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KENYA Aquatica

A Scientific Journal of Kenya Marine and Fisheries Research Institute

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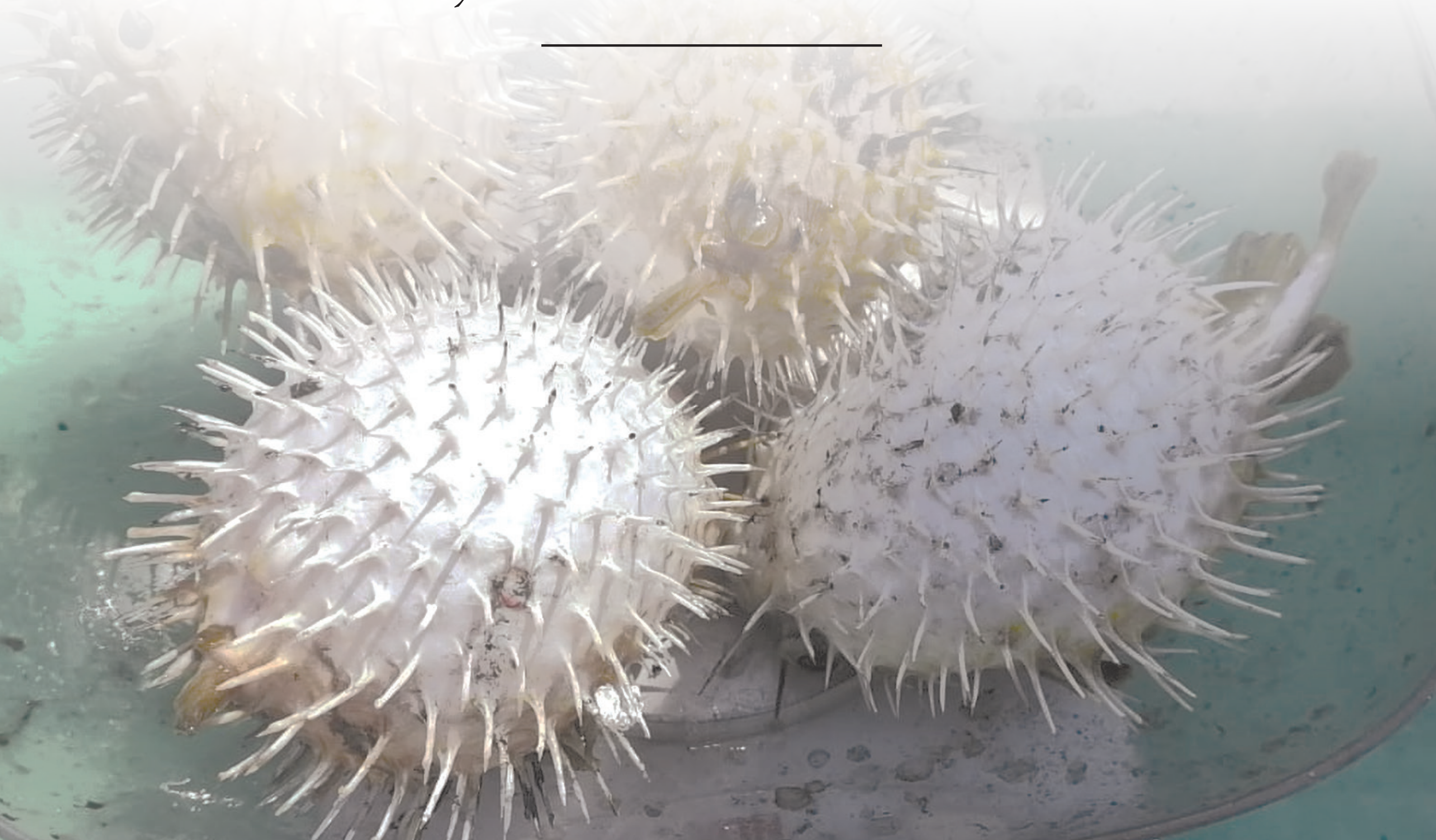

Editorial

Preparation and production of the current Kenya Aquatica Volume 8(1) was supported by the Western Indian Ocean Marine Science Association (WIOMSA), through the Marine and Coastal Science for Management (MASMA) programme.

The Chief Editor, the Editorial Board and the management of Kenya Marine and Fisheries Research Institute (KMFRI) – *the home of Kenya Aquatica*, sincerely thank WIOMSA and MASMA for the generous support and continued collaboration.

The current Volume covers outputs from research conducted in the Indian Ocean coast, lacustrine and riverine environments of Kenya. In the coastal environment, one paper presents preliminary assessment of post-harvest fish losses in Kwale and another the rapid assessment of the Indian mackerel. One lacustrine based paper profiles pesticide concentrations on Lake Victoria. In the aquaculture domain, one paper presents results on the growth performance of marine tilapia cultured in *hapa* nets, while the other demonstrates the potential of culturing eucheumoid seaweeds in deep waters.

The final paper describes the effect of the COVID-19 pandemic on slum dwellers living adjacent to Lake Victoria, while a short communication relates the alarming incidences of pufferfish in the Lamu seascape to possible imbalances in the marine ecosystem.

The Editorial Board acknowledges all the reviewers of the manuscripts. They include Mr. Collins Ongore of University of St. Andrews in the United Kingdom, Dr. Flower Msuya of the Institute of Marine Sciences of the University of Dar-es-Salaam (IMS/UDSM) in Zanzibar, Tanzania, Mr. Johnstone Omukoto of Lancaster University in the United Kingdom, Prof. Saeed Mwaguni and Dr. Cosmas Munga both of the Technical University of Mombasa (TUM), Prof. Bernerd Fulanda of Pwani University (PU) in Kilifi and Prof. Kaunda Arara of University of Eldoret (UoE).

KMFRI-affiliated researchers assisted immensely in the review and evaluation of the manuscripts at various stages: Dr. Mary Opiyo, Ms. Veronica Ombwa, Dr. Levi Otwoma, Mr. Boaz Ohowa, Dr. Joseph Kamau, Ms Linette Keteresi, Dr. Esther Fondo, Ms Veronica Wanjeri, Dr. Esther Wairimu, Mr. Kenneth Werimo, Dr. Cyprian Odoli, Ms Sarah Ater, Dr. Kevin Obiero and Dr. David Mirera. The quality of the resubmitted manuscripts following initial evaluation were substantially improved due to the critical assessment and input from reviewers.

About Kenya Aquatica

Kenya Aquatica is the Scientific Journal of the Kenya Marine and Fisheries Research Institute (KMFRI). The Aim of the Journal is to provide an avenue for KMFRI researchers and partners to disseminate knowledge generated from research conducted in the aquatic environment of Kenya and resources therein and adjacent to it. This is in line with KMFRI's mandate to undertake research in marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography.

Manuscripts may be submitted to the Chief Editor through aquatica@kmfri.go.ke

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Featured cover picture Sample of Porcupine fish bycatch from Lamu, Kenya (Source: Almubarak Athman)

Contents

A preliminary assessment of the post-harvest fish losses along selected fish supply chains in Kwale County, Kenya

Josephine Marigu[1]*, Peter Oduor-Odote[1], Cyprian Odoli[2], Raymond Ruwa[1], Rael Achieng'[1], Maurice Omega[1]

[1]Kenya Marine and Fisheries Research Institute, P.O Box 81651 – 80100 Mombasa, Kenya

[2]Kenya Marine and Fisheries Research Institute, Kisume Centre P.O. Box 1881-40100, Kisumu, Kenya

*Corresponding author: marigujosehine@gmail.com, (+254) 0 714 317377

Abstract

Artisanal marine fisheries play a critical role in enhancing food security and supporting the livelihoods of Coastal communities in Kenya. The sustainable exploitation of this resource is however threatened by post-harvest fish losses (PHFLs) occurring along the entire fish value chain. We conducted an assessment of the PHFLs at five landing sites in Kwale County to investigate the status of these losses along selected fish supply chains in the County. The Informal Fish Loss Assessment Method (IFLAM) and Questionnaire Loss Assessment Method (QLAM) were used to collect data from key informants and value chain actors operating at the landing sites. Sixty-five percent of the respondents reported having experienced PHFLs with the highest scale of loss at 34% and 15% being reported in Mkunguni and Jimbo landing sites, respectively. The fishing and marketing nodes of the fish value chains represented points at which the highest losses were encountered at 28% and 17%, respectively. The inadequacy of preservation infrastructure at the landing sites and the lack of preservation during fishing were the main factors contributing to the PHFLs. Provision of cold chain facilities, adequate drying racks and capacity building on fish handling are recommended as priority interventions to reduce the PHFLs.

Keywords: fish preservation, mitigation, fish spoilage, coast, artisanal fisheries

Introduction

Fisheries exploitation contributes significantly towards food and nutritional security, revenue generation and poverty alleviation (Mavuru *et al.*, 2022). Artisanal fisherfolk and local coastal communities rely heavily on fisheries for food provision and livelihood support (Purcell and Pomeroy, 2015). Globally, artisanal fisheries directly support 60 million livelihoods and contribute approximately 50% of fish consumed in developing countries (Tilley *et al.*, 2021). Small-scale marine fisheries in Kenya directly support above 60,000 coastal households and account for 6% of the coastal economy (Nyawade *et al.*, 2021). The sustainable exploitation of artisanal fisheries, therefore, has the potential to contribute towards socioeconomic stability through the provision of food for subsistence and income generation (Kimani *et al.*, 2018).

Fish is a highly nutritious source of animal protein, vitamins, fatty acids and minerals (FAO, 2020); and thus represents an affordable source of nutrition for low-income communities (Adewolu and Adoti, 2010). Fish is, however, a highly perishable commodity, prone to rapid spoilage induced by post-moterm microbial and biochemical activity which results in post-harvest fish losses (PHFLs) (Akande and Diei-Ouadi, 2010;

Ikape and Cheikyula, 2017). The Food and Agriculture Organization of the United Nations (FAO) defines PHFL as fish that is either discarded or sold at a relatively low price because of quality deterioration or owing to market dynamics (Wood, 1984). Morrissey (1988) defines the term post-harvest as the period of time from when a fish is separated from its growth medium; including the time a fish enters a net, is caught on a hook or in a trap. There are three main means of PHFLs, i.e., physical, quality and market force loss. Physical losses refer to fish which is discarded or eaten by insects while quality losses occur due to microbial/ biochemical/ structural changes which result in the reduction of the market value of the fish. Market force loss is caused by changes in supply and demand dynamics resulting in fish fetching a low revenue despite being of good quality (Ward and Jeffries, 2000).

The inherent high perishability of fish relegates the fisheries industry to comparatively higher post-harvest food losses which are generally estimated at 14% globally across all agricultural sectors (Tesfay and Teferi, 2017). It is estimated that artisanal fisherfolk in low and middle-income countries experience PHFLs of approximately 40% owing to poor fish handling practices and limited preservation infrastructure along the fish value chains (Prodhan *et al.*, 2022). Owing to its high perishability, preservation of the fish is imperative immediately after catch to limit microbial growth and slow down enzymatic activities which are the main drivers of fish spoilage. Temperature control is one of the most effective preservation ways to retard the spoilage of fresh fish throughout the value chain (Tesfay and Teferi, 2017).

Accurate quantification of PHFLs occurring along the artisanal fish value chain (fishing, processing, distribution and sale) is crucial to enhance accurate identification of the main factors contributing to the losses and inform the development of suitable mitigation measures (Ward and Jeffries, 2000). The dispersed nature of artisanal fisheries and the dynamic nature of the fish value chain necessitate the combination of different methods to assess all factors contributing to the three types of losses encountered. This study focuses on the determination of the scale of postharvest losses encountered in Kwale County, based on a case study conducted at 5 landing sites i.e., Jasini, Jimbo, Shimoni, Mkunguni, and Gazi. The assessment was implemented based on two methods as proposed by FAO i.e., Informal Fish Loss Assessment Method (IFLAM) and Questionnaire Loss Assessment Method (QLAM) (Diei-Ouadi and Mgawe, 2011). The IFLAM is an informal method based on participatory rural appraisal (PRA) principles while QLAM relies on interviewing a population sample in a community or geographical area using a questionnaire to validate data generated by the IFLAM. The objective of the study was to conduct a preliminary quantification of the postharvest losses across the selected fish value chains and propose suitable measures towards the reduction of these postharvest losses.

Materials and methods

Study area

The study was conducted in Kwale County, which is located in the South of the 640 km long Coast of Kenya (Kimani *et al.*, 2018). Five (5) landing sites i.e. Jasini, Jimbo, Mkunguni, Shimoni and Gazi were selected to represent the main fisheries and variations of catch volumes. Artisanal fisherfolk at Jasini and Jimbo predominantly land and process sardines while at Shimoni and Mkunguni, mixed reef fin fish dominate the catches. The catch landed at Gazi landing site constitutes a combination of both. Seasonal North East and South East Monsoon winds have a major influence on the patterns of fisheries exploitation with the former season which occurs from September to April being characterized by comparatively higher catches (Johnson *et al.*, 1982)

Study design

The study was conducted using a combination of two post-harvest loss assessment methods as recommended by FAO (Diei-Ouadi and Mgawe, 2011), with both methods relying predominantly on qualitative data collection techniques through questionnaire administration and observation.

Informal Fish Loss Assessment Method (IFLAM)

The IFLAM phase reconnaissance visits to the five (5) landing sites were conducted followed by detailed interviews using semi-structured key informant interview guides (Appendix 1) administered to key informants i.e. selected leaders of the respective Beach Management Unit (BMUs). The key informants provided information on the status of the respective landing sites in terms of gear types, catch volumes, main species landed and post-harvest dynamics including the number of value chain actors, fish handling activities, the approximate scale of post-harvest losses and measures implemented to reduce the losses. The provided information was subsequently validated through the use of pre-formulated observation guides to assess the activities conducted at the landing sites by the fish value chain actors. The main sources of post-harvest losses as well as assess the status of the infrastructure at the sites were noted.

Questionnaire Loss Assessment Method (QLAM)

Semi-structured questionnaires (Appendix 2) were designed and administered to a sample of respondents from each landing site (n = 30) to obtain detailed information on their experiences including the volume and type of fish handled, fish preservation and processing techniques and scale of post-harvest losses encountered. The selection of the respondents was based on a purposive sampling technique. Each sample contained representatives of the main actors involved in the fish value chain i.e. fishermen, fish processors and fish traders. The questions were administered to each respondent as descriptively as possible to enable the respondents to differentiate the types of losses occurring along the supply chain.

Data entry and analyses

All data from the questionnaires was converted into electronic form by entry into MS Excel spreadsheets. Open-ended responses were pre-analysed and coded based on the main themes identified. The datasets were then subjected to cleaning and harmonization. Data analysis was conducted using MS Excel and mainly involved descriptive statistics, summaries such as percentages and generation of graphical illustrations.

Results and discussion

Fishing and fish handling infrastructure based on the IFLAM

During the IFLAM phase of the survey, it was reported and observed that majority of the artisanal fishermen at the landing sites use traditional wooden fishing vessels such as dugout canoes, outrigger canoes, sailboats and dhows (Table 1), with a carrying capacity of 2 to 20 crew depending on the size of the vessel; which was largely determined by the target fishery as highlighted by Nyawade *et al*. (2021).

The key informants interviewed during the IFLAM phase reported that fisherfolk targetting reef finfish used smaller vessels while vessels used to exploit the sardine fishery and offshore fisheries were larger with outboard engines. 89% of the reported 450 fishing vessels were unmotorized; contributing significantly to long delays during transit to and from the fishing grounds. A variety of fishing gear was used at all the landing sites depending on the target fisheries. These included handlines, gill nets, reef nets, barricades, basket traps, monofilaments, seine nets and longlines and spear guns. Basket traps and ring nets were the most commonly used at the 5 landing sites (Table 1). The type of gear and fishing vessels used by artisanal fisherfolk have been reported to contribute to the significant losses encountered in small-scale fisheries in developing, tropical countries (Mavuru *et al*., 2022; Mramba and Mkude, 2022). Infrastructural insufficiencies were observed particularly in the preservation and processing functions at the landing sites; resulting in lack of/ inefficient fish preservation (particularly icing of harvested fish) and/or use of unconventional and/or traditional processing techniques which exposed the harvest to conditions favouring rapid spoil-

Table 1. Status of key fishing and fish handling infrastructure at the selected landing sites as identified during the Informal Fish Loss Assessment Method (IFLAM) phase.

Category	Types	Landing Sites					
		Jasini	Jimbo	Shimoni	Gazi	Mkunguni	Total
Fishing Vessels	Fibre boat	0	0	18	5	3	26
	Mtumbwi	1	6	70	25	79	181
	Ngalawa	1	0	1	4	20	207
	Mashua	10	0	8	0	1	19
	Hori	0	17	0	0	0	17
	Total	**12**	**23**	**97**	**34**	**103**	**448**
	Motorized (No.)	***10***	***6***	***27***	***5***	***4***	***52***
	Motorized (%)	***83%***	***26%***	***28%***	***15%***	***4%***	***11%***
Fishing Gear	Basket traps	✓	✓	✓	✓	✓	5 landing sites
	Handlines		✓	✓	✓	✓	4 landing sites
	Longlines		✓	✓	✓		3 landing sites
	Ringnets	✓	✓	✓	✓	✓	5 landing sites
	Gillnets			✓	✓	✓	3 landing sites
	Baricades		✓	✓			2 landing sites
	Hook & stick		✓	✓	✓	✓	4 landing sites
	Reef seine		✓	✓	✓	✓	4 landing sites
	Monifilament			✓			1 landing site
	Main gear	***Ringnets***	***Ringnets***	***B. traps***	***B. traps***	***B. traps***	
		B. traps	***B. traps***	***Gillnets***	***Ringnets***	***Hand lines***	
Infrastructure	Cooler boxes	X	NS		X	X	
	Ice (Flakes/ Blocks)	X	X	✓	X	X	
	Freezers	X	NS	✓	NW	✓	
	Ice flaking machine	X	X	NW	X	X	
	Potable water	✓	✓	✓	✓	✓	
	Raised drying racks	X	NS	X	NS	X	
	Toilets	X		✓	✓	✓	
	Status	***NS***	***NS***	***NS***	***NS***	***NS***	

Key: NS = Not Sufficient; NW = Not Working; X = Not Present; ✓ = Yes/ Present

age such as high temperatures. Similar results have been reported in studies on post-harvest fish losses occurring along fish value chains (Tesfay and Teferi, 2017; Kimani *et al.*, 2018; Keerthana *et al.*, 2022).

Value chain activities identified based on the IFLAM

A variety of activities were performed by specific value chain actors based at the landing sites i.e. fisherfolk, traders, and processors (Figure 1) were observed and explained in detail by the key informants during the IFLAM phase. From the observations made, 3 main value chains i.e. fresh, fried, and dried fish value chains were identified and scrutinized to understand the stages involved. Fishermen and fresh fish traders were mainly involved in handling the fresh fish. The UN-FAO strongly recommends the chilling of fish immediately after harvest to mitigate spoilage (Shawyer and Medina, 2003). However, in the present study, it was reported that none of the fishermen at the five landing sites preserve their catch using ice. Rather, they rely on timing their fishing activities based on experience to approximate the time that they would require to

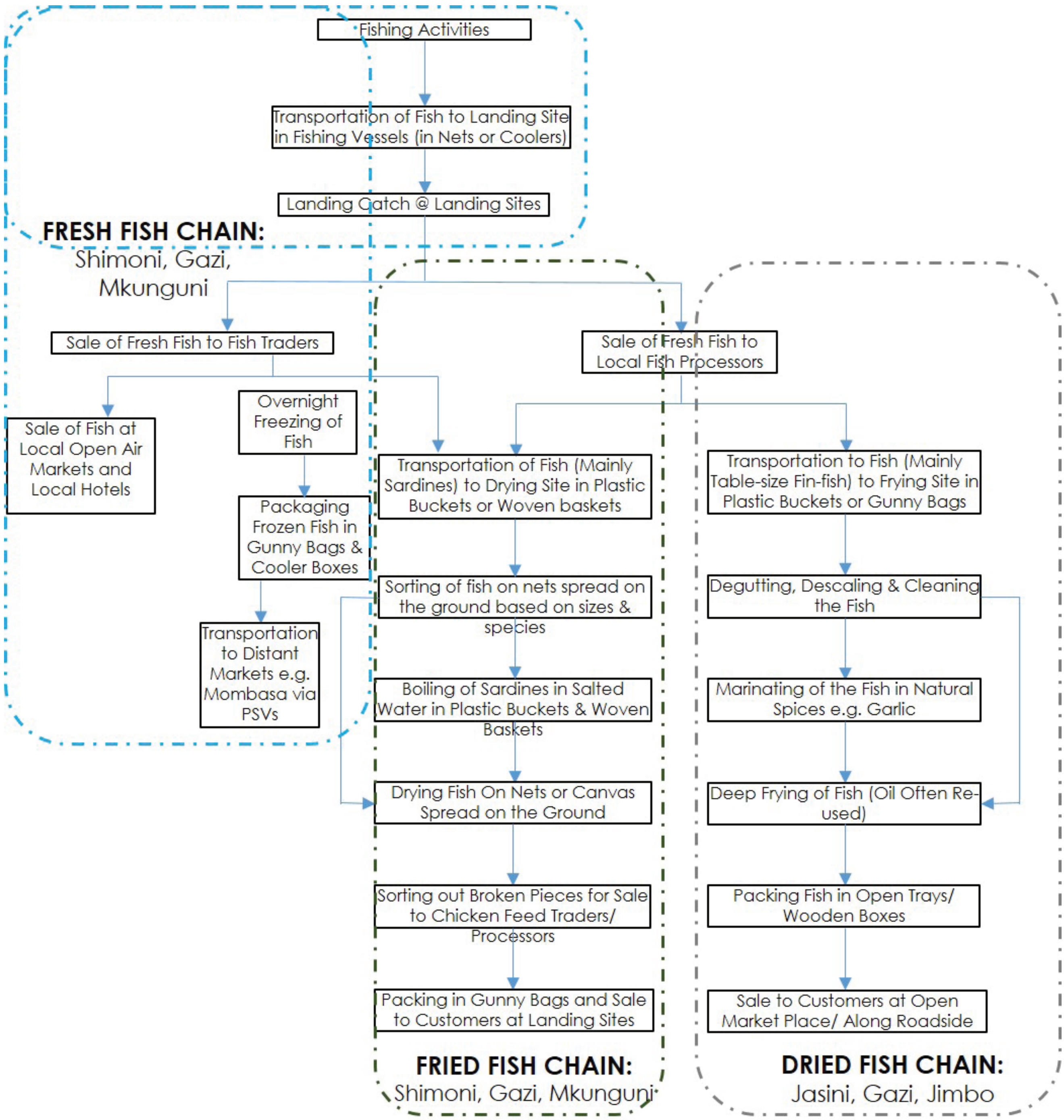

Figure 1. Flowchart of key fish handling activities at the landing sites in fresh, fried and dried fish value chains as identified during the Informal Fish Loss Assessment Method (IFLAM) phase

transport their catch to the landing site promptly and storing the fish away from direct sunlight to slow down the spoilage rates. The absence of cold-chain facilities on-board artisanal fish vessels thus contributes to the landing of fish whose quality is already compromised as reported in related studies (Kruijssen *et al*., 2020). The fish traders use freezers and cooler boxes to preserve fish while in transit from the landing site to the market while the fish processors (drying and frying) ensured the purchase of fresh fish by assessing the quality of the landed fish. However, it was observed that they did not utilize any temperature control techniques to prevent further quality deterioration of fresh fish after purchase and during transit to the processing sites. The aforementioned findings are in line with the characteristics of most artisanal fishers in developing countries as outlined by Purcell and Pomeroy (2015).

Drivers of post-harvest losses identified based on the IFLAM and the QLAM

It was noted that the cross-cutting factors (Table 2) such as poor fish handling, insufficient fish preservation and processing infrastructure and market dynamics related to seasonal fluctuations in catch volumes were the main contributing factors towards the occurrence of significant losses at all the landing sites. Trends in the losses were driven mainly by the seasonal variations in catch volumes influenced by ocean dynamics during the NEM and SEM seasons. The former occurs between November and March and is characterized by warm temperatures light rains, calm seas and steady light winds; easing fishing activities and resulting in bumper harvests. The latter, on the other hand, takes place from April to October and is characterized by cool temperatures, long heavy rains, rough seas and strong winds (Kimani *et al*., 2018). It was reported that the conditions during the NEM season contributed towards significant quality losses, particularly in the dried fish value chain which often requires ample solar insolation for sufficient drying to occur. These findings align with research conducted on seasonal variations in the scale of post-harvest losses in other regions (Ward and Jefries, 2000) and underscore the importance of developing climate-resilient fish value chains All the key informants were of the opinion that improvements in fish preservation/ processing infrastructure at the respective landing sites and capacity building on fish handling could have a significant impact on the reduction of post-harvest losses thereby improving the livelihoods of the value chain actors. Similar suggestions were noted in a study undertaken by Diei-Ouadi and Mgawe (2011).

Demographic profile of QLAM respondents

A total of 152 respondents drawn from the 5 landing sites were interviewed to validate the data collected during the initial two stages of the study. Fishermen represented the highest proportion of value chain actors interviewed across the board at 41% followed by fish processors (fried and dried fish) at 34% (Figure 2). This may have been influenced by the target population which was mainly fishers in the current study.

Table 2. Summary of key cross-cutting post-harvest loss dynamics identified based on feedback from interviewed fish value chain actors

Type of loss	Cause of loss	Stakeholders affected by loss	Time/season/trend of loss	Impact of loss	KIs' perception
1. Quality losses in fresh table-sized fish value chain (Shimoni, Gazi & Mkunguni)	☞ Insufficient/ Irregular supply of ice for fishermen to preserve fish during fishing and while in transit. ☞ Insufficient cold storage equipment (freezers, cooler boxes) at the landing sites	☞ Fishermen ☞ Fresh fish traders ☞ Local fish processors (i.e. Mama Karanga)	☞ All year round ☞ The losses are on the increase due to the influx of new value chain actors who are not trained on best fish handling practices	☞ Reduced income by fishermen and traders increases the poverty index ☞ Fish products unable to meet standards required for export to high-end markets	☞ Donor agencies and government agencies should frequently re-train all fish value chain actors and monitor adherence to the training skills
	☞ Poor fish handling skills (unsanitary & rough) during fishing and landing resulting in contamination of fish		☞ All year round ☞ Ice-flaking machines in Shimoni gradually accrued high operational costs which BMU members were unable to meet. The machine often remains unoperational	☞ Low returns for fishermen and traders from the sale of low-quality fish ☞ High downstream losses for fried fish traders due to the short shelf life for processed products using low-quality	☞ The BMU should be supported by local and national government to meet operational costs of the ice-flaking machine ☞ Fishermen require training on the importance of using ice to preserve fish at sea

2. Quality losses in fresh sardines value chain (Jasini, Jimbo & Gazi)	☞ Lack of spacious cold storage compartments in fishing vessels	☞ Fishermen ☞ Fresh sardine traders ☞ Sardine processors	☞ All year round ☞ During bumper harvests in the NEM season, the scale of losses is even higher as the fishermen haul in tonnes of fish which remain exposed to weather elements throughout fishing and during transit	☞ Wastage of catch through discard of excess catch owing to lack of sufficient storage space in the vessel	☞ Fishermen need commercial fishing vessels provided by the Government to enable them effectively handle and store catch in all seasons
	☞ Lack of ice flaking machine at Jimbo, Jasini and Gazi landing sites for a steady supply of ice to preserve landed sardines	☞ Fishermen ☞ Fresh sardine traders	☞ All year round	☞ Rapid deterioration in the quality of unpreserved fish results in a reduction in the market price of fish forcing fishermen and traders to sell at throw-away process Production of poor-quality dried sardines	☞ Installation of ice flaking machines near the landing sites is crucial
	☞ Lack of raised racks for sorting sardines before boiling	☞ Sardine processors	☞ All year round	☞ Sardines contaminated with sand particles end up having low eating quality thus are not attractive to consumers or have to be sold at low process as fish feed ☞ Fish products unable to meet standards required for local and international high-end markets	☞ Most processors lack knowledge on available innovations to prevent sardine contamination. ☞ Creation of awareness as important as the provision of the raised racks

3. Quality losses in the dried sardines value chain (Jasini, Jimbo & Gazi)	☞ Use of plastic and woven containers to boil sardines during processing – introduced contaminants and carcinogens ☞ Broadcasting sardines on the ground for drying thus exposing them to high contamination	☞ Sardine processors	☞ All year round ☞ During the rainy/ cold season losses of sardines during processing are particularly high due to incomplete drying/ spoilage onset as a result of damp weather conditions	☞ Sardines contaminated with sand particles end up having low eating quality thus are not attractive to consumers or have to be sold at low process as fish feed ☞ High losses when spoilage of sardines occurs due to unfavourable weather	☞ The available drying racks are insufficient. Increase the number of drying racks with polythene covers to keep moisture at bay ☞ Overhaul of the processing system through introduction of food-safe boiling containers is necessary. Creation of awareness on the dangers caused by heating plastics is crucial.
4. Quality losses in the fried fin-fish value chain (Shimoni, Gazi & Mkunguni)	☞ Provision of low-quality fresh fish by fishermen and traders ☞ Lack of preservation equipment for storage of purchased fresh fish during transit and before processing ☞ Contamination of fish during storage due to exposure to contaminants such as dust and kerosene smoke/spills when selling using open display shelves	☞ Fried fish processors	☞ All year round	☞ Discard of spoilt fried fish resulting in low returns and high losses	☞ Mama Karanga require training on the identification of low-quality fresh fish, proper fish handling techniques and value addition for product diversification ☞ Provision of ample preservation equipment e.g. freezers & cooler boxes and food-safe fish display containers

5. Quantity losses in the dried fish value chain (Jasini, Jimbo & Gazi)	☞ Discards at sea during bumper harvest season due to limited space ☞ Lack of ample storage space in fishing vessels ☞ Insufficient processing equipment resulting in broadcasting of sardines on the ground when sorting and drying resulting in predation and dropping of pieces of sardines ☞ High quantity of sardine fragments after drying due to constant moving of the sardines from the ground during drying	☞ Sardine fisherfolk ☞ Sardine processors	☞All year round ☞Losses are higher during bumper harvest season and in cold weather	☞ Reduced income for fishermen due to discard of catch ☞ Unsustainable fishing practices (discarding) endangering ecosystem health ☞ Reduced volume of final products (dried sardines) due to fragmentation resulting in lower income as fragments are sold as chicken feed	☞ Provision of spacious fishing vessels ☞ Sardine processors require more processing facilities such as raised racks to avoid drying on the ground
6. Market losses in fresh fish and sardines (All sites)	☞ Insufficient infrastructure for storage and preservation particularly during bumper harvests	☞ Fishermen ☞ Fish traders	☞ During bumper harvest season when catch volumes are very high	☞ Low returns from sale of fish and fish products at throw-away prices to avoid losses. Contributes to increased poverty	☞ Value chain actors require assistance in creation and maintenance of strategic market linkages, including in the export market ☞ *Provision of bulk storage facilities to provide ample space for all at all seasons*

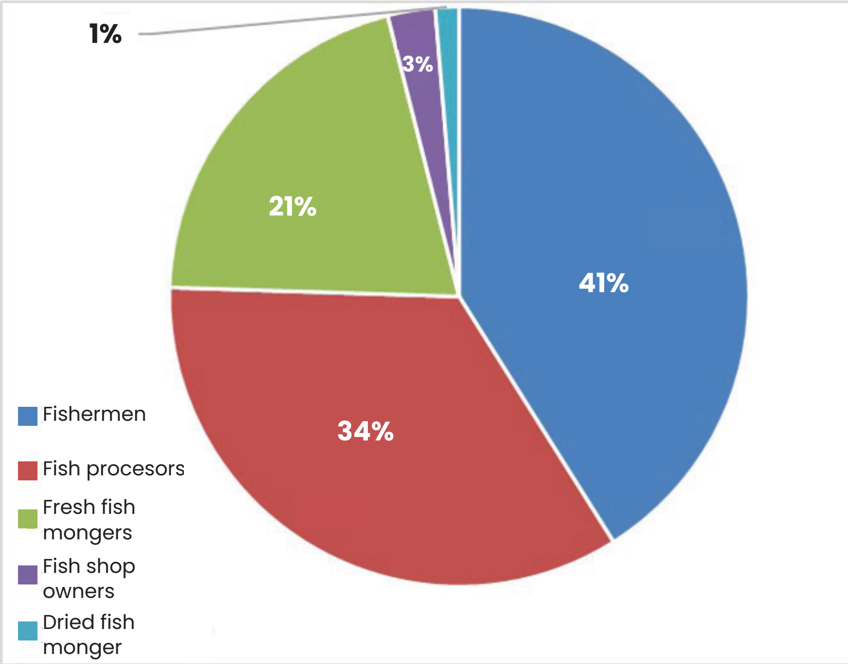

Figure 2. Occupations of respondents interviewed during the Questionnaire Loss Assessment Method (QLAM) phase.

The findings show that 70% of the 152 respondents were male and 30% female while the youth (≤35 years old) represented 23%, with 70% of the actors being engaged in fish value chain activities for 6 to 7 days a week – indicating that these activities were their main source of livelihood and are male-dominated. According to Manyungwa-Pasani *et al.* (2017), male players constitute a significantly larger proportion of fish value chain actors globally in comparison to their female counterparts. Women, however, play key roles that are essential to the sector including fish processing and repair of artisanal fishing gear such as fishing nets (Williams, 2010). Diei-Ouadi *et al.* (2014) recognized that addressing this disproportionate gender representation in fish value chains has the potential to contribute towards the reduction of post-harvest losses by amplifying the contribution of women in sustainable fisheries management.

Catch volumes and composition based on the QLAM

The value chain actors reported handling a variety of nearshore (reef) and offshore fish species. The main fish species landed and processed (drying or frying) included *Siganus spp* (*Tafi*), *Lethrinus spp* (*Changu*), *Leptoscarus spp* (*Pono*), Caranx (*Kolekole*), *Parupeneus spp* (*Mkundaji*), Tunas (*Viboma*), Kingfish (*Nguru*), Snappers and Sardines (*Kimarawali, Katashingo* and *Simsim*). The catch volumes varied at the different landing sites based on the monsoon-based seasons (NEM & SEM). Figure 8 illustrates the variation in the average seasonal catch volume reported per individual at each landing site. The seasonal bumper harvests in selected fisheries such as sardines were associated with significant losses due to limited infrastructure to preserve the massive landings. While species-specific post-harvest fish losses were not quantified in this study, research conducted in other regions indicates that the scale of losses encountered often differs with the type of fish harvested (Prodhan *et al.*, 2022). A subsequent study using the load tracking method (Ward and Jeffries, 2000) would enable the quantification of losses occurring in specific marine fisheries in Kenya.

Scale and frequency of post-harvest losses based on the QLAM

The respondents reported that spoilage of fish i.e. quality deterioration was the main type of loss that was encountered at most landing sites (Table 2); with quantity losses being reported mainly in the dried sardines value chain. Most respondents (65%) reported having encountered post-harvest losses at some point in their fish value chain activities; with a significant majority reporting loss frequencies of up to twice a month (Kimani *et al.*, 2018). The scale of the losses varied from one landing site to another (Fig. 9); with respondents at Mkunguni reporting the highest proportion of total catch lost per individual at 34%; followed by the Jimbo landing

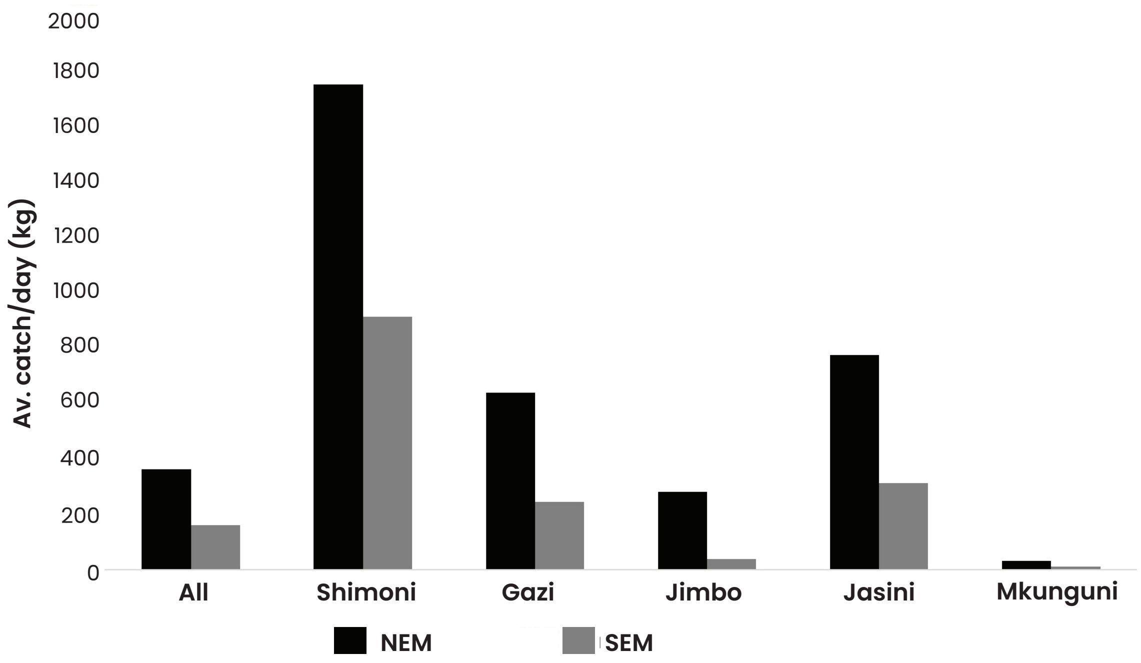

Figure 3. Seasonal fish catch volume (kg) variations at the landing sites. NEM: North East Monsoon season; SEM: South East Monsoon Season.

site at 15%. The points at which the losses occurred along the value chain were fishing (28%), at the fresh fish markets (18%) and during processing (17%). The observed variations in the post-harvest losses encountered at different landing sites were attributed to the differences in the catch compositions and preservation infrastructure present at the selected sites. This illustrates the need to develop inclusive implementation frameworks that will drive the provision of the requisite post-harvest management infrastructure along all fish value chains in Kenya as proposed by Odoli *et al.* (2019). Respondents reported that the low-quality fish is often split, heavily salted and dried into a product locally known as *ng'onda*; which fetches lower prices than fresh fish due to the moisture loss in the process of drying. While drying was reported as an innovative technique used by the respondents in this study to upcycle low-quality fish, the use of rotten fish to produce dried fish for human consumption was noted as a significant malpractice. This observation justifies the need to capacity-build the artisanal fisherfolk on the best practices in fish handling and processing to produce value-added products that are fit for human consumption (Kumolu-Johnson and Ndimele, 2011).

Factors contributing to post-harvest losses & proposed solutions

Several factors were identified as the main causes of the post-harvest losses (Table 3). Chief among these was the lack of necessary cold-chain infrastructure and equipment such as freezers, cooler boxes and ice flake-making machines, in addition to the prohibitively high cost of electricity bills accruing from cold-chain facilities connected to the national grid. This was the situation at Shimoni, Gazi and Mkunguni landing sites where modern facilities were available but frequent breakdowns led to inconsistencies in fish preservation, which contributed to significant losses – a common challenge in the fish cold chain in the tropics (Ikape and Cheikyula, 2017). Within the sardine value chain in Gazi, Jimbo and Jasini, the main cause of losses highlighted was the inadequacy of drying racks resulting in high quality and quantity sardine losses due to drying the fish on the ground. Research findings have provided evidence of the impact of improving fish drying infrastructure

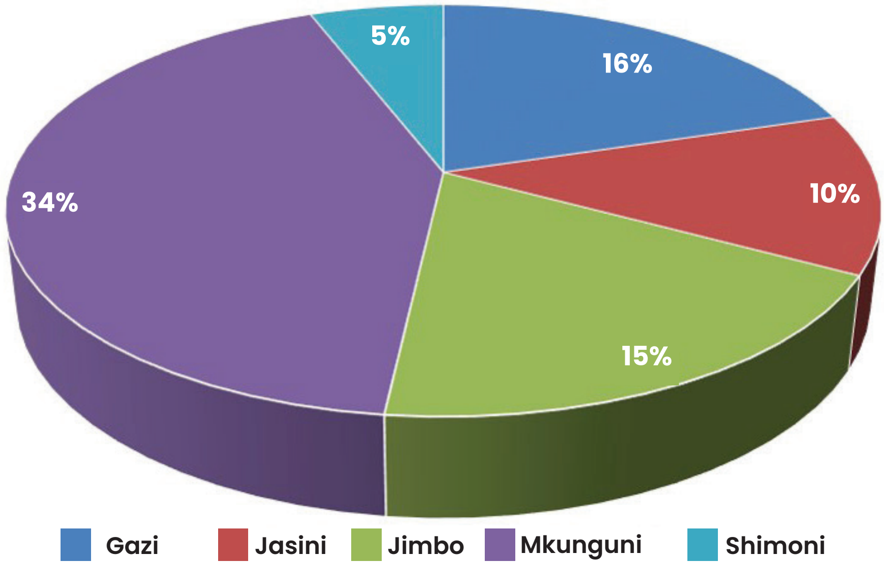

Figure 4. Proportion of total fish lost post-harvest per value chain actor at the landing sites.

on the reduction of post-harvest losses in the sardine fish value chain (Mhanga and Mwandya, 2022).

Cold chain equipment such as cooler boxes, freezers and cold rooms were requested by a majority of the respondents who insisted that without fresh fish from the fishermen, losses would continue to be encountered at other downstream nodes of the value chains. Processors of fried and dried fish requested for improvement of infrastructure such as drying racks and provision of high capacity processing infrastructure to reduce the delays during processing occasioned by the use of small equipment. Fishermen requested the provision of modern fishing vessels with inbuilt cold rooms and/or the provision of cooler boxes with sufficient capacity to arrest spoilage during fishing and while on transit to the landing sites. Infrastructural development and provision of preservation equipment across the value chains were suggested as the main intervention which would enhance mitigation against the losses. This aligns with recommendations from related studies proposing the provision of requisite post-harvest management infrastructure as a strategy to reduce losses, particularly among artisanal fishing communities (Alhaji *et al.*, 2015; Odoli *et al.*, 2019). Capacity building of fish value chain actors on the best practices in fish handling, preservation and processing was also identified as a major intervention that could contribute significantly towards the reduction of post-harvest losses (Keerthana *et al.*, 2022).

Conclusion and recommendations

The study revealed the occurrence of significant post-harvest losses occurring along the three value chains evaluated and at all the representative landing sites. These losses mainly occurred in the fresh fish value chain resulting in spoilage during the subsequent trading and

Table 3. Summary of the key factors contributing to high post-harvest losses at all the sampled landing sites.

Factor	Responses	
	No.	%
Lack of cold chain equipment/ infrastructure including cold rooms, freezers and cooler boxes	35	35%
Unfavourable weather conditions during sardine drying	10	10%
Delays during fishing resulting in commencement of fish spoilage before hauling the fish in	28	29%
Lack of proper fish-handling skills at the landing/ processing site	15	15%
Inadequate drying racks and sardine handling infrastructure	10	10%

processing stages in the value chain. Quality losses in the fresh fish supply chain were largely attributed to lack of adequate fish preservation infrastructure such as ice production machines, cooler boxes, freezers and cold rooms. The inadequacy of processing infrastructure further contributed to losses in the dried fish value chain where sardine processors were relegated to drying fish on the ground due to the insufficiency of drying racks, resulting in contamination and high losses, especially during bumper harvest seasons. Improving the fish preservation infrastructure at all the landing sites, coupled with continuous capacity building of the fish value chain actors on the best practices in fish handling are recommended as key mitigation measures against PHFLs in Kwale County. The incorporation of the load tracking method in subsequent studies is recommended to enable the quantification of the losses occurring along the value chains and inform the implementation of target-based mitigation techniques aimed at reducing the losses to a measurable extent.

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Appendixes

Appendix 1. IFLAM Tool: Observation/ Key Informant Interview Guide.

The target: Conduct a pilot baseline survey to quantify fish post-harvest losses in Kwale County (Vanga, Jimbo, Shimoni, Gazi and Mkunguni) to inform management by 30th June 2020 (30%)

Phase One: Informal Fish Loss Assessment Method

Observation Guide

Landing site................................Observer................................Date........................

1. What are the main types of fishing vessels used?

Fishing vessel	Size(M)	Propulsion mode	Construction Material	Number of vessels	Photo taken

Are oil and fuel kept separate in the fishing vessels?

....

2. What are the main types of fishing gear used?

Fishing gear	Mesh/ Hook size	Photo taken

What are the five main species harvested?

Species	Approx. % of Total Catch	Photo taken

What are the measurement units used for the catch?..

3. What type of containers are used to hold the harvest during transportation to the landing site? Indicate the number of observations for each based on whether each has ice or not.

WITHOUT ICE			WITH ICE		
Type of holding container	Number observed	Photo taken	Type of holding container	Number observed	Photo taken

Are fish handled carefully to avoid damage?..

4. How many observations of fish icing after landing or lack thereof are observed?

Fish icing observations (Number): ....

Lack of fish icing observations (Number):...

5. Are the insulated storage facilities, (if present) adequate? ....

....

6. Is the landed fish gutted at sea or at the landing site?

Gutting stage	Number of observations	Photo taken
At sea		
At the landing site		
At market		
By the consumer		

Approximately how long does it take to offload and preserve the fish prior to processing/sale?

....

7. How is the fish processed/ preserved after landing?

Preservation	Processing

Are fish being processed adequately?..

....

8. Describe the personal hygiene of crew, handlers and processors?

....

9. Where are fish placed during processing?

Surface	Number of observations	Photo taken
Directly on the ground		
On rocks		
On fishing nets		
On the floor		
On clean surfaces		
On a clean mat or canvas		
Other:		

What is the source(s) of water used during handling of the fish?

....

10. Are sanitary conditions adequate? [1]Yes [2]No Elaborate

....

....

11. Which animals are wandering freely where fish are handled or processed, etc.?

....

12. Which pests/insects are noticeable at the fish landing/processing site etc.?

Landing..

Processing..

13. How are harvested fish isolated from potential contaminants?

....

14. Are landed fish protected from direct solar insolation?

15. How are fish protected from the rain?

....

16. What type of containers are used to hold the harvest during transportation to the market? Indicate the number of observations for each in the table below depending on whether the container contains ice or not.

WITHOUT ICE				**WITH ICE**		
Type of holding container	**Number observed**	**Photo taken**		**Type of holding container**	**Number observed**	**Photo taken**

How are fish transported and does this cause any damage or other loss?

Transport means	**Description of damage/loss caused**

What mitigation strategies are being used at the site to control losses?

....

17. How effective are loss reduction measures?

....

....

Appendix 2

PHFLA using the Questionnaire Loss Assessment Method (QLAM)

Questionnaire No…………………Interviewer………………………Date……………………BMU……………………Landing Site…………………

Name	
Gender	[1] Male [2] Female
ID number	
Year of Birth	
Village	
Cell phone Number	
Role	[1] Fish farmer [2] Mama Karanga [3] Fish processor [4] Fish shop owner [5] Fresh fish Monger [6] Other (specify)
BMU Official	[1] Yes (specify position) ………………………………………… [2] No

For how long have you been engaged in fishing/ fish selling/ fish processing activities?

1. Where have you been fishing/ purchasing the fish for sale or processing (most of the time)?
2. How many days in a week do you fish/ sell/ process fish?

1		2	3	4	5	6	7

On average, how many kilos of fish do you catch / buy for sale/ process per day?

During high season (Kaskazi)		During low season (Kusi)	
Lowest	**Highest**	**Lowest**	**Highest**

On average, how many hours per day do you spend at fishing ground/ or purchasing fish @ the landing site?

During high season (Kaskazi)		During low season (Kusi)	
At least	**At most**	**At least**	**At most**

On average, how many hours do you spend to transport the fish from the fishing ground to the landing site OR from the landing site to the processing/selling site per day?

During high season (Kaskazi)		During low season (Kusi)	
At least	**At most**	**At least**	**At most**

What are the **5** main species of fish caught/ sold/ processed?

Fishermen Only	Fresh fish traders only	Fish processors only
8. a. Type of fishing vessel: b. Propulsion mode:	**8**a. Type of trade [1] Retail [2] Wholesale [3] Both b. Location of market(s):	**8.** Main processing method:[1] Frying [2] Boiling then drying [3] Salting then drying [4]
9. a. Main fishing gear(s) used: b. How long does it take to haul in a single batch of fish using this gear?	**9.** Market type:[1] Open[2] Shop [3] Door-to-door [4] Institutions [5] Other	**9.** How do you prepare the fish for processing? [1] Degutting [2] Descaling [3] Cleaning [4] Salting [5] Other:
10. On average, what proportion of the catch do you keep for subsistence per day?	**10.** Average time to market (s): Nearest…………………..Farthest……………….	**10.** How long do you take to prepare the fresh fish before frying starts?
11a. How often do you discard fish while at: i. Sea:**1.**Daily**2.**Weekly**3.**Monthly**4.**Rarely**5.**Never ii.Landing: **1.**Daily**2.**Weekly**3.**Monthly**4.**Rarely**5.**Never **11b.** What amounts of discards do you lose at a go? Discards at a go (Sea): Min……....kg; Max......…..kg Discards at a go (Landing): Min......kg; Max...…....kg	**11. a.** How many hours/ days does it take you to clear off (sell) a single batch of fresh fish?	**11.** How many hours/ days does it take you to clear off (sell) a single batch of processed fish?

Fishermen Only

12	Selling Price of Harvested Fish			
	High season Ksh./kg			
	High season Ksh./kg		Low season Ksh./kg	
	Highest	***Lowest***	***Highest***	***Lowest***

Fresh fish traders only

12	Buying Price of Fresh Fish			
	Low season Ksh./kg		High season Ksh./kg	
	Highest	***Lowest***	***Highest***	***Lowest***
	Selling Price of Fresh Fish			
	High season Ksh./kg		Low season Ksh./kg	
	Highest	***Lowest***	***Highest***	***Lowest***

Fish processors only

12	Buying Price of Fresh Fish			
	Low season Ksh./kg			
	Highest	***Lowest***	***Highest***	***Lowest***
	Selling Price of Fresh Fish			
	High season Ksh./kg		Low season Ksh./kg	
	Highest	***Lowest***	***Highest***	***Lowest***

What factors contribute to price fluctuations?..

....

....

………
………..

1. Have you ever lost fish due to spoilage? **[1]** Yes **[2]** No
2. If yes, how many kilos of fish have you ever lost at a go? **Min.**:…...kg of ……kg **Max..**:…….kg of ……..kg
3. If yes, how often do you encounter fish spoilage? **[1]** Daily **[2]** Once weekly **[3]** Several times in a week **[4]** Once monthly **[5]** Twice monthly **[6]** Once in a while (Specify)……………………………………………………
4. If yes, at what point (s) along the value chain do you encounter the highest proportion of the losses? **[1]** During fishing **[2]** During transportation of the fish to the landing site **[3]** During transportation of fresh fish to the market **[4]** While waiting to sell the fresh fish at the market **[5]** Before processing **[6]** During processing **[7]** During transportation of fresh fish to the market **[8]** While waiting to sell the processed fish at the market **[9]** Other(specify)……
5. If yes, how do you handle the spoilt fish? **[1]** Discard **[2]** Salting and drying **[3]** Consumed at home **[4]** Sold fresh at throw away prices **[5]** Other (specify) ..…………………………………………………………………………………………………..
6. If sold, how much money do you make from the sale of a batch of dried fish(*'ng'onda'*) or spoilt fresh fish?

Spoilt Fish (Fresh)		**Dried Spoilt Fish (Ng'onda)**	
Lowest: ……………..………… Ksh./kg	Highest: ……………..….Ksh./kg	Lowest: ………………….Ksh/kg	Highest: ……………………..Ksh./kg

What factors do you think contribute to fish spoilage……………………………………………………………………………………...

………
………..

7. How do you process/preserve your fish (especially fresh fish) to minimize/ prevent spoilage?

1. Icing	**2.** Freezing	**3.** Gutting	**4.** Washing	**5.** Beheading	**6.** Filleting	**7.** Salting	**8.** None	**9.**Other

On average, how much money do you spend per day on preservation of fish to minimize spoilage?

During high season (Kaskazi)		**During low season (Kusi)**	
Lowest: Ksh……………	Highest: Ksh……………	Lowest: Ksh……………	Highest: Ksh……………

What challenges do you encounter while mitigating post-harvest fish lossess and what strategies would you propose to counter these challenges?

a.Challenges encountered during fish preservation	b.Strategies proposed / Recommendations to mitigate spoilage

Rapid assessment of the Indian mackerel *Rastrelliger kanagurta* fishery in Kenya's coastal waters

Gladys M. Okemwa*, Almubarak A. Abubakar, Esther Fondo, Johnstone Omukoto, Boaz Orembo, Edward Kimani, Jane Nyamora, Fatuma Mzingirwa, Nina Wambiji, Nimrod Ishmael

Kenya Marine and Fisheries Research Institute. P.O. Box 81651 - 80100, Mombasa, Kenya

*Corresponding author: gokemwa@kmfri.go.ke, (+254) 20 8021561

Abstract

The Indian mackerel, *Rastrelliger kanagurta* is a highly migratory epipelagic species in the family Scombridae. The species plays a significant role in supporting the food security and livelihoods of coastal communities in the Western Indian Ocean. The exploitation status of *R. kanagurta* in Kenya's waters is uncertain. This study evaluated the *R. kanagurta* fishery using available catch data collected from 2014-2015 and 2017-2020. The study described the catch dynamics and utilized a suite of length-based approaches to derive diagnostic indicators of the exploitation status. Four gear types were documented that target the species, dominated by ring nets (79%) and reef seines (11%). Catch rates and selection patterns of fishing gears targeting *R. kanagurta* varied between gear types. Reef seines caught the highest proportion (80%) of immature *R. kanagurta* below size at maturity (L_{50}), while the lowest (0%) was by handlines and set gillnets. There were statistically significant differences in the proportion of *R. kanagurta* caught below L_{50} between gear types and years. Overall, the spawning potential ratio (SPR) was within optimal levels at 0.48 and was above the target reference point of 0.4 during all years. The assessment provides a case study for the rapid evaluation of fishery performance for Kenya's data-limited fisheries.

Keywords: small-scale fisheries, length-based approach, gear selectivity, spawning potential, pelagic fish, data-limited fisheries

Introduction

Small-scale fisheries (SSF) support food security and livelihoods for millions of coastal communities worldwide. In Kenya, SSF contributes approximately 90% of annual marine fisheries landings. An estimated 25,000 metric tons of fish are landed annually, of which pelagic species (including tunas and mackerels) constitute about 27% of this production. Mackerels, locally referred to as *Sehewa* or *Una*, are some of the key target species in Kenya's small-scale purse seine (ring net) fishery (SSPSF) which mainly targets small and medium pelagic species. The Indian mackerel *Rastrelliger kanagurta* is the dominant species landed along the Kenyan coast (Bett *et al.*, 2021). *It is a relatively short-lived species* occurring at depths ranging from 10 m to 100 m (often above 25 m) across the tropics of the Indo-West Pacific region (Akib *et al.*, 2015). Because the species moves in large aggregations, it is usually caught in high numbers providing an affordable and easily available source of protein for the coastal communities. Mackerels are generally marketed fresh, chilled or frozen. Studies assessing the fishery, biology, population dynamics, and exploitation status of *R. kanagurta* have been conducted in various regions of the Indian Ocean (Abdussamad *et al.*, 2010) and the Yemeni coast (Al-Mahdawi and Mehanna, 2010), with the earliest reported study being in Mozambique (Sousa and Gislason, 1985). However, the exploitation status of *R. kanagurta* stock in Kenya remains uncertain as information is limited.

Towards achieving the 2030 Sustainable Development Goals (SDGs), Goal 14.4.1 emphasizes the need to ensure that all fisheries are assessed and well-managed within biologically sustainable levels. However, assessing and managing small-scale fisheries remains challenging as the collection of reliable data is difficult due to the highly diverse vessel and gear types used, high diversity of species, and diffuse landing sites, some of which are located in remote, inaccessible areas where consistent data collection and monitoring is difficult (Pita *et al.*, 2019). Consequently, most small-scale fisheries are categorized as data-poor or data-limited. Data-poor fisheries arise when certain key parameters needed to run the quantitative models are either not available or are collected inconsistently (FAO, 2020).

Over the last decade, various length-based methods have been developed, which have made it possible to conduct simple diagnostic assessments of the exploitation status for data-poor fisheries (Froese, 2004; Cope and Punt, 2009; Hordyk *et al.*, 2015; Prince *et al.*, 2015; Froese *et al.*, 2018). These methods are now being integrated widely (Babcock *et al.*, 2013; Gough *et al.*, 2020; Prince *et al.*, 2020). This is because length-frequency data is easy to collect and is hence the most readily available stock parameter for most data-poor fisheries. This study applies selected length-based approaches to rapidly assess the exploitation and stock status of the Indian Mackerel *R. kanagurta* fishery, based on catch and length data collected over a 6-year period from 2014 to 2020 at selected landing sites along the Kenya coast. The specific objectives of the study were to assess annual changes in catch rates and selection patterns of fishing gears targeting *R. kanagurta* and to derive stock status diagnostics using a suite of length-based indicators.

Materials and methods

Data collection

Data used for this study was obtained from a catch sampling programme undertaken by KMFRI at selected landing sites along the Kenya coast. Key landing sites where *R. kanagurta* was recorded were four: two at the South Coast of Kenya (Vanga and Gazi) and two landing sites at the North Coast of Kenya (Takaungu, Mayungu, and Kilifi) (Fig. 1).

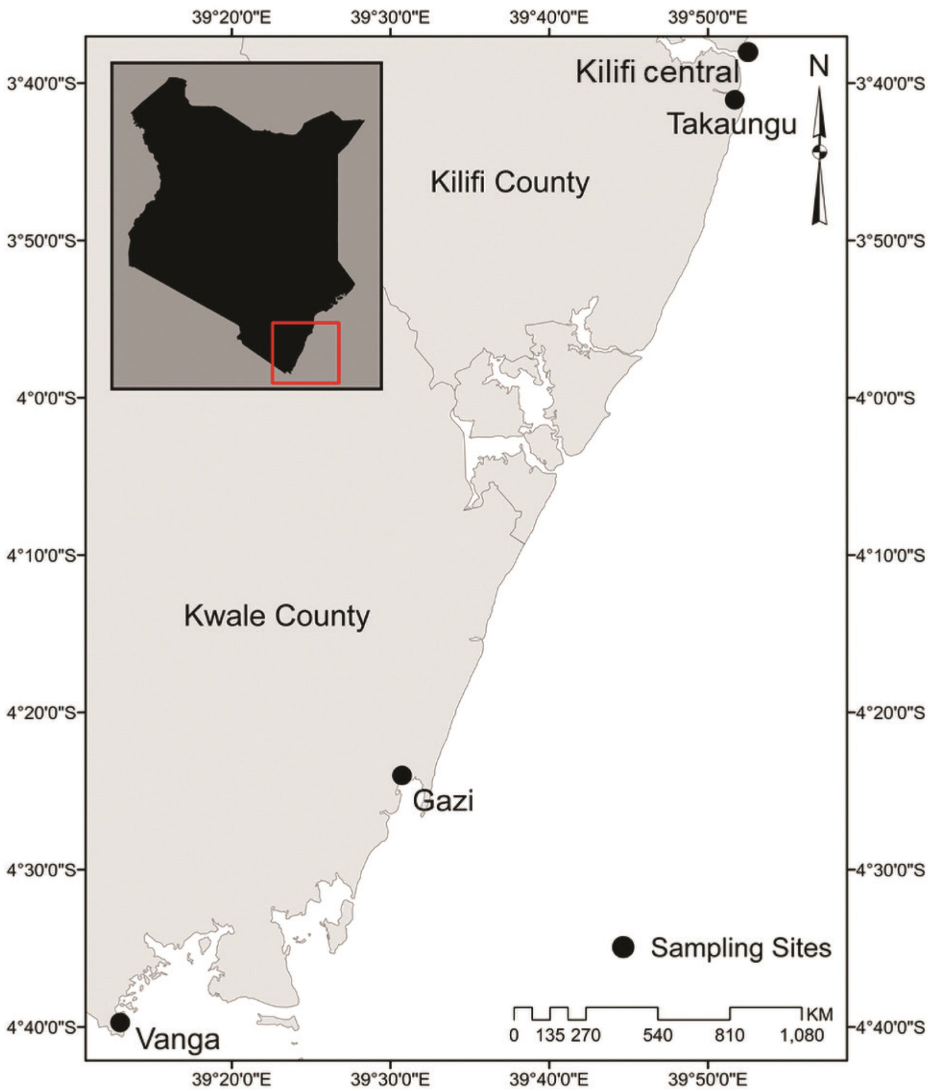


Figure 1. Map showing the location of landing sites along the Kenya coast monitored during the study period (Source: Authors).

The catch sampling programme entailed the collection of the following information for each sampled fishing trip: vessel and gear type used, number of crew, total catch (kg), and species. Fish were identified to species level and the total catch for each species component in each sampled trip was estimated by number and weight. The total length (cm) and body weight (kg) of each specimen was measured and then weighed using an electronic weighing balance to the nearest 0.1 cm and 0.1 kg, respectively. Total length was measured from the tip of the upper jaw (snout) with the mouth closed to the tip of the longer lobe of the caudal fin.

Data processing and analysis

A raising factor (rf) for each fishing trip was calculated to extrapolate the sampled catch and number of individuals caught to the total catch using the formula:

$$rf = W_t / W_s$$

where W_t is the total weight of all the fish caught during a fishing trip and W_s is the weight of the sampled fish.

The raising factor for each fishing trip was then multiplied by the total sampled weight of each species to estimate the total species weight in the catch. The data for all fishing trips which caught *R. kanagurta* was extracted for this assessment. The catch per unit effort (CPUE) for each fishing trip was standardized as kilograms per vessel (kg $vessel^{-1}$ $trip^{-1}$). Each length measurement was first rounded off to the nearest 1 cm. The length data were then grouped into 2 cm class intervals and a frequency histogram plotted to visualize the length distribution. Variation in mean length between gear types and between years was assessed using a one-way analysis of variance (ANOVA). If significant, a paired post hoc Tukey HSD test for unequal sample sizes was applied to identify the significant interactions.

The length-based spawning potential ratio (LB-SPR) model was then applied to quantify the spawning potential of the exploited population during each sampled year. Spawning Potential Ratio (SPR) is defined as the proportion of natural or unfished reproductive production left in a population when under fishing pressure. The ratio is a function of the relative fishing mortality (estimated as the ratio of fishing mortality to natural mortality, F/M), selectivity, and life history ratios (M/K and L_m/L_∞). K is the von Bertalanffy growth coefficient, L_m is the size at maturity, and L_∞ is the asymptotic size (Hordyk *et al.*, 2015). The model defines maturity and selectivity ogives by logistic curves and estimates selection length at 50% (SL_{50}) and 95% (SL_{95}). The relative fishing mortality (F/M) is also estimated to compute SPR. The model considers an SPR of 0.40 and 0.20 as target and limit reference points for stock productivity as postulated by Hordyk and Carruthers (2018), and assumes an equilibrium state and asymptotic selectivity. In addition, the model assumes that the full spectrum of lengths in the population is represented in the sampled catch (Prince *et al.*, 2015). Length at 95% maturity (L_{95}) was calculated as L_{50}×1.15 following Prince *et al.* (2015). The Natural Mortality tool and LBSPR tool available at GitHub (2020) were used to estimate natural mortality and SPR. Table 1 provides a summary of the growth parameters used in the LBSPR model.

Table 1. Growth parameters and maturity size for *Rastrelliger kanagurta* used in the LBSPR model

Parameter	Estimate (Source)
Natural Mortality (M)	1.99 (Natural mortality tool)
Growth coefficient ($year^{-1}$) (K)	1.3 (Froese and Pauly, 2023)
M/K ratio	1.53 (Calculated)
Asymptotic length (L_∞)	39 (Froese and Pauly, 2023)
Size at 50% maturity (L_{50})	20.5 (Sousa and Gislason, 1985)
Size at 95% maturity (L_{95})	23.6 (Calculated)

Results

Gear and vessel use

The data containing catches of *Rastrelliger kanagurta* represented 71 fishing trips consisting of 6,440 kg of *R. kanagurta* over the 6-year period. The main gear types catching *Rastrelliger kanagurta*were ring nets (94% of the sampled catch), and to a much lesser extent reef seines (5%) (Fig. 2).

Five vessel-gear combinations were identified, dominated by *mashua*-ring nets representing 59 fishing trips (84%). Canoe-reef seines represented five trips (7%), canoe-gillnet represented three trips (4%), fibre-boat-handline represented two trips (3%), canoe-handline and outrigger-handline represented one trip (1%) each. Catch per unit effort (kg $vessel^{-1}$ $trip^{-1}$) for *R. kanagurta* varied among the four gear types ranging from 2.7 kg ± 1.1 kg/trip for handlines to 101.9 kg ± 18.6 for ring nets (Table 2).

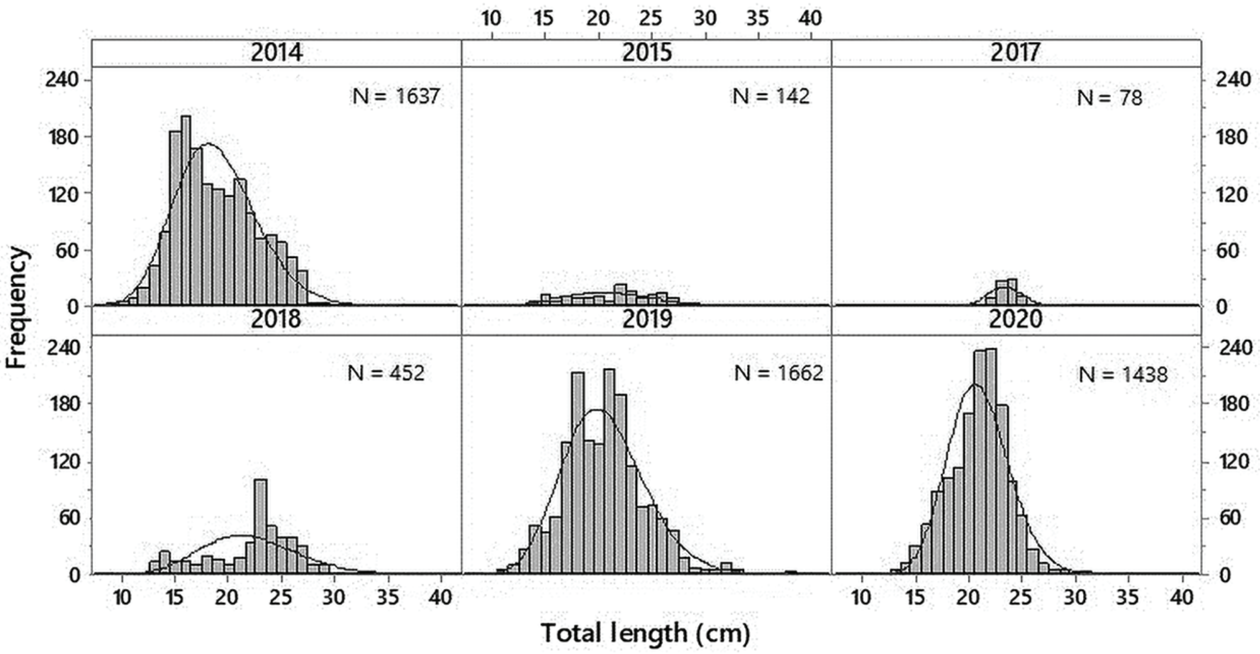


Figure 2. Length frequency distribution of *Rastrelliger kanagurta* sampled from artisanal landings at three landing sites between 2014 and 2020 at three landing sites along the Kenya coast.

Table 2. Mean catch per unit effort (CPUE, kg vessel-1 trip-1), mean length (total length, cm) and the proportion below size at maturity (L_{50}) of *Rastrelliger kanagurta* caught by four gear types along the Kenyan coast.

Gear type	Proportion of total landings	Mean CPUE (kg vessel^{-1} trip^{-1})	Mean length (TL, cm) ± SE	% <L_{50}
Handlines	4%	2.7 ± 1.1	23.9±0.2	10.1
Gillnets	6%	9.6 ± 4.0	22.9±0.2	28.4
Reef seines	11%	57.4 ± 15.3	20.6±0.1	80.0
Ring nets	79%	101.9 ± 18.6	19.7±0.1	55.0
All groups	100%	90.7 ± 17.5	20.2±0.1	33.9

Length composition and selectivity

The length distribution of *R. kanagurta* during the different years is shown in Figure 2. It was evident that the data was collected inconsistently with under-sampling occurring in some years e.g. 2015, 2016 and 2017. The overall mean total length was 20.2 cm (Table 1). The total length ranged from 6 cm to 35 cm (Fig. 3a).

Individuals ranging from 20 - 23 cm dominated landings accounting for 40% of the sampled catch. Results of the one-way ANOVA showed significant differences in mean sizes among the gear types ($p < 0.05$). The highest proportion of immature sizes (below L_{50}) was caught by reef seines constituting 80% of the sampled catch; while mature sizes dominated handline catches representing 90% (Table 1). On the other hand, the proportion of immature fish caught by ring nets was about 55% indicating a relatively balanced harvest.

Annual change in mean length and spawning potential ratio

Annual changes in the mean length of *R. kanagurta* remained stable over the 6-year period ranging from 18.9 ± 3.8 cm in 2014 to 23.4 ± 1.5 in 2017 (Figs. 3b and 4). Results of one-way ANOVA showed significant differences in mean length over time ($p < 0.05$); the post hoc Tukey HSD test revealed 2014 and 2017 as significantly different in mean size from the other years. The SPR for the entire study period was estimated at 0.48 indicating a relatively healthy state. Annual estimates of the SPR revealed that the fishery was above the target reference point of 0.4 during all the years (Fig. 5).

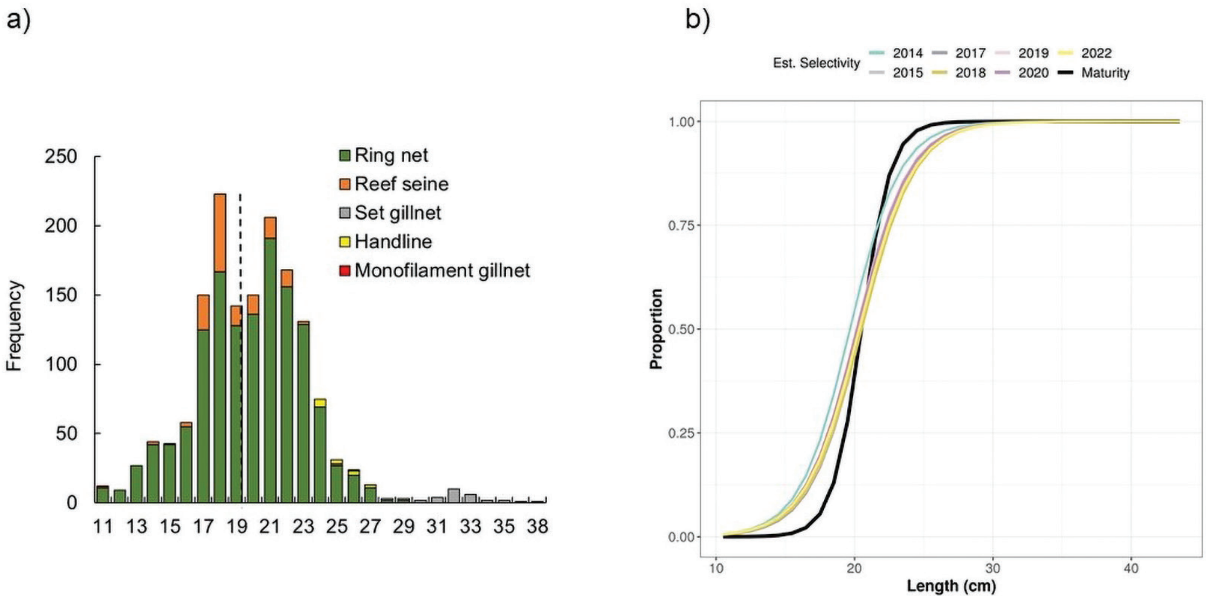


Figure 3. Length distribution of *Rastrelliger kanagurta* artisanal fishery landings stacked along the Kenya coast during 2014-2020 stacked by gear type (a) and the maturity and selectivity ogives for the years sampled (b).

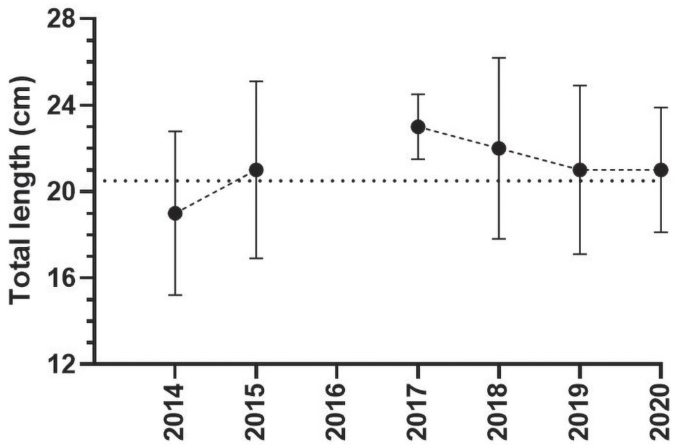
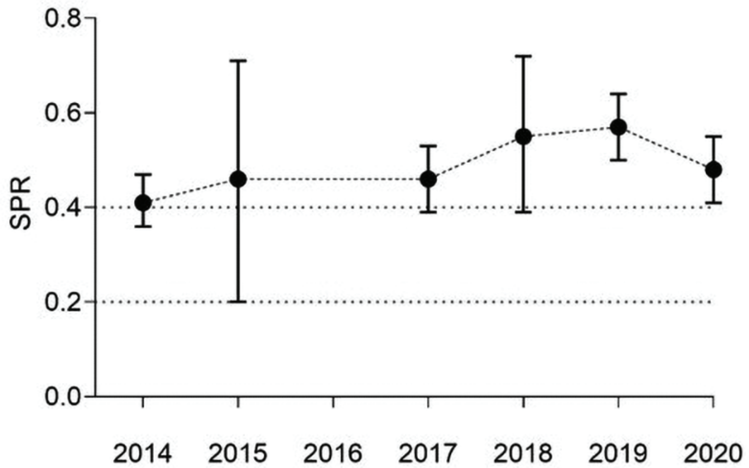


Figure 4. Annual change in mean total length of Rastrelliger kanagurta in landed artisanal catches along the Kenya coast. Whiskers represent the minimum and maximum length. Dashed reference line represents the size at first maturity (L_{50}).

Figure 5. Annual trend in Spawning Potential Ratio (SPR) of *Rastrelliger kanagurta* sampled from artisanal landings in Kenya's waters between 2014 and 2020.



Discussion

The present study represents a first attempt to assess annual trends in the artisanal fishery targeting *R. kanagurta* in Kenyan waters. The species was mainly caught using ring nets, which had the highest catch rates compared to other gear types. Ring nets are known to be highly efficient in targeting schooling pelagic fish and are hence the most preferred gear type for targeting Mackerels. High catch rates of *R. kanagurta* by ring nets have been reported in Malaysia (Amin *et al.*, 2014) and in Indonesia (Arrafi *et al.*, 2016), similar to this study. Most of the *R. kanagurta* catches are landed at the South Coast of Kenya in Gazi and Vanga which is strongly influenced by the Pemba channel which has been reported to support small high numbers of small and medium pelagic species (Kizenga *et al.*, 2021). Observed length ranges were within the range reported within the Indian Ocean region (Ganga, 2010). The differences in mean sizes and proportions of mature fish among different gear types may reflect differences in catchabilities associated with accessibility to nearshore vs offshore fishing grounds.

Conclusion and recommendations

The study shows that the *R. kanagurta* population was fished at optimal levels during the study period, indicating a low risk of overfishing. A major assumption of the study was that the data fully met the SPR model assumptions. The study demonstrates utility in the application of length-based approaches to rapidly diagnose the status of Kenya's data-poor fisheries to inform decision-making on research directions and precautionary management. The *R. kanagurta* fishery has been prioritized for further stock assessment under various ongoing initiatives. Going forward, the scope of assessment should be broadened to include other length-based indicators (LBIs) to further validate the findings of this rapid assessment. Continued catch and biological monitoring of the fishery is emphasized to improve the data quality, particularly with regard to sampling frequency and consistency.

Acknowledgements

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Limnological status of Lake Oloidien in Kenya's Rift Valley between 2020 and 2021

Alice Mutie*, **Edna Waithaka, George N. Morara, Patrick Loki, Beatrice Obegi**

Kenya Marine and Fisheries Research Institute, Naivasha Station, P.O. Box 837-20117, Naivasha, Kenya

*Corresponding author email: alis.mutheu@gmail.com, (+254) 0 721 764162

Abstract

Water samples were collected between August 2020 and March 2021 and analyzed for physico-chemical parameters to ascertain the current limnological status of Lake Oloidien. The maximum mean depth of the lake recorded was 7.7 m in November, which corresponded with a high water transparency value (69.0 ± 3.4 cm) in the same month. There were no significant variations in temperatures among the sampled stations, mean ranges were 23.15 ± 1.15°C and 23.93 ± 1.09°C. Dissolved oxygen (DO) concentrations were high in September (13.99 ± 0.01 mg L^{-1}) with depth profiles of DO between August 2020 and March 2021 differing significantly (p = 7.955E-06). Conductivity mean values ranged from 414.0 ± 23.89 µS cm^{-1} and 730 ± 11.54 µS cm^{-1}, with January recording the highest value while October recorded the least value. It was observed that only pH levels had significant variation across the months sampled with p = 0.506 and a mean of 8.55 ± 0.56. The mean values for nitrates ranged from 2.04 ± 1.30 mg L^{-1} and 4.78 ± 0.045 mg L^{-1} across the months sampled and the highest chlorophyll-a levels were recorded in August at 83.3 ± 56.06 mg L^{-1}. In the past years, the lake has been alkaline-saline with high conductivity levels, and chances of fish survival were limited. Currently, the environmental factors are now favourable for fish survival.

Keywords: Lake Naivasha basin, dissolved oxygen, nitrates, phosphates, physicochemical

Introduction

Lake Oloidien is located immediately Southwest of the main basin of Lake Naivasha at 1,885 meters above mean sea level (mamsl) in the central valley of the Great African Rift Valley in Kenya. It is one of the three lakes of the Naivasha basin, the other two being the main Lake Naivasha and the Crater Lake. The local climate is warm and semi-arid because much of the monsoonal rainfall in the region is intercepted by the Mau Escarpment on the West and the Nyandarua (Aberdare) Range on the East (Verschuren, 1994). Its surface area is 550 hectares, separated from the main lake by the papyrus swamp *Cyperus spp* (Benun and Njoroge, 1999).

The basin of Lake Oloidien is a caldera of a crater with the shape of a truncated cone. It is shallow and lacks direct physical input from the main lake. Verschuren *et al.* (2000) reported that the water level in Lake Oloidien is maintained by rainfall, evaporation, and subsurface inflow from Lake Naivasha through a permeable sill. When Lake Naivasha's level rises above 1,886.5 mamsl, Lake Oloidien becomes confluent with Lake Naivasha and inputs into the Oloidien Bay. Thus, the underground connection allows L. Oloidien levels to fluctuate in synchrony with the main lake (Harper *et al.*, 2011). Consequently, Lakes Naivasha and Oloidien experience periods of being one or separate water bodies. In the 1980s when decreasing lake levels led to a separation of L. Oloidien from L. Naivasha, the conductivity was 660 µS cm^{-1}. In the period 2001–2005, a conductivity of 3,890 to 5,270 µS cm^{-1} was measured (Ballot *et al.*, 2009). The lake has an open, grassy shoreline with no emergent or floating macrophytes.

It was initially believed that Lake Oloidien is too alkaline to support any freshwater fish species but currently, there are ongoing fishery activities at the lake with approximately active 26 boats. This could be attributed to the fact that recently the lake has been connected with the main lake due to an increase in water level. The main sources of nutrient input to Lake Oloidien originate from cattle and goat herds watering at the lake and local women washing clothes using detergents.

Lake Oloidien is threatened by unsuitable physicochemical conditions (Ballot *et al.*, 2009). Its water quality and quantity have been under increasing pressure due to fluctuations in water levels and increasing water demand from the fast-expanding agricultural activities around the lake (Hubble, 2000). Anthropogenic activities within the lake's catchment provide both point and non-point sources of nutrients to the water column. Changes in water quality characteristics have a direct linkage to aquatic production. The rapid growth of human settlement around the lake and the associated urban waste disposal are potential sources of biological micro-contaminants in the lake and could cause undesirable effects on the aquatic environment. This study aimed to ascertain the limnological status of Lake Oloidien over the period 2020 - 2021.

Material and methods

Study area

Lake Oloidien is located about 100 km northwest of Nairobi at an altitude of 1890 m above sea level at 0°48′ 57.3768″ S and 36°15′ 46.7748″ E (Njuguna, 1988; Hickley *et al.*, 2002) (Fig. 1). It is a satellite lake of L. Naivasha found in a hydrologically closed basin. The lake's depth and surface area usually fluctuate depending on the prevailing dry and wet seasons and range between 4-19 m and 4-7.5 km^2, respectively. During periods in which Lake Naivasha's water level is high, it dilutes L. Oloidien, making its water fresh. Conversely, during the dry seasons when the lake water level is low, the two lakes are separated, resulting in a saline Lake Oloidien (Verschuren *et al.*, 1999). Four stations representative of the lake were select-

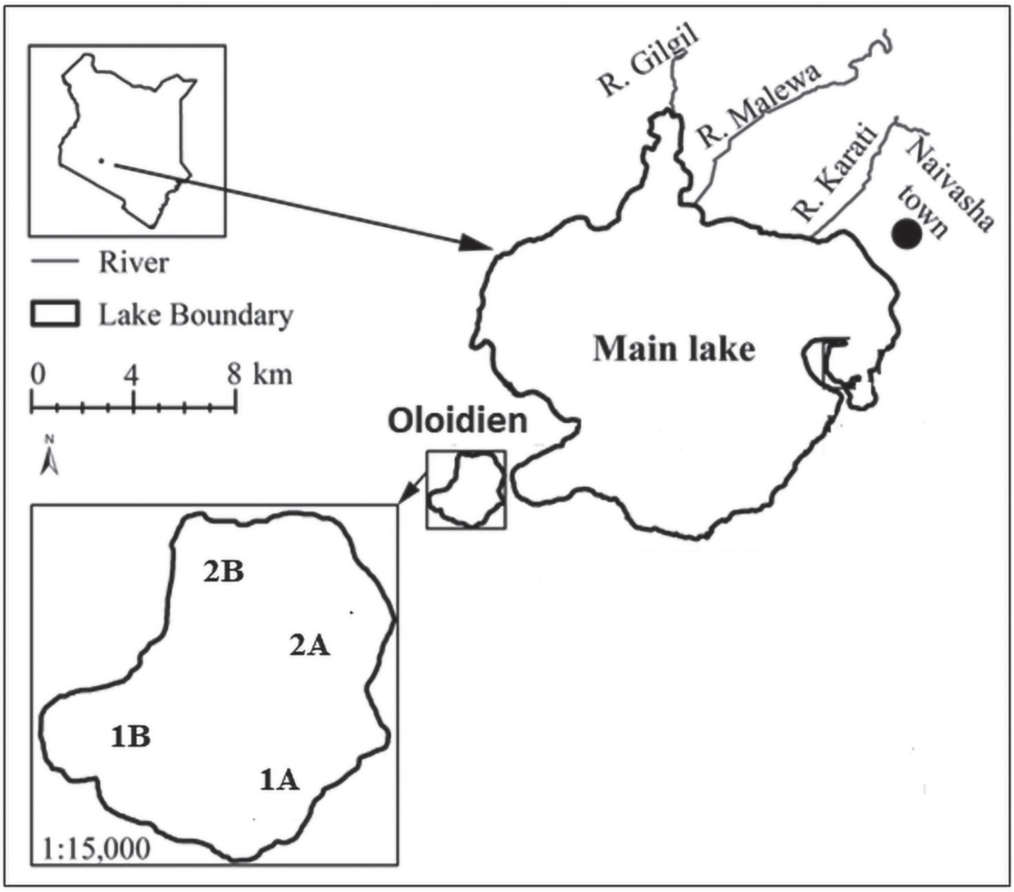

Figure 1. Map of Lake Oloidien showing the sampling stations (Oloidien 1A, 1B, 2A, and 2B) (Source: Maina *et al.* 2018).

ed during the study, i.e. Oloidein 1A, Oloidein 1B, Oloidein 2A, and Oloidien 2B. The study was done between August 2020 and March 2021.

Water sample collection and analysis

Water quality parameters including temperature, pH, dissolved oxygen (DO), conductivity, total dissolved solids (TDS) and salinity were measured *in situ* using a portable multiparameter meter (YSI Professional Pro Plus). The parameters were recorded in each site at a depth of 1 m. Water transparency was measured using a Secchi disk, 20 cm in diameter. The disk was lowered up to the point of its disappearance and lifted to the point of appearance. The average depth of the two points was recorded as water transparency (Secchi depth). Water samples for nitrates, phosphates, total suspended solids (TSS), and Chlorophyll-a (Chl-a) were collected using a Van Dorn sampler and emptied into one-liter polyethylene bottles. The samples were stored in cooler boxes at a temperature of about 4°C for analysis in the laboratory. Samples for Soluble Reactive Phosphorus (PO_4^{3-}) were filtered using 0.45 μm membrane filters followed by the analysis of the filtrate using the molybdate assay method (APHA, 1998). Nitrates (NO_3^-) were analyzed using Palintest Photometer 7500 Bluetooth method. This method uses the principles of optical absorbance and scattering of visible color light representing specific analytes upon reactions with spectrophotometric reagents. Samples for chlorophyll-a determinations were filtered through glass fiber filters and extracted in 90% acetone in distilled water. Chl-a values were measured in a 1.0 cm length cell at the absorbencies of 665 and 750 nm, respectively, using a spectrophotometer and concentration according to Pechar (1987). Total suspended solids (TSS) were determined, first by recording the initial weight of a filter paper before a known volume of sample water was filtered through the same filter paper, and dried in an oven at 104°C for 24 hours. The resultant weight of the filter was recorded as the final weight and TSS was calculated as shown below.

$$TSS\ (mgl^{-1}) = \frac{Final\ weight\ (mg) - Initial\ weight\ (mg)}{Sample\ volume\ (l)}$$

Spatial variations of the same parameters were compared using one-way analysis of variance (ANOVA) at a 95% confidence limit.

Results

Surface water temperature

Figure 2 shows the spatial and temporal variation of temperature in the surface water of L. Oloidien during the sampling period. It comprises a pair of graphs showing a) spatial and b) temporal temperature variations in the lake. Results show that there were no significant variations in temperature between the sampling sites ($p > 0.05$) with mean temperature ranges of 23.15°C to 23.93°C. Temperature values had significant variations ($p < 0.001$) among the months sampled with November and December recording high values at 24.9°C and 24.5°C respectively.

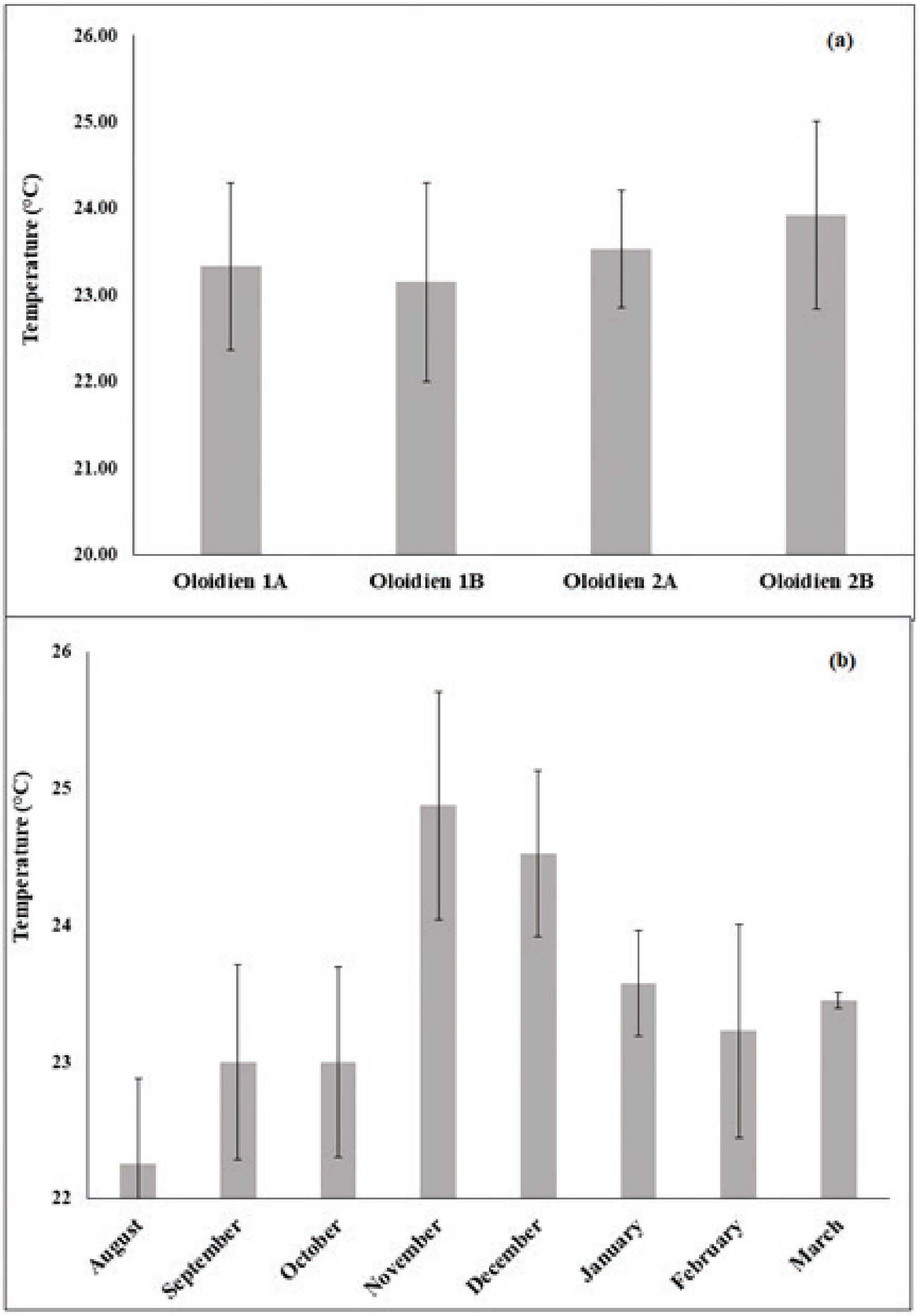

Figure 2. Spatial and temporal variations of temperature (°C) in Lake Oloidien's surface water between August 2020 and March 2021.

Surface dissolved oxygen

Figure 3 shows the spatial and temporal variations of dissolved oxygen (°C) in Lake Oloidien's surface water between August 2020 and March 2021. There was no significant variation (p = 0.69) in dissolved oxygen among the stations sampled. However, there were significant variations ($p < 0.001$) in DO concentrations among the months sampled, with September recording the highest surface DO concentrations at 13.99 ± 0.98 mg.L^{-1} while January recorded the least at 6.88 ± 0.31 mg L^{-1}.

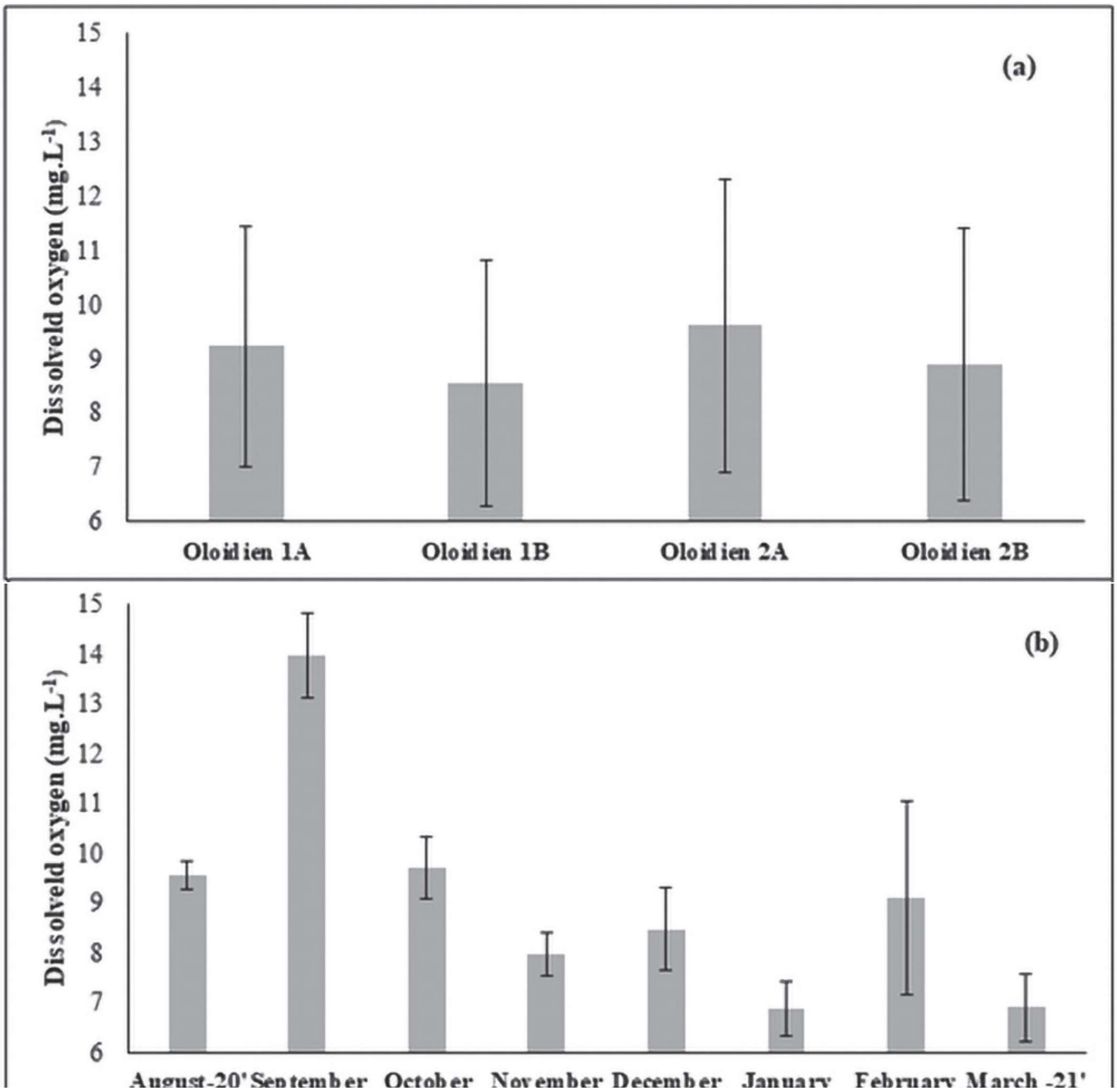

Figure 3. Spatial and temporal variations of dissolved oxygen (°C) in Lake Oloidien's surface water between August 2020 and March 2021.

Vertical patterns of water temperature and dissolved oxygen in the lake

Figure 4 shows the mean vertical temperature and oxygen profiles during the study period. The temperatures decreased gradually from the surface to the bottom with no distinct vertical stratification. Temperature fluctuation between surface water and the deepest point did not exceed 2°C. A rapid change in temperature with depth was only experienced in November, between 0 m and 2-3 m depth. The variations of DO depth profiles between the months differed significantly (p = 7.955E-06), with steep gradients in DO concentration from the surface towards the bottom observed in February while the lowest DO concentrations were recorded at 9 m in November (0.2 mg L^{-1}) and March (0.9 mg L^{-1}).

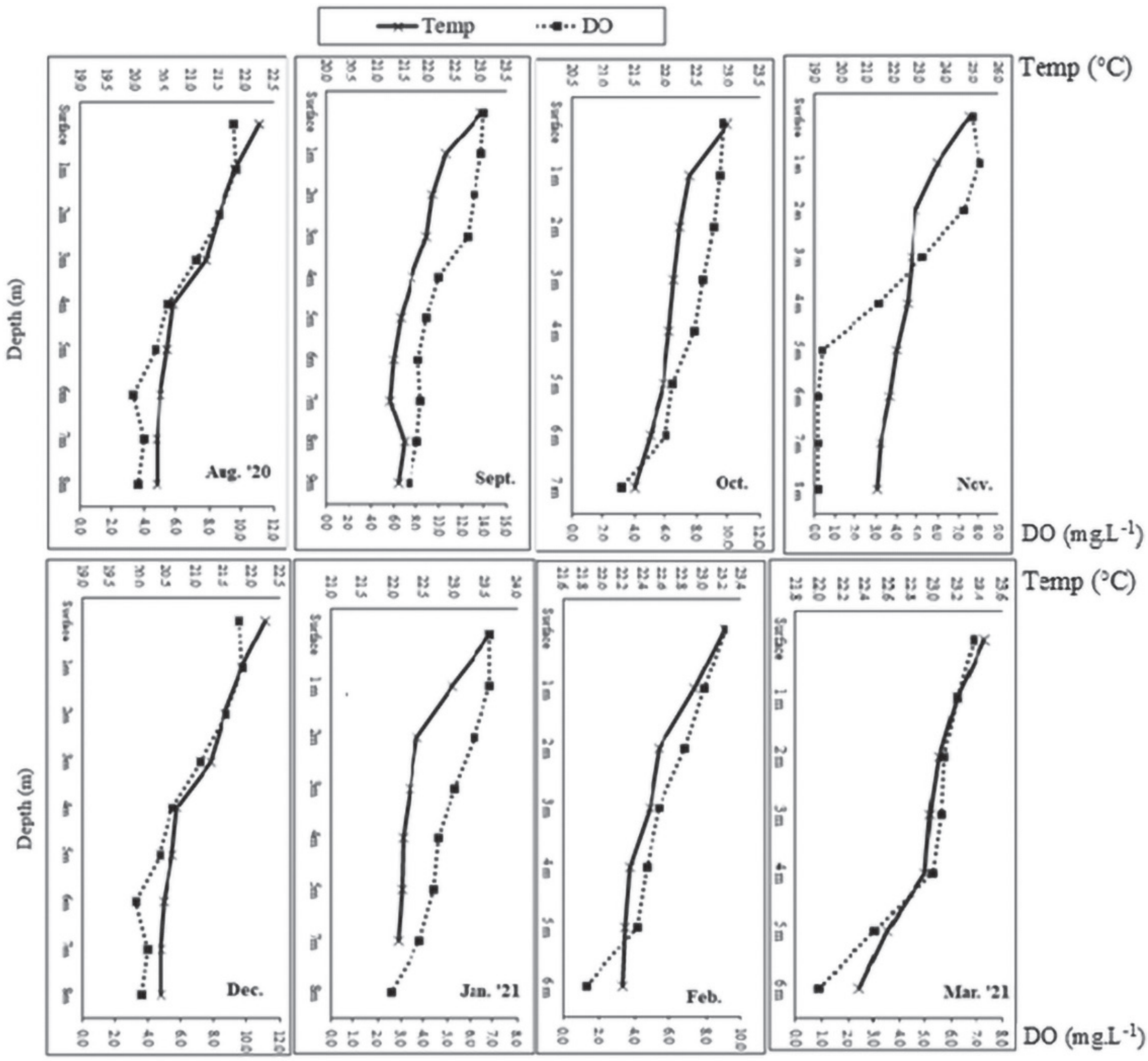

Figure 4. Mean vertical temperature and oxygen profile of L. Oloidien during the study period.

Electrical conductivity and pH

Figure 5 shows the pH levels and conductivity fluctuation in Lake Oloidien from August 2020 to March 2021. The mean conductivity values were observed to increase from August through March, with January recording the highest (730 ± 11.54 µS cm^{-1}). The study observed slightly fluctuating range of pH values between the months. pH values were lowest in August at 7.24 ± 2.00 and highest in February at 9.03 ± 0.01.

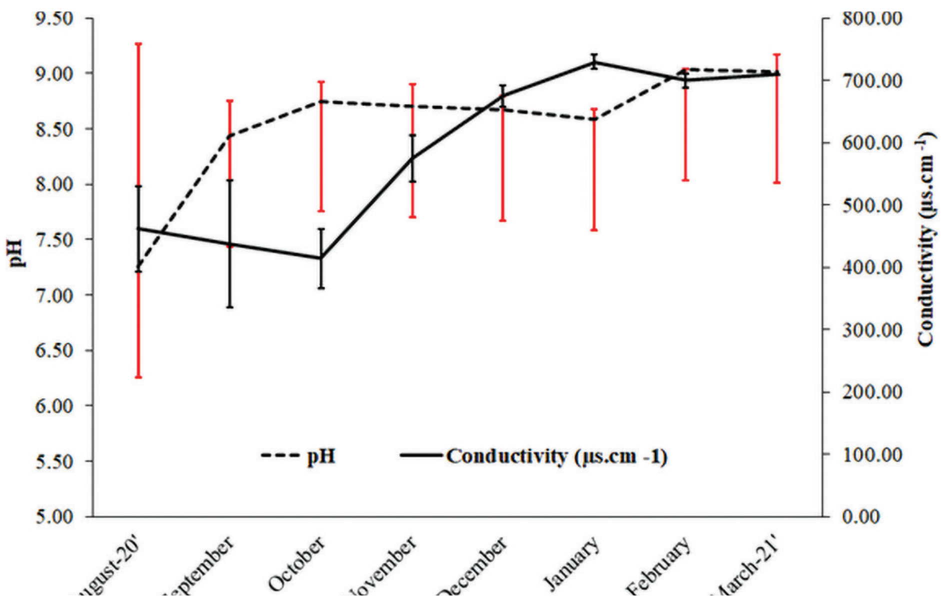

Figure 5. Water pH levels and conductivity fluctuation in Lake Oloidien for August 2020 to March 2021.

Salinity, total dissolved solids, and total suspended solids

The summary of mean values of TDS, Salinity, and TSS is shown in table 1. The results show a slightly increasing trend with small variations in TDS and salinity levels from August to March. Mean TSD values ranged from 0.28 and 0.48 g L^{-1}. It was also observed that salinity levels varied minimally between the stations with November through March having no variations (Table 1). The concentration of total suspended solids ranged between 9.75 ± 2.98 m g L^{-1} and 35.67 ± 18.01 mg L^{-1}, with the highest recorded in August and the lowest in February.

Water transparency and depth

Figure 6 shows the mean Secchi disc readings (water transparency) and mean depth in Lake Oloidien between August 2020 and March 2021. Results show the highest mean depth of the lake during the entire sampling period was 7.7 m in November with the deepest point recorded at 10.15 m in the same month at Oloidien 1B, and the least mean depth recorded in March (5.94 m). The highest water transparency was recorded during the November sampling period with a mean of 69 ± 0.34 cm, while the lowest transparency was observed in August at 36.9 ± 5.4 cm. The overall mean depth of the lake was 6.8 ± 0.71 m. Water transparency readings reflected a significant difference (p = 5.05E-09) across the months.

Table 1: Summary of mean values of TDS, Salinity, and TSS across the sampling months (August 2020 to March 2021)

Month	Mean (±SD)		
	TDS g L^{-1}	Salinity (ppt)	TSS (mg L^{-1})
August -'20	0.31 ± 0.04	0.22 ± 0.033	35.67 ± 18.01
September	0.30 ± 0.064	0.22 ± 0.049	11.63 ± 1.11
October	0,28 ± 0.029	0.21 ± 0.018	15.5 ± 6.02
November	0.37 ± 0.006	0.28 ± 0	18.5 ± 0.57
December	0.44 ± 0.006	0.33 ± 0	23.5 ± 9.33
January	0.48 ± 0	0.36 ± 0	14.33 ± 0.57
February	0.47 ± 0.004	0.35 ± 0	9.75 ± 2.98
March - '21	0.48 ± 0	0.36 ± 0	31.75 ± 7.27

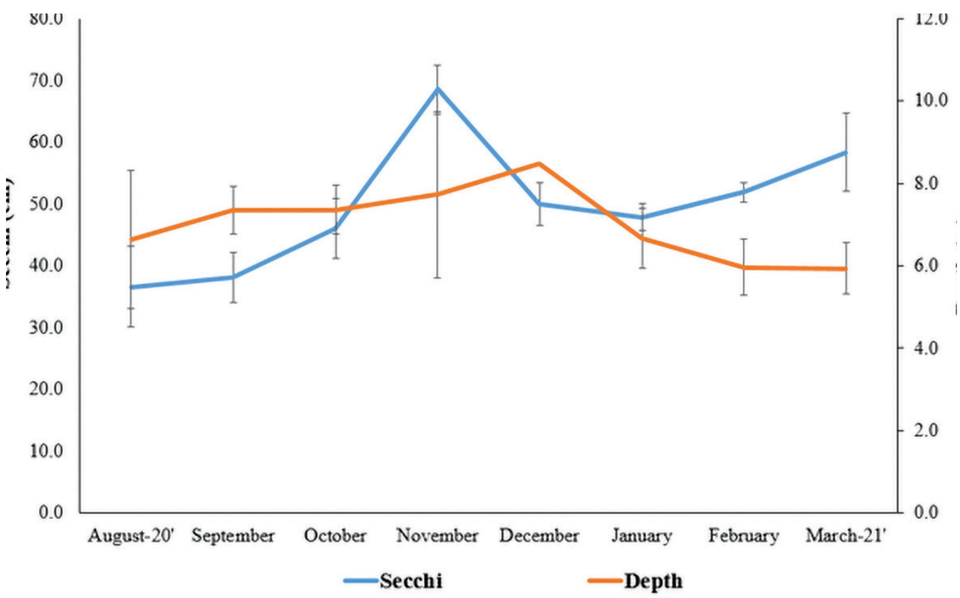

Figure 6. Mean Secchi disc readings (water transparency) and mean depth in Lake Oloidien between August 2020 and March 2021.

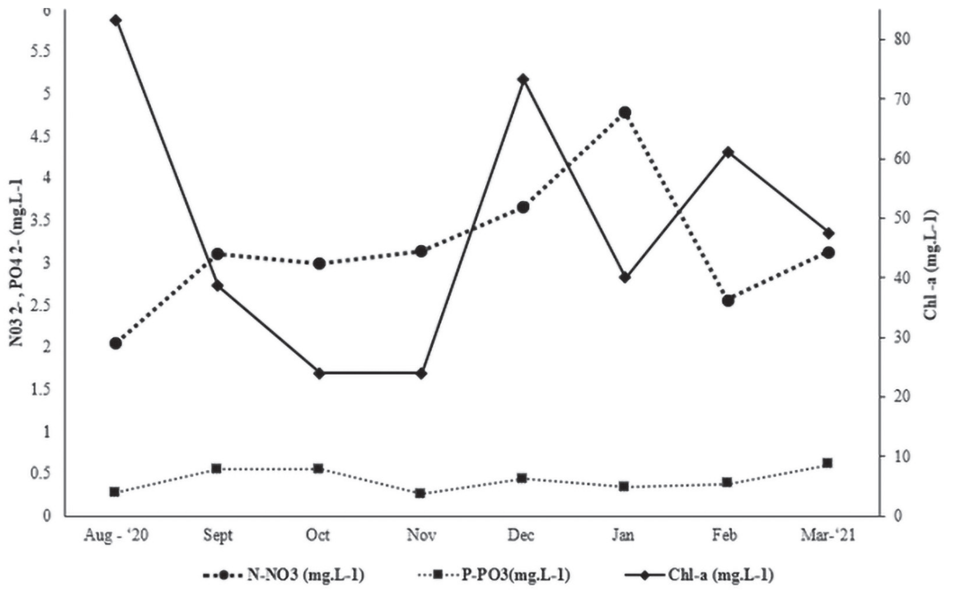

Figure 7. Trends of mean nitrates, soluble reactive phosphorus and chlorophyll-*a*, from August 2020 to March 2021 in L. Oloidien.

Nitrates, phosphates, and chlorophyll-a concentration

Figure 7 shows the trends of mean N-NO_3^- (nitrates), soluble reactive phosphorus, and Chl-a, from August 2020 to March 2021. It was observed that the mean nitrate concentrations across the months ranged between 2.04 ± 1.30 mg L^{-1} and 4.78 ± 0.45 mg L^{-1}. Soluble reactive phosphates (P-PO_4^{3-}) concentrations were below 1.0 mg L^{-1} during the entire sampling period. High levels of Chl-a concentrations were recorded in August (83.3 ± 56.06 mg L^{-1}). It was also observed that when the levels of nitrates were low, Chl-a concentrations were high, and vice versa.

Discussion

Generally, Lake Oloidien has low water transparency as is evident from the observations made in the study, which is an indication of the high biological productivity of the lake. This could be attributed to high levels of Chl-a recorded in this study of up to 83.3 mg L^{-1}. Despite low transparency levels during the sampling period, there was a slight but consistent increase in Secchi depth values over the sampling period. Similar studies have shown an increase in water transparency since the year 2017 (Mutie *et al*., 2020). Tropical lakes are thought to be permanently stratified due to low seasonal variations in temperature (Catalán and Donato-Rondón, 2016). However, the low-temperature gradient between the surface and the maximum depth of measurement and the lack of a permanent thermocline was an indication of the total water mixing of the whole water column. This could be attributed to the shallowness of the lake and a wide-open basin, which allows exposure to the winds, which easily causes mixing. As a result, the water column was found to be well-oxygenated with DO levels ranging from 6.88 mg L^{-1} to 13.9 mg L^{-1}. Surface water was well-oxygenated, but at the bottom, it was depleted of oxygen (anoxic). Studies have shown that the depth of the lake, anaerobic conditions, and prevailing environmental conditions affect the amount of dissolved oxygen in the water (Siriwardana *et al*., 2019). The high levels of dissolved oxygen concentration at Oloidien surface waters could be due to the effect of photosynthesis coupled with the high densities of algae in the water which is evident in the high levels of Chl-a concentration. Photosynthesis is usually highest during mid-day, hence the high production of oxygen during this period of the day led to a significant increase in the amounts of dissolved oxygen in the water. Comparable results from a study done by Grotzschel and Beer (2002) showed that oxygen concentration increased from 0 to 100% saturation due to photosynthetic activity.

Conductivity values observed in this study were generally low (414 - 730 µS cm^{-1}) compared with other studies which documented higher values of conductivity, for instance, Mutie *et al*. (2020) reported a value of 2,916 µS cm^{-1} while Ballot *et al*. (2009) reported 5,270 µS cm^{-1}. The current lower values of conductivity could be attributed to the rising levels of Rift Valley lakes whereby Lake Oloidien is currently connected to the main Lake Naivasha, therefore bringing about the dilution effect. High levels of pH observed during the sampling period were attributed to higher photosynthetic activity and also due to the dilution effect of the rains. Previous studies have shown pH levels of up to 6.6 - 6.71 (Kaoga *et al*., 2013; Mutie *et al*., 2020).

Results from this study indicate that Lake Oloidien is a phosphorus-limited aquatic system. This is in agreement with previous studies. For example, Ballot *et al*. (2009) reported total phosphorus (TP) concentrations of between 0.4 and 1.0 mg L^{-1}. In the same study, nitrogen concentrations range between 0.9 and 6.3 mg L^{-1}, which falls within the same range reported in the current study. It is observed that during the wet season, there are higher levels of nutrients in most lakes, and these are presumably the result of mixing events that redistribute nutrients to the surface water, and inputs from runoff (Zinabu, 2002). Chl-a concentration, which is a proxy for phytoplankton biomass, increased as nitrate concentration decreased. It has been shown that as phytoplankton consume nitrates and bloom, the concentration of nitrate decreases proportionally (Li *et al*., 2010). In the past years, the lake was alkaline and conductivity levels were high, and chances of fish survival were limited. Currently, the environmental factors are more favourable for fish survival as reported by a study by Mutie *et al*. (2020), with *Oreochromis niloticus* condition factor (K) of above 1.

Conclusion

The limnology of Lake Oloidien has changed over time from a shallow saline lake to mildly saline and it can be classified to be productive in its current state. This is based on the physicochemical parameters of the Lake which have changed over time from a shallow saline lake to mildly saline and could be termed as favourable for fishery production.

Acknowledgement

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Profiling pesticide concentrations for sustainable lake-use management in Lake Victoria Basin, Kenya: Are they within the recommended limits?

Christopher M. Aura[1*], Joseph Nyaundi[1], Nathan L. Mrombo[1], Melckzedeck Osore[2], James M. Njiru[2]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 1881-40100, Kisumu, Kenya.

[2]Kenya Marine and Fisheries Research Institute, P.O. Box 81651-80100, Mombasa, Kenya.

*Corresponding author: auramulanda@yahoo.com or aura.mulanda@gmail.com, (+254) 0 711 233774

Abstract

It is crucial to have a coordinated mapping of banned pesticide contaminants in aquatic systems to assess the risks associated with water and fish consumption. The objective of this study was to evaluate pesticide residue levels in Lake Victoria, Kenya, with respect to global thresholds using water and sediment samples collected from representative sites (Kisumu, Awach, Oluch, Mbita, Sondu, and Yala) between 2013 and 2018. The solvent-phase extraction (SPE) method was used to extract the samples. The results of the pesticide distribution analysis in natural water indicated higher mean HCH isomer residues in Winam Gulf compared to open waters. Since water is a vital resource for humans and fish, these concentrations are of particular concern. The highest observed concentration in sediment samples was the mean *p,p'*-DDT (58.80 ± 3.618 $\mu g\ kg^{-1}$). Organochlorine residues in water samples were below the recommended limits set by the World Health Organization (WHO), but sediment samples exceeded these limits. As a result, there is a continuous need for regular monitoring of both local and regional data from point and non-point sources to ensure human and environmental health is safeguarded and to implement mitigation measures.

Keywords: Winam Gulf, pesticides residues, organochlorines, WHO guidelines

Introduction

A pesticide is defined as a substance or a combination of substances designed to prevent, destroy, repel, or alleviate any type of pest, which may include insects, mites, nematodes, weeds, and rats, among others. This category encompasses insecticides, herbicides, fungicides, and a wide range of other compounds used for pest control (US EPA, 2007). The history of pesticides at a global level can be categorized into three distinct phases. The first phase occurred before the 1870s and involved the use of natural pesticides such as sulphur in ancient Greece to manage pests. The second phase took place between the 1870s and 1945 and was characterized by the use of inorganic synthetic pesticides as well as natural substances. The third and most recent phase started after 1945 and has been defined by the use of organic synthetic pesticides known as chemical pesticides, including compounds like DDT, 2,4-D, and later HCH, such as α-HCH, δ-HCH and cyclodienes including endosulfans and methoxychlor (Wasswa *et al.*, 2011; Zhang *et al.*, 2011).

The worldwide consumption structure of pesticides has undergone significant changes since the 1960s. The proportion of herbicides in pesticide consumption increased rapidly, from 20% in 1960 to 48% in 2005 while the proportion of consumption of insecticides and fungicides/bactericides declined despite the increase in their sales (Mbabazi, 1998; Wheelock *et al.*, 2008). The application of chemical pesticides, in particular, organic synthesized pesticides i.e. herbicides greatly protects and facilitates agricultural productivity leading to enhanced agricultural intensification and productivity (Wheelock *et al.,* 2008; Nyaundi *et al.,* 2020). Without pesticide application, the loss of fruits, vegetables, and cereals from pest injury would reach 78%, 54% and 32% worldwide, respectively (Cai, 2008). Crop loss from pests declined to 35% from 42% when pesticides were used (Pimentel, 2009; Dhaliwal *et al.,* 2010). Over the period from 2007 to 2008, herbicides ranked first in three major categories of pesticides (insecticides, fungicides, bactericides, and herbicides). Fungicides and bactericides increased rapidly and were ranked second. Europe is now the largest pesticide consumer in the world, seconded by Asia. In terms of countries, China, the United States, France, Brazil, and Japan are the largest pesticide producers, consumers and traders in the world (US EPA, 2007; Pimentel, 2009; Dhaliwal *et al.,* 2010). Most pesticides are not spontaneously generated and are highly toxic to humans and the environment and their degraded products flow and accumulate freely in the atmosphere, soils, and rivers (WHO, 2019).

Organochlorine pesticides (OCPs) are parts of persistent organic pollutants (POPs), which include HCH, DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, HCB, etc. POPs are a group of compounds that remain intact in the environment for long periods, become widely distributed in nature and accumulate in the fatty tissue of humans and wildlife. Exposure to POPs can lead to serious health effects including certain cancers, birth defects, dysfunctional immune and reproductive systems, greater susceptibility to disease and even diminished intelligence (WHO, 2019). To substitute these persistent organochlorine pesticides, agricultural sectors have shifted towards organophosphate pesticides. However, organophosphate pesticides are generally much more toxic to vertebrates compared to other classes of insecticides even though they rapidly degrade in the environment (Chambers *et al.*, 2001; Gupta and Doss, 2022).

According to the "Stockholm Convention on Persistent Organic Pollutants", nine in twelve POPs are organochloride pesticides and there are more than 26 million human pesticide poisonings with about 220,000 deaths per year (Peter *et al.*, 2002; Richter, 2002; Gunnell *et al.*, 2007). In general, detailed and continuous data are still lacking on the impact of pesticides on human health and the environment (Kubiak-Hardiman *et al.*, 2022). Three major areas of pesticide use in Africa have been and remain agriculture, livestock development, and human health (Wandiga, 2001). Pesticide consumption in Africa accounts for about 3% of global use, with South Africa making up about 2% of pesticide consumption in the world (FAO, 2022).

Lake Victoria is an ecosystem of global concern since it is the largest tropical and the second-largest freshwater lake in the world with a surface area of 68,000 km^2. It is shared by Uganda (43%), Tanzania (51%) and Kenya (6%) (Njiru *et al.,* 2012). In recent years, the ecological health of the Lake is being threatened by rapid urbanization and industrialization. This development, coupled with a population of over 60 million people (Nyamweya *et al.*, 2020) in its catchment area has resulted in increased anthropogenic activities that exert pressure on the lake ecosystem (Banadda *et al.*, 2009; Wasswa *et al.*, 2011). In addition, riparian wetlands which previously played a vital role in tertiary purification of effluent before discharge into the lake have long been encroached on for settlement (Wasswa *et al.*, 2011). Pollution to the environment through pesticide accumulation is one such example of increased anthropogenic influence.

In Kenya, organochlorine pesticides have been in use in farming and livestock since the 1940s (Aucha, 2017). Lindane was the first organochlorine pesticide introduced in 1949 for the control of ticks. This was followed by the import of toxaphene in 1950, DDT in 1956, and dieldrin in 1961 (Abong'o *et al.*, 2014). They were imported for sole use by white farmers for livestock rearing (Aucha, 2017). DDT was banned in Kenya in 1985, while aldrin and dieldrin were banned in 1992 (PCPB, 2022). Organochlorine pesticides which remained officially in use in Kenya are endosulfan, alpha, gamma-BHC, and alachlor (Madadi *et al.,* 2006; Aucha, 2017). Because of its threats to human health and the environment, a global ban on the manufacture and use of endosulfan was negotiated under the Stockholm Convention in April 2011. The ban took effect in mid-2012, with certain uses exempted for five additional years. Most of the pesticides used in the Nyando catchment area are organophosphate and are moderately hazardous, but some individual farmers still use banned or restricted organochlorine pesticides (Musa *et al.*, 2011; Abong'o *et al.,* 2014; Nyaundi *et al.*, 2020).

Incidences of pesticide poisoning of fish were highlighted by the press in May 1999. The fish was purportedly harvested from the lake by using endosulfan; an organochloride insecticide. This resulted in a ban by the European Union (EU) on all fish imports from Lake Victoria (LVEMP and MoALD, 1999), greatly affecting the economies of the three riparian countries. The total loss of income due to the ban was estimated to be more than US $ 300 million (LVEMP 2003). There are individual reports on pesticide concentrations in fish (Henry and Kishimba, 2006), water (Getenga *et al.*, 2004), soil and sediments (Abong'o, 2009; Osoro *et al.*, 2016) and from parts of the lake.

River Nyando, located in Western Kenya, is identified as the most contaminated drainage basin on the Kenyan side of Lake Victoria by Shepherd *et al.* (2000). The river system traverses agricultural and industrial zones, making it a recipient of various pollutants from tea, coffee, lime, and sugar factories that utilize a diverse range of pesticides. Additionally, it exhibits the highest slope and sediment transport rate among all the rivers that flow into Lake Victoria. The unfavourable land-use management practices and excessive use of agrochemicals have led to a high influx of nutrients and sediments, negatively affecting the river and Lake Victoria ecosystems (Peters and Meybeck, 2000).

There is a tremendous need for coordinated and accessible mapping of pesticides and micro-contaminant concentrations in the Lake Victoria Basin to focus on the current pollution status as well as ensure that the fish ban by the EU in 1999 does not recur. Thus the present study sought to provide the status of pesticide concentrations and their impact in Lake Victoria, Kenya, in order to advice on the lake use and fishery industry in relation to the set limits.

Materials and Methods

Study area

The study area constituted sites outside and in Winam Gulf, a shallow inlet connected to the main lake by the deep, narrow Rusinga Channel, about 4 km wide (Fig. 1). The main lake is connected by a narrow channel which is a region of active interchange involving the main lake and the gulf, with an average depth of 8 m, a width of about 25 km and extends for 64 km from Kisumu City to the channel. The gulf receives an average annual river discharge of about 2.4 km^3, hence draining rich intensive farming areas, municipalities, and manufacturing areas, all of which supply heavy loads of suspended sediments and nutrients into the gulf (Njiru *et al.*, 2012).

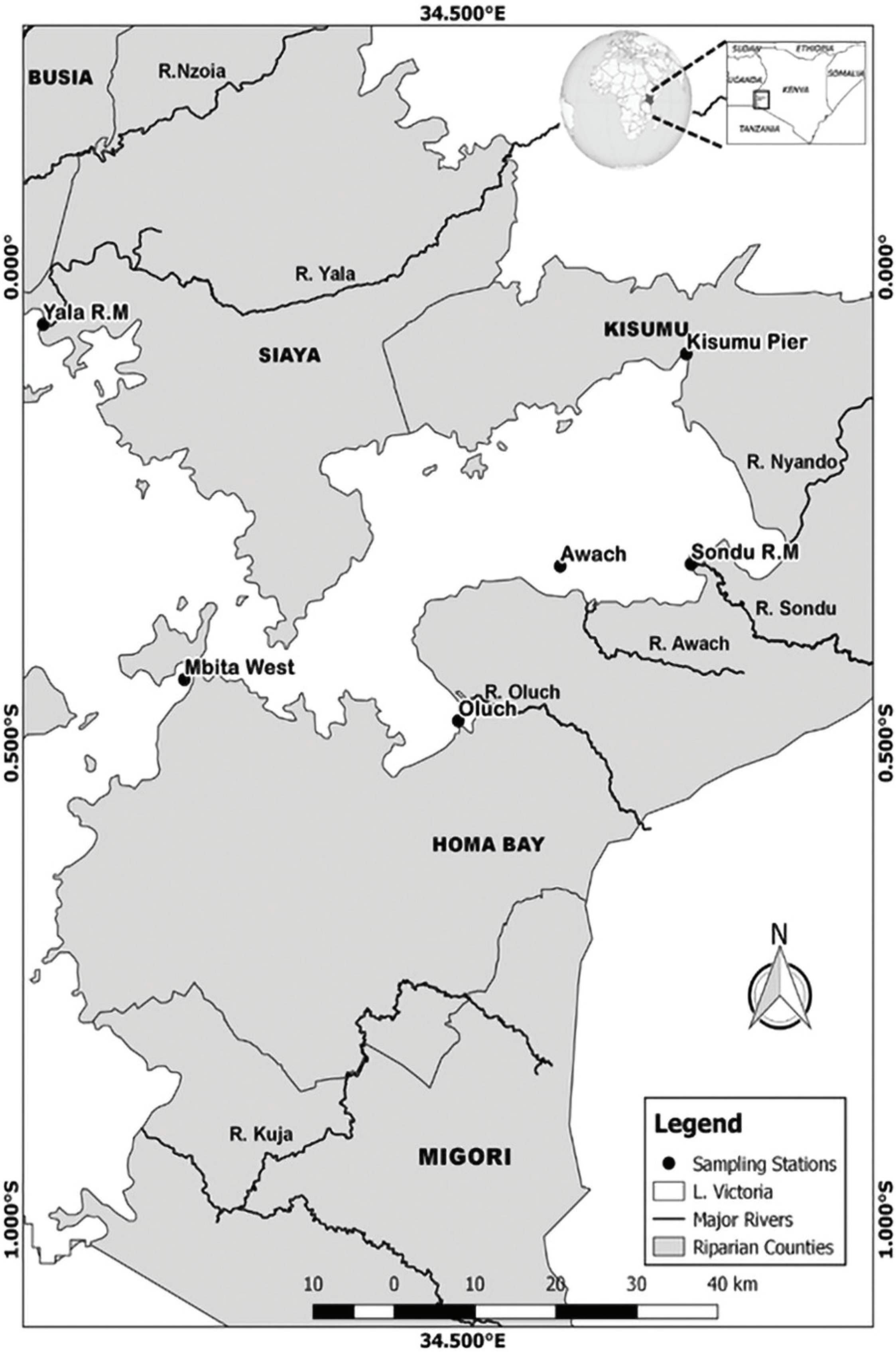

Figure 1. Lake Victoria, Kenya showing the various sites sampled during the study (Source: Authors).

Average rainfall in the eastern side of the catchment is seasonal, about 1,550 mm yr^{-1}, with two maxima. The main rain season occurs between March and May, with an intermittent short rain period (September-November). The minimum monthly air temperatures range from 16.0°C - 18.0°C while the maximum temperatures lie between 27.5°C and 30.0°C. The winds occur in a south-westerly direction and are strongest in the afternoons. The representative sampling sites which included the Kisumu river mouth, Awach river mouth, Oluch river mouth, Mbita river mouth, Sondu river mouth and Yala river mouth (Fig. 1) were chosen since they act as a confluence of anthropogenic discharges.

Sampling regime and sample collection

Sampling and analyses of pesticides were undertaken as per standard methods as shown in various literature (Getenga *et al.*, 2004; Henry and Kishimba, 2006; Abong'o, 2009; Osoro *et al.*, 2016). Figure 2 shows the schematic representation of the procedure undertaken to relate pesticide field data to the set limits. Sampling stations were marked using a GPS (Magellan Global Positioning System, 315 Meridian). Water and sediment pesticide data were taken from six sampling sites on a quarterly basis, between March 2013 and December 2018 in the Winam Gulf, Lake Victoria to coincide with the long rain (April-May), the dry (July) and the short rain (September) seasons. Water samples, taken in composites, were obtained using the grab method (APHA, 2012), into 2.5 L amber glass bottles that had been pre-washed with distilled water and dried.

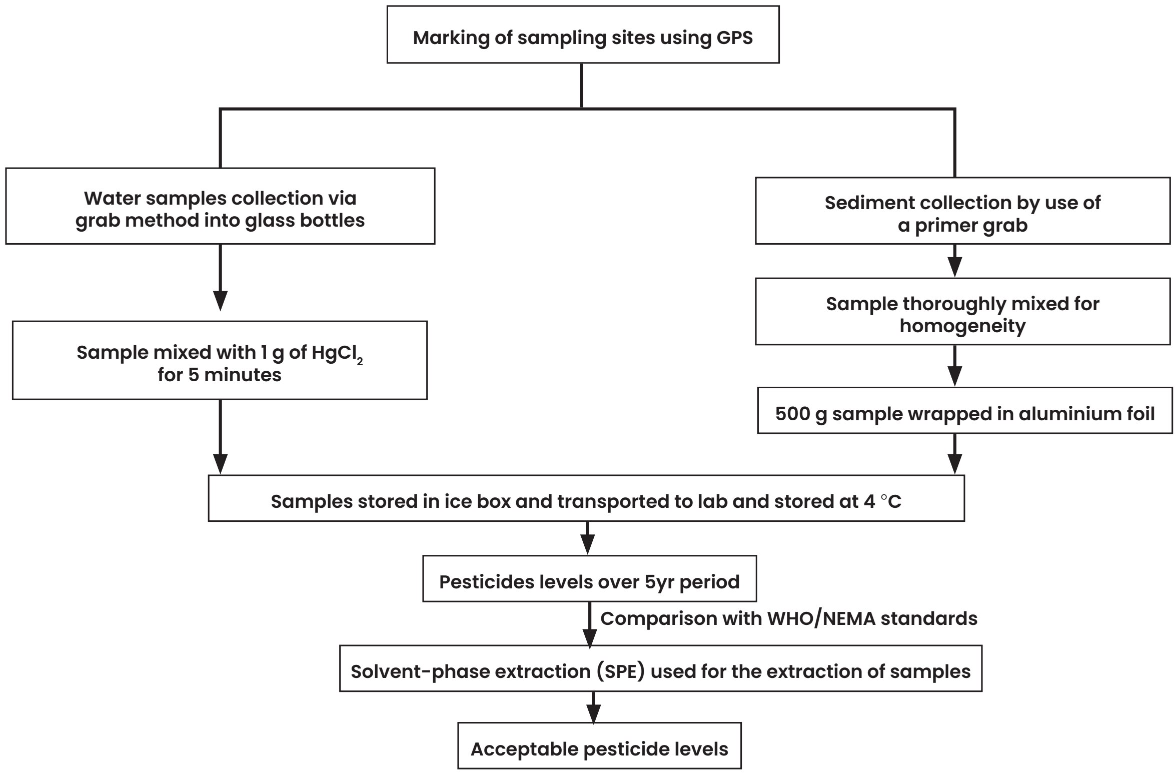

Figure 2. Sampling and sampling preparation framework towards the mapping of pesticide concentrations in Lake Victoria, Kenya.

After the collection of the water samples, 1.0 g of mercuric chloride was thoroughly mixed with the sample for 5 minutes. This was used as a treatment option to avoid the degradation of pesticides by microorganisms. Sediment samples were also obtained from the same sampling sites using a Punner grab and thoroughly mixed to homogenize before a 500 g aliquot was carefully separated and wrapped in aluminium foil. Before extraction, all the samples were temporarily stored in an icebox with wet ice, transported to the laboratory and kept in a standard fridge at 4°C. Solvent-phase extraction (SPE) method was used in the extraction of all the samples.

Sample extraction, clean-up and analysis

The method described is a modified version of the EPA Method 3545 for the extraction of organic compounds from water, soil, and sediment samples as described by Houck (2000) and Krieger (2001). Used glassware was soaked in detergent for 24 hours, washed and rinsed in distilled water before being oven-dried at 100°C for 24 hours. Solvent-phase extraction (SPE) method was used in the extraction of water samples. Subsequently, 50 ml of 0.2 M dipotassium hydrogen phosphate buffer was added to a water sample of 2.0 L and later transferred into a separatory funnel. Its pH was adjusted to 7.0 by adding drops of 0.1 M sodium hydroxide and 0.1 M HCl solutions to neutralize the sample. About 100 g sodium chloride was then added to salt out the pesticides from the aqueous phase, while slowly releasing pressure, 60 mL triple distilled dichloromethane (DCM) was added to this solution and shaken for two minutes.

Separation of the phases was achieved after allowing the sample to settle for 30 minutes. A 250 mL Erlenmeyer flask was then used to collect the organic layer and extraction was repeated twice using 60 mL portions of dichloromethane. After storage in a refrigerator at 4°C, the extracts were combined and cleaned by passing them through an Al_2O_3 chromatographic column topped with anhydrous sodium sulphate. Pesticide residues were sequentially eluted with 175 mL n-hexane. It was necessary to concentrate the elutes to 1 mL using a rotary evaporator at 40°C, and to reconstitute them in 0.5 mL HPLC grade isooctane for GC analyses.

Before mixing, the sediment samples were allowed to thaw for 4 hours in the laboratory. The EPA method 3540 Soxhlet extraction of sediments was then applied before transferring the sediment samples to the Soxhlet thimble. Triplicates of 20 g samples were dried overnight using activated anhydrous sodium sulphate (Na_2SO_4), then extracted with 200 mL of hexane to acetone (3:1 v/v) in 250 mL round-bottomed flasks for a minimum of 16 hours.

After storage in a refrigerator at 4°C, the extracts were combined and cleaned by passing them through an Al_2O_3 chromatographic column topped with anhydrous sodium sulphate. The elutes were concentrated to 1 mL using a rotary evaporator at 40°C, and reconstituted in 0.5 mL HPLC grade isooctane for GC analyses. The final samples were analyzed by a Varian Chrompack CP-3800 GC equipped with an electron capture detector, under the conditions specified. The following organochlorine pesticide residues were identified: α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p'*- DDD, *p,p'*-DDE, *p,p'*-DDT, aldrin, endrin, dieldrin, endrin aldehyde, endosulfan I, endosulfan II, endosulfan sulphate, heptachlor, heptachlor epoxide, and methoxychlor.

Quality control

Replicate sampling was employed as well as extraction and analysis of the samples collected for quality control and assurance. The detection limit of each pesticide investigated was handled using international standards and pure distilled water as blanks. Spiking of water samples was carried out using 2 L of distilled water and sediments busing 20 g of anhydrous Na_2SO_4 to a sample concentration of 0.1 μg L^{-1}.

Identification and quantification of pesticide residues in the samples obtained were done by the use of a high-quality pesticide standards mixture of over 99% purity. The pesticide standards were obtained from Dr. Ehrenstorfer GmbH, (Augsburg, Germany). Solvents such as dichloromethane (DCM), acetone, isooctane, and hexane were sourced from Fisher Scientific (USA). Other consumable chemicals such as hydrochloric acid (HCl), methanol (CH_3OH), sodium chloride (NaCl), aluminium oxide (Al_2O_3), sodium hydroxide (NaOH), copper (Cu) and anhydrous sodium sulphate (Na_2SO_4), all of analytical grade, were also obtained from Fisher Scientific (USA). General purpose reagents (GPR) were triple distilled in all-glass apparatus before use.

Data analysis

The data obtained were recorded in MS Excel sheets and subjected to analyses in R version 3.5.0 (R Core Team, 2014). The significance level was set at $p < 0.05$. The ranges and means for the pesticides were obtained for comparison with the National Environment Management Authority (NEMA) and the World Health Organization (WHO) recommended guidelines.

Results and discussion

The study revealed a total of 17 different organochlorine pesticides (OCPs): α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p'*- DDD, *p,p'*-DDE, *p,p'*-DDT, aldrin, endrin, dieldrin, endrin aldehyde, endosulfan I, endosulfan II, endosulfan sulfate, heptachlor, heptachlor epoxide, and methoxychlor, both in water and sediment samples over a period of five years. Organochlorine pesticide residues from six target sampling sites ranged from below detection limit (BDL) to detection level, indicating local input of the detected contaminants within the study area. NEMA and WHO pesticide threshold limits in Lake Victoria, Kenya, are listed in table 1. Concentrations from analyzed water and sediment samples produced a total of 17 different organochlorine pesticides (OCPs) identified during the study period (Table 2).

Table 1. Pesticide limits in water and sediments as recommended by NEMA and WHO (FAO and WHO, 2016).

Pesticide Name	NEMA ($\mu g\ L^{-1}$)	WHO ($\mu g\ L^{-1}$)
Aldrin	0.03	0.03
Endrin	NR	0.6
p,p'-DDT	2	1
Heptachlor	0.03	0.03
Heptachlor Epoxide	0.02	0.03
Endrin Aldehyde	NR	0.6
α-HCH	2	2
β-HCH	2	2
γ-HCH	2	2
δ-HCH	2	2
Endosulphan I	0.01	-
Dieldrin	0.25	0.03
Endosulphan II	0.01	-
Methoxychlor	20	20
Endosulphan sulphate	-	-
p,p'- DDD	-	1

Table 2. Overall mean pesticide residues for the period from 2013 to 2018 in Lake Victoria, Kenya in relation to WHO-recommended concentration limits.

Pesticide	Water (µg L^{-1})	Sediment (µg L^{-1})	WHO (µg L^{-1})
α-HCH	0.03	39.67	2
β-HCH	0.13	8.69	2
g-HCH	0.02	12.56	2
d-HCH	0.03	14.32	2
Heptachlor	0.13	25.81	0.03
Aldrin	0.06	21.45	0.25
Heptachlor Epoxide	0.08	15.93	0.02
Endosulphan I	0.01	36.99	0.01
p,p'-DDE	0.02	4.78	0.01
Endrin	0.02	12.58	0.01
Dieldrin	0.01	26.63	0.25
Endosulphan II	0.03	12.05	0.01
p,p'- DDD	0.04	8.76	0.01
Endrin Aldehyde	0.06	44.93	0.03
p,p'-DDT	0.21	58.80	1
Endosulphan sulphate	0.29	44.18	0.01
Methoxychlor	0.76	24.67	20

Exposure to methoxychlor, an insecticide, can occur when spraying deter insects such as mosquitoes, cockroaches and flies and is known to be toxic both to aquatic animals and humans. Additionally, methoxychlor can bio-accumulate in the tissues of these organisms. Mean results from this study indicated that methoxychlor residue levels ranked highest in water samples analyzed from the Kisumu Bay site (1.31 ± 0.002 µg L^{-1}), Mbita (1.13 ± 0.01 µg L^{-1}), Sondu Miriru (1.05 ± 0.005 µg L^{-1}) and Yala (0.79 ± 0.2 µg L^{-1}) and second highest in Oluch (0.13 ± 0.003 µg L^{-1}) and Awach (0.14 ± 0.002 µg L^{-1}) (Fig. 5). However, this was still well below WHO threshold levels of 20 µg L^{-1} in natural water (Fig. 3). Overall results obtained in all the target sites indicated that it recorded the highest score in sampled water, at a mean value of 0.76 ± 0.003 µg L^{-1}. This indicates that either methoxychlor is still being used on crops, livestock, and in animal feed or carried downstream via runoff. Once methoxychlor is deposited in the ground after its application on forests, food crops and animals, it adheres strongly to the soil. These soil particles are either blown by the wind or carried downstream as runoff (Rodríguez-Eugenio *et al.,* 2018).

Endosulfan sulphate in water samples was the highest in Awach (0.19 ± 0.01 µg L^{-1}), followed by Sondu Miriu (1.04 ± 0.002 µg L^{-1}) and Oluch (0.06 ± 0.001µg L^{-1}) (Figs. 3 & 5). Overall, endosulfan sulphate ranked second highest in analyzed water samples (0.29 ± 0.005 µg L^{-1}) and the third highest in sediment samples (44.18 ± 1.412 µg L^{-1}) within the period under study (Fig. 6). NEMA (2012) provides no guideline value for endosulfan sulphate since its occurrence in drinking water is documented to be at concentrations that don't arouse health concerns. Mean *p,p'*-DDT pesticide concentrations for water samples were the highest in Sondu Miriu (0.63 ± 0.004 µg L^{-1}) and lowest at Awach (0.08 ± 0.0001 µg L^{-1}) (Fig. 3). The concentrations were well below the WHO-recommended value of 1 µg L^{-1}. *p,p'*-DDT ranked first in sediment samples from Kisumu (92.01 ± 5.162 µg L^{-1}) and first in the overall concentrations of the sediment samples over a five-year span with 58.80 ± 2.013 µg L^{-1} (Table 2).

Cases of DDT use have been reported previously in vector-borne disease control efforts within the Lake Victoria Basin, and it is known to survive in soils and air for up to 30 years. In addition, a study by Golfinopoulos *et al.* (2003) has shown that thunderstorms and rains could cause residual DDT to be carried in flush floods, ending up in the lacustrine ecosystems. A study carried out by M'Anampiu (2011) also revealed that the degradation of DDT and mirex in exposed fish was very slow compared to other pesticides and that there was very little excretion of the pesticide via urine and gills even after 48 hours of exposure and this can pose very serious public health concerns.

Analyzed bottom sediment samples showed methoxychlor pesticide residue levels with high mean concentrations which were above the WHO global recommended standards of 20 µg kg^{-1}. Kisumu Bay site recorded a high mean value of 82.07 ± 3.201 µg kg^{-1}, while 44.79 ± 1.271 µg kg^{-1} was recorded at the Oluch station and 115.59 ± 4.372 µg kg^{-1} in the Sondu Miriu sampling station (Figs. 4 & 6).

Mean endosulfan pesticide concentrations in bottom sediments was four times higher in the Awach sampling station (144.42 ± 1.072 µg kg^{-1}) as compared to the Sondu Miriu site (59.01 ± 3.102 µg kg^{-1}) (Figs. 4 & 6). However, its environmental impact on other organisms should be taken into consideration. Endosulfan sulphate has not been classified by NEMA as toxic since its quantities in natural water are much lower (NEMA, 2012). However, according to a study conducted by Shetty *et al.* (2000) on the biodegradation of cyclodiene insecticide endosulfan by *Mucor thermohyalospora,* it was reported that endosulfan, a parent compound, can be persistent and toxic to non-targeted organisms such as fish and should therefore be of environmental concern (Singh and Singh, 2011).

The concentration of DDT in water samples is considered more significant compared to its levels in the sediments due to its availability in the former for use by humans and fish. Results from this study, however, showed concentrations that were below the recommended limits by FAO/WHO compared to residue levels in sediments whose values were way above these globally recommended standards. The presence of DDT pesticides in analyzed sediment samples, although it had been banned from use decades ago in Kenya (1994), could probably be due to previous use in the catchment under study (Mbabazi, 1998; Getenga *et al.*, 2004; Nyaundi *et al.*, 2020) as it is known to bio-magnify and persist in the environment for a long period.

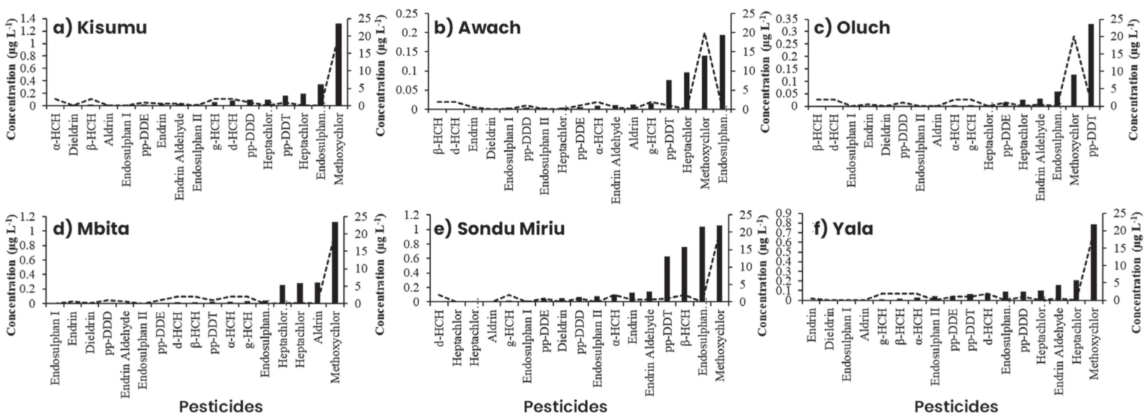

Figure 3. Organochlorine pesticide residue means in water samples from the selected study sites in Lake Victoria, Kenya over a five-year period from 2013 to 2018. The dotted line represents WHO recommended limits.

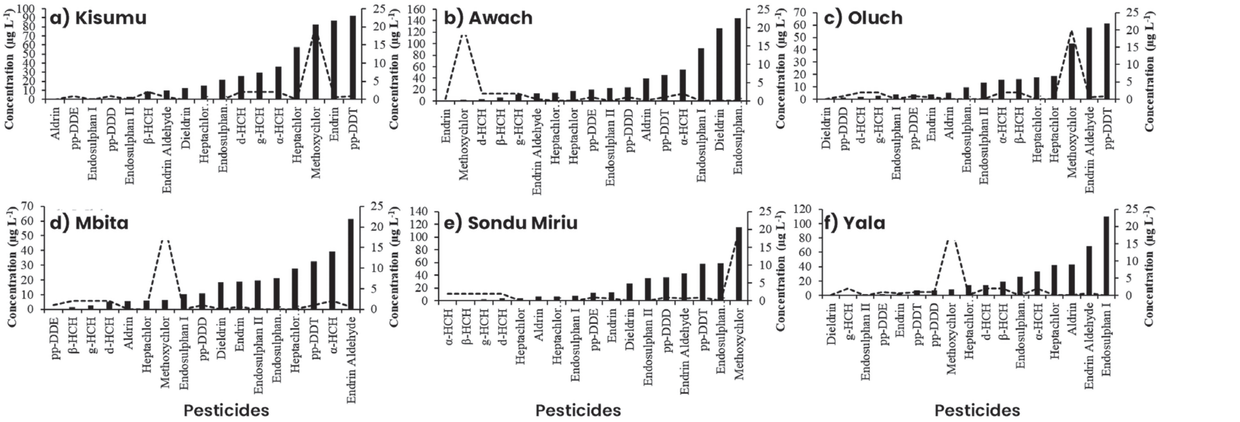

Figure 4. Organochlorine pesticide residue means in sediment samples from the selected study sites in Lake Victoria, Kenya over a five-year period from 2013 to 2018. The dotted line represents WHO recommended limits.

Heptachlor pesticide and its oxidized product heptachlor epoxide were detected in water samples in insignificant spatial variations (p = 0.142). However, the Yala river mouth sampling station showed a mean value of heptachlor in sampled water at 0.21 ± 0.004 µg L^{-1} residue level whereas heptachlor epoxide recorded a mean value of 0.1 ± 0.001 µg L^{-1}. At the Mbita sampling site the values recorded for heptachlor were 0.27 ± 0.02 µg L^{-1} and 0.26 ± 0.006 µg L^{-1} for heptachlor epoxide while at the Kisumu station, the mean contamination levels recorded for heptachlor were 0.17 ± 0.002 µg L^{-1} and 0.1 ± 0.0001 µg L^{-1} for its degraded compound, heptachlor epoxide (Fig. 3).

Concentrations of the parent compound heptachlor and its dissipated compound heptachlor epoxide in sediment samples were detected at varying levels during the study. Mean residue levels were recorded as: 57.84 ± 2.016 µg kg^{-1} and 14.89 ± 1.732 µg kg^{-1} in Kisumu; 42.24 ± 3.005 µg kg^{-1} and 0.02 ± 0.001 µg kg^{-1} in Yala, 18.46 ± 0.8421 µg kg^{-1} and 17.85 ± 2.003 µg kg^{-1} in Oluch and 6.09 ± 0.005 µg kg^{-1} and 27.83 ± 2.021 µg kg^{-1} in Mbita for heptachlor and heptachlor epoxide pesticides in sediment samples, respectively (Fig. 4). The overall concentrations for the period under study were 0.13 ± 0.006 µg L^{-1} and 0.08 ± 0.0001 µg L^{-1} for heptachlor and heptachlor epoxide,

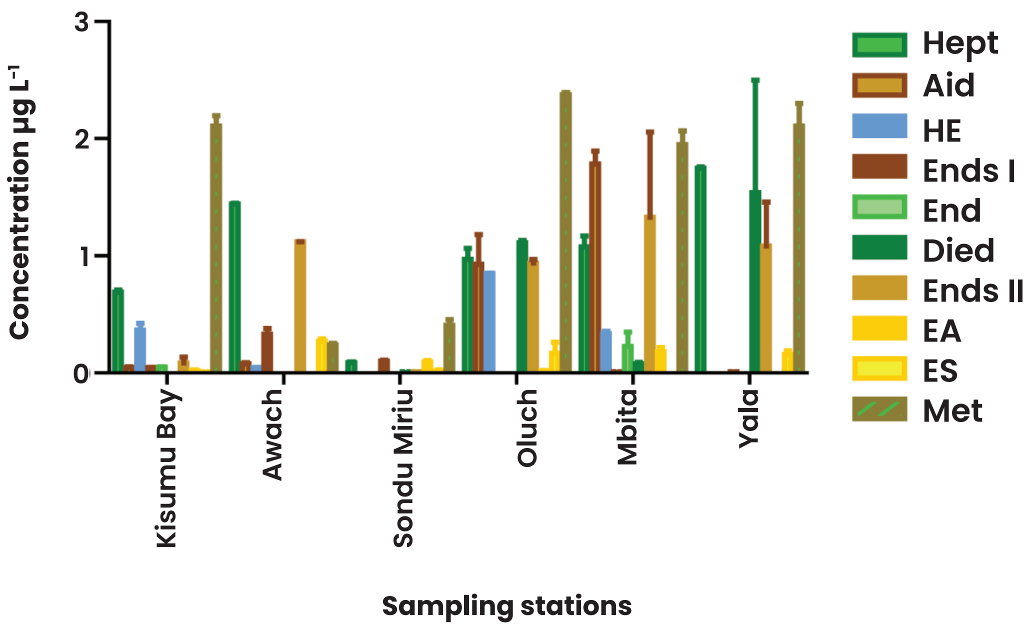

Figure 5. Generated pesticide levels in water obtained from the sampling stations during the study period.

respectively, in water samples and 25.81 ± 2.021 µg kg^{-1} and 15.93 ± 3.101 µg kg^{-1} heptachlor and heptachlor epoxide, respectively for sediment samples (Table 2).

The sample analysis results show that these concentrations were above the NEMA recommended value of 0.03 µg kg^{-1} for both heptachlor and heptachlor oxide in bottom sediment samples. The presence of heptachlor and its degradation product is an indication that heptachlor has been used in the area in recent times and is still currently in use. The higher concentration of heptachlor epoxide compared to heptachlor in Mbita shows that the rate of application was higher in the past than it is currently according to Abong'o *et al.* (2015), since this is a degraded compound from its parent compound. Heptachlor residues were detected probably due to its application as a household insecticide, termite control agent as well as an herbicide, in agricultural settings whereby it ended up being transported downstream as runoff. These levels should be of concern since heptachlor and heptachlor oxide have been reported by ATSDR to accumulate in fish, livestock and the body fat of humans and could still be detected up to three years after exposure (SRC, 2007). Prolonged exposure to these compounds can cause humans to experience dizziness, weakness, headache and feelings of 'prick and pin' on human skin (Hughes *et al.,* 2014).

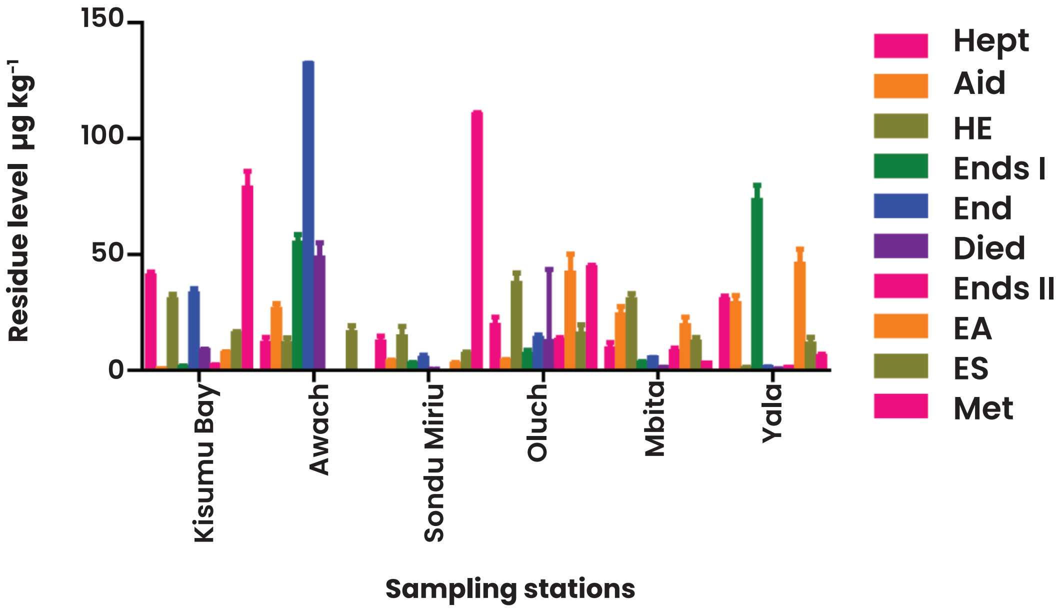

Figure 6. Generated pesticide levels as observed in sampled stations during the sampling period.

Endrin was undetectable in water samples from other sampled stations, except in the Kisumu Bay site (0.02 ± 0.0001 µg L^{-1}) and Sondu Miriu (0.13 ± 0.0001 µg L^{-1}) analysed water (Fig. 3). In the bottom sediment samples, endrin concentrations recorded were higher, at 86.7 ± 4.061 µg kg^{-1} in Kisumu, 19.2 ± 0.007 µg kg^{-1} in Mbita, and 13.13 ± 1.002 µg kg^{-1} residue levels in Sondu Miriu sampled stations (Fig. 4). Overall, endrin had a concentration of 0.01 ± 0.001 µg L^{-1} and 12.58 ± 0.724 µg kg^{-1} for water and sediment samples, respectively (Table 2). These concentrations were well above the WHO recommended limit of 0.6 ± 0.003 µg L^{-1} for drinking water as mean values observed in bottom sediments in this study exceeded the global thresholds. There is need to ensure continuous pesticides monitoring of its spatial and temporal loading variations since endrin can persist in the soil for more than a decade, and exposure to it causes severe harmful health effects to the central nervous system, vomiting, and convulsions and eventually leading to death in humans and livestock (Pathak *et al.,* 2022).

According to Abong'o *et al.* (2014), the main sources of organochlorine pesticide residues in the Lake Victoria region are agricultural activities and use for public health vector control, such as mosquitoes. The high levels of pesticide residues detected in the sediments during this period occurred during the wet season and this was attributed to the runoff from the farms where the pesticides were previously applied. No organophosphates were detected in any of the water and sediment samples. *p,p'*- DDD which was identified at all sampling sites over a five-year span. Its results showed a markedly higher concentration followed by cyclodienes and the least was HCHs, in the order (DDTs > cyclodienes > HCHs), respectively.

Detection of pesticides methoxychlor, endosulphan, heptachlor, endrin and DDT which stand banned in Kenya pose serious risks to public health. According to Abongó *et al.* (2014), in a study on the impacts of pesticides on human health and the environment in the River Nyando catchment, pesticides were responsible for the development of symptoms of ill health where several farmers fell ill after exposure to these pesticides, although the authors could not point to any specific pesticide. For example, pesticides such as heptachlor have been reported to be highly toxic to humans causing hyperexcitation of the central nervous system and harm to the liver (US EPA, 2007).

Conclusion and recommendations

Even though a ban on the use of these OCPs took effect in Kenya almost two decades ago, the results of this study indicate that they are still within the Lake Victoria Basin. Fluxes were noted between different sampling sites with some residual concentrations, especially in sediments exceeding the WHO and NEMA recommended limits. Notably, concentrations in water samples than in sediments are considered crucial in this case due to their direct availability for use by biota and humans. However, public health may be under threat owing to the continued use of contaminated water since compounds such as heptachlor are persistent organic pollutants capable of biomagnifying in the food chain (Pérez-Ruzafa, 2000).

The rapid population growth and urbanization within Lake Victoria Basin in the last decade, coupled with intensive agricultural practices for food could be attributed to these pesticide residues encountered during this study. Therefore, due to environmental and public health concerns, there is a need for continuous mapping of point and non-point sources of pollution and monitoring of residual levels of these organochlorines to help in providing mitigation measures.

Acknowledgement

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Comparative growth performance of marine Tilapia (*Oreochromis niloticus*, L.) cultured in *hapa* nets at different stocking densities using animal and plant protein diets

Anthony M. Kamau[1]*, Esther W. Magondu[2] and Fredrick L. Tamooh[1]

[1]Kenyatta University, P.O. Box 16778-80100, Mombasa, Kenya.
[2]Kenya Marine and Fisheries Research Institute, P.O. Box 81651-80100, Mombasa, Kenya
*Corresponding author: kamaumbuthia30@gmail.com, (+254) 0 797 327161

Abstract

Aquaculture as an enterprise is hampered by the high cost of fish-based protein diets which account for 30 - 70% of the production cost. Alternative plant-based protein diets are paramount in guiding fish farmers on feed efficacy and fish stocking densities. This study analyzed the growth performance of marine acclimatized Nile tilapia (*Oreochromis niloticus*) using fish meal (animal protein), soybean (plant protein) and wheat bran (control) formulated diets. Nile tilapia fingerlings weighing 13 -17 g were cultured in *hapa* nets in three concrete-based ponds at stocking densities of 15 fish/m^3, 10 fish/m^3 and 5 fish/m^3 for each feed treatment. Monitoring of water quality parameters (temperature, dissolved oxygen (DO), and salinity), as well as the initial and final fish body length and weight, was done fortnightly during the experimental period. Two-way ANOVA was used to determine if stocking density and feed treatment(s) had a significant effect on fish growth performance. Weight gain was highest in fingerlings cultured using the soybean-formulated diet (10.28 ± 2.44 g). Marine acclimatized *O. niloticus* fingerlings had a high feed utilization for soybean meal. The stocking density of 5 fish/m^3 recorded the highest percentage survival rate of 85.6% on wheat bran treatment. An optimal stocking density of 5 fish/m^3 is therefore recommended to optimize and maximize their fish production.

Keywords: fish meal, alternative proteins, optimal stocking density, Nile tilapia

Introduction

Globally, human population is on the rise and is projected to hit the 8 billion mark by the year 2030 (Khan *et al.*, 2013). According to the UN-FAO (2000), seafood consumption is projected to reach between 150-160 million tons per year in 2030. However, with the rampant decline in wild capture fisheries due to the overexploitation of fisheries resources, achieving this target is not possible without calling upon the aquaculture sector to fill in the gap (Khan *et al.*, 2013). Aquaculture is expected to compensate for the decreasing fish protein from the capture fisheries and hence bridge the gap between demand and production.

In the aquaculture industry, fish feeds comprise the main input in fish production, accounting for 30 - 70% of the cost of production (El-Sayed *et al.*, 2004). Therefore, efficient feeds are a necessity for profit realization in aquaculture. Additionally, balanced diet feeds, sound nutrition and adequate feeding are essential to the production and culture of fish in captivity (Khan *et al.*, 2013). With an estimated more than 1 billion people relying on fish as the major protein source in their diets, aquaculture is likely to play a critical role in food security by combating hunger and boosting human health by contributing towards the elimination of malnutrition (Pradeepkiran, 2019).

For optimum fish growth, lipids, carbohydrates and proteins are essential macronutrients required in the rearing of Nile tilapia, *Oreochromis niloticus*. Most importantly, protein is critical to good health, nutrition and the physiological processes of fish including energy production (Banrie, 2013). In the intensive farming of *O. niloticus*, proteins are provided in form of shrimp meal, fish meal and fish oil.

As an animal-based protein, fish meal has been the main source of protein in the aqua feed industry due to its palatability and well-balanced amino acid profile (Al-Thobaiti *et al.*, 2017). Imbalances may however be created among animal-based proteins due to lack of one or more essential amino acids (Tacon, 1993). Moreover, volatility in fish meal supply and the high demand by the livestock feed industry has led to prolonged efforts in seeking alternatives. Plant-based proteins such as soybean meal can be viable alternatives due to their relatively low cost, availability and their capability to partially or completely reduce reliance on high-cost fish meal. However, plant-based proteins are deficient in essential amino acids such as methionine, lysine, tryptophan and isoleucine.

Overdependence on fish meal as a feed constituent has resulted in increased pressure on natural marine resources especially the reduction of pelagic fisheries known for their source of fish meal and fish oil (Kaushik and Hemre, 2008). This can lead to a disruption in the marine ecosystems' food chain. Therefore, there is need for concern over striking a balance between reducing the overdependence on fish oil and fish meal in the aqua feed industry, while at the same time meeting the amino acid and protein requirements of fish (Kaushik and Hemre, 2008). For future development of the aquaculture sector, fish meal replacement with locally available and cheap feedstuffs is recommended (Khan *et al.*, 2013).

The government of Kenya has played a significant role in boosting aquaculture since the year 2006. The stagnation of the sector since its inception in 1950 was due to lack of efficient feeds for various stages of fish development and the availability of low-quality seed (Munguti *et al.*, 2014). Aquaculture in Kenya has made tremendous progress and is expected to grow even further with the government's and other stakeholders' support. However, this may only be achieved if a response is made to address the compelling need for restructuring the fish feed industry. Over time, lack of quality feeds has been the main challenge among the fish farmers in Kenya and when quality feeds are available, they remain unaffordable for fish farmers (Shitote *et al.*, 2013). However, as the long wait for the right information continues, the government should continue playing its oversight role on agrovet-supplied feeds to determine their compliance with the stipulated quality standards (Munguti *et al.*, 2014). In addition, farmers' partnership with the private sector can help boost their access to reliable information through extension messages via local media.

Common plant and animal protein sources used in feed formulation include fish meal, shrimp meal, cottonseed meal, sunflower seed, soybean meal, and rice and wheat bran. Currently, fish meal has dominated as a major source of protein by providing more than 50% of the fish protein requirements for fries and juveniles (Montoya-Camacho *et al.*, 2018). Shrimp meal is a high nutritional quality animal protein source and can be substituted with its counterpart fish meal. However, like fish meal, it is scarce and hence not readily available in some countries, making fish production even more expensive (Liti *et al.*, 2006). Wheat bran is a carbohydrate source obtained from the grinding of wheat cereals and is suitable for culturing acclimatized Nile tilapia, *O. niloticus*, for a weight below 140 g (Liti *et al.*, 2005).

The efficiency of plant-based proteins depends on several factors which include the levels of inclusion (complete or partial substitution) and toxicity levels. For instance, higher amounts of soybean meal in the *O. niloticus* diet may compromise fish growth performance (Webster *et* *al*., 1999). This is due to the slow digestion rate of high concentrations of soybean meal by the fish (Ambardekar *et al*., 2009). However, this may vary between feeding regimes, strains, sex, age and health status of fish amongst other factors. Moreover, as inclusion levels of plant-based proteins increase, fish growth performance decreases and vice versa (Khan *et al*., 2013).

Stocking density denotes the carrying capacity of a fish culturing facility and potentially has an effect on fish growth performance. Although the stocking densities of *O. niloticus* range from 3,000 to 4,000 fry/m^3, densities, beyond 2,670 fry/m^3 significantly affect fish growth performance and survival (Ntanzi *et al*., 2014). Moreover, densities as high as 20,000 fry/m^3 are viable depending on the water quality management technique throughout the fish-rearing period and feed efficiency is realized at the highest stocking densities (Yildiz and Bekcan, 2017). Generally, stocking density potentially affects heterogeneity and homogeneity of growth among fish. A lower stocking density is associated with heterogeneity due to the aggressive behaviour of *O. niloticus*. Some fish show territorial dominance and grow at a faster rate than those that show low dominance. This leads to appetite suppression and low food intake. A high stocking density promotes homogeneity in fish growth due to reduced territorial dominance hence reducing chronic stress among the low-dominating fish (Ntanzi *et al*., 2014). The improved growth however signifies reduced growth for the fast growers and increased growth for the slow growers rather than fast growth for every individual fish. Thus, the current study was conducted to test the growth performance of marine acclimatized *O. niloticus* using plant and animal protein sources in diet formulation. The effects of stocking density on growth performance were also investigated.

Materials and methods

Experimental Site

The experiment was carried out using concrete ponds located at the Kenya Marine and Fisheries Research Institute (KMFRI) in Mombasa, Kenya (-4.054757° S and 39.682621° E; Fig. 1). It is located along the shoreline of the Indian Ocean.

Figure 1. A map showing the experimental site at KMFRI (Google Maps, 2023).

Experimental design and stocking

The experiment was conducted in three concrete-based tanks of dimensions 4 m x 3 m x 1 m. The tanks were fitted with three *hapa* nets of dimensions 1 m x 1 m x 1 m to accommodate the three levels of fish stocking densities, i.e., 15 fish/m^3, 10 fish/m^3 and 5 fish/m^3. A total of 90 mixed-sex *O. niloticus* fingerlings with average weights of 13 ± 0.06 g, 14 ± 0.06 g and 17 ± 0.06 g were selected from a holding tank, and stocked in densities of 5, 10, and 15 fish/m^3 respectively per concrete tank. Figure 2 illustrates the setup of the experiment.

Initial fingerling weight and length measurements were taken using an analytical weighing balance (Sartorius TE4100 Talent Analytical Balance) and a fish sticker length ruler respectively to the nearest gram and cm, respectively before stocking. The treatments were then acclimatized for 24 hrs before feeding commenced (Khan *et al*., 2013). The experiment was conducted for 57 days from 15th June to 11th August 2021.

Experimental diets and feeding

Three culture diets were formulated i.e., fish meal, soybean meal and wheat bran using cassava, fish meal (*Omena*), soybean and wheat bran as ingredients. Fish meal and soybean meal were formulated to contain a 30% crude protein level. The control diet was formulated using wheat bran as the single main ingredient. Ratio determination for various feed proportions was done using the Pearson square method (Catacutan, 2002). In the formulation process, dry feed ingredients were mixed thoroughly before adding water to moisturize the feeds. Diets were then passed through an improvised pelleting machine, made into "spaghetti-like" strands (Thompson *et al*., 2020) and sundried for 24 hrs to obtain dry pellet feeds which were used to feed the fingerlings. Fish meal formulated diet, soybean meal diet and the wheat bran diet (control) were fed to fingerlings in tank 1, tank 2 and tank 3 respectively. The fish fingerings were fed manually twice a day at 9.00 a.m. and 3.00 p.m. at 3% body weight to apparent satiation at each feeding with feeding adjustments during the experimental period (Mapenzi and Mmochi, 2016).

Proximate composition analysis of experimental diets

The proximate composition of diet feeds and their respective ingredients was analyzed to determine their percentage moisture, crude protein, crude lipids, crude fibre, ash content, carbohydrate, calcium and phosphorus using standard procedures defined by the Association of Official Analytical Chemists (AOAC, 2000). Analysis of crude protein level was done using the Kjeldahl method. Samples were digested in a digestion unit for approximately 45 minutes. The digester was then distilled and titrated using 0.2 M HCl and crude protein was obtained by multiplying nitrogen with a conversion factor of 6.25. Moisture content was determined by AOAC procedure 930.15, by oven-drying feed samples at 105°C until a constant weight was obtained.

Ash content was determined by AOAC procedure 942.05 by obtaining calcinations in a muffle furnace at 550°C for 4 hours. Determination of crude lipid was done through the

Figure 2. Setup of the experiment using *hapa* nets for marine tilapia rearing (Source: Authors)**.**

extraction of a weighed sample with acetone in a Soxhlet extraction unit. Crude fibre was determined through AOAC procedure 962.09 by digesting weighed samples with sulphuric acid and with a few drops of octane in the digestion unit for 30 minutes. The acid was then removed through filtering and washing and thereafter a residue was obtained. The residue was then boiled with potassium hydroxide and then washed in boiling water and acetone before oven-drying at 130°C and ignited in a muffle furnace at 500°C. Crude fibre content was then determined based on the weight difference. The results of the proximate analyses are presented in Table 1.

Table 1. Proximate composition of the formulated diets. Key: FM-fish meal; SB-soybean meal; WB-wheat bran

	Treatment Diet		
Component	Diet 1 (FM)	Diet 2 (SB)	Diet 3 (WB)
Moisture	11.6	10.8	11.7
Crude protein	25.71	22.74	14.2
Crude Lipids	7.92	5.58	2.31
Ash content	9.01	6.81	5.7
Crude Fiber	4.3	5.23	7.6
Carbohydrate	21.72	21.7	18.17

Table 2. Proximate composition of the feed ingredients

	Feed ingredients			
Composition %	Fish meal	Soybean	Wheat bran	Cassava (binder)
Moisture	10.21	9.21	9.7	10.14
Crude protein	51.36	38.23	16.34	2.1
Crude Lipids	5.53	28.2	5.1	1.34
Ash content	33.74	4.29	3.62	3.32
Crude Fiber	1.42	5.34	8.6	1.71
Carbohydrate	-	16.48	23.48	89.62

Sampling protocol

Sampling to monitor the growth of individual fingerlings was done fortnightly (Mapenzi and Mmochi, 2016). Sample weight and length were measured using an analytical weighing balance and a fish sticker length ruler respectively. Water quality control was done manually by use of an outlet system in each of the concrete ponds which served as a continuous filtration system throughout the experimental period. Water quality parameters (temperature, oxygen, pH, salinity and dissolved oxygen) were measured twice a week throughout the experimental period using a hand-held portable multi-parameter (YSI ProQuatro model).

Determination of growth performance

The following fish growth parameters were used to determine growth performance.

i. Specific growth rate (%)= $\frac{\ln W_f - \ln W_i)}{T} * 100$

ii. Survival rate (%)= $\frac{N_f}{N_i} * 100$

iii. Food Conversion Ratio (FCR) = $\frac{\text{Total feed/Diet consumed}}{\text{Total weight gain}} * 100$

Where, T is the number of days of the experiment; W_i and W_f are the initial and final mean body weights and N_f and N_i are the numbers of harvested fish at the end of the experiment and the initial number of stocked fish respectively.

Data analysis

Collected data were tabulated in a MS Excel worksheet and analyzed using two-way ANOVA to determine if stocking density and feed treatments had significant effects on the growth performance of *O. niloticus*. All statistical analyses were computed using SPSS (version 22).

Results and discussion

In situ measurements of water quality parameters

Most of the water quality parameters were within the acceptable range for *O. niloticus* culture. The mean values for *in situ* (inside the *hapa* nets) water quality parameters monitored throughout the experiment including temperature, oxygen (mg L^{-1}), pH, salinity and total dissolved solids (TDS) were computed (Table 3). pH and DO had a comparable effect on the FCR. Increasing pH by one unit would improve FCR by about 0.5 unit. On the other hand, decreasing DO from the highest level investigated i.e., 11 mg L^{-1} to 3 mg L^{-1}, which is the minimum level required for tilapia production, would lead to an increase of 0.9 unit FCR (Mengistu *et al.*, 2020).

Table 3: Mean water quality (mean ± SE) parameters inside the *hapa* nets for feed treatments at different stocking densities.

Water quality parameters	Diet			Density		
	Fish meal	Soybean	Wheat bran	15	10	5
Temp (°C)	26.87 ± 0.15	26.84 ± 0.07	26.78 ± 0.07	26.69 ±0.08	26.84 ± 0.94	26.95 ± 0.03
Dissolved Oxygen (DO)	4.03 ± 0.05	5.30 ± 0.10	4.69 ± 0.05	4.66 ± 0.28	4.65 ± 0.43	4.71 ± 0.42
Total Dissolved Solids (TDS)	26937.24 ± 35.56	27075.28 ± 18.87	26937.23 ± 35.56	26936.56 ± 67.89	27006.64 ±18.77	27006.56 ± 51.39
Salinity	26.57 ± 0.01	26.58 ± 0.08	26.55± 0.01	26.59 ± 0.04	26.59 ± 0.03	26.53 ± 0.55
pH	6.74 ± 0.01	6.74 ± 0.01	6.75 ± 0.01	6.75 ± 0.01	6.75 ± 0.03	6.74 ± 0.01

Efficiency of diet on fish growth performance and survival rate

After 57 days of culture, mean individual weight gain was highest in the Soybean treatment (10.28 ± 2.44 g) while the survival rate was highest in the wheat bran (control diet) treatment (85.55%). There were no statistically significant differences in average stocking weight for both stocking density ($p > 0.05$) and feed treatment ($p > 0.05$). The food conversion ratio (FCR) was not significantly different in samples exposed to the different treatments ($p > 0.05$). The growth performance of *O. niloticus* fingerlings is as presented in Table 4. Results are presented as mean ± standard error of the mean (SE).

Table 4: Calculated means of growth and yield (Mean ± SE) of *O. niloticus* fed on three different diets and cultured at different densities.

	Treatment Diet			Density (Fish/m³)		
Growth and yield parameters	Fish meal	Soybean	Wheat bran	15	10	5
Individual stocking length (cm)	9.06±0.07	9.6±0.39	9.46±0.13	9.30±0.22	9.71±0.29	9.11±0.16
Individual final length (cm)	11.82±0.21	11.96±0.16	11.27±0.28	11.35±0.23	11.68±0.31	12.03±0.12
Individual stocking weight(g)	17.67±4.32	14.86±1.14	13.78±0.61	13.8±0.81	19.41±3.48	13.09±0.633
Individual final weight (g)	23.7±0.81	25.14±1.63	21.84±1.99	21.48±1.42	24.18±1.60	25.02±1.43
Individual weight gain (g)	6.03±3.71	10.28±2.44	8.06±2.42	7.67±1.84	4.77±3.09	11.93±2.06
Survival rate (%)	83.33±16.67	64.44±12.37	85.55±2.93	86.67±7.69	60±15.28	86.67±6.67
SGR (% day)	1.3±0.45	1.29±0.32	1.09±0.29	1.23±0.49	0.98±0.167	1.5±0.26
FCR	13.63±6.96	17.5±5.64	1.77±5.64	4.03±9.48	24.78±16.60	4.10±4.10
DGR	0.11±0.07	0.19±0.05	0.22±0.04	0.14±0.03	0.09±0.06	0.22±0.04

Stocking density potentially influences fish growth performance and the overall yield in aquaculture. In this study, a positive growth of fish occurred in all treatments. The 5 fish/m^3 stocking density had a marginally higher SGR, weight gain and a slightly higher survival rate than other density treatments including the control treatment. FCR was lower in the 10 fish/m^3 than in the 15 and 5 fish/m^3 densities. However, the parameters did not vary significantly between the treatments ($p > 0.005$). Figures 2 and 3 depict the growth trend curves for *O. niloticus* under different densities and dietary feed treatments. In Figure 2, growth trend curves depicted growth declines after fish attained approximately 23 g, with the 5 fish/m^3 density depicting a higher positive and consistent growth response compared to 10 and 15 fish/m^3 densities. In figure 3, growth declines were observed at approximately 24 g with soybean meal (SBM) depicting a positive growth response compared to other dietary feeds i.e., wheat bran and fish meal.

Effects of stocking density on growth performance and survival rate

Stocking density of 5 fish/m^3 had the highest weight gain, SGR and survival rate compared to densities of 15 fish/m^3 and 10 fish/m^3 while stocking density of 10 fish/m^3 had the least weight gain (4.77 ± 3.09 g) and the lowest survival rate (60 ± 15.28%). Weight gain, SGR and survival rate did not vary significantly. Stocking density had no significant effect on fish growth performance ($p > 0.187$).

Results from the study demonstrate that soybean treatment had the highest growth response in terms of weight gain (10.28 ± 2.44 g) compared to fish meal and wheat bran diet treatments. Soybean meal had a moderate fibre content. Despite both fish meal and soybean diets having a 30% crude protein level, moderate content of crude fibre in soybean may have aided in its digestibility compared to fish meal and wheat bran. A study by Phumee *et al*. (2011) however, reports that the high fibre content in soybean meal affects its digestibility. The findings of the present study concur with Obirikorang *et al*. (2020) in which Nile tilapia fry was used to test the effects of soybean meal on its growth performance and concluded that low contents of soybean meal can improve feed digestibility. However, the presence of anti-nutritional factors such as phytic acid, trypsin inhibitors and saponins in soybean meal can inhibit growth (Francis *et al*., 2001). Wheat bran treatment had a significant effect on growth performance compared to fish meal. Soybean had a balanced chemical composition based on the diet feeds' proximate analysis compared to fish meal and wheat bran.

Dissolved oxygen is one of the main limiting environmental variables that potentially affect fish growth performance and can possibly affect feed intake by reducing digestibility (Tran-Duy *et al*., 2012). Feed assimilation is improved at high DO due to improved blood flow to the gastro-intestinal tract (Axelsson *et al*., 2002) and lower energy cost of feed digestion and absorption of nutrients (Duan *et al*., 2011). Energy for growth will therefore be available. According to Tran-Ngoc *et al*., (2017), Nile tilapia recorded significantly lower performance in terms of SGR, FCR and final body weight, under hypoxia (3 mg L^{-1}) compared to its performance under normoxia (5 mg L^{-1}) which represents 50% of DO saturation. In addition, the study found that hypoxia affected intestinal morphology negatively. Optimum DO is therefore an important environmental factor for improving FCR. Dissolved oxygen in this study was within the optimum range between hypoxia and normoxia and was statistically significant ($p = 0.000$) and highest on treatments fed on Soybean (5.30 ± 0.10 mg L^{-1}) and lowest on treatments fed on fish meal (4.03 ± 0.05 mg L^{-1}). This may have aided a high feed consumption for soybean compared to fishmeal and wheat bran treatments. Lower concentrations of DO on treatments fed on fish meal might have caused stress in fish or constrained fish metabolism which might have led to a reduction in growth performance. Oxygen

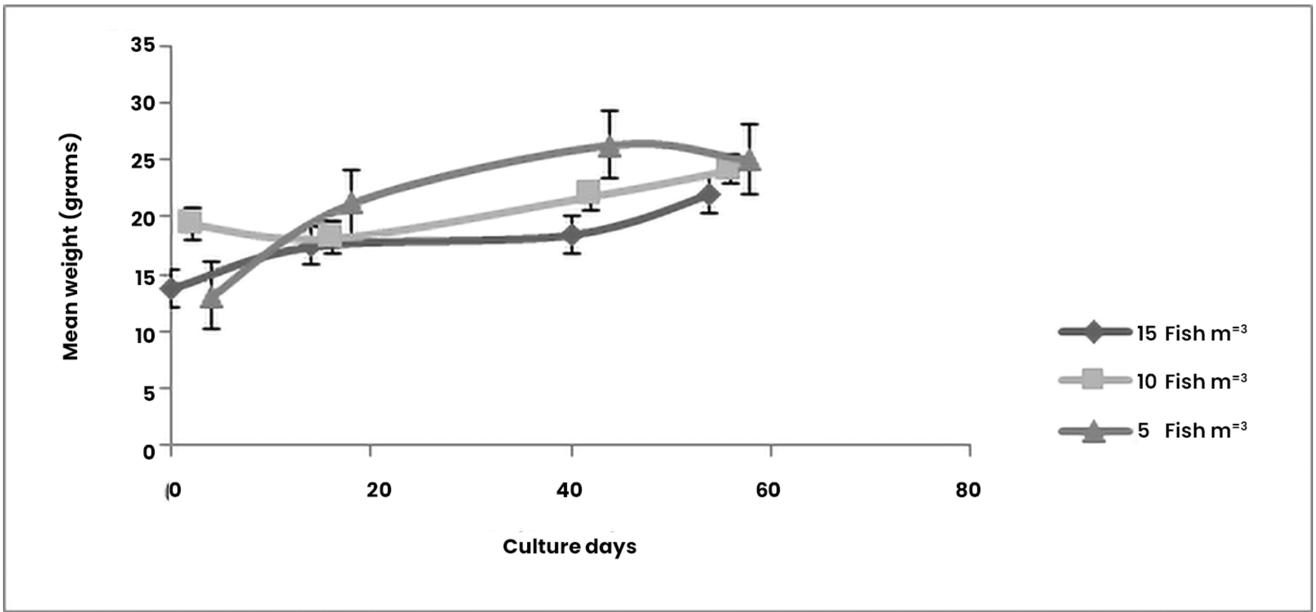

Figure 3. Mean weights of *O. niloticus* in different stocking densities during the experimental period. Values are means (± SE) for the different feed treatments per sampling date.

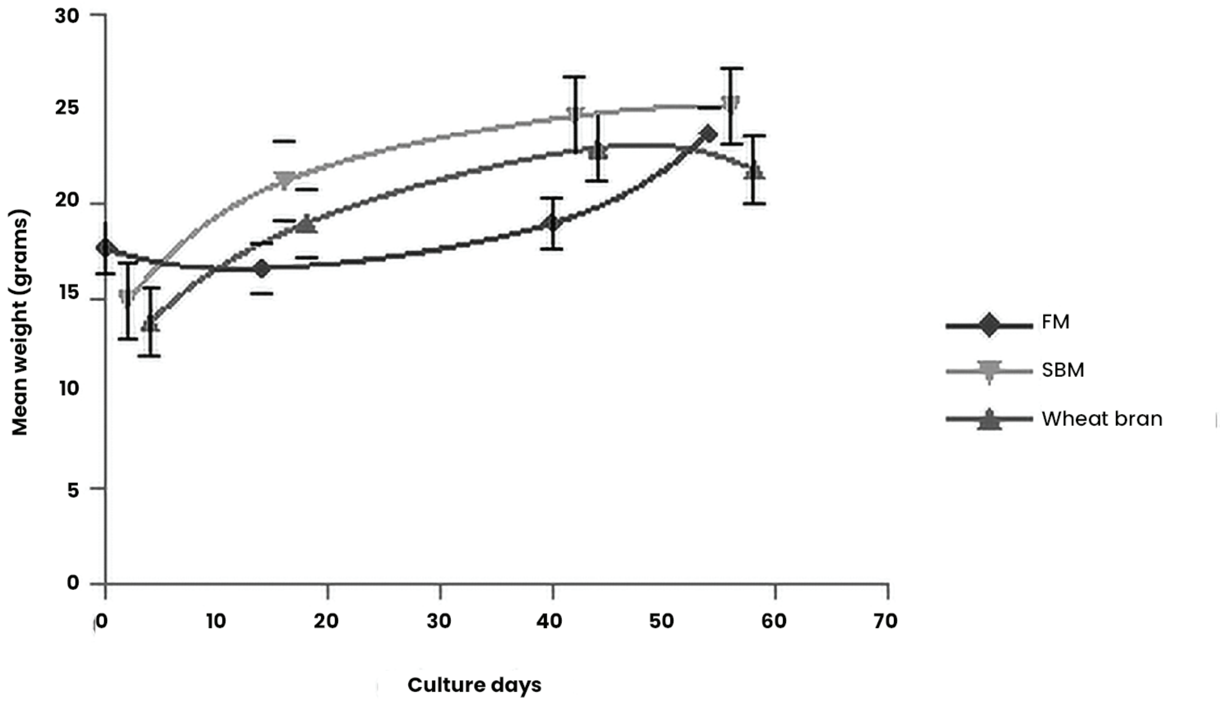

Figure 4: Mean weights of *O. niloticus* fed on different diet treatments. Values are means (± SE) for different feed treatments per sampling date.

concentration levels have been shown to have a positive effect on fish growth performance (Mallya, 2007).

Survival rates were greater on fishmeal (83.3%) and wheat bran (64.4%) treatments compared to soybean (64.44%) but were not statistically significant (p =0.361). The maximum survival rate in this study, 86%, differed from that of Mapenzi and Mmochi (2016), which reported a maximum survival rate of 90%. A low survival rate in this study may have been due to poor acclimation to saline conditions as the fish tried to adapt. Some may have been unable to cope with the harsh salty conditions and hence resulting in the higher mortalities observed in the present study. In addition, the handling method during sampling might have led to a low survival rate, to some extent. The higher survival rates observed in this study may be due to the ability of the fish to tolerate adverse conditions of low temperature and oxygen. This is as was observed by Ahmed *et al*. (2013) who observed a slightly lower survival rate (75.55%) for monosex tilapia compared to this study while evaluating the production performance of monosex tilapia under homemade feed in earthen mini ponds. Furthermore, the results of this study fall within the range of research findings of Kohinoor *et al*. (2007) who observed that the survival rate of monosex tilapia varied from 79 - 92%.

Stocking density has the potential ability to influence fish growth. Stocking density of 5 fish/m^3 had the highest mean survival rate, weight gain and SGR compared to 15 fish/m^3 and 10 fish/m^3 densities. However, stocking density in this study was not statistically significant (p =0.187). The results agree with those of Mapenzi and Mmochi (2016) who found a nonsignificant result on stocking density. Furthermore, nonsignificant findings on stocking density also concur with Mengistu *et al*. (2020) who found a nonsignificant result in two of the three models used for analysis. Moreover, Mengistu *et al*. (2020) cite that, as part of what is generally observed in aquaculture, as stocking density increases, FCR is negatively affected and that an increase in one unit of stocking density would lead to an increase in FCR by about 0.01 kg feed per kg biomass harvest. However, stocking density and stocking size differs from country to country under small-scale tilapia production systems.

Specific Growth Rate (SGR) varied for wheat bran but not between fish meal and soybean. This may be attributed to the 30% crude protein level in the two diets, fish meal and soybean. Protein and ash content levels relate to fish size. Specific Growth Rate of wheat bran might have been affected by a low content of crude protein and ash content. Specific Growth Rate was however not statistically significant (p =0.905), with its values in this study (0.98 - 1.5) being lower than those reported by Mapenzi and Mmochi (2016) (8.33, 8.3, 7.8) but in range with values reported by Iluyemi *et al*. (2010) (0.77 - 1.49) for red tilapia. However, the SGR values reported by Iluyemi *et al*. (2010) were statistically significant and decreased with feed supplementation. High SGR values in the Mapenzi and Mmochi (2016) study were attributed to the use of hybrids of *O. niloticus* and *O. urolepis*. The hybrids might have had enhanced genetic traits inherited from both of their parents that promoted high SGR values.

Food Conversion Ratio, the fish's ability to convert food into biomass was not significantly affected by stocking density and feed treatments. The optimum feeding rate is the rate that gives the lowest FCR (Mengistu *et al*., 2020). Best FCR values were observed at densities of 15 fish/m^3 and 5 fish/m^3 and on wheat bran treatment. The recommended FCR range for *O. niloticus* is 3.4 - 4.0 (Liti *et al*., 2006). In this study, FCR was higher than the recommended FCR range for *O. niloticus*. Reasons for a poor FCR may have been due to stress. Stress causes inappropriate dietary energy utilization attributable to physiological alterations, which leads to poor growth (Mapenzi and Mmochi, 2016). Factors such as pH and DO have a comparable effect on FCR. The Mengistu *et al*. (2020) study found the best FCR and growth to be within a pH range from 7 to 9. The pH levels in this study were below the range requirements for optimizing FCR.

Weight gain and final mean weight, on the other hand, were highest at the lowest stocking density, 5 fish/m^3. This was similar to observations made by Ferdous *et al*. (2014) and Mapenzi and Mmochi (2016). However, mean weight gain did not vary significantly in this study.

Conclusion and recommendation

Marine acclimatized *O. niloticus* fingerlings have a high feed utilization for soybean meal compared to fish meal and wheat bran. The results indicate that soybean meal had a higher growth performance as a diet for the fingerlings of marine acclimatized Nile tilapia. Furthermore, Nile tilapia are capable of utilizing plant protein sources in their diets, achieving growth in their early life stages. Therefore, growth and feed utilization results from the study can serve as a basis for recommending the formulation of cost-effective feeds for the nursery culture of fingerlings of Nile tilapia using locally available plant ingredients.

Stocking density of 5 fish/m^3 promoted fish growth due to less or no energy expenditure on food and space competition compared to 15 fish/m^3 and 10 fish/m^3 densities that promoted a high expenditure on space and food competition resulting in a low growth rate. Soybean meal and a stocking density of 5 fish/m^3 can therefore be adopted by fish farmers for optimization and maximization of their fish produce. However, there is need for further research on soybean meal efficiency.

On seasonality, the study was carried out during the Southeast Monsoon season. There are no arguments on whether seasonality significantly affects fish growth performance since similar yields may still be obtained no matter the season. However, conditions such as temperature and availability of water for experimental ponds may affect yield in the long run. Consequently, male and female *O. niloticus*, have different growth rates. In this study a mixed-sex population was used, thus, there is need to monitor growth using monosex tilapia.

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The potential of three culture techniques to mitigate environmental challenges and enhance yields of Eucheumoids (Rhodophyta; Gigartinales) in deep water on the Kenyan Coast

Alex G. Kimathi[1,*], Joseph G. Wakibia[2], Moses K. Gichua[2], David Mirera[1]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 81651, Mombasa, Kenya

[2]Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya

*Corresponding author: kimathi_alex@yahoo.com, (+254) 0 721 400063

Abstract

Relocation of seaweed farms from shallow to deeper waters has been recommended to remedy seasonal infestation of seaweeds by ice-ice disease and epiphytes. However, data supporting the best culture technique for farmers' adoption is scarce. In the present study, the production potentials of one shallow, fixed off-bottom (FB) and two deep water techniques; modified off-bottom (MB) and floating raft (FR) techniques were evaluated by comparing the yields of *Eucheuma denticulatum* and *Kappaphycus alvarezii* while monitoring the environmental factors. Each of the cultivation techniques was set at a low tide water depth of 1 m. Experiments were established at Mkwiro and Kibuyuni in the South Coast and data were collected fortnightly for nine months. The net yield (dw ha^{-1} yr^{-1}) was significantly higher at Mkwiro (32.4 t) than at Kibuyuni with 22.8 t ($p < 0.05$). The net yield (dw ha^{-1} yr^{-1}) of 30.2 t in the FR was significantly higher than 20.4 t and 10.9 t in MB and FB respectively ($p \leq 0.05$). The net yield (t dw ha^{-1} $year^{-1}$) of *E. denticulatum* (30 t) was significantly higher than 12 t for *K. alvarezii* ($p < 0.05$). Although the FR was the best in mitigating environmental challenges of seaweeds, the three techniques can be adopted to improve seaweed production in deep water.

Keywords: South Coast, cultivation technique, ice-ice disease, net yield, *Eucheuma denticulatum*, *Kappaphycus alvarezii*,

Introduction

There are three basic types of seaweed; red (rhodophytes), brown (bryophytes) and green (chlorophytes). These versatile marine plants have diverse economic importance. While the brown and green seaweeds are used directly as food (Paull and Chen, 2009), red seaweeds are sources of anti-oxidants/microbial agents (Gupta and Abu-Ghannam, 2011) and phycocolloids - agar, carrageenan and alginate are used as industrial binding agents (McHugh, 2003). The red seaweeds; *Eucheuma denticulatum* Collins and Hervey, and *Kappaphycus alvarezii* (Doty) Doty ex Silva are the main sources of kappa and iota carrageenans respectively that have gained a high demand in food, cosmetic and pharmaceutical industries (Wakibia *et al.*, 2006; Anis *et al.*, 2017). To meet the global demand for carrageenans, *K. alvarezii and E. denticulatum* (carragenophytes) are commercially cultivated in countries with tropical coastlines, with Asian countries such as Indonesia leading in production (FAO, 2018). Aquatic cultivation of carragenophytes in Indonesia enhanced the increase in seaweed output from less than 4 million tonnes in 2010 to over 11 million tonnes in 2016 (FAO, 2018). Away from giant seaweed producers in Asia, cultivation of carragenophytes has spread to the Western Indian Ocean (WIO) countries of Mozambique, Madagascar, Tanzania and Kenya in the recent past (Wakibia *et al*., 2011; Msuya *et al*., 2014; Msuya and Hurtado, 2017). In 2020, annual productions of carrageenophytes in Tanzania and Madagascar were 102,960 and 53,370 tonnes (fw), respectively. However, in Kenya, the production of eucheumoids is still low, standing at approximately 1,000 tonnes (fw) in 2020 (Msuya *et al.,* 2022).

Seaweed cultivation in Kenya shares similar challenges experienced in other WIO countries. Reported challenges include poor gate price of harvested seaweeds that demotivates farmers' over-reliance on the same strain (*E. denticulatum* and *K. alvarezii*) that is exposed to inbreeding and the perennial use of one culture technique i.e., off-bottom (Hurtado *et al*., 2015). Moreover, the location of farms is limited to shallow beds within the sub-littoral zone where water depth hardly exceeds 0.5 m at low tide because the majority of the farmers are women with inadequate swimming capabilities to expand their farms to deeper areas (Kimathi *et al.,* 2018). This farming behaviour has resulted in some farms being located in areas without water at low tide thus exposing seaweed cuttings directly to hot air and water temperatures above 33°C (Msuya *et al.,* 2014). For instance, in 2008, a water temperature range of 36-38°C recorded in January and February in Zanzibar and Songo Songo was reported to increase die-offs of *K. alvarezii* due to severe ice-ice disease attacks (Msuya, 2010). The ice-ice disease has been described as an unhealthy condition of seaweeds manifested by the degeneration of seaweed thalli by rotting and turning to a pale white colour similar to ice (Wakibia *et al*., 2006). However, it has been shown from various studies that the conducive season of seaweed is during the cold season (June-September) and also during short rains (October-November) when temperatures are 25-30°C, while low growths are recorded during the hot season (December -February) when temperatures are above 30°C (Msuya, 2010). Through prudent use of this information, farmers have maximized their production and inspired their colleagues thus increasing in number at Kibuyuni, Mkwiro, Gazi, Funzi and Nyumba Sita villages in the South Coast of Kenya. Just like in Tanzanian seaweed farming, women farmers on the southern coast of Kenya are today well recognized in the community setups because of their economic contributions to the households (Msuya and Hurtado, 2017; Mirera *et al*., 2020).

Relocation of seaweed farms from shallow sites to deep sites where the water quality is relatively stable for their growth has been recommended as a remedy to curb ice-ice disease (Msuya *et al*., 2014). Lack of adequate data on the best culture technique for seaweeds in deep water sites could compound the challenges of seaweed farmers in Kenya. With a focus on encouraging farmers to relocate their seaweed farms from shallow to deep sites to curb the ice-ice disease and epiphyte challenges, a study to compare the net yield of seaweeds *E. denticulatum* and *K. alvarezii* using different culture techniques in deep water was therefore critical. In the present study, we discuss the results of an experiment in which three culture techniques, fixed off-bottom (FB), modified off-bottom (MB) and floating raft (FR) were deployed at sites with low tide water of 1 m deep and monitored concurrently by measuring the net yield of seaweeds and environmental variables for nine months (September 2015 to May 2016) at Kibuyuni and Mkwiro. The study was key in providing information to inform decision-making and formulation of appropriate policies to increase seaweed production and consequently protect a livelihood that ensures food security for the marginalized coastal communities in the WIO region.

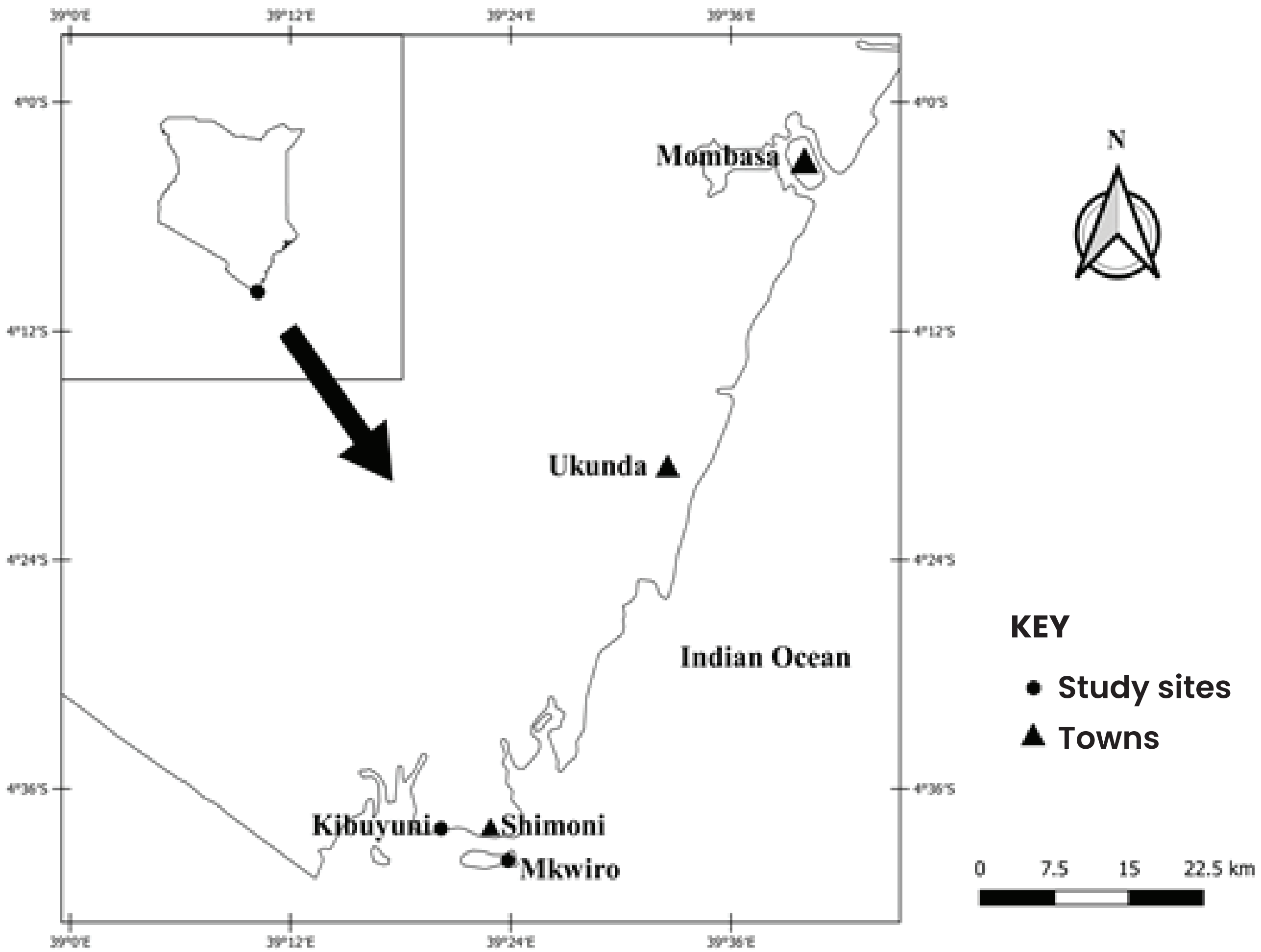

Figure 1. Map of the Kenya coast showing the location of the two study sites at Kibuyuni and Mkwiro (Source: Authors)**.**

Materials and methods

Study sites

The sites of study are shown in figure I below. The study was conducted at the villages in Shimoni; Kibuyuni (4° 38′ 17.77″ S, 39° 20′ 26.11″ E) and Mkwiro (4° 39′ 53.31″ S, 39° 24′ 5.27″ E). Kibuyuni is located about two km South of Shimoni town while Mkwiro is situated at the southern Mkwiro-Wasini Island.

The two farming sites are about 5 km apart and have intertidal zones that share similar characteristics. Both sites have a narrow (20 m) belt of mangrove species on the shore and an exposed rocky flat of about 100 m wide running parallel to the shore. A high diversity of thermal-tolerant seaweed species such as *Gracilaria spp* are common. Between the rocky flat and the sub-tidal zones of each site is a wide and shallow (0.2 m - 1.5 m deep) seagrass bed comprising species including *Thalassodendron ciliatum* (Forskal) Hartog 1970, *Thalassia hemphrichii* (Ehrenberg) Ascherson 1871, *Syringodium spp, Cymodocea spp, Hophila spp.*, among others. All the seaweed farms at both sites are located within this area. Although a depth of 1.0 m could be accessed by farmers at low tide, their farms hardly exceeded 0.5 m water depth at low tide. From the seagrass beds of each site is a narrow coral biotope running parallel to the beach, with water depths ranging from 0.5 m - 2 m at low tide. The availability of commercial farms at these sites assured ideal sources of seaweeds for stocking the anticipated experiments. In addition, the availability of local farmers (both male and female) with prior knowledge of the basic seaweed farming protocols, would enhance the capacity of the individuals to be hired in providing the necessary support to the project with minimum supervision. The farming communities provided free space and protection for experimental setups during the study period. To implement the experimental design, the field activities were coordinated by the researcher. Rotational criteria designed by the seaweed group leaders provided 2 men and 3 women during each sampling period to participate in the activities of setting up field experiments, especially the preparation of the ropes and seed stocking. This strategy ensured that the maximum number of different farmers benefited from the training and also developed confidence working in deep water (1 m) at low tide.

Seaweed and planting materials

Two rhodophytes; *E. denticulatum* and *K. alvarezii* used in the present study were similar to those imported from Zanzibar for culture trials in Kenya in 2001 (Wakibia *et al*., 2006). The species were distinguished by the branching pattern of the thalli, with *E. denticulatum* having spinose branchlets while *K. alvarezii* has smooth thalli. The first stock of fresh, young and clean seedlings of *E. denticulatum* and *K. alvarezii* were bought from farmers at Kibuyuni and Mkwiro to set the first month's experiment. All the other monthly experiments were stocked with seaweeds harvested from the previous month's experiments. The farming materials which included polypropylene ropes, tie-ties, bamboo, mangrove poles, tape measures, *pangas* (machetes), knives, metallic rings, spring balance, Plaster of Paris (POP) and tennis balls were purchased locally. The refractometer and thermometers were provided by the laboratory at KMFRI.

Experimental design

An experimental design that ensured that the seaweed growth for that particular month of the year was measured during the spring tides was emphasized in the present study. A completely randomized design (CRD) was adopted, in which five replicates of seaweed-stocked ropes for each species were randomly planted in three different culture techniques namely; fixed off-bottom (FB) method, modified off-bottom (MB) method and floating raft (FR) method during spring tide at water depths of 1 m. Each of the cultivation techniques was located at a distance of 50 m away from the other. The sampling unit was the seaweed-stocked rope with 25 cuttings and an initial known stocking density. After 30 days of growth, each of the seaweed-stocked ropes was harvested and weighed. The farm layouts of all the cultivation techniques were modifications of techniques described by Msuya and Hurtado (2017). However, the MB technique was adopted from Kimathi *et al*. (2018). The water temperature, salinity, diffusion factor, ice-ice disease symptoms, herbivory, epiphytes and plant loss were monitored every month. This farming procedure was replicated at Mkwiro and Kibuyuni for nine months.

Cultivation techniques

Fixed off-bottom (FB) technique

In figure 2, the FB technique during planting (D1) and during harvesting (D30) after 30 days is presented. In the FB technique, two opposite rows of six mangrove posts (0.76 m height), were fastened to the sea bottom perpendicular to the beach. The distance between the rows was 5 m (rope length) and 0.5 m between posts in each row. The polypropylene ropes used to culture seaweeds were 8 mm thick. Twenty-five thin and short raffia strings (tie-ties) were fixed at intervals of 0.2 m along the length of a 5.0 m polypropylene rope. Twenty-five seaweed cuttings of each species were then attached to different ropes using tie-ties. Each seaweed cutting was 50 - 80 g and five replicates ropes were stocked for each species and each technique. Similar initial weight of each stocked rope was maintained and recorded before being taken to the water for growth in the respective cultivation technique. For the FB system, the stocked ropes of both species were randomly tied to opposite ends of short mangrove posts by suspending

Figure 2. The fixed off-bottom technique during planting (D1) and during harvesting (D30) after 30 days (Source: Usi Mohammed).

them in water at a depth of 0.3 m above the substrate. The stocked ropes were then left for about 30 days to grow.

The structural setup of the FR during planting (D1) and harvesting (D30) after 30 days is shown in figure 3. The FR technique consisted of a floating 4 m x 5 m bamboo device anchored to the bottom of a 5 m deep lagoon by a polypropylene rope (0.01 m diameter). The anchoring device was a 100 kg rectangular block constructed of cement, concrete and sand in different proportions. The same set of stocked polypropylene ropes (as those in FB) for both species were each weighed and stretched along the length of the bamboo raft. The distance between stocked ropes was approximately 18 - 20 cm with each raft having a total of 10 stocked ropes. The experiment was repeated after 30 days (monthly).

Modified off-bottom (MB) technique

The structural setup of the MB technique presented in figure 4 employed the principles of both the fixed off-bottom and floating raft methods but differed in the structural design (Fig. 4). Unlike in the FB where the ropes were suspended in water using short (0.76 m) wooden posts, in the MB

Figure 3. The floating raft technique (FR) during planting (D1) and during harvesting (D30) after 30 days (Source: Alex Kimathi).

technique, longer mangrove poles (5.0 m), equivalent to the highest tidal depth at the site were used and a floating mechanism that ensured the cultivated seaweeds ascended and descended with the tidal direction along the height of the supporting poles was designed. One-end sharpened long poles were slowly dipped in the water and vertically pressed deep into the soft sediments for stability. A circular metallic ring prepared locally was then inserted on the long pole from the top and settled on the bottom to rest on a small wooden material fixed by nails on the long pole at 0.30 m from the bottom. Another wooden material was fixed on the other end (top) of the long pole to prevent the ring from being pushed out of the pole at high tide. At the end of the exercise, two opposite rows, each with ten poles were constructed and the distance between rows was 5 m. The initial weight of each polypropylene rope stocked with seaweed cuttings (as those in the FB and FR techniques) was taken and later tied to the circular metallic rings on the pole for growth. Three - 5 L empty plastic bottles were tightly cocked and tied to the middle of each seaweed-stocked rope at equal intervals using thin nylon ropes. The empty plastic bottles provided buoyancy to the stocked rope so that it could rise and fall with tidal direction. The seaweeds were then cultured for 30 days. Figure 4 shows the structural setup of the MB technique during planting and harvesting of the seaweeds.

Young, healthy thalli were selected from every harvest of each cultivation technique and served as new transplants for the next month's stocking. This procedure was repeated for all techniques at the two sites and experiments were conducted for nine months from September 2015 to May 2016 to obtain growth data for yield and productivity analysis.

After a culture period of 30 days, the final weight of each rope in each culture system was averaged to the number of cuttings present. The net yield of the seaweeds for each rope was then calculated as the difference between the final weight and initial weight per unit area under cultivation according to the formula described by Wakibia *et al.* (2011).

$$\text{Net yield (kg wet wt m}^{-2}\text{ 30 d}^{-1}) = \frac{W_f - W_i}{A}$$

Where W_f is the weight of harvesting after 30 days (kg); W_i is the initial weight (kg) and is the area under cultivation (m²)

Biotic factors

After every fortnight, the number of missing cuttings and those with signs of ice-ice disease, epiphytes and grazing were recorded from each stocked rope. During analysis, the number of missing cuttings in each rope was computed as a percentage of the original number of cuttings on the planting day while those with ice-ice disease, epiphytes and those grazed upon were computed as a percentage of the total number of cuttings present during the sampling day.

Specific grazers were identified by swimming gently over the seaweed lines at mid-tide. During the monitoring, the *in situ* grazing behaviour of the prevailing fish species was mastered to aid future identifications. For example, the fish-bitten thalli were differentiated from those with urchin bites by exhibiting the 'nipping' nature as described by Ateweberhan *et al.* (2015).

Abiotic factors

During the sampling period, daily salinity and water and air temperatures were recorded at midday. The seawater salinity was measured fortnightly using a refractometer (Atago, Japan) while the temperatures were measured using a clinical mercury thermometer. The monthly temperature ranges were recorded usinga maximum/minimum thermometer fixed on the bottom of a selected wooden peg. Water motion was measured fortnightly by monitoring the rate of dissolution of spherical Plaster of Paris (POP) balls according to a modified clod card method (Wakibia *et al.*, 2006). To prepare the balls, a mixture of water and POP (1:1) was poured into tennis ball moulds of 5 cm diameter. A stick (15 cm long, 0.5 cm diameter) was

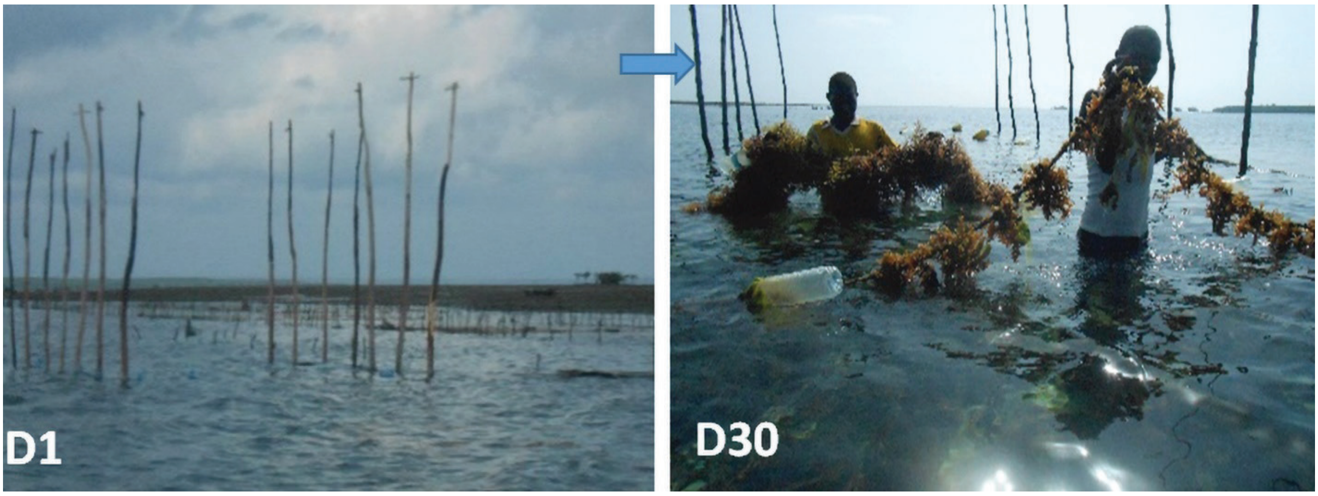

Figure 4. The modified off-bottom (MB) technique during planting (D1) and during harvesting (D30) after 30 days (Source: Abdalla Darusi).

then inserted into the wet POP mixture of each ball. After two days of hardening in air, the tennis ball moulds were removed using a sharp blade and the rough surfaces smoothed with sandpaper. The initial weight of each smoothened ball was measured using an electronic top-loading balance (Satorius model). The diffusion index factor (DIF) was measured by the deployment of 3 sets of POP balls at each of the three experimental setups in the two sites. A thin string (usually a tie-tie) was used to attach the hanging POP ball to the polypropylene ropes stocked with seaweed cuttings. The POP balls were left in the water column and retrieved after 24 hrs. Upon retrieval, the POP balls were rinsed with fresh water, dried in the oven at 40°C and weighed to a constant weight. The final weight was compared with the average final weight of five control POP balls left for 24 hours in a 20-litre motionless bucket of seawater of equal salinity placed in the laboratory. Seawater samples for determination of nitrate and phosphate levels were collected 20 cm below the surface seawater at each site fortnightly using five 125 mL high-density polyethylene bottles. The samples were fixed immediately using mercuric chloride, labelled and stored in a cooler box at 40°C before being transported to the KMFRI laboratory for analysis. The samples were analyzed using the modified automated method of Parsons *et al*. (1984) as applied in the Technicon Auto Analyzer II system.

Data analysis

All data were analyzed using MS Excel and SPSS software (version 26.0). ANOVA was conducted to test the individual main factor effect on net yields and the interaction effects of subjects and net yields. To confirm the suitability of the ANOVA test, the homogeneity of variance was tested by conducting Levene's test (Levene, 1960). A post hoc pairwise comparison test using Turkey HSD was conducted to determine significant differences between the means of the three culture techniques. Two sample t-test was used to determine significant differences in net yield between sites and species. The Pearson product-moment correlation coefficient test was conducted to establish the relationships between net yield and environmental factors.

Results and discussion

Growth conditions

The diffusion factor varied significantly over the eight months at the two sites ($p < 0.05$), with the highest (4.4 ± 0.5) being recorded in March and the lowest (2.8 ± 0.3) in January. The diffusion factor was highest in the FR technique (4.2 ± 0.2) followed by MB (3.9 ± 0.2) and lowest in FB (2.8 ± 0.1). These diffusion factors were significantly different ($p < 0.05$), However, the diffusion factors of 3.63 ± 0.1 and 3.51 ± 0.2 obtained at Mkwiro and Kibuyuni, respectively were not significantly different ($p > 0.05$). The salinity levels in the South Coast of Kenya ranged between 35.0 and 35.5 ‰, with a mean of 35.1 ± 0.3 ‰. No significant difference was observed in salinity between culture techniques and between sites ($p > 0.05$).

The air temperature, minimum and maximum water temperatures at Kibuyuni (A) and Mkwiro (B) are displayed in figure 5. The average minimum water temperature ranged between 27°C and 29.9°C and a mean of 28.3°C while the average maximum water temperature was 30.4°C ranging from 28.0°C to 32.7°C. Maximum water temperatures were highest in December (32.7°C) and February (32.7°C) and the lowest value was recorded in May (25°C). The minimum water temperature was neither significantly different between sites nor between techniques ($p > 0.05$). However, the maximum water temperatures did not vary significantly between the sites but did between the culture techniques ($p < 0.05$) with the FB technique having the highest, followed by MB and FR having the lowest. During the study period, the mean air temperature at the South Coast of Kenya was 27.7°C with the lowest (25°C) and highest (29.5°C) being obtained in May and January respectively. No significant difference was observed in air temperature between sites and techniques ($p > 0.05$).

The mean nitrates and phosphate concentration (μmoles L^{-1}) were 1.31 ± 0.2 and 0.746 ± 0.1 respectively at Kibuyuni while at Mkwiro, the mean nitrate and phosphate concentrations were 1.2 ± 0.1 and 0.624 ± 0.1 respectively. There were no significant variations in nutrient concentration both between sites and cultivation techniques ($p > 0.05$).

Water motion (diffusion factor) in the South Coast of Kenya has been described earlier, with higher water motion being reported at Gazi than at Mkwiro and Kibuyuni (Wakibia *et al.*, 2006). The water motion was not significantly different between the MB and FR techniques but was indeed higher than in the FB technique ($p < 0.05$). This observation could be attributed to the higher speed of surface tidal currents experienced in FR and MB techniques than at the bottom where the FB technique was positioned. Water motion in the FR technique has been associated with wave action generated by wind (Ask and Azanza, 2002). The highest water temperatures observed in this study coincided with the North East Monsoon (NEM) season while the lowest temperature aligned with South East Monsoon (SEM) season. Our observations are consistent with the findings of Obura *et al.* (2000), who reported the highest sea surface temperatures during NEM, with an average of 28.4°C, a maximum of 29°C and lowest temperatures during

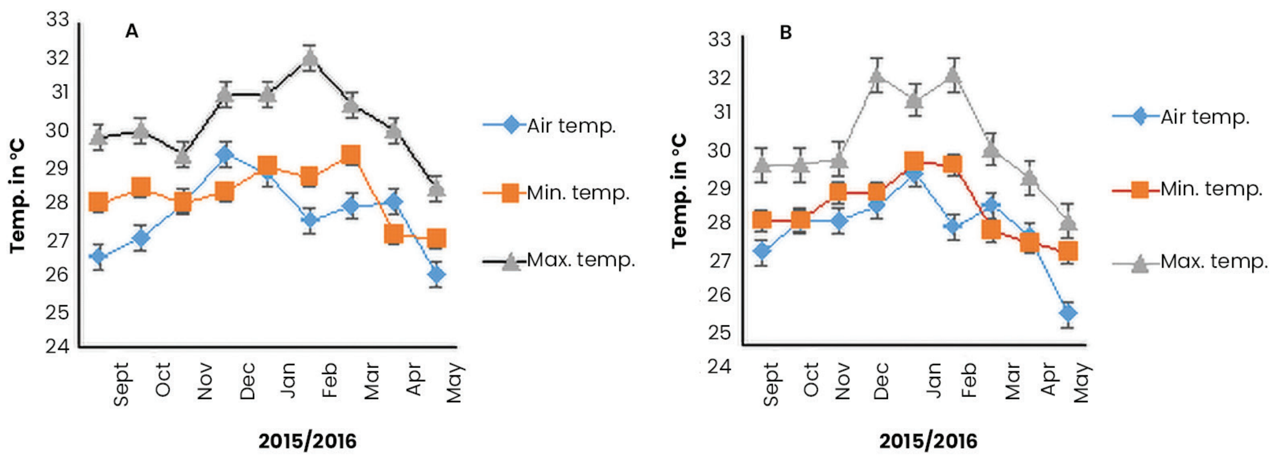

Figure 5. The air, minimum and maximum water temperatures at Kibuyuni (A) and Mkwiro (B) at the South Coast of Kenya.

SEM (24-26°C). The present study observed no significant variation in water nitrate and phosphate concentrations between Kibuyuni and Mkwiro. The incidence of the ice-ice disease of eucheumoids was higher in the FB culture technique than in the MB and FR techniques probably due to the presence of significantly lower water motion and higher minimum and maximum water temperature in the FB than in the MB and FR techniques. Lower water motion may have prolonged stagnation of water in the FB than in the MB and FR techniques leading to the accumulation of water pollutants such as metabolic products which exacerbated the effects of ice-ice disease on seaweeds.

The environment under which seaweeds were cultured in the FR technique appeared to have been also conducive for the growth of epiphytes. The two algae species thus seemed to favourably compete for space and nutrients without significant harm to each other. On the other hand, the epiphytic load in the FB technique may have been proliferating to occupy the space left by the lost seaweeds, thus increasing food diversity and the number of foraging herbivores. Epiphytes have been shown to provide ecological niches, food and protection for animals including grazers (Bittick *et al.*, 2010).

Growth performance

A higher incidence of ice-ice disease, herbivory and plant loss on eucheumoids occurred between December and February, a period when the highest air and water temperatures were also observed. Significant variations of the biotic factors between the three culture techniques were observed with the ice-ice disease, plant loss and herbivory being higher in FB than in the MB and the FR techniques ($p < 0.05$). Epiphytic load (%) was highest in FR and lowest in MB techniques. Further analysis showed that all the biotic factors were significantly higher in *K. alvarezii* than in *E. denticulatum* ($p < 0.05$).

The fish population observed during the nine months of the study was dominated by Siganidae (60%), Scaridae (30%), and Acanthuridae (10%). These fish were encountered more at Kibuyuni than at Mkwiro and were more abundant during high tides than at low tides. The thalli of eucheumatoid cuttings stocked in the FB ropes showed the highest signs of nipping and the lowest in MB technique at both sites. Aggregations of 10-20 individuals of the sea urchin *Tripneustus gratilla* were also observed crawling on the bottom of all the culture techniques. However, there was no clear evidence of seaweed grazing by urchins.

Net yield of seaweeds

The net yields of eucheumoids presented in figure 6 show a general trend of net yields in the FR and MB techniques with high net yields from September to January and a drop in February. This observation contrasts with that of net yields in FB where high net yields were observed from September to November and declined in December and January. The net yields of eucheumoids in FR and FB seemed to recover in March in both sites but a continuous decline was observed thereafter in the MB technique. Positive and negative growth of seaweeds were encountered in all the culture techniques during the cultivation period. The growth variation coincided with changes in the prevailing environmental conditions. For instance, the growth rate was highest during the wet season compared to the hot season. However, during the wet season, there was negative growth of seaweeds in the MB technique because the structure supporting the cultivated seaweeds was destroyed by a strong typhoon.

A statistically significant variation of eucheumoid net yields across the nine months of cultivation was observed in the three culture techniques $F(8, 448) = 60.8, p < 0.001$). The mean net yield of eucheumoids at the South Coast of Kenya was 2.3 kg wet wt m^{-2} 30 d^{-1} with FR showing its highest yield (kg wet wt m^{-2} 30 d^{-1}) in October (4.33) and both MB and FB showing their highest net yields in November (MB = 2.234, FB = 1.14). The lowest net yields (1.98 in December, 0.44 in

February, and 1.13 in January) were observed in FR, MB and FB techniques, respectively.

According to multiple comparison tests, the cultivation techniques had statistically different net yields (kg wet wt m^{-2} 30 d^{-1}) with the FR, MB and FB having 2.6 ± 0.2, 1.7 ± 0.1 and 1.0 ± 0.1, respectively ($p < 0.05$).

The mean net yield at Mkwiro was 2.7 kg wet wt m^{-2} 30 d^{-1} ranging from 0.7 to 7.7 kg wet wt m^{-2} 30 d^{-1}, with the lowest and highest being observed in December and February respectively. On the other hand, Kibuyuni had a net yield mean of 1.9 kg wet wt m^{-2} 30 d^{-1} ranging from 0.4 to 4.3 kg wet wt m^{-2} 30 d^{-1}. T-test analysis showed that the mean net yield (kg wet wt m^{-2} 30 d^{-1}) obtained at Mkwiro was significantly higher than that obtained at Kibuyuni and that the net yield (kg wet wt m^{-2} 30 d^{-1}) of *E. denticulatum* (3.0 ± 0.2) was significantly higher than that of *K. alvarezii* with 1.6 ± 0.1 ($p < 0.001$).

Correlation of eucheumoids net yields and environmental parameters

Table 1 shows the correlations between environmental parameters with the net yields of eucheumoids. Significant correlations of eucheumoids net yield with both biotic and abiotic factors were observed at $p < 0.05$ and $p < 0.01$, respectively. Among the abiotic factors, diffusion factor showed a positive correlation with the net yield of both species while air and maximum water temperature and phosphate concentration were inversely correlated with the net yields of both species ($p < 0.05$). On the other hand, all the biotic factors had negative correlations with the net yields of both eucheumoids (Table 1). However, based on the stepwise multiple regression analysis, there was no single environmental factor that could explain 50% of the variation in the eucheumoid net yield.

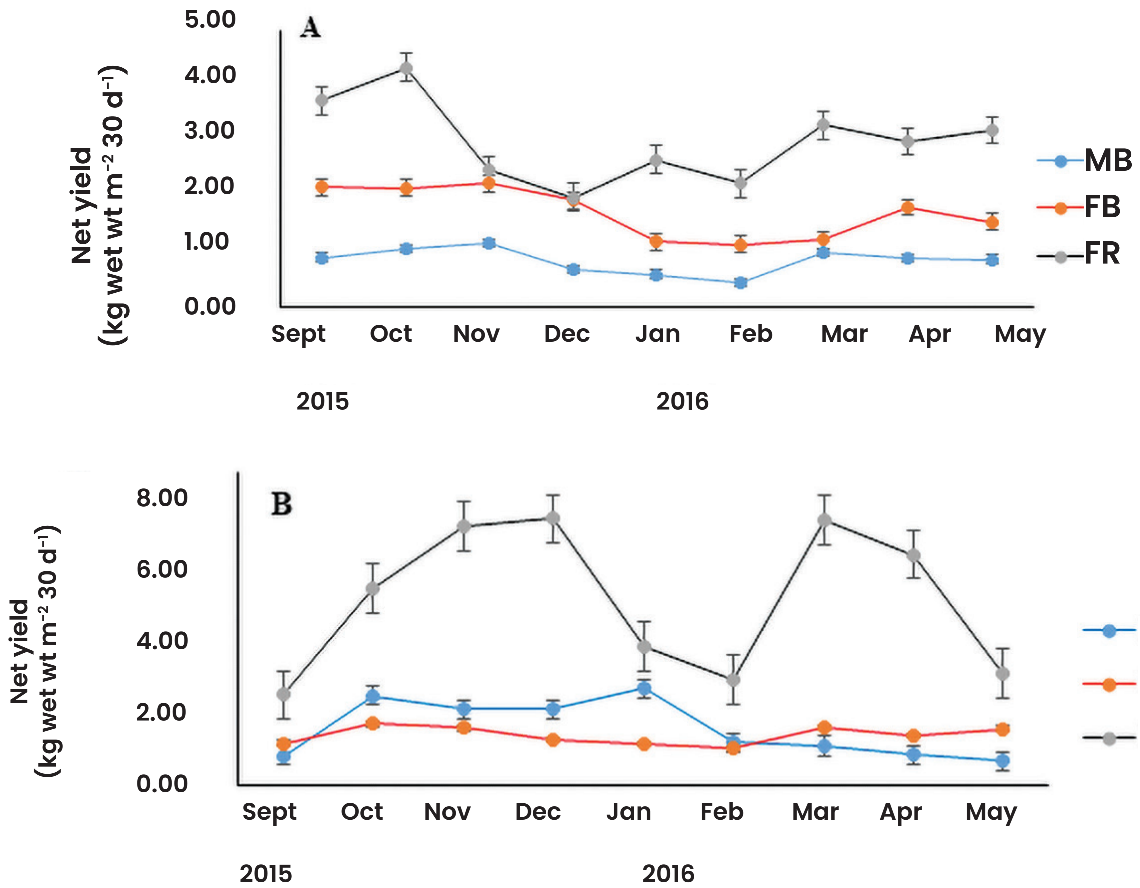

Figure 6. Monthly net yield of eucheumoids at two sites i.e., Kibuyuni (A) and Mkwiro (B) in the southern coast of Kenya, (n = 91 - 97, mean ± SEM).

Net yields

The significant relationships expressed in the correlation analysis in table 1 could suggest that the monthly variations in eucheumoid net yields in the present study were associated with monthly changes in environmental conditions including diffusion factor, water temperature, incidence of ice-ice disease, herbivory and plant loss. The monthly trends in eucheumoid net yields observed in this study, are typical of seasonal variations in eucheumoid growth rates observed in previous studies. Kimathi *et al*. (2018) observed high growth rates of eucheumoids in September and October and the lowest between December and February. Low net yield of seaweeds following the outbreak of ice-ice disease and epiphytes during regimes of abnormal increase in air and surface water temperature has been reported in Malaysia (Vairappan *et al*., 2006) and Tanzania (Msuya *et al*., 2014). In the Philippines, Hurtado and Agbayani (2002) reported that moderate to strong water movement contributed between 70-80% of seaweed productivity in southern Mindanao. In the WIO region, the negative effects of ice-ice disease and epiphytes were responsible for a drop in biomass production of *K. alvarezii* from 1,000 tonnes (dry wt) to only 13 tonnes in Tanzania while the epiphytic algae and ice-ice disease infestations seriously hampered growth of *K. alvarezii* in Kenya (Msuya and Kyewalyanga 2006; Wakibia *et al.*, 2006; Msuya *et al.*, 2014). In the present study, the highest net yields of eucheumoids were observed between September and January when the water temperature was lower and water motion was moderate, thus reducing the incidences of ice-ice disease, and plant loss. This observation contrasted with the lowest net yield observed in February when the highest water temperature was observed and incidences of ice-ice disease, epiphytes and plant loss were higher. In his study, Vairappan (2006) reported that cultured seaweed in the dry seasons becomes susceptible to epiphytes and that the outbreak of epiphytic filamentous red algae correlates with drastic changes in seawater temperature and salinity.

Destruction of the culture facility (MB technique) by the storm (typhoon) between April and May led to a continuous decline of eucheumoids biomass during the period and consequently impacted the mean net yield of eucheumoids negatively. However, the high biomass accumulated by plants in the MB technique in the previous months ensured that the MB technique had a better overall performance than the FB tech-

Table 1. Correlation coefficients (r) of eucheumoid net yield of two species with environmental factors and seaweed parameters in South Coast Kenya.

	Eucheuma denticulatum		*Kappaphycus alvarezii*	
Variable	r	p-value	r	p-value
Diffusion factor	0.247	0.001**	0.222	0.001**
Air temperature (°C)	-0.213	0.007**	-0.138	0.005**
Maximum temperature (°C)	-0.041	0.503	-0.286	0.001**
Nitrate (µM)	0.097	0.116	0.115	0.063
Phosphate (µM)	-0.229	0.001**	-0.200	0.001**
Herbivory (%)	-0.221	0.001**	-0.342	0.001**
Ice - ice disease (%)	-0.208	0.001**	-0.346	0.001**
Epiphytic load (%)	-0.271	0.001**	-0.468	0.001**
Plant loss (%)	-0.368	0.001**	-0.336	0.001**

r is significant at $p < 0.05$, where p has **, r is highly significant at $p < 0.05$

nique. The damage of seaweed farms due to typhoons in tropical regions has been reported in Argentina which resulted in the mean net yield of eucheumoids reducing from 4.27 ± 0.23 kg wet wt m^{-2} 30 d^{-1} to 0.02 ± 0.04 kg wet wt m^{-2} 30 d^{-1} (Valderrama *et al.,* 2013). In the Philippines, the challenges of typhoons are annual occurrences that negatively impact seaweed yield (Hurtado and Agbayani, 2002). The results of this study thus suggest that if mechanisms are devised to improve the stability of the MB technique in deep water to resist strong typhoons, then it could be an effective technique for seaweed cultivation in deep water. Nevertheless, the study observed that the high biomass in the MB technique could have been influenced by the position of seaweeds on the surface at all times where grazers were minimal and the water temperature was stable. Contrastingly, the permanent fixing of seaweed ropes on the sea bottom in the FB technique exposed seaweeds to many grazing hazards and subsequently to bacterial infections, ice-ice disease and plant loss.

The highest diffusion factor, lowest maximum water temperature, lowest herbivory, ice-ice disease and capacity to overcome the typhoon were attributed to the highest net yield observed in the FR technique compared to the other techniques. The interaction of the cooler environment and higher water motion could have triggered positive results. In a previous study in Kenya, Wakibia *et al*. (2006) observed significantly higher growth rates of *E. denticulatum* in comparison to *K. alvarezii* at a site where water motion was highest.

The net yields (kg wet wt m^{-2} 30 d^{-1}) of 3.0 ± 0.4 and 1.6 ± 0.1 in the present study for *E. denticulatum* and *K. alvarezii* (1.6 ± 0.1) respectively were higher than those reported in the previous study. Wakibia *et al.* (2011) reported net yields (kg wet wt m^{-2} 30 d^{-1}) of 0.57 - 0.99 for *K. alvarezii* and 0.77 for *E. denticulatum* in South Coast Kenya. When compared to net yields from other regions, the net yields of *Kappaphycus* (0.57 - 0.99 kg wet wt m^{-2} 30 d^{-1}) were lower than 4.8 kg wet wt m^{-2} 30 d^{-1} in Indonesia, 2.1 kg wet wt m^{-2} 30 d^{-1} in Hawaii and 2.8 kg wet wt m^{-2} 30 d^{-1} in the Philippines (Hurtado-Ponce *et al*., 1996). The higher prevalence of ice-ice disease, herbivory, epiphytic load and plant loss in the *K. alvarezii* than in the *E. denticulatum* accounted for a higher mean net yield (3.0 ± 0.4 kg wet wt m^{-2} 30 d^{-1}) of the former compared to the latter (1.6 ± 0.1 kg wet wt m^{-2} 30 d^{-1}). *E. denticulatum* possesses the capacity to produce H_2O_2 during oxidative burst which is suspected to be part of its chemical defence mechanisms against epiphytic attack (Collen *et al.,* 1995). This characteristic could portray that in an environment where both species are challenged by epiphytes, *E. denticulatum* has a greater capacity to maintain a higher growth rate and biomass compared to *K. alvarezii*. In Tanzania, a drop in biomass production of *K. alvarezii* from 1,000 t (dry wt) to only 13 t (dry wt) was associated with ice-ice disease (Msuya *et al.,* 2014). In other studies, the abundance of *Kappaphycus* decreased from 62.5% to 15.9% in five months in Hawaii by a single *Tripneustes gratilla* foraging within an enclosure of 0.25 m^2 (Conklin and Smith, 2005).

Conclusion and recommendations

The study demonstrates how the exposure of seaweed species to environmental challenges may influence variations in its biomass accumulation. The abiotic factors (water motion and water temperature) and biotic factors (ice-ice disease, epiphytes and herbivory) significantly influenced the variations of euchemoid net yields between the cultivation techniques on the South Coast of Kenya. All the techniques were suitable for the production of *E. denticulatum* in deep water but the FR technique had the highest potential for commercial application since it supported the production of both *E. denticulatum* and *K. alvarezii* in deep water. The positive observations of the FR technique were associated with its ability to mitigate ice-ice disease challenges in deep water environments. On the other hand, MB was the best technique to mitigate epiphyte challenges. However, the structural design of the MB technique could not resist occasional typhoons leading to the highest loss of seaweed biomass during the SEM. Consequently, mechanisms to improve the stability of the MB technique to overcome strong destructive oceanic waves (typhoons) in deep water should be devised. The FB is a favourable seaweed cultivation technique for adoption by new farmers, especially those with limited swimming ability and low confidence in working in deep water. Further research should be conducted to determine the economic feasibility of FR and MB techniques before commercial adoption. The government of Kenya in collaboration with donor agencies should mobilize resources to promote seaweed cultivation in deep water using the floating raft technique. Such efforts would boost national seaweed production and contribute significantly to ensuring food and job security for coastal communities and the sustainable development of the Blue Economy.

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COVID-19 Ripples: Vulnerability to food insecurity and coping strategies for low-income fisheries-dependent lacustrine urban dwellers

Charlotte I. Peter[1], Nancy Kibet[1], Julia A. Obuya[2], Patrick W. Otuo[2], Horace Owiti[2]*

[1]Kisumu National Polytechnic, P. O. Box 143 - 40100, Kisumu, Kenya
[2]Kenya Marine and Fisheries Research Institute, P.O. Box 1881-40100, Kisumu, Kenya
*Corresponding author: owitihorace79@gmail.com, (+254) 0 719 669227

Abstract

The Coronavirus disease (COVID-19) measures were counter-productive in the food and nutritional security landscape for households that were already vulnerable before the pandemic. Our study assessed the food insecurity experiences of low-income, fisheries-dependent, urban dwellers of Manyatta slum in Kisumu, Kenya, during the implementation of the COVID-19 regulations. Data was collected from 24 households in July 2021 for a period of 14 days using a standard food security assessment questionnaire. Results indicate that the main sources of food during the pandemic were small shops (50%) and rural open-air markets (42%), with major shopping malls less frequented for food purchases. Further, most (83%) respondents had a reduction in their income during the pandemic. Overall, affected Manyatta slum dwellers were affected by increased food prices, reduced income and limited access to food products. The coping mechanism was borrowing money or food to meet the shortfall. The availability and affordability of fish, which is the main source of animal proteins for the community, was negatively impacted by the dusk-to-dawn curfew, which curtailed night fishing. Subsidies for nutritionally important food items such as fish, and increased access to credit for vulnerable slum dwellers to help them meet their food budgets during pandemics are recommended.

Keywords: pandemic, food security, nutrition, fisheries, lake, urban

Introduction

The COVID-19 pandemic was reported to have started in Wuhan-China in December 2019 (Kumar *et al*., 2020; Lin *et al*., 2020). The disease spread rapidly to many other countries globally resulting in the death of millions of people worldwide and significant impacts on the global economy (Onyeaka *et al*., 2021). The virus is mainly spread through close contact with respiratory droplets released when an infected person sneezes, talks or coughs. Symptoms range from mild to severe, with the most common being fever, cough, and laboured breathing (Parvin *et al*., 2020; Wilson and Wilson, 2021).

To curtail the spread of the pandemic, many governments developed regulations that restricted the movement of people and goods through the enforcement of curfews, quarantines, travel bans, social distancing, and limitations on social gatherings (Aura *et al*., 2020). These measures varied in length depending on the country and were frequently supported by financial assistance for individuals and companies affected by the pandemic (Koh *et al*., 2020). The regulations disrupted food production systems and trade, thereby leading to serious socioeconomic implications such as loss of employment, social unrest, reduced access to food products and widespread food insecurity (Aday and Aday, 2020; Meuwissen *et al*., 2021).

In addition to food insecurity, lack of consistent access to nutritious food sources during pandemics was a leading cause of malnutrition and mental health problems (Fang *et al*., 2021; Paslakis *et al*., 2021). The Food and Agriculture Organization of the United Nations predicted that the COVID-19 pandemic would increase global food insecurity due to several factors, including the restrictions on access to sufficient or diverse nutritious foods that may have resulted from disruptions in trade and market supply chains (FAO, 2020).

Studies have shown the existence of socioeconomic vulnerabilities that worsen food insecurity during pandemics. For instance, poverty (Pereira and Oliveira, 2020), presence of children in a household (Ahn and Norwood, 2021), race and ethnicity (Morales and Ali, 2021), neighbourhood or residential area (Larson *et al*., 2021), among others. Similarly, several social unrests (Campedelli and D'Orsogna, 2021) and political upheavals (Censolo and Morelli, 2020) have been witnessed during the pandemic in response to unwelcome government regulations and worsening living conditions. The impacts of the COVID-19 pandemic on food supply chains, food access, and food security were more severe in low-income countries (Udmale *et al*., 2020). All these indicate that many citizens expect a more economically friendly environment during pandemics, yet many governments are mostly caught unprepared (Dodds *et al*., 2020).

In Kenya, the COVID-19 pandemic was reported at a time when the country was already experiencing food shortages and hunger among 5.5% of its population (USAID, 2020). The government of Kenya moved with speed to enforce measures such as the ban on social gatherings, closure of all learning institutions and places of worship (Agwanda *et al*., 2021). In addition, lockdowns of the capital city (Nairobi) and the second largest city (Mombasa) and shutdown of eateries and bars were also enforced (Lau *et al*., 2021). Countrywide restrictions on movement except for essential goods and services, a dusk-to-dawn curfew, social distancing, frequent hand sanitization and mandatory wearing of masks were also among the regulations enforced (Mwesigye, 2021). Moreover, the importation of second-hand items such as clothing was banned (Curran *et al*., 2021). Given that the country comprises about 14.5 million people engaged in informal employment (implying that 90% of the total number of people are employed) (Aura *et al*., 2020), the immediate observable impact was the loss of employment to millions of Kenyans (Schwettmann, 2020). Tourism earnings also dropped by more than 80% (Wanjala, 2020).

The massive loss of employment, disruption of supply chains for goods and services, and termination of feeding programmes for school children during the COVID-19 pandemic worsened the food insecurity situation within the already hunger-stricken population (Kansiime *et al*., 2021). Yet, while the government offered some remedies such as tax reduction, waivers of transaction fees on electronic transactions and suspension of credit bureau listing (Banga and te Velde, 2020; Ouko *et al*., 2020), there was no government-led programme that efficiently or continuously availed food to needy households. Many food-insecure households reside in the slums of major cities (Kimani-Murage *et al*., 2014; Wanyama *et al*., 2019). This is because, if they cannot afford adequate food (though food is a basic commodity) they will highly likely not be able to afford the secondary costs that are associated with a decent living. Life in slums is much fairer for them because the cost of housing is cheaper and at a minimum (Huchzermeyer, 2008). Slum dwellers also account for most of the labour force engaged in informal employment (Meagher, 2016). An assessment of the socioeconomic experiences of slum dwellers in the wake of the implementation of COVID-19 regulations thus gives useful insights into the extent to which the pandemic affected the ability of households in slums to access food and maintain food security.

Regulations are important in safeguarding the health of citizens during a pandemic (Dos Santos *et al.*, 2021). However, just as pandemics pose a significant threat to human health, access to sufficient and nutritious food is also a key determinant of human health and well-being (Kundu *et al.*, 2021). The fear of the COVID-19 pandemic caused many governments to focus more on controlling the disease without considering the welfare of their citizens (Ferreira *et al.*, 2021), and Kenya was no exception. Therefore, government regulations mostly impacted poor populations who were already experiencing socioeconomic challenges such as food insecurity (Van Barneveld *et al.*, 2020). Since the level of impact on these communities may not be known, the study investigated the extra burden that slum communities bore due to government regulations, including the coping strategies that they adopted during the COVID-19 pandemic. The study builds on existing research to establish a link between socioeconomically vulnerable communities and their livelihood safety nets during pandemics.

Materials and methods

Study area

The study was conducted within Manyatta Estate (Fig. 1). Manyatta is a peri-urban neighbourhood on the eastern outskirts situated within the slum belt of Kisumu County, Kenya's third-largest city (Baker, 2002). It is subdivided into two Wards - Manyatta A and B. The neighbourhood is predominantly characterized by informal settlements. According to the 2019 census, the population density in Manyatta was 60,000 people living in an area of five square miles (KNBS, 2019). The area has several female-headed households due to the high prevalence of HIV/AIDS-related deaths of male partners (Miller *et al.*, 2021). The main activities in the area are small-scale fish trade and groceries with many households living on less than a dollar a day (Kiaka *et al.*, 2021). The sanitation of the area is relatively poor, with more than 50% of the households either living in semi-permanent or temporary structures (Anderson, 2016; Othoo *et al.*, 2020). Manyatta slum provides features of a vulnerable community, which was of interest to

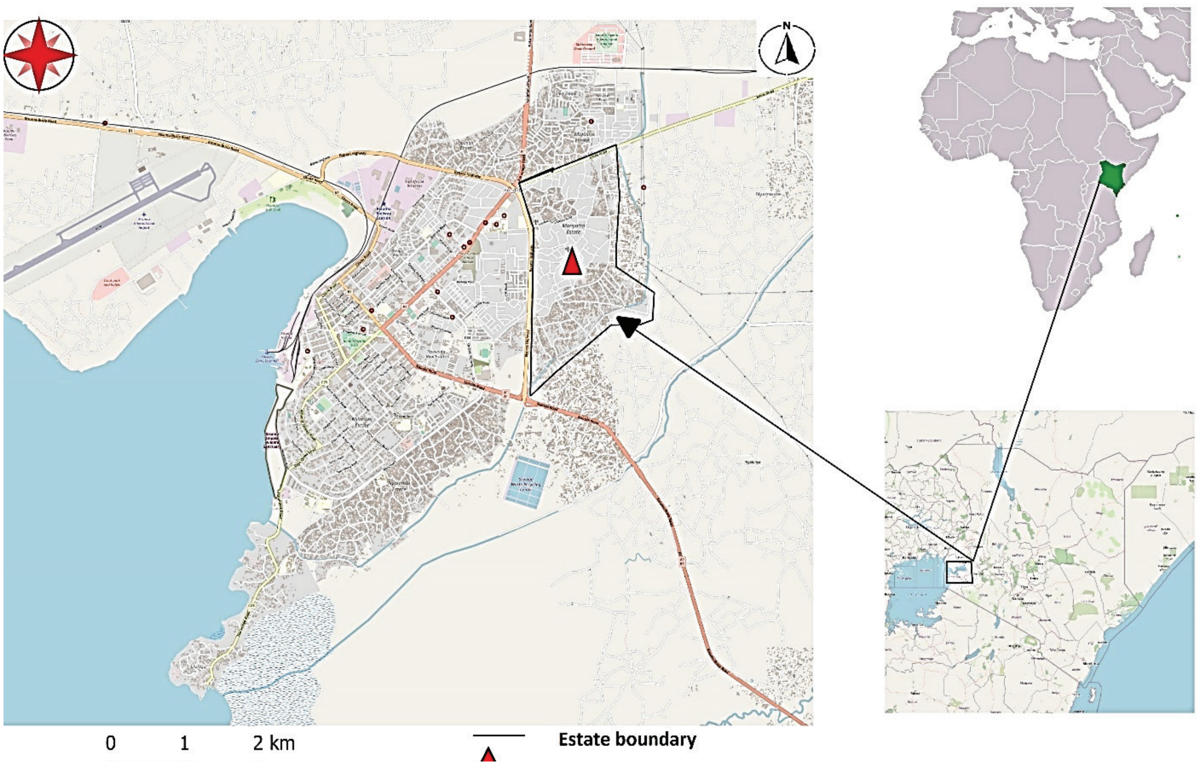

Figure 1. Map showing the location of the Manyatta Estate (Slums) in Kisumu County, Kenya (Source: Authors).

our study on the impact of COVID-19 regulations on household food security. Other factors, such as the availability of resources, including funding and ease of access to the community also played a role in the choice of the Manyatta slum.

Sampling

Manyatta has a population density of 2.4 people per square kilometre. The estate has about 8,600 households. The present study focused on Manyatta Centre due to the ease of accessibility and financial constraints. The Centre hosts about 300 households (KNBS, 2019). A sample of 24 (~10%) households were randomly selected at Manyatta Centre for the interviews in the month of July 2022. The sample size was thus largely moderated by resource constraints. Households which declined to participate in the survey cited limited availability, competing economic activities, and lack of funds for prior compensation for their interview time.

Ethical considerations

The study adhered to the ethical principles of confidentiality, anonymity, transparency, and no harm to the participants. Before the interviews began, the purpose of the study, data collection procedures, the absence of risks, and the benefits of participating in the study were explained to the respondents who verbally provided consent. The survey was designed and administered in a culturally sensitive manner, taking into account cultural and linguistic differences among the study participants. Consideration was also given to the vulnerable and marginalized members of the community to avoid bias.

Data collection

Semi-structured questionnaires were administered to the household representatives who were often the breadwinners, but in instances where the respondent was male and married, he mostly responded to questions on the preparation of food for the household with the assistance of the female partner. It is important to note that some chores within the household were given based on gender roles largely defined by cultural norms (Alonso *et al*., 2018). In some societies, cooking and food preparations are considered women's work, therefore, men are often deemed not to have as much knowledge or experience in this area (Taillie, 2018). As a result, it was considered more suitable for the male respondent to seek assistance from his wife or other female family members while answering questions about household food preparations. The questionnaire included questions on household socio-demographic characteristics, the food security situation during COVID-19 and before, and coping strategies during the pandemic. Each interview session lasted for a period of at least 30 minutes while the duration of the entire study was 14 working days.

Data entry and analyses

Raw data from the questionnaires were entered into an electronic form (Google®) which was transmitted into the Kobo Collect system for onward transmission and archiving. This mode of data entry was meant to minimize errors and to utilize inbuilt analytical features in Google Sheets to speed up the data analysis process (Aura *et al*., 2023). The data was later downloaded into a MS Excel sheet for data cleaning and validation. Further analyses were also performed in MS Excel. The main analyses performed included summaries such as means, percentages, and graphic visualization. Qualitative data or long explanations were subjected to thematic analyses.

Results and discussion

Socio-demographic characteristics

Figure 2 shows the socio-demographic characteristics of the respondents. A proportion of 53% of respondents originated from Manyatta B ward with the rest residing in Manyatta A. The majority (75%) of respondents were female, with at least 75% of the respondents having either primary

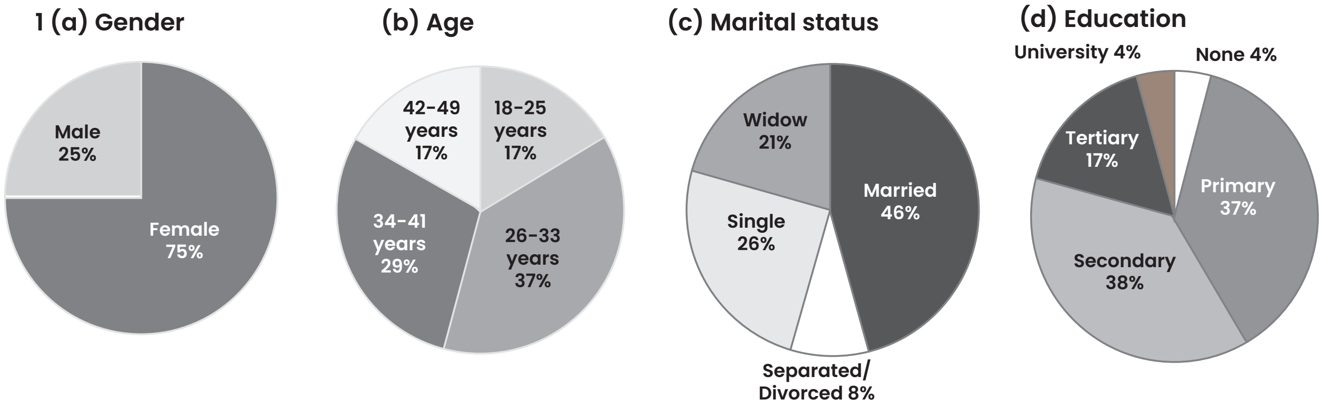

Figure 2. Socio-demographic characteristics of respondents showing (a) gender, (b) age, (c) marital status and (d) level of education amongst the residents of Manyatta Slums.

(37%) or secondary (38%) education. This could be attributed to the involvement of women in household chores as compared to men (Alonso *et al*., 2018). Most of the households sampled were represented by youths (26-33 years, 37%), with fewer households represented by either much younger (18-25 years) or much older citizens (42-49 years). Most households were in marital unions.

Figure 3 shows the mean monthly income of the respondents. The respondents relied on several casual jobs and some low-paying salaried jobs. These included security guards, hairdressing, small-scale grocers, fish trade, social work, and hotel services. Their income levels were relatively low (mostly less than USD 100 per month) ranging from KES 5,000-20,000 a month (1 USD = KES 117 in 2022) which is the dominant income level for peri-urban and urban dwellers in informal settlements (KNBS, 2019).

Income during COVID-19

Figure 4 shows the outcome when respondents were asked about the changes in income, which they experienced during the COVID-19 pandemic due to the regulations. During the interviews, respondents were probed to help identify the factors that may have contributed to income reduction during the pandemic, such as job loss, and decreased demand for products or services. From the results, most respondents (83%) had a reduction in their income, with none indicating any increase in income. This exhibits the possible negative effect that COVID-19 regulations had on these households' livelihoods. Similar findings were reported in other studies conducted on the impact of the COVID-19 pandemic (Aura *et al*., 2023).

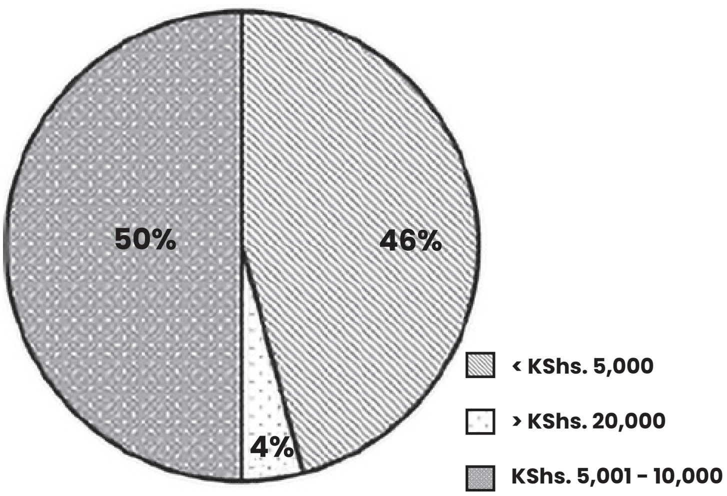

Figure 3. The mean monthly income of slum dwellers in Manyatta, Kisumu, based on a survey of 30 respondents conducted in 2022.

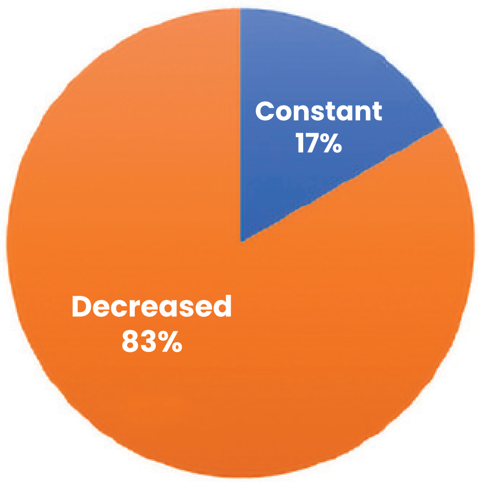

Figure 4. Change in income during implementation of COVID-19 regulations.

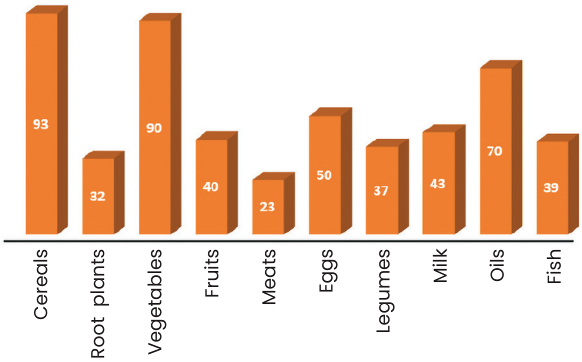

Figure 5. The frequency of food types accessed by slum dwellers in Manyatta, Kisumu during implementation of COVID-19 regulations, based on a survey of 30 respondents conducted in 2022.

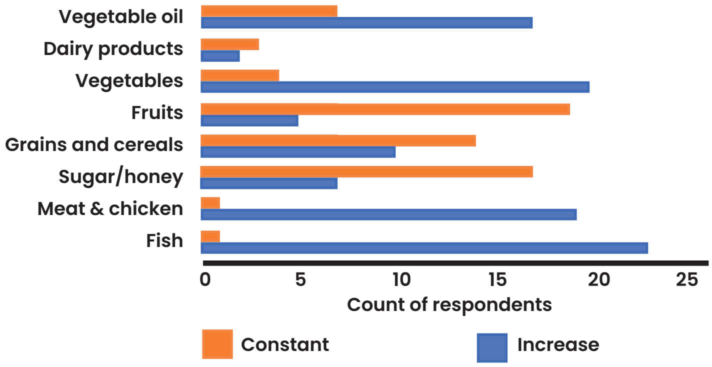

Figure 6. The average prices of common food products accessed by slum dwellers in Manyatta, Kisumu during implementation of COVID-19 regulations, based on a survey of 30 respondents conducted in 2022.

Food accessibility

Figure 5 shows responses on the types of food that the respondents accessed during the pandemic. Most respondents reported accessing cereals, vegetables, and oils as their primary food sources during COVID-19 regulations. Meat products were the least accessible product to households in Manyatta. This could be attributed to the relatively higher price of meat, making it a lesser priority during economically difficult times.

Food Prices

Figure 6 shows the trend of food prices. Most food prices were reported to have increased during the implementation of COVID-19 regulations. The greatest increase was noted for prices of fish, meat, vegetables/vegetable products and dairy products whereas prices of sugar, grains and fruits were mostly constant. The COVID-19 pandemic thus had an upward effect on the prices of food commodities. However, other market factors such as changes in global trade, production costs, and consumer preferences could have also influenced the prices of food commodities (Anderson and Martin, 2021; Nekmahmud, 2022).

Impact of regulations on access to food

Figure 7 shows the respondents' rating of the effect of various categories of COVID-19 regulations on food access. Among the regulations, the dusk-to-dawn curfew was rated to have had the

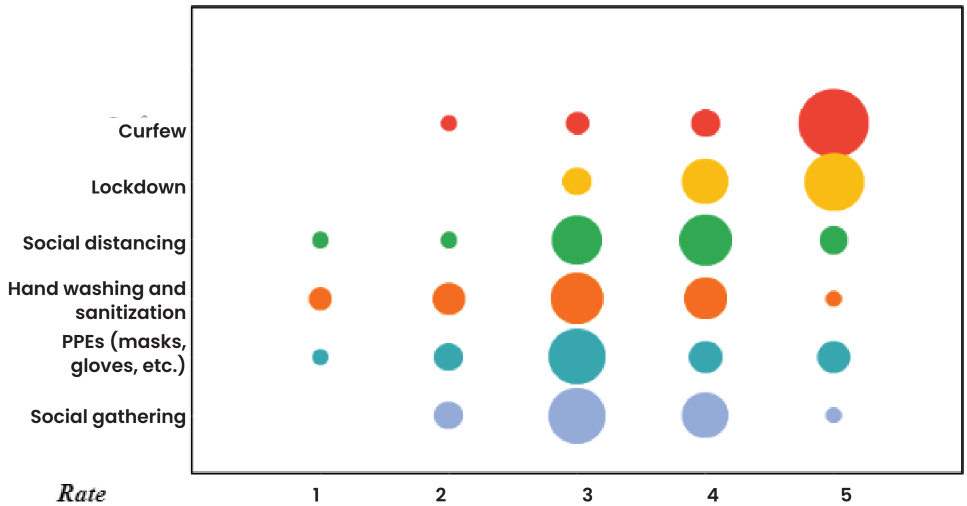

Figure 7. Respondents' rating of the effect of COVID-19 regulations on food access. The different colours represent the various regulations enforced during the COVID-19 pandemic, whereas the size of the dots shows the magnitude of a particular regulation on food access in the area.

most effect on food access for the slum dwellers. Most perishable food items are sold during periods of cooler temperatures of the day within slums due to limited refrigeration facilities. This implies that most trading in perishable food products is effective at dusk or dawn, possibly explaining the relatively high rating for the curfew regulation as the regulation that has the highest impact on food access among residents of Manyatta (Fiorella *et al*., 2021).

Food source during COVID-19 regulations

Figure 8 shows major sources of food consumed by respondents during the regulation period. Most respondents purchased food from small shops (50%) and rural markets (42%). Unlike many urban dwellers of the middle and upper classes (Mandal *et al*., 2021), the Manyatta residents rarely visited supermarkets for food products during the periods of government-imposed restrictions following the COVID-19 pandemic.

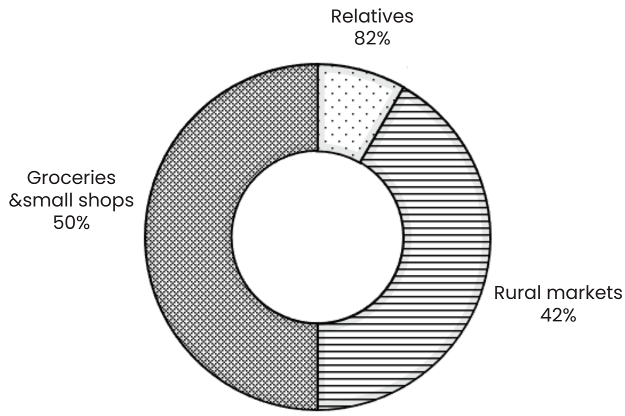

Figure 8. Food sources during the implementation of COVID-19 regulations.

Coping strategies

Figure 9 shows the variety of food-related coping strategies employed by the respondents. The main coping strategies used by Manyatta slum dwellers were the purchase of food on credit, borrowing food from friends or relatives and reduction in meal portions. This finding provides a possible insight into how access to credit facilities may have served as a useful buffer for these residents in economic difficulty. The finding could be useful in the future for government agencies and development partners who are interested in improving access of these communities to finances. Financial services could be tailored by existing banking or microfinancing institutions to meet the needs of this unique sector of clients and enable them to mitigate livelihood risks during pandemics.

Conclusion and recommendations

This study established that the COVID-19 pandemic severely affected Manyatta slum dwellers in Kisumu City. Manyatta, as one of Kenya's largest and most densely populated slums, provides a representative case study of the experiences of low-income groups in urban regions. As a result, the study's findings are likely to mirror the situation in other low-income suburbs in Kenya and other African countries. The main effects of the pandemic included an increase in food prices, the reduction in income sources, and the reduction in access to food products. Food products like meats and fruits, which are nutritionally very

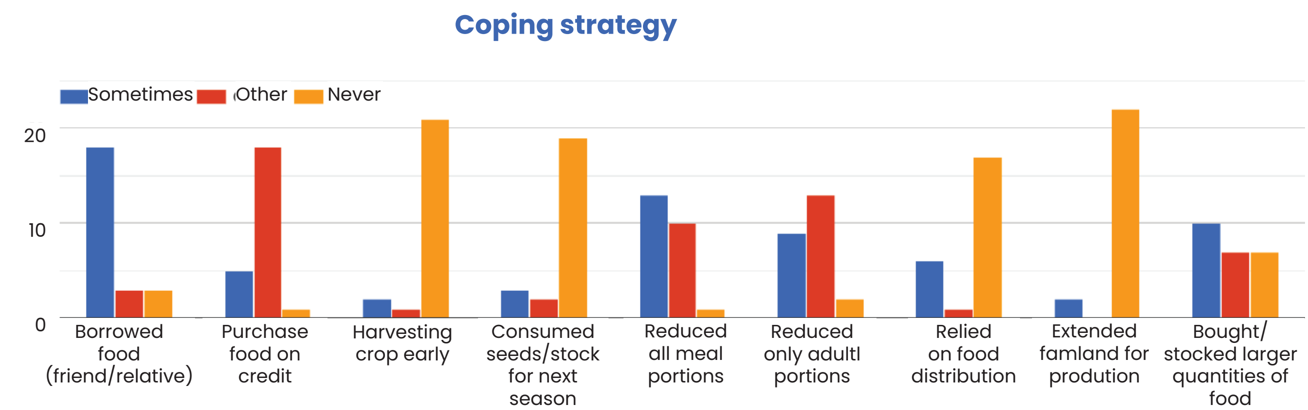

Figure 9. The frequency of coping strategies employed by slum dwellers in Manyatta, Kisumu during COVID-19 regulations, based on a survey of 30 respondents conducted in 2022.

important, were the least accessible during the pandemic. This implies that the pandemic affected both food and nutritional security. These findings are especially significant because they emphasize the critical need for initiatives to address the pandemic's impact on vulnerable communities and improve their food security and general well-being. The main sources of food were donations and rural markets while the dusk-to-dawn curfew was rated as the severest regulation with respect to food access. The main coping strategy for these communities was borrowing to meet their shortfall in food expenditures. Policymakers should thus consider adopting measures to support vulnerable communities during pandemics, such as providing social safety nets, access to credit facilities, and improving the availability and affordability of essential food products. These measures could help to build community resilience and enhance the ability of low-income communities to cope with the challenges of future crises. The study, therefore, recommends the following:

i. Subsidizing expensive food products that are nutritionally important for households during pandemics. These include all classes of meat and fruits.

ii. Increasing access to credit for vulnerable slum dwellers during pandemics to help them meet their food budgets.

Acknowledgements

The authors would like to express their sincere gratitude to the Kisumu National Polytechnic for their support in carrying out this project. We also extend our appreciation to the community of Manyatta for their participation in the study and for providing valuable insights into the impact of COVID-19 on their livelihoods.

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Short communication

Alarming incidence of porcupinefish bycatch in the Lamu seascape beach seine fishery: Could this be a sign of an ecosystem imbalance?

Gladys M. Okemwa[1]*, Almubarak A. Abubakar[1], George W. Maina[2], Melckzedeck Osore[1]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 81651-80100, Mombasa, Kenya
[2]The Nature Conservancy, Africa Regional Office, P.O. Box 19738-00100, Nairobi, Kenya
*Corresponding author: gokemwa@kmfri.go.ke, (+254) 20 8021561

Abstract

Overfishing and destructive fishing practices are strongly associated with loss of biodiversity and habitat degradation resulting in the proliferation of non-target and resilient species. In the long-term, this may also lead to an ecosystem imbalance. This short communication documents a worrying trend of high catch ratios of porcupinefish in the Lamu seascape beach seine fishery observed during catch assessment surveys conducted in 2021 – 2023. The increasing incidence high puffer bycatch is alarming fishers due to concerns over economic loss. Unfortunately, there is very limited data and information on the status of the puffer populations and ecosystem impacts within the seascape. A comprehensive study is recommended to better understand patterns of seasonal abundance as well as ecological and socioeconomic impacts. Research on alternative commercial uses of the harvested puffers can also be explored. However, such exploitation must be undertaken with caution considering the potential risk of incentivizing direct targeting which may secondarily encourage increased beach seine fishing effort. As part of a multi-institutional collaboration to restore the critical marine ecosystems of the Lamu seascape, it is hoped that a gear exchange programme will encourage beach seine fishers to exit the fishery and adopt other more environment friendly fishing practices.

Keywords: Overfishing, impacts, climate change, management

Introduction

Porcupinefish form a large proportion of the discarded bycatch in Kenya's artisanal fishery. Porcupinefish belong to the order Tetraodontiformes, which contains nine other families: Tetraodontidae (pufferfish), Balistidae (triggerfishes), Molidae (molas), Monacanthidae (filefishes), Ostraciidae (boxfishes), Triacanthidae (triplespines), Triacanthodidae (spikefishes), Tridontidae (threetooth puffers), and Aracanidae (deepwater boxfishes) (Panão *et al*., 2016). Worldwide, at least 19 different species of porcupinefish have been discovered (Leis, 2006; Matsuura, 2014). Although they can reach lengths of up to 100 cm, they usually measure 20 - 50 cm. *Diodon liturosus, Diodon holocanthus*, and *Diodon hystrix* are three species that are regularly found along the Kenyan coast and are locally referred to as *Bunju* in the South Coast and *Matoetoe* in the North Coast up to Lamu (Froese and Pauly, 2023). They are typically solitary and inhabit a wide range of habitats such as inner reef flats and lagoons, where they can be found in seagrass beds, sandy and muddy bottoms,

Figure 1. A typical beach seine catch dominated by parrotfish, *Leptoscarus vaigiensis* (left) and bycatch dominated by porcupinefish, *Diodon holocanthus* (right) (Source: Almubarak A.).

estuaries, coral reefs, rocky substrates, seagrass beds, mangroves, artificial structures, pelagic open water, tide-pools, as well as deep-water habitats (Froese and Pauly, 2023). Their diet is diverse, consisting primarily of algae, molluscs (like clams), and crustaceans (like crabs and lobsters). Although population trends are unknown, the World Conservation Union (IUCN) has classified all three porcupine species as least concern (LC).

Incidence of porcupinefish bycatch

In contrast to the rest of the Kenyan coast, the Lamu seascape is regarded as a global biodiversity hotspot sustaining highly productive marine ecosystems and fisheries (Kairo *et al*., 2021). In some areas of the seascape, fishermen have reported an increase in the frequency of large porcupinefish capture ratios in beach seine catches over the past three years (Fig. 1). Alarm has been raised by the new trend due to worries about a possible underlying environmental imbalance. The high bycatch ratios have an unknown underlying explanation, but there is a nagging doubt as to whether this could be connected to a population boom. Porcupinefish population surges have been documented all across the world, including in India, where the overfishing of predators was blamed for the phenomenon (Padate *et al*., 2022). Sharks, lizardfish, sea snakes, catfish, cobia, skipjack tuna, and octopus are some of the few natural predators of porcupinefish (Stump *et al*., 2018; Ulman *et al*., 2021). As a result of previous overfishing, which altered food webs (trophic cascades), most apex predators, including sharks, have unfortunately suffered (Azzurro *et al*., 2019). Overfishing of sea urchin predators, particularly triggerfish, was blamed for the early 1990s population explosion of sea urchins at numerous locations along the Kenyan coast (McClanahan and Shafir, 1990).

Management interventions

Interventions to control overfishing and habitat degradation include promoting use of more selective and environment friendly fishing methods in addition to mitigating use of harmful fishing practices. Due to their high catch efficiency and close interaction with seagrass and reef environments, beach seines are among the most harmful fishing methods (McClanahan and Mangi, 2004; Samoilys *et al*., 2011; 2017). Effective enforcement of the 2001-enacted national beach seining prohibition is necessary to limit the usage of beach seines. When they are dragged down the sea floor, they not only destroy vital fish spawning and feeding grounds, but they also increase juvenile fish catch rates and hence contribute towards overfishing. A typical beach seine net is up to 300 m long and is lined with buoys or floats at the top to keep the upper part afloat and lead sinkers at the bottom to keep the net submerged in the water. In order to catch fish that are herded into the net through the water, the net may additionally feature a cod end. Beach seining is a labour-intensive activity that requires a sizable workforce (8-40 people), hired by the owners of the equipment.

It is also possible to conduct research on alternative applications for harvested porcupinefish bycatch. For the treatment of cancer, it has been discovered that the extracted toxin possesses anti-tumour characteristics (Fouda, 2005; Lago *et al*., 2015; Bucciarelli *et al*., 2021). Any commercial exploitation, however, needs to be done cautiously and with due regard for the potential risk of rewarding direct targeting, which might subsequently stimulate more beach seine fishing effort.

On porcupinefish populations and catches around the Kenyan coast, there are, regrettably, very few data and details available. To better comprehend the causes, as well as the ecological and socioeconomic effects of excessive porcupinefish bycatch, a thorough study is recommended. There is an urgent need to map the incidents, estimate the overall catch and bycatch rates, and evaluate the seasonality of occurrence in beach seine catches. The exercise may encompass a scaled-up version of any ongoing partnerships with relevant stakeholders, including the fishing communities. The purpose of this partnership would be to lessen the use of destructive fishing methods such as beach seines in Lamu. A beach seine gear exchange initiative undertaken by KMFRI, The Nature Conservancy (TNC), Kenya Wildlife Service, County Government of Lamu and the Northern Range Trust (NRT) is also ongoing as part of this multi-institutional collaboration to entice beach seine fishermen to transition to utilizing other more environmentally friendly fishing gears like handlines and traps. The program makes use of important takeaways from earlier gear exchange initiatives and directly incorporates local fishing communities and Beach Management Units in decision-making. Fisherfolk collaborate closely with KMFRI and other partners in co-production and knowledge sharing to identify best practices and provide information for adaptive management. These initiatives and the suggested management strategies are anticipated to make a significant contribution to the restoration of vital marine ecosystems that constitute the Lamu seascape, while minimizing any potential ecosystem imbalance.

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