in Table 27. The rank is how much they agree to being susceptible to a loss risk or harm, and it was put at 1 (Highest Vulnerability) – 21 (Least Vulnerability). The ranking of the vulnerabilities was based on the mean of the weighted responses on the 5- point Likert scale. The result reveals that the loss of equipment/fishing gear constitutes the highest vulnerability to fishers, followed by the loss of boats and canoes. The thirdly ranked is “risk to life due to bad weather”, and the fourth is “declining income/profit”.

Table 27: *Vulnerabilities of Fishers in Ibeju-Lekki*

Vulnerabilities	**Strongly agree Agree**	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly disagree**	**Score**	**Mean**	**Rank**
	5	***4***	***3***	***2***	***1***			
Natural Assets								
Marine plankton loss	39	184	32	105	0	1237	3.44	**17**
Poor water quality	12	182	43	120	3	1160	3.22	**18**
Loss of fishing grounds	15	269	35	29	12	1326	3.68	**16**
Loss of landing sites	5	79	31	189	56	868	2.41	**20**
Decrease in fish availability	160	73	10	113	4	1352	3.76	**14**
Decrease in quality	163	70	11	110	6	1354	3.76	**14**
Physical Assets								
Loss of Housing	16	52	25	181	86	811	2..25	**21**
Boats/Canoes loss	250	82	3	21	4	1633	4.54	**2**
Infrastructure loss	20	81	29	193	37	934	2..59	**19**
Fishing gears loss	267	75	2	15	1	1672	4..64	**1**
Human Assets								
Risk to life due to bad weather	131	208	15	4	2	1542	4.28	**3**
Health challenges	114	224	13	7	2	1521	4.23	**6**
Decline in skilled fishers	112	184	30	26	8	1446	4.02	**10**
Financial Assets								
Declining income	128	213	8	9	2	1536	4.27	**4**
Poor savings	115	231	0	13	1	1526	4.24	**5**
Lack credit	114	212	8	14	2	1502	4.17	**7**
Lack of insurance	112	178	7	46	17	1402	3.89	**12**
Social Asset								
Social relationship loss	80	248	26	0	6	1476	4.10	**8**
Lack of association	79	215	25	36	5	1407	3.91	**11**
Loss of diversity	80	203	25	46	6	1385	3.85	**13**
Sense of insecurity	114	198	7	34	7	1458	4.05	**9**
Weighted Score	10630	13844	1185	2622	267	28548		
% of Respondents affected	***37.24***	***48.49***	***4.15***	***9.18***	***0.94***	***100***		

Source: Field Survey, 2021

It can also be noted that they are more susceptible/vulnerable to the loss of fishing grounds/area (16) than the loss of housing (21). Therefore, although climatic effects may not make them lose their place of abode, they are losing part of what can be defined as their territory and suffer the loss of livelihoods. The results from the vulnerability table can also be corroborated by the fishermen's responses on the severity of the loss of their assets. From the ranking (Table 28), they suffer the most severe losses on their fishing equipment, the fishing net and fishing vessel (boat/ canoe), followed by the fishing area.

Table 28: ***Severity of Fishers' Loss of Assets in Ibeju-Lekki***

Assets	**Extremely Severe**	**Severe**	**Moderate**	**Mild**	**None**	**Score**	**Mean**	**Rank**
	5	*4*	*3*	*2*	*1*			
Fish catch	128	144	35	22	31	396	**3.88**	4
Fishing net	151	160	19	4	26	486	**4.13**	2
Fishing area	148	131	42	36	3	465	**4.07**	3
Fishing vessel	190	122	25	23	0	559	**4.33**	1
Housing	65	3	1	12	279	43	**1.79**	6
Family	114	29	3	12	202	21	**2.56**	5
Weighted Score	*3980*	*2356*	*375*	*218*	*541*	*7470*		
% of Respondents	**53.28**	**31.54**	**5.02**	**2.92**	**7.24**	**100**		

Source: Field Survey, 2021

Regarding the forms of assistance they have received from the Government in the face of these vulnerabilities, the fishermen's responses reveal that most of them have not been benefiting from incentives that come through the Government. Although the Government may have been trying to assist, it may be that the incentives are not being passed through the right channel, and the distribution of such incentives does not get to the affected fishermen who need them.

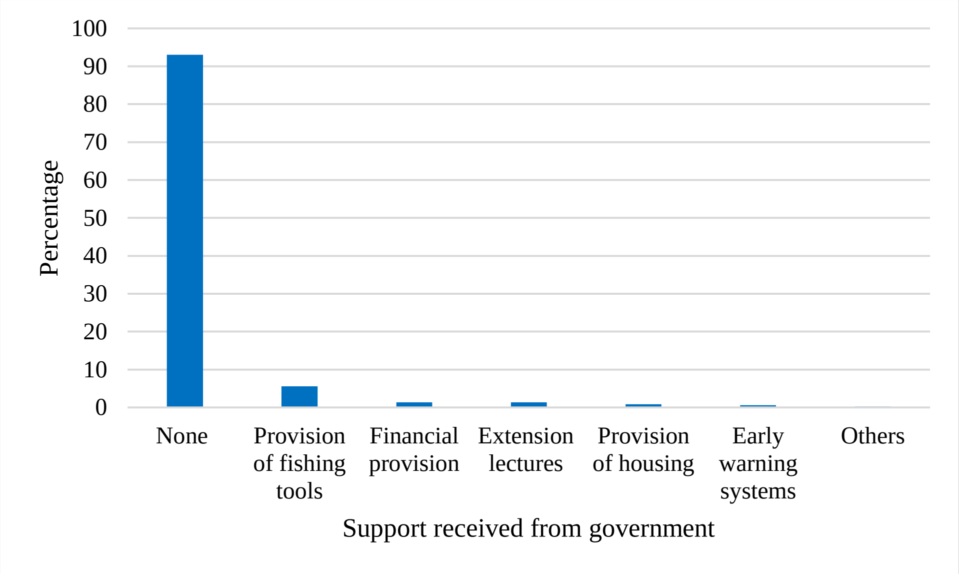

Figure 49: Support received from the government by fishers in Ibeju-Lekki

About 93.06% of fishers indicated that they have not benefited from government support (Figure 49). Over five percent (5.56) indicated they benefited from the government through the provision of fishing tools, 1.39% through the financial provision and extension services, 0.83% provision of housing for affected fishers, 0.56% through early warning systems, and 0.28% through other forms of assistance.

Fishers' perception of resilience to future climate change effects

The fishers think they can prepare for possible climate change by getting incentives and palliatives to improve their present conditions (95.28%). They also indicated provision of fishing tools/acquiring more fishing inputs such as nets, boats and engines (89.44%), financial support from the government (84.17%), early warning signs (82.5%) and getting access to climate information (76.94%). Only 2.2% indicated movement to other livelihoods.

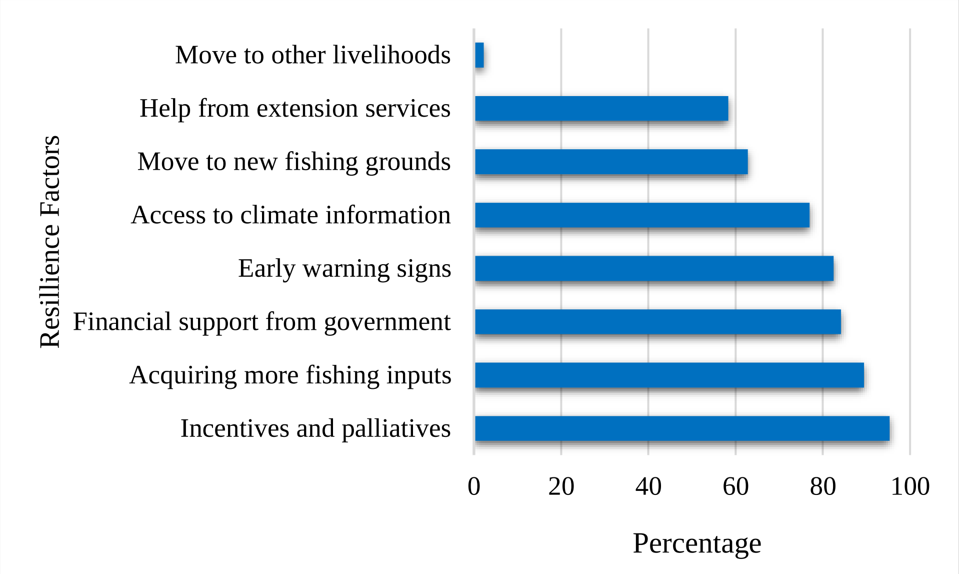

Figure 50: Fishers' perception of factors that aid resilience to climate change and anthropogenic activities effects in Ibeju-Lekki

From the fishers' responses, *S. maderensis* is mainly found at a depth of between 5-25 fathoms and less than 250 fathoms into the water from the shore. That is why it is vulnerable to anthropogenic activities such as dredging, stone pilling (Figure 51), construction works, pipe laying and others, presently around the coast in the study area.

Figure 51: Stone pilling construction for cargo landing at the Ibeju-Lekki

Fishing for Sardinella is done mainly in the evening and night, and each fishing trip takes an average of 7-12 hours. 95.83% of the fishers use the motorised boat as the paddled canoes are gradually being phased out. The regularity of catch is not specific; the fishermen emphasized that it varies with season, and the catches are sold to market/middle women and individual customers. The average weight of their catches is between 101kg-200kg. 92.78%, 94.4% and 95.56% of the respondents stated that catches have been reducing in the past ten years, five years and one year, respectively. Over eighty percent (81.94%) specified that the main reason contributing to the decrease in fish catch is the encroachment of fishing areas, while 47.78% attribute it to increased seaweeds.

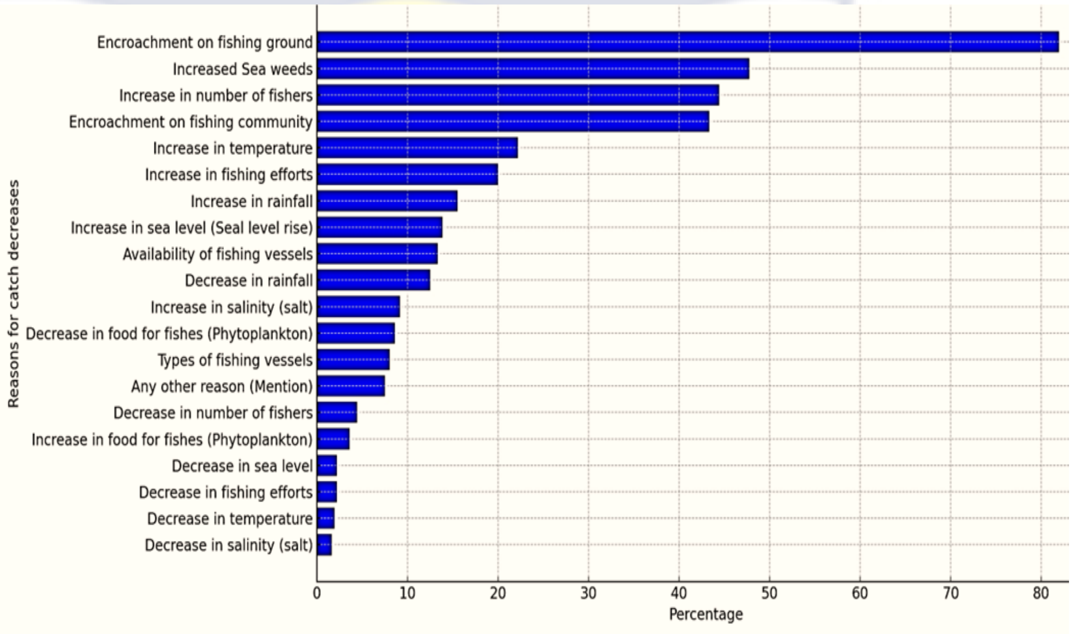

Figure 52: Reasons for the decrease in the catch of *Sardinella maderensis* in Ibeju-Lekki

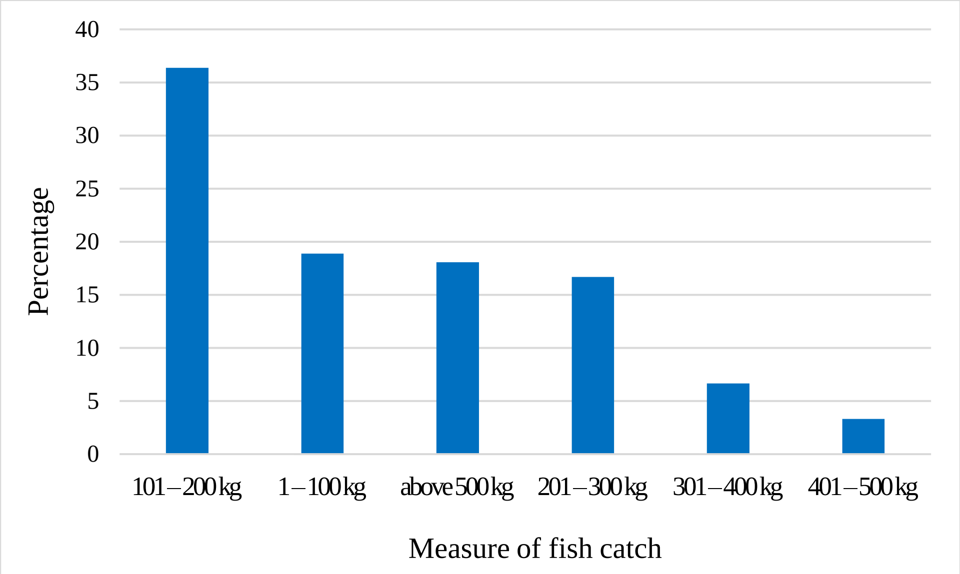

Figure 53: Average weight of fish catch per trip in Ibeju-Lekki

The fishers' mean length of stay in the present location is 25 years. Most of the fishermen fish within the local government because they do not have the capacity to move out to other places within the state or country; hence once their livelihood is affected, there would not be an alternative source to fish. Although only 20% are located in fishing communities in government-zoned industrial areas, 95% affirmed that industrial development negatively affects *Sardinella maderensis* fishing in their community. Moreover, they observed that other anthropogenic activities like residential development, commercial development, recreational/tourism development and religious activities at the beaches do not negatively impact their fishing activities.

The main social amenity they have access to in the community is Primary school education (86.39%). On the other hand, electricity and pipe-borne water are accessed by only 10.56% and 8.33%, respectively (Figure 54).

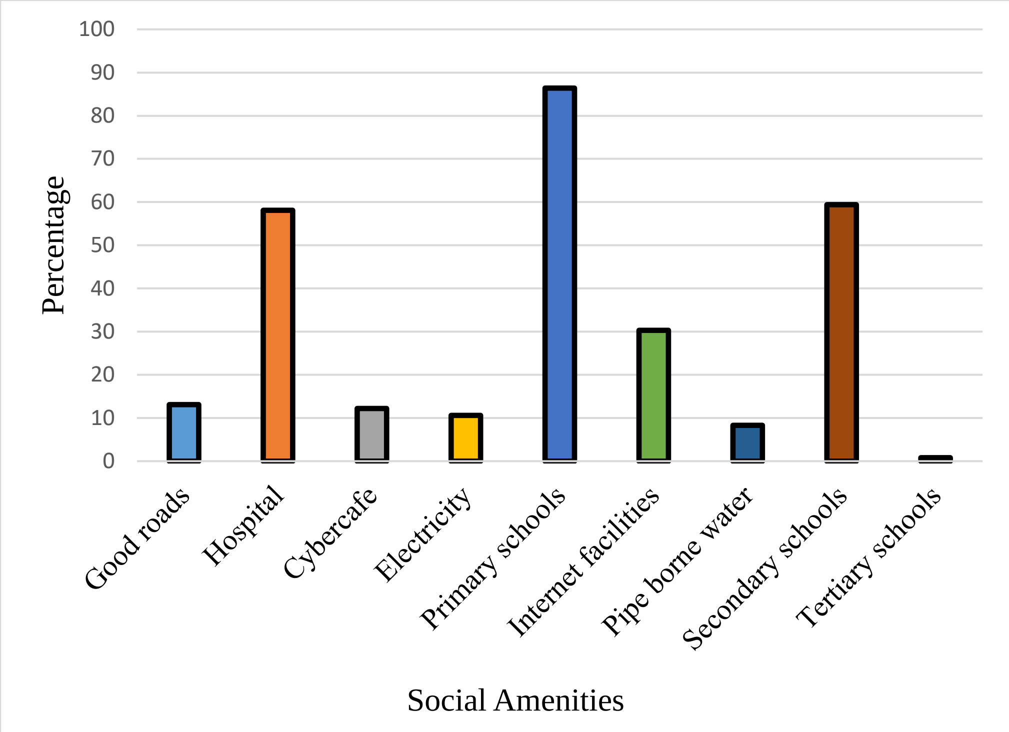

Figure 54: Fishers' response to access to social amenities in Ibeju-Lekki

Concerning what the government should do to assist fishers in the community, 96.94% suggested financial incentives, 85.28% stated electricity, 74.17% -Pipe borne water, 69.17% - Good roads, 68.06 – Hospitals, 63.33% - Primary/secondary schools, 41.67%-internet facilities while 38.61% stated promotion of extension services. 87.22% do not belong to any fishermen's society/cooperative society, and getting government incentives was the primary reason for those that joined. Out of the 12.78% that belong to fishermen's society, 6.39% alluded to the fact that it is moderately functional. Most fishers (90.83%) stated that they have not had any gains from the association. In addition many (88.61%) do not attend meetings with extension agents, and instead of the stipulated fortnight meetings, the average meeting period for those that participated was once in 3 months.

Correlation of fishers' socio-demographics with perceptions

The fishers' socio demographics was correlated with their perception of the effect of climatic variability and anthropogenic activities on their livelihood. The correlation of gender and marital status with fishers' perception were not statistically significant, which implies that they do not affect the fishers' perception. However, age, nationality, level of education (Household Head), and period of fishing (in years) were statistically significant and thus have effect on the fishers' perceptions. There was a negative correlation between level of education and fishers perception, while age, nationality, and period of years in fishing had a positive correlation with fishers perception (Table 29).

Table 29: ***Correlation of Fishers' Socio-demographics with Perceptions***

Variable	N	Pearson Correlation	Sig. (2-tailed)	Remark	P
Gender	360	1	-	NS	-
Age		0.107	0.042	S	P<0.05
Nationality		0.402	0.000	S	P<0.01
Marital Status		0.031	0.501	NS	p>0.05
Level of Education		-0.130	0.003	S	P<0.01
Years in fishing		0.182	0.001	S	P<0.01

S = Significant; NS = Not Significant

Emerging Themes from the Focus Group Discussions (FGDs)

The focus group discussion analysis evolves as themes, the main points picked from the discussions. These emerging themes are the points that occured in virtually all seven (7) FGDs. The themes are presented literally as the speakers put them; however, pseudo-names are given to the speakers for anonymity.

Responses on climatic variability

Mr B: “There is a difference in the way the rain has been falling before. When it falls before, we get fish to kill very well, but as it falls now, we cannot kill fish like before.”

Mr E- “If rain is plenty, fish will come, like two years ago. If the sun is too much, fish will not come, but if there’s rain, everybody will be happy because it will bring fish out”.

Mr E-“If the rain is too much, it will not allow us to do our work; if the rain falls too much, we will not be able to go out to fish”.

Mr D- “The temperature has changed because the rain too has changed. The heat is more than before because the rain is not falling like before”.

Mr A- The water, too, has changed regarding the level.

Mr D- “The water level is higher than before and is roughly more than before.”

Mr E- “Some years ago, where we built our house was far from the sea, but now because some people are fetching the sand (dredging), we now see the sea has come near us”.

Mr G- “The sea is getting closer to us. Not like it was, 30years ago. It was when refinery construction came that we started getting affected; a lot of our coconuts had been carried away by the sea”.

Mr D- “Saltiness of the sea is still the same”.

Mr E- “The saltiness of the water has reduced”.

Mr F- “The food of fish has reduced; if fish food is plenty in the water, we will get plenty of fish to catch”.

Mr E- “The flower (aquatic weed) started like ten years ago (2011), and it spoils the fishing net.

Responses on effects of anthropogenic activities

Mr A –"Refinery work is affecting us; the dredging and laying pipes in the water disturb our fishing."

Mr C-"The work has spoilt the water. On my way home, I saw oil films on the water, making fish run away."

Mr G – "The water has not been flowing in this direction like before." Construction work has blocked it around the Lekki, Magbon Segun, and Idaso; the flow of the tide that brings fish does not reach here again."

Mr D- "The dredging does not allow the net to touch the water bottom. Before, the net could touch the bottom, but now Sawa escapes and passes under the net."

Mr E-"The pipes they have laid inside the water tear and spoil our net."

Mr G- "Water has carried our coconuts away"(Figure 55).

Mr A- "Church/ religious activities do not disturb us. They are doing their own, and we are doing ours".

Mr V- "Fishers are using the same inches of the fish net."

Mr M- "Everyone has a designated landing site."

Figure 55: Coastal erosion leading to eroding of coconut trees at Ibeju-Lekki

Mr D- “No fishermen cooperative, some have in their community, but most are not functioning.”

Mr C -“I will not be able to do another work.”

Mr E- “I don’t have another means of livelihood.”

Mr K- “We don’t have other things to do; we did not learn welding or carpentry”.

Mr Y-“If they say where is your ID card, it is here on our palms which are so rough, typical of a fisherman.”

Mr K- “No help from the government.”

Mr G- “It does not come to us; some put themselves together as fishers’ cooperatives, but they are not fishers; they collect fishing tools from the government or Fadama and then sell to real fishers, they usually politicize it”.

Mr C – “We don’t know about insurance”.

Mr C- “Only one government hospital is at Akodo, few communities have health centres, and many do not have adequate facilities and staff”.

Mr U-“No primary and secondary in this community; children trek or take vehicles to schools in neighbouring communities”.

Mr A-“There is a primary and secondary school in this location, but no tertiary institution in the study area.”

Responses on their needs

Mr A, B, C- “Provision of engines, nets, boats and net accessories.”

Mr D- “If we are given and told to refund the money at a reduced price, it will help a lot.”

Mr E – “Government should help us to pile stone to reduce the effect of the sea waves on the shorelines”.

Furthermore, an observational checklist was used to assess some of the physical structures in the study area to describe how communities are affected quantifiably (Table 30). The results of the observational checklist showed that of the 30 communities where *S. maderensis* fishing is done, 15 are close (within 10km) to the industrial area. Although only 15 are within 10km of industrial area, there are 24 that have signs of erosion on their beaches. As of the study period, a few (3) communities have their houses affected by erosion. These few numbers indicate why the loss of housing under vulnerability is low because out of the 30 communities, only three are vulnerable to loss of habitation.

Table 30: ***Observational Checklist Result***

S/N	Observation Checklist	Yes	No
1.	Is the community close to an industrial area	15	15
2.	Are there signs of erosion on the beach	24	6
3.	Are houses affected by erosion	3	27
4.	Are there construction sites	11	19
5.	Are there other structures like the processing facilities affected	0	30
6.	Are they affected by aquatic weeds, remnants of aquatic weeds on the shore	30	0
7.	Is the mangrove along the beach still intact	12	18
8.	Does the community have a landing site	25	5
9	Is the landing site close to the residential area	18	12
10	Are there industrial sand dredging activities in the area	6	24
11.	Are there signs of receding shoreline	26	4
12	Is there an access road to the community	24	6
13.	Has the fishing ground in the community encroached	19	11
14.	Can construction activities be sighted close to the community	14	16
15.	Are there fishing activities at the beach	27	3
16.	Is there a recreational centre on the beach	3	27
17.	Are there religious centres at the beach	3	27
18.	Is there an industry cited in the community	7	23

All the communities are affected by the aquatic weed menace, as its remnants can be seen on their beaches. Only 12 of the 30 communities have their mangroves along the coast intact. Twenty-five have their landing site intact, and the five communities (Lekki, Apakin, Itamarun, Oriyanrin and Otolu) that have lost their landing space have to land in other communities. However, 18 of the 25 who still have a landing site have a site close to the residential area, implying that the site is also gradually being eroded.

Industrial sand dredging activities were seen taking place in 6 communities, 26 of the communities have signs of receding shorelines, while 6 of the communities do not have access roads. Nineteen have their fishing grounds being encroached. Construction activities can be sighted in close to 14 communities. Twenty-seven still have fishing activities at their beaches. At the same time, there are no longer fishing activities in some communities, and the fishers there have to join colleagues in neighbouring communities to go fishing.

Few (3) communities have recreational centres at the beach. The fishermen affirmed that recreational centres are not a threat to them and do not disturb their fishing activities but rather promote them because when tourists come to such centres, they sometimes buy fish from them or rent their boats. Similarly, religious centres were found on a few (3) of the beaches, and in such communities, fishers also confirm that religious centres are not equally a threat to their fishing activities. Although only seven communities presently have industries cited in them, virtually all of the communities in the study area already feel the impact of industrial activities.

Chapter Summary

This chapter presented the study's findings. These included the phenotypic and genetic identification of the fish species, the trends of climatic variables and historical catch data and the forecast of the future trend of climatic variables and fish catch in the study area. The effects of climatic variabilities and anthropogenic activities on the fish species' abundance were also presented. The morphometric characteristics, length-weight relationship and condition of the fish were also presented. In addition, the analysis of fishers’ responses to their perception of climate change and anthropogenic effects, vulnerability to these effects, physical observations and emerging themes from the FGDs in the study area were presented.

CHAPTER FIVE

DISCUSSION

This Chapter discusses the fish species identification and the genetic analysis which confirms the species of *sardinella* in the fishery. It also discusses the effects of climatic variabilities and anthropogenic activities on *sardinella* fishery and the fish morphometrics, length-weight relationship and condition of the fish species in the study area. The Chapter further considers the impact of climatic and anthropogenic factors on the small-scale fishers' livelihoods and strategies for resilient small-scale fisheries in the study area.

Fish Species Identification

The genus *Sardinella* has different species reported on the West African coast. They are said to be migratory; therefore, there are speculations that there could have been a mix in the species population. The uncertainties about the state of the stock brought the need to determine whether the *Sardinella* in the Ibeju-Lekki coastal waters are mainly *maderensis* or a blend of *Sardinella* species. The various *Sardinella* species that have been reported in estuaries, lagoons and open sea include *maderensis*, *aurita*, *rouxi* and *lemuru* (Aderinola et al., 2020; Ibim et al., 2020; Marcus, 1989; Ogunola & Onada, 2017; Olopade et al., 2019).

The fish samples in this study showed features as described by Whitehead (1985) and Gourene and Teguels (2003). It has an elongated body with a belly fairly sharply keeled, 18-23 dorsal soft rays and 17-23 anal soft rays, 70-166 lower gill rakers, upper pectoral fin rays white on the outer side, and the membrane black. It resembles *S. aurita* but can be differentiated by the following features, in *maderensis*, the pelvic fin is one unbranched and seven branched, but one unbranched and eight branched in aurita. The samples had flat bodies with a black area just behind the gill opening, unlike aurita, which is round-bodied and has a black spot on the posterior part of the gill cover (Fischer et al., 1981; Whitehead, 1985). A prominent distinguishing feature is that *S. maderensis* has a black spot at the base of the dorsal fin while *S. aurita* does not (FAO, 1990). *S. maderensis* also has a lot of resemblance with *S. rouxi*. Still, it can be distinguished by having more lower gill rakers (30-40) in *S. rouxi* and grey caudal fin, almost black tips vs pale yellow with distal margin dusky in *S. rouxi* (Fischer et al., 1981; Froese & Pauly, 2017; Gourène & Teugels, 2003; Whitehead, 1985).

After the species identification was made morphologically, genetic analysis was conducted for confirmation. The NCBI BlastN search of the complete mtDNA sequence showed up to 100% identity to the sequence of the *Sardinella maderensis* mitochondrion. Hence, the genetic analysis results also confirmed that the fish samples were *S. maderensis*. This study detected low levels of genetic differentiation similar to Takyi (2019), suggesting that there is only one population across the communities. The results from this study can represent samples from the Central Stock (Nigeria and Cameroon) of the CECAF, which Takyi (2019) could not obtain in her research. The results can also serve as a baseline for future studies on this population.

This study also confirms Brainerd's (1991) assertion that most *S. maderensis* “adults remain confined over the shallow half of the continental shelf.” Compared to the *S.aurita*, the adult *S.maderensis* is more sedentary and is restricted to the continental shelf's shallow half, which corresponds with the findings of Nemba et al. (2020) who observed in their study that *S. maderensis* was found in the coastal region of the littoral in the Cameroon waters. The result of this research is also in line with Bolaji's (2018) findings. Only one *S. maderensis* was among 50 sardinella species samples he collected offshore the Nigerian coastal waters where the industrial trawlers fish, confirming that *S. maderensis* is endemic to the coastal waters near shore along the Nigerian coastline.

Furthermore, although the species has been the subject of several ecological and morphological research, its entire mitochondrial DNA (mtDNA) sequence in the Nigerian coastal waters has not been reported. From the studies of Takyi (2019), "Nigeria samples were excluded from the analysis because so few average contigs matched the reference assembly compared to the other populations, indicating that the fish obtained were not *S. maderensis*".

In addition, the first analysis using the universal animal ID results revealed some bacteria output. As Rudin and Inman (2001) stated, PCR is a very sensitive procedure which may show a differing result if there are contaminants. Hence the output may be a result of the bacteria contamination on such fish, and the primer could have been able to detect it since it is a universal primer/ animal ID. The bacterium detected is *Brevundimonas nasdae.* Genus *Brevundimonas* was first proposed by Segers et al. (1994). *Brevundimonas spp* are aerobic gram-negative oxidase and catalase-positive organisms, belonging to the class Alphaproteobacteria and family Caulobacteraceae (Segers et al., 1994). According to Ryan and Pembroke (2018), *Brevundimonas spp*. have been isolated from multiple environments, including numerous aquatic habitats (Abraham et al., 2010), deep subsea floor sediment (Tsubouchi et al., 2014), purified water (Penna et al., 2002) and soils (Ryan & Adley, 2014; Segers et al., 1994; Soto-Giron et al., 2016; Wang et al., 2012). Brevundimonas species are emerging global pathogens; they are non-fermenting bacteria that are a problem in clinical settings and a frequent source of nonsocomial infections (Ryan & Pembroke, 2018). Some other species, such as *B. vesicularis* and *B. diminuta*, have been used as a potential bioremediator of marine oil pollution, including diesel, n-alkanes and some other hydrocarbons (Guermouche et al., 2015; Wang et al., 2016). There is therefore a possibility that the bacteria is on the fish samples to help bioremediate the environment by detoxifying contaminants such as heavy metals and aromatic hydrocarbons in the water. The occurrence of bacteria in fish samples can be looked into for further research. The result of the analysis with the Ward et al. (2005) primer came out with all the samples as *S. maderensis*, confirming the adequacy of the primer for the genetic analysis of Sardinella.

Effects of Climatic Variabilities on *Sardinella maderensis* Abundance

Climate change's combined rates and magnitude are already resulting in a global-scale biological response (Pecl et al., 2017). As stated by IPCC, 2014 "climate will continue to change for at least the next several hundred years, given the inertia of the oceanic and atmospheric circulation systems". In understanding climate change scenarios, trend analysis has been a valuable tool and an active area of interest (Addisu et al., 2015; Alemu & Dioha, 2020; Kawale et al., 2011; Keskin et al., 2018; Mudelsee, 2019; Stergiou, 1990). Therefore, the ARIMA time series model was used to understand time series data on climatic variables and historical fish catch data to predict future values. The time series analysis of the climatic variables shows the trend of each variable. There were fluctuations in the rainfall and temperature trends in line with the projections made by USAID (2018) which states that rainfall and temperature variability is likely to increase. The trends also show that the mean sea level is rising in line with their projection and that of others like Serdecny et al. (2017) and Merem et al. (2019b).

In contrast, chlorophyll-a and sea surface salinity show a downward trend. The downward trend in salinity is similar to the findings of Dasgupta et al. (2015), who reported that the slight and moderate saline areas on the coast of Bangladesh would experience a decrease in salinity trend in the coming years. It is also in line with projections stated by Stormer (2011).

The ARIMA model indicated that the catch trend would continue to decline hence the need for management interventions. The model corroborated complaints from fishers who have noticed a decline in their catches in recent years. The trend results for this study differ from the result from the Colombian Pacific Ocean by Selvaraj et al. (2020) on mullet, which shows slight increases in landings in the future. However, the results were similar to that of Makwinja et al. (2021) on the stock exploitation in Lake Malombe, Malawi, which showed a downward trend.

Regarding the effects of the climatic variables on fish abundance, the linear regression analysis reveals that the climatic variables Rainfall, Chlorophyll-a, Mean Sea Level, Sea Surface Salinity, and Sea Surface Temperature have sigificant effect on the Catch Per Unit Effort representing abundance. The result implies that variations in climatic factors will affect fish catch. This corroborates the assertion by Muringai et al. (2021), Anderson et al. (2013), and Poloczanska et al. (2016) that changes in mean temperature, rainfall, sea-level changes and water salinity affect the productivity and abundance of warm water species. In addition, each of the variables significantly predicts Sardinella abundance.

Rainfall had significant effect on CPUE and indicated that, on average, a one-unit increase in rainfall will decrease the value of CPUE. Naturally, an increase in rainfall is supposed to lead to a rise in fish catch. From the fishers' responses, they have observed that fish swims up in the water when rain falls, allowing them to catch more fish. However, it is not always the case in this fishery. This study's findings reveal that excessive rainfall decreases fish catch because the increase in the rain leads to a rise in sea level, making the water level high and boisterous. Consequently, because the fisherfolks use crude implements, they cannot go to the sea due to excessive rain. Therefore, excessive rainfall leads to sea level rise, reduced fishing activities and reduced fish catch.

Chlorophyll-a significantly predicted the abundance of fish. The reason is not far-fetched, *Sardinella maderensis* is a planktonic feeder, and chlorophyll is an indicator of plankton availability in the water. Therefore the availability of chlorophyll-a will determine the abundance of sardinella in the waterbody. Conversely, fish abundance will also be affected if it is not in sufficient quantity. According to Puspasari et al. (2019), the most important factor for predicting sardine output in Bali appears to be Chl-A concentration. Their study revealed that there was a 5-month lag between between high Chl-A abundance and high sardine output. Similarly, Lanz et al. (2009) showed that Chl-A concentrations significantly affect Pacific sardines in the gulf of Califonia. The delayed effect of Chl-A on sardinella was also reported by Sartimbul et al. (2010) and Rintaka et al. (2014), which could be related to the fact that there is an amount of time required for materials to move between trophic levels.

In addition, the study showed that Mean Sea Level has a significant effect on CPUE. Sea level rise significantly affects coastal zones and especially important fish stocks that inhabit coastal waters (Mendenhall et al., 2020; Yanda et al., 2019). The result of this study conforms with the assertion of several authors concerning coastal areas that sea level rise is expected to worsen because coastal areas are low-lying and more vulnerable to flooding and land loss due to climate change (Byravan & Rajan, 2010; Colburn et al., 2016; Martinich et al., 2013; Melet et al., 2016). Furthermore, in their studies, Yanda et al. (2019) stated that coastal resources, including fish and mangroves, are impacted by sea level rise.

Sea Surface Salinity did not have significant effect on CPUE. This may be due to the fact that *S. maderensis* is known to tolerate a wide range of salinity fluctuations, which might be why salinity variation does not affect its abundance. However, the result is different from the findings of De-Felice et al. (2021), who found that the abundance of *S. aurita* in the Mediterranean sea was influenced by salinity.

Sea Surface Temperature had a significant effect on CPUE. It indicates that there will be an increase in fish catch when the water is warmer. This is in line with the studies by Jim-Saiki and Ogunbadejo (2004) on the peak of fish production in Ibeju-Lekki. They reported that although fishing activities are done throughout the year, the availability of fish is seasonal, with a peak in the dry season when the sea is warm and calm. They added that the peak period for Sardinella species abundance is from November to February; fishers' responses also corroborate this; however, this study's observations differ slightly from this assertion. According to the historical data records, there was low availability of sardinella, especially during the January period in most years. This may be attributed to climate variability, making the trend to differ from year to year and introducing uncertainties.

In conclusion, rainfall, chlorophyll-a, mean sea level, and surface temperature significantly have significant effects on *Sardinella maderensis* abundance. However, sea surface salinity did not significantly predict the abundance of *Sardinella maderensis* because it tolerates a wide range of salinity.

Effects of Anthropogenic Activities on *Sardinella maderensis* Abundance

This study's findings indicate that anthropogenic activities will significantly affect fish catch in the study area as variance in fish catch is explainable by land use, social amenities, and fishing effort. In line with Amosu et al. (2012)'s assertion that those elements affected by human-based activities are endangering Nigeria's renewable coastal resources, and they are often associated with high population, industrial activities (and unsustainable use of natural resources). Increased land use and fishing effort will affect fish catch negatively while increasing social amenities will help to improve the fish catch.

Land use had significant effect on fish catch, indicating that, a one-unit land use increase will decrease the value of fish catch. As Arowolo and Deng (2017) reported, human activities have significantly influenced land use in Nigeria. The high rate of urbanisation with associated population growth has produced changes in land use and land cover in several areas of Sub-Saharan Africa (Merem, Twumasi, Wesley, Alsarari, Fageir, Crisler, Romorno, Olagbegi, Hines, Mwakimi, et al., 2019a; Sahalu, 2014). The land in the Ibeju-Lekki fishing community is being used for industrial activities at an increasing rate. There is a need to regulate the proliferation of industries in that environment to avoid jeopardizing or compromising the sustainability of natural resources.

Social amenities had significant effect on fish catch, indicating that increase in social amenities will increase the quantity of fish catch. The fishers have abandoned some communities because of the lack of access roads. The fishers left the community because buyers could not access their beach to come for fish purchases. Electricity is another amenity that will be very helpful to the fishers to help in preserving their catch. Currently, unavailability of electricity makes the fishers to spend much of their income on fuel to power electricity-generating sets, affecting their livelihoods in the long run.

Fishing effort had a significant effect fish catch, indicating that, increase in fishing effort will decrease the value of fish catch. This result implies that fishing efforts in the study area should not be increased further to ensure the sustainability of the fishery. According to Dayton et al. (2002), fishing provides many benefits, which include food, employment and business opportunities, and these benefits must continue to be available in the future. Therefore for effective management of fish resources, there must be a dynamic balance between obtaining the benefits of exploitation and minimising its impacts to avoid harmful effects. Hence, it is essential to reduce the adverse effects to improve ecosystem health and potentially increase fishery yields.

The physicochemical parameter analysis result shows that water temperature values ranged between (25 - 27)°C, which is still within the above

24°C value reported to be preferred by *S. maderensis* (Brainerd, 1991; FAO, 2021). It is also within its preferred temperature range stated by Froese (2020), which is 18 - 27.9, with a mean of 21°C. The temperature value is also similar to the range recorded (24.8 - 25.4) by Mahmoud et al. (2019) in the Egyptian coastal waters but less than the values reported by Spanton and Saputra (2017) in Tuban, Indonesia coastal waters (29 - 31°C) and Mary et al. (2017) in Pondicery, India (32°C). Conversely, to the historical data trend, the temperature is higher than the required temperature for sardinella, confirming the projection that SST may get warmer. Further increments in the temperature could put the specie at risk. Industrial activities, sand dredging and other activities around the water body could contribute to warming the water.

The water's pH (7.32 - 8.06) was within the required range for fish species according to the USEPA (1985) standard. pH indicated alkaline conditions peculiar to saline waters (7.71 – 7.81), which is still within the range (6.5 - 9) suitable for fish. pH range detected in all stations were within the optimal range necessary to support aquatic life, similar to reports by Okyere (2015) and Murdoch et al. (2001), but varied a little from the values (6.5 - 8.6) observed by Adesalu et al. (2014) in the Lagos Lagoon.

The salinity in the water body ranged between 24.86 - 32.17 ppt, although the salinity is low for a marine water body which is usually about 35 ppt. However, *Sardinella maderensis* is reported to have tolerance for low salinities (Tous et al., 2015; Whitehead, 1985); hence the salinity level will still be adequate to survive. The total dissolved solids (TDS) values ranged between 11500 mg/L-30000 mg/L. The values are higher than the acceptable 2000mg/L set by the Federal Environmental Protection Agency. Spanton and Saputra

(2017) stated 1000mg/L in their studies. These high TDS values may affect gill and kidney functions that impact the survival and size of the fish. The value from this study is similar to what was reported (30940mg/L) by Mary et al. (2017) in Pondicherry coastal waters in India during their research on some fish samples that included Indian sardine, *Sardinella longiceps.* Mahboob et al. (2022) recorded higher values of TDS in the Arabian Gulf, near Dammam, Saudi Arabia. They had similar features to Ibeju-Lekki as anthropogenic activities prevalent there, reported by El-Sorgy et al. (2018), included sand dredging, landfilling and oil spills.

During the sampling period, dissolved oxygen values (4.80 mg/L – 15.80 mg/L) were within acceptable limits. However, the minimum value was almost as low as the chronic protective value for growth, 4.8mg/L (USEPA, 2000). Oxygen is vital for every aquatic organism, and the amount of DO in water is significant because it affects the organisms' growth, survival, distribution, behaviour and physiology (Elahi et al., 2015).

Nutrient levels, nitrates (0.01 mg/L – 2.11 mg/L) and phosphates (0.01 mg/L – 0.70 mg/L) were within acceptable limits and relatively low. The low values could be ascribed to the fact that farming activities are not so common in the study area since nitrates are strongly associated with agricultural land and grasslands (Duque et al., 2020; Ferrier et al., 2001). It could also be attributed to the high level of heavy metal and total petroleum hydrocarbon in the water as the results align with the finding of Akubugwo and Duru (2011), who observed reduced concentrations of sulphate, phosphate, and nitrate in water as a result of human activity.

The Biological Oxygen Demand (BOD) values occasionally fall within an acceptable range but sometimes exceed the lethal limit with values as high as 11 mg/L. According to Hynes (1960), BOD values higher than 8 mg/L point to severe pollution. While the chlorophyll-*a* values which depicts the presence of food organisms for the fish, is at a grossly inadequate level in the water body.

Although *Sardinella spp.* can withstand a wide range of temperatures, pH values, salinities, and DO levels; comparative analysis of the physicochemical components of water and its development revealed that the differences influenced the species' condition on the Balochistan coast of Pakistan (Elahi et al., 2015). Moreover, it is possible to directly alter the quality of coastal waters by exploiting coastal areas for long-term human habitation and transportation means; and dumping untreated residential, industrial, and agricultural waste into the sea through rivers (Bat & Gökkurt, 2014) thus affecting fish negatively.

The results of the heavy metal analysis reveal that the level of lead (0.20±0.17) mg/L, cadmium (0.06±0.06) mg/L, iron (2.62±0.51) mg/L, manganese (0.19±0.11) mg/L and nickel (0.64±0.19) mg/L were within the national limit set by the Federal Environmental Protection Agency in Nigeria. However, the values were above the international standard limit by the United States Environmental Protection Agency. The value for chromium (1.73±2.09) mg/L was above both the international and the Nigerian standard limits. The Cr value was also higher than the value from the study of Mary et al. (2017) on the coastal water in India, but the Pb and Cd values were less than the concentration they observed. The values from this study were higher than those derived by Mahboob et al. (2022) from the analysis of the seawater in the Arabian golf of

Egypt and that of Ekweozor et al. (2017) from the creek of Portharcourt, Nigeria. They were however similar to the results from the study of Chinedu & Chukwuemeka (2018) who observed high levels of heavy metal concentration in the Niger Delta area of Nigeria. The high values of these heavy metals may not be unconnected with the industrialisation in Ibeju-Lekki especially with activities involving crude oil as it occurs in the Niger Delta. Several authors have attributed heavy metal pollution to anthropogenic activities. (Alharbi & El-Sorogy, 2017) stated that anthropogenic activities cause heavy metal pollution in coastal waters. For instance, Mansour et al. (2011) reported that lead could occur from oil spills, motorboats and untreated wastes. In addition, Mahboob et al. (2022) attributed higher concentrations of metals to anthropogenic activities such as corrosion of marine construction, landfilling and construction residual. Hence, the presence of these heavy metals in Ibeju-Lekki coastal waters could be because many industries have just started functioning within the last few years.

According to Taslima et al. (2022), “heavy metal pollution threatens the aquatic environment and its inhabitants when their concentrations exceed safe limits”. Some dangers to fish health are reduced gonad somatic index, fecundity, hatching rate fertilisation success, reproduction failure and abnormal shape of reproductive organs. Heavy metals are toxic to aquatic organisms and substantially threaten human health. The majority of these heavy metals are extremely carcinogenic, and they can also result in serious health issues like liver problems, cardiovascular issues, kidney dysfunctions, and in some situations, extreme conditions (Taslima et al., 2022). The aquatic environment contains naturally occurring trace amounts of heavy metals. Yet, their levels have increased because of geochemical structures, mining and agricultural operations, industrial wastes, and other factors (Zeitoun & Mehana, 2014). They form the most dangerous side of chemical pollution due to their ability to bioaccumulate and biomagnify and cannot be eliminated from the body by metabolic activities.

In addition, the total petroleum hydrocarbon values in the waters of Ibeju- Lekki communities exceeded the limits of the Nigerian Environmental Protection Agency Standard. The TPH analysis results indicated that the water in all the sample stations throughout the year was polluted with hydrocarbon. The values exceeded the TPH permissible limit for coastal waters in Nigeria (10mg/L) (DPR, 2011). It was observed that the values for August 2021 were very high compared to other sampling periods, and it could be that there was an oil spillage around that period which spread across all the communities, similar to the report by Daniel & Nna (2016) regarding their study on the Cross River Estuary in Nigeria. The high level of TPH in the water calls for a serious intervention to regulate the quantity of hydrocarbon waste allowed to be deposited or get into the water body. According to MAPRES (2008), large spills of oil and related petroleum products in the marine environment can have severe biological and economic impacts. Conclusively, some of these measured parameters reveal that the waters of the Ibeju-Lekki coastal community in Nigeria are not good enough for marine health.

The phytoplankton diversity and quantity result shows more taxonomic groups (taxa_S =12) in October and December compared to other months similar to the observation of Adesalu et al. (2014) on Lagos Lagoon. However, those taxa did not translate into many individual phytoplankton. April had only eight (8) taxa but had the highest number (338) and percentage (24%) of individuals. The availability of many individuals during the rainy months of April, June and August depicts that phytoplankton abundance was more in the wet season. This is contrary to the finding of Fonge et al (2013) in Douala Estuary, Cameroon and Yusuff (2020) in Nasarawa Reservior, Nigeria, whose results had more phytoplankton species in the dry season. Moreover, the reduced number in the dry season may be due to higher toxicity during that period as a result of anthropogenic activities in the study area. According to Akagha et al (2020) anthropogenic activities are among the forcing factors that influence phytoplankton community. Species richness was highest (1.997) in December but lowest (0.192) in February, also contrary to the finding of Okogwu and Ogwumba (2013) in Asu River, Nigeria, it may however be due to the fact that condition of the water bodies are different since they worked on riverine ecosystem.

On the other hand, species diversity was highest (1.338) in October but lowest (0.325) in February. Low diversity index values indicates dominance by one or two species, while high diversity index values indicates that the species numbers are more evenly dispersed. This probably explains the low Shannon (H) and Margalef (d) values recorded when *Microcystis aeruginosa* was more prevalent (both in February) among the samples. In addition, the Shannon-Weiner diversity index value of < 1 is classified as being heavily polluted and 1-3 is moderately polluted while >3 depicts clean water (Wilm & Dorris, 2007). Hence the Ibeju-Lekki water can be classified as ranging between heavily polluted and moderately polluted water.

Regarding zooplankton diversity and quantity, the result shows that zooplanktons have fewer taxonomic groups and individuals than phytoplankton similar to the findings of Dimowo (2013), Nkwoji (2010). A lesser amount of zooplankton than phytoplankton is expected in a natural ecosystem; since the phytoplanktons are in the lower layer of the web, they are supposed to be more in number so as to have ecosystem balance. There were more taxonomic groups (taxa_S =3) in October and December compared to other months, similar to what we have in the phytoplanktons. However, this translated to more individuals than the case with the phytoplanktons. December had three (3) taxa with the highest number (17) and percentage (35%) of individuals. The availability of many individuals during the dry months of February, October and December depicts that zooplankton abundance is more in the dry season similar to the findings of Onyema and Ojo (2008). Consequently, the species richness was highest (0.630) in December but lowest (0) in August.

Length-Weight Relationship and Condition of *S. maderensis* in Ibeju-Lekki

The population of *Sardinella maderensis* is reportedly declining due to climate change and overfishing, and its average size is reducing as a result (Olopade et al., 2019). According to FAO (2006), in the following two years. The publication added that "over the ten years, the average size of this fish has decreased from 35 cm to 32 cm". In addition, “the International Union for Conservation of Nature (IUCN) has rated its status as vulnerable” (Tous, Sidibe, Mbye, De Morais et al., 2015). Based on this background and for effective management of the fishery, it was essential to know the status of the fish population (Cheung et al., 2021; Dar et al., 2012; Ogunola et al., 2018; Saygin et al., 2016).

The male-to-female ratio of the fish samples was 59% males to 41% females. The sex ratio favoured the males in line with the findings on *S.aurita* by Dienye et al. (2022) and Lawson and Doseku (2013) in New Calabar river, Niger Delta, Nigeria and Majidun creek, Lagos, Nigeria, respectively. This is however in contrast with the findings of Konoyima et al. (2020), which showed a female-dominant (59%) population from their study on *S. maderensis* in Sierra Leone. The migratory nature of this species could also explain the prevalence of males since females frequently arrive at the spawning site later than males (Dienye et al., 2022) and spawning sites are usually one of the targets for fishing. This may lead to competition for mating partners among them.

The maximum length and mean values for this study's total length (TL) and fork length (FL) are 31.9cm, 23.6±5.16cm and 25.4cm, 18.8 ± 3.74cm, respectively, while the maximum standard length (SL) and mean length were estimated at 23.2 cm, 17.4± 3.45cm. Compared with the maximum size (SL) of 30.0 cm and the common length of 25.0 cm reported by (Whitehead, 1985); and the average size of 32cm by FAO (2006), results from this study show that there has been a further decrease in the size of *S. maderensis*. Additionally, Ba et al. (2016) reported a size range of 13-31cm (FL) for the study in Senegal, while the fork length for this study ranged between 6.2-25.4cm. The mean length was, however, better than the values (maximum length-22.9 cm, mean length 15.1± 2.8 cm) estimated from the study of Ofori-Danson et al. (2018) on *S.maderensis* at Tema harbour along the coasts of Ghana. However, the minimum value from the range derived from their study (9.3 cm – 22.9 cm) is higher than that from this study (l5.5cm – 23.2cm). The small minimum size indicates heavy fishing pressure; according to Wehye et al.(2017), the presence of juvenile *S. maderensis* signifies an occurrence of overfishing. The maximum weight from this study is 300g, much lower than the maximum published weight reported by Samb (1990).

The calculated slope (b) from this study was 3.09 at a significance level of p-value = 0.0, indicating that the length-weight relationship for *S. maderensis* had a positively allometric type of growth where the fish body grows bigger as it increases in length. The result from this study is similar to the b value estimated by some authors (Abowei et al., 2009; Ba et al., 2016; Dienye & Olopade, 2018; Froese et al., 2014) based on LWR estimates for *S. maderensis*. However, the following authors (Abdul et al., 2016; Ofori-Danson et al., 2018; Ogunola & Onada, 2017) reported isometry (b =3.0) in their studies. In contrast, the result of this study differs from that of Aderionola et al. (2020), who observed negative allometry(-0.62) from the *S. maderensis* sample examined from Badagry creek in Lagos, Nigeria. Negative allometry (0.99 and 1.60) were also recorded by Bolaji (2018) and Konoyima et al. (2020) in the Nigerian offshore waters and Sierra Leone, respectively.

Also, the correlation coefficient (r) obtained (r= 0.9899, 0.8737, 0.8929 and 0.9839) in combined sexes, male, female and undetermined sexes specimens, respectively) revealed a strong positive correlation between the weight and length.

As a valuable index for monitoring fish growth rates, feeding intensity, age and general wellness of fish (Aderinola et al., 2020), the mean condition factor for the samples for this study was estimated, and gave a value of were either greater than or equal to 1. The result is similar to the value obtained by Ofori-Danson et al. (2018), which was estimated at 1.25 for *S. maderensis*. The average condition factor in combined sexes, male, female and undetermined sexes specimens implied that the fish were in good physiological condition. The results of the condition factor is similar to the findings of Ofori Danson et al. (2018), Tema harbour, coastal Ghana and Ogunola and Onada (2017) Okrika Estuary, Nigeria, Abowei et al. (2009) and Abdul et al. (2016). The value was, however, higher than that estimated (K< 1) from the study of Konoyima et al. (2020) in Sierra Leone.

A thorough understanding of population factors, such as the connections between length and weight, is necessary to manage a fishery properly. Fisheries biology depends on this connection because it establishes a mathematical relationship between them and estimates the average weight of fish in a particular length group (Beyer, 1987; Mendes et al., 2004; Sinovčić et al., 2004). The fish samples for this study exhibited positive allometric growth, implying that the fish becomes bigger with an increase in length.

The r value of *Sardinella maderensis* from Ibeju-Lekki indicates a high correlation between the length and weight, implying further that as the length of the fish increases, the weight also increases. However, there was a higher correlation between the length and weight of the undetermined compared to the males and females. The coefficient of determination was also high in the combined sexes, male, female and undetermined sexes specimens respectively, which indicated that the model used for the analysis fits the data (Andem et al., 2013).

Length-weight relationship in fish is affected by several factors such as sex, diet, gonad maturity, health and stomach fullness (Ofori-Danson et al., 2018). By implication, 97.99% of the weight gained in combined sexes is explained by the increased length due to the feeding habit; other unaccounted-for external factors explain the remaining 2.01%. The increase in length explains 76.33% of the weight gained in males due to the feeding habit, with the remaining 23.67% explained by other external factors unaccounted for. Furthermore, the increase in length explains 79.73% of the weight gained in females as a result of the feeding habit; the remaining 20.27% is explained by other external factors unaccounted for. In addition, the increase in length explains 96.80% of the weight gained in the undetermined sexes due to the feeding habit, while other unaccounted-for external factors explain the remaining 3.2%.

The higher percentage of weight gained through feeding can be linked to the fact that the undetermined sexes may be feeding better than the adults. There were no empty stomachs in the undetermined sexes, while the male and females had 5% and 10% empty stomachs, respectively. In contrast, the undetermined sexes had 19% of full stomachs, whereas the male and females had 7% and 10% of full stomachs, respectively.

Vulnerabilities of Small-Scale Fishers of *Sardinella maderensis* in Ibeju-Lekki, Lagos

Coastal communities worldwide have relied on marine resources for several decades as a primary source of income and livelihood (Saldaña, 2019), and these communities are vulnerable to climatic and anthropogenic changes. Given their significant reliance on natural resources and a deep commitment to coastal places, small-scale fishing communities are especially vulnerable to local and global change processes (Allison et al., 2005; Allison et al., 2007; Chuenpagdee & Jentoft, 2015; Islam, 2011). Some of the causes of vulnerability have been discussed earlier in this study, including climatic variability, poor water quality, land use changes, lack of social amenities, and overfishing.

The susceptibility of these small-scale fishers is in line with several authors' assertions that fishing communities worldwide face several challenges in maintaining their livelihoods (Allison et al., 2005; Andrew et al., 2007; Bavinck et al., 2018; Chuenpagdee et al., 2019; Schuhbauer & Sumaila, 2016; Song et al., 2018; Stoll et al., 2018). The factors predisposing them to vulnerability affect their livelihood sustenance ability and response to changing conditions. Furthermore, according to Aheto et al. (2011), vulnerability assessments provide the bedrock for the required adaptation strategy and help in management planning, especially regarding climate change and anthropogenic effects.

The fishers' socio-demographics reveal that they were all males from Nigeria, Ghana and Togo, hence various nationals are involved in fishing in the study area. mostly married. Their main physical asset is the boat which is usually powered by an outboard engine of 20-40hp; the outboard engines are within the range (of 15-60hp) to that reported in Senegal by Diankha et al. (2017). About forty-nine per cent (48.9%) ended schooling at secondary level, which is similar to their children's educational level. Fishing was their primary occupation, and they had been fishing for an average of 20 years, mainly on a full-time basis. The fishers do not have any secondary occupation, which means that fishing is their only source of livelihood, confirmed by the fact that about the same percentage (84.5%) affirmed that their household income is only from fishing. The mean number of household members involved in fishing is two, while the most frequently occurring number is one implying that most fishers no longer want their children to be involved in fishing because of the declining profit. Fishers fish mainly on a full-time basis, and for those on a part-time basis, above 50% of their income still comes from fishing. They do not have access to bank loans; instead, they take loans from money lenders, especially the fishmongers that buy fish from them. Mostly the credit is not adequate. Although there is majorly no or moderate interest rate and most times the payback period is not clearly defined, the fishers typically struggle to pay back on time to be left off the hook of their creditors.

The fishers' responses concerning their perception of variation in climatic factors depict that a significant percentage (58.3%) of the fishers have not heard of climate change, but most (97.5%) have observed that climatic parameters have changed in recent years. Rainfall and Temperature are the most observed fluctuating, and they noted that the sea level has risen.

Regarding the correlation between fishers' socio-demographics and their perceptions, gender and fishers' perception could not be calculated since all the fishers were male. Females were not usually allowed to go fishing because it was considered strenuous. Conversely, in post-harvest activities as reported by Benson et al. (2018), more females were involved compared to males. Marital status was not statistically significant meaning that it did not affect the fishers' perception. However, age, nationality, level of education, and period of years in fishing were statistically significant and thus had effect on fishers' perception.

Specifically, there was a negative correlation between level of education and fishers perception, this indicates that the more the education the less the catch per unit effort. Implying that fishers tend to move away from the fishing business as they get more educated, in line with the findings of Ogunsola (2019), who stated that age and fishing experience significantly affects fishers technical efficiency. Additionally, as mentioned by Anetekhai et al (2018) age is an important socio-demographic characteristic since it has effects on productive capacity and output.

Responses on vulnerability revealed that 95% of the fishers have experienced the loss of fishing tools (equipment and vessels) to bad climate, hence when asked to state their level of agreement concerning their vulnerabilities, "loss of fishing equipment" ranked highest (1) followed by "loss of boats and canoes" (2). The third is "risk to life due to bad weather", and the fourth is "declining income/profit". It can also be noted that they are more susceptible/vulnerable to the "loss of fishing grounds/area "(16) than the "loss of housing" (21). Therefore, although climatic effects may not make them lose their place of abode, they are losing part of what can be defined as their territory and suffer the loss of livelihoods.

Most (93.06%) fishers have not received support from the Government. However, some said they are aware that on some occasions government or projects like the Fadama II Development Project (FDP) had tried to distribute incentives to the fishers. Still, the incentives did not get to most of the fishers who needed them. They attributed the situation to how the distribution is done and emphasised that the real fishers are not usually involved, but the process is politicised. The fishers think they can prepare for possible climate change by getting incentives and palliatives to improve their present conditions (95.28%). They also indicated the provision of fishing tools/acquiring more fishing inputs such as nets, boats and engines (89.44%), financial support from the government (84.17%), early warning signs (82.5%) and getting access to climate information (76.94%). Contrary to the response from Elmina (Ghana) fishers reported by Dzantor et al.(2020) that they were willing to switch jobs, only 2.2% of the fishers in Ibeju-Lekki indicated movement to other livelihoods. This showed that most of the fishers are not willing to diversify into other means of livelihood; this mindset puts them more at risk and makes them more vulnerable. Therefore, according to Adewale et al. (2017), "fishers need to be encouraged to take up alternative businesses, such as aquaculture, to help reduce the adverse effects of vulnerability".

Fishers' responses on the fishery of *Sardinella maderensis* indicated that are mainly found at a depth of between 5-25 fathoms and less than 250 fathoms into the water from the shore. That explains why it is vulnerable to anthropogenic activities such as dredging, stone pilling, construction works, pipe laying and others, presently around the coast in the study area. 95.83% of the fishers use the motorised boat as the paddled canoes are gradually being phased out. The regularity of catch is not specific; the fishermen emphasised that it varies with the season. Many of the fishers indicated that the abundance of Sardinella has reduced in recent years. The reduction was attributed chiefly to anthropogenic activities in the study area, the emergence of a newly occurring weed and the changing climate.

The newly occurring aquatic weed has constituted a serious menace to virtually every community in the study area. The weed samples were collected, taken to the Herbarium of the Botany Department, University of Lagos, Nigeria, for identification and was identified as *Sargassum muticum*. The locals refer to it as the "red flower". The stalk is composed of leaves and hollow berrylike/seedlike floats. The leaves are fusiform and light brownish when wet but reddish brown when dried. Most fishers indicated that Sardinella maderensis is mainly found at a distance of 2km and beyond as well as 11-20m depth, and Sargassum is found on the surface water column, which is *S. maderensis*' habitat. In addition, several authors have linked the Sargassum invasion to climate change (Adet et al., 2017; Louime et al., 2017; Sanchez-Rubio et al., 2018), and there are speculations that the global rising temperature levels could be a contributing factor to the Sargassum bloom.

Emerging themes from the focus group discussion revealed that the fishers attested to the fact that there is observable climate change in terms of fluctuating rainfall and temperatures. They also alluded to the fact that when the rain is excessive, they will not be able to go out, which is in line with the findings from the historical data that there is less catch when there is extreme rainfall. The fishers explained that sea-level rise is observed, sometimes making it difficult for boats to berth, so they had to move to neighbouring communities for landing. They noted that the sea is rougher and the level is higher than before. Their responses also confirmed the trend in sea surface salinity, which they stated is still the same as before. They affirmed that fish food (a measure of Chlorophll-a) has reduced, alluding to the fact "The food of fish has reduced, if fish food is plentiful in the water, we will get plenty fish to catch". As emphasized in the individual interview responses, they reiterated the disturbances from the aquatic weed Sargassum saying, “the weed spoils our nets, prevents us from catching fish and causes itching when it comes in contact with our skins”.

Furthermore, regarding discussions on anthropogenic activities, they emphasised that human activities such as building residential estates, religious activities and recreational activities; do not disturb their fishing. Noting that recreational centre even enhances their fishing business because resort people sometimes buy fish from them. They added that the building of estates only has some minor indirect effect because heavy vehicles that come to drop construction material sometimes spoil the roads, making them unmotorable for customers who buy fish.

They, however, had serious complaints about the industrial works around them. Among them are the construction of a multibillion-dollar refinery and a deep seaport (worth 1.5 billion dollars), also undergoing construction in the study area at the time of the data collection. These industrial constructions involving activities such as sand dredging and laying pipes in water in some construction sites along the coast have been affecting fishing. Communities affected by sand dredging have between 1-5 km or more of their shorelines eroded. One of the main reasons why dredging is usually done is to allow ships that bring equipment and other utilities for refinery construction to dock. The dredged sand is also being used for landfilling the industry site. The sand dredging has made stones in the water bed that is supposed to be buried in the sand come up and invariably spoils the net when it is dragged during fishing operation. Some fishers cannot fish at the fishing sites close to their communities again and have to go far to fishing grounds in other communities. It has also caused flooding and erosion to some beaches and houses, especially in communities near the dredging activities.

Moreover, fisher folks indicated that *Sardinella maderensis* was previously found at closer ranges. They complained that there had been receding shorelines, depriving them of their landing sites and sweeping away mangroves which serve as an alternative source of livelihood, especially during the fishing offseason. The mangrove vegetation (coconut trees) that lined the beach has been eroded, and the land previously occupied by these trees has been taken over by water in many communities. According to the fishers, coconuts used to be their major secondary income source, and they depended on them for livelihood, especially during the fish off-season. The refinery activities are still in the construction phase; however, there are speculations and fears that the situation may be worse when production starts as there would be the transportation of crude oil within the water body. Although presently, fishers stated that they have started observing oil films on the water and are agitated that the situation may worsen when the refinery begins operation. The fishers are, therefore, anxious and fearful for the nearest future.

Regarding the rejuvenation of their environment, which is being constantly degraded through industrial activities, the fishers explained that they are not aware of any plans by the government concerning the conservation of natural resources in the area. Most of them reaffirmed that they could not do any other work besides fishing. Many communities lack basic social facilities such as electricity, good roads, pipe-borne water, hospitals and schools. The lack of good access roads prevents some fishers from landing at their landing site and having to land in a neighbouring community where buyers can be more easily reached. Fishers observed that getting fish now requires moving farther from the shore and covering more distances than before to get fish. Fishers' association is not functional in many communities, and they rarely receive extension services. The help needed was also reemphasised as the provision of fishing nets, boats, engines and other net accessories. They also suggested that government should help them build structures that can reduce the effect of sea waves on their shorelines. The observational checklist results also confirm the fishers' responses through the interviews and the focus group discussions.

Strategies for Resilient Small-Scale Fisheries in Ibeju-Lekki

This study has shown a need to manage the artisanal fishery of *Sardinella maderensis* in Nigeria, and management has three main focuses: maintaining biodiversity, high catch, and high employment. These three aspects must be taken care of simultaneously to achieve the desired output. To ensure biodiversity conservation, we should maintain water parameters at the uptimum level; industrialisation should be regulated, sustainable catches through compliance to mesh regulations, and the fishers' employment should be intact. In maintaining water parameters, the industrial activities on the coasts should be regulated, and proper monitoring should be done for strict compliance. This study has revealed a decline in primary production in the water, which is one of the key factors that sustain biodiversity. The decline is in line with the projection that "primary production of the global ocean, on which the marine food web and ultimately fish rely, is expected to decline by 6 per cent by 2100 and by 11 per cent in tropical zones" (Kwiatkowski et al., 2017). Moreso, with anthropogenic activities disturbing the coastal environments, the decline could be worse.

Since climate change is not easy to control by individuals, justice demands that those contributing so much to the GHG emission should be made responsible for compensating these fishers and reducing their emissions to forestall future climate change effects. In addition, humanity has a moral obligation towards individuals displaced from their homes and livelihoods mainly owing to sea-level rise (SLR) from global warming. As scientific evidence for the negative effects of human-induced climatic variability grows substantially, it is becoming increasingly clear that the situation requires concerted international political action (Byravan & Rajan, 2010).

There are sound reasons for the world to act on the fishers' behalf because they are in the situation, not by their making. Their position is of urgent practical interest and requires both local and international political collective action. This study argues for their rights to be protected because they have been displaced involuntarily not because of their own will or fault but due to environmental, or climate change-induced circumstances. The harm caused them is loss of property, territory and livelihoods; however, the situation of these fishers makes the job of intervention easier because their needs are based more on compensation than reparation. More so, according to Badjeck et al. (2009), "the increased investment needed for local communities to adapt to climate change, if properly targeted, can produce both direct and indirect advantages in the short and long terms, yielding positive returns on investment. and 'win-win' situations".

The fishers think they can prepare for climate change by getting incentives and palliatives to improve their present conditions. Acquiring more fishing inputs such as nets, boats and engines, financial support, early warning signs, and access to climate information are some of the assistances they look up to. One of the major assistances these fishers are asking for, in their words, is “if the government can give us inputs at subsidized rates, we are ready to pay back”. The study by Jinadu (2000) proposed rejuvenating the defunct subsidy scheme to assist small-scale fishing operators in Nigeria. The situation is still very much the same, as the fishers cannot be said to be maximising the full potential of the coastal waters presently. Concerning the aquatic weed menace, harvested pelagic sargassum can be used positively; for instance, Thompson et al. (2020) suggested its use for energy generation and production of fertiliser in Barbados, the Caribbean. Fishers can be renumerated for the sargassum they can harvest from the sea, and then the weed is used to produce economically viable items.

In addition, since the challenges of these fishers are also caused by anthropogenic activities, the government and the local industries in the study area should come to the fishers' rescue. Secondly, various stakeholders should come together to agree on terms for marine spatial planning (MSP) to harmonise industrial development effectively without compromising or jeopardising the conservation and sustainability of the natural resources in Ibeju-Lekki. Furthermore, a social and environmental impact assessment should be done regularly to make necessary adjustments to management plans as the need arises. According to Bell and Bahri (2018), the responsibility for paying close attention to practical adaptations for the most vulnerable populations falls to national and regional organisations. If not, small-scale fisheries' significant contributions to the Sustainable Development Goals relating to eradicating poverty and ensuring food security will probably be jeopardised.

Moreover, the few that indicated they could venture into other livelihoods can be targeted first to establish viable enterprises for them, which will serve as a model to other fishers to encourage them on alternative livelihoods. It will also be imperative to include the small-scale fisheries sector in national climate change policies, such as national adaptation plans and ensure that the sector benefits maximally from incentives determined at the national level. Such actions would increase the sector's resilience and support the socioeconomic benefits they bring, which is vital for a developing country like Nigeria. Assistance available through climate finance schemes to execute top-priority adaptations can also be accessed.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATION

Summary

This study assessed the effects of climatic variability and anthropogenic activities on the *Sardinella maderensis* fishery of Ibeju-Lekki in Lagos, Southwest Nigeria. This was done by considering the concept of the ecosystem to encompass assessing the effects on the components of the environment, which comprises land and water, the fish and people involved in fishing. Summarily, the contributions the project has made to the body of knowledge include:

The study has been able to provide information on the genetics of *Sardinella maderensis* in the Nigeria coastal waters and establishes that *S. maderensis* is "vulnerable to the effects of climate change", in line with the findings of IUCN (2014) hence the decline in fish catch.

It is also established that anthropogenic activities, especially land use, have caused a decline in fish catch in Ibeju-Lekki. It was also confirmed that while climate change has accounted for rising sea levels, human activities have further aggravated coastal erosion and flooding.

The current situation of the length-weight status of *Sardinella maderensis* and its present condition in the Nigerian coastal waters, which data has been lacking, has been documented. Previous studies have focused on sardinella in estuaries and lagoons. Additionally, baseline data on the physicochemical parameters, level of heavy metals and TPH in the water body before the commencement of full operation of the two major projects (Refinery and Seaport) in the Ibeju-Lekki has been provided.

The study concludes that if the government wants small-scale fisheries, which supply 80% of the needed fish in Nigeria, to thrive, there must be concrete policies to help fisheries' resilience and sustainability. Projects have either focused on the quantitative aspect but this project has incorporated the perspectives of the fishers to better understand the situation of climatic and anthropogenic impact on the fishery

In general, a wholistic approach was used to understand issues around the effects of climatic variabilities and anthropogenic activities in the coastal area by firstly combining quantitative and qualitative approaches and secondly using the ecosystem approach which incorporates the various components of the ecosystem, the fish, the environment (land, water) and the humans to better understand the dynamics.

Conclusion

Sardinella maderensis fishery is an essential part of feeding and nutrition among the Nigerian populace and the fishers' livelihoods in fishing communities, especially in Ibeju- Lekki, where it is regarded as the most abundant and economically valuable fish species. The following conclusions were made:

1. The study has helped to confirm that genetic species in the coastal waters of the Nigerian stretch of the Atlantic Ocean are the *Sardinella maderensis* stock.

2. The study also revealed that climatic variability significantly affects the abundance of *Sardinella maderensis* species. The trend of the variation in climatic factors indicates that the effects will continue to be felt by the species. The ARIMA model shows that the catch trend would continue to decline hence

the need for management interventions. The model result is corroborated by complaints from fishers who have noticed a decline in their catches in recent years.

3. Similar to the effects of climatic variabilities, anthropogenic activities also significantly affect the abundance of the species. With increasing developments in the study area, the trend may continue if nothing is done to ensure the sustainability of this natural resource. There is an increasing land use for industrial purposes in the study area, and analysis reveals that an increase in land use will lead to a decrease in fish catch. Presently, the fishers' responses affirm that the fishery is experiencing a decline. Therefore, if nothing is done to regulate the proliferation of industry, the catch will continue to decline. There are various amenities needed, especially access roads to Imedu, Iwerekun, Mosirikogo and Mopo Onibeju; and electricity in all the communities, which, if provided, will help to increase fish abundance. Increase in fishing effort would decrease the value of the fish catch in the study area. However, incentives and palliatives should be made available to maintain the current fishers in the business. In addition, the level of the TDS, chlorophyll-a, BOD, heavy metals and TPH reveal that the waters of the Ibeju-Lekki coastal community in Nigeria are dangerous for marine health.

4. There have been reports of a decrease in the size of *Sardinella maderensis* through pieces of literature and this study shows that there has been a further decrease in the fish size. However, the general condition of the fish is still relatively good. Notably, the presence of juvenile *S. maderensis* in the catch signifies an occurrence of overfishing, indicating a need for monitoring and

enforcement of regulation on mesh size since harvesting fish species is mostly mesh size dependent.

5. Fishers fish full-time and primarily depend on fishing income, making them very vulnerable. Any disturbance in their livelihood from fishing would lead to no other means of sustenance for the fishermen and their households and, by extension, reduced protein supply for the community and the nation. The fishers are highly vulnerable to the loss of their fishing equipment and vessels; hence their requests for support are mainly on the supply of these items, to be provided either as incentives or given to them at subsidised rates.

Recommendations

1. There is a need for government to embark on and apportion substantial funds into data gathering and storage for fish catch data that can be used for analysis to provide management advice and generate policy recommendations.
2. Continuous Environmental and Social Impact Assessments should be conducted by the Federal Ministry of Environment in Nigeria, to assess the water body for heavy metal and TPH pollution and ensure regulation of the effluents to be discharged into the water body.to regulate the number of industries in the study area to forestall the further impact of increased land use on fish abundance.
3. Compliance to mesh size regulation should be ensured by the Federal Department of Fisheries since harvesting of fish species is mostly mesh size dependent.
4. Fishers should be encouraged to take up alternative livelihoods to reduce their vulnerability. Afforestation projects like planting of coconut trees

should be embarked on by NGOs, national, state and local governments to revive the natural ecosystem and provide substitute income source for fishers.

5. There is a need for Marine Spatial Planning (MSP) in the study area to promote the prudent use of the ocean, land and natural resources for development. MSP will help synchronise the ocean's multiple uses involving the energy sector, industry, government, conservationists and recreation, and regional planners to make informed and coordinated decisions about using the ocean sustainably.

Suggestions for Further Research

1. Further genetic analysis should be carried out on the sardinella along the remaining Nigerian coastal stretch.
2. There should be further investigations with broader spatial and temporal scope to provide more strategies for climate change adaptation and mitigation..
3. This study's focus on assessing heavy metal and TPH concentration was on the coastal water, therefore studies on assessing heavy metal concentration in fish species in the Ibeju-Lekki are recommended.
4. Studies based primarily on assessment of *S.maderensis* stock should be conducted regularly to help estimate the state of the stock.

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APPENDICES

Appendix A

Structured Interview Schedule

University of Cape Coast

College of Agriculture and Natural Sciences

Department of Fisheries and Aquatic Sciences

Confidentiality Statement: Please kindly note that data provided in this study shall be handled with the utmost confidentiality and used solely for academic purposes. Your participation in the survey is completely voluntary. Enumerators shall provide you with a copy of the researcher's contact details. Kindly contact researchers between the time of data collection to the next three months should you be interested in withdrawing from the study. Thank you.

Questionnaire No:……………………….……………

Date:………………………..

Select Community:

CODE	NAME	CODE	NAME	CODE	NAME
1	Mopo Ijebu	11	Tiye	21	Ita-Marun
2	Mosirikogo	12	Imobido	22	Oriyanrin
3	Iwerekun	13	Idaso	23	Otolu
4	Igando Orudu	14	Magbon Segun	24	Okegelu
5	Debojo/Idado	15	Okunraye	25	Lepiya
6	Badore/Eleko	16	Olomowewe	26	Ikegun
7	Magbon Alade	17	Origanrigan	27	Folu
8	Orimedu	18	Oshoroko	28	Okun Ise
9	Orofun	19	Lekki	29	Akodo Ise
10	Akodo	20	Apakin	30	Imedu

SECTION A: Socio-Demographic Data

1. Gender: (a) Male ( ) (b) Female ( )
2. Age……………………..
3. Nationality ………………..State of Origin:……………………….
   Tribe ……………………………..
4. Marital Status: (a) Single ( ) (b) Married ( ) (c) Divorced ( )
   (d) Widowed ( )
5. Household Size: …………………………………
6. No of: (a) Children ( ) (b) Spouse (Wife/Husband) ( )
   (c) Other Dependants ( )
7. What are the physical assets you have? Please tick all that applies:
   (a) vehicles, ( ) (b) canoe ( ) (c) land ( ), (d) well settled family ( ), (e) building ( ) (f) good health ( ) (g) outboard engine ( )

8. Level of Education of household members. State number of children under each qualification*******

Level of Education (years)	None (0)	Primary Education (1)	Secondary Education (2)	OND/ NCE (3)	First Degree (4)	PGD/ MSc (5)	Not Available (6)
Head (Male/Female)							
Spouse (1)							
Spouse (2)							
Spouse (3)							
Children /Other Dependent							

9. Type of primary/ secondary occupation

Indicate	Fishing	Farming	Govt. Job	Water transport	Car transport	Okada transport	Sand mining	Net making	Boat construction	Fish processing	Fish mongering	Others specify
Primary Occupation												
Secondary Occupation												

a. Other types of primary occupation (please specify)……… ………………

b. Other types of secondary occupation (please specify)……… ……………

10. How long have you been fishing (in years) ………………………………

11. On what basis do you do your fishing (a)Full-time ( ) (b)Part-time ( ) (c) Occasionally ( )

12. What is the number of your household members involved in fishing……………………………

13. Is your household income only from fishing? Yes ( ) No ( )

14. If the answer to **Section A, Q.13** is **NO**, what percentage of household income comes from fishing?

a)75% and above ( ) b) 50% to 74% ( ) c)25% to 49% ( )d) 24% or less ( )

15. Do you have access to credit facilities (loans)? Yes ( ) No ( )

16. If your answer to the question above is yes, what are your sources of credit facilities?

Source of Credit	**Amount**	**Interest rate**	**Payback period(Yr)**	**Adequacy (Yes/No)**
Commercial/Agric Bank				
Relatives				
Non-Govt. Organization				
Moneylenders				
Esusu/Ajo				
Fishmongers				
Coop. Credit & Thrift Society				

SECTION B: Fisher's Perception of Vulnerability and Adaptation to the Effects of Climatic Variabilities

A Perception

1. Have you heard of climate change or global warming? Yes ( ) No ( )
2. Which of the following (variations/changes) do you agree is related to climate change?

Climate Change Indicators	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly disagree	I do not know
Variations in sea temperature						
Variation in rainfall						
variation in the sea level						
Variation in water salinity						
Variation in primary productivity (Ocean Colour)						

3. Have you notice **any** of the climate change indicators mentioned in **Q.2** in the past 10 Years: Yes ( ) No ( )
4. If answer to **Q.3** is **yes**, how long have you noticed the change ………(*indicate the number of years*)
5. If answer to **Q.3** is **YES**, ***how often*** have you noticed these changes in the past 10 years?

Climate Change Indicators	**Always**	**Often**	**Neutral**	**Rarely**	**Never**	**I do not know**
Variation in sea temperature						
Increase in rainfall						
Rise in the sea level						
Variation in water salinity						
Variation in primary productivity (Ocean Colour)						

6. Have you ever changed your location of fishing due to any of the climate change indicators mentioned in **Q.5** above? (a) Yes ( ) (b) No ( )
7. What change have you noticed in fish catch in your present fishing location/place of operation (a) more catch (b) less catch (c) the same catch as before
8. Would you prefer that the climate keep on changing: Yes ( ) No ( )
9. What supportive role have you noticed from the government (Tick all that applies):

   (a) Provision of housing for flood victims ()(b) Provision of fishing tools ()

   (c) Financial provision for affected fishermen ( )

   (d) Extension lectures on how to cope ( ) (e) None of the above ( )

   (f) Others (specify) ……………………

9.b. If your answer to the previous question (Q.9) is OTHERS, please specify……………

B Vulnerability

10.a. Have you ever lost any of your assets due to bad weather? Yes( ) No ( )
10.b. Which of the following assets have you lost due to bad climate?
10.c. Please, indicate the time (Month/Year) you lost some assets to bad climate

S/N	ASSETS	YES/ NO	QUANTITY	YEAR	SEASON/ MONTH
a.	Fish catch				
b.	Fishing net				
c.	Fishing tools				
d.	Fishing area				
e.	Fishing vessel				
f.	Revenue				
g.	Housing				
h.	Family				

11. Rate the asset loss or damage experienced from climate change

S/N	ASSETS	Extremely Severe	Severe	Moderate	Mild	None
a.	Fish catch					
b.	Fishing net					
c.	Fishing tools					
d.	Fishing area					
e.	Fishing vessel					
f.	Revenue					
g.	Housing					
h.	Family					

12. Which of these effects of climate change do you agree is present in your community?

Vulnerabilities	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly disagree	I do not know
Natural Assets/Capital						
Loss of Marine planktons (food)						
Poor water quality/pollution						
Loss of fishing grounds/area						
Loss of landing sites						
A decrease in the availability of *S.maderensis*(Shawa)						
A decrease in quality (size, etc) of *S.maderensis*(Shawa)						
Loss of breeding ground for *S.maderensis*						
Physical Assets/Capital						
Loss of Housing						

Loss of basic infrastructure						
Loss of equipment/fishing gears						
Human Assets/Capital						
Risk to life due to bad weather						
Health challenges						
Decline in skilled fishers/labour						
Economic/Financial Capital						
Declining income/profits						
Poor savings/lack of cash						
Increase debt/ Lack credit/loans						
Lack/high cost of insurance						
Social Asset/Capital						
Loss of social relationships						
Lack of affiliations/association						
Loss of diversity(cultural diversity, ethnic diversity						
Sense of insecurity and lack of safety						

C. Adaptation

13.How do you think fishers can prepare for possible future climate change? ………………………………………………………………..

14.What do you prefer that government should do to help fishers cope better with possible climate change?

Preferred adaptation strategies by government	Most preferred	More Preferred	Preferred	Less Preferred	Not Preferred
provision of housing and basic infrastructure for affected fishers					

provision of fishing tools					
financial provision for affected fishers					
extension lectures on how to cope					

(e) others (specify) …………………………

SECTION C –Anthropogenic activities and Artisanal fisheries of *Sardinella maderensis*

1. What sea depth is *S. maderensis* normally found? (1m=3.28ft)

   a) Less than 10m b) 11m-20m c) 21m-30m d) 31mg-40m

   e) 41m-50m f) 51m and below

2. State the distance to the coastline *S. maderensis* is normally found (1m=3.28ft)

   a) Less than 500m(0.5km) b) 501m-1000m (1.0km) c) 1001m-1500m(1.5km) d) 1501mg-2000km (2.0km) e) 2001km-and and beyond

3. When do you go for fishing *S. maderensis*?

   (a) Morning ( ), (b) Afternoon ( ), (c) Evening ( ), (d) Night ( )

(e) Anytime ( )

4. How long does each fishing trip take? ………………………………………

(a) 1-6 hours( ), (b) 7-12 hours ( ), (c) 12-18 hours ( ), (d) 19-24hours ( ) more than a day ( )

5. Do you own a canoe or boat? Yes ( ) No ( )

6. How regular is your catch? (a) Daily ( ), (b) weekly ( ), (c) fortnightly ( )

7. How do you market your catch? (a) Through middle women ( ),

(b) directly to the customer ( )

8. Who are the buyers you sell to? (a) Individual ( ), (b) Companies ( ),

(c) Market women ( ), Middle women ( ), (e) Directly to consumers ( ), (f) others specify (

9. What is the average weight/quantity of each catch? ………………………

(a) 1-20kg( ), (b) 21-40kg hours ( ), 41-60kg ( ), (d) 61-80kg ( ) e)80-100kg ( ) f)above 100kg

10.What do you notice in your daily catch of *S. maderensis*? Tick as appropriate

Abundance of *Sardinella maderensis*	**Reducing**	**Increasing**	**Unchanged**
In the last 10 years			
In the last 5 years			
In the last 1 year			
In the last 6 months			

11.a. What reasons contribute to increase in fish catch for Sardinella specie?
11.b. What reasons contribute to the decrease in fish catch of the sardinella?
12. Length of time of stay in your present location (i.e. the number of years)
13. In time past, which locations have you been to for fishing activities?
(a) Within the community ( ), (b) within the local government ( ) (c) within the state ( ) (d) within the country ( ) (e) outside the country ( )
14.Is your fishing community in a government zoned industrial area?
Yes ( ) No ( )
15.Is your fish landing site or fishing community located less than 10 km from the industrial plants? Yes( ) No()
16. In the last five years, what changes did you notice in the number of fishers in this community:

Number of fishers operating in the community	**Reducing**	**Increasing**	**Unchanged**
In the last 10 years			
In the last 5 years			
In the last 1 year			
In the last 6 months			

17.What are the reason(s) why people leave fishing?
18.Which of the following social amenities do you have access to in your community: (a) Good roads( ) (b) Hospital ( ) (c) Cyber café ( ) (d) Electricity ( ), (e) Primary schools ( ), (f) Internet facilities( ) (g) Pipe borne water (h) Secondary schools ( ), (i) Tertiary schools ( )
19.Which of the following do you prefer that government should do to assist fishers in your community

Preferred assistance from government	**Most preferred**	**More Preferred**	**Preferred**	**Less Preferred**	**Not Preferred**
Good roads					
Hospital					
Electricity					

Primary/secondary schools					
Internet facilities					
Pipe borne water					
Financial Incentives					
Promote extension services					

SECTION D –Artisanal fisheries of *Sardinella maderensis*

1. Do you belong to any fishermen association? (a) Yes ( ) (b) No ( )

2. If your answer in Section D Q.1 is Yes, why did you join? Indicate all that applies

a) To have access to financial capital

b) To get fishing inputs

c) Access to timely and accurate information

d) To improve fishing skills and capacity

e) To get government incentives

3. If the answer to the question in Section D Q1 is Yes, how functional is the association?

(a) not functional ( ), (b) moderately functional ( ), (c) highly functional ( )

4.What has been your gain from this association so far: (a) enlightenment through lectures ( ), (b) loans ( ), (c) nothing (), (d) others specify …………………………..

5. Do you attend meetings with extension agents? (a) Yes ( ), (b) No ( )

6.If yes, how often do you receive extension services?

(a) fortnightly ( ), (b) monthly ( ) (c) once in 3 months ( ) (d) once in 6 months ( ) (e) others (specify)

7.How do you get money to procure inputs?

Source	Regularly	Occasionally	Always
Bank Loan			
Personal Savings			
Money Lenders			
Cooperative Society			
Friends/Relatives			
Others specify			

Appendix B

Focus Group Discussion (FGD) Guide

ASSESSING THE CLIMATIC AND ANTHROPOGENIC EFFECTS ON SARDINELLA SPP FISHERYOF IBEJU-LEKKI, LAGOS, NIGERIA.
SECTION A: Socio-Demographic Data

Group Name:………… **Group leader's contact:……………**

Community:…………………………

SECTION A: Fishers' Perception, Vulnerability and Adaptation to the effects of Climate Variability

To examine the effects of climate variability on *Sardinella* species abundance

1. Can you briefly describe the present weather/ climate of this area in terms of rainfall, atmospheric temperature, humidity and wind?
2. How was the climate like in the past 30 to 35 years (1985/1990) ago?
3. Are there changes/variations between the climate of the past 30-35 years and the present?
4. As fishermen, is there any variation in your fish (*Sardinella*spp) catch now and that of the past 30 to 35 years?
5. In your view, is there any relationship between the variations in the climate and that of your fish catch?
6. Apart from the identified effects of climate variations on the fishery industry, are there other effects of climate variability that you face as communities in this area?
7. How are you fishermen and your communities coping with the variations in the climate of this area?

SECTION B –Anthropogenic activities and Artisanal fisheries of *Sardinella spp*

6. To examine the effects of anthropogenic activities on the *Sardinella spp*species abundance

8. What are the common anthropogenic challenges confronting *Sardinella* spp fishermen in recent times in the communities here?
9. How are these challenges affecting the *Sardinella* fishing activities?

10. Are you aware of any plans for ecosystem conservation and restoration of degraded areas in these areas?
11. Do fishermen of the fishing communities here keep to regulations on catch in the area?
12. Are there designated landing/ fishing areas?
13. Do fishers have licenses and/ or identity card?

SECTION C – Artisanal fisheries of *Sardinella spp*

7. To develop strategies for resilient artisanal fisheries of *Sardinella spp*

14.Survival : Do you have other fishing grounds outside the community where you fish ?

15. Social Identity: Do you belong to a fishers group or cooperative society?.

16. Diversification: Are you ready to leave fishing if the needs arises?

17.Availability of government incentives: Has there been any form of incentives from government?

18. Health care: Are there health care facilities and how adequate are they?

19. Education: do your children have access to good education?

20. Insurance: have you insured your life and/ property, which insurance policy (life and property)?

21. Recommendations of what can be done to sustain fishers in the business.

Appendix C

Observational Checklist

University of Cape Coast

College of Agriculture and Natural Sciences

Department of Fisheries and Aquatic Sciences

Observational Checklist No:………………. **Date**:………………………..

Name of Community:

S/N	Observation Checklist	Yes	No
1.	Is the community close to an industrial area	☐	☐
2.	Are there signs of erosion on the beach	☐	☐
3.	Are houses affected by erosion	☐	☐
4.	Are there construction sites	☐	☐
5.	Are there other structures like the processing facilities affected	☐	☐
6.	Are they affected by aquatic weeds, remnants of aquatic weed on the shore	☐	☐
7.	Is the mangrove along the beach still intact	☐	☐
8.	Does the community have a landing site	☐	☐
9	Is the landing site close to the residential area	☐	☐
10	Is there industrial sand dredging activities in the area	☐	☐
11.	Are there signs of receding shoreline	☐	☐
12	Is there access road to the community	☐	☐
13.	Has the fishing ground in the community been encroached	☐	☐
14.	Can construction activities be sighted close to the community	☐	☐
15.	Are there fishing activities at the beach	☐	☐
16.	Is there a recreational centre on the beach	☐	☐
17.	Are there religious centres at the beach	☐	☐
18.	Is there an industry sited in the community	☐	☐

Appendix D

ETHICAL CLEARANCE (UCCIRB)

UNIVERSITY OF CAPE COAST

INSTITUTIONAL REVIEW BOARD SECRETARIAT

TEL: 0558093143 / 0508878309
E-MAIL: irb@ucc.edu.gh
OUR REF: UCC/IRB/A/2016/895
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0009096

4TH FEBRUARY, 2021

Temitope Adejoke Adewale
Department of Fisheries and Aquatic Sciences
University of Cape Coast

Dear Adewale,

ETHICAL CLEARANCE – ID (UCCIRB/CANS/2020/09)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted **Provisional Approval** for the implementation of your research titled **Assessing the Climatic and Anthropogenic Effects on Sardinella spp Fishery of Ibeju-Lekki, Lagos, Nigeria.** This approval is valid from 4th February, 2021 to 3rd February, 2022. You may apply for a renewal subject to submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Samuel Asiedu Owusu, PhD
UCCIRB Administrator

ADMINISTRATOR
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST

Appendix E

ETHICAL CLEARANCE (CMUL)

COLLEGE OF MEDICINE, UNIVERSITY OF LAGOS

HEALTH RESEARCH ETHICS COMMITTEE

CMUL HREC Registration Number: NHREC/19/08/2019B

Office Address: 2nd Floor Biomedical Engineering Block
College of Medicine University of Lagos, Idi-Araba, Lagos
P.M.B.12003, Lagos Nigeria

Telephone: 08028642463, 08025187265, 08023119431

E-mail: hrec@cmul.edu.ng *website*: cmul.unilag.edu.ng

Chairman:
Prof. Sunday A. Omilabu
BSc. (Hons), Ife, MSc. (Ibadan)
PhD. (Ibadan)

Vice Chairman:
Prof. Kolawole S. Oyedeji
BSc (Uniport) MSc (Ife), MSc (Unilag)
MSocSci-HRE (South Africa), FMLSCN (Nig)
CPHPM (Ilorin), PhD (Unilag).

26th October, 2020

Re: Assessing the Climatic and Anthropogenic Effects on *Sardinella spp* Fishery of Ibeju-Lekki, Lagos, Nigeria.

CMULHREC Number: CMUL/HREC/10/20/784
Name of Principal Investigators: Adewale Temitope Adejoke
Date of receipt of valid application: 6th September, 2020
Date of meeting when final determination of research was made: 26th October, 2020

APPROVAL LETTER

The above named proposal has been adequately reviewed; the protocol and safety guidelines satisfy the conditions of **CMULHREC** policies regarding experiments involving human and or animal participants.

Therefore, the study under its reviewed state is hereby **approved by the Health Research Ethics committee of College of Medicine of the University of Lagos.**

26/10/2020

PROF. S.A. OMILABU ----------------------------------
Name of CMULHREC Chairman ***Signature & Date***

26/10/2020

PROF. K. S. Oyedeji ----------------------------------
Name of CMULHREC Member ***Signature & Date***

This approval is given with the investigator's responsibility declaration as attached and that;

i) You will submit in CMULHREC prescribed forms, annual progress report during the course of this study, if it is more than one year and final report as the case may be if less than one year and after completion of the study.

ii) The CMULHREC reserves the right to monitor and review this approval; even after the commencement of your study and inform you of any further changes or amendments that may be required for your compliance.

This approval dates from **26/10/2020 to 25/10/2021.** If there is delay in starting the research, please inform the HREC so that the dates of approval can be adjusted.

Appendix F

Regression and one-way ANOVA of log length – log weight relationship in combined sexes of *Sardinella maderensis* collected from Ibeju-Lekki, Lagos (January 2021 - March, 2022)

SUMMARY OUTPUT								
REGRESSION STATISTICS								
MULTIPLE R	0.989886182							
R SQUARE	0.979874654							
ADJUSTED R SQUARE	0.979861147							
STANDARD ERROR	0.050471164							
OBSERVATIONS	1492							
ANOVA								
	df	SS	MS	F	Significance F			
REGRESSION	1	184.7991943	184.7991943	72545.99375	0			
RESIDUAL	1490	3.795534188	0.002547338					
TOTAL	1491	188.5947284						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
INTERCEPT	-1.78679201	0.014117558	-126.565232	0	-1.81448441	-1.7590996	-1.81448441	-1.75909961
LOG L	3.085784345	0.011456682	269.3436351	0	3.063311406	3.1082573	3.063311406	3.108257284
SLOPE, B VALUE =	3.085784345							
INTERCEPT, A =	0.016338342							
REGRESSION, R =	0.989886182							

VITA

Temitope Adejoke Adewale

Email: adewaleta7@gmail.com

Education:

- **University of Cape Coast, Ghana -** Doctor of Philosophy in Fisheries Science, 2019 – 2023
- **Uthman Dan-Fodiyo University, Nigeria** - Postgraduate Diploma in Education, 2009 - 2010
- **University of Ibadan, Nigeria** - Master of Science in Fisheries Management, 2001 - 2003
- **University of Ibadan, Nigeria** - Bachelor of Science in Fisheries Management, 1994 – 2000

Research Interest:

Research in climate change assessments, land use change analysis, water quality monitoring, environmental impact assessments, coastal ecosystems management, fisheries management and socio-economic impact of climate and anthropogenic activities on livelihoods.

Awards:

- Scholarship Award for PhD Program from the Africa Center of Excellence in Coastal Excellence, University of Cape Coast, Cape Coast, Ghana, 2019
- Sponsorship from the Wageningen Center for Development and Innovation, Netherlands, to attend an International Course on Climate Change Adaptation in Food Security and Natural Resources Management, held at Makerere University, Kampala, Uganda, 2017
- Best Graduating Student Award, Wildlife & Fisheries Department, University of Ibadan, 1998/99 Session, 2000

Membership of Professional Associations:

- Member, Fisheries Society of Nigeria (FISON)
- Member, American Fisheries Society (AFS)
- Nigerian Women in Agricultural Research for Development
- Member, Teachers' Registration Council of Nigeria (TRCN)

Research and Teaching Experience

- Current research is on assessing the impacts of climatic variability and anthropogenic activities on the Flat Sardinella (*Sardinella maderensis*) fishery of Ibeju-Lekki, Lagos, 2019 - 2023
- Teaching of Fisheries and Environmental Science related courses at the at the Lagos State University of Education, Lagos, 2008 - 2019
- Research Assistant, Nigerian Institute of Oceanography and Marine Research Victoria Island, Lagos, 2000 -2001

Selected publications

- **Adewale, T.**, Aheto, D., Okyere, I., Soyinka, O., & Dekolo, S. (2024): Effects of Anthropogenic Activities on *Sardinella maderensis* (Lowe, 1838) Fisheries in Coastal Communities of Ibeju-Lekki, Lagos, Nigeria. Sustainability, 16, 2848. https:// doi.org/10.3390/su16072848
- Soyinka O.O., **Adewale T.A**., Banjoko B.L. & Okereke B.O (2021): Observations on the Fish Species Composition of Lagos Lagoon After Four Decades of Investigations. Journal of Scientific Research and Development, University of Lagos, Nigeria. Vol 19(2): 375 – 383. http://jsrd.unilag.edu.ng/index.php/jsrd
- **Adewale T.A**. & Kehinde D. (2020)**:** Gender Analysis of Catfish Farmers in Lagos State, Nigeria. International Journal of Scientific Research in Educational Studies and Social Development, Vol 4(1), p-ISSN: 2579-1052, e-ISSN: 2579-1060.
- **Adewale T.A.**, Fregene B.T, & Adelekan I.O. (2017): Vulnerability and Adaptation Strategies of Fishers to Climate Change: Effects on Fishing Communities in Lagos State, Nigeria. A Chapter in Climate Change Adaptation In Africa Fostering Capacity To Adapt.Springe Walter Leal Filho, Belay Simane, Jokasha Kalangu, Menas Wuta, Pantaleo Munishi, Kumbirai Muysiwa eds, http://www.springer.com/series/8740.728-746p.
- Adebosin, W.G, Adebayo, A.A. & **Adewale. T.A.** (2013): Climate Change and Farm Productivity among Farming Household in Lagos State. In: Global Advanced Research Journal of Agricultural Science (ISSN: 2315-5094), 2 (10), October 2013.
- Fregene B.T & **Adewale T.A.** (2012)**:** Integrated Fish Farming in Ogun State, South West of Nigeria, The Nigeria Journal of Agriculture Extension, ISSN: 0331-7757, 17 (1).

Seminar Contributions

- **Adewale T.A.**, Aheto D.W., Okyere I. & Soyinka O.O. (2023): Assessing the Effects of Heavy Metal and Total Hydrocarbon Pollution for Promoting Marine Environmental Health along the West African Coast: A Case Study of Ibeju-Lekki, Lagos. Presented at the West Africa Marine Science Symposium (WAMSS), Accra, Ghana. 18th- 21st August, 2023.
- **Adewale T.A.**, Soyinka O.O., Aheto D.W. & Okyere I. (2021): Menace and Potential Benefits of Sargassum on the Sardinella Fishery of Ibeju-Lekki, Lagos, Nigeria. Presented at the International Conference on Sargassum, Lagos State University, Lagos. 1st-2nd Dec 2021.
- **Adewale T.A.** & Fregene B.T. (2019): Communicating Fisheries Conservation and Adaptation Strategies to Mitigate Climate Change Effects on Fishers. A Poster Presentation at the RUFORUM Annual General Meeting held at the University of Cape Coast, Ghana from 2nd-6th Dec. 2019.
- **Adewale T.A.**, Ademiju P.U., & Adebosin W.G. (2016): Climate Change, Malaria Incidence on Farm Productivity. Presented at the Symposium on Climate Change Adaptation in Africa held at Addis Ababa, Ethiopia on 21st-23rd February 2016.
- **Adewale T.A**, Adewale A.A, & Olugbemi. P.W (2013): The Use of Pond Waste Water in Sustainable Agriculture: Means for Enhancing Food Security, In the Book of Abstracts and Proceeding (NSE) for the International Conference, Exhibition and Annual General Meeting. Held at Abuja, Nigeria, between 9th-13th December, 2013.

Workshops and Trainings

- ACCESS Summer School to train PhD and Early Career Researchers on Championing Climate and Environmental Social Science, which took place from 12-14 September 2023 at Dartington Hall, Devon, UK.
- International (Virtual) Conference on Research and Utilization of Sargassum held between 30th November to 1st December 2021. Organised by the Center of Excellence on Sargassum Research, Lagos State University, Nigeria.
- A Summer School on Research, Teaching and Service in an Uncertain Age organized by the Ife Institute of Advanced Studies, Obafemi Awolowo University, Nigeria, from July 26 - 6th August 2021.
- EAF-Nansen Programme Training workshop on Monitoring and Assessing Data and Capacity – Poor Fisheries in the Context of the Ecosystem Approach to Fisheries. Held on the 25th – 26th November 2020.
- Collaborative Institutional Training Initiative (CITI PROGRAM) Biomedical Research - Basic/Refresher (Curriculum Group) Biomedical

Research - Basic/Refresher (Course Learner Group) 1 - Basic Course (Stage) by Medical Education Partnership Initiative in Nigeria (MEPIN) Completion Date 29-Sep-2020. Score- 92%, Record ID 38513477.

- A 3-Day Training on Systematic Review and Meta-Analysi at the University of Cape Coast, Cape Coast, Ghana from 4th-6th February 2020.
- RUFORUM (15th) Annual General Meeting on Delivering on Africa's Universities Agenda for Higher Agricultural Education, Science, Technology and Innovation (AHESTI): What Will It Take? With Project Management & Interdisciplinary skills Training held at the University of Cape Coast, Cape Coast, Ghana, from 30th November – 3rd December 2019.
- International Course on Climate Change Adaptation in Food Security and Natural Resources Management, held at Makerere University, Kampala, Uganda, 30th January-10th February 2017.
- Symposium on Climate Change Adaptation in Africa held at Addis Ababa, Ethiopia on 21st – 23rd February 2016.
- CAAST-Net Plus Africa-EU Research and Innovation Collaboration Platform on Climate Change Workshop on Strengthening Research Capacities for the Uptake of Sustainable Agricultural Intensification held at Mensvic Grand Hotel in Accra, Ghana from 21- 23 November 2016.
- African Regional Research Conference on Sustainable Development Strategies held at Kenyatta University, Kenya, East Africa on 1st-3rd December 2015.

Works in Progress

- Effects of Climatic Variability on Flat Sardinella (*Sardinella maderensis)* Fishery of Ibeju-Lekki, Lagos, Nigeria**.** Article manuscript in progress
- Fisher's Vulnerability to Climate Change Impact and Strategies for Resilient Small-scale Fisheries in Coastal Fishing Communities of Lagos Nigeria. Article manuscript in progress