UNIVERSITY OF CAPE COAST

ASSESSMENT OF ENVIRONMENTAL INFLUENCES ON FECUNDITY OF BLACKCHIN TILAPIA (*Sarotherodon melanotheron*) IN SELECTED COASTAL LAGOONS OF GHANA

BY

JEREMIAH SAMSON KAPATU

Thesis submitted to the Department of Fisheries and Aquatic Sciences of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy degree in Fisheries Science.

OCTOBER 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

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

Name: …………………………………………………………………………...

Supervisors' Declaration

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

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

Name: …………………………………………………………………….………

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

Name: ………………………………………………………………………

ABSTRACT

Coastal lagoons provide small-scale fisheries as a source of livelihood for coastal dwellers. Unfortunately, anthropogenic activities in Ghana are greatly degrading these lagoons which also serve as habitats for fish, including blackchin tilapia (*Sarotherodon melanotheron*). Yet, scientific information on the influence of these degraded lagoons on fish in Ghana is presently scarce. Given that *S. melanotheron* forms the mainstay of brackishwater fisheries in Ghana, this study was therefore carried out to assess environmental influences on fecundity of *S. melanotheron* in selected coastal lagoons of Ghana. A total of 744 fish from five selected lagoons were sampled for fecundity during the major breeding season (March – May). Within the same period, physicochemical parameters were measured monthly. Stomach content analysis was conducted to determine the diversity of food items consumed by *S. melanotheron*. Results showed significant variations ($p < 0.05$) in both fecundity and physicochemical parameters across the five lagoons. Among these physicochemical parameters, temperature, pH, dissolved oxygen, salinity, biochemical oxygen demand and food diversity markedly influenced fecundity ($R^2 = 0.98$). By inference, environmental conditions play a remarkable role in the dynamics of reproductive performance of *S. melanotheron*. The negative impacts of these environmental factors on the reproductive capacity of *S. melanotheron* threaten the sustainability of lagoon fisheries in Ghana with consequences for food security. Hence, strict environmental management and conservation measures such as proper waste management should be instituted to discourage deleterious anthropogenic activities carried out around water bodies in Ghana.

KEY WORDS

Anthropogenic activities

Blackish water

Physicochemical parameters

Pollution

Reproductive performance

Water quality

ACKNOWLEDGEMENTS

I would like to express my profound gratitude to my supervisors, Prof. Joseph Aggrey-Fynn and Dr. Evans Kwasi Arizi both of the Department of Fisheries and Aquatic Sciences, for their excellent supervision, guidance, suggestions, advice, encouragement and love with which they guided this project work. I am really very thankful for their marvelous job.

I am also grateful to members of the Department of Fisheries and Aquatic Sciences (DFAS), lecturers, laboratory technicians, including Mr. Albert Koomson, Mr. Benjamin Owusu and Mr. Thomas Robin Davis for their immense support during the laboratory activities.

I also extend my sincere appreciation to my beloved wife Mayamiko Kamwendo for her moral support and encouragement, my roommate Kofi Ntsunyo Kudiabor for the beautiful and cheering moments we shared in Ghana which made me feel at home, my classmates of Fisheries class and to all my colleagues of ACECoR project for their love and support.

Finally, special thanks go to the World Bank, Africa Centre of Excellence in Coastal Resilience (ACECoR) and the Government of Ghana for their financial support without which this research work would not have materialized.

DEDICATION

I dedicate this work to my beloved daughter: Abigail Kapatu

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ACECoR	Africa Centre of Excellence in Coastal Resilience
AIC	Akaike Information Criterion
ANOVA	Analysis of variance
BOD	Biochemical oxygen demand
BW	Body weight
DO	Dissolved oxygen
FD	Food diversity
SE	Standard error
SPSS	Statistical Package for Social Scientists

CHAPTER ONE

INTRODUCTION

Background to the Study

Fish reproduce to add new individuals to increase its population size in an ecosystem (Issa, Olufeagba, & Raji, 2005). It is through this process that their population is maintained at equilibrium by striking a balance with mortalities to avoid depletion and extinction. Whether reproduction in fish is successful or not, depends on a number of factors that maintain a close interaction with the fish in their habitat.

Environmental factors such as temperature, nutritional status of the fish, dissolved oxygen (DO) and salinity are some of the factors known to have influence on the reproduction of fish (Mule & Sarve, 2017). These factors can either promote or suppress reproduction depending on their quantity of occurrence. Food, for instance, is a source of energy which is often allocated to growth and reproduction and this means that inadequate amount of food will distort a range of reproductive performances such as fecundities and spawning (Kuzuhara et al., 2019).

Food supply has been found to be directly proportional to the fecundity of fish (Siddiqui, Al-Harbi, & Al-Hafedh, 1997). Defined as the number of eggs likely to be deposited by a female fish at a given spawning period (Towers, 2014), fecundity is a measure of the reproductive capacity of the female fish. Variations in the environmental conditions which can be exacerbated by anthropogenic activities, can contribute to variations in fecundities of fish populations even of the same species or within the same stocks of fish (Kingdom & Allison, 2011). Variation in fecundity has been observed in Blackchin tilapia

(*Sarotherodon melanotheron)* populations in Benya, Fosu and Domunli lagoons (Arizi, Obodai, & Aggrey-Fynn, 2014; Blay, 1998); it is however not certain whether the variation is as a result of environmental influences.

Sarotherodon melanotheron, commonly known as Blackchin tilapia, is a tilapia species belonging to the family of cichlidae that is endemic to the West Africa coast from Senegal to the Democratic Republic of Congo and it inhabits both freshwater and brackish water ecosystems (Mireku, Blay, & Yankson, 2016). It is one of the most dominant fish species occupying lagoons and estuaries (Blay, 1993) and it can survive extreme harsh conditions in most lagoons (Dankwa, Quarcoopome, Owiredu, & Amedorme, 2016).

The species is valuable as it holds high potential of being cultured under commercial aquaculture systems (Pauly, 1976) and being a dominant fish species in most lagoons, it provides an important source of cheap protein and livelihood for folks that dwell around these lagoons (Arizi et al., 2014).

Biologically, *S. melanotheron* is a prolific breeder and it reaches maturity faster than many other species of the same family (Eyeson, 1983). One other extra-ordinary feature is the ability of species to respond to varied environmental conditions. It has unique strategies to adapt to different harsh conditions in the environment but beyond optimal limits, reproduction and growth of fish are impaired (Gue`ye, Tine, Kantoussan, Ndiaye, & Thiaw, 2012).

Statement of the Problem

Ghana is one of the countries located in the Gulf of Guinea and the country is well endowed with many brackish water ecosystems including over 90 lagoons and other coastal wetlands located along the 550km coastline (Entsua-Mensah, Ofori-Danson, & Koranteng, 2000). These ecosystems support Ghana's artisanal fisheries, thereby providing livelihood opportunities for the coastal dwellers (Lamptey & Ofori-Danson, 2014). *S. melanotheron* is one of the most dominant species inhabiting some well-known lagoons such as Keta lagoon, Songor lagoon, Fosu lagoon, Benya lagoon and Domunli lagoon (Arizi et al., 2014; Blay, 1998; Dankwa et al., 2004). By implication, *S. melanotheron* forms the backbone of brackish water fisheries in Ghana.

Aspects of fecundity of *S. melanotheron* in some Ghanaian lagoons have been studied (Arizi et al., 2014; Quarcoopome & Owiredu, 2016). In the Fosu lagoon, for example, Quarcoopome and Owiredu found that at least 98% of the sampled fish had absolute fecundity below 200 eggs with a weak correlation between body parameters and absolute fecundity. Elsewhere, 200 eggs is reported to be the minimum number that the species is capable of producing (Trewavas, 1983).

An average fecundity of 78 eggs reported recently for *S. melanotheron* in the Fosu lagoon is relatively lower than 206 eggs of the same species in the Domunli lagoon (Arizi et al., 2014; Quarcoopome & Owiredu, 2016). This suggests that deteriorating and varied environmental conditions of various coastal lagoons in Ghana are responsible for declining and varied fecundities of the species (Quarcoopome & Owiredu, 2016).

Most lagoons in Ghana are in deplorable states as they are suffering from a great deal of pollution, siltation or sedimentation and other forms of environmental pollution (Dankwa et al., 2016; Entsua-Mensah et al., 2000; Quarcoopome & Owiredu, 2016) and this can have devastating effects on fish health as these anthropogenic stressors distort the stable natural processes and conditions of water bodies that support aquatic life (Patricio et al., 2016).

Fecundity is a function of fish population size implying that any slight change in this parameter can have an influence on population dynamics of the species or stock biomass (Hunter, Macewicz, Chyan-Huei Lo & Kimbrell, 1992). Although some works have been done to understand the reproductive biology of *S. melanotheron* in the Ghanaian waters (Arizi et al., 2014; Mireku et al., 2016; Quarcoopome & Owiredu, 2016), no study has been carried out to assess the environmental influences on the fecundity of the species in Ghana.

The existing studies only emphasize actual counting of eggs and relative fecundity of the species but do not explicitly capture the impacts of environmental conditions on the reproductive performance of the species (Arizi et al., 2014; Mireku et al., 2016; Quarcoopome & Owiredu, 2016). Against this background, this study sought to assess how the fecundity of *S. melanotheron* and environmental conditions are related in Ghana's coastal lagoons to contribute knowledge towards sustainable management of the fish.

Purpose of the Study

The general purpose of this study was to assess environmental influences on fecundity of *S. melanotheron* in selected coastal lagoons of Ghana, including Domunli, Benya, Fosu, Sakumono and Keta lagoons.

Research Objectives

The study was aimed at assessing environmental influences on the fecundity of *S. melanotheron* in selected coastal lagoons of Ghana. Specifically, the study sought to:

1. Determine and compare physicochemical parameters of the selected lagoons;
2. Determine the diversity of food items consumed by *S. melanotheron* in the lagoons;
3. Determine and compare variations in the fecundity of *S. melanotheron* populations in the lagoons;
4. Examine relationships between fecundity and body parameters of *S. melanotheron* in the lagoons; and
5. Examine relationships between physicochemical parameters and fecundity of *S. melanotheron* in the lagoons.

Research Hypotheses

In line with the research objectives, the following were the research hypotheses:

1. Variation in the physicochemical parameters among the selected lagoons is not statistically significant.
2. The diversity of food items consumed by *S. melanotheron* is not statistically different among the lagoons.
3. Fecundity of *S. melanotheron* populations is not statistically different among the lagoons.
4. There are no relationships between fecundity and body parameters of *S. melanotheron* among the lagoons.

5. There are no relationships between environmental parameters and fecundity of *S. melanotheron* among the lagoons.

Significance of the Study

The study will contribute to knowledge on how the fecundity of the species is responding to the deteriorating ecological health conditions of the lagoons. The knowledge can serve as a guide for management authorities towards decision making and formulation of policies which are relevant to conserve the species and ensure sustainable lagoonal fisheries. This knowledge can be used to address the challenges of food insecurity, malnutrition and poverty confronting fisher folk in the coastal areas of Ghana.

Delimitations

The study covered only five lagoons spread along the entire coast of Ghana with each coastal region represented by at least one lagoon. The coast of Ghana has over 90 lagoons and coastal wetlands but for the purpose of this study, only five of them were studied which included Domunli lagoon in Western Region, Benya and Fosu lagoons in Central Region, Sakumono lagoon in the Greater Accra Region and finally Keta lagoon in Volta Region.

Of so many environmental factors that may have influence on fecundity of fish, only nine key parameters were studied which included temperature, pH, dissolved oxygen, salinity, turbidity, phosphate, nitrate, biochemical oxygen demand and lastly food diversity. Some factors not studied but could be of importance in fecundity determination include riparian vegetation around the lagoons, total dissolved solids, total suspended solids and ammonia concentration.

Limitations

The use of food diversity index as a measure of food abundance is inadequate approach for the quantification of food availability in the lagoons. The lagoon may contain diverse food items but those food items may not be enough for the healthy growth or survival of the fish.

The determination of biochemical oxygen demand using the five-day incubation period method may not be very precise owing to the possibilities of numerous human errors when collecting water samples from the lagoon in which it is inevitable to take with few water bubbles due to the waves and turbulence of the water system and this may affect the actual amount of oxygen consumed by the bacteria for the decomposition of organic matter.

Ideally, data of this type of work is supposed to be collected in a period of more than one to capture both dry and wet season to get accurate results. However, in this study, only dry season was considered and the results might be underreported.

Definition of Terms

Some of the terms and their definitions as used in this study are:

Fecundity:

This is referred to as the number of eggs likely to be deposited by female fish at a given spawning period

Hypoxia:

A scenario of having too low concentration of dissolved oxygen in a system usually below 2 mg/l

Biochemical oxygen demand:

This is the amount of oxygen needed by bacteria to decompose the organic matter

Organisation of the Study

This work is organized in the following sections: Title page, Declaration, Abstract, Key Words, Acknowledgements, Dedication, Table of Contents, List of Tables, List of Figures, List of Acronyms, Introduction, Literature Review, Research Methods, Results and Discussion, Summary, Conclusions, and Recommendations, References, and lastly Appendices.

Chapter Summary

This chapter has fully provided the background information of blackchin tilapia including its reproductive biology and geographical distribution. The species is endemic to West Africa coast from Senegal to the DRC. The term fecundity has also been defined as number of eggs deposited by female fish at a given spawning period. A background of how some environmental factors affect reproductive performance of fish has also been stated in this chapter.

CHAPTER TWO

LITERATURE REVIEW

General Description of Lagoons, Their Importance and Issues Surrounding Them

Coastal areas have a diverse range of wetlands and ecosystems. Lagoon ecosystems are among such wetlands and they play a significant role of supporting coastal dwellers with livelihood opportunities as well as other ecological roles. Lagoons are shallow bodies of water usually less than 6 meters deep, formed in between terrestrial areas of the coast and marine ecosystems (Avornyo, 2019).

Lagoons have different salinity levels especially at different seasons of the year hence classified as either freshwater lagoons or brackish water lagoons or even hypersaline lagoons (Kjerfve, 1986). It is important to state that these lagoons could either be permanently open lagoons that connect with the ocean throughout the seasons or intermittently closed lagoons that are separated from the ocean by a bar of any barrier such as sand and usually open into the sea only during the rainy season through a restricted opening.

It is also imperative to point out that lagoon ecosystems are a valuable treasure to coastal dwellers as they offer multifaceted functions which include provision of good natural sites for both primary and secondary productions such as plankton growth and complex food webs which in turn makes them suitable and valuable for significant aquaculture and fisheries production and also useful for salt extraction (Kjerfve, 1994). Despite the value of the lagoons outlined, they continue to be misused and degraded by both natural and anthropogenic activities across the globe (Odjer-Bio, Belford, & Ansong, 2015). Odjer-Bio et al. (2015) notes that these lagoons are primary recipients of both organic and inorganic compounds from the surrounding areas and this makes them act as material sinks and material filters which consequently cause changes in the environmental parameters in the lagoons.

Lagoons in Ghana

Ghana is located in West African coast along the Gulf of Guinea. It is well endowed with many brackish water ecosystems including over 90 lagoons and other coastal wetlands located along the 550 km coastline (Entsua-Mensah et al., 2000). These ecosystems support Ghana's artisanal fisheries, thereby providing livelihood opportunities for the coastal dwellers (Lamptey & Ofori-Danson, 2014).

The Central Coast of Ghana has the highest concentration of these lagoons with about 65 lagoons on a 330 km coastline (Yankson & Obodai, An update of the number, types and distribution of coastal lagoons in Ghana, 1999). Avornyo (2019) reports that Ghanaian lagoons harbour a diversity of flora and fauna and that there is no one species that dominates these lagoons. However, several other notable researchers have reported that *Sarotherodon melanotheron* is a dominant species when it comes to fish species composition across these lagoons and is conspicuously the mainstay of seasonal artisanal fisheries of the said lagoons (Blay, 1993; Blay, 1998; Lamptey & Ofori-Danson, 2014).

Like in many parts of the world, Ghana's lagoons are facing similar issues of environmental pollution as a result of anthropogenic influences. Urbanization for example is resulting in encroachment of Ghana's coastal lagoons leading to pollution from both industrial and domestic waste (Agbemehia, 2014; Lamptey & Ofori-Danson, 2014; Dankwa et al., 2016).

Contamination of these lagoons by the pollutants can affect water quality hence posing a threat to fish biodiversity and artisanal fisheries in general.

Significance of Tilapias

Tilapias are cichlids which are native to Africa and Middle East and the name Tilapia originated from an African indigenous language which means fish (El-Sayed, 2020). In all other parts of the world, tilapia species were introduced through breeding programmes upon assessment of their genetic advantage to fisheries production (Pullin et al., 1991).

Tilapia as a broad term has three important genera which are distinguished on basis of their reproductive biology and these are *Tilapia*, *Oreochromis* and *Sarotherodon*. The *Tilapia* are substrate spawners with both parents providing care and defense to the spawning nest or substrate. *Oreochromis* are maternal mouth brooders while *Sarotherodon* are paternal or sometimes biparental mouth brooders (Mjoun, Rosentrater, & Brown, 2010).

As human population keeps booming, pressure on capture fisheries keeps increasing which is levelling off capture fisheries due to unstoppable demand for this resource and aquaculture seems to be the only available option to ease this pressure (Subasinghe, Soto, & Jia, 2009). Interestingly, it is reported that tilapia contributes not less than 40% of aquaculture production (Scorvo, Frascá-scorvo, Alves, & Souza, 2010). Therefore, having deep understanding of all the biological processes of the fish is of importance as the fish constitutes one of the right candidates for aquaculture, which according to Prabu, Rajagopalsamy, Ahilan, Jeevagan, & Renuhadevi (2019), comes second after carps as top farmed fish in the world. It is advisable to culture tilapia in its native abode, Africa, especially knowing that fisheries sector has potential of addressing food insecurity, eradicating poverty and reducing malnutrition in Africa's poverty stricken communities (Béné and Heck, 2005).

Apart from being a source of protein, the fish is also one of the healthiest delicacy as it contains lowest levels of contaminants due to its feeding behaviour which is primarily a planktivorous fish, hence feeds low in the trophic level (Mjoun et al., 2010). Tilapias are hardy and can tolerate wide fluctuations of environmental conditions (Prabu et al., 2019).

Distribution of *Sarotherodon melanotheron*

Sarotherodon melanotheron (Ruppel, 1852), commonly known as the Blackchin Tilapia, is a tilapiine species belonging to the family of cichlidae that is endemic to the West Africa coast from Senegal to Democratic Republic of Congo and it inhabits both freshwater and brackish water ecosystems (Mireku et al., 2016). It is one of the most dominant fish species occupying lagoons and estuaries (Blay, 1993) and it can survive extreme harsh conditions in most lagoons (Dankwa et al., 2016). The species is valuable because it has high culture potential under commercial aquaculture systems (Pauly, 1976). It provides an important source of cheap proteins and livelihood for folks that dwell around these lagoons (Arizi et al., 2014).

Biologically, *S. melanotheron* is a prolific breeder and the species reaches maturity faster than other species of the same family (Eyeson, 1983). Several authors have reported that *S. melanotheron* is the most dominant species inhabiting some well-known lagoons such as Keta, Fosu, Benya and Domunli lagoons (Arizi et al., 2014; Blay, 1998; Dankwa et al., 2004) and this implies that *S. melanotheron* forms the backbone of brackish water fisheries in Ghana. Through visible sexual dimorphism, males can easily be distinguished from their female counterparts by examining operculum colouration, which is golden in males and purple in females (Blay, 2009), making sorting a bit easier.

Fecundity in Fish

Reproduction is an important life history trait in fish since it is the process that brings new individuals to maintain fish population at equilibrium (Issa et al., 2005). Majority of female fish species produce eggs in their gonads. The number of eggs that the female fish can produce in the gonads prior to spawning at a given period of time is referred to as fish fecundity (Towers, 2014). It can therefore be deduced that fecundity is one of the proxy measures of fish reproductive capacity; the higher the fecundity, the higher the reproductive capacity.

Fecundity is a function of fish stock populations. Therefore, any slight change in fecundity of fish can have an influence on its population dynamics (Hunter et al., 1992) though other external factors, including migration and mortality also play a role in the dynamics. While fecundity influnces fish population dynamics, it is dependent on a number of environmental factors. It is therefore not surprising to observe variations in fish fecundity of the same species or within the same stock of fish as it can be attributed to different environmental or habitat conditions (Kingdom & Allison, 2011).

Fecundity of fish can be determined using whole count method (Arizi et al., 2014; Ezenwaji & Offiah, 2003;). This method involves direct counting of individual eggs in ovaries. Although the method is simple, it is diffiult to apply to highly fecund species which produce tons of eggs. There are other methods (e.g. sub-sampling method) for determining fecundity but they are somehow problematic because they are prone to producing inaccurate results. Hence, it is advisable to use the whole count method, especially if the fecundity of less fecund species is to be determined.

Eggs extracted directly from the ovaries are very soft and they must be hardened and separated before actual counting is perfomed. Fixing the eggs in 10% formalin (Arizi et al., 2014; Mireku et al., 2016) has been very useful as a way of hardening soft eggs, although the method seems not to work well with other researchers due to unpleasant strong smell of formalin and it is carcinogenic. The method also requires ample time. For instance, Arizi et al. (2014) indicates that actual counting of eggs can commence after fixing the eggs in formalin for at least two weeks when hardening might have taken place.

Fecundity of Blackchin Tilapia

Aspects of fecundity of *S. melanotheron* in some African tropical waters have been studied (Arizi et al., 2014; Quarcoopome & Owiredu, 2016). In Fosu lagoon in Ghana, for example, Quarcoopome and Owiredu (2016) discovered that at least 98% of the sampled fish had absolute fecundity of less than 200 eggs. The fecundity ranged from 20 to 370 eggs with a mean fecundity of 78 eggs. Two hundred eggs however was reported as minimum number that the species is capable of producing in lagoons found in Lagos, Nigeria (Trewavas, 1983). Quarcoopome and Owiredu (2016) pointed out that environmental factors like pollution and siltation were responsible for low fecundity observed in the lagoon. According to Blay (2009), a previous unpublished study in Fosu lagoon indicates that the lagoon registered higher average fecundity than the one reported by Quarcoopome and Owiredu (2016). This may be an indication that the water quality of the lagoon is deteriorating.

In Domunli lagoon, the fecundity of *S. melanotheron* ranged from 97 to 397 with an average fecundity of 206 oocytes (Arizi et al., 2014). The fecundity in this lagoon is described as generally low and Arizi et al. attributed this low fecundity to a number of suggested factors. These factors include changes in water levels of the lagoon throughout sampling period and mouth brooding nature of *S. melanotheron* which determines the number of eggs to lay in regard to holding capacity of the mouths. It was also observed in that study that there was variation in fecundity within the population and different feeding intensities within the population was suggested to be the contributing factor.

Both studies in Fosu and Domunli lagoons leave a lot to be investigated. The authors made a lot of speculations as probable causes of low and varied fecundities in the lagoons. However, speculations can not be used to generate management policies unless verified by independent research. This is why it is important to incoporate environmental aspects in fecundity studies for better understading of how environmental conditions and fecundity are related. Fecundity and body parameters of *S. melanotheron* in Domunli and Fosu lagoons are poorly correlated (Arizi et al., 2014; Quarcoopome & Owiredu, 2016). According to Kjesbu, Witthames, Solemdal and Greer (1998), larger individuals produce more eggs than smaller individuals within the stock. However, there was no indication that larger individuals produced more eggs than their smaller counterparts in Fosu and Domunli lagoons.

In the Brimsu reservoir of Ghana, the species had higher fecundities with a range of 187 to 732 eggs with an average of 434 oocytes (Mireku et al., 2016). This could be indication and evidence that environmental or habitat conditions have a great impact on the number of eggs that this species is producing in different water bodies. From the foregoing, the reproductive performance of *S. melanotheron* in the Brimsu freshwater reservoir is higher than in coastal brackish water ecosystems of Ghana.

Physicochemical Parameters and how they Influence Fish Reproductive Performance

Temperature

A number of notable researchers have documented the effect of temperature on fish growth and development including reproducction, e.g., Faruk, Mausumi, Anka and Hasan (2012), EI-Naggar, EI-Nady, Kamar and Al-Kobaby (2000) and Issa et al. (2005) . Temperature is an important element of water quality and variation or alteration in this aspect of water quality can certainly have multiple physiological impact on aquatic biota since most aquatic organisms are poikilotherms which means their internal temperature is determined by temperature of their surrounding (Avornyo, 2019). Also, high temeperatures can reduce concentration of dissolved oxygen as more oxygen gets dissolved easily in cold water and this can result in mulfunctioning of various metabolic processes in aquatic organisms (Dallas, 2009).

Primary production is also affected by temperature. Phytoplankton are natural feed for fish like the blackchin tilapia and if adverse levels are recorded, it can affect dietary abundance of the fish which will have an impact on fish reproduction. It is reported that an increase in temperatures results in a shift of classes of algae from diatoms below 20℃ to green algae at a range of 15℃ to 30℃ and to blue green algae above 30℃ (DeNicola, 1996). Pollutants become too toxic at higher temperatures of water and can result in detrimental consequences to aquatic life. A study conducted on a Nile tilapia hatchery reported an increase in egg production at temperatures ranging from 25℃ to 28℃ as the most productive period (Faruk, Mausumi, Anka, & Hasan, 2012). in terms of egg production with. The highest number of eggs was obtained at temperature of 25℃ while 33℃ of temperature produced the lowest number of eggs .

A similar observation of temperture influencing fish reproductive performance was registered when there was total cessation of all spawining activities in Nile tilapia at temperature below 19℃ and resumed with at an increasing rate following an increase in temperatures but within the range of 22℃ to 27℃ (EI-Naggar, EI-Nady, Kamar, & Al-Kobaby, 2000). However, EI-Naggar et al. (2000) observed that temperature changes did not have significant effect on actual fecundity of the fish. This was attributed to the fact that once oogenesis has already taken place in any fish, external factors usually have little or no influence on the number of eggs that will be produced by the fish.

Another assessment of temperature impact on egg production was done to five different treatments in hapas and Nile tilapia was used and it was found out that the optimal temperature range which recorded highest number of eggs was from 29℃ to 31℃ (Alam, Sarkar, Miah, & Rashid, 2021). Further increase in temperature above 32℃ resulted in a decrease in egg production and production of eggs halted at temperatures above 33℃.

All these findings show similar trends of general impact of temperature on reproductive performance of fish. From Kigera reservoir, four tilapia species were studied and their fecundity recorded in relation to environmental conditions and it was observed that the highest fecundity was recorded at temperature range of 27°C to 29°C hence an inference was made that the rate of temperature was indirectly proportional to fish fecundity (Issa et al.,, 2005). It is however unfortunate that most work documented on this topic is from either laboratory experiments or pond experiments. Not much is documented about the effect of temperature on wild or natural populations of tilapia species, especially black chin tilapia.

Salinity

Different concentrations of salts in water can have different effects on so many processes in fish, including reproduction. *S. melanotheron* and tilapia species in general are known to tolerate wide ranges of salinities but impaired growth and precocious reproductive characteristics are reported in *S. melanotheron* in salinities beyond a certain threshold (Gue`ye et al., 2012). According to Gue`ye et al. (2012), absolute fecundities were significantly different among different salinities. Absolute fecundity was highest at location with salinity of 37 ppt followed by freshwater (0 ppt) and the saline environment (66-127 ppt) was least. It can be deduced from these findings that absolute fecundity of blackchin tilapia is directly proportional to salinity of a water body but up to a certain limit as hypersaline condition results in lowest absolute fecundity. Gue`ye (2012) further reports that in seawater and hypersaline water, fecundity was higher in rainy season than in dry season which indicates that the fish allocates less energy to osmoregulation in rainy season than in dry season and the saved energy can easily be channeled to reproduction during the rainy season.

For food resource availability, it is reported that salinity conditions might determine the amount of food resources in the locations as there is an inverse relationship between salinity and food resource availability (Gue`ye et al., 2012). In contrast, a similar study in a laboratory experiment in Senegal reported no significant differences in reproductive performance of *Sarotherodon melanotheron heudelotii* in locations with salinity 0 ppt (freshwater) and salinity 35 ppt (seawater) but a notable significant difference was observed between these two sites and one with salinity 70 ppt which is a hypersaline condition (Dugue et al., 2014).

Dissolved Oxygen

Aquatic organisms use oxygen in its dissolved form and photosynthesis by aquatic plants is one of important processes that supply dissolved oxygen in aquatic habitats. Low levels of dissolved oxygen (less than 2 mg/l), commonly known as hypoxia, can result in long term reproductive impairments in fish as reported in a study involving marine medaka in which low levels of oxygen had affected reproductive success by impairing ovarian development which consequently led to fewer vitellogenic oocytes despite multiple primary growth oocytes (Lai et al., 2019).

In an experiment involving Gulf killifish exposed to hypoxia conditions (1.34 mg/l) for 30 days, significant reduction in egg production was recorded compared to control treatment under normoxia (6.68 mg/l) (Landry, Steele, Manning, & Cheek, 2007). According to Landry et al., wild populations generally experience cyclic hypoxia but if it is prolonged, it can have the same negative effects on reproductive performance of the fish, although wild species tend to emigrate to areas with higher DO concentration within the aquatic system (Eby & Crowder, 2002). Landry et al. (2007) mentions that hypoxia conditions are being exacerbated by anthropogenic activities such as uncontrolled nutrient input in addition to global warming and climate change.

Another set of interesting observations were obtained in fathead minnows which responded differently to different DO treatments in which egg production was lower at DO level of 5.5 mg/l than in control (7.5 mg/l) while higher at DO level 5.7 mg/l than in control (7.5 mg/l) (Fisher, 2009). This phenomenon clearly shows that some species have optimum DO levels to achieve maximum production of eggs. Below and above these optimum levels, fecundity of fish might be affected. For instance, Alam et al. (2021) reported that egg production in Nile tilapia reached highest peak when DO concentration was 4.6 mg/l and lowest record was reported at 2.9 mg/l of DO. The DO optimum range for egg production was from 4.6 mg/l to 6 mg/l.

pH

pH plays an important role in determination of fish reproductive success. pH of water ranges from 0 to 14 in which pH below 7 is regarded as being acidic whilst pH above 7 is regarded as being basic. According to Alam et al. (2021), highest egg production in experimental treatments was recorded at a pH range of 8 to 8.8 which was regarded as optimum pH for that experiment while pH above 9.3 resulted in low production of eggs. A study on effects of exposing brook trout to different pH levels revealed that egg production was highest at pH value of around 7.34 and lowest at low pH or at acidic level and this was attributed to acidic stress that the fish went through resulting in negative effect on fish metabolism which yielded poor growth of the fish (Tam & Payson, 1986).

It was reported in one study that water acidification or low pH stressed the fish by depriving it of important sodium and chloride ions from body fluid which resulted in plasma osmotic pressure (Ikuta et al., 2000). Unlike in many experiments which showed that low pH caused low egg production, one experiment on coral reef fish produced surprisingly unique and different results in which increased CO_2 responsible for acidification seemed to stimulate reproduction and resulted in more eggs than in both control and moderate treatments and this was attributed to hermetic reaction of the fish (Miller, Watson, Mccormick, & Munday, 2013).

Turbidity

Turbidity measures clarity of water. It is about how murky or cloudy water is. It is an important water quality characteristic as it has both direct and indirect impact on aquatic organisms. If the water is not clear, it can affect the amount of light penetrating the water column for photosynthesis thereby reducing primary production which will affect fish physiology including reproduction due to inadequate nutrition, it can affect detection of food items by fish that rely on sight to find food, it can make some fish susceptible to predation and several other impacts.

Various substances contribute to high turbidity, including particulate matter such as sediments which include algal bloom, aquatic microscopic organisms, inorganic compounds, silt and clay, etc. (Minnesota Pollution Control Agency, 2008). The report outlines a number of both natural and anthropogenic sources of pollutants responsible for high turbidity levels. Phosphorus from wastewater industrial plants, agriculture and sewage load can initiate algal bloom resulting in increased turbidity of water. According to

Minnesota standards of water quality, a turbidity of 25 mg/l is considered suitable for both warm water fishery and indigenous fish whilst a turbidity of 10 mg/l is suitable for cold water fishery. This shows that various fish species have their own favourable turbidity limits to maintain their physiological or biological reactions. In Nile tilapia, a turbidity range of 15 to 35 cm produced highest number of eggs (Alam et al., 2021).

Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) gives an amount of oxygen required by bacteria to successfully decompose available organic matter in the water. It provides a good measure of extent of anthropogenically induced pollution in an aquatic environment as it indicates quantity of organic load entering a water body and, in many instances, used as pollution index (Ndimele, 2012). Fish physiological processes such as reproduction can be affected if BOD is not within permissible limits for sustaining fish life. A water body with BOD range from 1.0 mg/l to 2.0 mg/l is considered very clean; moderately clean at BOD range of 3.0 mg/l to 5.0 mg/l, and nearby pollution at BOD level greater than 5.0 mg/l (Koda, Miszkowska, & Sieczka, 2017).

Nutrients (Phosphate and Nitrate)

Human activities such as agriculture and industrialization are known to contribute to higher levels of both phosphates and nitrates in water bodies. The resulting effect may include eutrophication which reduces quality of water and consequently affect aquatic biota. Eutrophication as a result of excessive nitrates and phosphates can lead to harmful algal blooms, anoxia and hypoxia conditions and acidification of water body (Ngatia, Johnny, Moriasi & Taylor, 2019) which all have negative consequences on reproductive performance of fish. A study for example on viviparous fish indicated that higher nitrate concentrations resulted into significantly fewer numbers of mature gravid females and this was attributed to the fact that nitrates or its metabolites have potential to affect vitellogenesis hence the observation (Edwards, Miller, & Guillette, 2006).

Food Abundance

Availability of food items in a water body is very essential to aquatic animals, including fish. Food is an important source of energy which is fuel for various metabolic processes that take place in a living organism. Different water bodies may have different food spectrum depending on efficiency of primary or secondary productivity.

There are several known incidences that food abundance has been found to affect fish reproduction in both wild and cultured populations. In hybrid tilapia, total fecundity of 8018 was yielded from fish fed on 3% of body weight per day compared to fecundities of 6490, 3685, 3003 from fish fed on 2%, 1% and 0.5% of body weights per day respectively (Siddiqui et al., 1997). In capital breeders, which use energy stored from food taken before aestivation, fecundity was associated with an amount of food that was made available to the fish before they went for aestivation in which 6297 eggs were produced by fish fed on high ration and 2251 eggs were harvested from fish fed on low ration and there was great correlation between the amount of food and number of eggs produced (Kuzuhara et al., 2019).

Another evidence showing food influence on fecundity was seen in *Channa striatus* which had the highest absolute fecundity after being fed on largest quantities of crude protein compared to those fed on lower levels of crude protein (Ghaedi, Hosseinzadeh, & Hashim, 2019). All these findings indicate that restricted food supply has a negative impact on reproductive performance of fish. It takes a water body with good water quality to produce a diversity of food items for fish which benefit the fish with healthy growth and survival. This is why when analyzing fish stomach contents, it is important to also analyze food diversity using Shannon-Werner diversity index as was done at Sakumo II lagoon (Ofori-Danson & Kumi, 2005) since it gives a clear picture of how productive a system is if a proper comparison with another system is to be made and if food abundance is to be correlated with such physiological aspects as fish fecundity.

Chapter Summary

Relevant studies on the topic have been reported and a critique has been provided in this chapter. The chapter has reported existence of over 90 wetlands along the coast of Ghana and the importance of these wetlands has been documented. The taxonomic classification of *S. melanotheron* has been given which among other things says that the species belongs to the family cichlidae. These wetlands provide an important livelihood to coastal dwellers in form of small-scale fisheries. It has also been reported in this chapter that the Blackchin tilapia is the most dominant species of fish occupying many of these wetlands. The chapter has further documented how some key parameters such as temperature, DO, BOD, pH, etc. affect the reproductive success of fishes.

CHAPTER THREE

METHODOLOGY

Study Area

The study was conducted in five different lagoons of Ghana whose fish landings are dominated by *S. melanotheron*. These lagoons were Keta lagoon in the Volta Region, Sakumono lagoon in the Greater Accra Region, Fosu and Benya lagoons in the Central Region and Domunli lagoon in the Western Region (Figure 1).

Keta lagoon is located in the south-eastern part of Ghana near the Ghana-Togo border in the Volta Region lying between latitudes 5° 47′ and 5° 55′ N and longitudes 0° 57′ and 0° 59′E. *S. melanotheron* is among the four commercially important species inhabiting Keta lagoon; it is also the mainstay of fisheries in the lagoon (Lamptey & Ofori-Danson, 2014). Keta lagoon is the largest of all the coastal lagoons found in Ghana with an estimated area of 30 000 ha (Dankwa et al., 2004). The lagoon has been given special recognition as one of the world's important wetlands under the Ramsar Wetlands Convention and fishing forms a major livelihood activity in the area (Gyampoh, Atitsogbui, & Obirikorang, 2020). Unfortunately, the well-being of Keta lagoon is reportedly threatened by urbanization (Lamptey & Ofori-Danson, 2014).

Sakumono lagoon is a Ramsar Site located in the Greater Accra Region of Ghana. As shown in Figure 1, the lagoon is situated along Accra-Tema Road, 3km west of Tema and is geographically represented by latitudes 5°36' N and 5°38' N and longitudes 1°30' W and 2°30' W with an estimated area of 1 364 ha (Nartey et al., 2011). The fish landings from the Sakumono lagoon are also dominated by *S. melanotheron*. The lagoon is however polluted and heavily affected by anthropogenic stressors (Agbemehia, 2014).

Fosu lagoon is located in Cape Coast lying between latitudes 5°06′ N and 5°07′ N, and longitudes 1°15′ W and 1°16′ W. The lagoon is well known as an important site for both annual festivals and fishing activities during off-fishing seasons of the sea. It is a closed lagoon, though it periodically opens into the sea, especially during peak rainy seasons. Being in the heart of the metropolis, the lagoon is vulnerable to pollution from both domestic and industrial wastes due to poor waste management regime employed (Dankwa et al., 2016).

Benya lagoon on the other hand is an open lagoon that remains connected to the sea all year round and it is also located in the Central Region at latitudes 5°04′ to 5°05′ N and longitudes 1°20′ to 1°22′ W within Elmina town (Armah, Ason, Luginaah, & Essandoh, 2012). Both Fosu and Benya lagoons are facing pollution problems (Dankwa et al., 2016; Vowotor, Hood, & Tatchie, 2014)

Domunli lagoon is a closed brackish water body found in the Western Region of Ghana. It lies between latitudes 5°1´ and 5 2´N, and longitudes 2°44´ and 2°47´W in Jomoro District with an estimated catchment area of 465,724.14 m^2. It is well covered with mangroves and coconut trees supporting neighboring communities with livelihood opportunities, including fishing (Arizi et al., 2014).

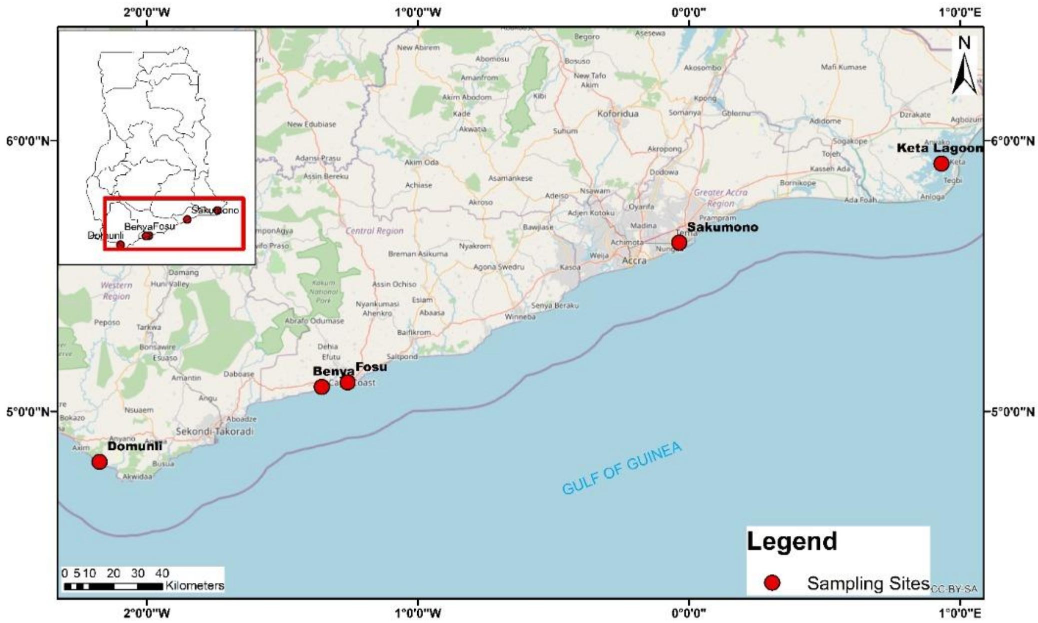


Figure 1: Map of Ghana showing location of study lagoons

Data Collection

Physicochemical Parameters of the Lagoons

Each lagoon was divided into three sections and physicochemical data was collected from all those sections monthly. Temperature, pH, dissolved oxygen and salinity of the lagoons were collected at three sampling stations in each lagoon at 9:00 am for all the lagoons by carrying out in-situ measurements using a multiparameter water quality checker (Horiba U-500 Japan) for a period of three months from March to May, 2022.

Water samples were also collected in 1000-ml plastic containers and dark bottles from the sampling stations and transported in a cool plastic box to the laboratory for further analyses to determine the turbidity, Biochemical Oxygen Demand (BOD), nitrates and phosphates. At each site, the DO concentrations of the water samples in the dark bottles were determined using water quality checker before they were transported to the laboratory. In the laboratory, some water samples in the 1000-ml plastic containers were filtered using 0.45 µm membrane filter paper for determination of nitrate and phosphate concentrations. Nitrate Ver. 5 reagent powder was added to filtered water samples to determine the concentration of nitrate whereas Phos Ver 3 reagent powder was added to filtered water samples to determine the concentration of phosphate.

DR 900 Colorimeter (HACH equipment) was subsequently used to determine the turbidity, phosphate and nitrate of each lagoon as described by American Public Health Association (2005). Water samples in the dark bottles were incubated in the laboratory for a period of five days after which DO levels were measured using water quality checker and the BOD was determined by subtracting final DO concentration (laboratory value) from initial DO concentration (field value). BOD was used as a proxy for determining the extent of pollution in each lagoon (Ndimele, 2012).

Food diversity available for *S. melanotheron* in each lagoon was indirectly determined by examining stomach contents of fish samples obtained from each lagoon. The fish were dissected on sites right after the capture and stomachs were extracted from the fish to prevent digestive enzymes from acting on the contents. The stomach contents composed of food items were preserved in 10% formalin solution and were transported to the laboratory for further analysis. From each lagoon, 30 fish specimens were examined monthly for stomach contents for a period of three months. While in the laboratory, different food items consumed by the fish were identified using online identification manuals (Perry, 2010) and later counted. The diversity of the food items consumed by the fish was determined using Shannon-Werner Diversity index

(Ofori-Danson & Kumi, 2005) for comparison among the lagoons. The index is given as:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$ (Ofori-Danson & Kumi, 2005),

Where H' is the diversity index, p_i is the proportion of each food item and ln is the natural logarithm.

Determination of Fecundity

Female fish samples from the selected lagoons were collected in the major breeding season (March to May 2022) as observed by Arizi et al. (2014) and Mireku et al. (2016) in Domunli lagoon and Brimsu reservoir, respectively. Local fishermen were hired to obtain the samples from the lagoons using prescribed fishing nets (seine nets) and fish traps. The sex of each fish specimen was determined by examining the color of the operculum: females have purple operculum while males have golden or yellowish operculum.

Having determined the sex, only the females were selected and were preserved in ice and transported to the laboratory for further analysis. The fish specimens were weighed to the nearest 0.01g using an electronic precision balance (Adam Equipment, HCB 602H) whereas standard length (SL) and total length (TL) were determined to the nearest 0.1cm using measuring board. The samples were dissected and visual inspection of gonads was carried out to identify the maturity stages of the fish and those in stages III (Late maturing) and IV (Ripe/Mature) were selected for fecundity determination (Quarcoopome & Owiredu, 2016). Ovaries were extracted from the fish and fixed in 10% formalin solution for at least one week for the eggs to harden for easy separation from the ovarian tissues. Whole count method was employed to determine the absolute fecundity of each fish specimen.

Data Analyses

Data were analyzed using IBM SPSS Statistics 25 software, Microsoft Excel version 2019 and R software version 4.2.0. ANOVA was performed to determine differences in the means of physicochemical parameters, food diversity index and fecundity among the lagoons. The normality of the data was checked for normal distribution and homogeneity of variances using Shapiro-Wilk test and Levene's test before ANOVA was performed. In a case where normal distribution assumption was violated, non-parametric Kruskal-Wallis test was performed to determine differences in the means and this preceded Dunn's post hoc test for multiple pairwise comparisons.

Where data were normally distributed but violated homogeneity of variances assumption, the Robust Tests of Equality of Means was considered for determining differences in the means. Under Robust Tests of Equality of Means, Brown-Forsythe's test was selected when the sample sizes of the variables were the same. Post hoc test was performed using Tukey post hoc test where data were normally distributed and equality of variances was assumed whereas Games-Howell test was used where data were normally distributed but equality of variances was not assumed.

Microsoft Excel was used to produce scatter plots for the relationship between fecundity and body parameters. Bar charts for environmental parameters and fecundity were also produced using Microsoft Excel.

In R programming software, the generalized multiple regression model was used to establish relationships between fecundity and the nine environmental parameters. Generalized multiple regression model was preferred since some of the datasets were not normally distributed. In the model, fecundity was the dependent variable whilst the environmental parameters were independent variables. Generally, the relationships were represented by this model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon$$

Where y is the dependent variable represented by fecundity, β_0 is the intercept, β_n is the n^{th} regression coefficient which shows the magnitude of change in dependent variable following a change in independent variable, x_n is the n^{th} independent environmental variable and ε is the regression error. Different regression models were fitted to the data on fecundity and environmental parameters to select the best fit.

The selection of the best fit was based on the Akaike Information Criterion (AIC) in which the model with the least AIC value was chosen as the best fit. The first regression model with intercepts was constructed using all the nine independent variables which included temperature, pH, dissolved oxygen, salinity, turbidity, phosphate, nitrate, biochemical oxygen demand and food diversity index. The subsequent models involved possible combinations of independent variables with or without intercepts to identify the best fit. Further analysis was performed to determine the interactive effects of the environmental parameters on fecundity. The R programming software was also used to run the multinomial test (goodness-of-fit) to determine if the sample sizes for determining fecundity were uniform.

Chapter Summary

Domunli, Fosu, Benya, Sakumono and Keta lagoons were purposively selected as study locations due to the important roles they play in small-scale fisheries and also due to the reported wetland degradation taking place in these lagoons. Physicochemical parameters were measured *in-situ* while some were transported to the laboratory for further analysis. Whole count method was employed in determining the fecundity of the species. Data collection was done for a period of three months. The use of food diversity index as a measure of food abundance is inadequate approach for the quantification of food availability in the lagoons.

Some of the limitations in the methodology include that the lagoon may contain diverse food items but those food items may not be enough for the healthy growth or survival of the fish.

Also, the determination of biochemical oxygen demand using the five-day incubation period method may not be very precise owing to the possibilities of numerous human errors when collecting water samples from the lagoon in which it is inevitable to take with few water bubbles due to the waves and turbulence of the water system and this may affect the actual amount of oxygen consumed by the bacteria for the decomposition of organic matter.

Ideally, data of this type of work is supposed to be collected in a period of more than one to capture both dry and wet season to get accurate results. However, in this study, only dry season was considered and the results might be underreported.

CHAPTER FOUR

RESULTS AND DISCUSSION

Results

A total of 744 fish specimens were obtained from the five lagoons for fecundity examination. The sample sizes for each lagoon is presented in Table 1. Additionally, thirty fish specimens were sampled monthly from each lagoon for stomach content examination. Chi-square's goodness-of-fit test revealed that the sample sizes for determining fecundity were uniform across the lagoons, $H(4) = 25.843$, $p = 0.7836$.

Table 1: Number of Fish Specimens Collected for Fecundity Examination Across the Lagoons During the Sampling Period (March – May, 2022)

Name of lagoon	Sample size (n)
Domunli	151
Fosu	158
Benya	148
Sakumono	136
Keta	151
Total	744

Variations in Physicochemical Parameters:

Temperature

Temperature varied significantly among the lagoons, $H(4) = 25.843$, $p = 0.000$. The highest mean temperature of 32.5 ℃ was recorded in the Keta lagoon whilst the lowest mean temperature of 30 ℃ was recorded in Sakumono lagoon (Figure 2). Dunn's post hoc pairwise comparison test revealed significant mean temperature variations between Fosu lagoon and Sakumono lagoon (p = 0.002), Keta lagoon and Sakumono lagoon (p = 0.000), Fosu lagoon and Benya lagoon (p = 0.004), Keta lagoon and Benya lagoon (p = 0.000), and Domunli lagoon and Keta lagoon (p = 0.011).

However, there was no statistically significant variation in the mean temperatures between Domunli lagoon and Fosu lagoon (p = 0.156), Domunli lagoon and Benya lagoon (p = 0.151), Domunli lagoon and Sakumono lagoon (p = 0.106), Sakumono lagoon and Benya lagoon (p = 0.858), and Fosu lagoon and Keta lagoon (p = 0.266).

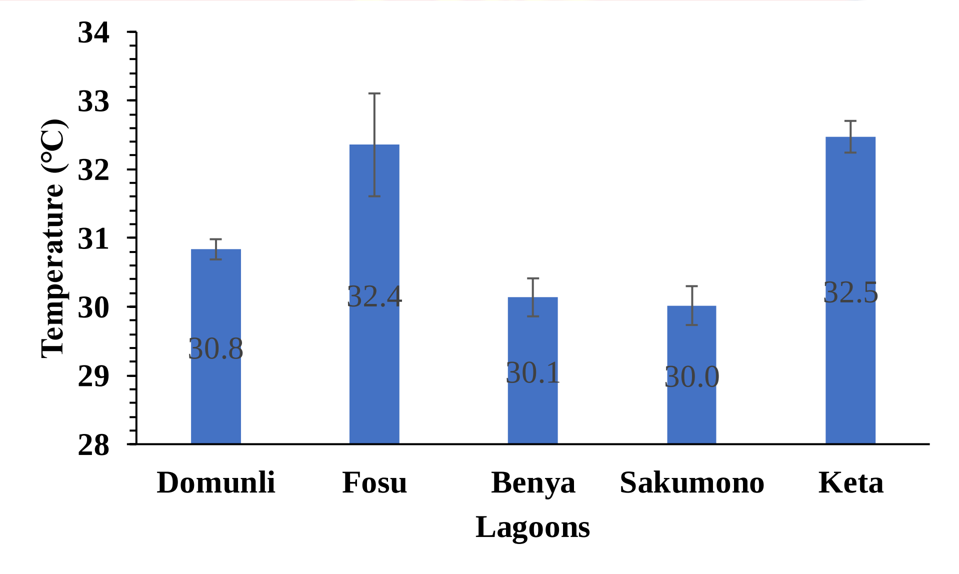


Figure 2: Mean temperatures (±standard error) prevailing in the selected lagoons of Ghana from March to May, 2022

pH

The pH levels varied significantly among the lagoons, $F(4, 25.476) = 69.989$, $p = 0.000$. Whereas the highest mean pH of 9.3 was recorded in the Keta lagoon, the lowest mean pH of 6.9 was recorded in the Domunli lagoon (Figure 3). Results from Games-Howell's post hoc test showed significance variations in mean pH values between Domunli lagoon and Fosu lagoon (p = 0.000, 95% C.I. = [-2.10, -0.85]), Domunli lagoon and Benya lagoon (p = 0.011, 95% C.I.

= [-1.48, -0.16]), Domunli lagoon and Sakumono lagoon (p = 0.000, 95% C.I. = [-2.71, -1.71]), Domunli lagoon and Keta lagoon (p = 0.000, 95% C.I. = [-2.86, -1.85]), Fosu lagoon and Benya lagoon (p = .048, 95% C.I. = [0.00, 1.31]), Fosu lagoon and Sakumono lagoon (p = 0.006, 95% C.I. = [-1.23, -0.24]), Fosu lagoon and Keta lagoon (p = 0.001, 95% C.I. = [-1.37, -0.38]), Benya lagoon and Sakumono lagoon (p = 0.000, 95% C.I. = [-1.94, -0.84]) and lastly between Benya lagoon and Keta lagoon (p = 0.000, 95% C.I. = [-2.08, -0.99]). There was no significant variation in mean pH values between Sakumono lagoon and Keta lagoon (p = 0.085).

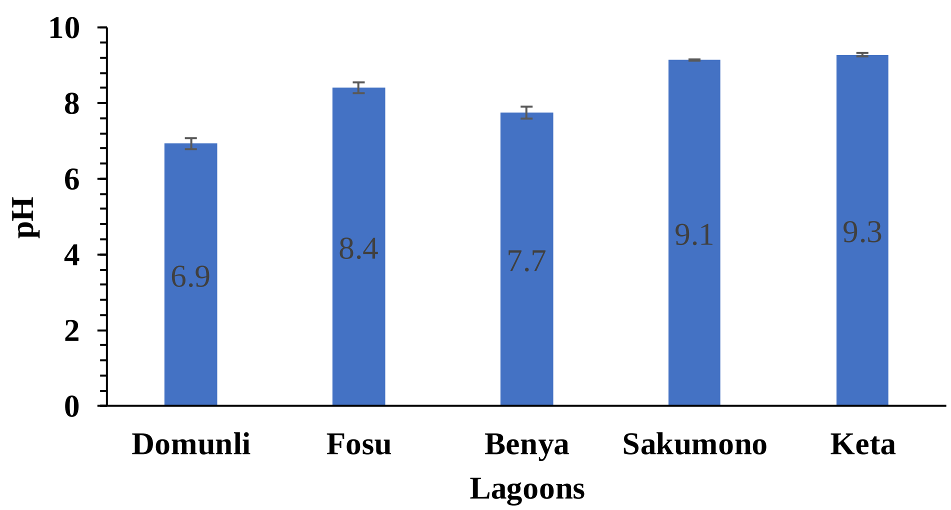


Figure 3: Mean pH values (±standard error) recorded in the selected lagoons from March to May, 2022

Dissolved oxygen (DO)

The highest mean DO of 5.5 mg/l was recorded in the Fosu and Keta lagoons whilst the lowest mean DO of 3.8 mg/l was recorded in the Sakumono lagoon (Figure 4). Kruskal Wallis test showed that DO concentration varied significantly across the lagoons, $H(4)$ = 19.964, p = 0.001. Multiple comparisons using Dunn's post hoc test revealed that DO levels varied significantly between: Keta lagoon and Domunli lagoon (p = 0.012); Keta lagoon and Benya lagoon (p = 0.001); Keta lagoon and Sakumono lagoon (p = 0.001); Benya lagoon and Fosu lagoon (p = 0.007); Fosu lagoon and Sakumono lagoon (p = 0.006). However, there was no statistically significant difference in the mean DO values between: Sakumono lagoon and Benya lagoon (p = 0.957); Sakumono lagoon and Domunli lagoon (p = 0.351); Benya lagoon and Domunli lagoon (p = 0.379); Domunli lagoon and Fosu lagoon (p = 0.070); Fosu lagoon and Keta lagoon (p = 0.484).

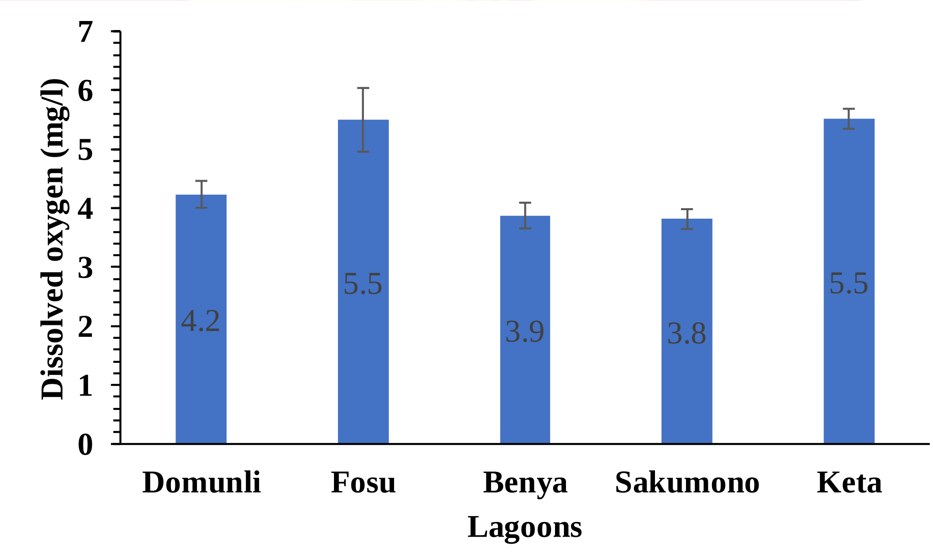


Figure 4: Mean dissolved oxygen concentrations (±standard error) in the selected lagoons from March to May, 2022

Salinity

The highest mean salinity of 35.7 ppt was recorded in the Benya lagoon whilst the lowest mean salinity of 7.5 ppt was recorded in Fosu lagoon (Figure 5). Kruskal-Wallis test indicated that salinity varied significantly among the lagoons, $H(4) = 39.576$, $p = 0.000$. Dunn's post hoc test showed that significant differences in the mean values of salinity existed between: Fosu lagoon and Keta lagoon (p = 0.026); Fosu lagoon and Sakumono lagoon (p = 0.000); Fosu lagoon and Benya lagoon (p = 0.000); Domunli lagoon and Keta lagoon (p =

0.033); Domunli lagoon and Sakumono lagoon (p = 0.000); Domunli lagoon and Benya lagoon (p = 0.000); Keta lagoon and Benya lagoon (p = 0.005). The difference in the mean salinity values was not statistically significant between: Fosu lagoon and Domunli lagoon (p = 0.929); Keta lagoon and Sakumono lagoon (p = 0.118); Sakumono lagoon and Benya lagoon (p = 0.216).

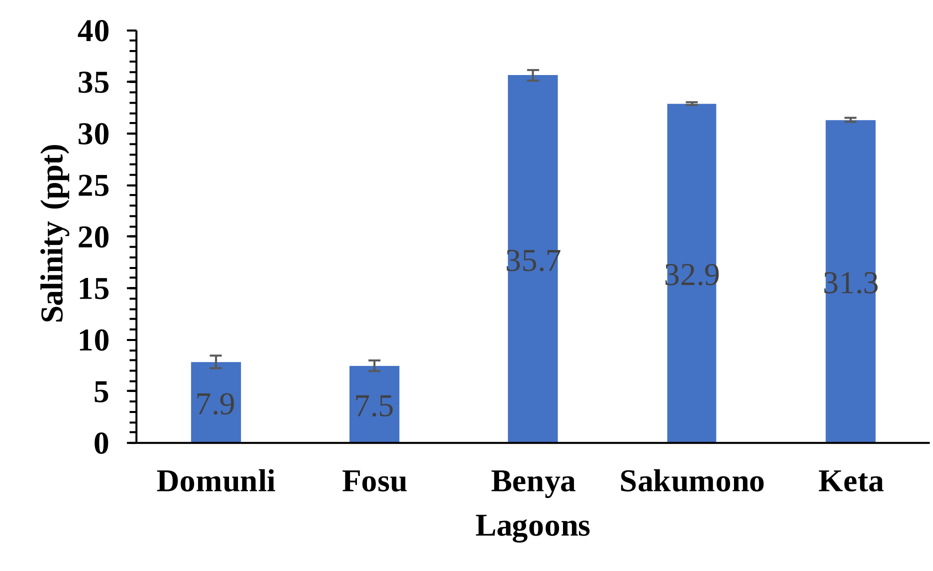


Figure 5: Mean salinity values (±standard error) recorded in the selected lagoons from March to May, 2022

Turbidity

Turbidity ranged from 7 mg/l in the Domunli lagoon to 69.4 mg/l in the Fosu lagoon (Figure 6). Kruskal Wallis test showed that mean turbidity scores from the sampling lagoons varied significantly, $H(4)$ = 38.240, p = 0.000. Dunn's post hoc test showed significant differences in the mean values of turbidity between Domunli lagoon and Fosu lagoon (p = 0.040); Domunli lagoon and Sakumono lagoon (p = 0.000); Domunli lagoon and Fosu lagoon (p = 0.000); Keta lagoon and Sakumono lagoon (p = .009); Keta lagoon and Fosu lagoon (p = 0.000); Benya lagoon and Sakumono lagoon (p = 0.027); Benya lagoon and Fosu lagoon (p = 0.001). On the contrary, there was no significant difference between Domunli lagoon and Keta lagoon (p = 0.099); Keta lagoon and Benya lagoon (p = 0.685); Sakumono lagoon and Fosu lagoon (p = 0.214).

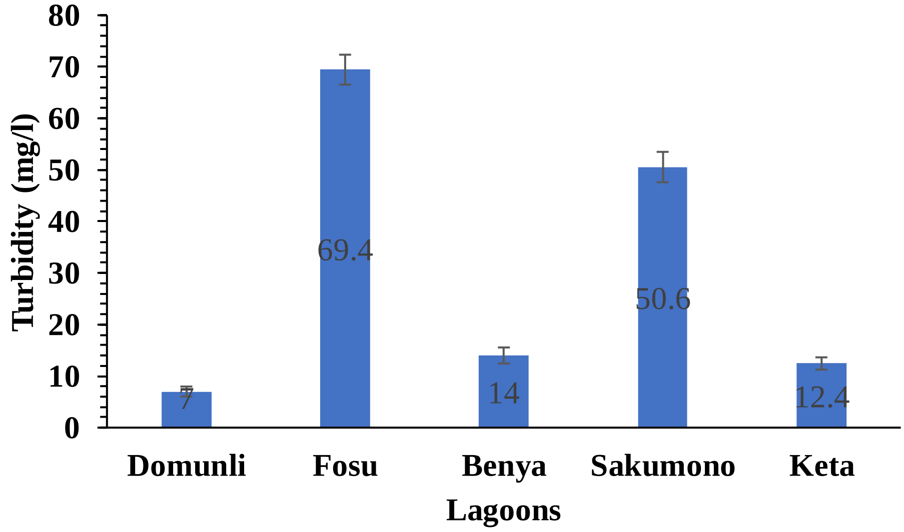


Figure 6: Mean turbidity values (±standard error) recorded in the selected lagoons from March to May, 2022

Phosphate

Phosphate concentrations in the lagoons ranged from 0.3 mg/l to 2.3 mg/l with the lowest concentration recorded in the Keta lagoon whereas the highest concentration was recorded in the Sakumono lagoon (Figure 7). Kruskal Wallis test revealed statistically significant variations in phosphate concentration among sampling lagoons, $H(4)$ = 27.647, p = 0.000. Dunn's post hoc test showed that significant variations in the mean values of phosphate were between: Keta lagoon and Benya lagoon (p = .002); Keta lagoon and Fosu lagoon (p = 0.000); Keta lagoon and Sakumono lagoon (p = 0.000); Domunli lagoon and Fosu lagoon (p = 0.017); Domunli lagoon and Sakumono lagoon (p = 0.002). However, there was no significant difference in the mean values of phosphate between: Keta lagoon and Domunli lagoon (p = 0.138); Benya lagoon and Domunli lagoon (p = 0.099); Benya lagoon and Fosu lagoon (p = 0.462);

Benya lagoon and Sakumono lagoon (*p* = 0.148); Fosu lagoon and Sakumono lagoon (*p* = 0.478).

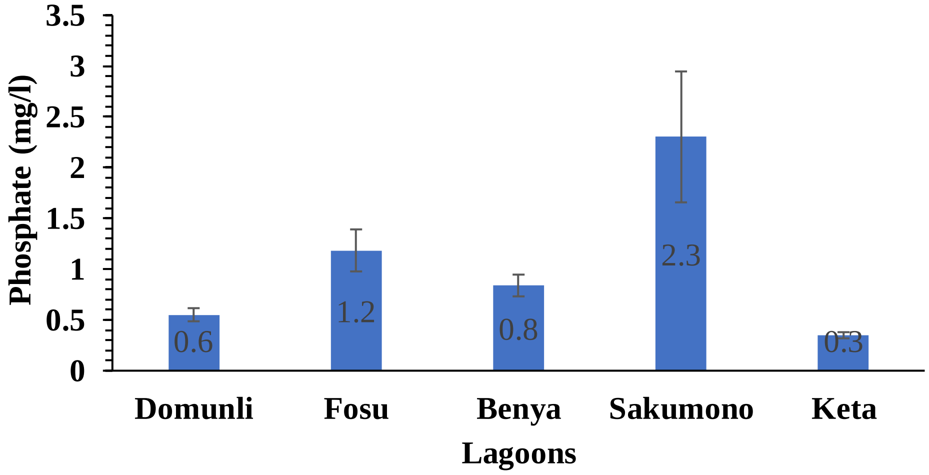


Figure 7: Mean phosphate values (±standard error) recorded in the selected lagoons from March to May, 2022

Nitrate

The highest mean nitrate of 11.3 mg/l was recorded in the Fosu lagoon whereas the lowest mean nitrate of 1.2 mg/l was recorded in Domunli lagoon (Figure 8). The results indicated that the nitrate concentration varied significantly among the lagoons, $F(4, 19.037) = 160.356$, $p = .000$. Games-Howell's Post Hoc test revealed significant pairwise variations in the mean values of nitrate between: Domunli lagoon and Fosu lagoon (*p* = 0.000, 95% C.I. = [-12.06, -8.07]); Domunli lagoon and Benya lagoon (*p* = 0.002, 95% C.I. = [-2.87, -0.64]); Domunli lagoon and Sakumono lagoon (*p* = 0.000, 95% C.I. = [-7.43, -5.70]); Domunli lagoon and Keta lagoon (*p* = 0.000, 95% C.I. = [-2.59, -1.03]); Fosu lagoon and Benya lagoon (*p* = 0.000, 95% C.I. = [6.24, 10.38]); Fosu lagoon and Sakumono lagoon (*p* = 0.001, 95% C.I. = [1.49, 5.51]); Fosu lagoon and Keta lagoon (*p* = 0.000, 95% C.I. = [6.25, 10.26]); Benya lagoon and Sakumono lagoon (*p* = 0.000, 95% C.I. = [-5.99, -3.63]); Sakumono lagoon and Keta lagoon (p = 0.000, 95% C.I. = [3.85, 5.66]). There was no significant difference in the mean values between Benya lagoon and Keta lagoon (p = 1.00).

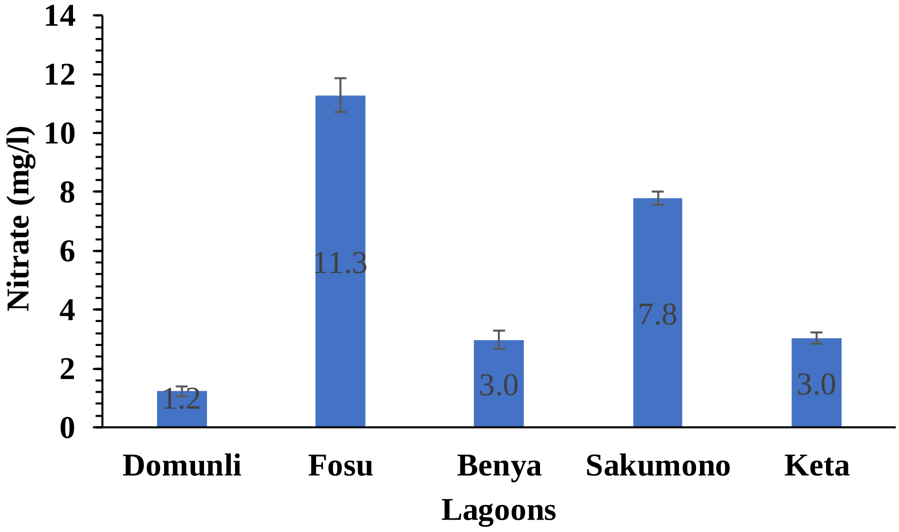


Figure 8: Mean nitrate concentration (±standard error) recorded in the selected lagoons from March to May, 2022

Biochemical oxygen demand (BOD)

The highest mean BOD of 4.0 mg/l was recorded in the Fosu lagoon whilst the lowest mean BOD of 1.3 mg/l was recorded in Domunli lagoon (Figure 9). The mean BOD levels varied significantly across the lagoons, $F(4, 12.484) = 69.989$, p = 0.000. Results from Games-Howell's Post Hoc test showed that significant variations in the mean values of BOD were between: Domunli lagoon and Fosu lagoon (p = 0.000, 95% C.I. = [3.84, -1.58]); Domunli lagoon and Benya lagoon (p = 0.022, 95% C.I. = [-0.96, -0.06]); Domunli lagoon and Sakumono lagoon (p = 0.000, 95% C.I. = [-1.52, -0.91]); Domunli lagoon and Keta lagoon (p = 0.000, 95% C.I. = [-2.24, -1.50]); Fosu lagoon and Benya lagoon (p = 0.001, 95% C.I. = [1.06, 3.33]); Fosu lagoon and Sakumono lagoon (p = 0.011, 95% C.I. = [0.37, 2.62]); Benya lagoon and Sakumono lagoon (p = 0.002, 95% C.I. = [-1.10, -0.31]); Benya lagoon and Keta lagoon (p = 0.000, 95% C.I. = [-1.80, -0.92]); Sakumono lagoon and Keta lagoon (p = 0.000, 95% C.I. = [-0.94, -0.37]). The difference was not statistically significant in mean phosphate values between Fosu lagoon and Keta lagoon (p = 0.177).

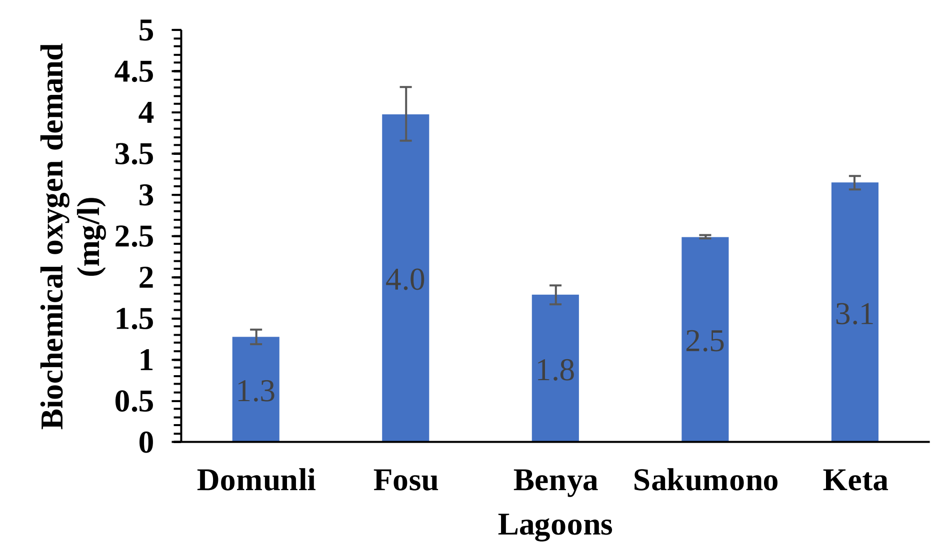


Figure 9: Mean Biochemical oxygen demand values (±standard error) in the selected lagoons from March to May, 2022

Variations in Food Diversity

Kruskal-Wallis test revealed that the Shannon-Werner diversity indices related to the food items in the stomachs of *S. melanotheron* did not vary significantly among the lagoons, $H(4)$ = .444, p = 0.979, implying that the diversity of food items consumed by the different populations in the lagoons did not differ. Green algae, blue-green algae, copepods, cladocerans, detritus, diatoms, fish eggs, fish scales, insects, rotifers and other unidentified organisms were common in the diets of the *S. melanotheron* populations.

Variations in Fecundity

S. melanotheron in the Domunli lagoon had the highest mean fecundity of about 285 eggs whilst those in the Keta lagoon had the lowest mean fecundity of about 82 eggs (Figure 10). Results further showed that absolute fecundity varied significantly among the lagoons, $H(4) = 478.764$, $p = .000$. Dunn's post hoc test of determining pairwise variations found all except one pair to be significant ($p < 0.05$); only absolute fecundity of samples from Sakumono and Keta lagoons did not vary significantly ($p > 0.05$).

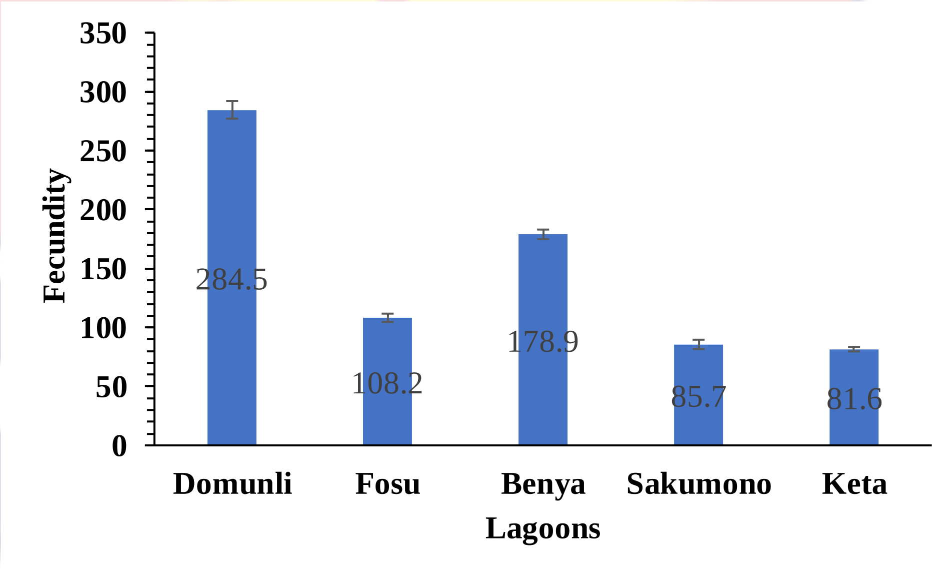
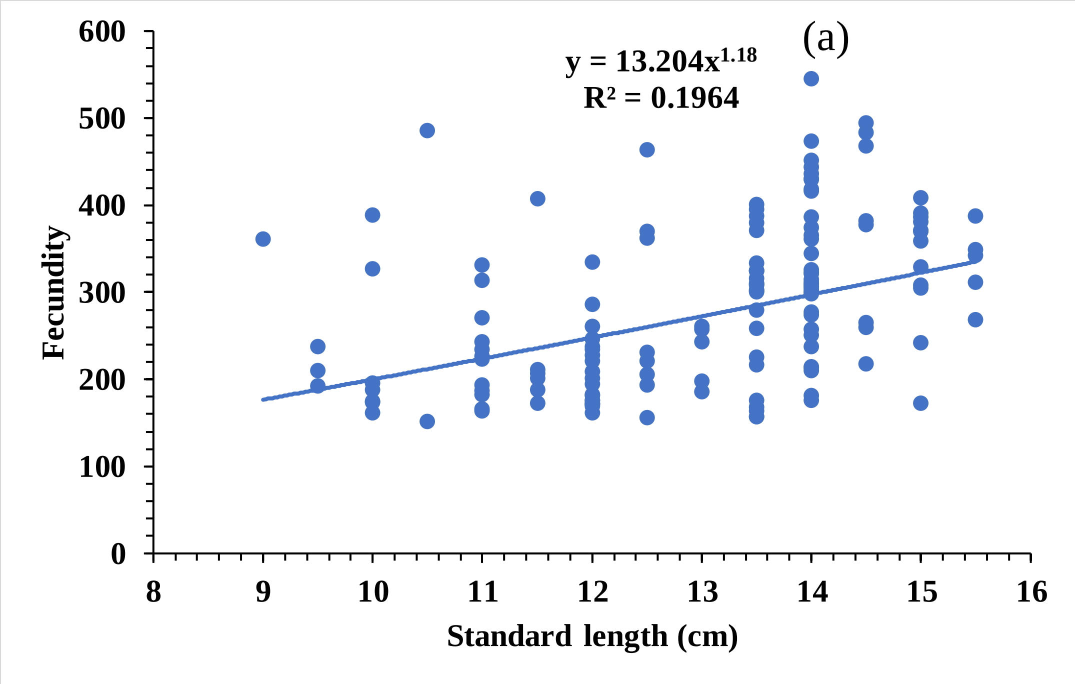


Figure 10: Mean fecundity (±standard error) of *Sarotherodon melanotheron* populations in the selected lagoons from March to May, 2022

Relationship Between Fecundity and Body Parameters

S. melanotheron in the Domunli lagoon had the highest means of standard length (SL) and body weight (BW) of 13.0 cm and 98.15 g, respectively. However, *S. melanotheron* population in the Sakumono lagoon had the lowest mean standard length and body weight of 5.3 cm and 5.79 g, respectively. The relationship between body and fecundity was generally weak in all lagoons (Figures 11, 12, 13, 14 and 15).



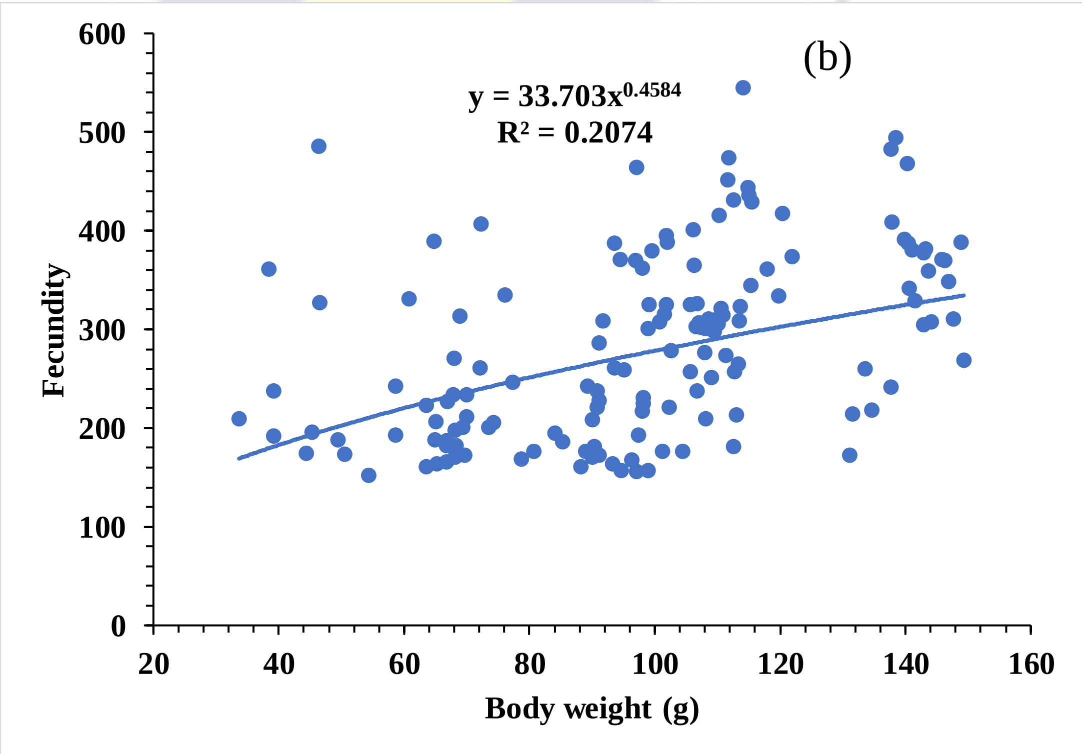
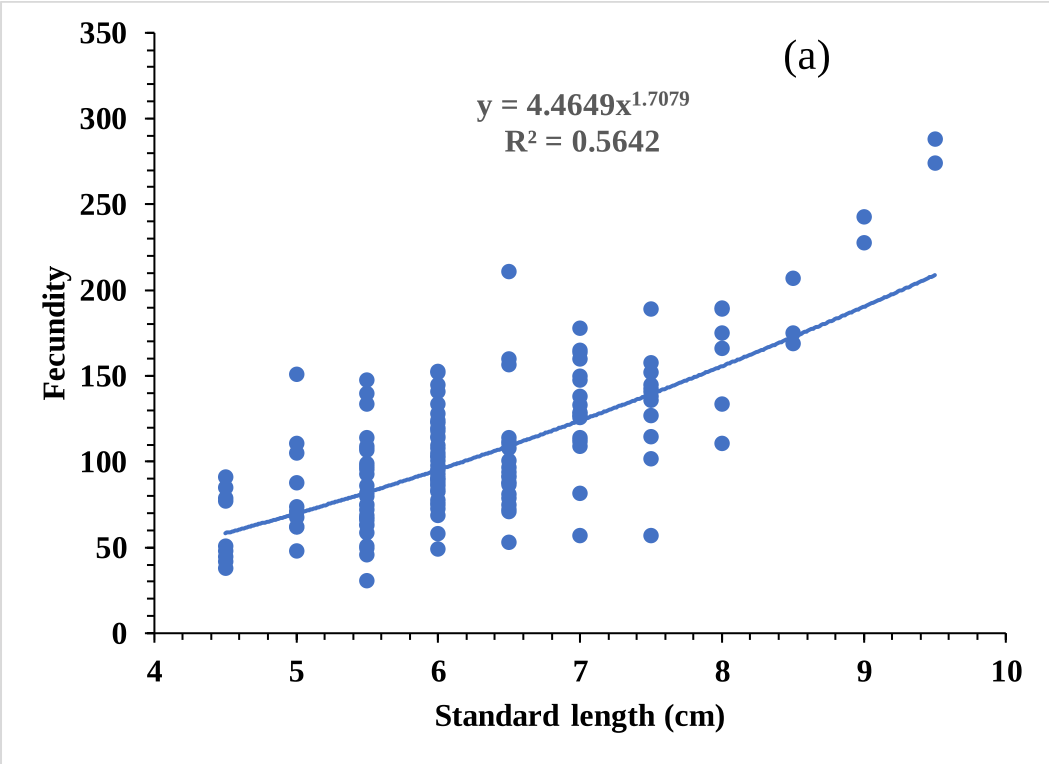


Figure 11: The relationship between: (a) standard length and fecundity; (b) body weight and fecundity of *Sarotherodon melanotheron* in the Domunli lagoon



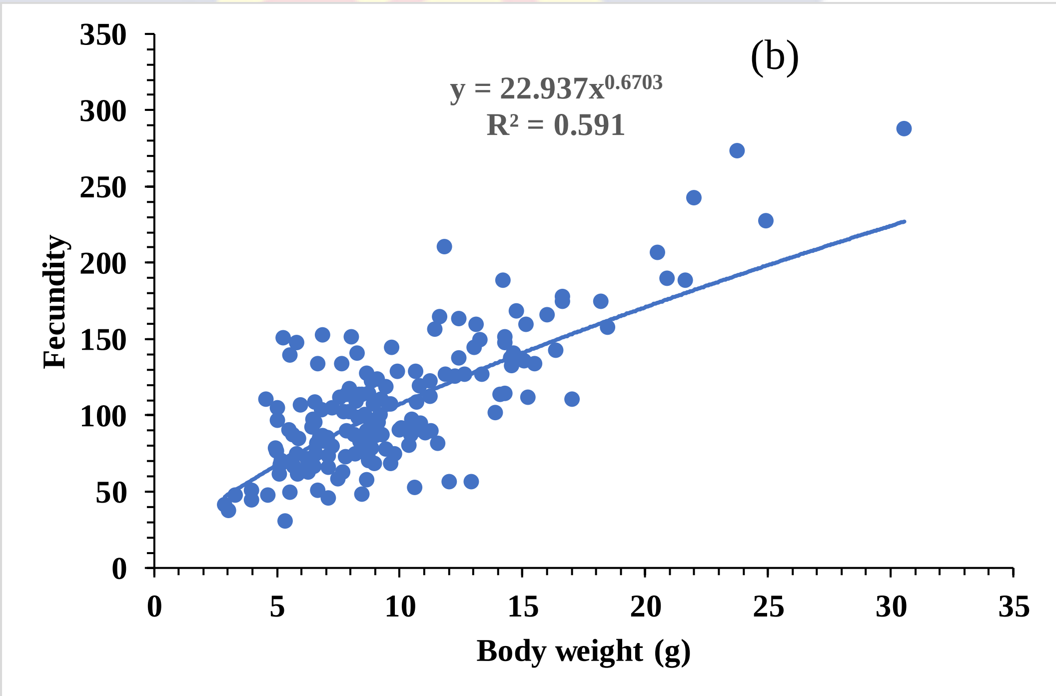


Figure 12: The relationship between: (a) standard length and fecundity; (b) body weight and fecundity of *Sarotherodon melanotheron* in the Fosu lagoon

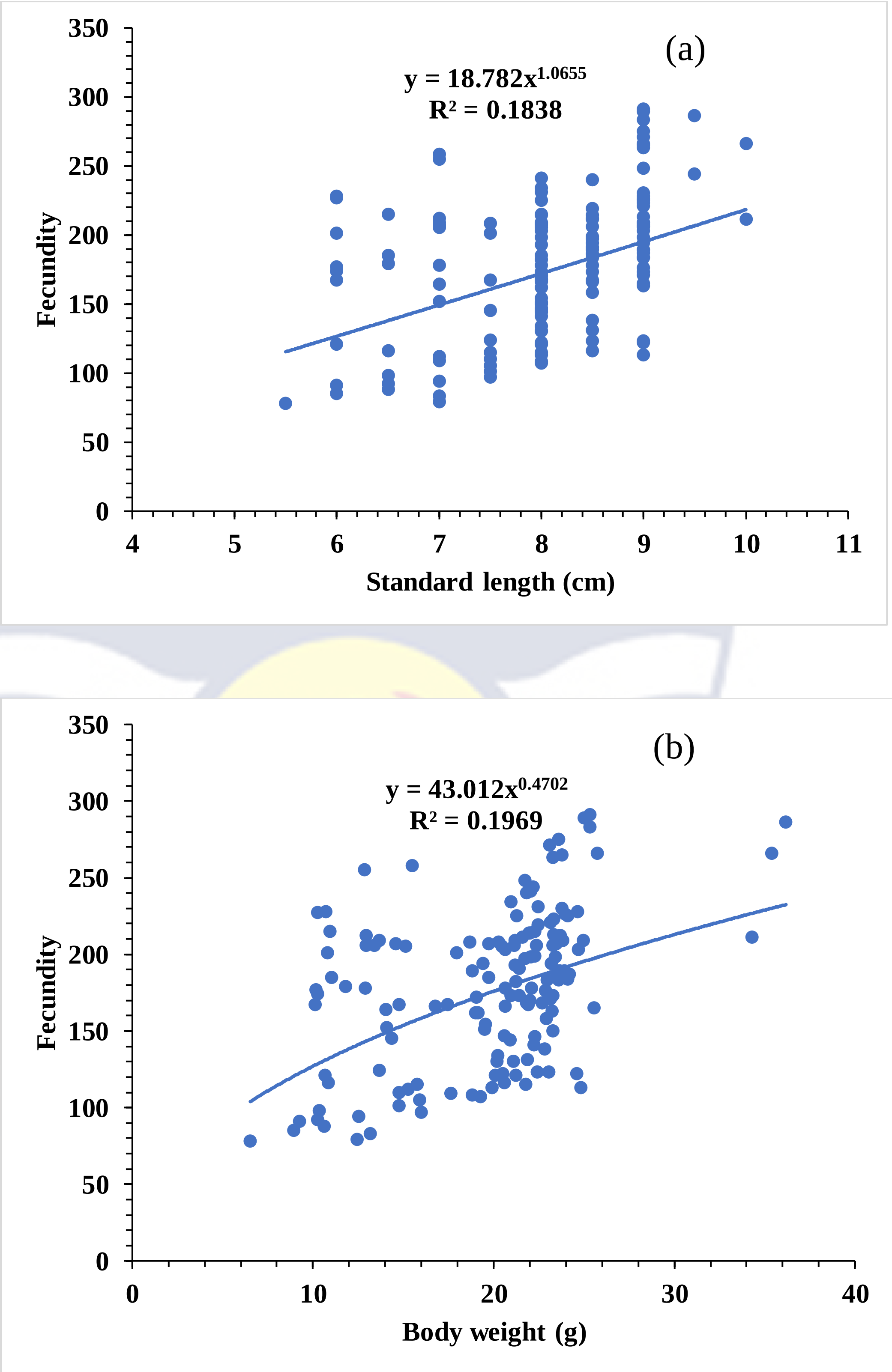
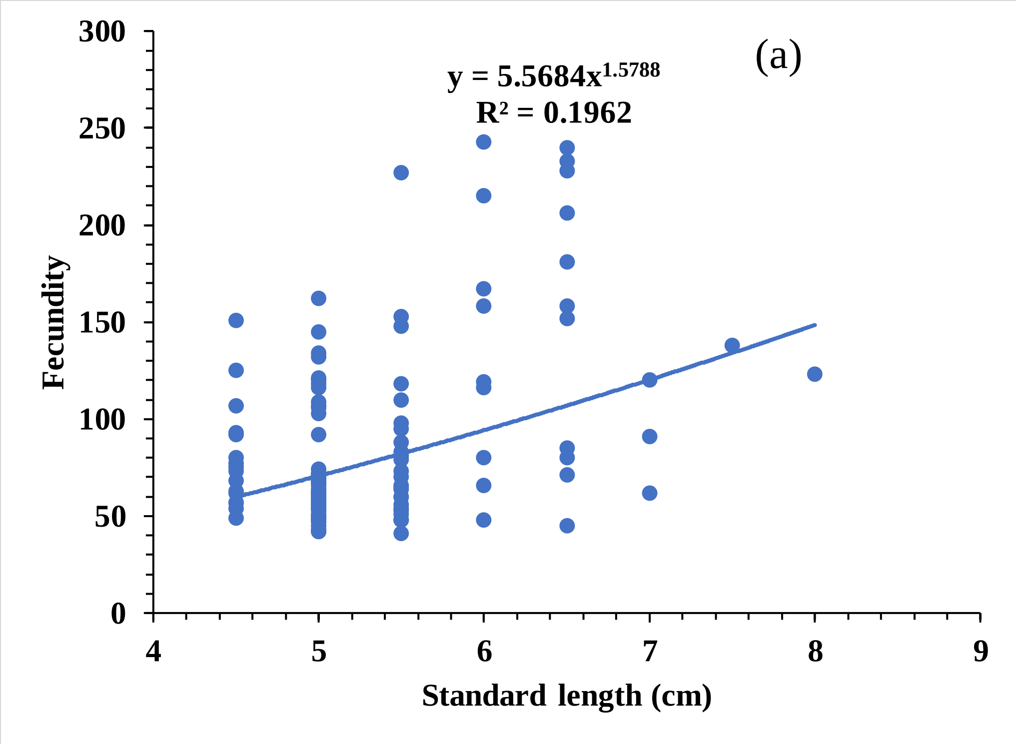


Figure 13: The relationship between: (a) standard length and fecundity; (b) body weight and fecundity of *Sarotherodon melanotheron* in the Benya lagoon



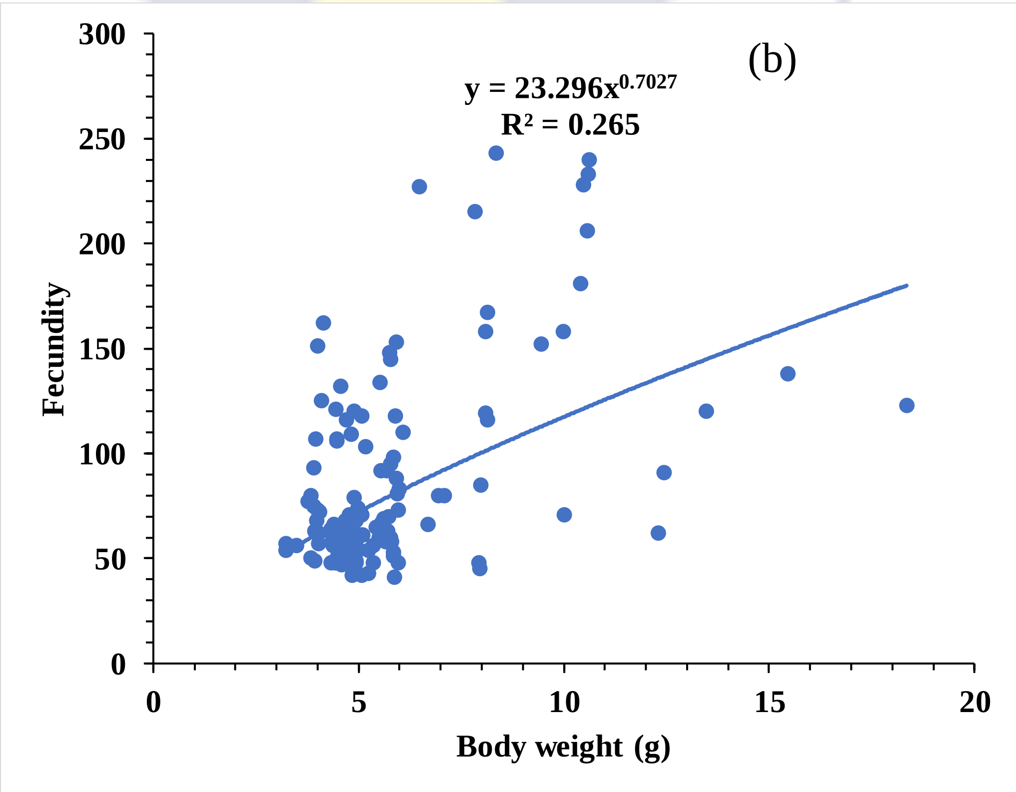
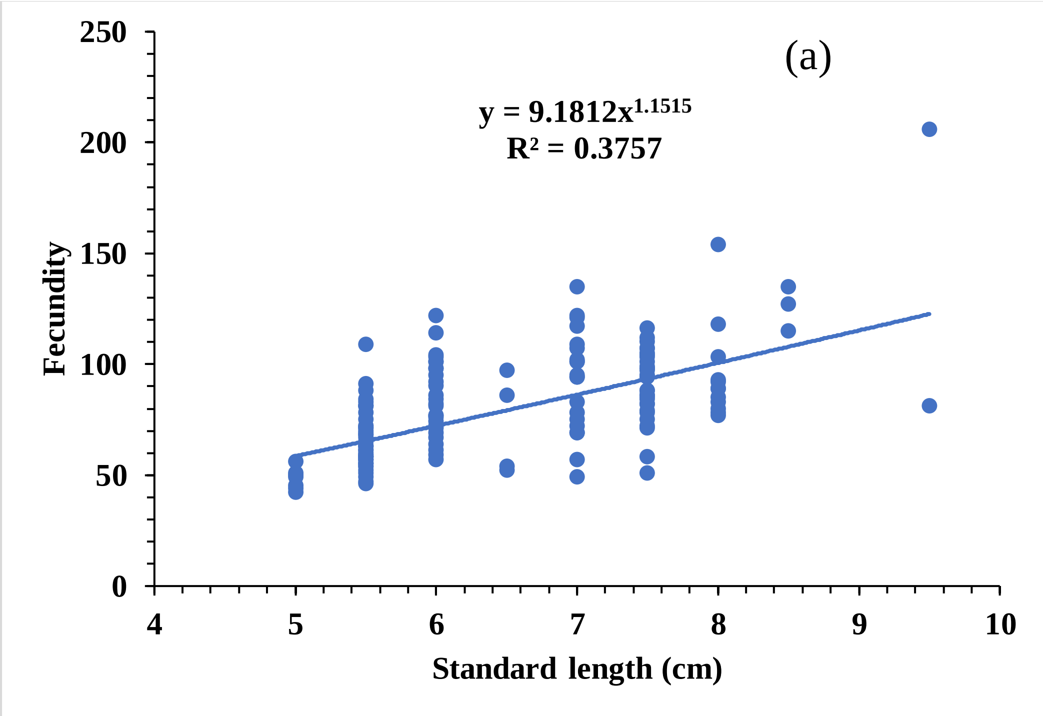


Figure 14: The relationship between: (a) standard length and fecundity; (b) body weight and fecundity of *Sarotherodon melanotheron* in the Sakumono lagoon



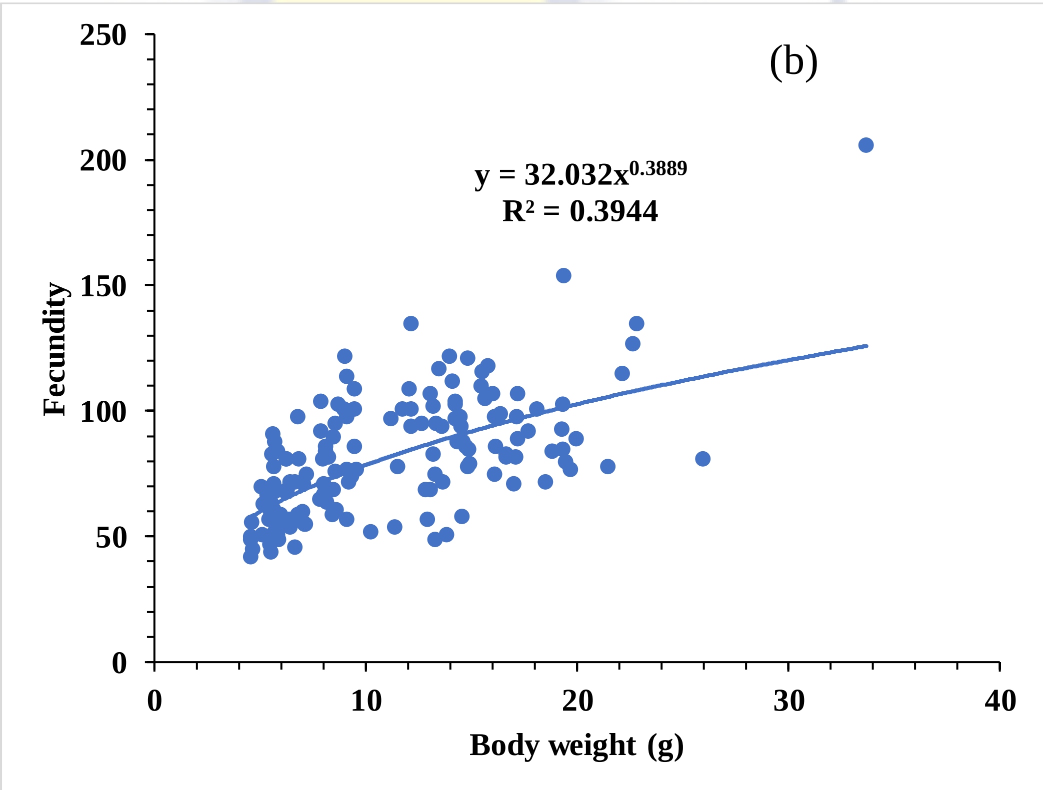


Figure 15: The relationship between: (a) standard length and fecundity; (b) body weight and fecundity of *Sarotherodon melanotheron* in the Keta lagoon

Relationship Between Fecundity and Physicochemical Parameters

A total of seventeen generalized multiple regression models involving fecundity (F) as dependent variable with temperature (T), pH, dissolved oxygen (DO), salinity (S), turbidity (T), phosphate (P), nitrate (N), biochemical oxygen demand (BOD) and food diversity (FD) as independent (predictor) variables were constructed. The best fit among the models was selected using the Akaike Information Criterion (AIC). The model with the least AIC value (127. 29) was selected as the best fit (Table 3).

The best model had temperature, pH, dissolved oxygen, salinity, biochemical oxygen demand and food diversity as environmental stressors influencing the fecundity of the species in the lagoons. The model had a very strong pseudo R^2 of 0.98 indicating that 98% of variations in fecundity could be explained by these factors. The model further revealed that temperature, pH, dissolved oxygen, salinity and biochemical oxygen demand significantly influenced fecundity but food diversity did not significantly influence fecundity (Table 4). Of all the environmental determinants in the selected model, only dissolved oxygen had a positive linear relationship with fecundity. The rest had negative linear relationship with fecundity.

Table 2: Fitted Generalized Regression Models Between Fecundity and Physicochemical Parameters

Model	Formula	AIC
Mod1	glm(Fe ~ Te+pH+DO+Sa+Tb+Pt+Nt+BOD+FD)	131.67
Mod2	glm(Fe ~ Te+pH+DO+Sa+Tb+Pt+BOD+FD)	129.87
Mod3	glm(Fe ~ Te+pH+DO+Sa+Tb+BOD+FD)	129.09
Mod4	glm(Fe ~ Te+pH+DO+Sa+BOD+FD)	127.29
Mod5	glm(Fe ~ Te+pH+DO+Sa+BOD)	131.26
Mod6	glm(Fe ~ pH+DO+Sa+BOD)	136.6
Mod7	glm(Fe ~ pH+Sa+BOD)	137.15
Mod8	glm(Fe ~ pH+BOD)	141.18
Mod9	glm(Fe ~ Te+pH+DO+Sa+Tb+Pt+Nt+BOD+FD-1)	135.03
Mod10	glm(Fe ~ Te+pH+DO+Sa+Pt+Nt+BOD+FD-1)	133.11
Mod11	glm(Fe ~ Te+pH+Sa+Pt+Nt+BOD+FD-1)	131.32
Mod12	glm(Fe ~ Te+pH+Sa+Nt+BOD+FD-1)	130.62
Mod13	glm(Fe ~ pH+Sa+Nt+BOD+FD-1)	130.98
Mod14	glm(Fe ~ pH+Sa+BOD+FD-1)	137.61
Mod15	glm(Fe ~ pH+BOD+FD-1)	140.98
Mod16	glm(Fe ~ pH+FD-1)	147.43
Mod17	glm(Fe ~ Te+pH+Sa+Tb+Pt+Nt+BOD)	132.38

Table 3: The Relationship Between Fecundity and Physicochemical Parameters Derived from the Best Fit Model

Parameter	Coefficient	S. E	p-value
Intercept	4266	1631.1	0.031
Temperature	-20.76	6.82	0.016
pH	-38.61	7.84	0.001
DO	50.16	13.15	0.005
Salinity	-1.6	0.44	0.006
BOD	-57.01	9.07	0.000
Food diversity	-1476.64	747.23	0.084

Pseudo R^2 = 0.98

Proposed multiple regression model versus estimated regression model

The proposed multiple regression equation took into account of one dependent variable against all nine investigated independent variables and it was as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon,$$

where y is the dependent variable, β_0 is the intercept, $\beta_1 x_1$ is the variance of dependent variable against one unit change in independent variable, *n* is the n^{th} number of independent variables and ε is the regression error.

Upon construction of possible models for the relationship, the estimated regression model with lower AIC took into account of one dependent variable against only six independent variables and was shortened to as follows:

$$F = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \varepsilon,$$

where F is the dependent variable (fecundity), β_0 is the intercept, $\beta_1 x_1$ is the variance of fecundity against a corresponding unit change in temperature, $\beta_2 x_2$ is the variance in absolute fecundity against a corresponding unit change in pH, $\beta_3 x_3$ is the variance of fecundity against a corresponding unit change in dissolved oxygen, $\beta_4 x_4$ is the variance of fecundity against a corresponding unit change in salinity, $\beta_5 x_5$ is the variance of fecundity against a corresponding unit change in biochemical oxygen demand, $\beta_6 x_6$ is the variance of fecundity against a corresponding unit change in food diversity and ε is the regression error. Upon inserting the actual estimates and coefficients, the estimated multiple regression model becomes:

$$F = 4266.00 - 20.76 * \mathrm{T} - 38.61 * \mathrm{pH} + 50.16 * \mathrm{DO} - 1.60 * \mathrm{S} - 57.01 * \mathrm{BOD} - 1476.64 * \mathrm{FD}$$

Where F = Fecundity, T = Temperature, DO = Dissolved Oxygen, S = Salinity, BOD = Biochemical Oxygen Demand and FD = Food Diversity

This is the equation that can be used to predict fecundity in these coastal lagoons by knowing the values of these environmental determinants which have been investigated and confirmed to influence 98% of the absolute fecundity.

Interaction effects of the variables from the chosen model

Results show that only changes in temperature upon having changes in dissolved oxygen and biochemical oxygen demand have significant influence ($p < 0.05$) on fecundity of the fish (Table 5). Other interactions show no significant influences ($p > 0.05$).

Table 4: Interaction Effects of Physicochemical Parameters on the Fecundity of *Sarotherodon melanotheron* in Selected Lagoons of Ghana

Interacting parameters	p-value
T:pH:DO	0.0612
S:BOD:FD	0.790
T:pH:BOD	0.0640
pH:DO:BOD	0.0713
T:DO:BOD	0.0423
T:pH:S	0.293
T:S:BOD	0.351
pH:S:BOD	0.0915
T:DO:S	0.0925
DO:S:BOD	0.427

Discussion

Physicochemical parameters can serve as metrics for determining health status and inhabitability of aquatic systems. Natural occurrences or anthropogenic activities can influence physicochemical parameters to some extent and this in turn affects the water quality of aquatic systems. This study reveals that there is a significant variation in physicochemical parameters among different lagoons in Ghana. Many of the parameters were within permissible limits for aquatic life, according to the values given by United States Environmental Protection Agency (1986).

Keta lagoon had the highest mean temperature of 32.5°C while Sakumono lagoon had the lowest mean temperature of 30.0°C. Generally, the temperatures of the lagoons were high probably due to high atmospheric temperatures experienced during the dry season which reduced water volumes in the lagoons due to evaporation. A highest mean water pH of 9.3 was recorded from Keta lagoon while a lowest mean pH of 6.9 was recorded from Domunli lagoon. A similar study also recorded higher mean pH value for Keta lagoon (Avornyo, 2019).

According to Avornyo (2019), some of the factors influencing pH include availability of bacteria and plant matter, organic acids, biological processes such as photosythesis and the closeness and influence of the open ocean. Keta lagoon had the highest mean DO concentration of 5.5 mg/l while Sakumono registered the lowest of 3.8 mg/l. A mean concentration of DO for normal aquatic life is given as 5.5 mg/l (United States Environmental Protection Agency, 1986). This means that only Keta lagoon was within the permissible limits.

Benya lagoon recorded highest mean salinity of 35.7 ppt while Fosu lagoon had the lowest mean salinity of 7.5 ppt. A mean salinity of 35.7 ppt for brackish water environment is generally high and this could be due to higher temperatures that caused evaporation of water thereby increasing salt concentration in the lagoons. Also, the nature in which a lagoon is connected to an open sea can influence salinity in the lagoons. Highest mean turbidity of 69.4 mg/l was recorded from Fosu lagoon while the lowest mean turbidity of 7.0 mg/l was recorded from Domunli lagoon.

According to the report by Minnesota Pollution Control Agency (2008), 25 mg/l is given as maximum permissible limit for normal aquatic life in warm waters. This implies that Fosu and Sakumono lagoons are extremely turbid and this may be due to municipal and industrial discharges from the metropolitan surroundings since they are located in the hearts of Cape Coast and Accra, respectively.

Highest mean phosphate of 2.3 mg/l was recorded from Sakumono lagoon while the lowest value of 0.4 mg/l was recorded from Keta lagoon. According to United States Environmental Protection Agency (1986), 0.1 mg/l is regarded as the starting point for eutrophication and it entails that all the lagoons are already out of normal ranges. Domestic, industrial and agricultural discharges may be responsible for this situation. Fosu lagoon recorded highest mean nitrate of 11.3 mg/l while the lowest value of 1.2 mg/l was recorded from Domunli lagoon.

The lagoons located in the cities had higher nitrate concentrations than the ones in rural or semi-urban areas. Urban areas have degraded by septic tanks, urban agriculture, municipal and industrial wastewaters as sources of nitrate discharges and this may explain the results obtained by the present study.

Highest mean BOD value of 4.0 mg/l was recorded from Fosu lagoon while the lowest mean value of 1.3mg/l was recorded from Domunli lagoon. BOD which is used here as a measure of the degree of pollution is still within the permissible standards for aquatic life in these lagoons according to the standards provided by Koda et al. (2017). BOD may be low in these polluted urban systems probably due to nature and types of pollutants being deposited into the water. Domunli lagoon recorded lowest BOD value possibly because of its location at a rural community unlike Fosu and other lagoons located in urban areas.

This means that wetland degradation is more serious in urban areas than in rural communities. *S. melanotheron* in all the lagoons seemed to be subsisting on similar diversity of food resources as there was no significant difference in the diversity of food items in the stomachs of the fish among the lagoons. The species is primarily planktivorous and lack of variation in food items across the lagoons may indicate adaptive or resilient nature of plankton to different growth or survival conditions since the study has established that there is significant variation in physicochemical parameters across different lagoons which ideally were supposed to contribute to corresponding variation in food diversity.

Also, the species may not be open to different food types found in its ecosystem. The main food items identified were green algae, blue-green algae, copepods, cladocerans, detritus, diatoms, fish eggs, fish scales, insects, rotifers and other unidentified organisms and this is in agreement with what was also reported in Brenu and Nakwa lagoons (Zuh, Abobi, & Campion, 2019) as well as a previous report from Sakumono lagoon (Ofori-Danson & Kumi, 2005). What might differ however is the efficiency of preying which according to Ofori-Danson and Kumi (2005) is reported to be dependent on fish sizes and with large sized populations found in Domunli lagoon, their preying efficiency may be more than the other populations.

Variation in fecundity or reproductive capacity of fish is not a strange phenomenon as it occurs even in fish that belong to the same species or stock (Kingdom & Allison, 2011). The present study provides a typical example of such a variation in fecundity of *S. melanotheron* across different locations. *S. melanotheron* in the Domunli lagoon had the highest fecundity with a mean absolute fecundity of about 285 eggs while those populations in the Keta and Sakumono lagoons had the lowest mean absolute fecundities of about 82 and 86 eggs, respectively.

A mean of 285 eggs from Domunli lagoon is relatively higher than 206 eggs reported through a previous study from the same lagoon by Arizi et al. (2014). An average of about 108 eggs was determined as an absolute fecundity for *S. melanotheron* in the Fosu lagoon which is higher than 71 eggs that was reported by a previous study conducted in the same lagoon by Quarcoopome and Owiredu (2016).

The differences between what was reported in the previous studies and the present study could be attributed to differences in sampling duration or period and sampling season as well as sampling intensity as the present study only covered the dry season and just once in a month for only three months.

Generally, there is a strong positive relationship between body parameters and number of eggs that the fish produces. Normally fish with larger sizes tend to produce more eggs than fish with smaller sizes. However, in this study, there were weak relationships between body parameters and absolute fecundity across the lagoons given that four of the five R-square values were below 0.50.

Arizi et al. (2014) also reported very weak relationships between absolute fecundity and some body parameters of the fish in the Domunli lagoon; Quarcoopome and Owiredu (2016) made a similar observation in the Fosu lagoon. These findings resonate with the present study. By implication, absolute fecundity does not solely depend on body size in *S. melanotheron* but may be influenced by environmental stressors.

Egg production in fish is influenced by a wide range of external factors in an environment (Mule & Sarve, 2017). This study has assessed some key factors that could be responsible for variations in fecundity of *S. melanotheron* in Ghana's coastal lagoons and it has revealed that absolute fecundity is significantly influenced by temperature, pH, DO, salinity and BOD.

Despite significant variations in turbidity, phosphate and nitrate across the lagoons, they however did not show any direct significant influence on the egg production in *S. melanotheron*. From the selected model, temperature, pH, salinity and BOD showed significant negative linear relationship with absolute fecundity indicating that an increase in the values of these environmental variables of the lagoons results in a direct decrease in the number of eggs that *S. melanotheron* produces.

Temperature significantly influenced fecundity in these lagoons. It however showed negative linear relationship with egg production. Keta lagoon which had the highest mean temperature of 32.5°C recorded the lowest mean egg production. On the other hand, relatively higher fecundities were recorded in the lagoons that had relatively lower temperatures. The results from the present study conform with what was found by Alam et al. (2021) in which egg production of Nile tilapia reached its peak at optimal temperature range of 29℃ to 31℃ but decreased above 32℃ and eventually halted above 33℃. Issa et al. (2005) also concluded that temperature was indirectly proportional to egg production in an experiment with four tilapia species in which temperature range of 27℃ to 29℃ tallied with highest fecundities in these species.

A study conducted on a Nile tilapia hatchery showed an increase in egg production at temperatures ranging from 25℃ to 28℃ while the lowest number of eggs was recorded at the temperature of 33℃ (Faruk et al., 2012). From the foregoing, it is evident that higher temperatures above 32℃ are not favourable for egg production in most tilapia species. It is important to note that enzymes in an organism's body have their own optimum temperature and higher temperatures are usually associated with denaturing of these enzymes hence this could explain why these high temperatures reduce the number of eggs deposited.

The pH levels of the Domunli, Benya and Fosu lagoons are within desirable or optimum range of 6.5 to 9.0 for fish egg production (OpreX Analyzers, 2020). However, the pH levels of the Keta and Sakumono lagoons are outside the optimum range. According to OpreX Analyzers (2020), a pH level that is above 9.0 results in physiological problems in fish which can affect reproduction and this can possibly explain why *S. melanotheron* in the Keta lagoon had the lowest fecundity.

OpreX Analyzers (2020) further explains that at pH levels above 9, cellular membranes are easily denatured and water chemistry is altered in which ammonium is converted to dangerous and toxic ammonia thereby impairing fish growth and well-being. The present study is also in agreement with findings from an experiment by Alam et al. (2021) in which a pH range of 8 to 8.8 resulted in high egg production whilst a pH of above 9.3 resulted in low egg production. According to OpreX Analyzers (2020), low pH below 5 stresses the fish due to acidic conditions but such low pH values were not recorded in the five lagoons.

According to Fondriest Environmental Inc (2013), the anthropogenic causes of fluctuations in pH are closely related to pollution and it is a point source pollution that has the ability to increase or decrease water pH depending on the chemicals involved; for instance, chemical spills containing soap or detergents materials make water to be more basic. Pollution is prevalent along the coast of Ghana (Dankwa et al., 2016; Entsua-Mensah et al., 2000; Quarcoopome & Owiredu, 2016) and this could be the reason for undesirable pH levels in some lagoons. A report by the Utah State University (2020) also indicates that aquatic organisms are well adapted to tolerable pH levels and any slight or moderate changes in pH can negatively affect fish health, including reduced egg production.

Oxygen which is available for fish use in its dissolved form is an important parameter for various metabolic processes including tissue respiration for energy release. This energy can be used for life processes, including reproduction. Inadequate amount of dissolved oxygen therefore can lower egg production in fish. A study conducted on Gulf killifish exposed to different levels of DO showed significant reduction in egg production for specimens under hypoxia conditions (1.34 mg/l) compared to those under normoxia conditions (6.68 mg/l) (Landry et al., 2007). In another study, Alam et al. (2021) reported that egg production in Nile tilapia reached highest peak when DO concentration was 4.6 mg/l and the lowest peak was observed at 2.9 mg/l of DO.

According to Alam et al. (2021), the DO optimum range for egg production in his study was from 4.6 mg/l to 6 mg/l. From the present study, DO maintained a significant positive linear relationship with fecundity and this implies that high concentration of oxygen is needed to increase the reproductive performance of *S. melanotheron*. What is not clearly understood from the present study is that the two lagoons (Fosu and Keta) which recorded highest mean DO concentrations of 5.5 mg/l each did not record highest mean fecundity. This phenomenon may be due to availability of high organic load in these lagoons as a result of pollution whose decomposition by bacteria requires high concentration of dissolved oxygen. This could be the possible reason for the high BOD in the Fosu and Keta lagoons.

A number of physiological processes in fish are known to be dependent on salinity of the water. *S. melanotheron* is known to tolerate wide ranges of salinities though impared growth and reproduction may occur beyond a certain threshhold (Gue`ye et al., 2012). According to Gue`ye et al. (2020), highest egg production was recorded at a location of sea water (37 ppt) followed by a location with freshwater salinity (0 ppt) while a location with hypersaline condition (66-127 ppt) recorded the lowest fecundity.

The paper further explains that the natural environment of the fish is saline water and therefore encounters lowest cost of adaptation to salinities; as a result, resource allocation goes to reproduction leading to higher fecundities at sea water salinity (37 ppt). However, the current study indicates a significant negative linear relationship between fecundity and salinity. Domunli lagoon with average salinity of 7.9 ppt had its *S. melanotheron* population recording the highest mean fecundity whilst that of the Keta lagoon with average mean salinity of 31.3 ppt recorded the lowest mean fecundity.

Comparing an average fecundity of 434 eggs reported in the *S. melanotheron* population of the Brimsu freshwater reservoir of Ghana (Mireku et al., 2016) with the findings of the present study, it can be deduced that *S. melanotheron* in Ghana performs well in freshwater environment despite utilizing sea water environment as its natural environment. This can be an advantage for fish farmers in Ghana who may want to culture *S. melanotheron* since most aquaculture farmers use freshwater ponds, hence making the species one of the excellent potential candidates for aquaculture.

Elsewhere, it was reported that there were no significant differences in reproductive performance of *Sarotherodon melanotheron heudelotii* between locations with freshwater salinity (0 ppt) and sea water salinity (35 ppt) (Dugue et al., 2014) and this indicates resilient nature of the genus *Sarotherodon* to varied environmental conditions.

BOD is used as a pollution index (Ndimele, 2012) implying that BOD level of a water body is a measure of the extent of its anthropogenically induced pollution. The regression model generated in this study also shows that there is a negative linear relationship between BOD and absolute fecundity. This means that an increase in BOD levels results in a direct decrease in egg production of *S. melanotheron.*

Highest mean absolute fecundity was recorded in Domunli lagoon which had the lowest mean BOD value of 1.3 mg/l. Higher BOD values mean less dissolved oxygen (DO) is available for fish respiration and for bacteria to decompose huge load of organic matter in the ecosystem. Consequently, respiration in fish is hindered resulting in less energy production much of it might be allocated to other prioritized processes such as growth or maintenance whereas a limited amount of the energy is channeled into reproduction. The BOD values indicate that Domunli lagoon is less polluted than the rest of the lagoons in questions. According to Koda et al. (2017), BOD range of 1.0 mg/l to 2.0 mg/l is considered very clean; moderately clean at BOD range of 3.0 mg/l to 5.0 mg/l, and nearby pollution at BOD level greater than 5.0 mg/l. This means that all sampled lagoons are still within permissible limits, although the impacts of increasing BOD levels have already started affecting reproductive performance of *S. melanotheron*.

Food resources greatly support egg production in fish (Kuzuhara et al., 2019); for instance, an ecosystem with abundant food contributes positively to egg production in fish (Siddiqui et al., 1997). It was envisaged that the lagoons would have different food spectra but it turned out that there was no significant difference in food diversity across the lagoons. The model indicated that food diversity influenced fecundity but the influence was not significant. This could be due to similar food spectra across the lagoons.

It is said that food is the most limiting environmental factor for fecundity since it affects growth and size which in turn affects reproductive performance (Siddiqui et al., 1997). It could be very informative if food diversity was assessed from the environment such as in water column or sediment and not only in stomachs of fish. Future researchers may also consider determining the abundance of food items in the environment in addition to food diversity to obtain a clear picture of how food abundance can affect reproductive performance in these lagoons since diversity alone may not translate to adequate supply of food in an ecosystem.

Of the nine factors investigated, three of them, namely turbidity, phosphate and nitrate did not have a pronounced impact on fecundity of the species according to the best fit model. For turbidity, the probable reason may be that it does not directly affect fish physiology like other factors do. Turbidity is about clarity of water. It may have an impact on light penetration across the water column, thereby affecting primary production, and may also affect detection of food items by fish that depend on sight.

Considering these effects, it can be logically concluded that firstly, primary production in these lagoons is not a problem as was also seen from similar diversity of food items across the lagoons. Lastly, *S. melanotheron* might have developed other adaptive features such as olfactory senses to detect food items in a situation where turbidity is too high and water is not clear. The turbidity impact on fecundity was not pronounced despite some lagoons recording higher values than 25 mg/l given as optimal value for both warm water fishery and indigenous fish (Minnesota Pollution Control Agency, 2008). Both phosphates and nitrates are nutrients that can lead to eutrophication if they are available in excessive amounts in water. For them not to have an impact on fecundity, implies that they do not occur in dangerous levels in these lagoons. One of the consequences of having excessive amounts of these nutrients is that eutrophication causes hypoxia (Ngatia et al., 2017).

Hypoxia is when dissolved oxygen gets too low, usually below 2 mg/l. The present study did not record any average DO below 2 mg/l which may suggest that eutrophication as a result of phosphate and nitrate in these lagoons has not reached harmful levels yet and this may be the reason that the two nutrients did not have pronounced impact on egg production by the species.

The present study was trying to ascertain the role of environmental factors on egg production of wild populations of *S. melanotheron* and it has been deduced that temperature, pH, BOD, salinity and DO have significant impact on variations of fecundity of this species across Ghana's coastal lagoons. Although the study has presented some important findings, it nevertheless has some shortfalls or caveats. Sampling in all the lagoons was not done simultaneously and so, the variations in the environmental conditions could be partly attributed to different days and hours in which the sampling was done.

Another caveat is that data were not collected for at least over a year. Ideally, data from this kind of research is supposed to be collected for an entire year to capture some seasonal variations in the trends of results. The current study rather focused on one major breeding season which happened to be the dry season in Ghana. Hence, future researchers can work on this aspect of seasonal changes or variations for a twelve-month period and even beyond.

Chapter Summary

As part of key findings, a good number of physicochemical parameters studied showed significant variations across the lagoons. These include temperature, pH, DO, salinity, turbidity, phosphate, nitrate and BOD. Food diversity did not vary significantly among the lagoons. Absolute fecundity varied significantly among the lagoons with highest mean fecundity of 285 eggs being recorded in Domunli lagoon and lowest mean fecundity of about 82 eggs in Keta lagoon. The relationship between body parameters and fecundity was generally weak in all lagoons. Temperature, pH, DO, BOD and salinity significantly influenced reproductive performance of the species.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study aimed to assess environmental influences on fecundity of blackchin tilapia (*Sarotherodon melanotheron*) in selected coastal lagoons of Ghana. The physicochemical parameters of the lagoons were assessed using appropriate instruments for measuring water quality parameters, including temperature, pH, DO, salinity, turbidity, phosphate, nitrate and BOD. Shannon-Wiener diversity index was used to determine diversity of food items consumed by *S. melanotheron* populations in the lagoons.

The body lengths and weights were measured using measuring boards and precision weighing scale, respectively. Female fish gonads were extracted and fixed in 10% formalin and individual eggs were counted after one week. Both parametric and nonparametric tests were used to analyze the data. One-way ANOVA tests were used to determine significant differences in the means of variables. For data that were not normally distributed, Kruskal-Wallis test was carried out to determine if there were significant differences in the variables in question. Scatter plots were used to establish relationships between body parameters and absolute fecundity while generalized multiple regression model was used to determine the influence of environmental stressors on absolute fecundity.

From the results, a number of physicochemical parameters in question showed significant variations across the lagoons. These parameters included temperature, pH, DO, salinity, turbidity, phosphate, nitrate and BOD. Food diversity did not vary significantly among the lagoons. Absolute fecundity varied significantly among the lagoons with highest mean fecundity of 285 eggs being recorded in Domunli lagoon and lowest mean fecundity of about 82 eggs in Keta lagoon.

The relationship between body parameters and fecundity was generally weak in all lagoons. Keta lagoon had the highest mean temperature of 32.5℃ while Sakumono lagoon had the lowest mean temperature of 30.0℃. A highest mean water pH of 9.3 was recorded from Keta lagoon while a lowest mean pH of 6.9 was recorded from Domunli lagoon. The highest mean DO level of 5.5 mg/l was recorded in Keta lagoon while the lowest of 3.8 mg/l was recorded in Sakumono lagoon. The highest mean salinity of 35.7 ppt was recorded in the Benya lagoon while the lowest mean salinity (7.5 ppt) was recorded in the Fosu lagoon. The highest mean turbidity of 69.4 mg/l was recorded in the Fosu lagoon while the lowest mean turbidity (7.0 mg/l) was recorded in the Domunli lagoon.

The highest mean phosphate of 2.3 mg/l was recorded in the Sakumono lagoon while the lowest value of 0.4 mg/l was recorded in the Keta lagoon. The highest mean nitrate of 11.3mg/l was recorded in the Fosu lagoon while the lowest value of 1.2 mg/l was recorded in the Domunli lagoon. The highest mean BOD value of 4.0 mg/l was recorded in the Fosu lagoon while the lowest mean value of 1.3mg/l was recorded in the Domunli lagoon.

Conclusions

Having successfully completed the study, the following conclusions have been drawn from the work:

1. The physicochemical parameters of the lagoons varied significantly and this indicates that the level of deterioration in environmental aspects of these lagoons is different.
2. There is similarity of food items across the lagoons, the implication is that food items available in one lagoon are also available in the rest of the lagoons. The common identifiable food items found in the stomachs of *S. melanotheron* during the study were green algae, blue-green algae, copepods, cladocerans, detritus, diatoms, fish eggs, fish scales, insects and rotifers.
3. Fecundity of *S. melanotheron* varied significantly across the lagoons; the *S. melanotheron* population in the Domunli lagoon had the highest average fecundity of about 285 eggs and this implies that many of the lagoons have unfavourable reproductive conditions for the species.
4. Generally, there was weak relationship between body parameters and fecundity of *S. melanotheron* from all lagoons. This means that the number of eggs produced by this species in these water bodies was independent of body sizes of the fish.
5. This study has revealed that absolute fecundity of *S. melanotheron* is significantly influenced by temperature, pH, DO, salinity and BOD out of nine factors that were being assessed. Turbidity, phosphate and nitrate did not show any pronounced relationship with egg production in *S. melanotheron*. Temperature, pH, salinity and BOD showed significant

negative linear relationship with absolute fecundity while DO showed positive linear relationship with absolute fecundity.

Recommendations

Based on the findings of this study, the following recommendations have been made:

1. There is need to monitor entry of dangerous pollutants from agriculture, septic tanks as well as industrial discharge to avoid dangerous levels of pH, BOD, temperature, etc. that have a direct impact with reproduction in fish. The district, municipal and metropolitan assemblies should be responsible for this.
2. District assemblies should consider relocation of programmes that are found in buffer zones of lagoons. An adequate fixed proportion of buffer zone must be declared as a no-settlement area and allow vegetation to take hold in those areas.
3. Environmental Protection Agency (EPA) or District Assemblies must take an initiative to regularly check and monitor water quality parameters in all coastal wetlands to have an early detection of water quality problem. The regular check and monitoring can be done on monthly basis.
4. The study has also given a wake-up call for city or community authorities to seriously address issues of environmental degradation in these coastal lagoons to promote sustainable lagoon fishery towards food security among coastal dwellers.
5. A year-round study on this topic is needed to understand seasonal changes in both fecundity and environmental stressors.

6. Further research will be required to determine the influence of other pollution indicators such as occurrence of microplastic ingestion on reproductive performance of this species in these lagoons due to accelerating levels of plastic pollution along the coastal areas which has become a global concern. This study has provided the basic knowledge of the influence of environmental factors on reproductive performance of the species. Only key enviromental characteristics were considered for the study. However, the concept of environmental factors in aquatic environments is very broad. BOD as an enviromental factor for example, measures the extent of pollution from anthropogenic activities. However, this normally deals with point source pollution that leads to organic load being deposited into aquatic ecosystems and it is biodegradable load. But the question lies on the pollutants that are non biodegradable such as plastic pollution. The present study skipped plastic pollution which most of them are non-biodegradable and end up being ingested by aquatic organisms and can have impact on so many physiological processes of the fish, including reproduction. The future study will help understand a broader picture of the extent of anthropogenic meddling on aquatic systems and influences on reproductive capacity of *S. melanotheron* and other species in these lagoons.
7. It could be very informative if food diversity was assessed from the environment such as in water column or sediment and not only in stomachs of fish. Future researchers may also consider determining the abundance of food items in the environment

REFERENCES

Agbemehia, K. (2014). *Effects of industrial waste effluents discharged into Sakumo II lagoon in Accra Ghana*. (Master's thesis, Kwame Nkrumah University of Science and Technology, Ghana). Retrieved from FishCom Ghana Web Site: https://fishcomghana.com/coastal-issues-and-management/effects-of-industrial-waste-effluents-discharged-into-sakumo-ii-lagoon-in-accra-ghana/.

Alam, S. M., Sarkar, S. I., Miah, M. A., & Rashid, H. (2021). Management strategies for nile tilapia (Oreochromis niloticus) hatchery in the face of climate change induced rising temperature. *Aquaculture Studies*, *21*(2), 55-62.

American Public Health Association. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Washington, DC: APHA.

Arizi, E. K., Obodai, E. A., & Aggrey-Fynn, J. (2014). Reproductive biology of Sarotherodon melanotheron in the Dominli lagoon, Ghana. *International Journal of Ecology and Environmental Sciences*, *40*, 245-253.

Armah, F. A., Ason, B., Luginaah, I., & Essandoh, P. K. (2012). Characterization of macro-benthic fauna for ecological health status of the Fosu and Benya lagoons in coastal Ghana. *Journal of Ecology and Field Biology*, *35*(4), 279-289.

Avornyo, S. Y. (2019). *Water quality assessment of some coastal lagoons in Ghana*. Beau Bassin, Mauritius: LAP LAMBERT Academic Publishing.

Béné, C., & Heck, S. (2005). *Fish and food security in Africa*. WorldFish. Cairo: WorldFish Center.

Blay, J. (1993). Assessment of the fishery of a stunted population of the cichlid , *Sarotherodon melanotheron* (Ruppel), in a “closed ” lagoon in Ghana. *Journal of Applied Ichthyology, 9*, 1-11.

Blay, J. (1998). Growth and mortality parameters of Sarotherodon melanotheron melanotheron (Teleostei : Cichlidae) in two brackish water systems in Ghana. *Ghana Journal of Science, 38*, 47-55.

Blay, J. (2009). *Lagoon tilapia: Bioprofile and prospects for coastal fisheries development: An Inaugural lecture delivered at the University of Cape Coast.* Retrieved from University of Cape Coast Web Site: https://ir.ucc.edu.gh/xmlui/handle/123456789/1751.

Dallas, H. (2009). *The effect of water temperature on aquatic organisms : A review of knowledge and methods for assessing biotic responses to temperature.* Cape Town.

Dankwa, H. R., Quarcoopome, T., Owiredu, S. A., & Amedorme, E. (2016). State of fish and fisheries of Fosu lagoon , Ghana. *International Journal of Fisheries and Aquatic Studies, 4*(2), 259-264.

Dankwa, H. R., Shenker, J. M., Lin, J., Ofori-Danson, P. K., & Ntiamoa-Baidu, Y. (2004). Fisheries of two tropical lagoons in Ghana. *Journal of Fisheries Management and Ecology, 11*, 379-386.

DeNicola, D. M. (1996). Periphyton responses to temperature at different ecological levels. In D. M. DeNicola, *Algal ecology* (pp. 149-181). Slippery Rock: Academic Press.

Dugue, R., Etienne, B., Moussa, G., Jean-christophe, A., Yan, C., Christophe, C., & Marc, L. (2014). Egg production in the euryhaline tilapia , Sarotherodon melanotheron heudelotii , experimentally maintained in fresh , sea and hypersaline waters. *Journal of Aquatic Living Resources, 27*, 63-72.

Eby, L. A., & Crowder, L. B. (2002). Hypoxia-based habitat compression in the Neuse River Estuary : Context-dependent shifts in behavioral avoidance thresholds. *Canadian Journal of Fisheries and Aquatic Sciences, 59*, 952-965.

Edwards, T. M., Miller, H. D., & Guillette, L. J. (2006). Water Quality Influences Reproduction in Female Mosquitofish (Gambusia holbrooki) from Eight Florida Springs. *Journal of Environmental Health Perspectives*, *114*(1), 69-75.

EI-Naggar, G. O., EI-Nady, M. A., Kamar, M. G., & Al-Kobaby, A. I. (2000). Effect of photoperiod, dietary protein and temperature on reproduction in Nile tilapia (Oreochromis niloticus). *WorldFish Sustainable Aquaculture Conference* (pp. 1-10). Cairo: University of Arizona.

El-Sayed, A.-F. M. (2020). Taxonomy and basic biology. In A.-F. M. El-Sayed, *Tilapia culture* (pp. 21-31). Alexandria: Academic Press.

Entsua-Mensah, M., Ofori-Danson, P. K., & Koranteng, K. A. (2000). Management issues for the sustainable use of lagoon fish resources. *ICLARM Conference Proceedings. 63*, pp. 24-27. ICLARM. Retrieved from AquaDocs Web Site: https://aquadocs.org/handle/1834/699.

Eyeson, K. N. (1983). Stunting and reproduction in pond-reared Sarotherodon melanotheron. *Journal of Aquaculture 31*, 257-267.

Ezenwaji, H. M., & Offiah, F. N. (2003). The biology of *Pellonula leonensis*, Boulenger, 1916 (Osteichthyes: Clupeidae) in Anambra River, Nigeria. *Journal of Biology Research and Biotechnology, 1*(2), 33-50.

Faruk, M. A., Mausumi, M. I., Anka, I. Z., & Hasan, M. M. (2012). Effects of temperature on the egg production and growth of monosex Nile tilapia Oreochromis niloticus fry. *Bangladesh Research Publications Journal, 7*(4), 367-377.

Fisher, S. E. (2009). *The effects of various levels of dissolved oxygen on fish reproduction* (Master's thesis, University of Saskatchewan, Canada). Retrieved from University of Saskatchewan Web Site: https://harvest.usask.ca/handle/10388/etd-04302010-120326.

Fondriest Environmental, Inc. (2013, November 19). *"pH of Water." Fundamentals of environmental measurements.* Retrieved from Fondriest Environmental Learning Centre Web Site: https://www.fondriest.com/environmental measurements/parameters/water-quality/ph/.

Ghaedi, A., Hosseinzadeh, H., & Hashim, R. (2019). Effect of different protein levels on reproductive performance of snakehead murrel Channa striatus (Bloch 1793). *Iranian Journal of Fisheries Sciences, 18*(4), 812-829.

Gue`ye, M., Tine, M., Kantoussan, J., Ndiaye, P., & Thiaw, O. T. (2012). Comparative analysis of reproductive traits in Black- chinned tilapia females from various coastal marine, estuarine and freshwater ecosystems. *PLoS ONE, 7*(1), 1-11.

Gyampoh, B. A., Atitsogbui, G., & Obirikorang, K. A. (2020). Understanding the neglected shellfish fishery of the Keta Lagoon, Ghana. *Journal of Fisheries and Coastal Management, 2*, 1-11.

Hester, F. J. (1964). Effects of food supply on fecundity in the female guppy , Lebistes reticulatus (Peters). *Journal of Fisheries Research Board of Canada, 21*(4).

Hunter, J. R., Macewicz, B. J., Chyan-Huei Lo, N., & Kimbrell, C. A. (1992). Fecundity, spawning, and maturity of female Dover sole Microstomus pacificus, with an evaluation of assumptions and precision. *Fishery Bulletin, 90*(1), 101-128.

Ikuta, K., Yada, T., Kitamura, S., Branch, N., Ito, F., Yamagichi, M., . . . Iwata, M. (2000). *Effects of acidification on fish reproduction.* Chugushi, Japan: UJNR.

Issa, E. A., Olufeagba, S. O., & Raji, A. (2005). *Effects of some environmental factors on the fecundity of tilapia species (family cichlidae) in Kigera Reservoir, New Bussa.* Retrieved from AquaDocs Web Site: https://aquadocs.org/handle/1834/21773.

Kingdom, T., & Allison, M. E. (2011). The fecundity, gonadosomatic and hepatosomatic indicies of Pellonula leonensis in the Lower Nun River, Niger Delta, Nigeria. *Current Research Journal of Biological Sciences, 3*(2), 175-179.

Kjerfve, B. (1986). Comparative oceanography of coastal lagoons. In B. Kjerfve, *Coastal lagoons* (pp. 63-81). Columbia, South Carolina: Academic Press.

Kjerfve, B. (1994). Coastal lagoons processes. *Elsevier Oceanography Series, 60*, 1-8.

Kjesbu, O. S., Witthames, P. R., Solemdal, P., & Greer, W. M. (1998). Temporal variations in the fecundity of arcto-Norwegian cod (Gadus morhua) in response to natural changes in food and temperature. *Journal of Sea Research, 40*, 303-321.

Koda, E., Miszkowska, A., & Sieczka, A. (2017). Levels of organic pollution indicators in groundwater at the old landfill and waste management site. *Journal of Applied Sciences, 7*(638), 1-22.

Kuzuhara, H., Yoneda, M., Tsuzaki, T., Takahashi, M., Kono, N., & Takeshi, T. (2019). Food availability before aestivation governs growth and winter reproductive potential in the capital breeding fish , Ammodytes japonicus. *PLoS ONE, 14*(3), 1-16.

Lai, K. P., Wang, S. Y., Li, J. W., Tong, Y., Chan, T. ,., Jin, N., . . . Kong, C. (2019). Hypoxia causes transgenerational impairment of ovarian development and hatching success in fish. *Journal of Environmental Science and Technology, 53*, 3917-3928.

Lamptey, M. A., & Ofori-Danson, P. K. (2014). The status of fish diveristy and fisheries of the Keta lagoon, Ghana, West Africa. *Ghana Journal of Science, 54*, 3-18.

Landry, C. A., Steele, S. L., Manning, S., & Cheek, A. O. (2007). Long term hypoxia suppresses reproductive capacity in the estuarine fish, Fundulus grandis. *Comparative Biochemistry and Physiology (CBP), Part A, 148*, 317-323.

Miller, G. M., Watson, S. A., Mccormick, M. I., & Munday, P. L. (2013). Increased CO2 stimulates reproduction in a coral reef fish. *Global Change Biology*, *19*, 3037-3045.

Minnesota Pollution Control Agency (2008). *Turbidity: Description, impact on water quality, sources, measures.* Retrieved from Minnesota Pollution Control Agency Web Site: https://www.pca.state.mn.us/sites /default/files/wq-iw3-21.pdf.

Mireku, K. K., Blay, J., & Yankson, K. (2016). Reproductive biology of Blackchin tilapia , Sarotherodon melanotheron (Pisces : Cichlidae) from Brimsu Reservoir, Cape Coast, Ghana. *International Journal of Fisheries and Aquaculture*, *8*(4), 42-54.

Mjoun, K., Rosentrater, K., & Brown, M. L. (2010). *Tilapia: Profile and economic importance of tilapia.* Retrieved from South Dakota State University Web Site: http://openprairie.sdstate.edu/extension_fact Recommended.

Mule, A. B., & Sarve, N. S. (2017). Role of different factors on reproduction of fish. *International Journal for Innovative Research in Multidisciplinary Field*, *3*(7), 86-93.

Nartey, V. K., Edor, K. A., Doamekpor, L. K., & Bobobee, L. H. (2011). Nutrient load of the Sakumo lagoon at the Sakumo Ramsar Site in Tema , Ghana. *West African Journal of Applied Ecology*, *19*, 94-105.

Ndimele, P. E. (2012). The effects of water hyacinth (Eichhornia crassipes) infestation on the physico-chemistry, nutrient and heavy metal content of Badagry creek and Ologe lagoon, Lagos, Nigeria. *Journal of Environmental Science and Technology*, *5*(2), 128-136.

Ngatia, L., Johnny, G., Moriasi, D., & Taylor, R. (2017). Nitrogen and phosphorus eutrophication in marine ecosystems. *Journal of Geophysical Research*, 1-17.

Odjer-Bio, N. T., Belford, E., & Ansong, M. (2015). What is happening to our Lagoons? The example of Butuah Lagoon in Ghana. *International Journal of Energy and Environmental Engineering (2015), 6*, 183-193.

Ofori-Danson, P., & Kumi, G. N. (2005). *Food and feeding habit of Sarotherodon melanotheron , Rüppell , 1852 (Pisces : Cichlidae) in Sakumo lagoon, Ghana.* Retrieved from University of Ghana Web Site: https://apps.ug.edu.gh/wajae/volume-10-2006?download=212:3-food-and-feeding-habit-of-sarotherodon-melanotheron-r-ppell-1852-pisces-cichlidae-in-sakumo-lagoon-ghana.

OpreX Analyzers. (2020). *pH in fish farming.* Retrieved from Yokogawa Web Site:https://www.yokogawa.com/library/resources/application-notes/ph-in-fish-farming/.

Patricio, B., Ferreira, B., Inniss, L., Marschoff, E., Rice, J., Rosenberg, A., & Simcock, A. (2016). *Overall assessment of human impact on the oceans.* United Nations.

Pauly, D. (1976). The biology, fishery and potential for aquaculture of Tilapia melanotheron in a small West African lagoon. *Aquaculture, 7*, 33-49.

Perry, R. (2010, January). *Guide to the Common Inshore Marine Plankton of Southern California.*Retrieved from https://dornsife.usc.edu/assets/sites/291/docs/HABWatch/3_Plankton_Guide_2010rev.pdf.

Prabu, E., Rajagopalsamy, C. B., Ahilan, B., Jeevagan, J. M., & Renuhadevi, M. (2019). Tilapia – An excellent candidate species for world aquaculture: A review. *Annual Research and Review in Biology*, 1-14.

Pullin, R. S., Eknath, A. E., Gjedrem, T., Tayamen, M. M., Macaranas, J. M., & Abella, T. A. (1991). *The genetic improvemnt of farmed tilapias (GIFT) project: The story so far.* Cairo: Naga.

Quarcoopome, T., & Owiredu, S. (2016). Aspects of the fecundity of the black-chinned tilapia sarotherodon melanotheron in the Fosu Lagoon, Ghana. *Ghana Journal of Science, 56*, 15-24.

Scorvo, F., Frascá-scorvo, C. M., Alves, J., & Souza, F. (2010). Tilapia culture and its inputs , economic relations. *Revista Brasileira de Zootecnia, 39*, 112-118.

Siddiqui, A. Q., Al-Harbi, A. H., & Al-Hafedh, Y. S. (1997). Effects of food supply on size at first maturity , fecundity and growth of hybrid tiiapia , Oreochromis niloticus (L .) x Oreochromis aureus (Steindachner), in outdoor concrete tanics in Saudi Arabia. *Aquaculture Research, 28*, 341-349.

Sikora, W. B., & Kjerfve, B. (1985). Factors influencing the salinity regime of Lake Pontchartrain, Lousiana, a shallow coastal lagoon: Analysis of a long-term data set. *Estuaries, 8*(2), 170-180.

Subasinghe, R., Soto, D., & Jia, J. (2009). Global aquaculture and its role in sustainable development. *Reviews in Aquaculture, 1*, 2-9.

Tam, W. H., & Payson, P. D. (1986). Effects of chronic exposure to sublethal pH on growth, egg production, and ovulation in brook trout, Salvelinus fonfinalis. *Canadian Journal of Fisheries and Aquatic Sciences, 43*, 275-280.

Towers, L. (2014). *Maturation and spawning in fish.* Retrieved from The Fish Site Web Site: https://thefishsite.com/articles/maturation-and-spawning-in-fish

Trewavas, E. (1983). *Tilapiine fishes of the genera Sarotherodon, Oreochromis and Danakilia*. London, England: British Museum (Natural History).

United States Environmental Protection Agency. (1986). *Quality criteria for water*. Washington, DC: United States Environmental Protection Agency.

Utah State University. (2020). *Water quality: What is pH?* Retrieved from Utah State University Extension Web Site: https://extension.usu.edu/ waterquality/learnaboutsurfacewater/propertiesofwater/pH.

Vowotor, M. K., Hood, C. O., & Tatchie, E. (2014). An assessment of heavy metal pollution in sediments of a tropical lagoon : A case tudy of the Benya lagoon , Komenda Edina Eguafo Abrem Municipality (KEEA) — Ghana. *Journal of Health and Pollution*, *4*(6), 26-39.

Yankson, K., & Obodai, E. A. (1999). An update of the number, types and distribution of coastal lagoons in Ghana. *Journal of Ghana Science Association*, *3*, 26-31.

Zuh, C. K., Abobi, S. M., & Campion, B. B. (2019). Comparative assessment of age , growth and food habit of the black-chinned tilapia , Sarotherodon melanotheron (Rüppell , 1852), from a closed and open lagoon , Ghana. *Journal of Fisheries and Aquatic Sciences*, 1-12.

APPENDICES

APPENDIX A: ANOVA TABLES

Table A1: Kruskal-Wallis One-Way ANOVA Test for Temperature

Temperature	Scores
Chi-Square	25.843
df	4
Asymp. Sig.	.000

Table A2: One-Way ANOVA's Robust Tests of Equality of Means for pH

pH	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	69.989	4	25.476	.000

a. Asymptotically F distributed.

Table A3: Kruskal-Wallis One-Way ANOVA Test for Dissolved Oxygen

Dissolved Oxygen	Scores
Chi-Square	19.964
Df	4
Asymp. Sig.	.001

Table A4: Kruskal-Wallis One-Way ANOVA Test for Salinity

Water Salinity	Scores
Chi-Square	39.576
df	4
Asymp. Sig.	.000

Table A5: Kruskal-Wallis One-Way ANOVA Test for Turbidity

Turbidity	Scores
Chi-Square	38.240
df	4
Asymp. Sig.	.000

Table A6: Kruskal-Wallis one-way ANOVA Test for Phosphate

Phosphate	Scores
Chi-Square	27.647
df	4
Asymp. Sig.	.000

Table A7: A one-way ANOVA's Robust Tests of Equality of Means for Nitrate

Nitrate	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	160.356	4	19.037	.000

a. Asymptotically F distributed.

Table A8: A one-way ANOVA's Robust Tests of Equality of Means for BOD

BOD	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	42.990	4	12.485	.000

a. Asymptotically F distributed.

Table A9: Kruskal-Wallis One-Way ANOVA Test for Food Diversity Index

Food Diversity	Scores
Chi-Square	.444
df	4
Asymp. Sig.	.979

Table A10: Kruskal-Wallis One-Way ANOVA Test for Fecundity

Fecundity	Scores
Chi-Square	478.764
df	4
Asymp. Sig.	.000

Table A11: Monthly Food Diversity Indices Recorded for *Sarotherodon melanotheron* Populations in the Lagoons from March to May, 2022

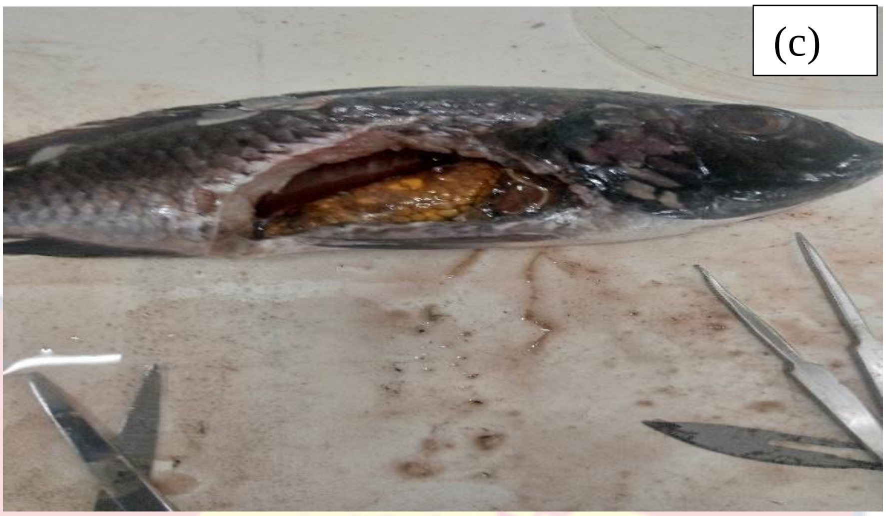
Month	Domunli lagoon	Fosu lagoon	Benya lagoon	Sakumono lagoon	Keta lagoon	P value
March	2.18	2.17	2.17	2.16	2.17	
April	2.16	2.16	2.16	2.17	2.17	
May	2.17	2.17	2.17	2.17	2.16	
P value						0.979

APPENDIX B: RANDOM FIELD AND LABORATORY PICTURES

Pictures: (a) In-situ measurements of physicochemical parameters at Domunli lagoon, (b) Dissection and gonadal extraction in the laboratory, (c) Gonad position in the fish body, (d) Gonads removed from the fish body, (e) Hardened ovaries after one week fixation in 10% formalin, (f) Eggs separated and ready for counting, (g) Some fish specimens from Benya lagoon, and (h) On-site preservation of stomach contents in 10% formalin at Keta lagoon

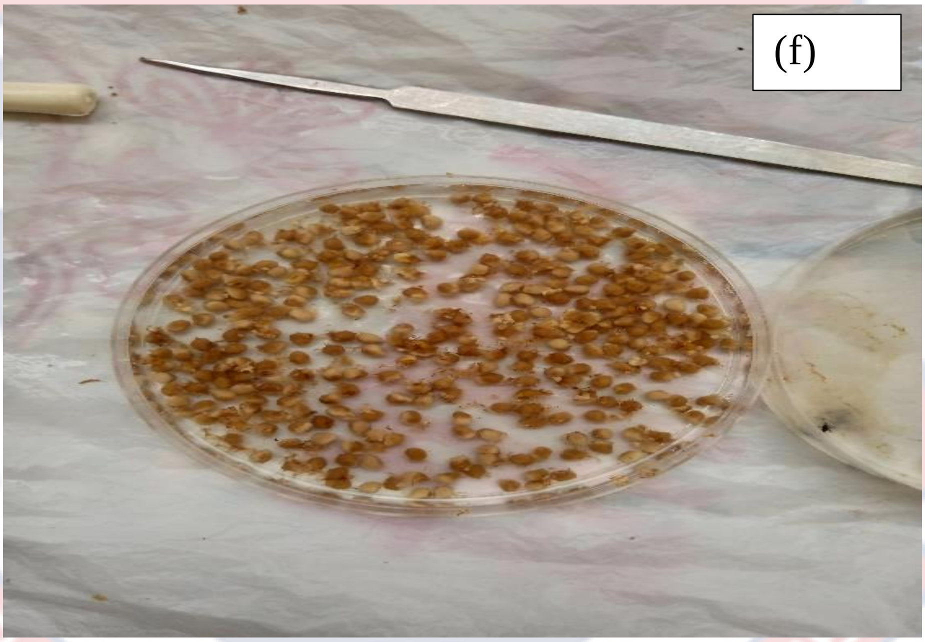
(a)

(b)



(c)

(d)



(g)

(h)