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IMPLICATIONS OF MARINE HEATWAVES FOR THE BLUE ECONOMY IN GHANA

LOUISA POKUA SARKODIE

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

2023

Declaration

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

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

(Signature):

A handwritten signature in black ink, appearing to be 'S. H. L. O.', written in a cursive style.

(Date):

26th September 2023

Supervised by: Professor Mary S. Wisz

Supervisor's affiliation: World Maritime University

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Abstract

Title of Dissertation: **Implications of Marine Heatwaves for the Blue Economy in Ghana**

Degree: **Master of Science**

A consequence of climate change is the increase in the occurrence and intensity of marine heatwaves (MHWs). MHWs can potentially have impacts on emerging blue economies across sectors, but there is so far little known about the degree to which blue economy stakeholders recognize and are prepared for MHWs. Recent years have shown an emergence of MHWs in Ghana, and blue economy stakeholder awareness of MHW and preparedness remains unknown. In order to address these gaps in knowledge, I used semi-structured interviews to explore the level of awareness, perceived impacts, and preparedness measures of stakeholders in Ghana's blue economy sector regarding MHW.

Interviewees demonstrated various levels of understanding of MHW and its implications for the blue economy. Some stakeholders reported that they had no knowledge about MHW occurrence in Ghana, while others claimed to have awareness. Some stakeholders discussed the potential impact of MHW on their respective sectors. The interviewees noted potential threats to marine resources and biodiversity, impacts on coastal communities and their livelihoods, and threats to eco-tourism. Some highlighted various measures they could take to prepare for and mitigate MHWs such as collaboration, capacity building, training, and awareness creation. Others noted that limited preparedness and/or no plans to mitigate MHWs existed within their sector. When asked to reflect on their own experiences with MHWs in the recent past, the interviewees' recollection of the time and location of MHW did not align with the time and locations of MHWs documented by scientists.

The results of my analysis of stakeholders perception highlight the need for targeted awareness, advocacy, education initiatives, and tailored interventions to enhance resilience and preparedness for MHW events in Ghana for a sustainable blue economy.

KEYWORDS: Marine Heatwaves, climate change, Ghana, Blue economy, Marine ecosystem, MHW Impacts, MHW Awareness, Preparedness, and Sustainable development

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List of Abbreviations

BE	Blue Economy
CSIRO	Commonwealth Scientific and Industrial Research Organization
DTU	Technical University of Denmark
GDP	Gross Domestic Product
GoG	Gulf of Guinea
IUU	Illegal Unreported and Unregulated
MHW	Marine Heat Waves
MHS	Marine Heat Spike
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
REC	Research and Ethics Committee
SST	Sea Surface Temperature
UNCTAD	United Nations Conference on Trade and Development
WMU	World Maritime University

1.0 INTRODUCTION

Marine heatwaves (MHWs) are defined as extended periods of unusually warm seawater. (Hobday et al., 2016) which, since the early 20th century, have become increasingly frequent and longer in duration. (Oliver et al., 2018). MHW is also usually defined as prolonged high ocean temperatures of warm sea surface temperature (SST) The duration of such events can range from several days to months, with an extent of space that may cover thousands of kilometres. (Hobday et al., 2016; Scannell et al., 2016; Frölicher et al., 2018; Hu et al., 2021). Hobday et al., (2016) describe a marine heat spike (MHS) as an SST that is higher than a certain limit. This is calculated as the daily 90th percentile of the local SST distribution over a long reference period. MHSs that last at least five days in a row correspond to MHWs (Hobday et al., 2016).

MHWs are described in terms of intensity, duration, and frequency. Satellite observation and earth system model simulations reveal that MHWs have increased and will increase further in terms of frequency, intensity, duration, and spatial extent (Frollicher et al., 2018). These are characteristics that describe MHW.

MHWs can be diagnosed by observation of SST from satellites. This has been an important tool for observing heatwaves by measuring and monitoring SST (Ocean Observatories Initiative., 2023). Also, observations of SST from different platforms such as satellites, ships, buoys, and Argo floats (National Oceanic and Atmospheric Administration, 2020) can also detect SST. MHW can be accurately predicted up to one year ahead of the event (Tandon & Zagoruichyk., 2022).

Global temperature extremes are increasing, and the oceans are warming significantly (Cheng et al., 2019). This causes MHW to become more intense and last longer (Hobday et al., 2016). MHWs can extend for thousands of kilometers and last for days to months (Oliver et al., 2018). The degree of MHW impacts varies based on the species, population, and event characteristics. (Straub et al.; 2022), e.g., In contrast to

species with broader thermal tolerances (eurytherm), species with a narrowed thermal niche (stenotherm) are more likely to be negatively impacted by MHWs; but populations may react differently to one another depending on the history of disturbances (Hughes et al., 2021).

The typical thermal conditions that living things have experienced over the course of evolution (i.e., their thermal niche) are what define how well they function within a range of temperature limits (MacLean et al., 2019). Performance declines beyond certain limitations, and mortality may eventually happen without any mitigating measures. The upper-temperature thresholds of organisms are being exceeded more frequently and by greater magnitudes as Earth's atmosphere and oceans warm (Frölicher et al., 2018; Oliver et al., 2018). These events can have significant impacts on marine ecosystems and the organisms that depend on them.

1.1 EXAMPLES AND IMPACTS OF MARINE HEATWAVES

MHW was highlighted by the occurrence of 'the Blob', long-lasting along the western coast of North America and Alaska from 2014 to 2016, This event resulted in severe population declines of Pacific cod, seabirds, salmon, and various other species, while simultaneously promoting the growth of toxic algae. In the summer and autumn of 2019, a major MHW affected the northeast Pacific. As a precautionary measure, the United States federal cod fishery in the Gulf of Alaska was closed for the 2020 season due to a significant decline in the population of cod in the region. (Andres, 2021).

Famous examples in the recent media include, "2017 Tasman Sea marine heatwave". SST in the southern Tasman Sea were above average throughout 2017 but began to rise significantly in November. Over the majority of the Tasman Sea south of 35 °S, temperatures reached 2 °C or more above average. They reached record-high levels in November over an area spanning from New Zealand to Tasmania. (NIWA, 2017).

Another example is the Australian East Coast marine heatwave (2018 to 2019). On 17 December 2019 University of Western Australia coastal oceanography Professor Charitha Pattiaratchi spoke about the events of MHWs and in his statement said. "Particularly in the last two weeks or so the ocean temperatures have been increasing — they're about two degrees warmer than what is normal for December," (Ceranic, 2019)

The North Atlantic Ocean has been experiencing significant temperature rises, characterized by a remarkable MHW event taking place around the coastlines of the United Kingdom and Ireland according to Paddison (2023). The eastern Atlantic, spanning from Iceland to the tropics, exhibits significantly elevated temperatures compared to average. However, the SST in north-western Europe, including the United Kingdom, exhibits some of the highest values on average. The head scientist of the Met Office, Stephen Belcher, stated in a statement. "May 2023 saw the highest temperatures of any May since 1850," he declared. But this is not the end of it. In terms of each individual month in the series, it has also been the most extreme month above average (Met Office, 2023).

Examples of impacts of MHW include reduced provisioning (e.g., fisheries), cultural (e.g., Tourism), regulating (e.g., carbon capture, water quality), and habitat (or supporting, e.g., restructuring, disease) ecosystem services as shown in (Table 1) by Smale et al (2019).

Table 1: Impact Of MHWS On Services Provided By Marine Ecosystems

SERVICE TYPE	ECOSYSTEM SERVICE	IMPACTS
Provision	Living resources (non-food)	Extreme temperature caused widespread mortality, local extinctions and range contractions of a diversity of taxa.
	Food	Changes in the distributions and abundances of commercial fisheries species.
Regulating	Carbon sequestration and storage	Reduced carbon burial and sequestration due to decreased growth and high mortality of seagrasses
	Moderation of extreme events	Complex, three-dimension biogenic benthic habitat was replaced by simple poorly structured habitat, altering hydrodynamics and sediment transport and reducing natural coastal defence
	Nutrient Cycling	Increased stratification and extreme temperature caused decreased phytoplankton and nutrient turnover widespread loss of productive benthic habitat (seagrass, kelp forests) disrupting carbon and nitrogen cycling
	Biological control	Anomalous warming events associated with influx of Invasive non – native species
Habitat or Supporting services	Habitat for species	Local extinctions, range contractions and high mortality rates of habitat-forming corals, seagrass and macroalgae, resulting in simplified habitat structure and depleted local biodiversity
Cultural	Tourism and recreation	Locations affected by intense warming event are less attractive for recreational activities and have decreased socioeconomic value

Source: (Smale et al, 2019)

1.2 THE BLUE ECONOMY AND MARINE HEATWAVES ON A GLOBAL SCALE

The blue economy refers to the responsible exploitation of marine resources in order to foster economic development and enhance quality of life while protecting the environment. (World Bank, 2017). The blue economy encompasses various sectors and activities such as fisheries, aquaculture, tourism, shipping, renewable energy,

biotechnology, and coastal management. According to the United Nations Conference by the United Nations Conference on Trade and Development (UNCTAD). The blue economy is worth an estimated \$3-6 trillion globally. However, the livelihoods of about 3 billion people who depend on the ocean for food and income are at risk due to climate change, pollution, and overfishing. (UNCTAD, 2020). The socioeconomic repercussions of MHW events are as destructive as their ecological effects.

Some examples of the impacts of MHWs on the blue economy from around the world include the decline of coral reef tourism in Australia due to coral bleaching and mortality caused by MHWs in 2016 and 2017. Coral reefs are estimated to generate about US\$6.4 billion per year for the Australian economy through tourism, fishing, and recreation (Deloitte Access Economics, 2017).

The loss of abalone fisheries in South Africa due to MHWs in 2015 and 2016. Abalone is a valuable shellfish that supports the livelihoods of thousands of small-scale fishers and contributes about US\$60 million per year to the South African economy (Blamey et al., 2018).

The disruption of salmon farming in Norway due to MHWs in 2018 and 2019. Salmon is one of the main export products of Norway, with a value of about US\$10 billion per year. MHWs can increase the risk of disease outbreaks, algal blooms, and oxygen depletion in salmon farms, leading to reduced production and profitability (Oliver et al., 2019).

These impacts happen because MHWs can alter the physical, chemical, and biological conditions of the ocean, affecting the health, productivity, and distribution of marine organisms and ecosystems. MHWs can also exacerbate other stressors such as overfishing, pollution, and invasive species, reducing the resilience and adaptive capacity of marine systems (Smale et al., 2019). To mitigate and adapt to the impacts of MHWs on the blue economy, it is essential to implement integrated and cross-sectoral approaches that combine scientific monitoring, management interventions,

policy frameworks, and stakeholder engagement. It is also important to enhance cooperation and coordination at regional and global levels to share best practices, lessons learned, and innovative solutions for a more sustainable and resilient blue economy (IUCN, 2021). As MHWs increase in frequency and severity, they run the risk of pushing ecosystems over their threshold, which would have long-term effects on marine biodiversity and the many millions of individuals whose livelihoods depend on it (Laffoley & Baxter, 2016).

1.3 GHANA'S BLUE ECONOMY AND MARINE HEATWAVES

The Gulf of Guinea (GoG) is also experiencing MHWs, where reports indicate a rise in SSTs, as documented by Acheampong et al. (2021). Ghana is situated in the Gulf of Guinea, which is a tropical West African nation positioned along the Atlantic Ocean's coastline, making it vulnerable to the intensification and frequency of MHW events.

Odekunle & Adebayo Oluwole Eludoyin (2008) examined and mapped the mean sea SST patterns over the Gulf of Guinea (GoG) from 1950 to 1998. The researchers documented temporal variations, as well as anomalies in SST. Although the goal of their study was to better understand the relationship between SST fields and precipitation in the GoG, some of the anomalies that were found may have been MHW instances (Asuquo & Oghenechovwen, 2019). Additionally, they suggested that certain positive anomalies identified in this region may be associated with the onset and intensification of MHWs. According to Acheampong et al., (2021), there is limited information available about MHWs in the GoG, and few studies have been conducted in this area.

As global climate change accelerates, the Gulf of Guinea has experienced a rise in SST, leading to prolonged and more frequent MHW that can have devastating

consequences on Ghana's marine ecosystems and coastal communities. As a developing coastal country, Ghana is potentially vulnerable to the effects of MHWs on its marine ecosystems and the blue economy (Acheampong et al., 2021; Sackey et al., 2020). Despite the increasing recognition of the importance of MHWs in Ghana's coastal development, there is limited research on the topic in the country (Apeaning Addo et al., 2020). Understanding the dynamics and drivers of these MHWs in the context of Ghana's unique coastal environment is crucial for devising effective mitigation and adaptation strategies to protect both the marine ecosystems and the coastal population.

Ghana has a growing blue economy and is represented by sectors such as fisheries, aquaculture, maritime administration, tourism, Ghana Navy, and the oil and gas industry. Some of these sectors support the local communities. Many of these sectors and coastal communities are potentially vulnerable to the effects of MHWs. These sectors can potentially be impacted by MHW and as such, the fisheries sector in Ghana is vulnerable to the impacts of MHWs, as high sea temperatures can result in reduced fish catches and changes in fish distribution (Danso et al., 2020; Ofori-Danson et al., 2019). Tourism, another important sector in the blue economy, is also potentially vulnerable to the impacts of MHWs. Warmer waters can result in coral bleaching, which can reduce the attractiveness of coral reefs to tourists (Ofori-Danson et al., 2019). Additionally, beach erosion due to sea-level rise associated with MHWs can also affect the tourism sector. Coastal communities in Ghana are also likely to be impacted by MHWs, as they rely on marine resources for their livelihoods. Reduced fish catches and changes in fish distribution due to MHWs can affect the income of fisherfolk, while beach erosion can result in the loss of land and homes for coastal communities. It is so far unknown if blue economy stakeholders in Ghana have detected MHWs in the past, and how they may have responded to MHWs.

Moreover, it is unknown how prepared blue economy stakeholders in Ghana are for future MHW events, especially if they increase in duration or intensity, and the impacts

become more intense. Despite the potential impacts of MHWs on the blue economy in Ghana, there is limited knowledge of the preparedness and awareness of stakeholders in the country.

To ensure a coordinated response to MHWs, policymakers, researchers, the corporate sector, conservationists, and civil society must be aware of the need to put forecasting mechanisms in place. It is essential to assess stakeholders' awareness and knowledge level of MHW to take necessary measures and climate-proof the blue economy where necessary. Therefore, this study aims to document stakeholders' perspectives on MHW and how prepared the blue economy sector of Ghana is in responding to MHW.

1.4 RESEARCH OBJECTIVES

The objective of this study is to examine the awareness and preparedness of blue economy sectors for MHWs in Ghana. In order for this to be achieved, the study will seek to achieve the following aims:

- i. Establish stakeholders' perspectives about the awareness of MHW in Ghana.
- ii. Document stakeholders' views on the impact of MHWs on their sector.
- iii. Document stakeholders' views on their preparedness as a blue economy sector for MHW.

1.5 RESEARCH QUESTIONS

This dissertation will use semi-structured interviews to address the following questions:

- i. What is the level of awareness of MHW among stakeholders in the blue economy sector of Ghana?
- ii. How do stakeholders perceive the potential impact of MHW in their various sectors?

- iii. What measures if any, have stakeholders taken to prepare for and mitigate the effects of MHW?
- iv. What do the stakeholders think should be done to improve awareness and preparedness in response to threats from MHW?

The findings of this study will provide valuable insights into the awareness and preparedness of stakeholders in the blue economy sector for MHW in Ghana. It will also provide recommendations for policymakers, industry players, and other stakeholders to improve their preparedness and response to MHWs. By doing so, the study will contribute to building the resilience of the blue economy sector in Ghana and ensure its sustainable growth and development in the face of climate change.

2.0 METHODS

For this thesis, I employed a qualitative research approach utilizing semi-structured interviews as the primary data collection method (Young et al., 2018). The use of semi-structured interviews was motivated by its flexibility, allowing for in-depth discussions and the opportunity to clarify and explore topics further during the interviews (Benitez et al., 2018). The interviews were designed to gain insights into stakeholders' perspectives regarding the awareness of MHWs in Ghana, as well as their perceptions of the potential impacts of MHWs and the preparedness of the blue economy sectors to address this phenomenon.

Through the use of semi-structured interviews, this study endeavours to shed light on the current state of awareness and readiness of the blue economy sectors in Ghana concerning MHWs. The insights gained from the interviews are expected to contribute significantly to achieving the research objectives and offer valuable guidance for enhancing preparedness and resilience in the face of MHWs' potential impacts on Ghana's marine ecosystems and blue economy.

2.1 INTERVIEW DESIGN AND QUESTION

The interviews comprised two sections. Section (A) includes questions on the participants' demographic information and job experience, whereas Section (B) includes questions about the participants' perceptions of MHW in Ghana. (see Appendix A for the complete interview questions). The interview guide was approved by the World Maritime University (WMU) ethics clearance committee. I reached out to participants from various institutions and organizations in Ghana via WhatsApp and Zoom calls using my WMU Gmail account, requesting an interview. Each scheduled interview was conducted in English between April and July 2023 and did not go longer than 40 minutes.

2.2 ETHICAL CONSIDERATIONS

This study adhered to the rules and procedures established by the WMU Research and Ethics Committee (REC) and was ethically approved by WMU before the research began. In order to confirm that participants participated voluntarily in this study, participant consent was also obtained. The study was conducted in absolute confidentiality both during and after. As a result, in the remaining sections of the study, the respondents are identified by the codes P1, P2...Pn. Furthermore, the information gathered is treated with the utmost confidentiality and won't be disclosed without the participant's permission. I openly address any potential biases that may already be present to accomplish this study's goals.

2.3 SAMPLING

Senior government officials, coastal community leaders, academics, and NGO workers directly involved in decision-making were the focus of the interviews. The availability of respondents from the targeted participants determined how the interviews were conducted. Additionally, I selected interviewees through snowball sampling. According to Flick (2018), the non-probability sampling method known as "snowball sampling" asks participants to recommend other specialists in the field who are relevant to the study. I was able to locate people using this method who would not have been accessible through standard web searches. Snowball sampling can be employed to achieve the desirable sample size. (Naderifar et al., 2017). A list of all participants in this study is provided in Table 2 below. The participants gave their permission for me to record the interviews for easier transcribing, and I made notes as I did so. The sample size intended was 15-20 (Braun & Clarke, 2013), but only 19 of the invited 25 interview candidates were actually interviewed. (i.e., an average of 76% response rate).

Table 2: List Of Interviewees, Their Code Names, Institutions Of Work (Duration Of Work And Experience), And The Sector Where Their Institutions Belong

S/N	Code Name	Date of Interview	Institution	Sector	Years of involvement in marine-related activities	Duration of Interview
1	P1	27/04/2023	Fisheries Commission	Public Sector	>20 years	37:35
2	P2	02/05/2023	Friends of the Nation Ghana	NGO	5 to 10 years	26:8
3	P3	02/05/2023	Hen Mpoano	NGO	5 to 10 years	26:11
4	P4	06/05/2023	Friends of the Nation Ghana	NGO	5 to 10 years	25:12
5	P5	15/05/2023	Hen Mpoano	NGO	10 to 15 years	18:45
6	P6	23/05/2023	Canoe and fishing gear owners' association	Artisanal Sector	>20 years	36:27
7	P7	24/05/2023	Environmental Protection Agency	Public Sector	10 to 15 years	20:27
8	P8	27/05/2023	Ghana Navy	Public Sector	1 year	24:48
9	P9	27/05/2023	Ghana Navy	Public sector	<1 year	22:15
10	P10	03/06/2023	Fisheries commission	Public Sector	>5 years	16:7
11	P11	04/06/2023	Local government	Public Sector	4 years	17:27
12	P12	11/06/2023	Ghana Ports and Harbours Authority	Public Sector	> 20 years	21:56
13	P13	13/06/2023	Ghana Maritime Authority	Public Sector	>15 years	18:9

14	P14	15/06/2023	Ghana National Fishermen and canoe council	Artisanal Sector	>20 years	25:28
15	P15	15/06/2023	Canoe and fishing gear owners' association of Ghana	Artisanal Sector	>20 years	23:53
16	P16	17/06/2023	Fisheries commission	Public Sector	>5 years	14:39
17	P17	21/06/2023	Ghana Marine Police	Public Sector	>10 years	25:14
18	P18	01/07/2023	ENI	Private Sector	>5 years	13:4
19	P19	06/07/2023	Ghana Tourism Authority	Public Sector	>10 years	24:48

2.4 METHOD OF INTERVIEW AND DATA ANALYSIS

I used the website oTranscribe (<https://otranscribe.com/>) to help me with the interview transcription, and I then used the deductive method of thematic analysis to group the data into common themes (Elliott, 2018; Clarke et al., 2015; Terry et al., 2017). This coding procedure finds relevant and significant elements of the gathered data that are related to the study's questions and goals (St. John et al., 2014).

2.5 MARINE HEATWAVE DATA FOR GHANA

To obtain a comprehensive review of the recent historical occurrences of MHWs in the territorial waters of Ghana so that they could be discussed with interviewees, I

obtained spatial and temporal MHW data summaries from the Technical University of Denmark, National Centre for Aquatic Resources (DTU-Aqua). DTU-AQUA post-processed SST data from the Marine Copernicus dataset, specifically the product identified as METOFFICE-GLO-SST-L4- REP-OBS-SST. Regional data pertinent to Ghana were extracted from a global dataset which spanned the time period 1982 to 2021 at a spatial resolution of 0.05°. MHW events were calculated from these data using the methodology delineated in Hobday et al., (2016). Following the approach of Chauhan et al., high-intensity MHW occurrences were identified by those events that fell outside the 95th percentile of the temperature distribution. DTU-AQUA summarized these results in time series graphs of (Figure 1A) average MHW duration and (Figure 1B) average MHWs cumulative intensity over the Ghana region (per km²) from 1982 to 2021. It also provided a time series of maps of Ghana showing the total MHW duration and of total MHW cumulative intensity from 2010 to 2021 (Figure 2).

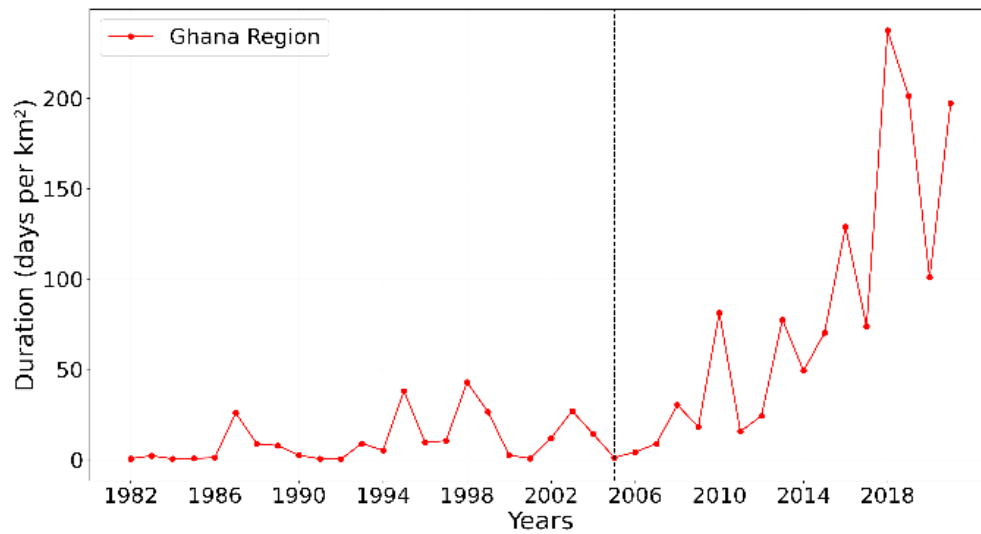
I shared these data summaries and maps (Figure 1 and Figure 2) with interviewees for discussion during the interviews. I asked the participants if they could relate their experiences to the MHW information in the MHW historical data, specifically the time and location of the MHW event, and any other details they might have recognized or remembered.

3.0 RESULTS

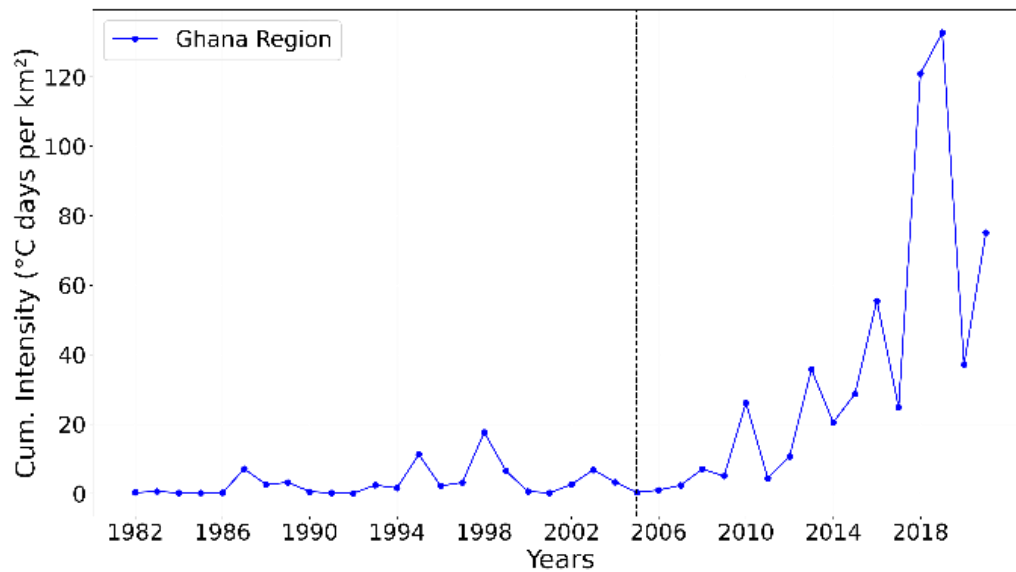
The results section is divided into two parts. The first describes patterns in the MHW time series and maps that were obtained from DTU Aqua. The second part discusses the results of the interviews that I conducted.

3.1 PATTERNS IN MARINE HEATWAVE DATA SUMMARIES

Figure 1: Temporal analysis of MHWs for the period 1982-2021



(A): Average MHWs duration over the Ghana region (per km²) from 1982 to 2021

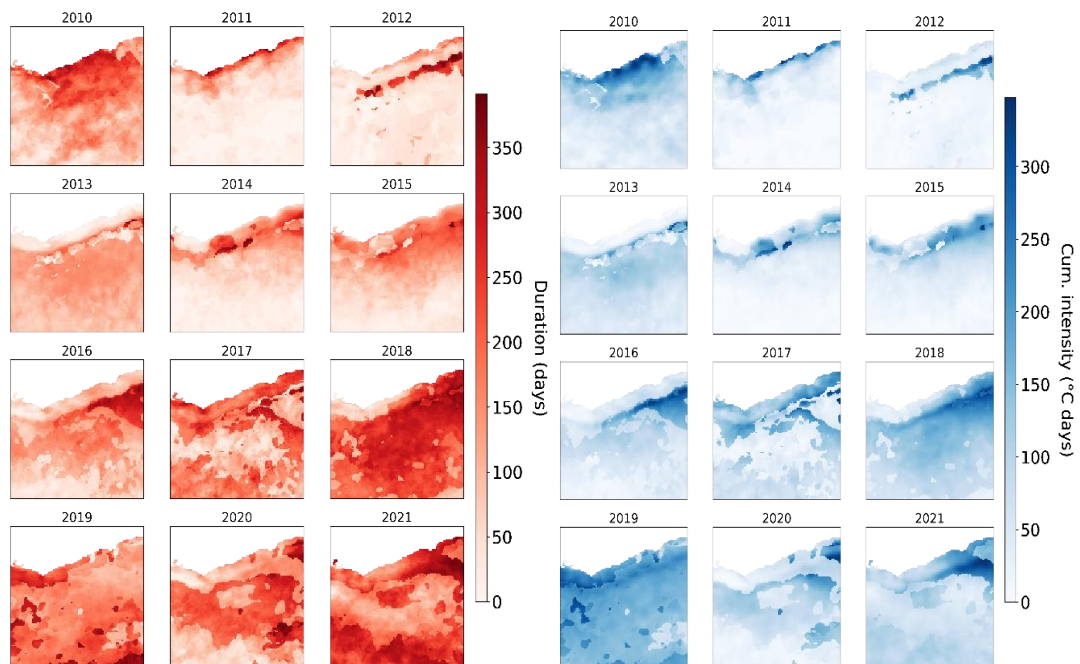


(B): Average MHWs cumulative intensity over the Ghana region (per km²) from 1982 to 2021

Fig1: (A), (B). The black dotted line shows the extent of the baseline used for calculating the MHWs ranges from 1982 to 2005. Fig1 shows the substantial increase in both the duration and intensity of MHWs spanning a four-decade period and both MHWs features seem to follow a similar trend in this region. Figure 1A is from a spatial map indicating events of MHW with 2005 as the base year. In 2010, the duration of days per km² was about 80 days per km² but this went as high as about 250 days per km² in 2018. During the baseline period and extending to four years after it (approximately 2010), the mean duration and aggregate intensity consistently remained below 50 days and 20°C days, respectively.

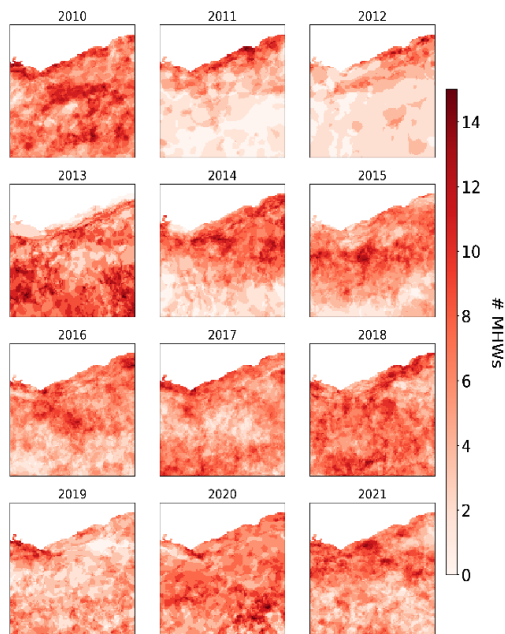
Figure 1B is the result from spatial maps showing the cumulative intensity in degrees Celsius of days per square kilometer over a period of time. With 2005 as the base year, there was the highest recorded cumulative intensity of an average of 130°C a steep decline to 40°C in 2020 and an increase again in 2021. Post-2009, the duration and cumulative intensity of MHWs increased steeply and fluctuated in the following years. Based on this analysis, the years 2018 and 2019 were the most severely impacted in terms of both the duration and cumulative intensity of MHWs.

Figure 2: Spatial analysis of MHWs for the period 2010-2021



(A): Total MHW Duration from 2010 to 2021

(B): Total MHW cumulative Intensity from 2010 to 2021



(C): Total MHW events from 2010 to 2021

Figure 2 illustrates the regional variability of MHWs in relation to their duration, cumulative intensity, and frequency of occurrences in a series of maps. Figure 2A shows MHW duration in days from 2010 to 2021 within Ghana's EEZ which is the prolonged period of time in days MHWs have occurred in Ghana over a period of time. Figure 2B shows the cumulative MHW Intensity of degrees Celsius in days from 2010 to 2021 of Ghana's EEZ, thus how intense MHW has occurred in Ghana's ocean in degrees Celsius over a period of days. Figure 2C also shows MHW events in Ghana's EEZ from 2010 to 2021 thus the various MHW events that have occurred in Ghana.

MHWs appear to be spread over the entire region with a high number of events except for the years 2011 and 2012 when they were predominantly confined to the coastal areas (as indicated in Figure 2C). In the year 2010, MHWs were relatively longer and more intense across the whole region (Fig A, B) while between 2011 and 2015, these events were notably prolonged and intensified in the coastal zones. This spatial pattern may be attributable to the region's bathymetry, as coastal areas tend to be shallower than offshore waters. However, it is crucial to acknowledge that other contributing factors could influence MHW dynamics. Post-2015, the entire region appears to have been adversely impacted by MHWs, with the year 2018 marked by the longest and most intense MHWs, exhibiting spatial variations.

3.2 RESULTS FROM SEMI-STRUCTURED INTERVIEWS

The second part of the results discusses interviewees being asked and some were able to identify areas along the coast they believe MHWs have impacted (P1, P2, P5, P6, P7, P10, P11, P12, P15, P17, and P19) some interviewees (P13 and P14) also believe that MHWs have been occurring all over Ghana's waters every now and then.

Table 3: *List of Areas Identified by Interviewees As Having Recently Experienced MHWS And The Interviewee(S) That Identified Them*

Name of locations that interviewees reported to have experienced a heat wave	Interviewee (P1 – P19)
Saltpond	(P1, and P19),
Elmina	(P1, P17)
Winneba	(P1)
Volta Region	(P2 and P19)
Keta	(P2)
Shaman	(P2)
Western Region	(P6, P15, P19)
Central Region	(P6, P15)
Greater Accra Region	(P15)
Jomoro – Half Assini	(P7, P10, P11)
Elembele District	(P7)
Axim	(P7)
Tema Port	(P12)

Experiences recalled by the interviewees did not align with the MHW data summaries in space or time.

Table 4 presents the common themes identified in the interview responses on MHW in Ghana, organized by participant numbers. The interview focused on various aspects related to MHWs and their impacts on different blue economy sectors in Ghana, such as fishing, maritime industry, and tourism.

I analysed three themes from the coded common themes. Awareness of MHW, stakeholders' perception of the potential impact of MHW in their various sectors, and

measures stakeholders have taken to prepare for and mitigate the effects of MHW, correspond to the interview guide questions (Appendix A). More detailed sub-themes can be found in (Table 4)

Table 4: *Common Themes on Stakeholders' Awareness, Perception, And Measures Regarding Marine Heatwaves in Ghana's Blue Economy Sector*

Question	Common Theme	Participants (P1-P19)
What is the level of (self-reported) awareness of MHW among stakeholders in the blue economy sector of Ghana?	Limited knowledge about MHW	P2, P6, P9, P13, P14, P16
	Adequate awareness of MHW	P1, P3, P4, P5, P7, P8, P12, P15, P19
	Indirect awareness through climate change	P7, P17, P18
	Indigenous and non-scientific knowledge	P10, P11
	MHW as a natural occurrence	P17
	Lack of formal notification	P16
How do stakeholders perceive the potential impact of MHW in their various sectors?	Negative impact on fish catch	P1, P3, P5, P7, P13, P15, P19
	Impact on tourism infrastructure and eco-tourism	P19
	Affects fishing industry and livelihood	P14, P16
	Reduced fish catch and economic impact	P4, P6, P12, P14, P19
	Depletion of fish species	P1, P3, P5, P8, P15
	Shift in fish migration patterns	P1, P3, P5, P8, P15, P19
	Threat to marine resources and biodiversity	P1, P3, P4, P6, P7, P8, P10, P11, P14, P19
	Potential impact on the maritime industry	P2, P5, P6, P13
	Affects coastal communities and local livelihoods	P2, P5, P6, P7, P9, P13, P14, P19
	Impact on fish stock availability	P4, P6, P7, P8, P9, P12, P13, P14, P16, P19
	Impact on artisanal fishing practices	P1, P2, P3, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P16
	Threat to aquatic ecosystems	P1, P3, P4, P6, P8, P9, P10, P11, P12, P14, P16, P19
	Potential reduction in catch quality	P1, P3, P5, P8, P15, P19
	Impact on marine police operations	P17
Impact on marine resources and coastal tourism	P4, P6	

What measures, if any, have stakeholders taken or would take? to prepare for and mitigate the effects of MHW?	Limited preparedness and no plans	P14, P16
	Need for education and awareness	P4, P5, P13, P14, P15, P16, P17
	Collaboration and stakeholder involvement	P5, P13, P14, P15, P17, P19
	Gathering and using data for adaptation	P14, P16
	Capacity building and training	P4, P5, P13, P14, P15, P17, P19
	Policy development and implementation	P4, P5, P13, P15, P16, P19
	Access to funds for research and adaptation	P4, P13, P15, P19
	Use of indigenous knowledge and practices	P10, P11
	Alternative fishing methods and technologies	P4, P14
	Proactive planning and regulation	P5, P14, P19

3.3 LEVEL OF AWARENESS OF MARINE HEATWAVES AMONG STAKEHOLDERS IN GHANA'S BLUE ECONOMY SECTOR

The self-reported level of awareness of MHW among stakeholders in Ghana's blue economy sector varied among the participants (P1 to P19). It ranged from limited knowledge to adequate awareness. While some participants expressed a clear understanding of MHW and its implications, others expressed a lack of formal information or indirect awareness through related concepts like climate change. The following codes emerged from the interviews:

Limited Knowledge about MHW:

Participants 2, 6, 9, 13, 14, and 16 expressed limited knowledge about MHW. These stakeholders indicated that they were not well-informed about MHW events and their potential impacts.

"I must confess that I don't have much knowledge about MHW. It's not something that has been extensively discussed within our sector." (Participant 2)

"MHW is not a term that I'm very familiar with. I haven't come across it in my line of work." (Participant 6)

Self-report Adequate Awareness of MHW:

On the other hand, participants 1, 3, 4, 5, 8, 12, and 15 self-reported adequate awareness of MHW. These stakeholders indicated that they were familiar with the concept of MHW and its relevance to the marine environment.

"Yes, I am aware of Marine Heatwaves. They are periods of prolonged heat in the ocean that can have significant impacts on marine ecosystems." (Participant 1)

"We have been monitoring MHW events and their effects on the marine environment. It's an important aspect of our research." (Participant 3)

Indirect Awareness through Climate Change:

Participant 7 self-reported indirect awareness of MHW through climate change. This stakeholder recognized that MHW events could be linked to climate change, reflecting a broader understanding of their potential association.

"While I may not have detailed knowledge about MHW specifically, I am aware that climate change can lead to extreme heat events in the ocean." (Participant 7)

Indigenous and Non-Scientific Knowledge:

Participants 10 and 11 mentioned indigenous and non-scientific knowledge about MHW. These stakeholders implied that traditional and local communities may have their own understanding of extreme heat events in the marine environment.

"In our community, we have observed unusual heat in the ocean during certain times of the year, and we attribute it to natural cycles." (Participant 10)

MHW as a Natural Occurrence:

Participant 17 perceived MHW as a natural occurrence in the marine environment. This stakeholder recognized that heatwaves in the ocean could be a part of the natural variability.

"MHW is something we encounter occasionally as part of the natural variability of the ocean. It has always been there." (Participant 17)

Lack of Formal Notification:

Participant 16 expressed a lack of formal notification or specific information about MHW events. This stakeholder implied that there might not be dedicated systems for communicating MHW occurrences.

"As an organization, we haven't received any formal notifications about MHW events, which suggests that there may not be a dedicated mechanism for that." (Participant 16)

3.4 STAKEHOLDERS' PERCEPTION OF THE POTENTIAL IMPACT OF MARINE HEATWAVES IN VARIOUS SECTORS OF GHANA'S BLUE ECONOMY

Stakeholders in Ghana's blue economy sector perceived various potential impacts of MHW in their respective sectors, ranging from the negative effects on fish catch and fish stock availability to the potential impacts on coastal tourism, local livelihoods, and marine ecosystems. The interviewees (P1 to P19) highlighted a range of concerns and potential consequences that MHW might have on their industries. The following codes emerged from their responses:

Negative Impact on Fish Catch:

Participants expressed concerns about the negative impact of MHW on fish catch. Participant 1 stated, *"Fish catch will decrease due to increased sea temperatures,"* emphasizing the potential reduction in fish catch caused by MHW. This sentiment was also shared by Participant 5 who mentioned, *"Fishers have reported that fish catch has declined in recent years due to the warming sea temperatures."* Other participants (P3, P7, P13, P15, and P19) echoed similar concerns about the adverse effects of MHW on fish catch in their sectors.

Impact on Tourism Infrastructure and Eco-tourism:

Participant 19 highlighted that MHW could impact coastal tourism infrastructures, leading to changes in biodiversity and affecting eco-tourism. This underscores the

potential consequences MHW may have on tourism-based sectors that rely on the health of marine ecosystems.

Affects Fishing Industry and Livelihood:

Several participants (P14, P16) expressed that MHW would have an impact on the fishing industry and the livelihoods of fishers. Participant 14 mentioned, "*MHW has affected the fish catch. Fishers expect pelagic to be common, but they do not get them,*" indicating a perception that MHW can disrupt traditional fishing practices and reduce catches.

Reduced Fish Catch and Economic Impact

Participants (P4, P6, P12, P14, and P19) highlighted concerns about reduced fish catch and the associated economic impact. Participant 4 (P4) remarked, "*Fish catch will decrease due to the impact of MHW, which will affect the fishing industry and the livelihoods of fishers,*" illustrating the potential consequences of MHW on both economic activities and livelihoods.

Depletion of Fish Species:

Participants (P1, P3, P5, P8, and P15) expressed apprehension about the depletion of fish species due to MHW. Participant 8 stated, "*MHW can lead to the depletion of fish species, affecting the biodiversity of our marine ecosystems,*" highlighting the potential threat MHW poses to marine biodiversity.

Shift in Fish Migration Patterns:

Stakeholders (P1, P3, P5, P8, P15, and P19) also mentioned concerns about the shift in fish migration patterns due to MHW. Participant 1 (P1) remarked, "*MHW can alter fish migration patterns, leading to changes in the distribution of fish species,*" indicating the potential disruptions to traditional fishing grounds and fishing practices.

Threat to Marine Resources and Biodiversity:

Numerous participants (P1, P3, P4, P6, P7, P8, P10, P11, P14, and P19) expressed concerns about the threat MHW poses to marine resources and biodiversity. Participant 7 stated, "*MHW can have significant impacts on marine resources and biodiversity, affecting the delicate balance of our coastal ecosystems,*" highlighting the potential ecological consequences of MHW.

Potential Impact on the Maritime Industry:

Participants (P2, P5, P6, and P13) identified the potential impacts of MHW on the maritime industry. Participant 2 (P2) mentioned, "*MHW may have adverse effects on maritime operations and logistics,*" suggesting that MHW could disrupt various aspects of the maritime sector.

Affects Coastal Communities and Local Livelihoods:

Several participants (P2, P5, P6, P7, P9, P13, P14, and P19) mentioned that MHW could affect coastal communities and their local livelihoods. Participant 9 (P9) expressed, "*MHW poses risks to coastal communities, as it affects fishing activities and local livelihoods,*" indicating the potential socio-economic consequences for communities dependent on marine resources.

Impact on Fish Stock Availability:

Participants (P4, P6, P7, P8, P9, P12, P13, P14, P16, and P19) voiced concerns about the impact of MHW on fish stock availability. Participant 7 remarked, "*MHW may reduce fish stock availability, leading to decreased catches and economic losses for the fishing industry,*" highlighting the potential repercussions for fish stocks and related economic activities.

Impact on Artisanal Fishing Practices:

A broad consensus was observed among participants (P1, P2, P3, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, and P16) about the impact of MHW on artisanal fishing

practices. Participant 12 mentioned, *"MHW can disrupt traditional artisanal fishing practices, affecting the livelihoods of local fishers,"* illustrating the potential implications for traditional fishing methods and their sustainability.

Threat to Aquatic Ecosystems:

Stakeholders (P1, P3, P4, P6, P8, P9, P10, P11, P12, P14, P16, and P19) expressed concerns about the threat MHW poses to aquatic ecosystems. Participant 3 (P3) remarked, *"MHW can cause harm to aquatic ecosystems, leading to cascading impacts on marine life,"* indicating the potential environmental repercussions of MHW.

Potential Reduction in Catch Quality:

Participants (P1, P3, P5, P8, P15, and P19) noted concerns about the potential reduction in catch quality due to MHW. Participant 5 (P5) stated, *"MHW might result in reduced catch quality, impacting the market value of fish,"* underscoring the potential implications for fish quality and market demand.

Impact on Marine Security Operations:

Participants (P8, P9, P17) highlighted the potential impact of MHW on the Ghana navy marine police operations, suggesting that changes in sea conditions and marine resources may affect the tasks and logistics of marine security operations and the marine police. Participant 9 stated *"It affects us because the fishers are our duty and we have to protect them. And with the ripple effect of the marine heatwaves, we have to go further into the ocean for their protection as they go further into the sea to fish"* emphasizing the fact that the people at sea must be protected regardless of the challenges MHW might present.

Impact on Marine Resources and Eco-Tourism:

The potential impact of MHW on marine resources and coastal tourism was recognized by participants P4, P6 and P19. These stakeholders emphasized the need to consider

the effects on marine ecosystems and the tourism industry. Participant 4 stated “*MHW is affecting the coastal tourism infrastructures which will lead to changes in biodiversity and affect the eco-tourism.*”

Participant 19 stated, “*Tourists are also concerned about their safety and well-being and destinations they find unsafe due to climate conditions are affecting the Tourism industry.*” He continued to add that “*For tourism, we have a value chain of fisher folks to provide fish to feed guests in hotels and restaurants. This has limited the harvest and number of fish for consumption.*” This shows how crucial MHWs is to the tourism sector.

3.5 INTERVIEWEES’ REFLECTION ON MEASURES TO PREPARE FOR AND MITIGATE THE EFFECTS OF MARINE HEATWAVES IN GHANA’S BLUE ECONOMY SECTOR

During the interviews, stakeholders reflected on ways to prepare for and mitigate the effects of MHWs. From the responses of participants (P1 to P19), it is evident that there is a growing awareness of the significance of MHW and a recognition of the need for collaborative efforts to address these challenges. The following codes emerged from the interviews:

Limited Preparedness and No Plans:

Participant 14 expressed concerns about the sector's preparedness and the lack of specific plans to tackle MHW, stating, “*There is limited preparedness as want it because we need to get the required resources to manage the situation. The conditions keep changing and cannot be managed properly.*” Similarly, participant 16 remarked, “*We are finding alternative ways of fishing by getting involved in aquaculture activities. So, I believe we are ready for this by finding alternative ways of fishing.*”

Participant 1 expressed a concern that *“We currently battling with other challenges including IUU fishing which has almost all the budget allocated to resolve that and this will make it more difficult for our sector. An external factor is going to be very difficult to control and a disaster for the country.”*

Education and Awareness:

Several participants emphasized the significance of education and awareness as key measures in preparing for MHW. Participant 5 stated, *“Officers should be trained with regards to SST and how it can be read,”* emphasizing the importance of equipping stakeholders with the knowledge to monitor and respond to changing SST. Participant 13 also stressed, *“There is a need for sensitization and education on the impact of MHW on fisheries and other marine-related activities,”* Participant 4 emphasized that *“More information is needed, and if the industry is able to do so, it will tell us more about how the environment is affected and these discussions will bring about how best we can mitigate it.”* highlighting the importance of raising awareness expressed by the participant.

Collaboration and Stakeholder Involvement:

Stakeholders recognized that addressing the challenges of MHW requires collaboration and involvement of various sectors. Participant 17 pointed out, *“Government must intensify the media on MHW issues to get a better understanding of it through their various agencies,”* emphasizing a perceived need for coordinated efforts involving government agencies.

Participant 19 also noted, *“Using expert organizations and NGOs to sensitize the communities in and around the mangrove on sustainable use, management, and the need for conservation of the mangroves on the values of the mangroves,”*

Participant 10 indicated that *“We should be involving the fishers also in a participatory approach that can make them acknowledge the existence of issues of MHW”*.

Participant 3 indicated *“Maritime stakeholders must foster collaboration among various sectors to help in the adaptation as MHW is a multi-sectorial challenge”* highlighting the importance of engaging experts and NGOs in community outreach.

Data Gathering and Usage:

Data-driven approaches were recognized as essential for effective adaptation to MHW. Participant 14 stated *“MHWs cannot be seen with our physical eyes so we need data to start with”*

Participant 10 clearly stated *“We should focus on taking quality data to influence our decisions and have details as to what extent it is increasing. And also have respective research stations that are equipped to be taking active real-time data. To be able to inform management decisions”*.

Participant 3 mentioned, *“We need to enhance research and monitoring to collect more data to understand MHW better and also invest in new technology to help the expertise with the analysis.”*

Participant 14 mentioned, *“We are finding alternative ways of fishing by getting involved in aquaculture activities,”* indicating the importance of collecting and utilizing data to explore new fishing methods. Similarly, participant 16 emphasized, *“Lack of expertise in this area, poor data accurate collection methods, lack of logistics,”* underscoring the need for improved data collection and analysis for informed decision-making.

Capacity Building and Training:

To enhance stakeholders' abilities to respond effectively to MHW, capacity building and training were identified as crucial measures. Participant 4 stated, *“We need to invest in training and awareness programs for our fishers to be aware of such climatic changes and how it affects their fishing activities,”* highlighting a perceived importance of providing fishers with the necessary knowledge and skills.

Participant 6 also mentioned, *“Technical capacity is needed to have a good approach and we are challenged as a sector”*.

Participant 13 also mentioned, *"Authorities must be proactive. Education and sensitization. Community engagements,"* Participant 7 mentioned *"We need to build capacity to diversify our livelihood in terms of additional activities that could support the fisherfolks. And to encourage them to abide by the use of proper gear."*

Participant 19 also said, *"As someone who works in the maritime sector, it will be great for everyone involved to know and have the opportunity to know about what MHW is and learn from other countries to build our own capacity in controlling it."*

Participant 12 indicated *"We are part of regional and international groups and we can build capacity from the members with experiences and knowledge on this."*

Participants shared the significance of capacity building at various levels within the sector.

Policy Development and Implementation:

Several participants highlighted the significance of developing and implementing policies to address MHW. Participant 15 emphasized, *"Policy change is critical. A well-structured policy will help us prepare for and mitigate the effects of MHW,"* indicating that effective policies can guide adaptation efforts. Similarly, participant 19 pointed out, *"Creating policy for the management of mangroves, and sourcing development partners for additional support and financing,"* suggesting that policy development should be complemented with partnerships to enhance financial support and expertise.

Participant 7 also indicated that *"currently I have not seen policy direction on that aspect but we will look at it based on the changes that come with it affecting resources"*.

Participant 12 added, *"No direct policy for MHW yet. So, we are not ready for the intensification of MHW"*.

Participant 18 mentioned, *"Policies must be set right by the maritime regulatory bodies and policymakers such as the Ghana maritime authority"*.

Participant 15 also indicated that *“Any implementation carried out will be in the best position for our canoe and gear owners to deliver to the fishers”*

Access to Funds for Research and Adaptation:

Financial support was mentioned by the interviewees as a critical requirement for research and adaptation measures. Participant 4 mentioned, *“The sector must be well-funded for research and technology to manage MHW,”* highlighting the need for financial resources to undertake essential studies and implement adaptive measures. Participant 13 also stressed, *“Intervention by international organizations will be helpful,”* similar to Participant 19 *“One way for the sector to adapt is through the availability of funds for research and possible measures.”* emphasizing the significance of external funding and support.

Participant 4 added *“For NGOs, we are more into channelling funds into projects that can benefit society. If there is no funding relating to MHW, it will be difficult. This is because the donors and funders also have their aims and objectives for giving out these funds. So, one major challenge will be how to convince them to channel their funds to support MHW projects”*.

Use of Indigenous Knowledge and Practices:

Participants 10, 11, and 15 recognized the importance of indigenous knowledge and practices in dealing with MHW. Participant 10 mentioned, *“Our traditional knowledge has helped us in predicting climate changes in the past,”* indicating that traditional wisdom can contribute to early warning and response mechanisms. Participant 15 said, *“Our knowledge of MHWs is more indigenous and not scientific.”*

Participant 2 mentioned, *“lack of leveraging on indigenous knowledge is a challenge for the sector to adapt TO MHW”*.

Alternative Fishing Methods and Technologies:

Participant 16 mentioned the exploration of alternative fishing methods and technologies as a potential measure.

Participant 16 stated, *“We are finding alternative ways of fishing by getting involved in aquaculture activities”*.

This suggests that innovation in fishing practices can reduce the pressure on marine resources affected by MHW.

Proactive Planning and Regulation:

Stakeholders acknowledged the significance of proactive planning and regulation to minimize the impacts of MHW. Participant 5 emphasized, *“We have a value chain of fisher folks to provide fish to feed guests in hotels and restaurants. This has limited the harvest and number of fish for consumption,”* highlighting the importance of anticipating changes in fish supply and demand and implementing measures to ensure sustainable fishing practices.

Participant 17 also stated, *“Proper organizational planning for operations is important to help the maritime industry adapt to MHW intensification”*.

3.6 INTERVIEWEES’ REFLECTION ON CHALLENGES FOR THE BLUE ECONOMY TO ADAPT TO MHW

“Lack of political will. This is a problem when decision-makers do not prioritize the environmental issues that come with human impacts on marine-related activities and prioritize only the revenue generated from the blue economy. As well as Lack of commitment from the collaboration of stakeholders to control MHW” (P3)

Through the interview, several stakeholders (P1, P3, P4, P5, P6, P7, P8, P10, P11, P13, P16, and P17) raised the issue that, fewer funds and budgets are channelled to marine-related activities and their impacts and as such, various blue economy sectors in Ghana lack the expertise, have lack of scientific tools and equipment for the accurate measurements and evidence-based science, lack of R&D and the necessary capacity, as well as the need to bring all stakeholders together to formulate the appropriate policies.

As mentioned above, financial constraints for MHW were a challenge to many and the interviewees expressed their worries such as P12 *“Budgetary allocation for research (Funding) is a major challenge and this comes down to vision and focus of the decision-makers.”*

P11 mentioned, *“Inadequate supply of logistics to counter the issues and financial constraints.”* And this was with regard to the protection of the people especially the fishers and alternative livelihoods for them.

P8 stated that *“one of the major challenges for the blue economy stakeholders to adapt to MHW is that we do not have the expertise and technical know-how on MHW. We don’t have the equipment to do the appropriate research and how we could tackle this as an issue in our waters.”* As such lack of adequate knowledge will make control measures difficult.

P9 stated a similar challenge to P8 that says *“We don’t have enough personnel for the work we do and this will make it challenging to tackle issues and responsibilities we are chattered for”.* Both P8 and P9 are challenges stated by maritime security personnel and P9 was concerned with the fact that as the fishers move deeper into the seas to fish, they still have to be protected and they will need more personnel to protect people at the shore and offshore.

Another challenge raised by several interviewees (P5, P6, P8, P10, P12) was the fact that various blue economy sectors in Ghana lack scientific tools and equipment for accurate measurements and evidence-based science, as well as lack of R&D departments to support the various sectors to look into MHW as a national problem. With regard to that P12 stated *“Getting the science behind this is a challenge, we do not have R&D and we need an external source to assist us. we currently do not have the capacity to do so.”*

P5 stated, *“We do not have the technology to accurately monitor the impact that MHW is having. Also, the researchers are not well funded, and that will demotivate and deprive the adaptation process”*

P6 added *“Technical capacity – we need to have a good approach and we can begin with the challenge of no data, no easy access to such information and we also don’t have the financial resources.”*

P8 in a few words on technology as a challenge stated *“We don’t have the equipment to research MHW and similar concerns”*

P10 mentioned *“Evidence-based science is important and a challenge. We should be taking active data and this could be done by involving the fishers also in a participatory approach that can make them acknowledge the existence of issues of MHW.”*

Apart from technology to help in the adaptation of MHW, interviews raised about the limited knowledge, technical skills, and expertise for detecting and addressing MHW in Ghana’s blue economy sectors. (P5, P8, P13, P16, and P17) and an interest in capacity building (P2, P6, P17).

In their own words, P17 mentioned *“We need people with requisite knowledge and understanding of MHW this will help and assist the blue economy sector on the necessary steps to take to enable us to adapt to MHW).”*

P13 added to this by saying *“The appropriate staff skills or technical skills is a challenge and this will affect how we adapt to MHW as a country.”*

P5 also said *“The government agencies are heavily under-resourced and feel they may not have the technical capacity”*

P16 added that *“As a nation, we do have a lack of expertise in this area, and this a challenge for us.”*

Finally, some interviewees raised concerns about governance issues. For example, The following interviewees exhibited different perceptions about the benefits of a participatory approach to addressing MHW management. (P1, and P19)

P1 stated; *“The mindset of the people that see enforcement of the commission as top-down approach or even punishment even though it was a participatory approach that got them involved. They usually assume decisions are taken solely by the people in power and as such, they are irrelevant and not needed.”*

P19 also mentioned *“Making everyone understand the intensity of MHW and its effects is a challenge, and the need of how to bring all stakeholders together to formulate policies is another challenge”* noting that some stakeholders feel alienated in the process.

3.7 INTERVIEWEES’ REFLECTION ON POSSIBLE OPPORTUNITIES FOR THE BLUE ECONOMY TO ADAPT TO MHW

Several opportunities could help the blue economy sectors in Ghana adapt to MHWs and these were identified by the interviewees. A number of interviewees highlighted opportunities for the blue economy in Ghana to adapt to MHWs is a clear indication that the current condition can be improved. Nearly all of the interviewees were optimistic about improving MHW preparedness and suggested options to improve the situation. Exceptions included (P5 and P14) who were unable to identify opportunities in this regard.

Several interviewees mentioned education and capacity building as major opportunities for the various sectors in Ghana’s blue economy to adapt to MHW. (P1, P8, P9, P12, P16, P17)

P1 stated briefly emphasizing that *“Most of the opportunities rely on capacity building.”*

P8 added *“Training personnel with regards to maritime life and effects of maritime life. We will be able to adapt more and learn about MHW concerns and concepts.”*

P9 stated categorically, *“As someone who works in the maritime sector, it will be great for everyone involved to know and have the opportunity to learn about what MHW is and learn from other countries to build our own capacity in controlling it.”*

The interviewee P9 continued to add that *“All the surrounding factors the ocean has to offer, we must be abreast with such issues and it is only right we know matters affecting the maritime environment and not just the security aspect and this will help improve the efficiency of our operations.”*

P12 looked at the opportunities of capacity building in a broader perspective through collaborations at the regional and international level and stated *“We are part of regional and international groups and we can build capacity from the members with experiences and knowledge on this. When the capacity and awareness are being created, we are very proactive and can work together as an organization to control MHW and climate change in our waters.”* This shows how willing some stakeholders are to help control MHW-related issues as long as they have the prerequisite knowledge.

P16 added that *“training officers to build the required capacity and be able to read accurate SST will enable has accurate data of our sea temperatures and the necessary steps to take.”*

P17 also added with regards to capacity building that *“engaging in capacity building programs for a good understanding of MHW will put our sector in a better situation to plan well towards MHW implications and execute the tasks very well”*

Interviewee P4 also appreciated the time engaged with him for input on this study and stated that *“Through efforts like the research and interviews you are carrying out, if there is more information, they could be channelled into projects which will enable them to source funding for it and do not become just a bookshelf work but something we can put resources to.”*

The aid and assistance of NGOs and expert organizations to sensitize the various communities, especially the coastal communities were raised as an opportunity by various interviewees (P4, P6)

P4 stated, *“It is an opportunity for communities to be sensitized to enable us to understand MHW better.”*

P6 explained *“We have the numbers; we have the support. About 6,000 canoe owners. We have been able to mobilize the canoe and gear owners as an association, The canoe and gear owners are the key stakeholders in the artisanal fishing sector. They own to decision making, they invest in resources. When you are able to mobilize the owners, the crew all depends on the owners. Having the owners organized is a very good step to reaching out to the crew. And sensitization in this direction will be helpful”*

P7 looked at the opportunities for the blue economy to adapt to MHW by linking this to the nation's plan towards acquiring an MSP and saw this as an opportunity such that, *“We have a strategic assessment of the use of the marine space as an institution and we have promoted the state of the marine environment to develop a Marine Spatial Plan for the marine space. To give us an idea of how the resources will be affected and how we should harmonize some of the activities within the marine space”*

The interviewees mentioned advocacy and awareness creation as one of the major opportunities for the blue economy stakeholders to adapt to MHW. (P6, P10, P18)

P6 stated, *“Most of the canoe owners are professionals including medical doctors and accountants. With their exposure, they are likely to appreciate some of these issues and be able to present the problems to the ordinary fishers in a manner that is understandable.”* elaborating how important the role of canoe owners as a blue economy stakeholder is in educating the fishers.

P10 also said *“Everyone must be educated on this even if your livelihood does not depend on marine activities, you probably feed from it. And when there is a shortage of fish, everyone will be affected. And each of us one way or the other, are contributing to it with activities such as harvesting timber for canoes and converting wetlands into infrastructural purposes. All these must be stopped and education and awareness will play a major role.”* This highlights the fact that advocacy and awareness of MHW must even be created among all personnel within the sectors of the blue economy as this could enhance the advocacy within Ghana’s blue economy.

P18 mentioned, *“Creation of awareness of awareness will change the attitude of the people to understand the implications of MHW to Ghana.”*

Policy formulations are equally important and an opportunity for the blue economy to adapt to MHW. (P18, P19)

P18 stated that; *“Consistent education for the formulation of the right policies will enable stakeholders to adhere to enforcement of regulations.”*

P19 *“Making everyone understand the intensity of MHW And the need to bring all stakeholders together to formulate policies will be a great opportunity for the stakeholders”*

4.0 DISCUSSION

My discussion is sectioned into four parts. These are the insights of analysis on MHWs in Ghana's waters, the awareness of MHW and knowledge limitations, the impact of MHW on blue economy sectors in Ghana, and the mitigation and adaptation of MHW in Ghana.

4.1 INSIGHTS OF ANALYSIS ON MHWs IN GHANA'S WATERS

Figure 1 showed a substantial increase in both the duration and intensity of MHWs and Figure 2 illustrated the regional variability of MHWs in relation to their duration, cumulative intensity, and frequency of occurrences in a series of maps. The data reveals that MHWs in Ghana's waters are intensifying and becoming longer, indicating potential concerns for Ghana in the future. These longer and more intense MHW events could have far-reaching consequences on Ghana's blue economy sector, including changes in the distribution and abundance of commercial fisheries species which include small pelagics such as sardinella and anchovies (El Ayoubi & Failler, 2012) It can also have ecological impacts such as high mortality rates of habitat-forming corals, seagrass and macroalgae, resulting in simplified habitat structure and depleted local biodiversity (Smale et al, 2019).

These figures are important as they provide a robust scientific basis for understanding the temporal and spatial patterns of MHW in Ghana's waters. They offer critical insights into the changing marine environment and its potential consequences for Ghana's blue economy, helping policymakers, researchers, and stakeholders make informed decisions as climate change in general is likely to become worse as cited by Gennaro D'Amato et al. (2014)

4.2 AWARENESS OF MHW AND KNOWLEDGE LIMITATIONS

The lack of awareness of MHWs at the national level indicates there is no way for blue economy stakeholders to prepare. Lack of awareness at the local level also reduces the adaptive capacity even further as there might be vulnerable groups who rely on resources from the ocean that will be affected by MHWs as stated by Climate Adapt (2023).

My results indicate varying levels of self-reported awareness of MHW among the participants. Some stakeholders self-reported a relatively high level of awareness regarding MHW and its implications, some participants mentioned indigenous and non-scientific knowledge about MHW while others expressed limited knowledge or indirect awareness of MHW and related concepts such as climate change in general. This study also found that very few stakeholders in the blue economy sectors have recognized or remembered the MHW that has been measured by scientists. This highlights that MHW might have to become more intense or longer in duration for the blue economy sector to feel its effects. Alternatively, it could mean that the potential impacts on the environment, if any, have not yet progressed to a degree for the blue economy sectors in Ghana to notice. These findings highlight the diverse levels of familiarity that stakeholders in Ghana's blue economy sector have with MHW and its potential implications and align with existing research on awareness and preparedness for MHW in coastal regions (Oliver et al., 2018; Kuroda & Setou, 2021).

The variation in awareness can also be attributed to differences in communication, information dissemination, and access to data and resources within the blue economy sector as stated by The European MSP Platform (2020). These disparities highlight the need for targeted and contextualized educational initiatives (Montez et al., 2019) to bridge the awareness gap and enhance the sector's preparedness for MHW. Awareness creation, knowledge building about the expected impacts of MHW, and the need to adapt are normally the starting point of capacity-building efforts as cited by Climate Adapt (2020).

My results highlight the opportunity for Ghana to know that science has detected trends that could affect the blue economy sectors which they have not yet noticed. MHW indicators have been noted by scientists in other parts of the world as well. Today we see e.g., Caribbean marine heat waves (NOAA, 2023), and Australian marine heat waves (Readfearn, 2023). Scientists have been warning of the potential of these for years, but few sectors have prepared for them. Ghana may not experience intense marine heat waves yet, but these could become worse in the coming years as has been experienced in other parts of the World. This aligns with previous work by Bove et al., 2022. In that study, Bove found that changes in the thermal environment, in addition to other stressors including fishing and pollution, have caused a dramatic shift in the composition and functioning of Caribbean coral reef ecosystems for at least a century.

4.3 IMPACT OF MHW ON BLUE ECONOMY SECTORS IN GHANA

My study shed light on the potential impacts of MHW on various sectors of Ghana's blue economy. stakeholders expressed concerns about reduced catch quality. Ghana has one of the highest rates of dependence on fish for nutrition in Africa, with fish providing about 60% of animal protein (USDA., 2022). This shows how critical the MHW's intensity will affect those relying on fishing to support their livelihoods and Ghana's economy at large.

The impact of MHW on marine police operations and the navy is also a maritime security threat for the blue economy sector. Fishers may have to spend longer at sea and travel further to catch fish, which also has the potential to lead to illegal and unregulated fishing (Mendenhall et al., 2020). This poses a significant maritime security threat that undermines Ghana's blue economy sector's sustainability (Widjaja et al., 2020). It also has implications for artisanal fishing practices and threats to aquatic ecosystems. Stakeholders self-reported that fishers may be forced to find other

means to fish in order to maintain or increase their catch due to the migration of species from near shore to deeper waters. This is because the decrease in catch has a ripple effect from the fish catch to being able to afford fuel for their vessels and canoes, and the vulnerability of coastal communities especially individuals who have fishing as their only source of livelihood as cited by Koomson (2021).

In 2021, travel and tourism in Ghana contributed over 3 billion USD to the country's GDP (Sasu, 2022). Ghana has an active tourism industry and many people visit the country to explore the beaches and resorts, which are unique relaxation spaces in Ghana (Siakwah, 2018). If MHW affects the biodiversity of the marine ecosystem, MHW could have an impact on eco-tourism. As stated by Khanh Chi & Pham (2022), Ghana may not be the desired destination for tourist who wants to see the beach when the marine ecosystem is impacted. This will also affect the blue economy sector and the livelihoods of the people who rely on eco-tourism for their livelihoods.

As indicated by OECD (2017) these insights can inform evidence-based policy and decision-making to promote the sustainable management of Ghana's blue economy sector amid increasing climate variability and extreme heat events.

4.4 MITIGATION AND ADAPTATION OF MHW IN GHANA

Stakeholders self-reported the importance of collaboration and stakeholder involvement as critical elements in addressing MHW as cited by Burton (2016) with regards to climate change in general. Engaging various actors, including government agencies, expert organizations, NGOs, and coastal communities, fosters a comprehensive response to MHW, in line with my study's research objective to gather stakeholders' views on their preparedness as a blue economy sector for MHW.

Participants self-reported financial support as a critical requirement for research and adaptation. Adequate financial resources are essential for conducting necessary research studies and implementing adaptive measures effectively (Neil et al., n.d.).

Stakeholders had difficulty relating to the degree of intensity of MHW that had been detected by scientists, and how this could have an effect on their sectors and the potential impacts. Not all sectors of the blue economy recognize the potential impacts of MHWs. This could have an implication for the speed Ghana's blue economy might prepare itself and the response for the society in the case of MHWs. The blue economy sector can forecast to reduce its risk by changing operational practices ahead of MHW events only if there is awareness. Ghana's blue economy should create awareness to respond to and reduce the negative impacts of undesirable ocean temperatures. The ability to act on forecast information and build resilience depends on the agility of Ghana's blue economy sector (Hartog et al., 2023).

Through capacity building, it is important that the MHW trends in Ghana be effectively communicated to the blue economy sector and wider society so that they can be prepared with adaptation and mitigation strategies in advance of MHW developments. For Ghana's blue economy sector to be ready for future MHW events, it is cited by IASC (2015) that emergency response preparedness should be dependent upon an in-depth knowledge of the planning, potential, and structures of both national and local authorities, coupled with the availability of relevant data. The Ghanaian government may have inadequate technological capacity and tools to set up systems to monitor SST, but there are other ways in which they might access SST data and stay informed. For example, the National Oceanic and Atmospheric Administration (NOAA) provides access to free global monthly reports on MHW.

My study revealed gaps in the blue economy sector's adaptive capacity, as some stakeholders mentioned limited preparedness and a lack of specific plans to tackle MHW, despite a level of awareness. Ghana does not have a specific management

strategy for MHW or a risk management plan for MHW and climate change in general. On the other hand, some countries are working on addressing MHW-related issues. For example, Australia has been particularly proactive in addressing MHW. The Australian government has implemented policies and initiatives to improve its adaptive capacity, which includes the MHW early warning system such that, their national forecasting system, jointly developed by the CSIRO and Bureau of Meteorology, will provide the fisheries and aquaculture industries with a notification period of up to six months warning the potential adverse consequences of MHW. (Foley, 2020). This MHW forecasting system provides alerts and information to relevant stakeholders to prepare for and respond to MHW. The U.S. NOAA also unveiled its first global MHW forecast in June 2023, and Chinese scientists are working to develop predictions for their coastal waters as well (Cornwall, 2023). Ghana's blue economy sector can adopt a similar process by implementing proactive policies to protect its marine ecosystems and environment. These findings highlight the need for proactive planning and comprehensive strategies to enhance the sector's resilience (Pertheban et al., 2023) to MHW-induced disruptions.

4.5 STUDY LIMITATION

While this study provides insights into the level of awareness, perceptions, and preparedness of stakeholders in Ghana's blue economy sector regarding MHW, my research was limited by a number of factors. The selection of participants for the study may introduce selection bias. Some of the participants who volunteered or were chosen to be part of the study might have a higher level of interest or awareness regarding MHW, which could skew the overall findings towards a more informed group. Moreover, the study's qualitative nature relied on self-reported responses from participants during interviews, which may be subject to recall bias or social desirability bias. Participants might provide answers they believe align with what is expected rather than their genuine perceptions or knowledge about MHW.

Also, my study only focused on stakeholders' perspectives within Ghana's BE sector and did not consider the perspectives of stakeholders from other sectors that represent interests in climate science, environmental advocacy, or social well-being which could provide additional insights into the broader implications of MHW. Future studies could benefit from including a wider range of stakeholders and perspectives to gain a more holistic understanding of MHW's impacts on various sectors and society.

5.0 CONCLUSIONS

This study examined stakeholder perceptions of the awareness and preparedness of Ghana's blue economy sectors regarding MHW. The research revealed a varied level of self-reported awareness amongst participants, ranging from limited knowledge to a deeper understanding of MHW and its implications. While some stakeholders self-reported a clear comprehension, others showed indirect awareness or lacked formal information about MHW. The study's significant contribution lies in shedding light on this critical aspect of Ghana's blue economy, filling a gap in the existing literature. By investigating stakeholder perspectives, the research highlighted the need for targeted awareness campaigns, education initiatives, and tailored interventions to enhance resilience and preparedness for MHW events. The findings serve as a foundation for future research and policy development, urging stakeholders to collaborate, engage local communities, and implement adaptive measures to address MHW impacts effectively.

In recent years, MHW occurred in the northeast Pacific Ocean from 2013–2016 (Di Lorenzo & Mantua, 2016), the Tasman Sea in 2015 and 16 (Oliver et al., 2017), and waters around tropical Australia in 2015/16 (Benthuisen et al., 2018) and in the Caribbean with consequences on their blue economy sector such as the incident that took place within the Gulf of Alaska, resulting in a reduction in population and reduced reproduction of Pacific cod. As a result, the commercial cod fishery, which holds an annual value of US \$103 million, was compelled to close operations for the 2020 season (Mæland, 2021) indicating the importance of this research to Ghana's blue economy sector.

Some participants attributed climate change to natural cycles, this highlights the need for capacity building to enhance resilience to Ghana's BE sector and preparedness for MHW and extreme climate change events in the future.

5.1 RECOMMENDATION

Based on the findings of this study on the awareness and perceptions of MHW among stakeholders in Ghana's BE sector, several important future directions and follow-up studies are warranted. The research highlighted the need for targeted awareness campaigns and education initiatives to bridge the knowledge gaps and improve preparedness for MHW events. Comprehensive assessments are essential to quantify the actual impacts of MHW on various sectors within the BE, including fish catch reductions, shifts in fish migration patterns, and effects on marine biodiversity and coastal communities. Additionally, integrating MHW awareness into climate change adaptation strategies and policy frameworks can enhance resilience to extreme ocean temperature events and promote sustainable practices.

Future research should actively engage local communities and incorporate their indigenous knowledge to contribute to early warning systems and community-based conservation efforts. Development of specific policy frameworks tailored to address MHW impacts, and support sustainable fishing practices is critical. Exploring alternative fishing techniques and enhancing data collection on ocean temperature patterns and MHW occurrences will further aid in adaptive strategies and timely responses. Overall, these future directions are essential to advance understanding and preparedness for MHW events in Ghana's BE, promoting a more resilient and sustainable marine environment for the benefit of coastal communities and marine ecosystems.

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Appendices

Appendix A: Interview Guide

Section A: Demographic Information

1. Which Institution Do You Represent?
2. What group do you represent?
 - Public Sector
 - Private Sector
 - Academia
 - Maritime Industry
 - Non-Governmental Organizations (NGO)
 - Local Communities
 - Other (please specify)
3. For how long have you been involved with marine-related activities?
 - Less than 1 year
 - More than 1 year
 - More than 5 years
 - More than 10 years
 - More than 15 years
 - More than 20 years
4. Do you have any idea what Marine Heatwaves are?
5. How many years?
 - Less than 1 year
 - More than 1 year
 - More than 5 years
 - More than 10 years
 - More than 15 years
 - More than 20 years

SECTION B: PERCEPTION OF MARINE HEATWAVES IN GHANA

1. Are you aware that Marine Heatwaves are occurring in Ghana?
2. Have the consequences of the marine heat waves been felt in your sector?
3. In what ways has this been felt?
4. Where and when has this been felt?
5. Which sector functions have marine heat waves impacted?
6. How did your sector respond to the challenges?
7. With climate change, science forecasts that MHW will intensify and spread more widely. How might the intensification of MHWs affect the future of your sector?
8. Do you believe your industry is ready for Marine heat waves being intense?
9. How do you believe your industry should adapt?
10. How do you believe your industry will adapt?
11. What challenges face the potential for your sector to adapt to MHWs?
12. What opportunities are available that could help your sector to adapt?

Appendix B: Consent Form



PARTICIPANT CONSENT FORM

Dear Participant,

Thank you for agreeing to participate in this research, which is carried out in connection with a Dissertation, in partial fulfillment of the requirements for the degree of Master of Science in Maritime at the World Maritime University in Malmo, Sweden.

The topic of the Dissertation is: **Implications of MHW For The Blue Economy For Decision Makers And Key Stakeholders: A Case Study Of Ghana.**

The information provided by you in this interview will be used for research purposes and the results will form part of a dissertation, which will later be published online in WMU's digital repository (maritime commons) subject to final approval of the University and made available to the public. Your personal information will not be published. You may withdraw from the research at any time, and your personal data will be immediately deleted. Anonymized research data will be archived on a secure virtual drive linked to a World Maritime University email address. All the data will be deleted as soon as the degree is awarded.

Your participation in the interview is highly appreciated.

Student's name: Louisa Pokua Sarkodie

Specialization: Ocean Sustainability Management Governance

Email address:

* * *

I consent to my personal data, as outlined above, is used for this study. I understand that all personal data relating to participants is held and processed in the strictest confidence and will be deleted at the end of the researcher's enrolment.

Name:

Signature:

Date: