frontiers in Sustainable Food Systems

ORIGINAL RESEARCH
published: 15 November 2021
doi: 10.3389/fsufs.2021.714187

Climate Change in Fisheries and Aquaculture: Analysis of the Impact Caused by Idai and Kenneth Cyclones in Mozambique

Valdemiro Muhala [1,2], Tomé Francisco Chicombo [3], Isadola Eusebio Macate [2], Auryceia Guimarães-Costa [2], Horácio Gundana [4], Celina Malichocho [5], Oliver Jolezya Hasimuna [6,7], António Remédio [8], Sahya Maulu [9], Lucinda Cuamba [10], Adam Rick Bessa-Silva [11,12] and Iracilda Sampaio [2]*

[1] Division of Agriculture, Higher Polytechnic Institute of Gaza, Chókwè, Mozambique, [2] Laboratory of Genetics and Molecular Biology, Institute of Coastal Studies-Federal University of Para, Bragança, Brazil, [3] Division of Economics and Management, Higher Polytechnic Institute of Gaza, Chókwè, Mozambique, [4] Laboratory of Chemistry, National Institute for Fish Inspection-IP, Quelimane, Mozambique, [5] Department of Aquaculture, National Institute of Fisheries Research, Maputo, Mozambique, [6] National Aquaculture Research and Development Centre, Department of Fisheries, Ministry of Fisheries and Livestock, Kitwe, Zambia, [7] Department of Fisheries and Aquaculture, Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi, [8] Beira Fishing Port, Mozambique Railways (CFM) Square, Ministry of the Sea, Inland Waters and Fisheries (MIMAIP), Beira, Mozambique, [9] Centre for Innovative Approach Zambia, Lusaka, Zambia, [10] Faculty of Agricultural Sciences, Zambezi University, Tete, Mozambique, [11] Laboratory of Evolution, Institute of Coastal Studies-Federal University of Para, Bragança, Brazil, [12] CIBIO-InBIO, Research Center for Biodiversity and Genetic Resources, University of Porto, Porto, Portugal

OPEN ACCESS

Edited by:
Henry Bikwibili Tantoh, University of South Africa, South Africa

Reviewed by:
Shyam Salim, Central Marine Fisheries Research Institute (ICAR), India
Robert Eliakim Katikiro, University of Dar es Salaam, Tanzania

***Correspondence:**
Valdemiro Muhala
valdemiro.muhala@ispg.ac.mz

Specialty section:
This article was submitted to Climate-Smart Food Systems, a section of the journal Frontiers in Sustainable Food Systems

Received: *24 May 2021*
Accepted: *08 October 2021*
Published: *15 November 2021*

Citation:
Muhala V, Chicombo TF, Macate IE, Guimarães-Costa A, Gundana H, Malichocho C, Hasimuna OJ, Remédio A, Maulu S, Cuamba L, Bessa-Silva AR and Sampaio I (2021) Climate Change in Fisheries and Aquaculture: Analysis of the Impact Caused by Idai and Kenneth Cyclones in Mozambique. Front. Sustain. Food Syst. 5:714187. doi: 10.3389/fsufs.2021.714187

Fisheries and Aquaculture are among the most popular activities in coastal regions of the world. In addition, both correspond to high-risk activities within a climate change context as they are vulnerable to environmental changes that threaten the socio-economic sustainability of the fishing communities that depend on fish for food security and income generation. In 2019, the central part of Mozambique was hit by two unprecedented cyclones: Idai and Kenneth that killed over 600 people and left nearly 2.2 million people in need of urgent assistance. The aim of the present study was to investigate the impacts these cyclones had on fisheries and aquaculture in the provinces of Sofala and Zambézia in Mozambique. The study further seeks to propose strategies that could be adopted by the communities to minimize the risks in the future. For the construction of the database, both secondary and primary data collection approaches were used to characterize the cyclone events. Secondary data was collected through sector reports and previously published articles, while primary data was collected through interviews with fishers, sector employees, and aquaculture producers in the affected provinces. The results revealed that these natural events had both a direct and indirect impact on fishing, as they affected more than 1,440 fishermen that lost 590 vessels, 1,800 fishing gear, and 67 boat engines in Sofala province. In Zambézia province, aquaculture producers lost 169 fish ponds, two cages, and 606,000 lost fry, while in Sofala province, 58 fish tanks, 204 cages, and 257,500 fish fry were lost. Overall, our study reveals the vulnerability of fisheries and aquaculture to extreme events particularly the cyclones

in Mozambique. Lack of knowledge regarding climate change, advanced preventive measures, and poor adaptive capacity makes the sectors more vulnerable to disasters. Therefore, it is recommended to improve awareness programs, introduce measures and policies that promote resilience and optimum adaptive efficiency.

Keywords: climate change, climatic events, aquaculture, fisheries, cyclone, Mozambique

INTRODUCTION

The effects of climate change on the ocean environment will continue to impact the fisheries, specially those areas that are suitable for the phenomena to occur (Mendenhall et al., 2020). This impacts brings profound implication to the coastel communities and ecological systems (Palacios-Abrantes et al., 2020; Whitney et al., 2020).

Some recent studies have shown evidence of how the impacts of climate change influence fish stocks and aquaculture production and also the negative effects on coral reefs, causing coral bleaching and altering the species composition and diversity (Munday et al., 2008; Pratchett et al., 2008; Daw et al., 2009; Ateweberhan et al., 2013; Belhabib et al., 2018; FAO, 2020). In this context, it is necessary to understand the impacts of extreme events such as increased temperature, sea-level rise, floods, droughts, and cyclones to predict and understand the dynamics of fish stocks and their impact on future food production systems, as the effects of these events are already being observed in the ocean and coastal areas, impacting the reduction of fisheries stocks (O'Reilly et al., 2003; Vollmer et al., 2005; Badjeck et al., 2010; Rezaee et al., 2016; Blanchard et al., 2017; Troell et al., 2017).

According to FAO (2020), the impacts of climate change tend to be greater in tropical regions of Africa and Asia, where temperatures are higher, contributing to the reduction of fishery productivity. Therefore, creating occupational alternatives to reduce fishing pressure, and increasing the adaptive capacity of fishermen based on the construction of resilient infrastructures in the fisheries and aquaculture sectors are urgently needed to minimize impacts.

The Mozambican coast is very rich in diversity of fisheries species, both for the composition of the different ecosystems that they host, as well as for the environmental characteristics (Hoguane et al., 2012). Fishermen and coastal communities in Mozambique depend mostly on fishery resources that are heavily influenced by climate dynamics (Allison et al., 2005; Badjeck et al., 2010). However, in the last three decades, production has been falling, not only due to the over-exploitation of the resources but also due to climate change (Blythe et al., 2014; FAO, 2020).

However, in recent years Mozambique has suffered cyclical natural events such as cyclones, floods, and droughts, with the central and northern zones being the most affected (Hussein et al., 2020; Malauene et al., 2021). These events directly or indirectly affect fisheries production, catches, and aquaculture production. Although coastal aquaculture is more vulnerable to climate change (Ahmed and Diana, 2015), the impacts of climate change are predicted in the future on continental aquaculture. Since the 2000s, the country has been the center of major climatic disasters in Southeast Africa, being (floods, droughts, cyclones) associated with climate change (INGC, 2009; Arndt et al., 2010; Naess et al., 2015; Samoilys et al., 2019).

In March 2019, the country recorded two major cyclones (Idai and Kenneth) that severely plagued the central region in the provinces of Sofala and Zambézia and part of the northern region in the provinces of Nampula and Cabo Delgado and about 600 people in total died, thousands were left homeless and several infrastructures were totally and or partially destroyed. This was the first time that two events of high magnitude had reached the country simultaneously in the same period leading to many lives being lost and many infrastructures destroyed [Instituto Nacional De Gestão De Calamidades (INGC), 2019; Hierink et al., 2020; Matos and Ndapassoa, 2020].

Studies addressing issues related to climatic events in Mozambique, such as cyclones and floods, mostly focus on health and nutrition, housing, and socioeconomic issues (Asante et al., 2009; Matos and Ndapassoa, 2020). Few studies bring the link between climate change in fisheries and aquaculture in Mozambique, except studies by Gammelsrød (1992) which shows the influence of environmental factors (rainfall) on the availability of shrimp fisheries at Sofala Bank, and by Hoguane et al. (2012) that relate rainfall to artisanal fishing on the tropical coast of northern Mozambique. Other studies highlights the consequences of climate change on both fisheries and aquaculture, creating problems for the sustainability of coastal communities (Blythe et al., 2014; Mucova et al., 2021), while other researchers point out that the quality of life of this communities reduces due to the negative impacts that climate change has on natural resources (Bunce et al., 2010; Techera, 2018). Hence, this study aimed to bring an understanding and characterization of the impacts caused by cyclones Idai and Kenneth on fisheries and aquaculture in the central provinces of Sofala and Zambézia in Mozambique. This brings an overview of the global impacts of the climate change in Mozambique channel and its influence on the artisanal fisheries and coastal community livelihoods. An appropriate understanding of the impacts of climate change is key to the development of appropriate measures for adopting and mitigating the impacts at both producer and policy formulation levels. Besides, the study will also fill the gaps in existing literature on the impacts of climate changing on the fisheries and Aquaculture by understanding the direct and indirect impacts of these two climatic events and also bring out aspects of resilience of fishing communities and aquaculture producers, vulnerabilities of coastal regions as well as the measures that must be taken to safeguard economic, environmental sustainability, and food security.

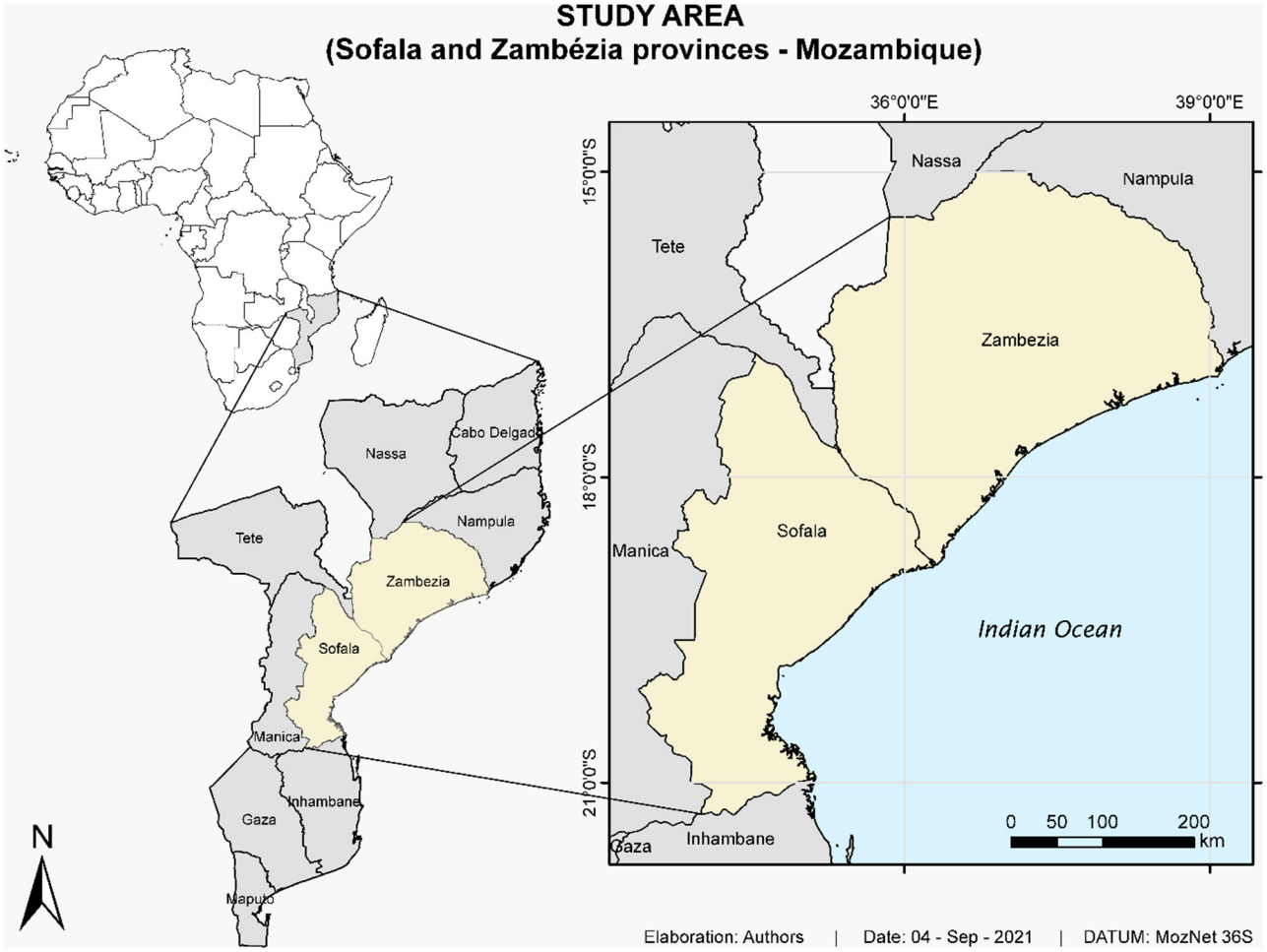

FIGURE 1 | Map showing the Province of Sofala and Zambezia and all the locations of the districts covered in the study. Source: Authors.

MATERIALS AND METHODS

Study Area

The data for this study were collected in March and April 2019 after cyclones Idai and Kenneth in the provinces of Sofala and Zambézia, both in the central zone of Mozambique (**Figure 1**). Mozambique is located in the southeast of the African continent. The country is ranked third among the most vulnerable nation from natural disasters, after Bangladesh and Ethiopia (Wheeler et al., 2007; Artur and Hilhorst, 2012). The study area comprises the two high vulnerable provinces of Mozambique, the province of Sofala and Zambezia. They are characterized by having a high level of exposure of costal climate hazard and cyclones (Niquisse et al., 2017). Although of high extension of vulnerability zone, the marine ecoregion and constaline of this two areas represents the main part of Sofala Bank (the largest fishing ground in Eastern Africa) (Charrua et al., 2020). In the last 20 years, among the biggest natural disasters (Floods, Droughts, Storms and Cyclones), Floods were the most frequent with more than 25 occurrences (49%) followed by severe storms, 15 occurrences (29%), period over 17 tropical cyclones occurred in Mozambique, with cyclone Idai and Kenneth being the most significant (EM-DAT, CRED/UCLouvain, 2020; Hierink et al., 2020). In 2000, the country experienced one of the greatest floods, in which it left more than 800 deaths, thousands of people displaced and several housing infrastructures destroyed (Artur and Hilhorst, 2012; EM-DAT, CRED/UCLouvain, 2020). Data published on disasters in Mozambique show that there is an increase in the frequency of occurrence and intensity of natural events such as cyclones, floods, and droughts in the country (Christie and Hanlon, 2001; Negrão, 2001; INGC and FEWS, 2003; Artur, 2013). Although natural disasters are cyclical in Mozambique, the construction of fisheries and aquaculture infrastructure still dominates in regions very close to the coast, creating conditions for vulnerability to disasters.

Study Design and Data Collection

The collected data was on impacts caused by cyclones Idai and Kenneth in the provinces of Sofala and Zambézia (**Figure 1**). Primary and secondary data were used, where the primary data consisted of field reports generated by the department of fisheries

and aquaculture after the events, and the secondary data were collected from qualified literature and information from different actors through non-structured interviewers (fishermen, fish farm managers) aquaculture production, and fisheries companies in the respective affected provinces. These group of information where taken separately and with specific question according to their action area (fishermen and aquacultures producers). The data was divided into three areas: Fisheries, Aquaculture, and vulnerability maps. In fisheries, the main issues that were addressed are related to direct impacts (loss or damage of vessels and engines, fishing gear, amount of fish lost) while for aquaculture, the direct impacts were: number of producers affected, production infrastructure (tanks, cages, and hatcheries) destroyed, lost fry, production area affected and lost production, while the indirect ones were difficulties in transporting inputs for aquaculture production and, damage of support infrastructures. Additionally, we used some fisheries report from the minister of Sea, Inland Waters and Fisheries in order to collect data of fisheries and aquaculture from previous years. Finally some relevant information was observed by the authors during field visits that consisted on the conversation with fishermen in some fishing centers regarding their vison of fisheries after the event and their challenges.

Data Analysis

The research data were characterized into quantitative and qualitative for analysis. In order to evaluate the impacts of the cyclone on the production and infrastructure of the fisheries and aquaculture, the data were grouped in Excel spreadsheets for the production of graphs and tables and Minitab version 16 statistical package was used for descriptive analysis, for later interpretation.

To understand the distribution of spatial patterns and affected areas, the data already included in excell, were imported into ArcGis to make the representation of data (losses of fingerlings, affected areas and destroyed tanks), so that it would provide a base of information to the government for possible prioritization of interventions in the recovery process. The equal class classification algorithm was also used to produce the thematic map, where the intervals were divided into equal sizes in order to emphasize the quantity of an attribute value in relation to the other values.

ArcGis was also used to prepare a global map of cyclone trajectories, a map of districts vulnerable to flooding and a hypsometric map. For the first two qualitative data referring to the shapefile format obtained from The Humanitarian Data Exchange portal were used, being represented in the form of a map. For the preparation of the hypsometric map, points quoted

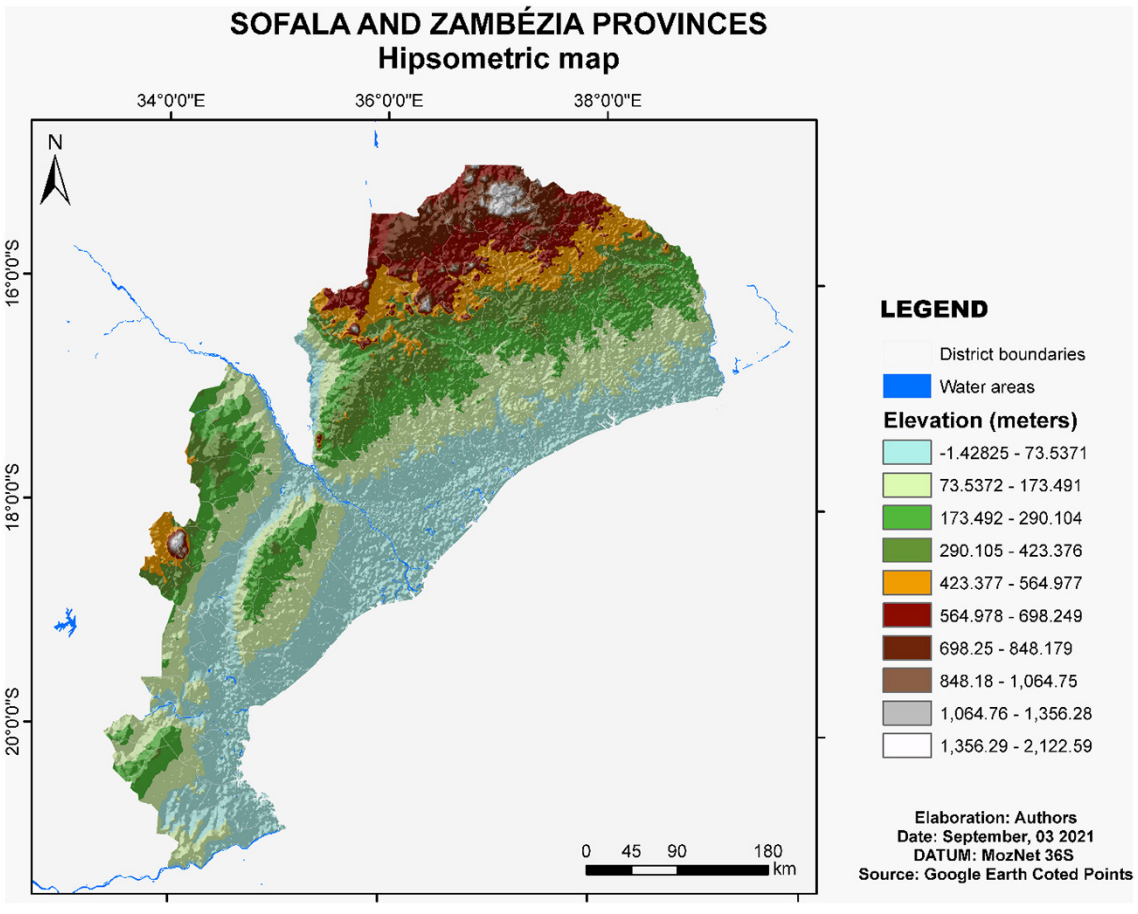

FIGURE 2 | Hypsometric map. Source: Authors.

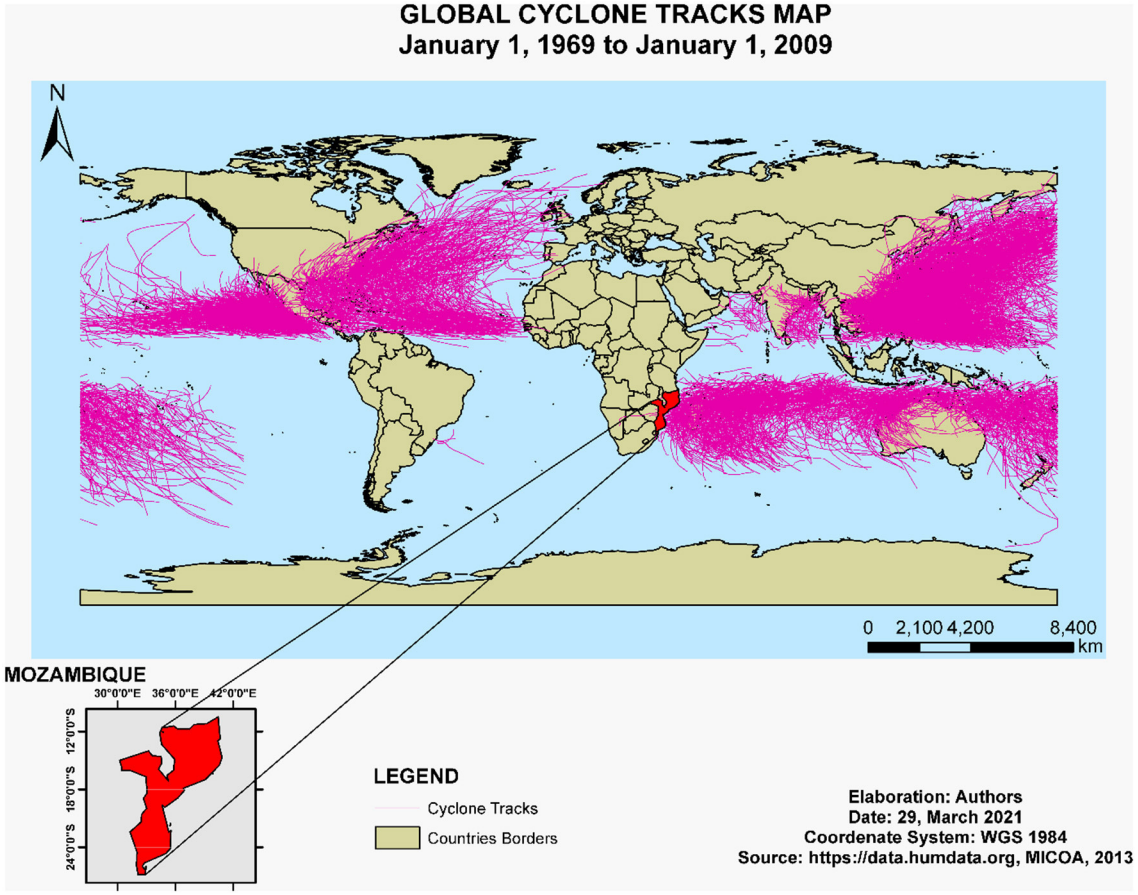

FIGURE 3 | Global cyclone tracks map. Source: Authors.

in google Earth were collected, which, after saved in KML format, were converted to GPX through the Online GPS Visualizer application and later converted in ArcGis to feature format and finally the Digital Elevation Model (MDE) was created.

RESULTS

Fishermen's Experiences Concerning Climate Change

The topographical location of Sofala and Zambezia are shown in **Figure 2**. Based on these locations, it appears that they are located in the coastal zone and predominantly of low altitude, with an extensive drainage network where three main rivers stand out, the Zambezi River and the Púnguè and Licungo River. Due to this characteristic of these regions, the occurrence of cyclones is usually accompanied by strong winds, tropical storms and rains followed by floods.

Conversations and information were collected in the post-cyclone field. Although many of the results presented here are directly linked to the impacts of cyclones, there is also information on what fishermen have observed over the years concerning, for example, the scarcity of fishing resources. During the conversations with fishermen, it was possible to observe that although they did not perceive the impacts of phenomena such as sea temperature rise, sea-level rise, changes in rainfall patterns, and changes in the salinity of the surface of the ocean, they were aware of the reduction in fisheries production over the years, alteration of places with fish abundance, disappearance or reduction of certain fish species and vulnerability of their regions.

TABLE 1 | Previous production (in tons) statistics in the two provinces in Mozambique affected by the cyclones (MIMAIP, 2020).

Province	Production	2017	2018	2019	
				Actual	Expected
Sofala	Fisheries (tons)	46.422	57.463	51.292	60.154
	Aquaculture (tons)	73.4	180	147	1,611
Zambezia	Fisheries (tons)	64.914	76.949	87.169	79.887
	Aquaculture (tons)	128.45	211	360	388

Vulnerability of Coastal Areas to Natural Disasters in Mozambique

Through the map (**Figure 3**), it can be seen that the trajectories of cyclones tend to form agglomerations, showing that these events have a defined spatial distribution and the Mozambique

TABLE 2a | Summary of impacts of cyclone Idai and Kenneth on the aquaculture sector in Sofala Province (a) and Zambézia (b).

Districts	No. of affected producers	Affected ponds	Affected cages**	Fry lost	Affected area		Production lost (Ton)
					Ponds (m^2)	Cages (m^3)	
Gorongosa	108	50	-	25,000	5,000	-	7,5
Muanza	24	2	-	5,000	1,000	-	1,5
Beira	2	1	50	141,000	1,800	340	42,3
Búzi	50	2	20	31,000	1,000	136	9,3
Dondo	116	-	56	-	-	380.8	-
Nhamatanda	4	3	40	47,500	600	272	14,25
Machanga	10	1	3	8,000	500	81.6	2,4
Total	314	59	169	257,500	9,900	1,210.40	77,25

***Cages were measured in cm^3.*

TABLE 2b |

Districts	Affected areas (m^2, ha)	Destroyed ponds	Fry lost
Dere	960	4	6,000
Gilé	7,200	24	36,000
Gurue	3,000	10	15,000
Ile	6,300	21	31,500
Inhassumge	3,825	7	10,500
Lugela	5,700	19	28,500
Maganja da Costa	900	3	4,500
Mocuba	7.6*	2 (Cages)	6,000
Morrumbala	900	3	4,500
Namacurra	8,100	8	32,000
Namaroi	3,300	11	16,500
Nicoadala	6,500	13	42,250
Nicoadala (Muziva)	13,900	33	350,000
Quelimane	4,550	13	22,750
Total	65,135**	171	606,000

***Total only for Ponds, *Cages were measured in cm^3.*

channel is covered by these agglomerations. This factor increases the risk for cyclone events that are generally characterized by strong winds and floods in this region. Among them, it is worth mentioning the cyclones Idai of category 2 in March 2019 and Kenneth of category 4 in April of the same year. The two cyclones caused widespread destruction, damage, and loss of human life besides affecting the fishing and aquaculture activities through destruction of infrastructures for production and the loss of fish and fish fry.

Fisheries and Aquaculture Production Statistics Before the Cyclones

The previous fish production statistics in tons by both fisheries and aquaculture in the two affected provinces of Mozambique as reported by the MIMAIP (2019) are shown in **Table 1**. As indicated, there was a steady increase in the production by fisheries and aquaculture in both Sofala and Zambezia provinces from 2017 to 2018. However, in 2019, the production by both fisheries and aquaculture decreased in both provinces, while an increase was observed in Zambezia for both production types. Furthermore, except for fisheries production in Zambezia, all the production quantities recorded in 2019 were less than what was projected. Surprisingly, the fisheries production in 2019 for Zambezia was more than the projected quantity.

Impacts on Aquaculture and Fisheries

In all the sampled areas, it was possible to verify that the indirect impacts were the most observed. In Sofala, where cyclones were more intense, 314 (34%) of producers were affected and the destruction of various production infrastructures including fry production facilities, in addition to 59 (12%) ponds and 169 (44%) floating cages (**Table 2a**). On the other hand, 74% of production was compromised due to the loss of more than 257,500 fry. The province of Zambézia, on the other hand, although it was not the epicenter of the cyclone, had a greater number of affected districts and, consequently, a greater affected area (**Figure 4**). The data show that 169 production ponds were partially or completely destroyed and 606,000 fry were lost (**Table 2b**).

DISCUSSION

Tropical cyclones are considered the most devastating of all-natural disasters given the level of destruction they cause to regions where they occur. In the case of the Mozambique channel, an anomalous eastern circulation associated with the Pacific La Ninã and hot SST in the southwest Indian Ocean were indicated as mechanisms that support repeated cyclogenesis of tropical cyclones (Chikoore et al., 2015). Thus, the vulnerability of coastal regions to floods (**Figure 5**) and storms is expected to increase with the future rise in sea level and the level of development along the coast, although this vulnerability also depends on the future characteristics of the storm (Knutson et al., 2010).

On the other hand, based on the topographic profile of the two provinces (**Figure 2**), it appears that they are located in the coastal zone and predominantly of low altitude, with an

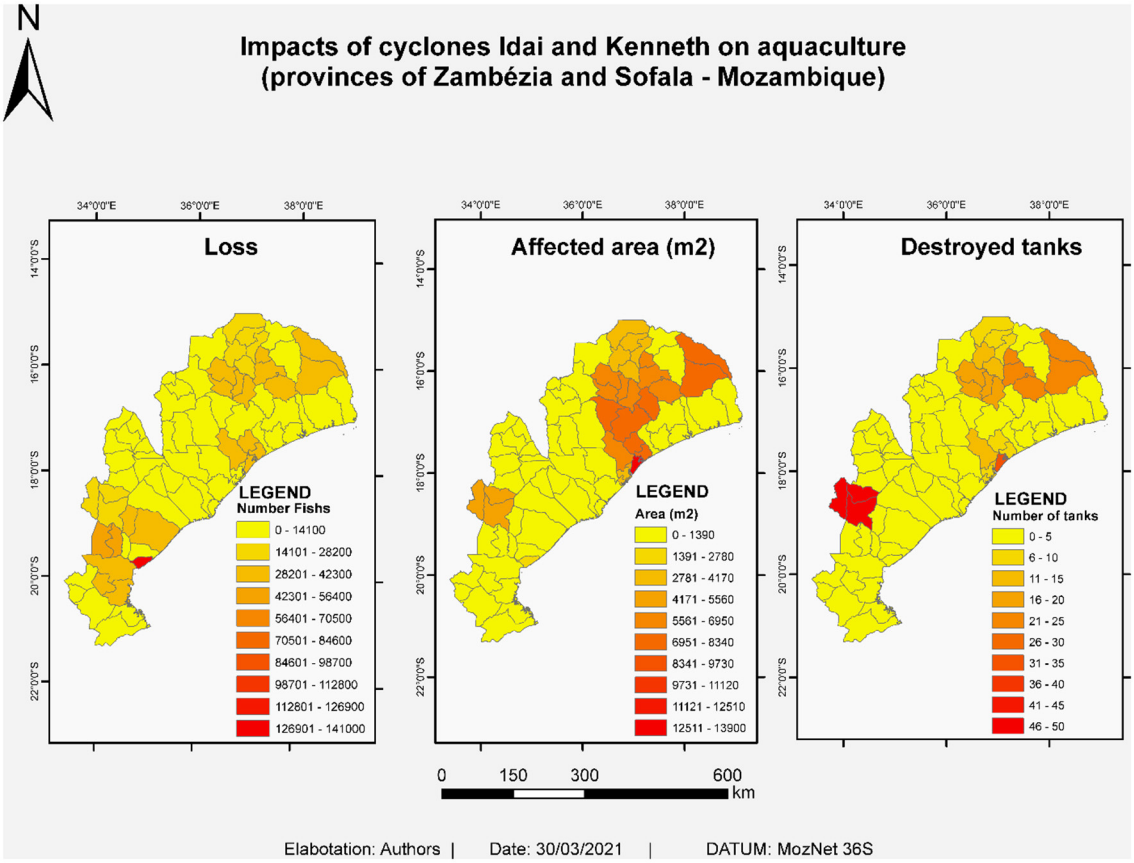

FIGURE 4 | Location of the impacted areas of the cyclones Idai and Kenneth in fisheries and aquaculture. Source: Author.

extensive drainage network where three main rivers stand out, the Zambezi River and the Púnguè and Licungo River. Due to this characteristic of these regions, the occurrence of cyclones is usually accompanied by strong winds, tropical storms and rains followed by floods.

It is therefore clear that the occurrence of cyclones is usually accompanied by flood events which leads to increasing the level of vulnerability and making the level of destruction to aquaculture infrastructure and loss of breeders and fry even greater. This vulnerability is expected to be further exacerbated by the effects of climate change, which are expected to cause the average sea level to rise to almost 1.0 m in 2100 due to global warming at 1.5°C, effects of tides, and tropical cyclones (Mavume et al., 2009; Aparecida de Araújo et al., 2020; Maulu et al., 2021).

Several impacts are associated with the occurrence of cyclones accompanied by floods which affect aquaculture and fisheries systems. Some of these include changes in aquaculture zoning, competition for space with coastal ecosystems providing defense services (i.e., mangroves), reduced freshwater availability, loss of areas such as mangroves and grassbeds that can protect coastal areas from waves, rising sea levels (Handisyde et al., 2014; Riddell and Rosendo, 2015). These impacts include increased infestation of fouling, organisms, pests, aquatic diseases, and changes in production levels (Handisyde et al., 2014; Maulu et al., 2021).

Generally, the impacts of climate change on fisheries and aquaculture are classified as direct and indirect impacts (Handisyde et al., 2006; De Silva and Soto, 2009; Maulu et al., 2021). Direct impacts are linked to the influence of physical and physiological factors that alter the fish stocks in a given production system, in the production of feed, and catches, as well as, influencing changes in species range and genetic variability. While indirect impacts affect the primary and secondary roads linked basically to the structure of production, prices of fishing inputs, production infrastructures, and all the services necessary for production to occur (De Silva and Soto, 2009; Knutsen et al., 2013; Freeman, 2017; Adhikari et al., 2018). The consequences of the climate Change is not restricted to fisheries and aquaculture. This events also causes effects on the coastal agriculture, maritime transportation and harbor damaging, as this area has been flooded and the adjacent area destroyed (Macassa et al., 2021; Montfort et al., 2021). Despite an overall increase in fish production even after the cyclones occurred, it was clear that the expected quantities based on several likely factors, such as the increase in the number producers as is often the case due to population increase. Therefore, climate change may not only decline the production in the fisheries and aquaculture sector but also decline the expected production.

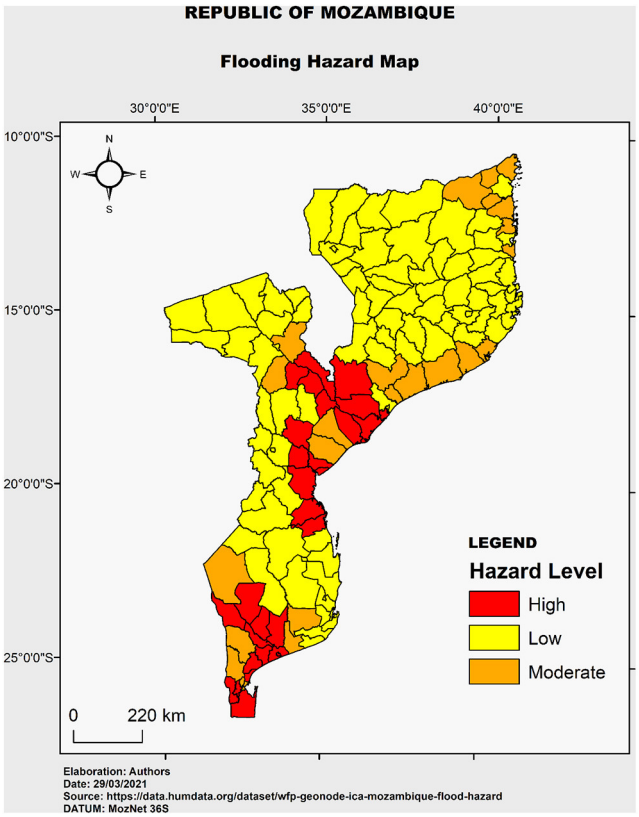

FIGURE 5 | Flooding hazard map. Source: Author.

TABLE 3 | Summary of the impacts of cyclones Idai and Kenneth in the province of Sofala.

Districts	Number of affected fishermen's	Boats affected	Fishing gear destroyed	Destroyed (Motors)	Fisheries lost (Ton)
Beira	372	362	-	37	789
Búzi	338	335	-	17	556
Dondo	350	328	-	-	478
Machanga	250	250	237	5	738
Cheringoma	240	240	-	-	189
Marromeu	202	197	-	-	356
Muanza	325	325	-	8	2,104
Total	2,007	2,037	237	67	5,210

In all the aspects analyzed, the province of Zambezia appeared to have had the greatest impact from cyclone due not only to the greater number of districts with aquaculture production initiatives but also with a greater number of production areas, that mainly small-scale for the livelihood of communities (Villasante et al., 2015; IDEPA Institute of Fisheries and Aquaculture Development, 2020; Muhala et al., 2021). Extreme climatic events such as cyclones, drought, and floods have increased dramatically in recent decades in Mozambique (EM-DAT, CRED/UCLouvain, 2020). Generally, these events have been accompanied by strong winds and heavy rains that lead to the destruction of aquaculture infrastructures. According to De Silva and Soto (2009), extreme events will continue to affect the tropical regions of the world, and coastal aquaculture will be most impacted. On the other hand, Rutkayova et al. (2017) and Maulu et al. (2020), claim that extreme events such as cyclones, floods, and storms, will negatively affect aquaculture production through loss of fish during the invasion of floodwaters in ponds, in addition to the introduction of new species that can create aquaculture unsustainability problems due to the entry of exotic species (Edwards, 2015). In addition, most production tanks in Mozambique are shallow and smaller in size, ranging from 150 to 300 m^2 on average (Companhia and Thorarensen, 2012; Muhala et al., 2021). This factor increases the vulnerability of the ponds to flooding mainly in the lower regions and the invasion of unwanted species [Intergovernmental Panel and Climate Change (IPCC), 2007; De Silva and Soto, 2009]. Some regions of Sofala and Zambezia were characterized by low-lying areas mainly due to the influence of several rivers such as Búzi, Púnguè, Zambezi, and Licungo, contributing to flooding in the surrounding areas during periods of extreme rain.

Most cage aquaculture production in tropical regions of Africa is carried out in lakes, reservoirs, and riverbeds (De Silva and Soto, 2009; Hasimuna et al., 2019; MIMAIP, 2019; Muhala et al., 2021). Cage production in Mozambique is an unremarkable activity. Although emerging, it does not escape the impacts of environmental changes, especially when there are extreme events such as storms and cyclones. In this study, 171 floating cages were affected by cyclones Idai and Kenneth in both provinces. Several studies show that cage aquaculture is the one that suffers the most mainly from mariculture, practiced in the open sea due to its vulnerability (De Silva and Soto, 2009; Maulu et al., 2021), contrary to what was observed in the present study. Edwards (2015), reported that aquaculture in cages on land also suffers the impacts of winds and cyclones, especially if the infrastructure is fragile.

Food security and sustainability from the ocean is a global challenge. Fisheries have been severely impacted by climate change (UN General Assembly, 2014). The central region of Mozambique comprises the most productive coastal oceanic area and covers the Sofala Bank which is the most productive fishing zone in the country where most communities depend on fishing for their livelihood (Hoguane et al., 2012; Darkey and Turatsinze, 2014). Artisanal fishing makes a significant contribution to the economic sustainability of local communities, reaching 70,000–100,000 fishermen and collectors who operate in coastal regions using small motorboats, wooden canoes, and a variety of fishing gear considered as trawls from the bottom, beach trawl, gillnets, handlines, traps and spears (Hoguane et al., 2002, 2012).

According to field observations and informants' testimonies, the effects of climate change were both direct and indirect. Indirect impacts, fishermen claim that they have noticed a decrease in catches and that variations in periods of rainfall and temperatures have influenced not only the type of resources available but also the quantity caught. Our findings were in

agreement with the report of Barange et al. (2018) who also noted that extreme events affectes not only infrastructure in the fisheries sector but also production quantities. Therefore, the impacts on the fisheries sector are not limited only to fishermen, but also to the sustainability and food security of the communities that depend on it (Blythe et al., 2014). The vulnerability of coastal communities in Mozambique is notable when a climatic event such as tropical storms and cyclones occur in the region. Mills et al. (2011) demonstrated that although there were other difficulties in the communities of Nigeria and Mali, they still suffered great vulnerability when it comes to fisheries. On the other hand, in some regions of the Sofala Bank, fishermen reported the scarcity of some species that were once abundant. These findings are not restricted to the Sofala bank alone (Barange and Perry, 2009; Brander, 2010; Lam et al., 2020). Regarding the impacts caused by the cyclones, our results revealed that besides the physiological and behavioral aspects described above, the fishing sector suffered high impacts and losses, having affected 2,700 fishermen including the destruction of 2,037 fishing vessels and 237 fishing gear (**Table 3**). Most of the affected fishermen belonged to the artisanal fisheries sector that makes up the majority of fishermen in Sofala Province. The fishing structure in Sofala is artisanal and consists of men and in some cases women who use surface trawls and catch crabs for subsistence (Darkey and Turatsinze, 2014). Motorboats and fishing canoes are the fishing vessel that was commonly used in Mozambique, particularly in the Sofala Bank region for capturing fishery resources (Mualeque and Santos, 2011; Blythe et al., 2014).

Furthermore, due to the precariousness of the materials used during manufacturing, these fishing vessels are destroyed when there are strong climatic events such as cyclones and storms allied to the drainage area that is not safe and without protection. The lack of timely communication of the occurrences of climatic events also leads to poor awareness and consequently negatively impacts fishing communities. Fishermen reported that during the cyclone, many vessels were moored on the edges of the beaches and some within the coastal part of the sea. These factors may have created conditions for them to suffer greater damage when the storms pass. According to Ramenzoni et al. (2020), the impacts of climatic events in the fisheries sector are varied, including changes in ecological conditions, acceleration of coastal zone degradation through soil entrainment, vegetation degradation. Our results agree with those reported by McConney et al. (2009), who identified the effects of climate change on small-scale fisheries in the eastern Caribbean where they indicated a negative biological response from fish when ocean temperatures changed due to climate change.

Challenges and Responses

Climate change and its effects pose challenges to everyone, especially developing countries where predictions of the occurrence of extreme events as a result of climate change have been made, and also the conditions for building resilient infrastructure are weak. Aquaculture production in Mozambique is mostly practiced by small producers and with low investment, needing a lot of help from the government and private sectors to implement it (Muhala et al., 2021). The same small investment scenario can be seen in the artisanal fisheries sector. The biggest challenges that are encountered include a lack of investments for the small-scale fisheries and aquaculture players, to enable them to acquire infrastructure and equipment that can withstand extreme events. On the other hand, poverty and lack of education in most of the actors contribute to the non-adaptation to the stresses caused by climatic events such as cyclones, floods, and storms (Blythe et al., 2014). The lack of education and other income-generating activities exacerbates the fishermen's dependence on fishing activities thereby creating additional pressure on the sector and declining fisheries.

On the other hand, the lack of adequate technical knowledge not only from fisheries and aquaculture actors but also from government and private sectors to create more appropriate measures to adapt to long-term climate change constitute an obstacle for small-scale artisanal fishing and aquaculture. Lack of knowledge for adaptation and monitoring have been reported as major constraints to reducing the impact of climate change on fisheries and aquaculture in Africa, mainly due to a lack of research and institutional development (Lam et al., 2012; Belhabib et al., 2016; Maulu et al., 2019; Samoilys et al., 2019). However, this is also likely to be worsened by the effects of extreme events through destruction on institutional capacity such as research and extension facilities.

CONCLUSIONS AND RECOMMENDATIONS

Climate change is expected to continue impacting Fisheries and Aquaculture as well as on those who depend on these sectors for their livelihoods. While there are efforts to map and show the diverse biological, ecological, and biophysical factors that climate change causes, there is a lack of a clear map to proceed with mediation and prevention when it comes to fisheries and aquaculture in Mozambique. Our study has revealed that the cyclones Idai and Kenneth affected part of aquaculture and fisheries production, leaving various infrastructures and equipment destroyed. Based on the findings of this study and the region's susceptibility, it can be concluded that the negative effects of cyclones will continue to occur and that the first issue that should be prioritized is promoting the adaptive capacity of communities that depend more on the fisheries sector for their survival. Therefore, there is a need to incorporate public policies for the comprehensive dissemination of timely information on the occurrence of climatic events to fishing and aquaculture communities so that preventive measures can be taken well in advance. Lastly, this study recommends that players in fisheries and aquaculture should build more resilient production systems to climate change, such as fish ponds, boats, and canoes.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The data can be found in the Ministry of Fisheries of Mozambique. Requests to access these datasets

should be directed to Ministry of Fisheries, Mozambique http://www.mimaip.gov.mz.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

The authors wish to thank the Ministry of the Sea, Inland Waters and Fisheries in Mozambique and the Provincial Department of Sofala and Zambezia who helped with relevant information for the study. Our special gratitude goes to the fishers and aquaculture companies who opened up and gave out all the information required for this research.

REFERENCES

Adhikari, S., Keshav, C. A., Barlaya, G., Rathod, R., Mandal, R. N., Ikmail, S., et al. (2018). Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India. *J. Fish. Sci.* 12, 16–21. doi: 10.21767/1307-234X.1000142

Ahmed, N., and Diana, J. S. (2015). Threatening "white gold": impacts of climate change on shrimp farming in coastal Bangladesh. *Ocean Coast. Manag.* 114, 42–52. doi: 10.1016/j.ocecoaman.2015.06.008

Allison, E. H., Adger, W. N., Badjeck, M. C., Brown, K., Conway, D., Dulvy, N. K., et al. (2005). *Effects of Climate Change on the Sustainability of Capture and Enhancement Fisheries Important to the Poor: Analysis of the Vulnerability and Adaptability of Fisherfolk Living in Poverty. Final Technical Report*. Food and Agriculture Organization, Rome, Italy.

Aparecida de Araújo, A., Chicombo, T. F., and Carneiro de Lima, J. (2020). Vulnerabilidade socioambiental: uma análise do ciclone Idai em Beira–Moçambique e suas implicações internacionais. *Int. Rev.* 17, 39–51. doi: 10.5752/P.1809-6182.2020v17n1p39-51

Arndt, C., Strzepeck, K., Tarp, F., Thurlow, J., Fant, C., and Wright, L. (2010). Adapting to climate change: an integrated biophysical and economic assessment for Mozambique. *Sustain. Sci.* 6, 7–20. doi: 10.1007/s11625-010-0118-9

Artur, L. (2013). "The political history of disaster management in Mozambique," in *Disaster, Conflict and Society in Crises* (Routledge), 54–73.

Artur, L., and Hilhorst, D. (2012). Everyday realities of climate change adaptation in Mozambique. *Global Environ. Change* 22, 529–536. doi: 10.1016/j.gloenvcha.2011.11.013

Asante, K., Brito, R., Brundrit, G., Epstein, P., Nussbaumer, P., and Patt, A. (2009). *Study on the Impact of Climate Change on Disaster Risk in Mozambique*. Maputo: National Institute for Disaster Management.

Ateweberhan, M., Feary, D. A., Keshavmurthy, S., Chen, A., Schleyer, M. H., and Sheppard, C. R. (2013). Climate change impacts on coral reefs: synergies with local effects, possibilities for acclimation, and management implications. *Mar. Pollut. Bull.* 74, 526–539. doi: 10.1016/j.marpolbul.2013.06.011

Badjeck, M. C., Allison, E. H., Halls, A. S., and Dulvy, N. K. (2010). Impacts of climate variability and change on fishery-based livelihoods. *Mar. Policy* 34, 375–383. doi: 10.1016/j.marpol.2009.08.007

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, A. L., Funge-Smith, S., and Paulain, F. (2018). *Impacts of Climate Change on Fisheries and Aquaculture, Synthesis of Current Knowledge, Adaptation and Mitigation Options.* Rome: FAO.

Barange, M., and Perry, R. I. (2009). Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. Climate change implications for fisheries and aquaculture.

Belhabib, D., Dridi, R., Padilla, A., Ang, M., and Le Billon, P. (2018). Impacts of anthropogenic and natural "extreme events" on global fisheries. *Fish Fish.* 19, 1092–1109. doi: 10.1111/faf.12314

Belhabib, D., Lam, V. W., and Cheung, W. W. (2016). Overview of West African fisheries under climate change: Impacts, vulnerabilities, and adaptive responses of the artisanal and industrial sectors. *Mar. Policy* 71, 15–28. doi: 10.1016/j.marpol.2016.05.009

Blanchard, J. L.,Watson, R. A., Fulton, E. A., Cottrell, R. S., Nash, K. L., Bryndum-Buchholz, A., et al. (2017). Linked sustainability challenges and trade-offs among fisheries, aquaculture and agriculture. *Nat. Ecol. Evol.* 1, 1240–1249. doi: 10.1038/s41559-017-0258-8

Blythe, J. L., Murray, G., and Flaherty, M. (2014). Strengthening threatened communities through adaptation: insights from coastal Mozambique. *Ecol. Soc.* 19:6. doi: 10.5751/ES-06408-190206

Brander, K. (2010). Impacts of climate change on fisheries. *J. Mar. Syst.* 79, 389–402. doi: 10.1016/j.jmarsys.2008.12.015

Bunce, M., Brown, K., and Rosendo, S. (2010). Policy misfits, climate change and cross-scale vulnerability in coastal Africa: how development projects undermine resilience. *Environ. Sci. Policy* 13, 485–497. doi: 10.1016/j.envsci.2010.06.003

Charrua, A. B., Bandeira, S. O., Catarino, S., Cabral, P., and Romeiras, M. M. (2020). Assessment of the vulnerability of coastal mangrove ecosystems in Mozambique. *Ocean Coast. Manag.* 189:105145. doi: 10.1016/j.ocecoaman.2020.105145

Chikoore, H., Vermeulen, J. H., and Jury, M. R. (2015). Tropical cyclones in the Mozambique Channel: January–March 2012. *Nat. Hazards* 77, 2081–2095. doi: 10.1007/s11069-015-1691-0

Christie, F., and Hanlon, J. (2001). *Mozambique and the Great Flood of 2000*. Bloomington, IN: Indiana University Press.

Companhia, J. M. S., and Thorarensen, H. (2012). *A Case Study of Small Scale Rural Aquaculture in Nampula Province, Mozambique. United Nations University.* Fisheries Training Programme, Iceland Final Project. Available online at: http://www.unuftp.is/static/fellows/document/jose11prf.pdf

Darkey, D., and Turatsinze, R. (2014). Artisanal Fishing in Beira, Central Mozambique. *J. Hum. Ecol.* 47, 317–328. doi: 10.1080/09709274.2014.11906766

Daw, T., Adger, W. N., Brown, K., and Badjeck, M. C. (2009). *Climate Change and Capture Fisheries: Potential Impacts, Adaptation and Mitigation*. Rome: FAO.

De Silva, S. S., and Soto, D. (2009). Climate change and aquaculture: potential impacts, adaptation and mitigation. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. *FAO Fish. Aquacult. Tech. Paper* 530, 151–212.

Edwards, P. (2015). Aquaculture environment interactions: past, present and likely future trends. *Aquaculture* 447, 2–14. doi: 10.1016/j.aquaculture.2015.02.001

EM-DAT, CRED/UCLouvain (2020). *www.emdat.be (D. Guha-Sapir)*. Available online at: https://www.emdat.be/emdat_atlas/sub_html_pages/sub_html_MOZ.html (accessed March 22, 2021).

FAO (2020). *The State of World Fisheries and Aquaculture 2020. Sustainability in Action.* Rome: FAO.

Freeman, E. O. (2017). Impact of climate change on aquaculture and fisheries in Nigeria: a review. *Int. J. Multidiscipl. Res. Dev.* 4, 53–59.

Gammelsrød, T. (1992). Variation in shrimp abundance on the Sofala Bank, Mozambique, and its relation to the Zambezi River runoff. *Estuar. Coast. Shelf Sci.* 35, 91–103. doi: 10.1016/S0272-7714(05)80058-7

Handisyde, N., Ross, L. G., Badjeck, M. C., Allison, E. H. (2014). *The Effects of Climate Change on World Aquaculture: A Global Perspective*. Available online at: https://www.researchgate.net/publication/265497647 (accessed April 12, 2021).

Handisyde, N. T., Ross, L. G., Badjeck, M. C., and Allison, E. H. (2006). *The Effects of Climate Change on World Aquaculture: A Global Perspective. Final Technical Report. Stirling: DFID Aquaculture and Fish Genetics Research Programme*. Stirling: Institute of Aquaculture.

Hasimuna, O. J., Maulu, S., Monde, C., Mweemba, M. (2019). Cage aquaculture production in Zambia: assessment of challenges and opportunities

in Lake, Kariba, Siavonga district, Egyp. *J. Aquat Res.* 45, 281–285. doi: 10.1016/j.ejar.2019.06.007

Hierink, F., Rodrigues, N., Muñiz, M., Panciera, R., and Ray, N. (2020). Modelling geographical accessibility to support disaster response and rehabilitation of a healthcare system: an impact analysis of Cyclones Idai and Kenneth in Mozambique. *BMJ Open* 10:e039138. doi: 10.1136/bmjopen-2020-039138

Hoguane, A. M., da Lucia Cuamba, E., and Gammelsrød, T. (2012). Influence of rainfall on tropical coastal artisanal fisheries a case study of Northern Mozambique. *J. Integr. Coast. Zone Manag.* 12, 477–482. doi: 10.5894/rgci338

Hoguane, A. M., Motta, H., Lopes, S., and Menete, Z. (2002). *Mozambique National Report on Integrated Problem Analysis. Development and Protection of the Coastal and Marine Environment in Sub-Saharan Africa". 125p, GEF MSP Sub-Saharan Africa Project (GF/6010-0016)*. Maputo: Não Publicado.

Hussein, I., de Fátima Alves, M., and Morgado, F. (2020). "Artisanal fishing and climate change: the case of Pemba, Mozambique," in *Climate Action. Encyclopedia of the UN Sustainable Development Goals*, eds W. Leal Filho, A. M. Azul, L. Brandli, P. G. Özuyar, T. Wall (Cham: Springer), 42–51.

IDEPA Institute of Fisheries and Aquaculture Development (2020). *The Strategy of Aquaculture Development*. Maputo: IDEPA.

INGC (2009). "Syntesis report," in *INGC Climate Change Report: Study on the Impacts of Climate Change on Disaster Risk in Mozambique*, eds B. van Logchem and R. Brito (INGC: Maputo).

INGC, U., and FEWS, N. M. (2003). *Atlas for Disaster Preparedness and Response in the Limpopo Basin*. Maputo: INGC.

Instituto Nacional De Gestão De Calamidades (INGC) (2019). *Balanço da época chuvosa e ciclônica 2018-2019*. Maputo: INGC.

Intergovernmental Panel and Climate Change (IPCC) (2007). "Summary for policymakers," in *Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (Cambridge; New York, NY: Cambridge University Press), 1–18.

Knutsen, H., Jorde, P. E., Gonzalez, E. B., Robalo, J., Albretsen, J., and Almada, V. (2013). Climate change and genetic structure of leading edge and rear end populations in a northwards shifting marine fish species, the corkwing wrasse (Symphodus melops). *PLoS ONE* 8:e67492. doi: 10.1371/journal.pone.006749

Knutson, T. R., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., et al. (2010). Tropical cyclones and climate change. *Nat. Geosci.* 3, 157–163. doi: 10.1038/ngeo779

Lam, V. W., Allison, E. H., Bell, J. D., Blythe, J., Cheung, W. W., Frölicher, T. L., et al. (2020). Climate change, tropical fisheries and prospects for sustainable development. *Nat. Rev. Earth Environ.* 1, 440–454. doi: 10.1038/s43017-020-0071-9

Lam, V. W., Cheung, W. W., Swartz, W., and Sumaila, U. R. (2012). Climate change impacts on fisheries in West Africa: implications for economic, food and nutritional security. *Afr. J. Mar. Sci.* 34, 103–117. doi: 10.2989/1814232X.2012.673294

Macassa, G., Militao, E., and Francisco, J. D. C. (2021). Is climate change contributing to food insecurity and poor health outcomes in mozambique? *Austin J Public Health Epidemiol.* 8:1092. doi: 10.26420/AustinJPublicHealthEpidemiol.2021.1092

Malauene, B. S., Lett, C., Marsac, F., Roberts, M. J., Brito, A., Abdula, S., et al. (2021). Spawning areas of two shallow-water penaeid shrimps (Penaeus indicus and Metapenaeus monoceros) on the Sofala Bank, Mozambique. *Estuar. Coast. Shelf Sci.* 253:107268. doi: 10.1016/j.ecss.2021.107268

Matos, P. A., and Ndapassoa, A. M. (2020). o ciclone idai e os desafios da ajuda humanitária em moçambique. *Paths Law Environ. Law Sustain. Dev.* 17, 167–188. doi: 10.18623/rvd.v17i38.1819

Maulu, S., Hasimuna, O. J., Haambiya, L. H., Monde, C., Musuka, C. G., Makorwa, T. H., et al. (2021). Climate change effects on aquaculture production: sustainability implications, mitigation, and adaptations. *Front. Sustain. Food Syst.* 5:609097. doi: 10.3389/fsufs.2021.609097

Maulu, S., Hasimuna, O. J., Monde, C., and Mweemba, M. (2020). An assessment of post-harvest fish losses and preservation practices in Siavonga district, Southern, Zambia. *Fish Aquat. Sci.* 23:25. doi: 10.1186/s41240-020-00170-x

Maulu, S., Munganga, B. P., Hasimuna, O. J., Haambiya, L. H., and Seemani, B. (2019). A review of the science and technology developments in Zambia's aquaculture industry. *J. Aquac. Res. Dev.* 10:567.

Mavume, A. F., Rydberg, L., Rouault, M., and Lutjeharms, J. R. (2009). Climatology and landfall of tropical cyclones in the south-west Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 8, 15–36. doi: 10.4314/wiojms.v8i1.56672

McConney, P., Nurse, L., and James, P. (2009). *Impacts of Climate Change on Small-Scale Fisheries in the Eastern Caribbean: A Final Report to IUCN*. Centre for Resource Management and Environmental Studies, Wanstead, Barbados.

Mendenhall, E., Hendrix, C., Nyman, E., Roberts, P. M., Hoopes, J. R., Watson, J. R., et al. (2020). Climate change increases the risk of fisheries conflict. *Mar. Policy* 117:103954. doi: 10.1016/j.marpol.2020.103954

Mills, D., Béné, C., Ovie, S., Tafida, A., Sinaba, F., Kodio, A., et al. (2011). Vulnerability in African small-scale fishing communities. *J. Int. Dev.* 23, 308–313. doi: 10.1002/jid.1638

MIMAIP (2019). *Proposal of the Economic and Social Plan 2019*. Available online at: http://www.mimaip.gov.mz/wp-content/uploads/2020/09/PES-2019.pdf (accessed September 15, 2021).

MIMAIP (2020). *Balance of the Economic and Social Plan for January-December 2019*. Available online at: http://www.mimaip.gov.mz/wp-content/uploads/2020/10/Balanco_2019.pdf (accessed September 15, 2021).

Montfort, F., Bégué, A., Leroux, L., Blanc, L., Gond, V., Cambule, A. H., et al. (2021). From land productivity trends to land degradation assessment in Mozambique: effects of climate, human activities and stakeholder definitions. *Land Degrad. Dev.* 32, 49–65. doi: 10.1002/ldr.3704

Mualeque, D., and Santos, J. (2011). Biology, fisheries and distribution of *Thryssa vitrirostris* (Gilchrist and Thompson 1908) and other Engraulidae along the coast of the Sofala Bank, western Indian Ocean. *Afr. J. Mar. Sci.* 33, 127–137. doi: 10.2989/1814232X.2011.575108

Mucova, S. A. R., Azeiteiro, U. M., Lopes, C. L., Dias, J. M., and Pereira, M. J. (2021). Approaching Sea-Level Rise (SLR) change: strengthening local responses to sea-level rise and coping with climate change in Northern Mozambique. *J. Mar. Sci. Eng.* 9:205. doi: 10.3390/jmse9020205

Muhala, V., Rumieque, A., and Hasimuna, O. J. (2021). Aquaculture production in Mozambique: approaches and practices by farmers in Gaza province. *Egypt. J. Aquat. Res.* 47, 87–92. doi: 10.1016/j.ejar.2020.11.004

Munday, P. L., Jones, G. P., Pratchett, M. S., and Williams, A. J. (2008). Climate change and the future for coral reef fishes. *Fish Fish.* 9, 261–285. doi: 10.1111/j.1467-2979.2008.00281.x

Naess, L. O., Newell, P., Newsham, A., Phillips, J., Quan, J., and Tanner, T. (2015). Climate policy meets national development contexts: insights from Kenya and Mozambique. *Global Environ. Change* 35, 534–544. doi: 10.1016/j.gloenvcha.2015.08.015

Negrão, J. (2001). *O Impacto Socioeconómico das Cheias. Oração de Sapiência por Ocasião da Abertura do Ano Lectivo 2001–2002*. Maputo.

Niquisse, S., Cabral, P., Rodrigues, Â., and Augusto, G. (2017). Ecosystem services and biodiversity trends in Mozambique as a consequence of land cover change. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* 13, 297–311. doi: 10.1080/21513732.2017.1349836

O'Reilly, C. M., Alin, S. R., Plisnier, P. D., Cohen, A. S., and McKee, B. A. (2003). Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature* 424, 766–768. doi: 10.1038/nature01833

Palacios-Abrantes, J., Sumaila, U. R., and Cheung, W. (2020). Challenges to transboundary fisheries management in North America under climate change. *Ecol. Soc.* 25:41. doi: 10.5751/ES-11743-250441

Pratchett, M. S., Munday, P. L., Wilson, S. K., Graham, N. A., Cinner, J. E., Bellwood, D. R., et al. (2008). Effects of climate-induced coral bleaching on coral-reef fishes—ecological and economic consequences. *Oceanogr. Mar. Biol.* 46, 257–302. doi: 10.1201/9781420065756.ch6

Ramenzoni, V. C., Borroto Escuela, D., Rangel Rivero, A., González-Díaz, P., Vázquez Sánchez, V., López-Castañeda, L., et al. (2020). Vulnerability of fishery-based livelihoods to extreme events: local perceptions of damages from Hurricane Irma and Tropical Storm Alberto in Yaguajay, Central Cuba. *Coast. Manag.* 48, 354–377. doi: 10.1080/08920753.2020.1802198

Rezaee, S., Pelot, R., and Finnis, J. (2016). The effect of extratropical cyclone weather conditions on fishing vessel incidents' severity level in Atlantic Canada. *Saf. Sci.* 85, 33–40. doi: 10.1016/j.ssci.2015.12.006

Riddell, M., and Rosendo, S. (2015). *Climate vulnerability and capacity analysis (CVCA), Report to WWF-Mozambique 84*. Quirimbas National Park, Cabo Delgado, Mozambique.

Rutkayova, J., Vácha, F., Maršálek, M., Beneš, K., Civišová, H., Horká, P., et al. (2017). Fish stock losses due to extreme floods-findings from pond based aquaculture in the Czech Republic. *J. Flood Risk Manage.* 11, 351–359. doi: 10.1111/jfr3.12332

Samoilys, M. A., Osuka, K., Mussa, J., Rosendo, S., Riddell, M., Diade, M., et al. (2019). An integrated assessment of coastal fisheries in Mozambique for conservation planning. *Ocean Coast. Manag.* 182:104924. doi: 10.1016/j.ocecoaman.2019.104924

Techera, E. (2018). Supporting blue economy agenda: fisheries, food security and climate change in the Indian Ocean. *J. Indian Ocean Reg.* 14, 7–27. doi: 10.1080/19480881.2017.1420579

Troell, M., Eide, A., Isaksen, J., Hermansen, Ø., and Crépin, A. S. (2017). Seafood from the changing Arctic. *Ambio* 46, S368–S386. doi: 10.1007/s13280-017-0954-2

UN General Assembly (2014). *Report of the Secretary-General Oceans and the Law of the Sea (UN Doc A/69/71)*. Available online at: https://sustainabledevelopment.un.org/content/documents/12504DOALOS_A_69_71_role%20of%20seafood%20in%20food%20security.pdf

Villasante, S., Rodríguez, S. R., Molares, Y., Martínez, M., Remiro, J., García-Díez, C., et al. (2015). Are provisioning ecosystem services from rural aquaculture contributing to reduce hunger in Africa? *Ecosyst. Serv.* 16, 365–377. doi: 10.1016/j.ecoser.2015.07.003

Vollmer, M. K., Bootsma, H. A., Hecky, R. E., Patterson, G., Halfman, J. D., Edmond, J. M., et al. (2005). Deep-water warming trend in Lake Malawi, East Africa. *Limnol. Oceanogr.* 50, 727–732. doi: 10.4319/lo.2005.50.2.0727

Wheeler, D., That, T. T., Meisner, C., Deichmann, U., and Buys, P. (2007). *Country Stakes in Climate Change Negotiations: Two Dimensions of Vulnerability*. Washington, DC: The World Bank.

Whitney, C., Frid, A., Edgar, B., Walkus, J., Siwallace, P., Siwallace, I., et al. (2020). "Like the plains people losing the buffalo": perceptions of climate change impacts, fisheries management, and adaptation actions by Indigenous peoples in coastal British Columbia, Canada. *Ecol. Soc.* 25:33. doi: 10.5751/ES-12027-250433

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.