KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF FISHERIES AND WATERSHED MANAGEMENT

KUMASI, GHANA

ASSESSMENT OF GROWTH AND MANAGEMENT OF THE CLAM *Galatea paradoxa* FISHERY AT THE LOWER VOLTA, GHANA

JERRY JOHN AMEDZRO

BSC (HONS) AGRICULTURE TECHNOLOGY

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A THESIS SUBMITTED TO THE DEPARTMENT OF FISHERIES AND WATERSHED MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF PHILOSOPHY (MPHIL.) IN AQUATIC RESOURCES MANAGEMENT

BY

JERRY JOHN AMEDZRO

BSC (HONS) AGRICULTURE TECHNOLOGY

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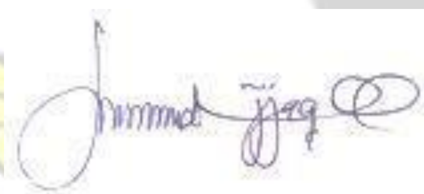
ABSTRACT

This study was undertaken to develop scenarios for the sustainable management and exploitation of the Volta clam *Galatea paradoxa* fishery by determining the effect of stocking density on the growth of seeded clams at the Volta estuary. The study was conducted at Agorta Zewukope and Agave Afedome, in the South Tongu District of the Volta Region over a 1-year period from June 2013 to June 2014. Five stocking densities of 50, 100, 150, 200 and 250 clams of mean length of 39.3±2.6 mm and mean weight of 18.5±3.1g were seeded in 1 m^{-2} area in duplicates. Length and weight measurements were taken every three months over the study period. Growth was negatively correlated with increasing stocking densities. At the end of the one-year trial period, the total weight (flesh weight+ shell weight) of clams stocked at 50 m^{-2} was 60.8±14.2g compared to 39.4 ±13.4 g for clams stocked at 250 m^{-2}. Negative allometric growth patterns were exhibited by all the clams grown under the different stocking densities. Focus group discussions with the fishing communities alluded to decreasing sizes of clams over the years. Majority of the respondents were in support of the introduction of minimum landing sizes to protect the fishery from collapse. Seeding of clams in privately-owned plots was seen as a proactive means of relieving the intense fishing pressure on the natural clam stock.

DECLARATION

I hereby declare that this work, submitted to the Department of Fisheries and Watershed Management of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, for the award of Master of Philosophy (MPhil.) is the result of original work carried out by myself under the guidance of Dr. Daniel Adjei-Boateng. Any technical and analytical assistance during the experimental period and citations of other work have been duly acknowledged. I further declare that the results of this work have not been submitted for the award of any other degree in the above-mentioned University or any other university elsewhere.



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Jerry John Amedzro Date

Certified by…………………………. …………………………….

Dr. Daniel Adjei-Boateng Date

(Supervisor)

Certified by ……………………………. ……………………………..

Dr. Daniel Adjei-Boateng Date

(Head of Department)

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CHAPTER ONE

INTRODUCTION

Background

Molluscs can be classified either as gastropods (single-shelled) or bivalves (two shells).The phylum Mollusca has six classes of which one is Lamellibranchia or Bivalvia (Purchon, 1963). Bivalves are the second most diverse group of mollusc found either in the freshwater or marine habitats. There are about 10,000 species of bivalves in the world and these include scallops, oysters, mussels, clams, etc.

The African mangrove oyster, *Crassostrea gasar* and *Anadara senilis* are some common species of bivalves that are found and exploited in West Africa. The habitat range of the most widely exploited West African bivalve (*Anadara senilis*) extends up to the sublitorial zones of the Atlantic Ocean (Okera, 1976). Scattered populations of *A. senilis* have been recorded in some lagoons in Ghana by Yankson (1982). The marine mollusc fauna in West Africa are very little known especially the bivalves, compared to those of other tropical regions. This is illustrated by the fact that between 1950 and 1986, twentyfour 24 new species were described. *Galatea paradoxa* (a hemi-freshwater clam) harvested immediately above the region of salt water penetration of the Cross River, Nigeria and Volta estuary of Ghana and *Aspatharia sinuata* (an established holofreshwater bivalve) obtained from inland waters are also examples of bivalves exploited in West Africa (Olayemi *et al.,* 2012).

The freshwater clam, *Galatea paradoxa* (Born 1778) is a bivalve mollusc which supports artisanal fisheries in some West African countries. This bivalve belongs to the order Tellinoidea and family Donacidae (Purchon, 1963). The species is often restricted to the lower reaches of some rivers in West Africa including the Volta in Ghana, the Cross and Nun in Nigeria and the Sanaga in Cameroon (Etim and Brey, 1994). In the Volta River the species is endemic to a narrow portion at the estuary (Attipoe and Amoah, 1989).

The habitat of the freshwater clam presently spans over a very small area of the lower Volta River, between Agave-Afedome which is about 15 km from the Volta estuary and Ada-Foah, 5 km from the estuary, compared to the pre-dam periods when the clam bed extended between Sogakope and Akuse which is about 32 -95 km from the Volta estuary (Lawson 1963; Amador, 1997).

Clams serve as a reasonably-priced source of protein and are consumed by the inhabitants along the lower reaches of the Volta and beyond (Amador, 1997). They are also a delicacy for travellers along the Accra –Lome and Accra –Ho highways. Nutritionally, clams have very high protein contents and also serve as a rich source of micronutrients such as B vitamins, iron, selenium, magnesium, copper, zinc and potassium (Kwei, 1965). The harvesting of the clams represents an important source of livelihood for the indigenes at the lower Volta. Additionally, the shell of the clam has several important uses: it mainly serves as a source of calcium in animal feeds especially poultry feed, it is also used to manufacture of whitewash, and is a substitute to stone chippings in concrete, and pavement material such as terrazzo floors. The shells are also partially embedded in the ground to overcome muddy conditions in village compounds in the southern parts of the Volta Region

(Obirikorang *et al*., 2010). Furthermore it can also be used in craftwork, and the manufacture of jewellery and buttons.

Despite these benefits, the Volta clam is seriously threatened, the stock is being exploited at a rate which requires immediate remedial action to prevent extinction of the species. This was evident in Adjei-Boateng *et al.,* (2009) work which established the trend of over-exploitation. They showed that, out of an average of 130 kg of clams (total weight) that were landed daily per canoe at Ada and its environs, 81% were clams that had shell lengths of < 60 mm. There is a trend of continuous decline in the clam output which is likely due to the fact that, it is an open resource thus; there are no restrictions on the quantity harvested or the sizes landed or marketed. All sizes are landed and marketed despite the fact that larger sizes fetch a higher price on the local markets. The introduction of improved harvesting techniques have resulted in improved access enabling clam fishers to harvest even at the deepest parts of the Volta and a higher efficiency in picking even the tiny ones which hitherto were not picked.

Traditionally, communities in the lower Volta have the practice of culturing *Galatea paradoxa* by seeding shallow shores with juvenile clams from their natural habitat in the Volta estuary to individual or family owned plots, for on- growing during the fishing season (March to December). This practice allows the provision of clams for domestic consumption and for sale during the closed season for the clams which starts from December to March each year. At the moment, the closed season and taboo days (Tuesdays) are the only laws regulating the clam fishery. These regulations were enacted and solely enforced by the traditional authorities of the clam fishing areas. The closed season only allows for the population to recover after spawning and does not prevent the harvesting of smaller sizes (Adjei-Boateng *et al.,* 2010).

The government of Ghana‟s food security and job creation agenda can be enhanced with a vibrant fishery sector especially in rural Ghana as it helps to alleviate rural poverty. *Galatea paradoxa* has for years supported a growing artisanal clam fishery which has helped improve the standard of living of the riparian communities around the Volta estuary. The clam industry has for decades provided jobs and a source of income for about two thousand men and women who engage in the clam fishery (Amador, 1997). Important as this resource is, its extinction will result in catastrophic socio-economic repercussions for the indigenes whose livelihood significantly depend on the fishery.

With the level of over-exploitation and the evidence of smaller sizes dominating the landings as shown by Adjei-Boateng *et al,* (2009), there is the need to research into sustainable ways of exploiting the resource including, experimenting on the optimum stocking density or seeding rate and its effects on the growth of the clams. There is also the need for the introduction of strategic management practices to salvage the situation.

Objectives

The objectives of the study were to:

i. Determine the effect of stocking density on the growth of seeded clams at the Volta estuary ii. Develop strategies for the sustainable management of the clam fishery

CHAPTER TWO

LITERATURE REWIEW

2.1 General Overview of the Fisheries Sector in the World

There is still a huge challenge in providing food to over 800 million people who suffer from chronic malnourishment, majority of whom are concentrated in the coastal regions of the world (FAO, 2014). According to FAO (2010), fisheries and aquaculture are very crucial in reducing malnourishment in many regions of the world. The fisheries and aquaculture sector represent sources of income and livelihood for hundreds of millions of people around the globe. The global fisheries sector has recorded growth rates faster than the world‟s population. In 2012, the sector represented 4.4% of the 1.3 billion people economically active in the broad agriculture sector worldwide compared to 2.7% in 1990 (FAO, 2014). Women representation accounted for more than 15% of this figure as far as direct involvement in the sector was concerned. With respect to inland fisheries, the direct participation of women was over 20% and as much as 90% in secondary activities (FAO, 2014). Estimates of the FAO (2014) indicated that fisheries and aquaculture guaranteed the livelihoods of 10–12% of the global population. Women therefore represent almost half of the total number of people working in the small-scale fisheries sector.

Looking at the broader issues in fisheries and aquaculture, FAO, (2010), stresses the necessity to focus particularly on policy and governance, especially with regards to job creation and poverty alleviation. The total output from capture fisheries and aquaculture accounted for 158.0 million tonnes (T) of fish globally in 2012 (FAO, 2014). Out of this total, 136.2 million T served as human food. This provided an estimated per capita fish consumption of about 19.2 kg which is higher than any previously recorded figure. Aquaculture accounted for 54% of the total fish output in 2012. Fish protein provides over 1.5 billion people globally with nearly 20% of their average per capita animal protein intake nearly as twice many people with at least 15% of their animal protein needs (FAO, 2010).

2.2 The Fisheries Sector of Ghana

The fishery sector in Ghana mainly comprises of marine fishery, inland (fresh water) fishery and aquaculture. It also involves other post-harvest activities such as fish storage, preservation, marketing and distribution. The sector accounts for about 3% of the total gross domestic products (GDP) and 6.9% of agricultural GDP (MOFA, 2012). Fish represents Ghana‟s most important non-traditional export and contribute significantly to the national economy. An estimated 10% of the country's population is engaged in different aspects of the fishing industry (GIPC, 2015).

The output from marine capture fisheries represents over 80% of the total fish consumption in Ghana (BoG, 2008). However, in recent times, aquaculture is increasingly contributing significantly to the supply of fish. The structure of the marine fishing industry in Ghana fishery sector is defined by the activities of four identifiable groups within the industry, namely the Artisanal, Semi-Industrial (inshore sector), Industrial (deep sea) and Tuna fleets (GIPC, 2015).

Ghanaian fisheries are based on resources from the marine, inland (freshwater), lagoon environment and also from aquaculture. The fisheries sub-sector is dominated by private sector capture fisheries and fish farming to a lesser extent (Bank of Ghana, 2008). Both pelagic and demersal fishery resources are exploited commercially in Ghana and accounted for approximately 326,000 mt in 2011, signifying a 2.3% increase over the 2010 output. Fish output from inland fisheries was 95,000 mt was in 2011 against 83,000 mt of fish in 2010, an increment of about 14.7%. In 2011, aquaculture recorded an output of about 19,000 mt compared to 10,200 mt in 2010 (Ghana Statistical Service, 2012). Despite this increase in aquaculture output, the monetary value of fish produced in 2011 declined by 8.7% against the value of fish produced in 2010.

The main sources of freshwater fish in Ghana are mainly from The Volta Lake, inland reservoirs and aquaculture. The Volta Lake fishery contributes about 90% of the total inland fish production in Ghana (Abban, 1999). The fish landings of the inland fisheries sector are dominated by tilapia species (38.1%), *Chrysichtys sp* (34.4%) and *Synodontis sp*. (11.4%) (MOFA, 2012). Aquaculture is a relatively new venture in Ghana which is growing rapidly in many parts of the country. There are about 1000 pond fish farmers engaged in fish culture in Ghana. Their collective farms accounts for a total of over 2000 ponds with a total surface area of about 350 ha (WTO, 2008). In 2006 export earnings from fish and fishing industry products amounted to nearly 96 million US dollars (Bank of Ghana, 2008). Fish is a favoured source of animal protein among Ghanaian consumers with around 75% of the total local production of fish consumed locally. Fish intake contributes about 60% of the protein intake of Ghanaians in diets (Sarpong *et. al*., 2005).

The per capita fish consumption in Ghana is about 25kg (Information on fisheries in Ghana, 2004)

2.2.1 The Inland Fishery of Ghana

The inland fishery in Ghana contributes immensely to the overall fishing sector of Ghana with about 80,000 fishers and 20,000 fish processors engaged in this sector ((MOFA, 2004).

The Volta Lake has a shoreline length of about 5200km and a length of about 400km from North to South making it the largest artificial lake in Africa. Fish landings are dominated by cichlids species and other fresh water species.

In addition to over 60 commercially important food fishes, the river supports prawn and clam fisheries at the lower reaches (Attipoe and Amoah, 1989). Before the construction of the Akosombo and Kpong Dams on the Volta River in 1964 and 1981 respectively, areas within Senchi and Atimpoku were noted for their prawn industry while the area between Akuse and Sogakope was considered the centre for the clam industry (Amador, 1997).

2.2.2 Economic Impact of the Fisheries Sector

The fishing industry in Ghana plays an important role in the country‟s economy. It provides employment opportunities for a significant number of people and is a major foreign exchange earner. A large section of the country‟s poor population is engaged in the fisheries sector. In all, about 150,000 fishers are directly or indirectly working in the fisheries sector, while over 500,000 people are engaged in ancillary work such as the fish processing, distribution, and sale (MOFA, 2012)

The country‟s total annual fish requirement is estimated at 880,000 T but production stands at an average of 428,697 T leaving a supply deficit of 450,303. This deficit is accounted for through fish imports. Ghana imported 175,341 tonnes of fish in the year 2012 (MOFA2012)

2.2.3 Rural Employment and Income

The fisheries sub-sector, particularly artisanal fisheries plays a very important role in creating rural employment and income for over 23,000 rural people not only through the fishing activity but also through processing, distribution and marketing activities (Ghana Statistical Service, 2012). There are a total of about presently about 150,000 fishermen in Ghana (MOFA 2012), against an estimated 123,000 in 2000 (Bannerman *et al.*, 2001), 91,400 in 1989 (Koranteng, 1990) and 104,000 in 1986 (Koranteng *et al*., 1987).

In addition to the fishermen, there are an estimated 1.5 million people who are involved in other aspects of the fishery. Besides the the canoe fishermen and their dependents, there is also a labour force participation in the artisanal fishing industry. The creation of employment for rural people, particularly women, has positively influenced food security (Seini, et al., 2002).

2.3 Molluscs (Phylum Mollusca)

The molluscs constitute a large phylum of invertebrates known as the Mollusca. This phylum has the second largest number of named species in the animal kingdom after the phylum Arthropoda. About 85,000 different species (50, 000 living species and some 35,000 fossil species) of molluscs are recognized (World Public Library, 2014). Their bodies are soft, consisting of a head, a muscular foot, a visceral hump containing the internal organs, and a mantle formed from the skin of the visceral hump and which secretes the shell. The edges of the mantle are extended to enclose the mantle cavity. (Agbeko, 2010, Klappenbach, 2012).

Molluscs comprise of about 23% marine organisms and represent the largest phylum in the ocean. A large number of molluscs also inhabit freshwater and terrestrial habitats. They are highly diverse with regards to their sizes, anatomical structure, and also in behaviour and in habitat (Das and Dev-Roy, 1981). The taxonomic divisions of the phylum typically results into 9 or 10 taxonomic classes, out of which two are entirely extinct (Das and Dev-Roy, 1981). The gastropods (snails and slugs) are by far the most abundant molluscs in terms of classified species accounting for nearly 80% of all molluscs (Agbeko, 2010).

The three most defining features of the modern molluscs are a mantle with a substantial cavity which aids breathing and excretion, a radula, and a nervous system (The Columbia Electronic Encyclopaedia, 2013). Molluscs feed with the aid of a rasping radula, and a complex digestive system. The generalized mollusc has two paired nerve cords, or three in bivalves. Molluscs serve as an important food source for humans globally (The Columbia Electronic Encyclopaedia, 2013).

2.3.1 The Class Lamellibranchia or Bivalvia

The Bivalvia comprise a class of marine and freshwater bivalves that possess laterally compressed bodies enclosed by a hinged shell comprising of two parts. They lack a defined head and radula. They have large and complicated gills which suspend in the mantle cavity. The two valves of the shell can be tightly closed by the action of the adductor muscles (The Columbia Electronic Encyclopaedia, 2013). The sexes are usually separate but various levels of hermaphroditism also exist (Agbeko, 2010)

Clams, oysters, cockles, mussels, scallops are typical examples of bivalves. There are numerous other bivalve families that live in salt and fresh water. They are predominantly filter feeders. The bivalve shell is composed mainly of calcium carbonate and consists of two, analogous parts called valves. These are joined together along the hinge line by a flexible ligament. This arrangement allows the shell to be opened and closed without the two halves becoming disjointed (The Columbia Electronic Encyclopaedia, 2013). Bivalve size vary over a wide range from fractions of a millimetre to over a metre in length, but the majority of species do not exceed 10 cm (4 inch) (Klappenbach, 2012).

The prevalent marine bivalve families are the Veneridae, with nearly 700 species and the Tellinidae and Lucinidae, each with over 500 species. The freshwater bivalves include seven families, the largest of which is the Unionidae, with about 700 species (World Public Library, 2014).

2.3.2 The order Tellinacea

The bronchial filaments of the gills of this order are united at regular intervals by vascular connections which turn the filamentous spaces into a series of fenestrate (Purchon, 1963).

The Tellinoidea are a taxonomic superfamily of saltwater clams.. The most significant structures of this superfamily are the very mobile separate siphons formed by fusion of the inner (muscular) lobes of the mantle edge, while the middle (sensory) lobe and the periostracal groove continue around the posterior margin of the shell bordering a deep siphonal space from the base of which the siphons arise (Yonge, 1949). The Tellinacea are a highly successful group of lamellibranchs which have evolved along characteristic lines with a success revealed by their vast abundance in suitable substrata within both the littoral and sublittoral zones (Yonge, 1949).

2.4 Biology and Growth of Bivalves

The most noticeable feature of bivalves is the two valves of the shell that in most cases are equal and may or may not completely enclose the inner soft tissues (Helm *et al*., 2004). Bivalve shells have a variety of shapes and colours depending on species and are mainly composed of calcium carbonate (Helm *et al.*, 2004). They usually have three layers; the inner or nacreous layer, the middle or prismatic layer that forms a large proportion of the shell, and the outer layer or periostacum, a brown leathery layer which is often missing through abrasion or weathering in older animals (Gosling, 2002). The umbo or hinge area, where the valves are joined together, is classified as the dorsal part of the animal. The region opposite the hinge is the ventral margin. In bivalve species such as clams there are obvious siphons and the foot is in the anterior-ventral position (Morton, 1960).

The soft parts inside the shells are covered by a mantle, which is composed of thin tissue sheaths which are thickened at the edges (Helm *et al.*, 2004). The thickened edges may or may not be pigmented and have three folds (Helm *et al.*, 2004). The mantle edge usually has tentacles which in clams are at the tips of the siphon (Shumway, 1991). In species such as scallops the mantle edge not only has tentacles but also several light sensitive organs which serve as eyes (Shumway, 1991). The main function of the mantle is to secrete the shell-forming compounds but it also has additional purposes (Gosling, 2002). It has a sensory function which facilitates the closure of the valves in response to unfavourable environmental conditions and controls inflow of water into the body chamber and, in addition, it has a respiratory function (Helm *et al.*, 2004).

In bivalves, sex can either be separate (dioecious) or hermaphroditic (monoecious) (Gosling, 2002). Gonads are often conspicuous and well-defined organs which occupy a major portion of the visceral mass (Yonge and Thompson, 1976). Gonads are generally only evident during spawning seasons and may in some cases form up to 50% of the body volume (Yonge and Thompson, 1976). Spawning periods in natural populations differ with species and geographical locations and may be triggered by environmental factors such as temperature, chemical and physical stimuli, water currents or a combination of these and other factors (Helm *et al.*, 2004). The presence of sperm in the water will frequently trigger spawning in other bivalves of the same species (Gosling, 2002). Cell division begins within minutes after fertilization and this is characterized by egg division into a two-celled stage (Gosling, 2002). The fertilized eggs which are denser than water sink to the bottom where cell division continues. The time taken for embryonic and larval development is species specific and temperature dependent (Helm *et al.*, 2004).

In terms of bivalve growth, only general statements can be made about growth in juveniles and adults since it varies greatly between species, geographic distribution. For example climate, location in the sub-tidal or intertidal zones, as well as differences in individuals and in their genetic make-up can significantly influence growth (Helm *et al.*, 2004). Growth can also fluctuate from one year to another and in temperate zones there are seasonal patterns in growth (Gosling, 2002). Growth can be measured in bivalves by different methods including increments in shell length or height, increases in total or soft body weight, or a combination of all of these factors. In tropical areas growth can also vary with season, although this variation is not as pronounced as in the temperate regions (Gosling, 2002). Bivalve growth in the tropics tend to be faster during or after rainy periods when nutrients are washed into the water in which they are found and lead to increased phytoplankton production (Kraeuter and Castagna, 2001; Gosling, 2002).

In temperate areas, growth is generally rapid during spring and summer when food is abundant and water temperatures are warmer. It virtually ceases in winter, resulting in annual checks in the shell. These winter checks can be used to age some bivalves (Gosling, 2002). In culture operations the important considerations in bivalve growth are length of time taken to grow to sexual maturity and to market size. The goal of bivalve culture is to grow bivalves to commercial size as quickly as possible to make the operation as economically attractive as possible (Helm *et al*., 2004).

2.5 Global Mollusc Production and Culture

The global mollusc production from aquaculture reached an all-time high volume of 15,171,000 mt in 2014, representing 23% of total aquaculture production and positioning molluscs as the second most important category of aquaculture products after finfishes (FAO, 2014). As with finfishes, China is the single largest producer of bivalves, accounting for almost 70% of the global bivalve culture. Clams and oysters are the mollusc species with the highest production levels, followed in descending order by mussels, scallops, and abalones (FAO, 2014).

The average growth in global bivalve production from the mid-90s to date is approximately 5% annually. This growth in annual output can be mainly attributed to the progressive increments in bivalve production in China (Globefish-FAO, 2013).

Aquaculture‟s contribution of bivalves to the overall bivalve production has also increased significantly from 72.8% in 1993 to almost 90% in 2014. The total output from wild harvest has on the other hand exhibited a downward trend and in fact its contribution declined from 21.5% to 10.7% (FAO, 2014). Although harvest of natural bivalve stocks will continue to contribute to total bivalve outputs, many wild stocks are already being collected at or beyond maximum sustainable limits making culture a sustainable alternative (Pawiro, 2010).

Bivalves are ideal animals for aquaculture: they are herbivores requiring no additional feeding apart from the natural algae content of the culture water and generally minimum husbandry. Although bivalve culture has been practiced for hundreds of years, advances in culture technology in recent years have led to the significantly higher annual productions (Helm et al., 2004).

A main requisite in any aquaculture operation is an abundant, consistent and inexpensive supply of juveniles or seeds. At present, most bivalve culture operations in the world obtain their seed by collecting from natural stocks. This is usually done by placing substrates in breeding areas to collect metamorphosing larvae. The collected seeds are transferred to growing areas for culture (growout) to market size (Helm et al., 2004). In other culture operations, juveniles or spats are gathered from areas where they are naturally abundant and transported to culture areas that may be distant from the source of the seed (Pawiro, 2010). The alternative to collection of seeds from natural bivalve populations is to produce them in hatcheries. Hatcheries have become an integral part of many bivalve culture operations and the major or sole source of seed. Hatcheries have several advantages over collection from natural populations. They are reliable and can supply bivalve aquaculturists with their seed requirements when it is convenient to them. They can supply seed that is not available to farmers from natural sets, for example, genetic strains that have improved biological traits for farming operations in local areas or a supply of exotic bivalve seed (Helm et al., 2004).

Although bivalve culture has gained prominence in Europe, Asia and South America, it is not a common practice in Africa. Commercial culture is practices extensively in South Africa with some culture activities taking place in North Africa and in some locations along the central West coast of the continent (Garrido-Handog, 1990; Olivier et al., 2013).

2.5.1 Bivalve Production in Africa

Bivalve culture in Africa is still in its developmental stages and remains almost completely unexplored (Olivier *et al*., 2013). It represents only 0.2% of the continent"s total aquaculture production (FAO, 2014). South Africa is the leading producer of bivalves in Africa (Olivier *et al*., 2013). The coastal town of Saldanha on South Africa"s West Coast has been identified as a prime site for mussel and oyster culture (Grant *et al*.

1998). The waters of the Saldanha Bay are part of the Benguela Large Marine Ecosystem. In summer, strong wind-driven coastal upwellings bring cold nutrient-rich water to the surface, providing a productive environment for phytoplankton growth as the water moves northwards (Olivier *et al*., 2013). Pulses of this rich water move into the Saldanha Bay every 6–10 days (Monteiro *et al.* 1998), creating a sheltered and well-circulated environment that is one of few suitable for oyster and mussel culture in Africa (Probyn *et al*. 2001). Saldanha Bay is among only four sites used for the culture of Pacific oysters (*Crassostrea gigas*) in South Africa. It is also the major site for the commercial production of the Mediterranean mussel (*Mytilus galloprovincialis*) (Britz *et al.* 2009).

2.6 The Volta Clam, (*Galatea paradoxa)* Fishery

The Lower Volta River (105km) is almost completely regulated by the Akosombo Dam with an average discharge of 1150 m^3/s. Further modifications have been imposed by the Kpong Reservoir, 25km downstream. Prior to the dams, saline water penetrated 30km upriver during the dry season, with a maximum penetration of 40km (Pople and Rogoyska, 1969). The boundary moved 20-25km seawards once the first turbines of the Akosombo Dam commenced operations and the salinity boundary stabilized 10-15km from the sea (Pople and Rogoyska, 1969). This boundary may have shifted further downstream when both the Akosombo and Kpong Dams reached full operational capacity (Davies and Walker, 1986)

Before the damming of the Volta River, the clam, *Galatea paradoxa,* supported an important local fishery from Sogakope (30km) to Akuse (85km) from the estuary. A significant aspect of the fishery was the collection of young clams at the beginning of the dry season (December- January), and their transportation upriver to “farms”, 60-80km from the mouth. Here, they were harvested at the end of the dry season (May-June) before the annual floods (Pople, 1966). This practice still persists, although, the breeding grounds are now restricted to areas nearer to the sea due to the shifting of the habitat with suitable salinity for breeding the clam (Davies and Walker, 1986).

This rather special fishery, the clam fishery has been operating on the lower Volta River for centuries and in present day yields between 4,000 -7,000 T/year (Purchon 1963; Pople, 1966; Moxon, 1969), although, a more recent report by Whyte (1981) (as reported in Brown, 2006) indicates a yield of up to 8000T/year. The clam which is locally referred to as „afane" and „adode" in Ewe and Twi respectfully is a highly priced delicacy especially among travellers who ply the Accra-Lome and Accra-Ho routes. It constitutes an important and affordable protein source to the riparian human communities of the rivers of its occurrence and those around the Volta are of no exception (Amador, 1997). The flesh of the clam is a good source of animal protein. Calculated on a dry matter basis, the average protein content of smoked clam fish is 46.5% (Kwei, 1965).

One interesting use to which the clam shells have been put in the South Volta is in the construction industry. Thus, the economic importance of the clam cannot be underestimated.

The reduction in seawater permeation into the river channel due to increased dam discharge (Pople and Rogoyska, 1969) negatively affected clam recruitment because of their requirement for brackish water during breeding. Petr (1974), however, observed that the clam population was not negatively affected by the construction of the Akosombo. He observed an increase in the clam habitats since some fishermen were transplanting spats further upstream. Clam harvesting from the natural habitat, however, became more difficult due to the increased and stabilized flow of the Volta. Access to the clam beds became even more difficult following heavy macrophyte growth which nearly wiped out the fishery (Nerquaye-Tetteh *et al*., 1984).

The culture of *Galatia paradoxa* in the lower Volta, which involved the transplanting of clams from areas along the Volta estuary where they breed, to family "owned" sites up the river for on-growing during the dry season is also a common practice which ensures the provision of clams for consumption and for sale during the closed season for clams which spans the entirety of the dry seasons, from December to March each year (Prein and Ofori, 1996, Brown 2006).

2.7 Habitat Description of the Freshwater Clams

Bivalves are among the most conspicuous members of the macro fauna of exposed sandy beaches (Brown and McLachlan, 1990). The clams lie buried in the coarse sand in clear water usually in shallow parts of a river, about waist deep (Purchon, 1963). Lawson (1963) also reported that clams inhabit shallow areas near the banks and in other shallow areas midstream. These are sedentary organisms moving not more than one metre from their position except during the annual floods when they may be washed downstream (Lawson, 1963). Unionids are bivalves that can crawl and change locations, and are capable of moving less than 10 feet per day. Most remain fairly stationary unless some habitat stress occurs (Crawford *et al.*2000).

These families of clams live in freshwater habitats ranging from small ditches and ponds, to lakes, canals, and rivers as opposed to saltwater, the main habitat type for bivalves. The Freshwater Clam obtains its nutrition from filtering food and detritus from the water column. The clams are usually buried in the sand with only their siphons protruding through the sand into the water (Lawson 1963; Purchon 1963. They orient themselves so that their head and foot are in the mud, and their rear end is up in the water column.

2.8 Geographical Distribution of *Galatea paradoxa* (Born 1778)

The freshwater bivalve mollusc, *Galatea paradoxa* (Born, 1778) is stenotopic, and is restricted in commercial quantities to some few large West African rivers namely: Volta River in Ghana, Nun and Cross Rivers in Nigeria, and Sanaga River in Cameroon (King and Udoidiong, 1991). It has a wide range of distribution which spans from the Gulf of Guinea to the Congo (Moses, 1990). There is inadequate information about this species, particularly about the prevalence and commercial exploitation despite its extensive distribution in the wider north-west African region (Moses, 1990). In Ghana, the clam bed is presently restricted to a very narrow stretch of the South Volta River, between Agave-Afedome (15 km from the Volta estuary) and Ada-Foah (10 km from the estuary) (Amador, 1997).

Before the construction of the Akosombo and the Kpong dams on the Volta River in the 1964 and 1981 respectively, seasonal overflows broke down the sandbars. Sandbars were mostly formed during the dry season so the seasonal overflows largely kept free of sandbars. However, after the construction of the dam and the subsequent absence of annual flood brought about the formation of sandbars at the estuary and with the passage of time virtually blocked it. The effect of this was the saline water which during high tides flowed upstream into the river channel completely ceased (UNEP, 2002).

The changes in the flow regime led to physico-chemical changes in the water and subsequently, created a shift in the habitat of *Galatea paradoxa* from the upper and midsection or the lower Volta towards the estuary with a decline in the abundance of the clam. By the late 1980s, the decline of the clams was becoming evident (UNEP, 2002). The dredging of the Volta estuary, initiated in 1990 and carried out in April 2009 by the Volta River Authority (VRA) was aimed at levelling an „island" built by heaps of sand at the estuary. The dredging process allowed the intrusion of some sea water into the river creating suitable conditions for the breeding of *Galatea paradoxa* hence the resurgence of the fishery some 4 to 10 km above the estuary. This increment in the clam industry does not however, match with what it used to be with regards to the fishing grounds size, the number of fishermen involved in the fishery (Amador, 1997). It is remarkable to note that the clam is endemic only to the lower reaches of the Volta. Throughout its geographic distribution, *Galatea paradoxa* supports a thriving artisanal clam fishery. Its exploitation in most African rivers is often not guided by any forms of management and conservation strategies which has resulted in over exploitation leading to a decline in abundance and sizes of the landed clams.

2.9 Management and Conservation of the clam Fishery

The most important management strategy used in the fishery is the closed-season which commences from 24th December to 11th March each year. This is to allow for spent populations to recover but not actually to prevent smaller sizes of the clams from being landed. The institution of the closed season was in response to the small size of clam meat during this period. Aside from the closed-season, Tuesdays are non-fishing days for all fishermen. The closed season is strictly adhered to and is maintained by traditional norms and rites. The reasons for the timing of the non-fishing day are based mainly on indigenous knowledge and traditional beliefs. It also allows the fishers to market their clams as

Tuesday is a market day. Although, the clam fishery is open access as no permit is required before entry, the chiefs of the Ada and Agave traditional areas have the responsibility to ensure compliance with the traditional laws and regulations. Apart from the traditionally imposed restrictions there are no restrictions on the quantity or the size of clam harvested. Another management strategy which has prevented the extinction of the species in the Volta River is the farming or fattening of juvenile or smaller clams. In order to supply the market with clams during the closed-season, clam fishers usually seed shallow areas of the river with small sized clams for periods ranging from 6 – 8 months. This enables the clams to double their size before being harvested for sale during the closed-season. Small sized clams are seeded to shallow zones of the river demarcated by sticks. The seeding of plots with clams and their harvesting is usually undertaken by women. Clams do not move more than a metre away from their seeded points and, therefore, remain within the plots of their owners (Adjei-Boateng *et al.,* 2012).

2.10 Economic Importance of the Volta Clam Fishery

Clams form a significant proportion of the global fisheries production. The global trend in the growth of human consumption of clams will undoubtedly continue. In 2000, landings of clams from capture fisheries and aquaculture operations on the Volta River totalled 14,204, 152 tonnes (Michael and Niel, 2004). During the decade from 1991 to 2000, there was a continuing increase in production of clams, and landings more than doubled from 6.3 million tonnes in 1991 to 14 million tonnes in 2000.

According to Adjei-Boateng *et al.* (2012) the gross total annual revenue generated per fisher ranged between GH¢ 18,880 and 37,760.The gross total annual revenue generated from the clam fishery ranges between GH¢ 4,720,000 and 9,440,000 or between US$

3,305,322 and 6,610,644 (Based on February, 2010 exchange rates)

2.11 Effects of Stocking Density on Bivalve Growth

The optimum stocking density or seeding rate is the number of clams that an area can optimally accommodate without compromising on growth and other density dependent factors. Identifying the optimum stocking density for a culture species is critical not only for designing an efficient culture system but for optimum husbandry practices (Leatherland and Cho, 1985). The number of clams that will be seeded on a plot matters a lot since they will compete for space, feed etc. Leatherland and Cho (1985) found that, increasing stocking density increased stress, and led to higher energy requirements, causing a reduction in growth rate and feed utilization. Also according to Kripa *et al.* (1999), shell length decreases with increasing stocking density and that larval growth is significantly influenced by stocking density. In an experiment conducted by Kripa *et al* (1999), where they sought to monitor the effect of stocking density on the growth of juvenile clams of stocking densities 500, 1000, 2000, and 3000, they found out after six months that, the clams attained an average length of 26.8 mm, 16.4 mm, 15.3 mm and 15.2 mm, respectively from an initial average length of 13.5 mm. Their findings further revealed that, the growth increment was high (13.3 mm) in stocking density 500 whiles in other stocking densities, the growth increment was negligible ranging from 1.5 mm to

2.9 mm in 6 months.

According to Raghavan *et al* 2008, larval development is considerably affected by stocking density with shell length decreasing with increasing stocking density. An extended planktonic stage was observed when larvae were stocked at densities > 5 larvae mL^{-1}. This trend appeared to be similar to those reported for the clam *Anadara granosa, M. opima*, bay scallop *Agopecten irradians* and *M. meretrix* (Duggan 1973; Narasimham, *et al.* (1988); Muthiah, *et al.* (1992); Wei & Xu (1996). Higher stocking densities negatively affect growth because with increasing stocking density, more metabolic wastes may be accumulated in the water and slow down growth. Survival of the larvae determined at days 6 and10 was not significantly affected by either diet or stocking density.

2.12 Minimum Landing Size (MLS)

Minimum landing size (MLS) therefore, is the smallest length at which it is legal to keep or sell a fish/clam. The minimum landing size varies around the world as there are legal definitions, which are defined by the legal regulatory authorities. This is done in other jurisdiction based on the scientific advice that protection will allow the population to reproduce at least once in their life time before they can be legally landed. The minimum landing size if introduced and enforced properly will be of enormous benefit to the stakeholders in the clam fishery, since according to (Adjei-Boateng *et al* 2012) extinction is imminent if management measures are not taken.

The benefit of the introduction of the minimum landing size when catalogued will include an increase in the quantity and size of the clams. It will also help to sustain the resource. More so, juvenile clams will be protected and there will be an increment in the recruitment to the spawning population stock. This will in turn increase the number and size of the clams available for capture for both commercial and domestic consumption. It will also help fill the gap in the protein needs of the nation and also revamp the economic activities of the women and the fisher folks in the area and hence its subsequent effects on the economy of the state.

The principal mechanism of preventing over exploitation of important stock is through the introduction and enforcement of minimum landing size. The methods used in preventing this over-exploitation actually differ from zone to zone due to differences in fishing practices and regional biology of the species involved.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out at Agorta Zewukope, latitude 05° 53 48.42" N and longitude 00° 39' 17.49" E and Agave Afedome, latitude 05°53 28.2" N and longitude, 00° 38' 24.7" E in the South Tongu District of the Volta Region (Figure 3: 1). The two sites are within the active clam fishing zones on the Volta River.

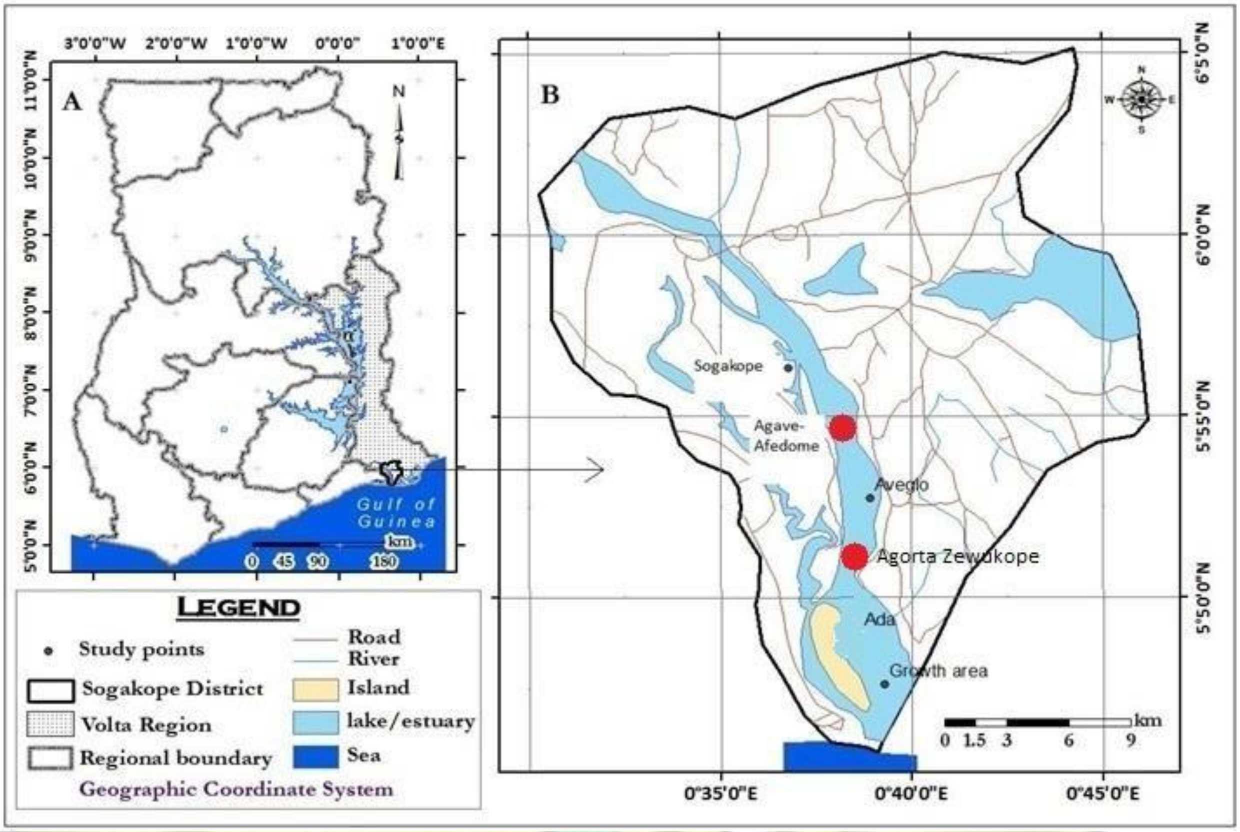

Figure 3. 1 Map of Ghana showing the study areas with the red dots in the South Tongu District of The Volta Region, Ghana.

3.2 Study Design

The growth trial was only carried out at Agorta Zewukope due to the inability to secure a plot at Agave Afedome for a similar growth study. The study was designed to generally model after the traditional clam seeding methods used at the study locations albeit with defined stocking densities.

3.2.1 Growth Experiment

This aspect of the research monitored the effects of seeding density on the growth of clams as practised at the Lower Volta. The site was set up by laying two rows of one metre quadrats with each row comprising five $1m^2$ quadrats. Each quadrat was marked with wooden poles at the edges and a rope tied around it. To make room for movement, the four sides of each quadrat was surrounded by one metre square of free space. Uniform-sized clams with initial average lengths and weights of approximately 40mm and 18g respectively were used. The weight (g) and shell length (mm) were measured with an electronic calliper (Powerfix Electronic Calliper) to the nearest 0.0l mm and weighing scale (Ohaus CL Series) to the nearest 0.1g. The selected clams were seeded at five different stocking densities (treatments): 50, 100, 150, 200 and 250 clams per m^2 in two rows in reversing order of stocking density as shown in Figure 3.1 with each treatment in duplicate.

	AG 1(50)		AG 2(100)		AG 3(150)		AG 4(200)		AG 5(250)	
	AG 5(250)		AG 4(200)		AG 3(150)		AG 2(100)		AG 1(50)	

Figure 3.1. The layout of plots for the clams seeding density experiments at Agorta Zewukope. **AG** =Agorta, and **1, 2,3,4,5** =plot numbers

To monitor growth, the seeded clams were sampled quarterly for growth in length and weight for a 12-month period. During sampling, 30 individuals were selected randomly from each plot; the length (mm) and weight (g) of each individual were taken using an electronic calliper and weighing scale and afterwards returned to their plots. Survival rates for each plot were determined at the end of the experiment by retrieving and counting the live clams and expressing the result as a percentage of the number of clams at the start of the experiment. Net yield was also calculated by multiplying the mean weight gained by the number of clams surviving at the end of the study period.

Sixty randomly selected individuals were sacrificed at the start of the growth trial for the initial dry and wet weights. For the dry weight measurements, samples were transported in an ice chest to the laboratory where the shells were opened and flesh oven dried at 60˚C for 48 hours. The empty shells were dried at room temperature for 24 hours after which the dry weights were taken.

3.2.2 Physiochemical Water Quality Characteristics

The following physiochemical parameters, conductivity, total dissolve solids, salinity, dissolved oxygen (late morning readings around 10 am), pH, and temperature were monitored at the study sites with a Hanna (HI 9828) multi-parameter probe. Water quality variables were measured quarterly from June 2013 to June 2014 at the time of sampling.

3.3 Data Collection for the Sustainable Management of the Clam Fishery

Key informant interviews as well as focus group discussions were held with the chiefs, elders and some other stakeholders of the two study locations as well as with two groups comprising of 10 randomly selected clam fishers at Agorta Zewukope and 11 at Agave Afedome on how the clam fishery could be sustainably managed. This was done firstly by meeting with the chiefs and elders as a group and discussing the possible ways of managing the fishery after which individual clam fishers were interviewed.

3.3.1 Brainstorming sessions

Separate brainstorming sessions were held with different stakeholders (assemblymen, chief fisherman and sub chiefs) on the sustainable ways of managing the clam resources. One aspect of the discussion was on their role in the enforcement of any management plan that will be introduced by the traditional authorities. Key informant discussions were also held with the chief fishermen and community elders of the two study locations to seek first-hand information on how to formulate an enforcement mechanism for the minimum landing size with the help of the traditional authorities.

3.3.2 Questionnaire Administration

Questionnaires (Appendix 2) were also administered to clam fishers at both Agave Afedome and Agorta Zewukope to ascertain how the various stakeholders will like to manage the fishery and how existing laws can be enforced. In all, 30 questionnaires were administered at each study location to clam fishers. The following issues were discussed during the questionnaire administration; how long individuals have been working as clam fishers , what the landings were in the past and how they are now, the difficulties currently confronting the fishery , the size of the clams preferred in the market, their suggestions on the restrictions of sizes to be landed, whether they have seeding plots, the benefits derived from the seeding plots, the challenges encountered using the plots, process of acquiring a seeding plot and modalities for improving the fishery.

3.3 Data Analysis

Data from the growth experiment were analysed using SigmaPlot ver. 12.0 (Systat Software, Inc). The graphs from the survey data were drawn with Microsoft Excel (Microsoft Office Suite 2010). Data were subjected to one-way analysis of variance (ANOVA) to test for differences in the growth variables (weight gain, specific growth rates and length gain) of the different treatments. The Tukey multiple comparison posttest was used to further test for specific differences among the treatment means. In all cases differences were considered significant at $p<0.05$.

The length and weight data collected were also used to evaluate the relationship between shell length and total weight of the *Galatea paradoxa* within each treatment using the non-linear regression equation $W = a * L^b$.

Where:

W = Total wet weight (meat + shell)

L = Total shell length
a = Regression constant (intercept) b = Regression coefficient (slope) which is

also an indicator of growth pattern

In order to confirm whether *b* values obtained in the linear regressions were significantly different from the isometric growth pattern value (b=3), the Student"s *t*-tests were used. This allowed for the determination of whether the growth patterns exhibited by the clams grown under the different stocking densities were isometric (b = 3) or within the allometric ranges (negative allometric: $b<3$ or positive allometric: $b>3$). In all cases a statistical significance was considered at $p<0.05$.

The Condition factor (K) which was calculated to give the general health or well-being of the clams in each plot using the formula:

$K = W/L^3$

Where W = Total body weight, L = shell length

One-way analysis of variance was used to compare differences among treatments and the Tukey"s multiple comparison post-test was further employed in cases where variations in the treatment means were significant ($p<0.05$).

CHAPTER 4

RESULTS

4.1 Water Quality Characteristics of the Study Site

The pH for the study area ranged from 6.41 to 7.55 during the trial. Temperature over the 12-month period varied within a narrow range of 27.7°C and 30.0°C. Dissolved oxygen (DO) levels ranged from 3.99 mg/l to 5.21 mg/l. Salinity levels were constant at 0.02 PSU throughout the study period. Total dissolved solids (TDS) were fairly constant ranging from 25 to 32 mg/l over the study period. Conductivity values ranged between 49 to 61µs/cm. The trends in the recorded physicochemical variables at the clam growth site at Agorta taken during the four sampling times are shown in Figure in 4.1.

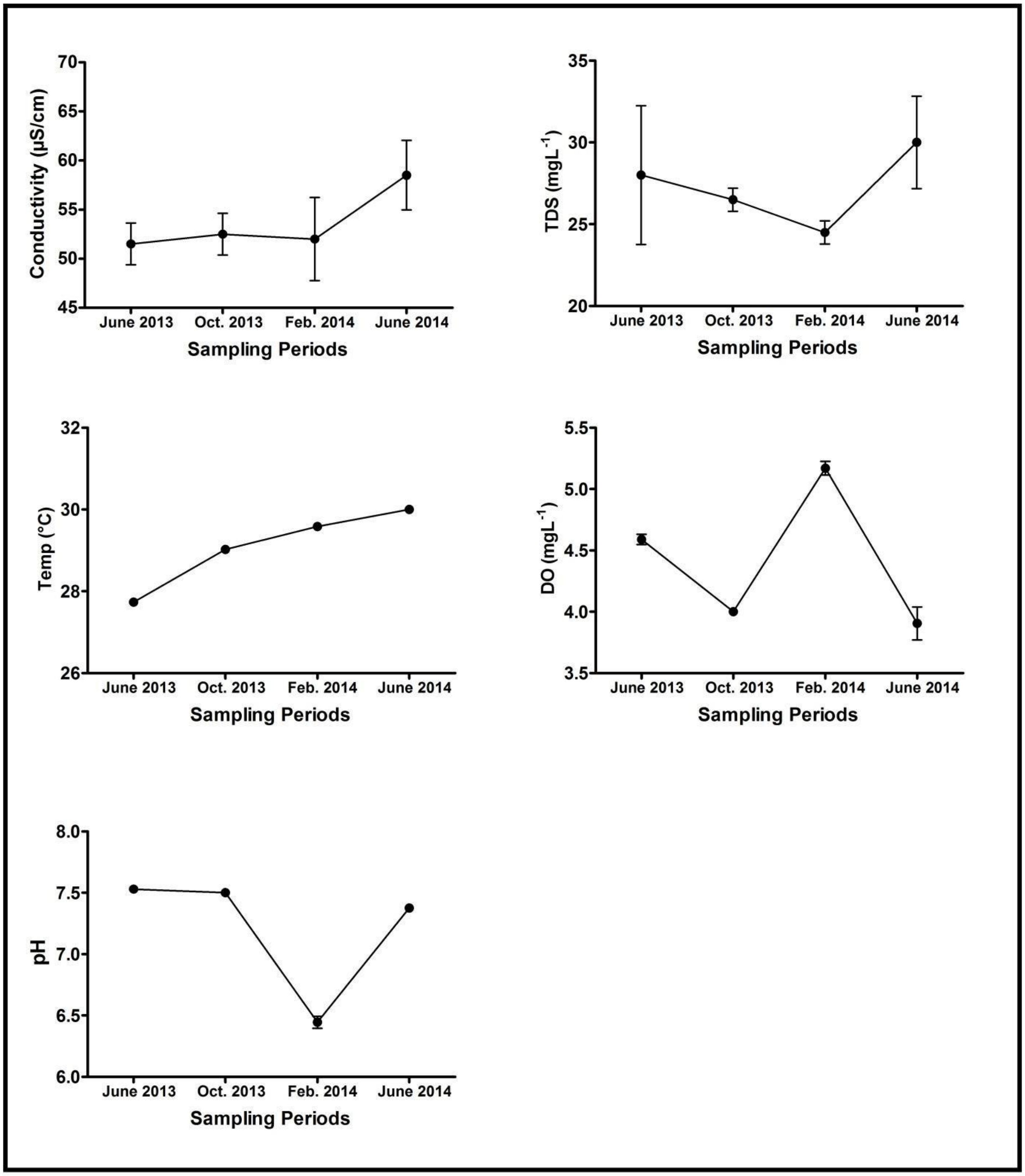

Figure 4. 1: Water quality variables: conductivity, total dissolved solids, temperature, dissolved oxygen and pH monitored at Agorta from June 2013 to June 2014.

4.2 Effect of Stocking Density on Growth

The seeded clams were carefully selected to ensure that the initial lengths and weights were similar (Table 4.1). At the end of the trial the stocking densities had significant effects ($p<0.0001$) on clam growth based on both length and weight. Growth progressively declined with increasing stocking densities (50 to 250) as shown in Table 4.1. At the termination of the experiment, the total weight of the clams stocked at 50 individuals m^{-2} was 60.8±14.2 g compared to 39.4±13.4 g those stocked at 250 individuals m^{-2}. Shell length and flesh wet weight increments over the trial period were inversely related to stocking density. The meat yield in the different stocking densities expressed per their respective final weights were, however, not significantly different ($p>0.05$) and ranged between 14.6±3.1 to 15.8±3.5 % for all the stocking densities (Table 4.1). Clams stocked at higher densities had a reduced growth in shell length and weight compared to those stocked at 50 individuals m^{-2}.

Table 4. 1: Growth performance of clams stocked at 50, 100, 150, 250 and 250 individuals/m^2 at Agorta Zewukope from June 2013 to June 2014

	50/m^2	100/m^2	150/m^2	200/m^2	250/m^2
ITW (g)	18.5±3.1	18.5±3.1	18.5±3.1	18.5±3.1	18.5±3.14
FTW (g)	60.8±14.2^{a}	52.7±11.4^{b}	50.3±11.6^{b}	42.9±10.9^{c}	39.4±13.4^{c}
WG (%)	225.6±1.5^{a}	184.6±2.0^{b}	171.6±2.1^{b}	131.2±2.4^{c}	112.6±3.0^{d}
ISL (mm)	39.3±2.6	39.3±2.6	39.3±2.6	39.3±2.6	39.3±2.6
FSL (mm)	62.4±5.2^{a}	59.9±5.6^{ab}	57.6±5.1^{b}	54.0±4.8^{c}	51.6±6.3^{c}
LG (%)	58.9±1.0^{a}	52.3±1.0^{b}	46.3±2.1^{c}	37.3±1.3^{d}	31.2±1.3^{e}
IFW (g)	3.0 ±0.8	3.0±0.8	3.0±0.8	3.0±0.8	3.0±0.8
FFW (g)	7.3±2.9^{a}	7.2±2.4^{a}	5.1±1.3^{b}	4.6±1.0^{b}	4.8±1.4^{b}
ISW(g)	14.7±2.5	14.7±2.5	14.7±2.5	14.7±2.5	14.7±2.5
FSW (g)	41.8±11.1^{a}	35.1±8.1^{b}	32.3±7.6^{c}	26.8±5.1^{d}	26.0±5.7^{d}
SGR (% day^{-1})	0.3±0.0^{a}	0.3±0.0^{a}	0.3±0.0^{a}	0.2±0.0^{b}	0.2±0.0^{b}
Survival (%)	94	95	100	98	92
Meat Yield (%)	14.8±3.5	15.8±3.5	14.6±3.1	14.8±2.8	15.4±3.2
SCI (%)	83.6±4.3	81.7±10.1	82.9±5.2	84.0±5.5	82.9±3.6

Meat Yield = (Wet Meat Weight/Total Weight)*100
Shell Component Index = (Shell Weight/Total Weight)*100
Weight Gain (%) = 100*(Final weight-Initial weight) /Initial weight
Length Gain (%) = 100*(Final Length-Initial length) /Initial Length
Specific Growth Rate (SGR) = 100* In (Final weight-Initial Weight) /Number of experimental days

ITW= Initial Total Weight
FTW= Final Total Weight
WG= Weight Gain
ISL= Initial Shell Length
FSL= Final Shell Length
LG= Length Gain
IFW= Initial Flesh Weight
FFW= Final Flesh Weight
ISW= Initial Shell Weight
FSW= Final Shell weight
SCI= Shell Component Index

Graphs of the shell length and total weight increments over the trial period indicated different growth patterns as far as the two parameters are concerned (Figure 4.2). Shell length increments were in a near-sigmoid fashion for clams under the different stocking density regimes. Growth patterns with respect to total weight showed marked increments from the first sampling period to the second one. Weight increments appeared to level-off after the second sampling period with only slight increments up to the end of the trial.

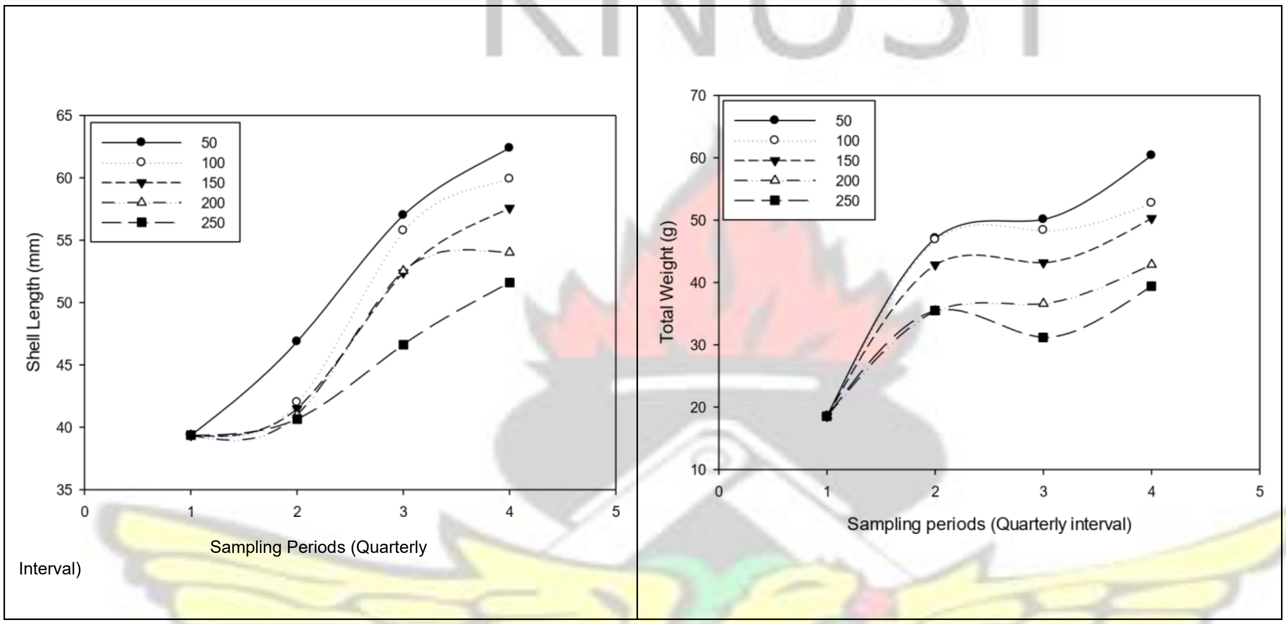

Figure 4. 2: Clam shell length and total weight increments from June 2013 to June 2014 at Agorta Zewukope.

4.3 Effects of Stocking Density on Growth Patterns

Negative allometric growth patterns were exhibited by all the clams grown under the different stocking densities. The calculated r^2 values of the length-weight relationships (Table 4.2) indicated a not-too-strong fit between the lengths and weights of the clams under the different stocking density regimes over the trial period. The student"s *t*-test indicated that all the calculated *b* values for the various stocking densities were significantly lower ($p<0.05$) than 3.

In the 50 individuals/m^2 stocking density, 67% of the sampled clams had final shell lengths above 50 mm. The calculated r^2 value for this stocking density was 0.65. The clam population for this stocking density exhibited a negative allometric growth pattern (b = 1.73) indicating slower increments in total weight relative to increments in shell lengths. Condition factor for this stocking density was 0.032. Figure 1.1 in appendix 1 shows the length-weight relationship of the sampled clams over the trial period.

An estimated 57% of the individuals stocked at 100 m^{-2} reached shell lengths exceeding 50 mm. The r^2 value (0.50) from the regression analysis indicated a weak fit between clam shell length and total body weight (Table 4.2). This was reflected in the negative allometric growth pattern exhibited by this stocking density group. The b value of 1.43 indicated a growth pattern that deviated strongly from an isometric growth. The condition factor for this group was calculated to be 0.028. The length-weight relationship of the sampled clams over the trial period is shown in Figure 1.2 in appendix 1.

Forty-five percent of the clams stocked at 150 individuals m^{-2} attained shell lengths >50 mm. Similar to the trend observed in the 50 and 100 stocking densities, the r^2 value (0.51) from the regression analysis indicated a weak fit between the increments in shell length and total body weight. The faster increases in the shell lengths of the stocked individuals relative to body weight gains resulted in an overall negative allometric growth pattern (b = 1.47) similar to what was observed in the other lower stocking density groups. The condition factor for this group was calculated to be 0.030. Figure 1.3 in appendix 1 depicts the length-weight relationship of the 150 clams.m^{-2} stocking density.

Following the trend of a progressive decrease in the proportion of individuals that attained shell lengths >50 mm, the stocking density of 200 individuals m^{-2} had 42% of clams with final shell lengths exceeding 50 mm. The calculated r^2 value (0.44) from the regression analysis indicated a weak fit between the increments in shell length and total body weight of the individuals in this group. Increments in shell lengths of the stocked individuals were faster relative to body weight gains and resulted in an overall negative allometric growth pattern (b = 1.33) similar to what was observed in the other lower stocking density groups. The condition factor of the clams in this stocking density was calculated to be 0.026. The length-weight relationship of the sampled clams in this stocking density over the trial period is shown in Figure 1.4 in appendix 1.

The 250-individual stocking density recorded the least proportion of individuals that attained shell lengths >50 mm; 27%. The calculated r^2 value (0.32) from the regression analysis also indicated the weakest fit between the increments in shell length and total body weight of the individuals in this group. Similar to all the other stocking densities, increments in shell lengths were faster relative to body weight gains and resulted in an overall negative allometric growth pattern (b = 1.47). The condition factor of the clams at this stocking density was 0.029. The length-weight relationship of the sampled clams in this stocking density over the trial period is shown in Figure 1.5 in appendix 1. Table 4.2 summarises the calculated conditions factors, growth patterns and r^2 values resulting from the regression analyses for the different stocking densities.

Table 4.2: Conditions factors, growth patterns and r^2 values of the clams stocked at 50, 100, 150, 200, 250 individuals/m^2 at Agorta Zewukope, Lower Volta

Stocking Density / Parameter	$50/m^2$	$100/m^2$	$150/m^2$	$200/m^2$	$250/m^2$
Condition factor (K)	0.032	0.028	0.030	0.026	0.029
Growth pattern (b)	1.73	1.43	1.47	1.34	1.33
r_2	0.65	0.50	0.51	0.44	0.32
% of population with shell lengths >50cm	67	57	45	42	27

4.4 State and Management of the Volta Clam Fishery

This section summarises the current state of the clam fishery and the management practices in place to protect the clam resource from overexploitation. It also assessed the willingness of the major stakeholders in the fishery to adhere to a possible introduction of a minimum landing size to regulate the fishery.

4.4.1 Demographics of the fisherfolks at the two sampling areas

There were 60 respondents, 30 each from the two clam fishing communities used in this study. The age distribution of the respondents showed that most of the clam fishers were within 18-44 years as shown in Figure 4.3.

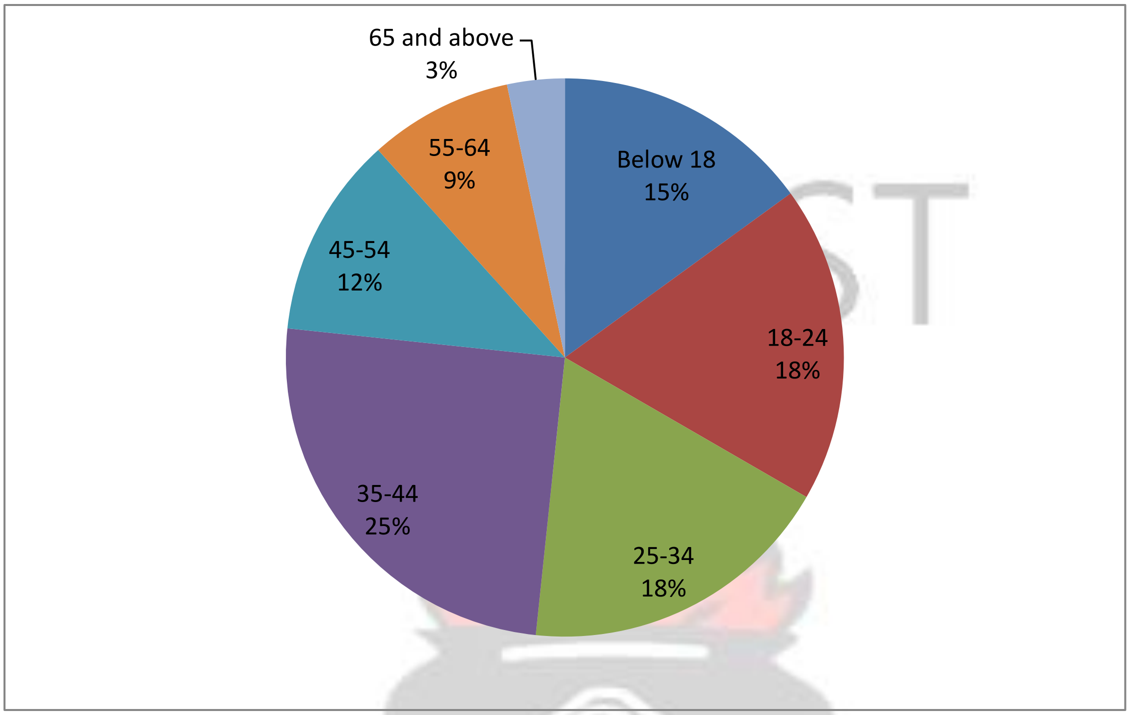

Figure 4. 3: Age (years) distribution of 60 clam fishers from Agave Afedome and Agorta Zewukope.

Figure 4.4 shows the breakdown of the number of years the respondents have worked in the clam fishery at Agave Afedome and Agorta Zewukope. A greater number of the respondents; 44 out of the 60 respondents (73%) have worked in the fishery for at least five (5) years whilst the remaining 16 respondents (27%) have worked for less than five years in the clam fishery.

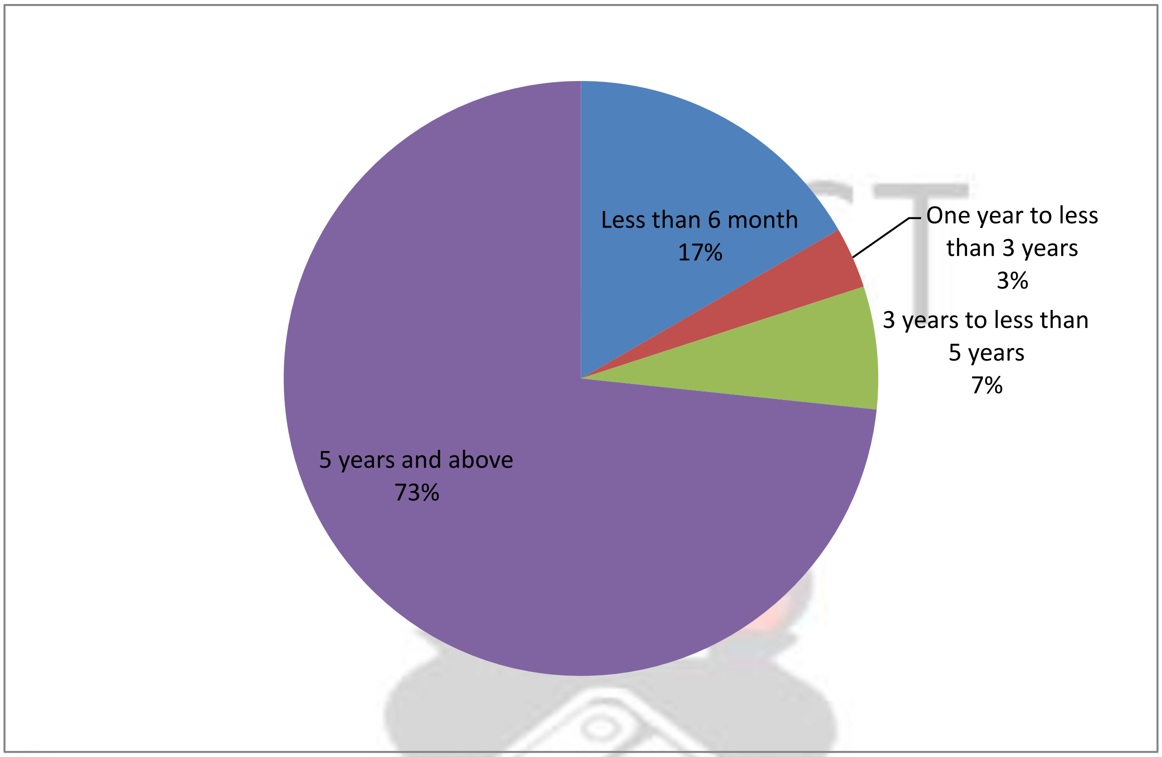

Figure 4. 4: Breakdown of the number of years the 60 fisherfolks have worked in the clam fishery at Agave Afedome and Agorta Zewukope.

4.4.2 Clam Fishery at Agave Afedome and Agorta Zewukope

This study counted the total number of clam fishers counted at Agave Afedome and Agorta Zewukope to be 35 and 45 respectively who reported an average daily clam harvest of 400 kg per fisher.

Despite the financial and nutritional benefits the fisherfolks derive from the clam fishery, there are concerns about the state of the clam fishery in the two communities. Their responses to the questionnaire, generally pointed to a trend of decreasing clam sizes over the years. Aside the dwindling sizes, they also encountered the following problems that are affecting the clam fishery: boundary demarcation of the fishing areas bringing about conflicts between the Adas and Tongus, harvesting of smaller sizes due to improved fishing methods and techniques, invasion of weeds in the river, injuries to the fisherfolks from the shell of the clams during harvesting and sometimes fatalities during diving.

Although, there was a general consensus on the reductions in the clam sizes, 66.7% of the respondents were satisfied with their present catches whilst the remaining 33.3% which mostly comprised of the older fishermen were not satisfied stating their past harvests as reasons for their dissatisfaction with current sizes harvested.

Larger clams are preferred at the various clam sales points. About 78% of the respondents indicated that buyers preferred larger sizes (>50mm) whilst 21.7% said the medium sizes (41-50mm) were most preferred. The smaller-sized clams (25mm-40mm) were not preferred because they are difficult to work with; particularly skewering and frying for sale and are mainly bought during the periods of clam scarcity or during the close season. Larger clam shells were also preferred on the shell market.

4.4.3 Management Strategies for the Clam Fishery

From the survey, it was realized that fishers seed smaller clams (<40mm) onto privately own plots for on-growing for up to a year. This is done mainly based on indigenous knowledge and past experiences; the clams are poured unto shallow, demarcated portions of the riverbed usually without taking into consideration stocking density and spacing.

A closed season is another management measure that is practiced at these two sites. As to whether the practices initiated are addressing the problems encountered in the sector, 78.3% asserted that the practices were not addressing the problems, 8.3% said the initiatives are addressing the problems but not in its entirety, whilst 13.4% asserted that the initiatives are addressing the problems. All the 60 respondents, however, believed that seeding the juvenile clams and proper demarcation of seeding and fishing plots will resolve the problem. On answering the about what can be done to reduce the landing of small clams, 15 out of the 50 interviewed fishers, representing 25% were of the view that there should be sensitization programmes to educate the fisherfolks on the need to harvest only larger clams. The other 45 people representing 75% were of the view that there should be an introduction of a size limit (minimum landing size) for landed and marketed clams and this regulation should be enforced by the traditional authorities and the district assemblies.

The main suggestions on how to improve the clam fishery were to seed more plots to reduce the pressure on the natural stock, to increase the mesh size of the collection nets to prevent the landing of the smaller sizes and that even if the smaller sizes are landed, they should be seeded onto plots. The respondents also advocated that the seeding of the juvenile clams should be scientifically done to achieve optimum growth. On how to sustainably manage the resources without affecting the income of the fisherfolks, they advised that the size limit should not be too high because the harvest currently landed does not have enough larger sizes and that a size limit within the range of 45-50mm in length should be considered since raising the size limit will affect their income.

The respondents also called for a standardization of collection nets with mesh sizes large enough to allow clams below the MLS to fall through back to the river bed. All the the opinion leaders pledged their support to enforce the law. They also promised to be a source of control for each other to ensure they sustain the fishery.

CHAPTER 5

DISCUSSION

5.1 Effects of Stocking Density on Clam Growth Patterns

This study showed that growth with respect to length and weight decreased with increasing stocking densities. The observed trend could well have been due to competition for space and food resources within the seeding plots. The calculated condition factors under the different stocking density regimes point to food and space availability dictating clam growth. Bivalves grown at high densities usually have relatively lower condition index (flesh dry mass/shell mass ratio) than those kept at low density (Alunno-Bruscia *et al.* 2001). Bivalves apparently respond to greater food competition or to high density by reducing or ceasing absolute tissue growth, but not absolute shell mass growth (Alunno-Bruscia *et al.* 2001). The observed reductions in growth with increasing stocking density is comparable to the findings of Liu *et al.,* (2006) who reported reductions in the growth of the clam, *Meretrix meretrix* with increasing stocking density in China. Other laboratory and field investigations (Hurley and Walker, 1996; Taylor *et al*., 1997a, 1997b) also reported negative effects of increasing bivalve density on growth in the Atlantic surf clam, *Spisula solidissima* and the silver-lip pearl oysters, *Pinctada maxima,* respectively. The explanations given for the reduced bivalve growth at high densities in the studies above were increased intraspecific competition for food and space, which is possibly what happened in the current study.

Although one of the objectives of the study was to identify the optimum stocking density that promotes optimum growth under culture conditions, all the growth patterns recorded under the different stocking densities were negative allometric. A study by Obirikorang *et al.* (2013a) on the length-weight relationship of *G. paradoxa* over a 24-month period indicated that the species exhibit an isometric growth pattern in their natural habitat. The growth patterns exhibited by the clams grown under the different stocking densities in this study were well out of the range of 2.4 and 4.5 reported for bivalve species in their natural habitat (Park and Oh, 2002; Rameesha and Thippeswamy, 2009).

In allometric length-weight relationship or the establishment of growth patterns, the most important component is the equilibrium constant b, whose variations from isometric value of 3 possibly suggests deviations in physiological or environmental conditions. The negative allometric growth pattern exhibited by all the stocking densities in this study possibly indicates that freshwater clams are more sparsely distributed in their natural environments than the lowest stocking density of 50 individuals m^{-2}.

Water depth has been noted as one of the important factors that affect bivalve growth (Claxton *et al*. 1998; Lajtner *et al*. 2004). The study site had a gentle slope however, a comparative analysis of the growth rates of the different stocking densities using a correlation analysis showed that the estimated depths of the seeding plots had no effect on clam growth. This suggests that the difference in plot depths were not large enough to induce any significant changes in growth rates.

Food is an important limiting factor on growth rate when bivalves are stocked at high densities (Liu *et al*., 2006). Food availability is an important factor that can influence tissue growth, storage and utilization, and can alter the ratio of body mass to shell length (Frechette and Lefauvre, 1990; Nakaoka, 1992; Alunno-Bruscia et al. 2001). Bivalves apparently respond to increased food competition at densities higher than optimum by reducing or in extreme cases ceasing absolute tissue growth, but not absolute shell mass growth (Alunno-Bruscia et al. 2001) which possibly explains negative allometric growth patterns (shell lengths increasing faster than soft tissue growth) observed in this study.

Another possible reason for the negative allometric growth patterns recorded under the different density regimes is the fact that materials for production of bivalve shell and soft tissue originate partly from different sources. Changes in soft tissue mass are typically driven by seasonal variation in food availability (Page & Hubbard 1987; Alunno-Bruscia *et al.* 2000), mechanisms of energy storage and utilization (Peterson & Fegley 1986), and the reproductive cycle (Páez-Osuna *et al*., 1995). On the other hand, the shell is formed largely by deposition of ions, mostly calcium from the water column (Wilbur & Saleuddin 1983). Thus, shell growth may be only partially dependent on metabolic carbon (Tanaka *et al.* 1986), and may be less susceptible to variability in food availability than tissue growth.

Despite the low growth rates, growth trends over the one year period were similar among all the treatment groups. The similar growth trend in all the stocking densities appeared to be in response to the reproductive cycle of the clams. The build-up of proteins and carbohydrates prior to spawning is known to significantly increase the total weight of bivalves (Latouche and Mix, 1982 and Páez-Osuna *et al*., 1995) as ripe gonads may account for up to 41% of total flesh weight (Galstoff, 1964; Etim *et al*., 1991). This biological process leads to an increase in the tissue weight of the clam and consequently an increase in total weight relative to shell length. Studies by Etim *et al*. (1991) in the Cross River in Nigeria and Adjei-Boateng *et al*. (2010) at the Volta estuary in Ghana showed that spawning in *G. paradoxa* starts in June, which coincided with the first sampling period of the study and is completed between October and November which also coincided with the second sampling period. The observed sharp increments (153.5% (50 individuals/m^2), 152.9% (100 individuals/m^2), 131.2% (150 individuals/m^2), 90.9% (200 individuals/m^2) and 91.37% (250 individuals/m^2)) in the total weights of the clams between the first sampling period (June) and the second period (October) could be linked to the build-up of gonad tissues of the clams during the spawning period. The slower rates of growth in all the stocking densities after the second sampling period in October are possibly indicative of the loss in tissue weight that occurs as a result of spent gonads after the spawning process. The inverse relationship found between increasing stocking density and growth is comparable to the findings of Parsons and Dadswell (1992) who studied the effects of stocking density on the growth, production and survival of the giant scallop, *Placopecten magellanicus.* The initial mean shell length in their study was 12.7 mm. The bivalves were stocked at 15, 30, 45, 60, 75 and 90 individuals per conical-shaped pearl nets with 37 cm diameters. Final mean shell lengths after 1year in the pearl nets, varied from 53.1 to 43.4 mm for lowest stocking density (15 individuals per net) and highest stocking density (90 individuals per net) respectively.

Although, there were differences in survival rate between treatments at the different rearing densities, there was no distinct relationship between mortality rates and stocking density, which is consistent with other studies on bivalves stocked at different densities and monitored for growth (Holliday *et al*., 1993; Cote *et al*., 1993; Mgaya and Mercer, 1995; Hurley and Walker, 1996; Ibarra *et al*., 1997; Taylor *et al*., 1997a,b).

The recorded physicochemical parameters at the growth sites are comparable to the levels recorded at the natural habitats of the clams by Obirikorang *et al*., (2013b). This indicates that as far as physicochemical variables are concerned, the clams were seeded in plots with similar conditions to their natural environment thus physicochemical variables might not have played a significant role in the observed growth rates.

Even though the 50 individuals/m^2 stocking density recorded the highest proportion of individuals (67%) attaining shell lengths >50mm, this translates into 34 individuals compared to the 200 individuals/m^2 stocking density which had 84 individuals attaining shell lengths >50cm. Despite the 50 individuals/m^2 stocking density supporting the best growth performance parameters such as mean weight and shell length gains and condition factors, it will be financially more rewarding from an economic perspective to stock at 200 individuals/m^2 since majority of the respondents indicated that buyers preferred larger sizes (>50mm). The smaller individuals can be left on the seeding plots for further on-growing. Beyond the 200 individuals/m^2 stocking density, the proportion of individuals attaining shell lengths >50cm after one year was markedly reduced to 68 individuals.

5.2 Management of the Clam Fishery

This study confirmed Amador (1997) and Adjei-Boateng *et al*., (2012) that the clam resources were regulated through the institution of a closed season and taboo days. The institution of the closed season was in response to the concerns of fishers about the small meat size from harvested clams during that period. All communities from the Volta estuary around Ada Foah up to the lower Volta Bridge at Sogakope observe the closed season. This closed season lasts for about 77 days, beginning from 24th December, to 11th March, each year. Its onset is announced by the chief priest of the Agave traditional area (Agbeko, 2010). Another reason for the institution of the closed season around that time is the Dzawuwu festival of the people of Agave which falls within this period that requires the full participation of all fishermen and women including clam fishers (Agbeko, 2010).

The recent increases in clam yields at the lower Volta is mainly as a result of an increase in fishing effort and the introduction of air compressors which enables clam fishers to dive in deeper areas of the river and to stay underwater for longer periods searching for clams

(Adjei-Boateng *et al*., 2012). Their study also cited the landing of smaller clams in recent times as another reason for the higher annual yield. Previously, smaller clams (< 50 mm) were not landed and fishing was restricted to shallow areas with hand collection as the only method of fishing (Adjei-Boateng *et al*., 2012). In view of this the suggested minimum landing size by the fishers can reduce the pressure on the clam stock. According to Gibson (2012), however, an increase in minimum size is not sustainable as a sole management measure because it will not by itself stop overfishing. Catch limits per day may thus need to be reduced to bring harvesting rates into balance with resource productivity. The suggested minimum size limits of clams can thus be coupled with other management measures such as reductions in catch or in fishing effort to significantly impact the stock enhancement of Volta clam fishery.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The study showed that stocking density has a significant effect on the growth of the freshwater clam, *Galatea paradoxa.* Growth performance declined with increasing stocking densities. Shell length and flesh wet weight were also inversely related to stocking density. Despite the differences in growth recorded for the different stocking densities, negative allometric growth patterns were exhibited by all the clams grown under the different densities.

The results of the survey pointed to a trend of decreasing sizes of clams landed over the years. There was a consensus that the current regulations were not yielding the desired larger sized clams. The fishers and traditional authorities were largely in support of the introduction of a minimum clam landing size to protect the fishery from collapse. They support the seeding of clams in privately-owned plots as a means of relieving the pressure on the natural clam population.

6.2 Recommendations

Based on the findings of this study it is recommended that:

- The study should be repeated using densities lower than 50 individuals m^{-2}.
- Growth studies with varying factors such as water depth should be carried out to evaluate the effect of depth on clam growth.
- It is also recommended that minimum landing sizes should be instituted and monitored through the District Assemblies and the local authorities of the clam fishing area.
- The collection nets used in harvesting the clams should also be made of uniform, larger meshes >40mm that will allow collected clams below the minimum size to fall through to the river bed.

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APPENDICES

Appendix 1

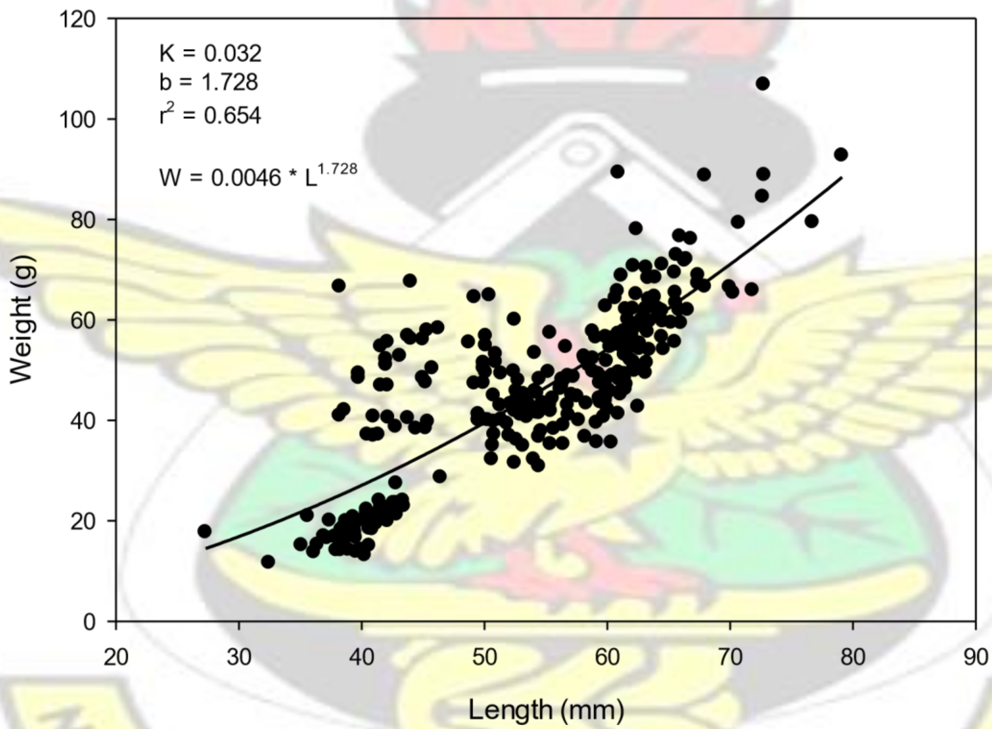

Figure 1.1: Length-weight relationship of the *G. paradoxa* grown under the 50 individuals/sq. m stocking density.

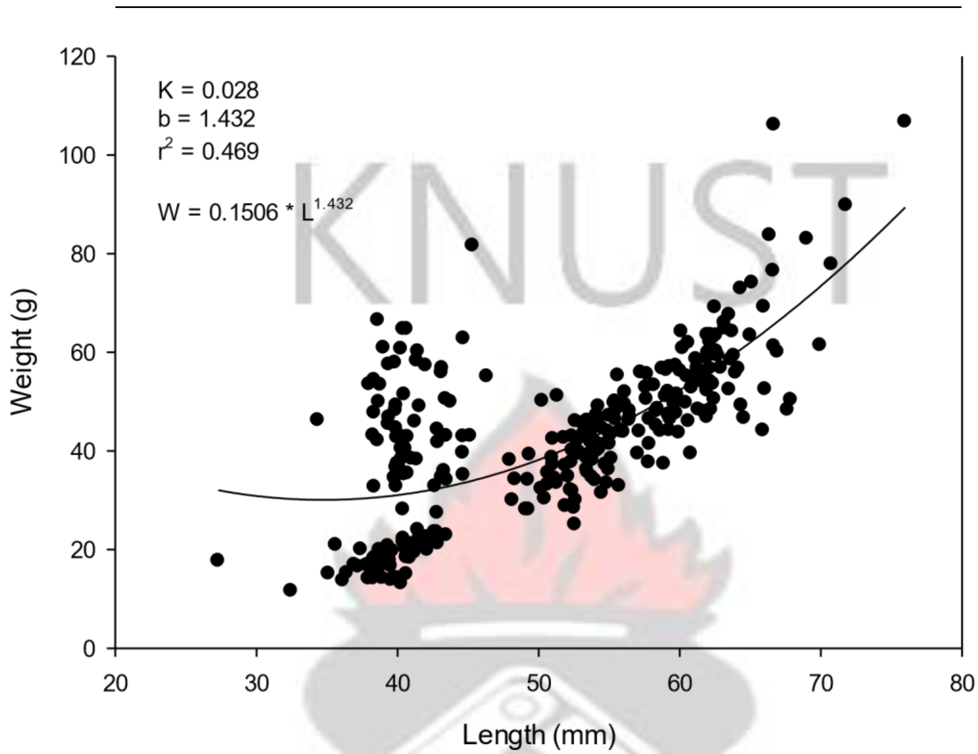

Figure 1.2: Length-weight relationship of the *G. paradoxa* grown under the 100 individuals/sq. m stocking density.

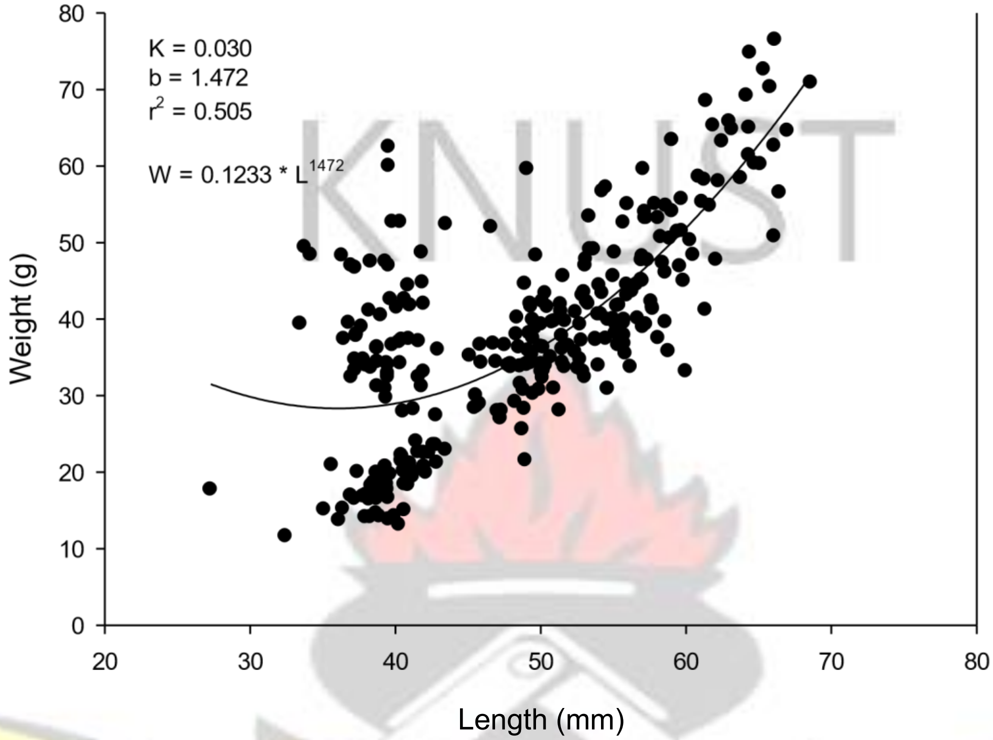

Figure 1.3: Length-weight relationship of the *G. paradoxa* grown under the 150 individuals/sq. m stocking density.

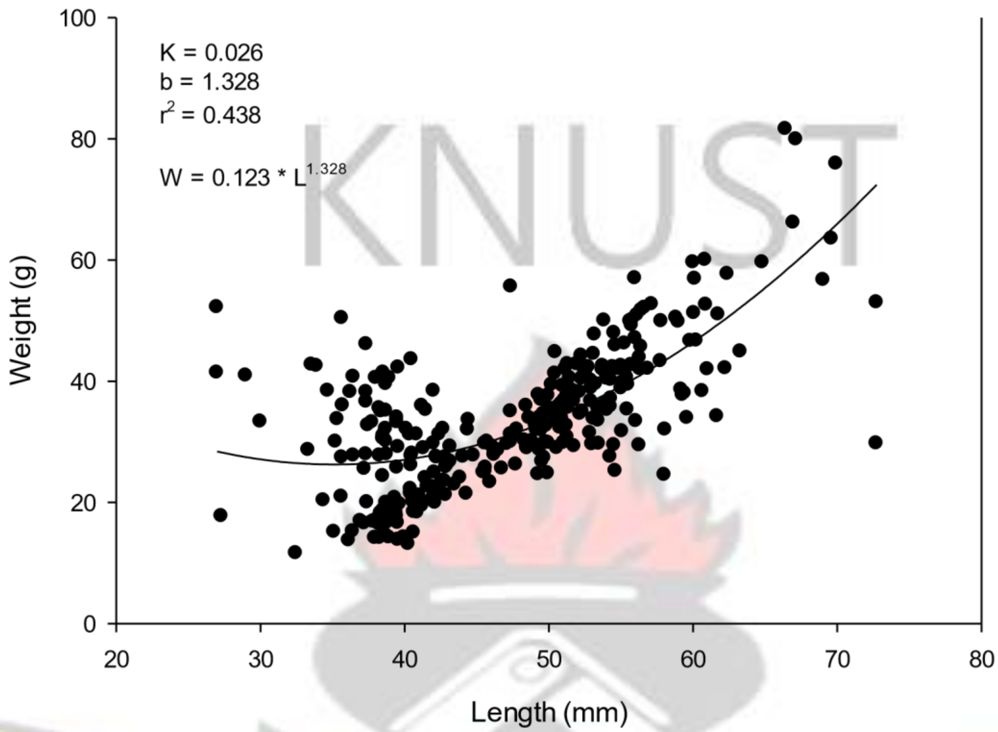

Figure 1.4: Length-weight relationship of the *G. paradoxa* grown under the 200 individuals/sq. m stocking density.

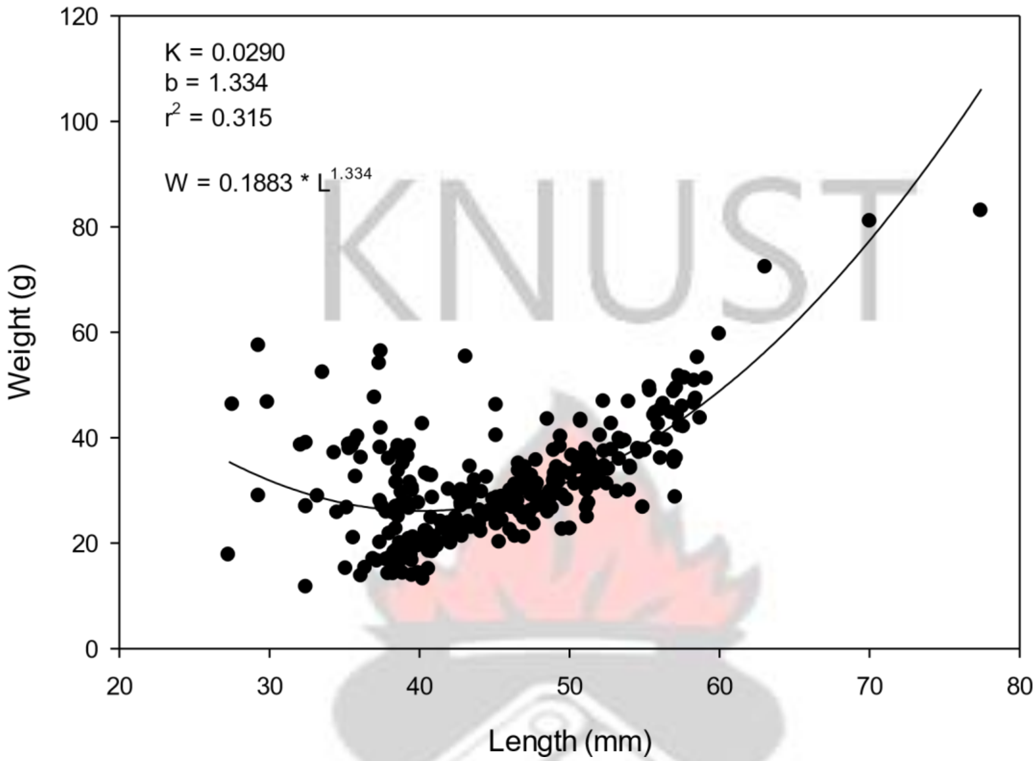

Figure 1.5: Length-weight relationship of the *G. paradoxa* grown under the 250 individuals//sq. m stocking density.

DEPARTMENT OF FISHERIES AND WATERSHEED MANAGEMENT

QUESTIONNAIRES FOR DATA COLLECTION

1. How old are you?

A) Below 18
B) 18-24
C) 25-34
D) 35- 44
E) 45-54
F) 55-64
G) 65 or above

2. How long have you being doing this job?

A) Less than 6 months

B) One year to less than 3 years C) 3 years to less than 5 years

D) 5 years or above

3. How have the harvest being like in terms of size since you started?

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4. What are some of the problems you encountered whiles working in the industry? …………………………………………………………………………………… …………

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5. What management procedures are in place currently?

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6. Are these management practices addressing the problems at hand?

A) Yes

B) No

7. If no, what do you suggest should be done to correct those problems?

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8. Are you satisfied with your harvests now in terms of the size and amount?

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9. What size of the clams is preferred in the market?

A) Large size

B) Medium size

C) Small size

10. In your opinion, what do you think can be done to reduce the small sizes being landed?

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11. Do you have a seeding plot?

A) Yes

B) NO

12. If yes what benefit do you derived from the seeding plots?

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13. State some of the challenges associated with the use of the seeding plots ………………………………………………………………………………………… …………

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14. Will any move to put a restriction on the size to be landed in order to increase stock for future use be accepted by you?

A) Yes

(reason)…………………………………………………………………………………
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B) No

(reason)…………………………………………………………………………………
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15. Any other suggestion to improve upon the clam fishery?

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