UNIVERSITY OF CAPE COAST

A STUDY OF SEA URCHIN POPULATIONS ALONG THE ROCKY COAST OF GHANA WITH A NOTE ON ITS FISHERY

BY

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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.

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Name: JULIET AFRAH OBENG

Supervisor's Declaration

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

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

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ABSTRACT

The research seeks to fundamentally outline the occurrence and diversity of sea urchin species along the coastline of Ghana. This work evaluates the growth parameters and some aspect of the sea urchin fishery in Ghana. Samples of sea urchins were taken from November 2020 to April 2021 at ten locations along the coast of Ghana; Tema, Nungua, La, Teshie, Nyanyano, Mumford, Cape Coast, Iture, Dixcove, and Axim. *Arbacia lixula, Eucidaris tribuloides* and *Echinometra lucunter* and an unidentified species were found during the sampling period. *Arbacia lixula* population dominated in the samples collected along the entire coastline of Ghana. Nyanyano had all sea urchin species in its waters. The size ranges of each species were *Arbacia lixula* (5.8 mm to 85.8 mm), *Eucidaris tribuloides* (24.7 mm to 47.7 mm), *Echinometra lucunter* (47.9 mm to 58.3 mm), and Unidentified sp. (20.2 mm to 27.7 mm) respectively. The diameter-weight and height relationships of the urchin species were defined by a significant positive linear relationship. *Arbacia lixula* (black sea urchin) and *Echinometra lucunter* (sea raster) were exploited at the subsistence level with few commercial engagements by some coastal dwellers. Sea urchin were harvested by 71.7 % males and 28.3 % females across the entire coast of Ghana. The minimum and maximum prices of roasted sea urchins were between USD 1.32 and 8.22 along the coast of Ghana. The active participation of both genders could be associated with proximity to the resource, diving and the use of less energy-demanding tools such as knives and sharp handy metals required for the exploitation. The sea urchin fishery presents a viable economic potential within the coastal communities which need considerable attention by policy makers.

KEY WORDS

Shellfishes

Subsistence

Exploitation

Resource

Echinoderms

Morphometrics

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DEDICATION

To my family: Father Jones, Br. John, Omanhene, Rex, Louis, Felicity, Francisca, Daniel, Alphonsus and Mary

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CHAPTER ONE

INTRODUCTION

Sea urchins belong to the phylum Echinodermata which mostly occur in shallow waters or deeper depths of the sea. Globally, among the echinoderm family, urchin fishery has been considered an essential and vibrant marine resource. Urchins are widely distributed within areas where their presence have been well reported (Lamare, 1997; Shang et al., 2014). The market value of Sea urchins continues to experience exponential growth at the international level (La Beur et al., 2019; Stefánsson et al., 2017). This high market value stems from the imbalance between the supply and demand matrix of the urchin resource worldwide owing to overexploitation (Andrew et al., 2002; Rahman et al., 2014; Stefánsson et al., 2017). The global decline of sea urchin stocks continues to reflect the substantial gaps in policies aiming at conservation which affects sustainability of the sea urchin fishery and any possible aquaculture development (Coppa et al., 2021). Sea urchins are mainly exploited for their gonads, which negatively impact recruitment for the targeted species (Andrew et al., 2002; James et al., 2017). Aside from overexploitation, habitat loss and climate change are considered some major factors accounting for the global decline of sea urchins (Andrew et al., 2002). Sea urchins are highly space-dependent for propagation which makes them good indicators for ecological health assessment (Leary et al., 2013).

With the enormous economic importance of sea urchins, assessment of the urchin population and their fishery are imperative. However, in Ghana, there is no scientific data available on the sea urchin species in terms of their diversity, biology, economic value and ecology. The available stocks and biomass, species, and quantities harvested, as well as the preferred harvestable sizes are unknown. The study also seeks to provide knowledge on sea urchin species that are consumed by coastal dwellers including the scale of exploitation and demographics of the harvesters as a first appraisal of the sea urchin fishery in Ghana.

Background to the Study

Sea urchins continue to attract the attention of the scientific community in the areas of embryonic development, evolution, ecological health assessment, and culture biology (Parvez et al., 2016). According to Bottjer, Davidson, Peterson, & Cameron (2006), echinoids originated from the Cambrian era approximately 520 million years ago. There are five classes of echinoderms namely; echinoids, crinoids, asteroids, ophiuroids and holothurians. Sea urchins belong to the echinoid group.

Sea urchin populations are highly invasive within coral reefs and rocky intertidal systems (Coma et al., 2011). Their aggressive herbivorous nature makes them prime targets for controlling algal dominance within an ecosystem (Tebbett & Bellwood, 2018). Economically, sea urchins are a priced commodity especially within the seafood industry and ornamental industry, especially in Asia. It is also an important economic source for many countries in South America, and the United States of America (Parvez et al., 2016). The enormous benefits from this resource coupled with the staggering demand that exceeds supply from aquaculture is attributed to overexploitation of wild populations leading to near extinction of some sea urchin taxa (Barnes et al., 2002; Parvez et al., 2016). Globally, sea urchin populations have declined since 1995 (Carboni, Addis, Cau, & Atack, 2012). However, Andrew et al.

(2002), reported on the resurgence of the Chilean sea urchin *Loxechinus albus* fishery following investment into stringent conservation measures.

On the international market, processed urchin gonads are valued to cost about AU$ 450 per kg in Japan, which keeps supporting many livelihoods within the marine communities (Parvez et al., 2016). The gonads are of high nutritive value such as low in fat and high caloric levels (Archana & Babu, 2016; Cook et al., 2000). Sea urchin eggs are consumed in most Asian states due to it aphroditic tendencies (Yur et al., 2003), and are rich in polyunsaturated fat (Rahman et al., 2014). Sea urchin is also rich in high-quality proteins, making it a viable alternative to meat, and fish (Archana & Babu, 2016).

Chiarelli (2019) conducted experiments on the sea urchin and indicated their sensitivity to pollution. The sea urchin was unable to withstand the slightest introduction of pollution during their research and became weak resulting in the loss of their spines. Therefore, their presence or absence in our marine waters could inform scientists of the level of pollution. The limited dispersion capacities of sea urchins, slow recovery and rapid sample collection are generally a danger to localized and serial depletion. A study by Andrew et al. (2002) described the occurrence of a “boom-bust” cycle in several sea urchin fisheries world-wide. As a result, strong management measures are required to preserve the species' long-term viability.

Over the years, there has been an increase in global demand for fish due to an increase in population leading to the overexploitation of various marine fisheries resources and a decline in fish stocks. This however complicates fish supplies needed to meet future demands, thereby raising concern for the need to provide baseline information of other marine resources that could potentially serve as viable alternatives or supplement to fish. In many developing countries urchins are highly underexploited (Andrew et al., 2002).

In South Africa, work on the biology of three different species of sea urchin, their distribution and life histories was documented by Drummond (1993). Tarr et al. (1996) also investigated the potential ecological shift that could disrupt traditional abalone-sea urchin fisheries in the South-West part of Cape Verde. In Ghana however, two publications highlighted on the occurrence of some sea urchin species in Ghanaian waters. Gauld and Bohana (1959) in a study considered the principal features of the rocky shore fauna in Ghana and found *A. lixula* and *E. lucunter* in Accra and Elmina. Also, a study by Atewebehen (1999) found *E. tribuloides* to occur in Princess town and Abokwe Island in an ecological survey within Nearshore rocky reefs in western Ghana. However, both studies did not account for the available stocks, species composition, biomass, quantities, sizes harvested and how the market operate locally in Ghana are unknown.

Although this resource is exploited by coastal dwellers (personal communication) at Accra. These are some concerns that need to be investigated to serve as baseline information for future studies. This research envisages building the baseline information of the sea urchin population and aspect of their biology within Ghanaian marine waters.

Statement of the Problem

In the developed world, information about the fishery and the population of sea urchin are numerous compared to developing countries. Thus, in developed countries, studies suggest that sea urchin stocks are declining due to overexploitation. However, in developing countries such as Ghana, limited information is available on sea urchin population which makes it difficult to account for the status of the sea urchin in Ghana's marine waters. It is therefore important that a baseline information on the biological aspects of sea urchin is provided for comparative assessments of sea urchin stocks in the Ghanaian waters. This is because the absence of information on sea urchin's species composition, size distribution, and growth morphometrics along the coastal waters of Ghana makes sea urchin studies insufficient. This information when established will improve sustainable utilisation and management of sea urchin on both subsistence and future commercial scales of the fish in Ghana.

Fish is a significant contributor to the economy of Ghana as 10% of Ghanaians depend directly and indirectly on the fisheries sector for sustenance (Nunoo et al., 2018). However, according to a recent stock assessment, small pelagic stocks are overfished and on the verge of depletion, resulting in a drop in pelagic fishery landings (Lazar et al., 2018). Several factors contribute to the depletion of fish stocks in Ghana's seas, such as excessive pressure on fish stocks (due to increased vessel numbers, gears used, number of days at sea and vessel size), climate change and illegal unregulated and unreported fishing (Nunoo et al., 2009). The exploitation of some fish resources is considered unsustainable.

Nevertheless, other sources of protein exist and could meet the rising demand for fish in Ghana. Majority of the scientific investigations in Ghana's fisheries have only been done on the finfishes, a few shellfish but with inadequate information on echinoderms. However, under stringent sustainable management, Sea urchin could be a viable income and protein supplement to the dwindling of fish stock. (Reynolds & Wilen, 2000).

The eggs of sea urchins are the most preferred consumptive part of the organism. An individual sea urchin is made up of millions of eggs (Rahman et al., 2012). Thus, unsustainable exploitation of sea urchin gonads could push the species to a point of local extinction. Although sea urchins are known to occur in Ghana, there is no official scientific data available on the urchin population to provide baseline information that could promote further studies.

Purpose of the Study

The research seeks to fundamentally outline the occurrence and diversity of sea urchin species along the coastline of Ghana. It also seeks to evaluate the growth parameters and some aspects of the sea urchin fishery in Ghana thereby contributing to the conservation and sustainable utilization of resources in the Ghanaian waters.

Research Objectives

The main aim of the study was to access the Sea urchin populations along the Coast of Ghana with a note on its fishery.

The specific objectives of this study were to:

1. Investigate the occurrence of sea urchin species in the coastal waters of Ghana.

2. Assess the diversity of sea urchin species in the coastal waters of Ghana.
3. Investigate biological parameters, morphometry and growth of the sea urchin populations in the coastal waters of Ghana.
4. Assess the sea urchin fishery in Ghana.

Significance of the Study

Information obtained from the study will serve as the fundamental report on sea urchins and a note on their fishery in Ghana. The study will enlighten the public on the distribution of sea urchin populations in Ghanaian waters. The study seeks to provide knowledge on urchin species that are harvested by most coastal dwellers and their economic value to help widen Ghanaians' scope of preference for shellfishes to boost economic growth. It will also provide baseline information on the sea urchin and its importance to the blue economy in contributing to the dwindling of fish stock. This research will go a long way to inform policymakers in their decision making towards sustainable utilization and conservation of the sea urchin species.

Limitations

During the study, there were some limitations that were encountered which were worth mentioning. Some sea urchins drain out parts of their coelomic fluid in response to stress when removed out of the water, which altered their total body weight during measurement. The development of sea defence structure (boulders) within some of the sampling stations made sampling of sea urchin in such areas difficult, impacting the quantities collected. Sea urchins hidden in deep crevices were challenging to remove by divers. Divers did not use any diving equipment when searching for sea urchins, which might have affected sampling more of a particular sea urchin species than the others since some populations exist in clusters. The difference in diving efficiencies by sampler affected the quantities collected in some sampling communities. Also, accessibility to sea urchin harvester during the socioeconomic survey in communities such as Iture, Mumford and Teshie were difficult due to migration of potential respondents. Although these limitations were beyond the researcher's control, they did not invalidate the study's findings or conclusions because of followed scientific methodologies and procedures.

Delimitations

Ten coastal communities in Ghana with rocky beaches were selected for this study. The communities were chosen to encompass three coastal regions in Ghana; Western, Central and Greater Accra. Volta Region was excluded since no rocky beaches were found in the area. The communities were; Axim and Dixcove in the Western Region, Iture, Cape Coast, Nyanyano and Mumford in the Central region and Tema, Teshie, La and Nungua in the Greater Accra Region. Also, the communities were chosen for data collection because they represent areas with active sea urchin harvesting engagement (personal communication). The data gathered on occurrence, body morphometrics and fishery in this study are useful baseline information for the assessment of sea urchin populations in a particular geographic area.

Definition of Terms

Overexploitation: This occurs when the number of species removed exceeds the amount needed to replenish the existing number of species within a particular system.

Boom-Bust: This occur when species experience long periods of practically exponential growth (boom) and a subsequent population drop owing to competition (bust).

Stocks: Typically refers to a population that is more or less isolated from other stocks of the same species and hence self-sustaining. OR a collection of organisms (all of the same species) that are genetically self-sustaining and geographically or temporally isolated throughout reproduction.

Resource: A resource is a substance or object in an organism's environment that it requires for proper growth, maintenance, and reproduction.

Roe: This refers to the gonad of the sea urchin.

Organization of Study

This thesis is organised into six chapters. Chapter one, the Introduction, gives a brief background of sea urchin, some economic and ecological importance, medicinal value, livelihood support, the decline of the sea urchin fishery in some part of the world and outlines the knowledge gaps in the aspect of the biology that need to be addressed. The study's aims are also explained, as well as the study's significance to academia, policymakers, stakeholders in the fishing industry, and the general public. Chapter two which is the literature review, borders on the biology of the sea urchin, global landing and decline of sea urchin, ecological and economic relevance, size and diameter distribution, environmental responses and mortality, sea urchin management, and the sea urchin value chain in a chronological manner to establish the theoretical basis of this study. Chapter three is about the materials and methods of the study with a focus on the study area, data collection and data analyses to mainly address the research objectives. The findings are presented in Chapter four, which comprised the figures and tables with statistical analyses as well as comments of the results. Chapter five is the discussion of the results with reference to relevant literature. Chapter six presents the summary, conclusions of the findings and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

Global Landings and Decline of Sea Urchins

The sea urchin fishery is documented worldwide to be the most economically important fishery among the echinoderm group (Parvez et al., 2016). According to Parvez et al. (2016), sea urchins contribute significantly to the fisheries sector of countries such as; Chile, Canada, France, Japan, and the United States of America. The increase in this fishery has been attributed widely to their high market demands within such countries (Lawrence, 2007; Rahman et al., 2014). According to Andrew et al. (2002) in a review, sea urchin production is spearheaded by countries such as Chile, Japan, and Taiwan. Global urchin landings peaked at 117,039 metric tons in 1995 and have continued to fall drastically ever since (Zilia et al., 2021) as shown in Figure 1.

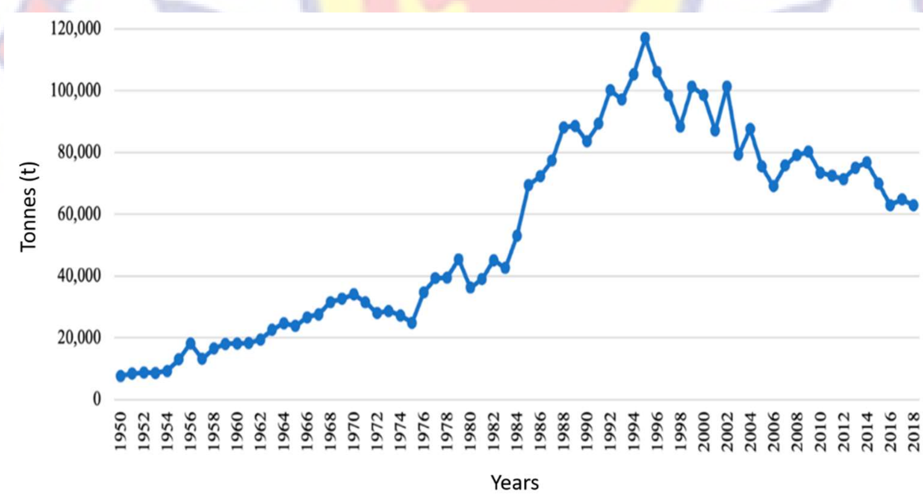

Figure 1: Global production of sea urchins from 1950 – 2018. Source; Zilia et al. (2021).

Although global catches had decreased, the Chilean *Loxechinus albus* fishery remains the world's largest, supplying around half of all of the global catch (Moreno et al., 2006). The New Zealand's Sea urchin fishery is also centred on a single native urchin species (*Evechinus chloroticus*). The general decline in sea urchin landing have been ascribed to be caused by several factors such as predator-prey relations and environmental factors but largely on overexploitation (Parvez et al., 2016). In France and Ireland, overexploitation of sea urchin gained traction within the scientific community in the 1980s, when the urchin *Paracentrotus lividus* population were overharvested to near extinction levels posing permanent damage to recovery (Barnes et al., 2002; S. Parvez et al., 2016). Similarly, according to Andrew et al. (2002) in Chile reported that, the *Loxechinus albus* fishery was heavily exploited presiding from the peak landing era, until intense management measures were implemented to sustain the fishery.

Sea urchins primarily feed on algae and also depend on slow-moving fauna such as mussels, Barnacles, jellyfish and dead fishes (Steneck, 2013). However, due to the high consumption of these urchin species by predators such as sea otters, humans, starfish, triggerfish and wolf eels which affect urchins populations to be considered Near-threatened (Steneck, 2013). Generally, assessment information on sea urchin is limiting. The only data available according to the international union of conservation of nature red list category was *Echinus esculentus* in 1996. The *Echinus esculentus* from the order Camarodonta and family Echinidae was considered near threatened. *Echinus esculentus* was extant in countries such as Denmark, Belgium, France, Netherlands, Norway, Portugal, Spain, Sweden, and the United

Kingdom (Baillie & Groombridge, 1996). These decreasing construct on sea urchin population promotes attention on ensuring proper management and policy guidelines to ensure conservation and breed development (Parvez et al., 2016). Some protection effort according to Andrew et al. (2002), six minor regions in Maine (USA) have been designated as marine protected areas and are no longer open to sea urchin fishing.

Biology of Sea Urchin

Sea urchins belong to the Phylum Echinodermata, the Class Echinoidea which includes the Order Physmosomatoida, Pedinoida (Simms, 2021), Cassiduloida (Caballero et al., 2021), Diademotoida, Clypeasteroida (Lin et al., 2020), Echinothurioida (Zeina, Darweesh, & Hellal, 2016), Spatangoida (Muñoz, & Londoño-Cruz, 2016), Arbacioida (Nagaoki, 2020), Salenioida (Raghunathan, Mondal, & Nigam, 2016), Temnopleuroida (Sastry, Mitra, Chitra, & Pattanayak, 2012), and Cidaroida (Rust & Grant, 2021).

Urchins are commonly spotted moving along the seafloor in all of the world's oceans. They inhabit tropical, temperate, and polar waters, often in the intertidal zone, however, several species can also be found in deeper waters, even up to 7340 m deep in the hadal zone (Stevenson & Kroh, 2020; Vinogradova, 1997). There are over 950 species of sea urchins globally with several yet to be discovered (Saravanan et al., 2018). Most common are *Strongylocentrotus purpuratus* (Perillo & Arnone, 2014), *Strongylocentrotus franciscanus* (Salas, Carpizo, Parés, Martínez, & Quintana, 2005), *Lytechinus anamesus* (Zigler & Lessios, 2004), *Centrostephanus coronatus* (Sotelo, Cupul, Rodríguez, Solís, & Rodríguez, 2018), *Arbacia lixula* (Privitera, Noli, Falugi, & Chiantore, 2011). *Eucidaris triboiloides* (McPherson, 1968; Santos, Coutinho, & Hajdu, 2002), *Tripeustes gratilla* (Dworjanyn, Pirozzi, & Liu, 2007)*, Echinometra lucunter* (McPherson, 1969), etc.

Urchins are spiny organisms covered with calcareous plated skeletons which appear globular in shape. *Arbacia lixula* with almost all the strong spines having the same length which makes it easy to differentiate from the other similar species (Guidetti, & Mori, 2005). Also, the pencil sea urchin *(Eucidaris tribuloides*), named for their thick blunt spines that resemble an old-fashioned pencil which makes them very distinctive and easily identified. Pencil urchins tend to be dark reddish-brown and live on intertidal rocky shores and in coastal waters to a depth of 80 m (Solandt & Wood, 2008). The pencil urchin is usually nocturnal, using its heavy spines to wedge itself into rocks during the day (Witman et al., 2017). This behaviour also helps ensure stability in areas with strong currents.

Food and Habitat Preferences

Sea urchins are essentially herbivores. Lawrence (2007) and Tertschnig (1989) have extensively documented their foraging behaviour and interactions with the alga *Eremosphaera viridis* and macrophyte populations. They serve a vital role in establishing the structure and function of seagrass ecosystems (Lawrence, 2007; Tertschnig, 1989). The black sea urchin, *Arbacia lixula*, is widespread in shallow rocky habitats to depths of 80m, where they are frequently found on vertical rock surfaces exposed to intense hydrodynamic stresses (McPherson, 1969). According to Privitera, Noli, Falugi, & Chiantore (2011), in the cohabitation of the two common sea urchins, *Paracentrotus lividus* and *Arbacia lixula*, under food-limited barren circumstances, niche differentiation is enforced. *Paracentrotus lividus* preferred non-encrusting species to encrusting corallines, whereas *Arbacia lixula* preferred encrusting corallines.

Similarly, some inhibit dark crevices of rocks where they are sheltered from predators and turbulence including *Echinometra viridis* (Blevins, & Johnsen, 2004). *Echinometra viridis* is found along the shoreline to the outer edge of the reef, at depths varying from 1-20 m, and feeds on seagrass *Thalasssia testudinum* and calcium carbonate particles (Blevins, & Johnsen, 2004; McPherson, 1969). In an animal-characterized boundary zonation survey along the Gulf of Guinea, Gauld, & Buchanan (1959), reported *Echinometra lucunter* and *Arbacia lixula* in Ghana to inhabit the lower belt of the Balanoid and Lithothamnia zone predominating the sheltered rocky substratum.

Most urchins inhibit the shallow water column because of the high productivity of seagrasses and algae facilitated by intense light penetration especially within the depths of 1 to 10m which reduces intraspecific competitions among inhabiting organisms (Smith & Koester, 2001). A typical example of such shallow dwelling sea urchins is the white sea urchin (*Tripneustes ventricocus*). Lewis (1958) and Pena et al. (2010) reported extensively on the occurrence of *Tripneustes ventricocus* in the shallow depths of 6–8 m from Barbabos and the eastern Caribbean respectively. The main food source for *Tripneustes ventricosus* was turtle seagrass (*Thalassia testudinum*), and they had been observed feeding on seagrass blades both during the day and at night (Tertschnig, 1989). This feeding observation of *Tripneustes ventricosus* by Tertschnig (1989) is corroborated by gut content analysis of *Tripneustes ventricosus* studies by Lawrence (2007).

Reproduction

Identifying the sexes of most sea urchin species externally is difficult or impossible in most cases. According to Cunningham & Jeffery (2009), in situations where gross sexual dimorphism does exist, it is consistently associated with non-planktotrophy. In extreme situations, female morphology has become modified to create depressions on the test where offspring may be sheltered throughout development (Cunningham & Jeffery, 2009). Moreover, since a number of the features used for taxonomic classification are lost on fossilization, it is difficult to identify fossil individuals as dimorphic males and females belonging to the same species (Parra-Luna, Martín-Pozo, Hidalgo, & Zafra-Gómez, 2020). Besides, the diagnosis of dimorphic taxa normally focuses on the striking female traits, thereby hindering the identification of the simpler male form within the ocean environment (Parra-Luna, Martín-Pozo, Hidalgo, & Zafra-Gómez, 2020).

Most sea urchin are gonochoric, where fertilization is external and broadcast is common (Gil et al., 2020). The embryo develops into planktotrophic larvae which live for several days before they sink to the bottom and use their tube feet to hold onto a rocky substrate where they metamorphose into juveniles (Cunningham, & Jeffery, 2009). According to Walker, Unuma, & Lesser (2007), gametogenesis and intra-gonadal nutrient storage and utilization are interrelated processes in sea urchins. Considering the nature of reproduction by the slate pencil sea urchin (*Heterocentrotus mammillatus*), Dotan (1990) described them of possessing a single annual reproductive cycle which are common among most echinoids. However, in *Eucidaris tribuloides,* the reproduction of the species has been observed to be responsive to seasonal cycles mainly for both the solar and the lunar cycles (Lessios et al., 1999).

The fertilization in this group also is external. Once hatched, these tiny urchins start their lives as larvae and take roughly two years to reach their full adult size (Smith, Cruz, Cameron, & Urry, 2008). Also, the reproduction of some sea urchins have been observed to occur all year as the study by Lawrence (2007) on *Tripneustes. ventricosus*. Lawrence (2007) described highest spawning period for the *Tripneustes ventricosus* to occur from April to August. Similar to *Eucidaris tribuloides*, fertilization in *Tripneustes ventricosus* occur externally. According to Lawrence (2007), the larvae of *Tripneustes ventricosus* are mostly drifted away from the parent populations by ocean currents during the developmental stage which could influence their wide distributions globally. Sea urchin recruitment and population sizes are extremely variable, and little is known about the causes of the population variability, making it difficult for any population size predictions to be made for management programs (Smith & Koester, 2001).

Occurrence and Distribution of Sea Urchin

Sea urchins and fishes are considered the most important reef ecosystem herbivores (Hughes et al., 2007) and they have a differential latitudinal gradient concerning their influence on primary producers (Gaines & Lubchenco, 1982). They are considered non-aggressive marine animals and inhibit oceans all around the world (Leu et al., 2020). Urchins have a higher affinity to cluster around rocky substratum. Sea urchins are distributed across the Arctic or tropic, shoreline, or within the deepest sea trenches (Schoenrock et al., 2018). Although sea urchins are distributed across both the tropical and temperate regions, they are highly predominant in the temperate reef systems (Hughes et al., 2007; Tuya et al., 2004). Sea urchin's distribution plays a vital role in the structural composition and dynamics of algae and coral ecosystems (Benítez-Villalobos, Gómez, & Pérez, 2008). Even though there is no substantial information of global distribution assessment of sea urchins, some species-based assessment indicates their distribution. Example, *Psammechinus miliaris* was assessed to be evenly distributed along the Southern North Sea of the UK and Irish coastline (Kelly & Cook, 2001).

Generally, *Psammechinus militaris* presences stretch from the Skaw Danish water into the western Baltic, Trondheim Fjord in northern Norway, Atlantic coast of Morocco and the Azores, British Isles, and Iceland (Mortensen, 1943). Tyler-Walters (2008) documented that *Echinus esculentus* is dominated in Norway- south to Portugal, north to Finmark, and North-East Atlantic from Iceland but absent from the Mediterranean. Geographically, *Echinometra viridis* can be found in the Caribbean Sea, from southern Florida and Mexico to Venezuela (Kroh, Mooi , Del Río, 2013). *Echinometra lucunter* are native to the nearctic, neotropical, and Atlantic Ocean (Dalmolin, Tozetti, & Pereira, 2020). They could be found from Bermuda through southern Florida and the Caribbean islands (especially Barbados) to Desterra, rock-boring urchins can be found all over the Caribbean and coastal South Atlantic subtropical region, Brazil (Ebert, Russell, Gamba, & Bodnar, 2008).

Studies carried out on sea urchins within the coastline of several African countries such as South Africa, Kenya, Cape Verde, Senegal, and Nigeria indicate the widespread of sea urchins in Africa. Within the continent, some occurring sea urchins include, *Parechinus angulosus* in the South-

Western Cape, South Africa, *Arbacia lixula* in Nigeria, *Echinometra lucunter* at Dakar (Senegal), *Diadema antillarum* at Cape Verde. And *Echinometra mathaei* in Kenya (Edokpayi, Adenle, & Lawal, 2010; Wirtz, 2009) The slate pencil urchin has been found to occur in both the temperate (North Carolina and Cape Hatteras) and the tropics (Rio de Janeiro). *Eucidaris tribuloides* has been found in the Gulf of Guinea (Cape Verde Islands), Ascension Islands and the Azores.

In Ghana, sea urchins have not been assessed however, a sample baseline study by Ateweberhan, Gough, Fennelly, & Frejaville (2012) on Nearshore Rocky Reefs of Western Ghana, West Africa identified *Eucidaris tribuloides* to be predominating in the study area. In 1999, a study by Lessios and other researchers assessed the phylogeography of the *Eucidaris sp.* and confirmed *Eucidaris* occurrence in Ghana to having similarities of *Eucidaris tribuloides.* A study by Gauld, & Buchanan (1959) only focused on the animal zonation at Teshie (Accra, Ghana) taking into account, algal zonation of Ghana. During the study, *Echinometra lucunter* and *Arbacia lixula* were the aforementioned echinoid species occurring within Ghana's coastal waters. However, there is limited information on the assessment of urchins along the coastline of Ghana of which this study seeks to address.

Size

Sea urchins are either regular or irregular in shape with their size ranging from 3 to 10 cm (1 to 4 inches) (Bandolon, 2014). In some cases, larger sea urchin species are capable of reaching approximately 36 cm (14 inches). Diverse sea urchin species experience different growth parameters due to variations in geographical locations (Bandolon, 2014). According to a study by Sainte-Marie (2020), the size-frequency distributions of the green urchins were different between North and South species studied. On Northern species were significantly larger, with shell diameter ranging from 24 mm to 102 mm (mean 66.8 ± 0.7 mm) compared to the shell diameter of the Southern species, ranging from 15 mm to 85 mm (mean 53.5 ± 0.6 mm). The shell length of the black sea urchin (*Stomopneustes variolaris*) from Mount-Lavinia reef, the Beruwala reef, and the Tangalle reef population were (5.55 ± 1.04 cm, 6.54 ± 0.86 cm, and 6.41 ± 1.05 cm) with an average weight of (101.40 ± 57.76 g, 147.90 ± 50.40 g, and 150.50 ± 59.45 g respectively (De Zoysa, Jinadasa, Edirisinghe, & Jayasinghe, 2018). According to Ebert, Russell, Gamba, & Bodnar (2008), *Echinometra lucunter* grow slowly with a long life span. The organism has an average life expectancy of more than ten years after reaching the age of one.

Diameter-Weight Relationships

Every urchin organism grows in diameter and weight throughout its life, and the relationship between the two is both practical and fundamental. The diameter-weight relations are one of the most used strategies for obtaining accurate biological data, and it is critical in fishery assessments (del Campo Barquín, 2002). The diameter weight relationship provides information on the growth of the urchin.

A study by De Zoysa, Jinadasa, Edirisinghe, & Jayasinghe (2018) evaluated the length-weight relationship of the black sea urchin (*Stomopneustes variolaris*) at three sampling sites in Sri Lanka. The study identified a significant link between *Stomopneustes variolaris* shell length and total body weight ($p < 0.05$). At all the three sampling sites a significant linear relationship was also observed between the logarithmic values of shell length and total body weight ($p < 0.05$). De Zoysa, Jinadasa, Edirisinghe, & Jayasinghe (2018) described the species of assuming a relative nagative allometric growth from all sampled sites. The isometric value $b = 3$ was considered for the length-weight relationship of the *Stomopneustes variolaris* for the study.

Similarly, Rahman et al. (2012) explored the length – weight relationship of the long-spined sea urchins (*Diadema sertosum*) form Pulau Pangkor, Malaysia. The study also presented the linear relationship between the shell length and total body weight in a logarithmic scale. From the study *Diadema sertosum* was observed to assume high negative allometry. Both studies De Zoysa, Jinadasa, Edirisinghe, & Jayasinghe (2018) and Rahman et al. (2012) inferred that feeding habit and environmental conditions could have a possible linkage to the negative allometry observed among the two organisms.

Typically, the understanding of the length-weight relationship of sea urchins is still evolving, resulting in difference in determination protocols among studies. The study by Tomšić et al. (2010), presented an exponential relationship between the shell diameter and body weight excluding spines of *Paracentrotus lividus* without log transforming the parameters. Tomšić et al. (2010) indicated a high variation of the length-weight groupings. del Campo Barquín (2002) documented that some seasonal variations, habitat, gonad maturity, sex, nutrition, stomach fullness, and changes in length ranges of the specimen captured could influence the diameter-weight relationship among sea urchins which needed investigation.

Ecological and Economic Importance of Sea Urchins

Sea urchins are considered ubiquitous marine animals as long as their main source of food, algae, is present (Tebbett & Bellwood, 2018). In most marine ecosystem communities, sea urchins are small organisms with a large ecological impact, capable of denuding kelp forest and keeping corals clear from algal overgrowth (Tebbett & Bellwood, 2018). A small cluster of Sea urchins are capable of destroying an entire reef ecosystem when populations are left on checked by their prevailing predators (Qiu et al., 2014). The gonads of urchins are preferably consumed by humans. In Japan, sea urchin gonads have long been considered a delicacy. (Parvez et al., 2016; Rahman et al., 2014). The product of processed gonads are considered a prized food source in the Mediterranean, and Asia countries, costing up to AU$ 450 per kg (Lawrence, 2007; Parvez et al., 2016; Rahman et al., 2014).

According to Archana & Babu (2016), the gonads of the sea urchins are of high nutritional and medicinal value to humans. Parvez et al. (2016) reported that a 100 g meal of sea urchin gonad, which is roughly 3.5 ounces, contains about 172 calories and 1.75 g of polyunsaturated fat. These fats help lower the overall cholesterol levels. Sea urchin's consumption can reduce the risk of irregular heartbeat and lower blood pressure due to the presence of omega-3 fatty acids (Parvez et al., 2016). Shang et al. (2014) and Agnello (2017) outlined the medicinal potentials of extracts made from sea urchin spins, shells and gonads such as the ability to treat ulcers, otitis media, cervical lymph node tuberculosis, and discomfort. In the Asian Pacific region's sea urchin gonads are used in boosting men's sexual prowess, particularly among the middle-aged men, since this facilitates the blood circulation within the reproductive organs thus improving sexual excitement (Yur'eva, Lisakovska, Akulin, & Kropotov, 2003).

According to Dincer & Cakli (2007), β-carotene and polyunsaturated fatty acids (PUFAs) are abundant in sea urchin gonads. Polyunsaturated fatty acids especially EPA (C20:5n-3) and docosapentaenoic acid (C20:5n-3) (DHA C226n-3), have substantial anti-arrhythmic, anti-cardiovascular, and anti-cancer properties. Also, Sea urchins play a vital part in the livelihood development of coastal communities as a commercially important marine invertebrate. It provides alternative jobs for most coastal dwellers. Four species of Echinoidea are utilized as ornamentals and curios in the Gulf of Mannar region (Chellaram, Samuel & Patterson Edward, 2003).

Environmental Responses and Mortality of Sea Urchins

The interactions between abiotic, biotic, and human environmental alterations are the main factors shaping Coastal marine assemblages (Micheli et al., 2005; Siikavuopio, Dale, Christiansen, & Nevermo, 2004). Environmental or water quality parameters affect the survival, development, welfare, and growth of aquatic species (Siikavuopio, Dale, Christiansen, & Nevermo, 2004). The temperature of the ocean plays a crucial role in the survival of urchins in their habitats. According to Miles, Widdicombe, Spicer, & Hall-Spencer (2007), purple sea urchin is tolerable to temperature ranges of 5 ºC to 23.5 ºC. Temperatures above approximately 26 ºC may lead to massive kills of such species. *Tripneustes ventricosus* is sensitive to variations in water temperature. At water temperature of 33 °C, *Tripneustes ventricosus* become lethargic, however at 40°C, they die (Lawrence, 2007).

In the benthic sea waters, greater wave action leads to breakage and dislodgment of benthic species such as sea urchins from their attachments such as rocks (Sebens, 1991). Sea urchin thrives well in the pH range of 6.0 and 9.0 (Andersson, Mackenzie, & Gattuso, 2011). According to Andersson, Mackenzie, & Gattuso (2011), sea urchins are better adapted to a neutral and slightly basic environment. Dissolve oxygen is an important water quality parameter that ensures the survival of most aquatic species. According to Sato, Powell, Rudie, & Levin (2018), low dissolved oxygen (13 - 42 $\mu molkg^{-1}$) zones in the water column render sea urchin species such as *Strongylocentrotus fragilis* weak, thereby reducing their fitness and making them susceptible to predation. Also, the substrate structure within the aquatic environment affects the life activities of certain types of benthic organisms like sea urchins as sandy surfaces and rocky ledges inhibit their grazing process (Adey, & Steneck, 2001).

During kelp feeding, both red and purple urchins scale rocky platforms, demonstrate their ability to travel quickly over flat, hard surfaces, however, only purple urchins' movement on soft surfaces is impeded (Laur, Ebeling, & Reed, 1986). Sea urchins are also consumed by seagulls which prey on intertidal sea urchins by breaking the shells and taking up the gonads (Snellen, Hodum, & Fernández-Juricic, 2007). Wolf eel is another specialized predator that feeds on almost all sea urchins (McClanahan, & Muthiga, 2016) whereas sea otter feeds commonly on purple sea urchins. Crab and Wrasse attack sea urchins and it remains respectively (Christie, Kraufvelin, Kraufvelin, Niemi, & Rinde, 2020). During bad weather conditions and unavailable food, sea urchins become more susceptible to disease infestation.

Common bacteria in the ocean known as Rhodospirillum genus affects the welfare and health of *Stronglyocentrotus sp.* thus causing purple necrosis (spots) on the outside of sea urchins (Haskell, 2008).

Management of the Sea Urchin Fishery

Sea urchin exploitation continues to be a major livelihood activity, employment, a source of income and food for most coastal dwellers (Warner, 1997). The first documented management effort within the urchin fishery occurred in Barbados was in 1879. Local authorities instituted a mandatory closure of the fishery from May to August to enhance recovery and conservation efforts within the area (Scheibling, & Mladenov, 1987). However, institution of a co-management strategy at St. Lucia that generated traction to the problems and the management efforts that have been taken to avert to collapse of the urchin fishery across the eastern Caribbean (Pena et al., 2010). In Barbados and St. Lucia, the common threat to the collapse of the urchin fishery identified was illegal harvesting. Illegal harvesting have been described the influence slow recovery of the urchin fishery in areas were management structured are well outlined (Scheibling & Mladenov, 1987; Smith & Koester, 2001).

Aside the fishery, Sea urchins are vital resource for ecological restoration initiatives. Sea urchins are important species use for restoring the coral reef ecosystem. Some work done by the Pacific Cooperative Studies Unit (PCSU) funded by National Oceania and Atmospheric Administration (NOAA) was able to plant more than 600,000 sea urchins into the wild to curb macroalgae overgrowth through aquaculture. *Tripneustes gratilla* were implanted to help control the invasive seaweed *Kappaphycus* (smothering seaweed) which had overpopulated local coral reefs.

Sea Urchin Value Chain

Value chain assessment provides essential information on the role and activities by stakeholders in the utilization of a particular resource. According to Rosales et al. (2017), within the small-scale fisheries, value chain perspective provides valuable information that enhances the sustainability of the fishery resource by revealing challenges and response strategies of stakeholders in a changing market of the shared resource. The sea urchin fishery is described to provide enormous economic benefits that supports livelihood in areas where active exploitations are ongoing. According to Kato (1972), the California sea urchin fisheries employ several actors within the industry, with operations spanning from Divers to the supplier.

In California, divers harvest *Strongylocentus franciscanus* and *Strongylocentus purpuratus,* using conventional hook gears from boats. The collected urchins are brought to the work station for them to be sorted and crushed to access the gonad. This was then forwarded to roe processors who rinse, dry and package the fresh roe for distribution. The distributors supplier the products to consumer outlets. In a case study of the urchin fishery in Grenada that explored the social-ecological network of the fishery (Nayar, Davidson-Hunt, Mcconney, & Davy, 2009). The market network of the fishery involved three main actors namely; divers, breakers and exporters. The divers were the collectors of sea urchins from the wild. The breakers, crush the shell to extract and processor the roe. The exporters were local distributors, mostly old divers who collect and distribute the processed roe to other neighbouring communities for sale. Similarly in Barbados, Pena et al. (2010) described the active role of people in the white sea urchin, *Tripneustes ventricosus* fishery as divers, breakers and vendors. On the shore, processing and sales of sea urchins' roe were engaged by women and children.

CHAPTER THREE

MATERIALS AND METHOD

Sampling Locations

Ghana has a coastline that stretches 550 kilometres bordering the Gulf of Guinea, interspersed with sandy and rocky beaches (BOG, 2008). Rocky beaches in three coastal regions of the country (Western, Central and Greater Accra) were earmarked for the study (Figure 2). The stations in Greater Accra Region were Tema, Nungua, La, and Teshie; in the Central Region, the stations were Nyanyano, Mumford, Cape Coast castle, and Iture. Also, sampling in the Western Region occurred at Axim and Dixcove as shown in Figure 2. The description of the sampling station is presented in Table 1.

Figure 2: Sea urchin sampling locations along the coast of Ghana.

Table 1: The Location Nature and Land-Use Description of the Sampling Stations

Stations	GPS Coordinate	Proximity to Communities	Nature of Beach	Land Use
Tema	5°39'18.32"N 0°1'57.29"E	Approx. 20 m	Rocky and sandy	Urban settlement
Nungua	5°35'46.21"N 0° 4'9.44"W	Approx. 10 m	Rocky and sandy	Landing site, Hotel
Teshie	5°34'18.54"N 0°6'40.38"W	Approx. 20 m	Rocky	Dump site
La	5°33'23.27"N 0°9'19.16"W	Approx. 15 m	Rocky and sandy	Landing site, Hotel
Nyanyano	5°28'0.41"N 0°24'22.28"W	Approx. 50 m	Rocky and sandy	Vegetation
Mumford	5°15'37.36"N 0°45'21.90"W	Approx. 25 m	Rocky	Vegetation and Sea defence
Cape Coast	5° 6'13.47"N 1°14'24.05"W	Approx. 10 m	Rocky	Landing site, Urban settlement
Iture	5°28'0.41"N 0°24'22.28"W	Approx. 10 m	Rocky	Settlement and Sea defence
Dixcove	4°47'36.88"N 1°56'38.86"W	Approx. 15 m	Rocky	Settlement and hotel
Axim	4°51'39.58"N 2°14'57.95"W	Approx. 50 m (Island)	Rocky (pebbles)	Vegetation and sea defence

Sea urchin samples taken from the aforementioned stations had four areas noted as sea urchin fishing communities (Nyanyano, La, Teshie, and Tema) and six non-fishing areas (Cape Coast, Iture, Axim, Mumford, Dixcove, and Nungua). For the non-fishing aeras, sea urchin was exploited at the subsistence level without any commercial activities.

Sampling Technique

Samples of sea urchins were collected within the period from November 2020 to April 2021. At each sampling station sea urchin samples were collected randomly from the rocks in the intertidal zone within a standardized time of 30 mins. Prior to sampling in-situ water temperature were recorded using a glass thermometer between the hours of 10 am and 3 pm. Sea urchins were collected by divers using a stainless-steel scraper and knives in the intertidal-subtidal areas at low tide. Specimens were placed into sacks hung on floating boards and brought to shore. Samples of sea urchins collected were preserved on ice and transported to the laboratory for sorting, identification and further analysis (Figure 3). The urchins were identified using an identification manual (Bariche, 2012) and images from the internet.

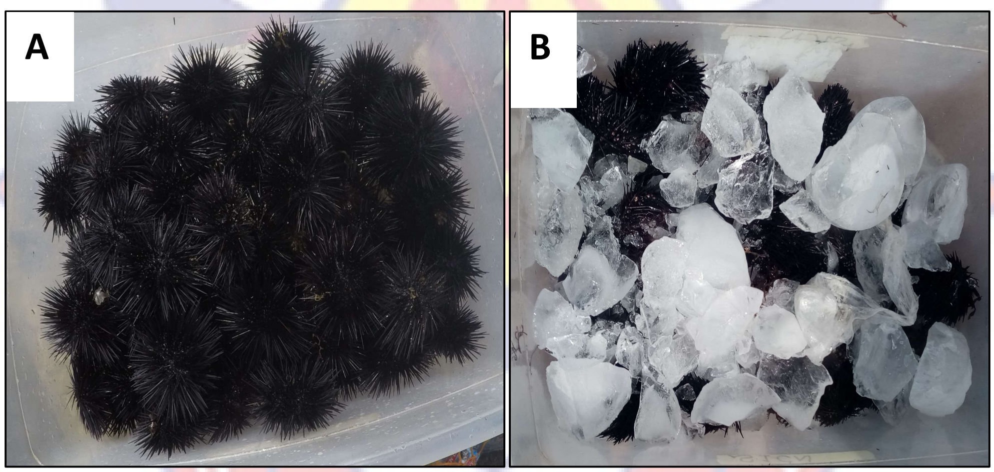

Figure 3: Sea urchin. A – Sea urchin samples in a plastic container and B – Sea urchin samples preserved on ice.

Biological Data Collection

Sample preparation and body measurements

All specimens collected were cleansed of debris (algae) attached to the spines. The spines of each specimen were removed with the use of a knife. The body weight of each specimen without the spines was measured using an electronic balance to the nearest 0.1 g as illustrated in Figure 4. Following removal of the spines, test diameter (TD), and test height (TH) were measured to the nearest 0.1 mm with Vernier callipers. The test diameter and test height were measured (Figure 5).

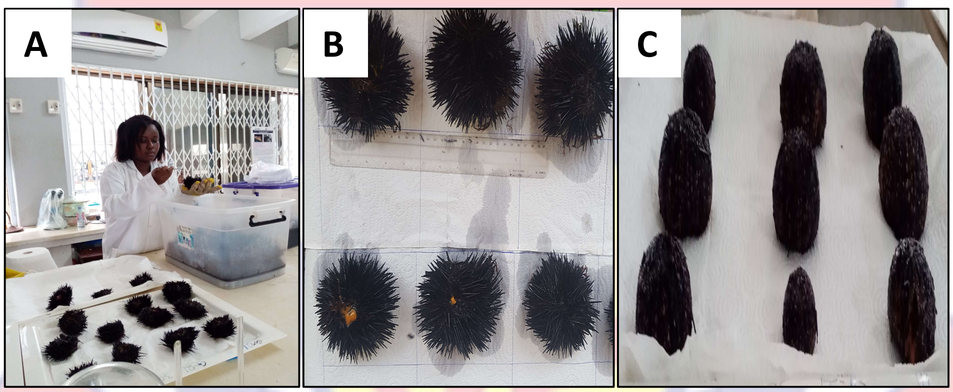

Figure 4: *Arbacia lixula* samples. A – Laboratory analysis of *A. lixula*, B – *A. lixula* with spines and C – *A. lixula* without spines.

Analysis of Sea Urchin Morphometric Data

The frequency distribution of test diameter and test height were presented in graphs. The diameter–frequency distribution of the sea urchins was determined at 5 mm size classes. The relationship between test or shell diameter (*TD* mm) and body weight (*BW* g) of specimens were established from a regression analysis. The relationship between diameter, and height was estimated by regression analysis, using the linear model where BW is body weight and TD is the test diameter, and TH is the test height, a is the intercept and b is the slope. The regression line was determined using the least-squares method to test the existence of growth in sea urchin. The coefficient of determination R^2 together with significance F and P-value were used as indicators of the quality of the regression. The ratio between the test height and test diameter of each specimen was calculated. The mean of the ratios was presented in a graph. A one-way ANOVA was used to determine the difference among the mean values of the parameters considered using the Minitab software.

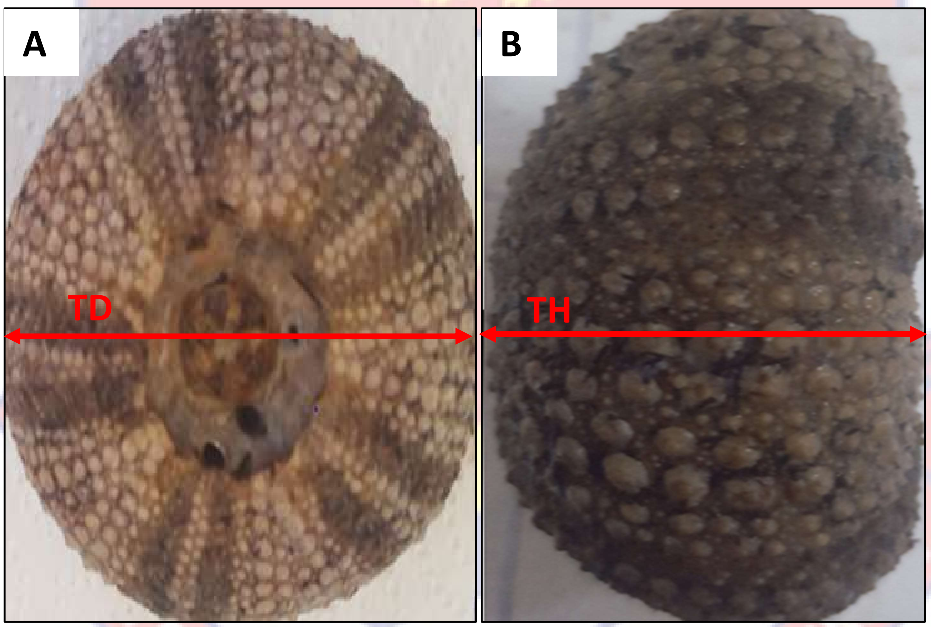

Figure 5: Test dimensions of *Arbacia lixula*. A – test diameter (TD), B – test height (TH).

Socio-Economic Assessment of the Sea Urchin Fishery

A structured questionnaire was used to examine some socio-economic issues in the communities where sea urchins were exploited, mainly demography and the economic importance of the sea urchin fishery. Respondents for the study were accessed using a snowball method. The survey questions were pretested and used to assess harvesters catch (yield), market prices, income generated, and knowledge on the sea urchins exploited. The structure of the study was based on three parts, where part A, addressed the demography of the sea urchin harvested whereas part B, scope of the sea urchin fishery and Part C, focused on economic importance of the sea urchin. Children below the ages of 12 years were not interviewed.

The survey was conducted in ten study areas that included Tema, La, Teshie, Nungua, Nyanyano, Mumford, Cape coast castle, Iture, Axim and Dixcove. Four languages were used during the survey which included Fante, Twi, Ga and English. At places such as Teshie and La, an interpreter was hired to translate the Ga language into Twi or English to ensure smooth data collection. A total of 124 respondents were included in the survey from all sampled stations as shown in Figure 6. Data from the survey were analysed using the SPSS software; responses were analysed for descriptive statistics to summarize the basic features of the data in the form of frequencies and their percentages. Responses to open-ended questions were grouped, coded, and analysed as categorical data.

Figure 6: Conducting field survey using Kobo tool collect on the phone.

CHAPTER FOUR

RESULTS

The results of the study are presented in this chapter, which was based on a six-month sampling from selected rocky beaches along Ghana's coastline from November 2020 to April 2021. It describes the size, species composition, morphological differences in sea urchin specimens found at different sites and socio-economic value of the fishery.

Description of Sea Urchin Species Occurring in the Coastal Waters of Ghana

Three species of urchins were identified during the sampling period, namely *Arbacia lixula, Eucidaris tribuloides, Echinometra lucunter* and an Unidentified species. A total of about 2,042 specimens were collected over the study period. Out of 2,042 specimens collected, *Arbacia lixula* constituted 1,967, *Eucidaris tribuloides* (58), *Echinometra lucunter* (8) and unidentified species (9) respectively.

Arbacia lixula

Arbacia lixula commonly known as the black sea urchin as shown in Figure 7A is distinctive. It has sharp spines of approximately the same size and are erect. They belong to Order Arbacioida and Family Arbaciidae, and are abundant along Ghana's coast. The Aristotle lantern (tooth-like structure) is located in the oral region, while the anus is located in the aboral region.

Eucidaris tribuloides

Eucidaris tribuloides commonly known as the slate pencil sea urchin belongs to the Order Cidaroida and Family of Cidaridae. It is reddish-brown in color with hair-like structures on the test and possess very thick spines (Figure 7B). The spines of the pencil sea urchin are mostly surrounded by fungus which are mostly white in colour.

Echinometra lucunter

The body features of the *Echinometra lucunter* are similar to that of the *A. lixula* with a black coloration. However distinguishably, the spines of this species are short and blunt (Figure 7C).

Unidentified species

These specimens are smaller in size with a grey colour and a blunt short spine. The spines are arranged horizontally around the test with short secondary spines found at the oral- aboral region as shown (Figure 7D).

Figure 7: Photos of the oral (left) and aboral (right) views of sea urchins. A – *A. lixula*, B – *E. tribuloides*, C – *E. lucunter* and D – Unknown Species

Species Composition

In Table 2, *Arbacia lixula* showed dominance (1967 specimens) among all the other species over the sampling stations. Nyanyano recorded all the species obtained during the sampling period. *E. tribuloides* occurred only at Tema and Nyanyano. *E. lucunter* also occurred both at Nyanyano and La whilst the Unidentified species was found at Tema and Nyanyano respectively.

Table 2: The Occurrence and Percentage Composition of Specimens

Locations	*Arbicia. lixula*	*Eucidaris tribuloides*	*Echinometra lucunter*	Unidentified species
Tema	97.5 (555)	1.4 (8)	-	1.1 (6)
Nungua	100 (81)	-	-	-
La	98.3 (174)	-	1.7 (3)	-
Teshie	100 (222)	-	-	-
Nyanyano	87.6 (410)	10.7 (50)	1.1 (5)	0.6 (3)
Mumford	100 (86)	-	-	-
Cape Coast	100 (155)	-	-	-
Iture	100 (200)	-	-	-
Dixcove	100 (36)	-	-	-
Axim	100 (48)	-	-	-

Values in bracket = total specimens collected per study site, Values outside bracket = % composition

Species Size Frequency Distribution

Figure 8, presents the size distributions of sea urchins from Ghana. The smallest *A. lixula* encountered was 5.8 mm and the largest, 85.8 mm in test diameter with a modal class in the 45 mm – 50 mm group. These had a test height range 2.3 mm to 48.2 mm (modal height = 20 mm – 25 mm) as shown in Figure 9. *Eucidaris tribuloides* had a test diameter range of 24.7 mm – 47.7 mm (mode = 40 mm – 45 mm) and a test height ranging from 15.7 mm to 33.1 mm (mode = 25 mm – 30 mm). The diameter of *E. lucunter* specimens measured 47.9 mm to 58.3mm with a bimodal class in the 45 mm – 50 mm and 50 mm –55 mm classes. These had a test height range of 20.2 mm – 27.7 mm (mode = 20 mm – 25 mm). The unidentified species had a shell diameter ranging from 21.8 mm to 31.8 mm with a modal diameter of 20 mm to 25 mm and their test heights were 10 mm – 15.2 mm with a mode of 10 mm –15 mm.

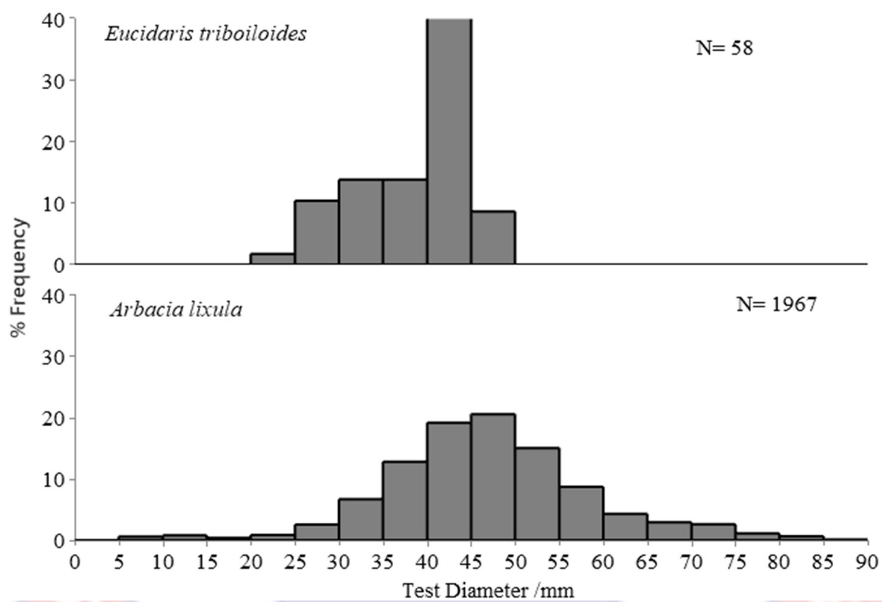

Figure 8: Test diameter frequency distribution of *Arbacia lixula* and *Eucidaris tribuloides*. N = Number of specimens collected.

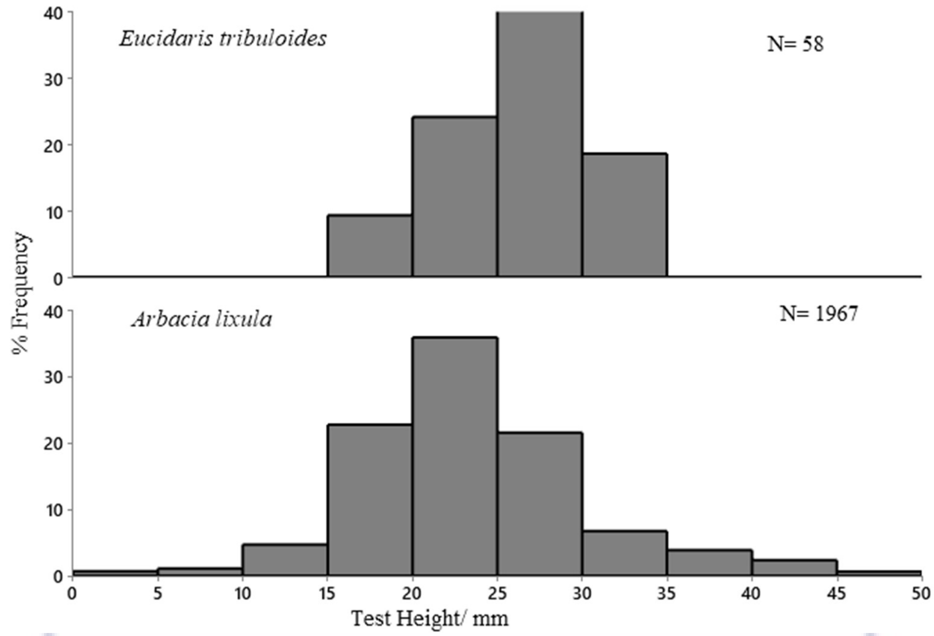

Figure 9: Test height-test diameter frequency distribution of *Arbacia lixula* and *Eucidaris tribuloides*. N = Number of specimens collected

Size Frequency Distribution of the Various Sampling Site

Arbacia lixula

The diameter frequencies of *Arbacia lixula* at the sampling stations are illustrated in Figure 10 and Table 3. The test diameter of Tema ranged from 14.7 mm – 70.6 mm with a modal length class of 45 mm – 50 mm. At Nungua, the test diameter of *Arbacia lixula* ranged between 14.4 mm and 75.9 mm with a bimodal class of 35 mm – 40 mm and 45 mm – 50 mm. *Arbacia lixula* at La had a test diameter of 13.5 mm – 69.6 mm and a modal class of 40 mm – 45 mm. Teshie had shell diameter ranging between 5.8 mm and 60.2 mm with a modal class of 40 mm – 45 mm. The test diameter range for *Arbacia lixula* collected at Nyanyano was between 24.8 mm and 85.8 mm with a modal class of 55 mm to 60 mm. The test diameter range for *Arbacia* *lixula* at Mumford was between 20 mm – 62.7 mm with a modal class of 40 mm to 45 mm. At Cape Coast castle, *Arbacia lixula* also had a test diameter ranging from 25.6 mm to 66.7 mm, modal class of 35 mm – 40 mm. The *Arbacia lixula* at Iture showed a test diameter ranges between 15.9 mm – 65.6 mm with a modal class of 45 mm to 50 mm. At Dixcove, the test diameter range of *Arbacia lixula* was from 25.3 mm to 51.8 with a modal class of 40 mm – 45 mm. The *Arbacia lixula* collected at Axim showed a test diameter range from 25.7 mm – 44.4 mm with a modal class of 35 mm – 40 mm.

Table 3: Size Frequency Distribution of *Arbacia lixula* at all Sampled Stations

Stations	Size range (mm)	Modal class (mm)
Tema	14.7 – 70.6	45 – 50
Nungua	14.4 – 75.9	35 – 40
La	13.5 – 69.6	40 – 45
Teshie	5.8 – 60.2	40 – 45
Nyanyano	24.8 – 85.8	55 – 60
Mumford	20.0 – 62.7	40 – 45
Cape coast castle	25.6 – 66.7	35 – 40
Iture	15.9 – 65.6	45 – 50
Dixcove	25.3 – 51.8	40 – 45
Axim	25.7 – 44.4	35 – 40

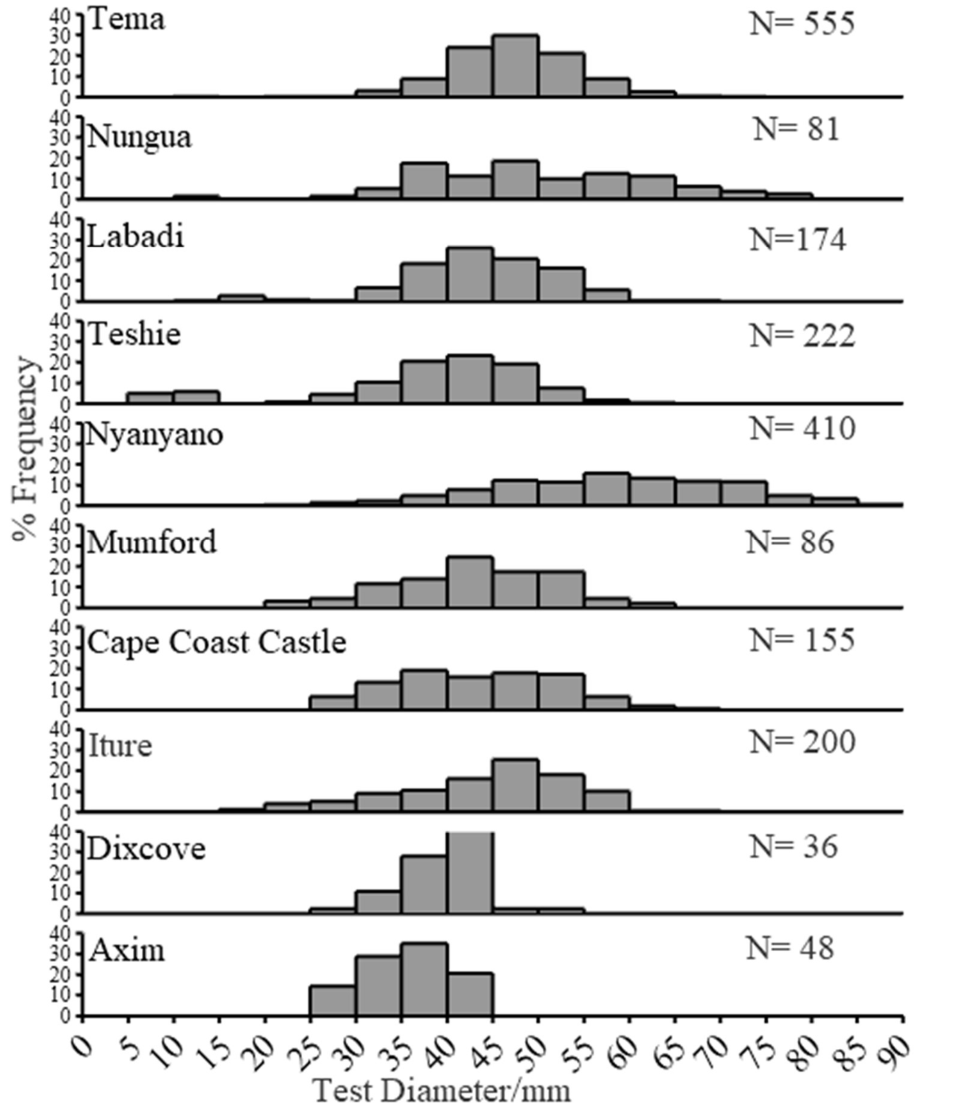

Figure 10: Size frequency distribution of *Arbacia lixula* at all sampled stations.

Eucidaris tribuloides

The test diameter of *Eucidaris tribuloides* at Nyanyano ranged from 24.7 mm – 46.2 mm with a modal length class of 40 mm – 45 mm as shown in Figure 11.

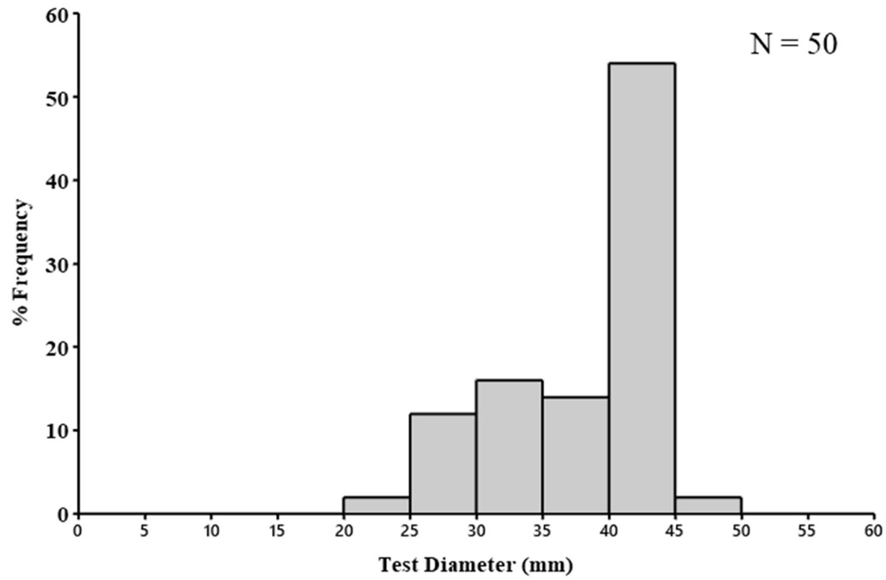

Figure 11: Size frequency distribution of *Eucidaris tribuloides* at Nyanyano.

Diameter-Weight Relationships for the Different Species

Arbacia lixula

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Tema was described by the equation BW= 0.9817TD + 3.0739 (Figure 12). The correlation coefficient ($r = 0.93$) and analysis of variance of the regression analysis ($F= 3446.84$, $df = 553$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Tema. The coefficient of determination ($R^2 = 0.86$) of the regression indicates that 86 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 0.98$) was significantly different from 1.0 ($t = 58.71$, $p < 0.05$) that specimens increased nearly equal in body weight to the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Nungua was described by the equation BW = 1.1481TD –

5.1748 (Figure 12). The correlation coefficient ($r = 0.91$) and analysis of variance of the regression analysis ($F= 600.18$, $df = 79$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Nungua. The coefficient of determination ($R^2 = 0.88$) of the regression indicates that 88% of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 1.15$) was significantly different from 1.0 ($t = 24.50$, $p < 0.05$) that specimens increased nearly faster in weight than the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at La was described by the equation BW= 1.0011TD + 1.4561 (Figure 12). The correlation coefficient ($r = 0.95$) and analysis of variance of the regression analysis ($F= 1549.70$, $df = 172$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at La. The coefficient of determination ($R^2 = 0.90$) of the regression indicates that 90% of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 1.0$) was equal to 1.0 ($t = 39.37$, $p < 0.05$) that specimens increased faster in body weight to the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Teshie was described by the equation BW = 1.0126TD + 1.0739 (Figure 12). The correlation coefficient ($r = 0.78$) and analysis of variance of the regression analysis ($F= 5564.60$, $df =220$, $p < 0.05$) indicate a strong positive relationship between the test diameter and wet body weight without spines of *Arbacia lixula* at Teshie. The coefficient of determination ($R^2 = 0.96$) of the regression indicates that 96 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 1.01) was equal to 1.0 ($t = 74.60$, $p < 0.05$) that specimens increased faster in body weight to the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Nyanyano was described by the equation BW = 2.1252TD – 54.433 (Figure 12). The correlation coefficient ($r = 0.78$) and analysis of variance of the regression analysis ($F= 1389.09$, $df = 406$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Nyanyano. The coefficient of determination ($R^2 = 0.81$) of the regression indicates that 81% of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 2.13) was significantly different from 1.0 ($t = 37.27$, $p < 0.05$) that specimens increased about nearly twice faster than the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Mumford was described by the equation BW = 1.179TD – 7.6505 (Figure 12). The correlation coefficient ($r = 0.96$) and analysis of variance of the regression analysis ($F= 1015.29$, $df = 84$, $p < 0.05$) indicate a strong positive relationship between the test diameter and wet body weight without spines of *Arbacia lixula* at Mumford. The coefficient of determination ($R^2 = 0.92$) of the regression indicates that 92 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 1.18) was nearly equal to 1.0 ($t = 31.86$, $p < 0.05$) that specimens increased nearly equal to the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Cape Coast castle was described by the equation BW = 1.0424TD – 1.472 (Figure 12). The correlation coefficient ($r = 0.95$) and analysis of variance of the regression analysis ($F = 877.32$, $df = 155$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Cape Coast castle. The coefficient of determination ($R^2 = 0.90$) of the regression indicates that 90 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 1.04$) was almost equal to 1.0 ($t = 37.29$, $p < 0.05$) that specimens increased nearly the same to the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Iture was described by the equation BW = 1.1666TD – 5.1315 (Figure 12). The correlation coefficient ($r = 0.96$) and analysis of variance of the regression analysis ($F = 877.32$, $df = 200$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Iture. The coefficient of determination ($R^2 = 0.92$) of the regression indicates that 92 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 1.17$) was almost close to 1.0 ($t = 48.1$, $p < 0.05$) that specimens increased nearly the same as the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Dixcove was described by the equation BW = 0.9595TD + 1.2622 (Figure 12). The correlation coefficient ($r = 0.95$) and analysis of variance of the regression analysis ($F = 313.5$, $df = 34$, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Dixcove. The coefficient of determination ($R^2 = 0.90$) of the regression indicates that 92 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 0.96) was significantly different from 1.0 ($t = 17.71$, $p < 0.05$) that specimens increased nearly the same the test diameter.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of *Arbacia lixula* at Axim was described by the equation BW = 1.2227TD – 6.7015 (Figure 12). The correlation coefficient ($r = 0.78$) and analysis of variance of the regression analysis ($F= 559.85$, df = 46, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula* at Axim. The coefficient of determination ($R^2 = 0.92$) of the regression indicates that 92% of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 1.22) was close to 1.0 ($t = 23.66$, $p < 0.05$) that specimens increased nearly the same as the test diameter.

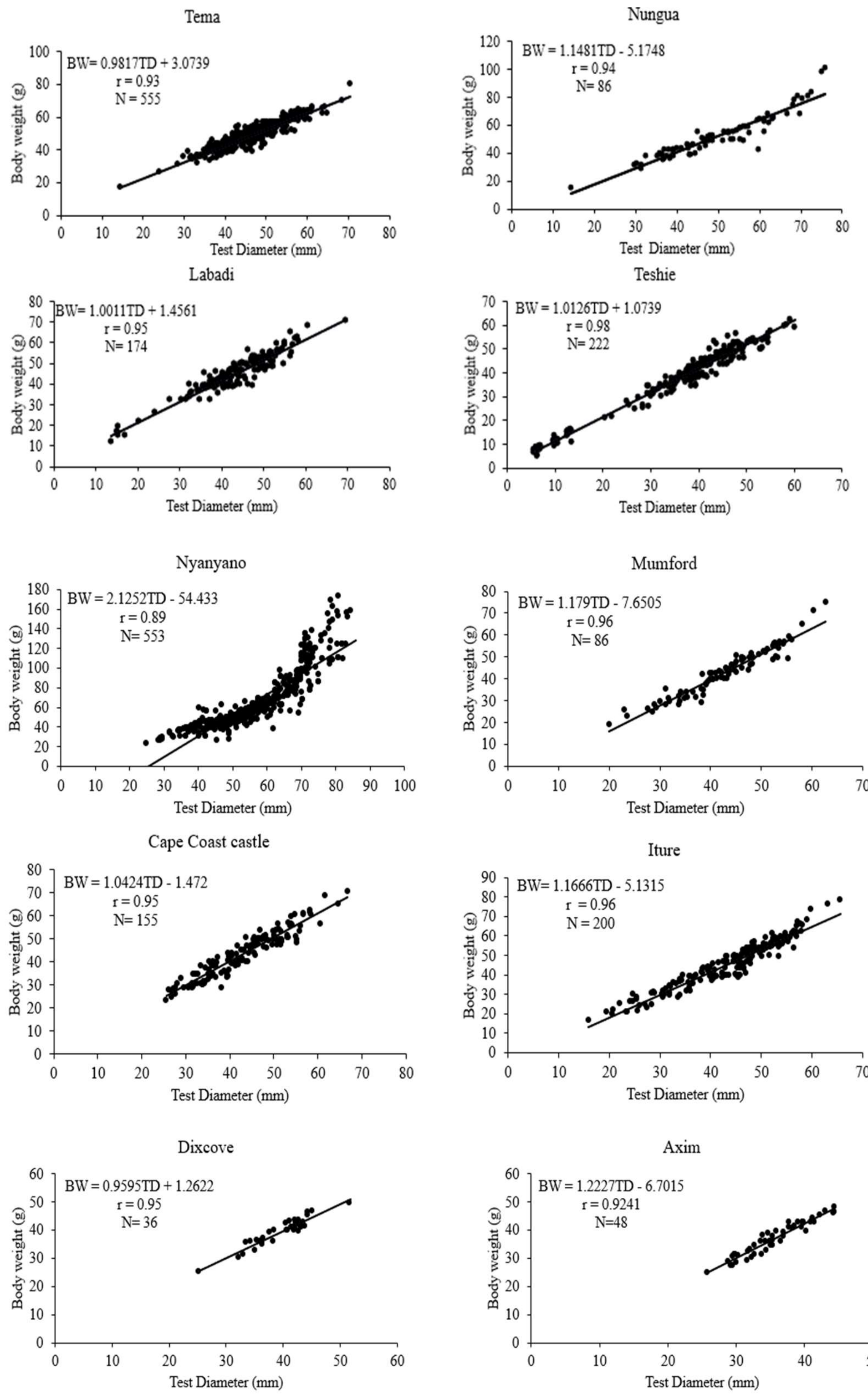

Figure 12: Test diameter-weight relationship of *Arbacia lixula*.

Table 4: Summary for Regression Analysis of *Arbacia lixula*

Stations	R^2	R	Slope	Intercept	F stat	T stat	P - value
Tema	0.8617	0.93	0.9817	3.0739	3446.848	58.710	0.00
Nungua	0.8837	0.94	1.1481	-5.1748	600.185	24.499	0.00
La	0.9001	0.95	1.0011	1.4561	1549.704	39.366	0.00
Teshie	0.9620	0.98	1.0126	1.0739	5564.596	74.596	0.00
Nyayano	0.8107	0.89	2.1252	-54.433	1389.094	37.271	0.00
Mumford	0.9239	0.96	1.1790	7.6505	1015.289	31.864	0.00
Cape Coast	0.9009	0.95	1.0424	1.4720	1390.778	37.293	0.00
Iture	0.9212	0.96	1.1666	5.1315	2314.620	48.111	0.00
Dixcove	0.9022	0.95	0.9595	1.2622	313.538	17.707	0.00
Axim	0.9241	0.96	1.2220	6.7015	559.848	23.661	0.00

R^2 = Coefficient of determination, r = correlation coefficient

Eucidaris tribuloides

The relationship between body weight (BW, g) and diameter (TD mm) of *Eucidaris tribuloides* at Nyanyano was described by the equation BW = 1.1565x – 21.088 as shown in Figure 13. The correlation coefficient ($r = 0.82$) and analysis of variance of the regression analysis ($F = 91.40$, $df = 46$, $p < 0.05$) indicate a strong positive relationship between the test diameter and body weight without spines of *Eucidaris tribuloides* at Nyanyano. The coefficient of determination ($R^2 = 0.675$) of the regression indicates that 68 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation ($b = 1.6$) was significantly different from 1.0 ($t = 9.56$, $p < 0.05$) that specimens increased about nearly faster than the test diameter.

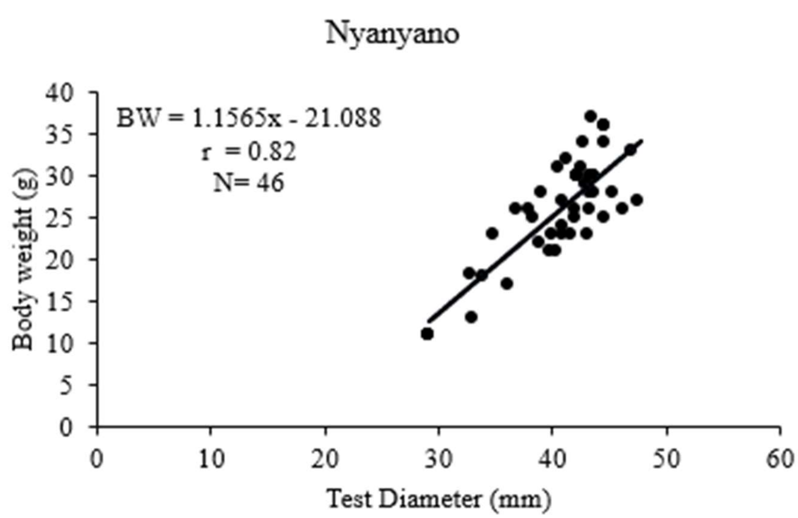

Figure 13: Test diameter-weight relationship of *Eucidaris tribuloides*.

Table 5: Summary for Regression Analysis of *Eucidaris tribuloides* at Nyanyano

Parameters	Values
R^2	0.675
R	0.82
Slope	1.1565
Intercept	21.088
F stat	91.39688
T stat	9.560172
P – value	0

R^2 = Coefficient of determination, r = correlation coefficient

Test Height-Diameter Relationships for the Different Species

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of overall *Arbacia lixula* at all sampling station were described by the equation BW = 0.5448TD – 2.1082 (Figure 14). The correlation coefficient (r = 0.95) and analysis of variance of the regression analysis (F= 877.32, df = 1967, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Arbacia lixula*. The coefficient of determination ($R^2 = 0.90$) of the regression indicates that 90 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 0.54) was significantly different from 1.0 (t = 132.03, $p < 0.05$) that specimens increased about twice faster in test diameter than the height.

The relationship between body weight (*BW*, g) and diameter (*TD* mm) of overall *Eucidaris tribuloides* at all sampled sites were described by the equation BW = 0.8049TD + 3.4072 (Figure 14). The correlation coefficient (r = 0.91) and analysis of variance of the regression analysis (F= 247.55, df = 52, $p < 0.05$) indicate a strong positive relationship between the shell diameter and body weight without spines of *Eucidaris tribuloides*. The coefficient of determination (R^2 = 0.83) of the regression indicates that 83 % of the increasing body weight could be predicted by the test diameter. The slope of the regression equation (b = 0.80) was significantly different from 1.0 (t = 15.7, $p < 0.05$) that specimens increased about nearly equal in test diameter to the height.

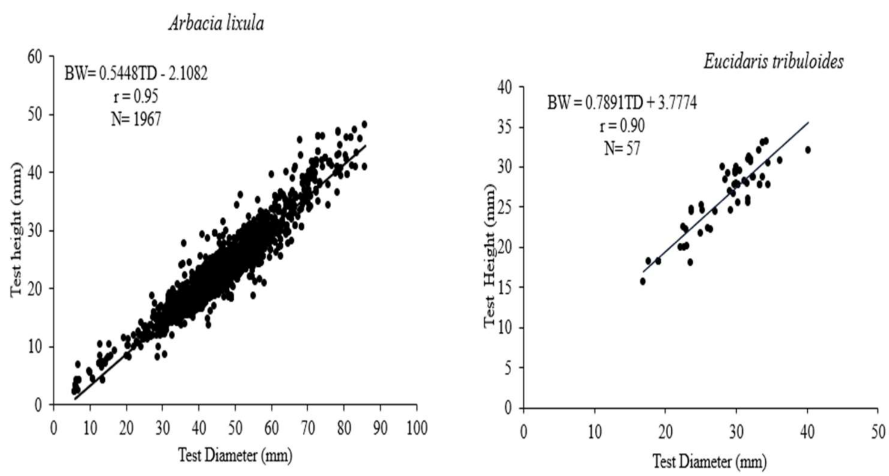

Figure 14: Test height-diameter relationship of *Arbacia lixula* and *Eucidaris tribuloides*.

Table 6: Summary for Regression Analysis of *Arbacia lixula* and *Eucidaris tribuloides*

Parameters	*Arbacia lixula*	*Eucidaris tribuloides*
R^2	0.9	0.8
r	0.95	0.91
Slope	0.54	0.79
Intercept	-2.11	3.78
F stat	17434.38	225.02
T stat	132.04	15
P – value	0	0

R^2 = Coefficient of determination, r = correlation coefficient

Ratio Between Test Height (TH) and Test Diameter (TD) of Sea Urchins along the Sampled Stations

The test height and test diameter ratio represent the structural variations that existed between the various specimens collected for all sampled stations. On the species base, it describes how each species varies in terms of size, shape and predicts trends with seasonal variations among them. It also influences phenotypic variation and disease in species.

The percentage mean ratio between the test height and test diameter of *Arbacia lixula* sampled was highest of 53 ± 0.07 % at Nyanyano and lowest of 48 ± 0.03% at Axim as shown in Figure 15. Statistically, significant difference was observed among the sampled stations at $p < 0.05$. The percentage mean ratio between the test height and test diameter of *Eucidaris tribuloides* recorded was equal at all stations sampled and highest 67% compared the ratios of the sea urchins sampled in the study. The highest percentage mean ratio between the test height and test diameter of *Echinometra lucunter* and the unidentified species were 56 ± 0.06 % and 52 ± 0.07 % at Nyanyano respectively. Statistically significant difference was not observed among the stations where *Eucidaris tribuloides, Echinometra lucunter* and the unidentified species were sampled at ($p < 0.05$) as summarized in Appendix C.

Temperature

The mean temperatures recorded during sampling at each station showed a minimum and maximum range of 27.733 °C and 32.767 °C at Dixcove and Cape Coast (Table 7). Statistically, significant difference was observed among the sampling stations at $p < 0.0001$.

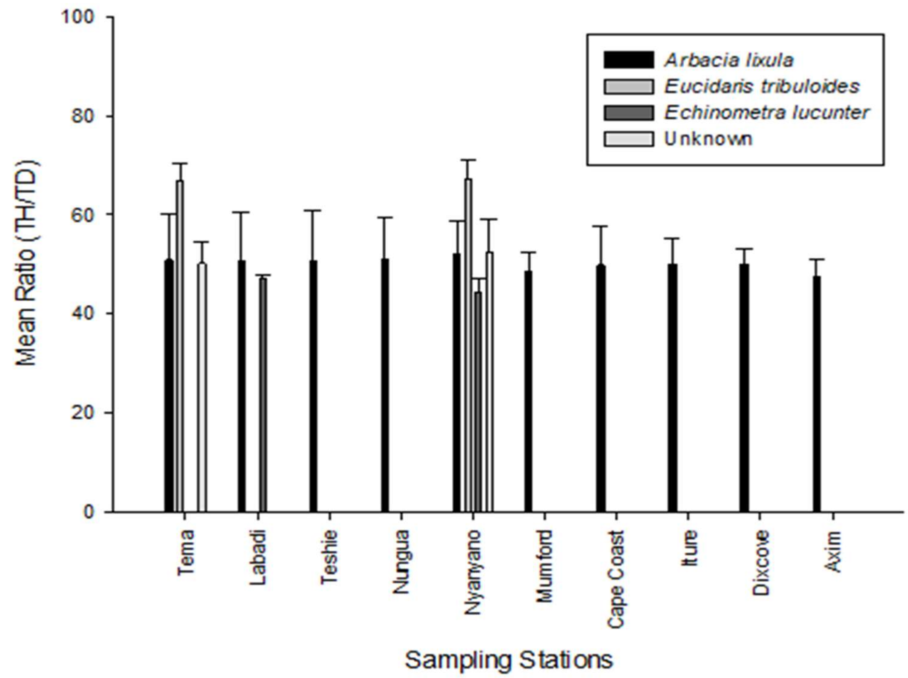

Figure 15: Percentage mean ratio of test height and test diameter of sea urchins sampled along the sampled stations.

Table 7: Mean Temperatures of the Sampled Stations

Station	Temperature (mean ± sd) ºC
Tema	29.295 ± 1.489 a
Nungua	29.267 ± 1.858 ac
La	29.670 ± 2.371 ac
Teshie	29.305 ± 1.519 ac
Nyanyano	28.385 ± 1.504 ac
Mumford	32.667 ± 0.577 ab
Cape coast	32.767 ± 0.252 ab
Iture	30.667 ± 0.057 abc
Dixcove	27.733 ± 0.643 ac
Axim	34.233 ± 2.892 b

Where stations with same letters represent no mean significant differences

Socioeconomic Assessments of the Ghanaian Sea Urchin Fishery

Demography of sea urchin harvesters

A total of 124 respondents were engaged for the socio-economic assessment of the urchin fishery along the coast of Ghana. The highest number of respondents engaged were in La and Nungua (18) and the lowest in Mumford (6).

Age and gender of respondents

Most of the coastal dwellers interviewed along Ghana's coast were in three age classes ranging from 13 to 19 years, 20 to 40 years and age group above 40 years. The dominant male and female age classes were between 13 and 19 years and 20 and 40 years, respectively, as shown in Figure 16.

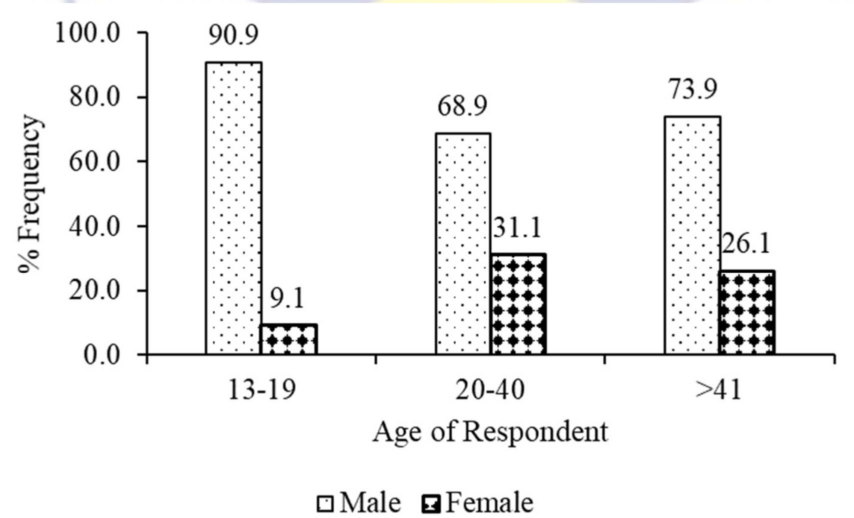

Figure 16: Graph of the percentage frequency of respondents age and gender.

The gender distribution of respondents at each station is presented in Table 8. Males were the dominant group interviewed in the fishery constituting 71.8% of the respondents while females made up 28.3 %.

Table 8: The Gender Dynamics of Male and Females at Sampling Station

Stations	% (Number)		Total
	Male	Female	
Tema	75 (9)	15 (3)	12
Dixcove	84.6 (11)	15.4 (2)	13
Nungua	61.1 (11)	39.9 (7)	18
La	77.8 (14)	22.2 (4)	18
Teshie	60 (6)	40 (4)	10
Nyanyano	75 (9)	25 (3)	12
Mumford	83.3 (5)	16.7 (1)	6
Cape Coast Castle	75 (9)	15 (3)	12
Iture	62.5 (5)	37.5 (3)	8
Axim	66.7 (10)	33.3 (5)	15

Education and occupation of respondents

The dominant participant interviewed at all the study sites had their highest education level at the Junior high school with the least at the O' level and tertiary as shown in Figure 17.

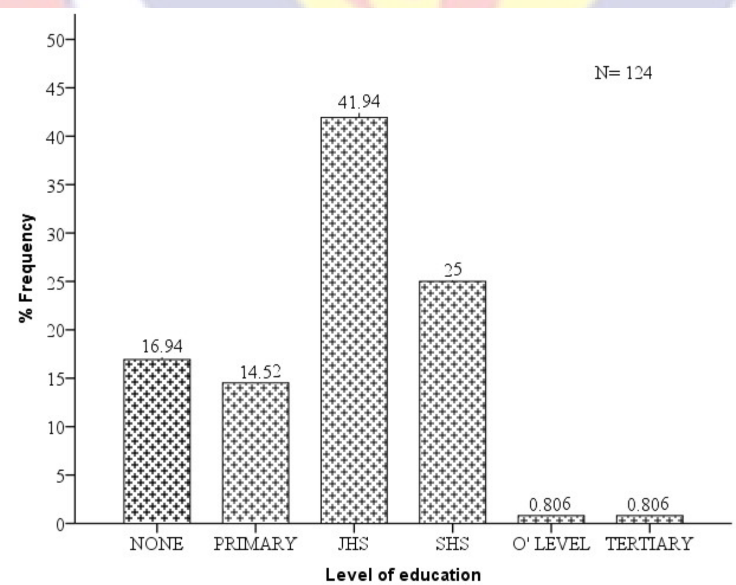

Figure 17: Education level of participant interviewed during the study.

The occupation of the participant interviewed revealed that sea urchin harvesters were predominately fishermen and unemployed individuals within the coastal communities studied as shown in Figure 18.

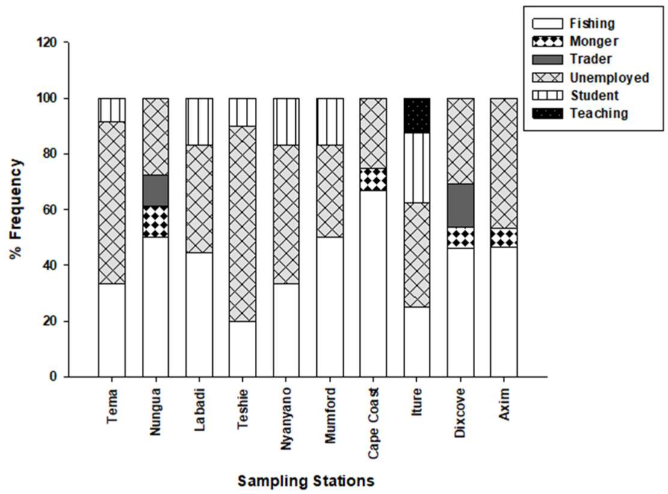

Figure 18: Occupation of participant interviewed during the study at each sampling.

The magnitude of the relationship between the effect size and categorized variables were explored using Cramer's *V*. The demographic spatial distribution of the respondents surveyed along the coast of Ghana is presented in Table 9. There were spatial variations in the demographics across the entire sampling stations at ($p < 0.05$) with proportions following highest females recorded at Nungua (20%) and highest males at La (15.7%). The proportion of age across the stations showed highest > 40 respondents at Axim (19%), 20 – 40 at Nungua (18.5%) and 13 – 19 at La (27.3%). The highest education level attained by the respondents indicated a wide spatial variation (χ^2 = 225.051, *df* = 5, P = 0.000), with Axim, Cape Coast and Nungua recording the highest non-educated respondents (20%). This was followed by highest primary education at La (50%) > JHS at Nungua and Nyanyano

(16.4%) > SHS at Tema (32.3%) > O' Level with occurring only at Teshie (100%) > Tertiary occurring only at Iture (100%).

The primary occupation of respondents involved with the sea urchin fishery across the sampling stations showed fishermen and Fish mongers dominating at Nungua with 17% and 50% respectively. Majority of the respondents who were students concentrated at La (30%), Respondents engaged in teaching were only encountered at Iture (100%), most of the traders were found at Dixcove and Nungua at 33.3% whiles majority of the unemployed respondents located at La, Tema and Teshie representing 14% across the station.

Table 9: Spatial Distribution of Respondents in Axim (N=15), Cape Coast (N=12), Dixcove (N=13), Iture (N=8), La (N=18), Mumford (N=6), Nungua (N=18), Nyanyano(N=12), Tema (N=12) and Teshie (N=10)

	Axim	Cape Coast	Dixcove	Iture	La	Mumford	Nungua	Nyanyano	Tema	Teshie	Measures of ass
Sex (%)											Pearson $\chi^2(1) = 129.220$
Female	14.3	8.6	5.7	8.6	11.4	2.9	20.0	8.6	8.6	11.4	Pr = 0.000
Male	11.2	10.1	12.4	5.6	15.7	5.6	12.4	10.1	10.1	6.7	Cramer's $V = 0.719$
Age (%)											Pearson $\chi^2(2) = 141.910$
> 40	19.0	14.3	9.5	9.5	14.3	9.5	4.8	9.5	4.8	4.8	Pr = 0.000
20 – 40	12.0	9.8	12.0	5.4	13.0	3.3	18.5	8.7	9.8	7.6	Cramer's $V = 0.615$
13 – 19	0.0	0.0	0.0	9.1	27.3	9.1	0.0	18.2	18.2	18.2	
Education (%)											Pearson $\chi^2(5) = 225.051$
No Education	20.0	20.0	10.0	5.0	5.0	5.0	20.0	10.0	0.0	5.0	Pr = 0.000
Primary	20.0	0.0	0.0	10.0	50.0	0.0	10.0	0.0	10.0	0.0	Cramer's $V = 0.548$
JHS	14.8	9.8	13.1	4.9	18.0	4.9	16.4	16.4	1.6	0.0	
SHS	0.0	6.5	9.7	6.5	3.2	6.5	9.7	0.0	32.3	25.8	
O' Level	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	
Tertiary	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	
Occupation (%)											Pearson $\chi^2(5) = 175.693$
Fishing	13.2	15.1	11.3	3.8	15.1	5.7	17.0	7.5	7.5	3.8	Pr = 0.000
Monger	25.0	0.0	25.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	Cramer's $V = 0.484$
Student	0.0	0.0	0.0	20.0	30.0	10.0	0.0	20.0	10.0	10.0	
Teaching	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	
Trader	16.7	16.7	33.3	0.0	0.0	0.0	33.3	0.0	0.0	0.0	
Unemployed	12.0	6.0	8.0	6.0	14.0	4.0	10.0	12.0	14.0	14.0	

Rows sum up to 100%

The survey considered knowledge on whether there were different kinds of sea urchin species along the coast of Ghana. A crosstabulation of communities and respondents' knowledge on different kinds of sea urchin are shown in Table 10. Along the coastline of Ghana, communities such as Axim, Mumford, La, Nyanyano and Teshie had different species of sea urchins occurring in their waters constituting about 100 % whilst respondents at Cape coast castle only indicated one type of sea urchin to be dominated in its waters.

Table 10: Distribution of Respondents on the Knowledge of Occurrence on Difference Kinds of Sea Urchin along the Coast of Ghana

Community (%)	Knowledge on the existence of different kinds of sea urchins		Measures of association
	No	Yes	
Axim	0.0	100.0	Pearson $\chi^2(9) = 102.517$
Cape Coast	100.0	0.0	
Dixcove	92.3	7.7	Pr = 0.000
Iture	12.5	87.5	Cramer's $V = 0.909$
La	0.0	100.0	
Mumford	0.0	100.0	
Nungua	5.6	94.4	
Nyanyano	0.0	100.0	
Tema	8.3	91.7	
Teshie	0.0	100.0	

A cross-tabulation of the community, occupation and age of respondents and how sea urchins are harvested showed significant difference among the respondents as shown in Table 11. Diving and picking of sea urchins were the main ways sea urchins were harvested. Diving was highly dominant at Cape Coast, Dixcove, La, Nungua, Nyanyano, Tema and Teshie.

Most of the fishermen surveyed were engaged in diving (73.6%), majority of the females were involved in picking sea urchin (97.1%).

Table 11: Distribution of Respondents on How Sea Urchins are Harvested Along the Coastline of Ghana

	How sea urchins are harvested		Measures of association
	Diving	Picking	
Community (%)			Pearson $\chi^2(9)$ =
Axim	6.7	93.3	37.072
Cape Coast	75.0	25.0	Pr = 0.000
Dixcove	84.6	15.4	Cramer's V = 0.547
Iture	12.5	87.5	
La	72.2	27.8	
Mumford	16.7	83.3	
Nungua	50.0	50.0	Pearson $\chi^2(5)$ =
Nyanyano	66.7	33.3	21.378
Tema	83.3	16.7	Pr = 0.001
Teshie	50.0	50.0	Cramer's V = 0.415
Occupation (%)			
Fishing	73.6	26.4	
Monger	0.0	100.0	
Student	70.0	30.0	
Teaching	0.0	100.0	
Trader	16.7	83.3	
Unemployed	42.0	58.0	
Sex (%)			Pearson $\chi^2(1)$ =
Female	2.9	97.1	53.204
Male	75.3	24.7	Pr = 0. 000
			Cramer's V = 0.655

The distribution of responses based on the community, occupation and age of respondents on sea urchin sales in Ghana are presented in Table 12. There was no commercial activity for the sea urchin fishery at Axim, Cape Coast, Dixcove and Iture. The sea urchins were mostly sold by students (70%), followed by unemployed people along the coast of Ghana. Based on the age demographics it was observed that the sale of sea urchins was mostly done by persons between the 13 and 19 years representing 81.8%.

Table 12: A Crosstabulation of Communities, Occupation and Age of Respondents on Sea Urchin Sales on Ghana's Coast

	Sale of the sea urchin harvested		Measures of association
	No	Yes	
Community (%)			Pearson $\chi^2(9) = 107.681$
Axim	100.0	0.0	Pr = 0.000
Cape Coast	100.0	0.0	Cramer's $V = 0.932$
Dixcove	100.0	0.0	
Iture	100.0	0.0	
La	0.0	100.0	
Mumford	100.0	0.0	
Nungua	77.8	22.2	
Nyanyano	8.3	91.7	
Tema	0.0	100.0	
Teshie	0.0	100.0	
Occupation (%)			Pearson $\chi^2(5) = 12.942$
Fishing	67.9	32.1	Pr = 0.024
Monger	75.0	25.0	Cramer's $V = 0.323$
Student	30.0	70.0	
Teaching	100.0	0.0	
Trader	83.3	16.7	
Unemployed	42.0	58.0	
Age (%)			Pearson $\chi^2(2) = 7.432$
> 40	66.7	33.3	Pr = 0.024
13-19	18.2	81.8	Cramer's $V = 0.245$
20-40	57.6	42.4	

A crosstabulation of the community of the respondents and knowledge on how sea urchins are processed is presented in Table 13. Across the entire stations in Ghana, sea urchins are processed either fresh, roasted or boiled. Sea urchins were only processed fresh at Axim, Cape Coast, Dixcove, La, Mumford and Nungua.

Table 13: Distribution of Respondents on How Sea Urchins are Processed

Community (%)	Processing of sea urchin for consumption		Measures of association
	Fresh	Roasting and boiling	
Axim	100.0	0.0	Pearson $\chi^2(9) = 44.291$Pr = 0.000
Cape Coast	100.0	0.0	Cramer's $V = 0.598$
Dixcove	100.0	0.0	
Iture	75.0	25.0	
La	100.0	0.0	
Mumford	100.0	0.0	
Nungua	100.0	0.0	
Nyanyano	66.7	33.3	
Tema	41.7	58.3	
Teshie	90.0	10.0	

Knowledge perception of sea urchin

Findings indicate that all participants had knowledge about sea urchin and knew about the existence of the organism since the sampling was purposive. According to the participants, sea urchins occur in the coastal waters of local communities where rocks were available. Participants at all sampled station also specified that there were about three different species of sea urchin in their locality which mainly included the black sea urchin, the white sea and brown sea urchin with some showing photos of the descriptions of the species as shown in Figure 19.

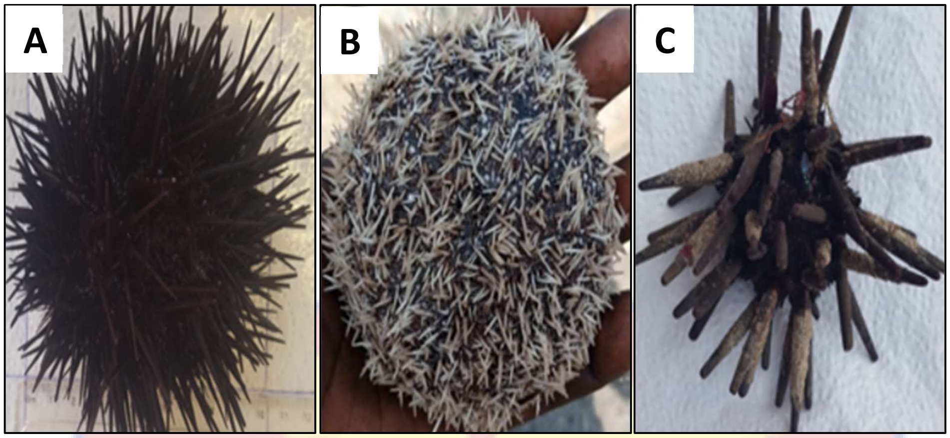

Figure 19: Sea urchins identified by respondents to exist in Ghana's coastal waters. A – *Arbacia lixula*, B – *Tripneustes ventricosus* and C – *Eucidaris tribuloides*.

The gleaners of sea urchin species at Tema only encountered the white sea urchin once awhile during harvesting period whereas the other stations harvest the black sea urchin. The brown urchin is unharvested due to its non-edible state, however communities such as Nyanyano, Nungua, Tema and La reported on the existence of the species in their locality. In describing the sea urchins, participants use body colour and the nature of spines to distinguish among the various sea urchin species. The different names were assigned to the organism by participants based on their local dialect as shown in Table 14. Findings also indicated that the sea urchins can be found in rocky environment. Specific communities where urchins could be found aside their localities mentioned included Accra, Nyanyano, Axim, Dixcove, Elmina, Apam, Half Asini, Mumford, Biriwa, Cape Coast and Elmina.

Table 14: Local Names of Sea Urchin Species Along the Coastline of Ghana

Scientific name	Common name	Local name	Places found
*Arbacia lixula****	Black sea urchin	Angbe	Tema, Teshie, Nungua, La
		ɛposen, ɛposile	Mumford, Nyanyano, Cape Coast, Iture, Dixcove, Axim
Tripneustes ventricosus ***	White sea urchin	Angbe Gezegeze, YoomƆ angbe	La, Tema
Echinometra lucunter ***	Black short spine urchins	Sea Raster	Nungua, La, Tema
Eucidaris tribuloides	Pencil/brown sea urchins	Sesaangbe, Angbe sesa, Angbe NumƆ	Tema, Teshie, Nungua, La
Unidentified species		ɛposaman	Nyanyano
		Angbe NiitsemƆ	Tema
		Saman atta	Nyanyano

*** = edible

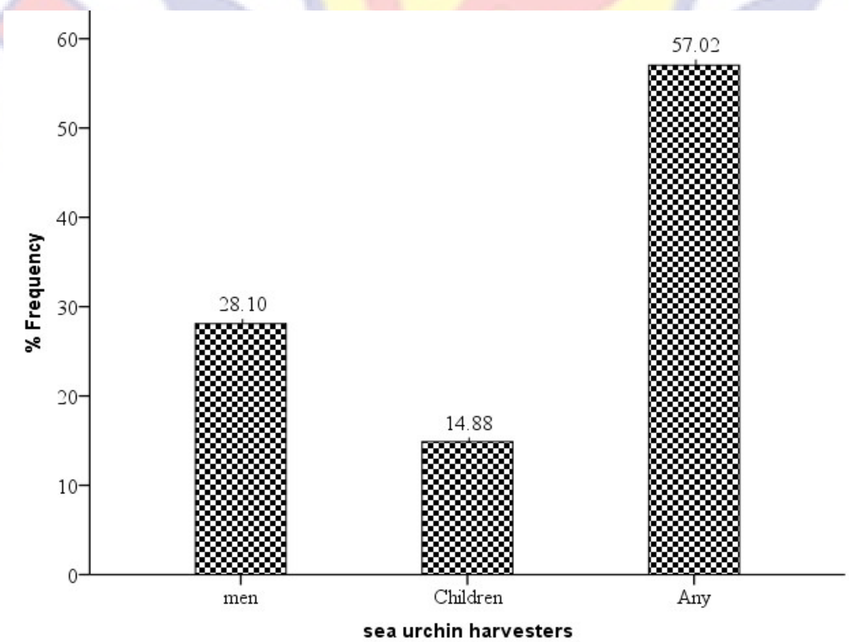

Figure 20: Participation of sea urchin harvesters.

Sea urchin fishing methods

Findings from the study indicated that majority of the urchin fishery in Ghana was mainly exploited at the subsistence level. However, the harvesting rate varies among fishing communities. Few commercial harvesting of sea urchins occurs at Tema, La, Teshie and Nyanyano which are classified as fishing communities. Non fishing communities included; Nungua, Mumford, Cape Coast castle, Iture, Dixcove and Axim. These category of non-fishing communities although are subsistence, harvesting was based on demands from individual harvesters. Almost everyone who could move to the beach or shallow dive collected urchins. Along the beach, sea urchins were easily accessible to locals because the species were visible to the naked eye when attached to the rocky substratum within the intertidal regions. Further, minimal diving equipment were needed during sampling around the nearshore areas. Participants reported that, Sea urchins are harvested in two forms namely; hand picking and diving.

Hand picking

This method mostly occurred at the upper intertidal areas during low tides. Urchins are collected by hand with sharp metallic objects or knives. Hand picking technique was mostly engaged by women and children between the ages of 13 and 40 years since it was less energy demanding. Hand picking of sea urchin were primary done at all sampled areas including Cape Coast castle, Iture, Nungua, Mumford and Axim etc.

Diving

This method was dominated mainly by males between the age groups of 13 and 40 years. Diving was done singly or jointly in groups of two or three where divers attached sacks with floating object (Styrofoam) to their waist to aid in buoyancy. Harvesting of sea urchin by divers were done only at low tides. Urchins were removed from the substratum with sharp metallic objects (which were locally made) and knives at the subtidal zone. In the active fishing communities such as Tema, La, and Teshie, diving of sea urchins within the region was how urchin were collected as illustrated in Figure 21.

Figure 21: Harvesting of sea urchin. A and B – Hand picking of sea urchins, C and D – Diving for sea urchins, E – Diver's sack and F – Metallic tool for removing sea urchins.

Pre-harvest of sea urchin in Ghana

According to some coastal dwellers at Tema (especially the women and children), before sea urchins were collected, samples were picked to access the ripening of the sea urchin gonads at areas where clusters or aggregation of sea urchins were dominant. Reports also from La and Teshie also indicated that during testing of the sea urchin gonads, opened urchin test sometimes contains water without eggs. In the instances where sampled urchins were observed to contain more fluid than roe, gave an indication to the locals of eggs shedding or gonad undeveloped period of the urchins and hence it prevented them from harvesting. This reason made divers in those communities' dived for sizable urchin with bigger gonads for marketing during those periods.

Post-harvest preparation of urchins in Ghana

The methods of post-harvest preparation of sea urchin were similar for all the harvesting communities. Prior to arranging the sea urchin for the market, the collected urchins are roasted in an open fire for approximately 20 mins to soften the spines on the test for easy removal whereas the roe of the urchin inside the test got cooked. The spines are gently removed and the cooked test are arranged on a board or head pan for the market or street hawked. Consumers buy the roasted urchins and sometimes request the vendors break the test for the them to access the cooked roes. Alternatively, the collected sea urchin was purchased live close to the landing site without roasting. The tests are broken to access the fresh roe which are mostly boiled directly before consumption or used in preparing stews and soups as shown in Figure 22.

Figure 22: Post-harvesting of sea urchin. A – Fresh urchins to be roasted with spines, B – Removing of spines after roasting, C – Roasted Sea urchin, D – Removing of spines before roasting, E – Cooked urchin eggs after roasting, F – Roasting of urchins without spine, G – Cooking of sea urchins and H – Fresh Sea urchin eggs.

How sea urchins are eaten

According to the participants, sea urchins are eaten directly from the shell or the roes are removed into a dish plate after processed through boiling or roasting. Before sea urchins are consumed, some participants gently pick the freshy boiled urchin and make a hole using knives or spoon in the underside of the urchin species (flatter side) to drain the coelomic fluid. They slowly cut a circle at the bottom of the shell to take of the base. Once open the visceral content including the digestive systems (black things) inside are removed and discarded leaving the roe (yellowish substances) which is edible. However, roasted sea urchins are crushed open using a knives or metallic rod. The same mechanism on the boiled urchin was administered thus eating of the roe and discarding the other visceral content. The roe could be used to prepare stews or eaten directly with other dishes including rice, kenkey, banku, yam and many more.

Also, other parts of the organism such as the spines, internal organs, test and the Aristotle lanten have no nutritional and economic value. According to some of the coastal dwellers, pregnant women eat a lot of sea urchin roe during pregnancy but they could not ascribe empirical or scientific reasons to it. Other participants also indicated that, eating of sea urchin roe provides them with some source of energy.

Economic value of sea urchin

The sea urchin fishery in Ghana provides viable income supplement for the harvesters that are engaged in the commercialization of the resource among the coastal communities. According to the survey, the sales of sea urchins varied by quantities per price between communities and individuals. The prices ranged from GH₵ 0.5 to GH₵ 5.00 (\$0.082 to \$0.82). On sale, roasted sea urchins are arranged in three grades namely based on the test diameter sizes; approximately 25 – 40 mm (small sizes), 41 – 60 mm (medium sizes) and above 60 mm (large sizes) as shown in Table 15. The average quantity on display during sales observed within all the communities trading in the sea urchin resource were 3 and 4 pieces (Figure 23). Sea urchins were mostly hawked in busy traffic and local communities by the harvester who mostly double as the vendors.

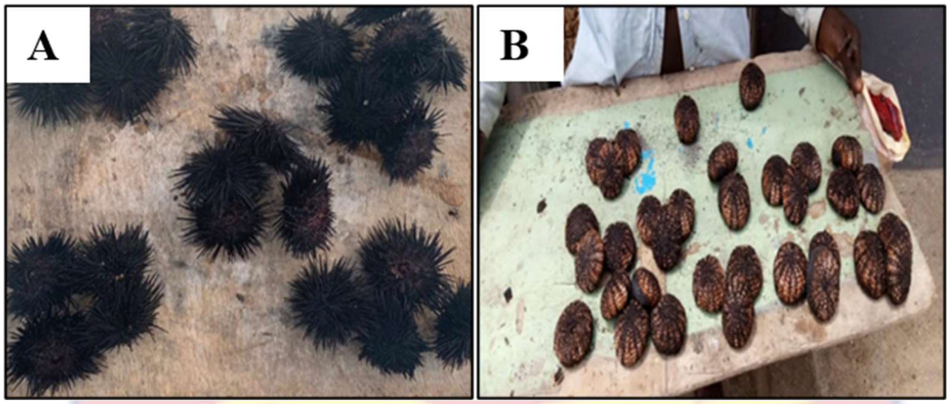

Figure 23: Sales of sea urchins on a wooden board. A – Sea urchin with spines and B – Sea urchin without spines.

Management

Among all the ten coastal community interviewed there were no institutions set in place in relation to sea urchin management. Within the communities, there were no personal, community or institutional strategy or stakeholders' engagement programme outlined or activities adhered towards the conservation and utilization of sea urchin species.

Table 15: Price of Sea Urchin Species in Ghana

Items	Size ranges (mm)	Quantity (Weight, g)	Total cost (GH₵)	Quantity sold /(day)	Income /(day) (GH₵)	Income /(day) ($)
Roasted	25 – 40 (small)	3-20 (39-260)	0.5-2	80-120	8-13	1.32-2.14
	41– 60 (medium)	5-20 (110-440)	1-5	70-100	15-25	2.47-4.11
	>60 (larger sizes)	1-13 (88-1144)	1-5	30-50	30-50	4.93-8.22
Fresh	2 – 40 (small)	7-30 (91-390)	0.5-2	100-120	8-13	1.32-2.14
	41–60 (medium)	5-20 (110-440)	1-3	80-100	5-20	0.82-3.29
	>60 (larger sizes)	3-16 (264-1408)	1-5	20-50	10-35	1.64-5.75
Roasted (Sacs)	> 30	> 100 (>3000)	50-100	1-2 sacs	50-200	8.22-32.88
Fresh (Sacs)	>30	> 150 (>4500)	30-60	1-3 sacs	50-100	8.22-16.44

Exchange rate: GH₵ 1 = $ 6.07 (2nd September, 2021)

CHAPTER FIVE

DISCUSSION

This chapter discusses the results obtained from analyses of occurrence, distribution and species composition of sea urchins in Ghana. Also, discussed are size structural features, shell diameter and body weight relationships, shell height-diameter relationships, and ratio of test height to test diameter. A note is made of the urchin fishery in the country.

Occurrence and Distribution of Sea Urchins

From the study, sea urchins were found present at all the sampled stations over the study period, which suggested that sea urchin populations were found across the rocky coast of Ghana. Sampling of sea urchins were limited within the rocky substratum around the intertidal regions in this study. The occurrence suggests that rocky beaches were the main driving forces influencing the prevalence of the sea urchin species within the study area. According Coma et al. (2011), sea urchins are highly invasive within coral reefs and rocky intertidal system. However, among the urchin species sampled, *Arbacia lixula* dominated the entire coastline of Ghana which stretched from the east to the west coast as shown in (Figure 2). The presence of *A. lixula* in Ghana has been reported by Gauld & Buchanan (1959) at Cape Coast, Elmina and Accra within the lithothamnia zone.

This contradicts findings by Ateweberhan, Gough, Fennelly & Frejaville (2012), in a baseline research on the nearshore rocky reefs of Western Ghana, that found *Eucidaris tribuloides* (Lamarck, 1816) to be the only sea urchin encountered in Ghana. This could be probably be due to their sampling technique used, habitat type and symbiotic associations with

Eucidaris tribuloides that could have contributed to their occurrence in the area. According to Madeira, Kroh, Cordeiro, Meireles & Avila (2011) and Gianguzza & Bonavirie (2013) described *Arbacia lixula* as highly prevalent within the topics and subtropics, with distribution spread across the entire Atlantic ocean. *Arbacia lixula,* have been reported to inhabit shallow rocky bottoms within depths of about 80m (McPherson, 1969), which could have made the species easily accessible to the collectors, thus skewing the findings towards their dominance in this study. Also, according to Bulleri et al. (2002) and Costa et al. (2018), *Arbacia lixula* were capable of defining the nature of marine ecosystem by reducing the availability of resources for other species.

Eucidaris tribuloides was found at Nyanyano and Tema. This study affirms the occurrence of *Eucidaris tribuloides* in Ghana. The occurrence of *Eucidaris tribuloides* in Ghana has been reported by (Lessios et al.(1999) and Ateweberhan, Gough, Fennelly & Frejaville (2012). According to Ateweberhan, Gough, Fennelly & Frejaville (2012), *E. tribuloides* was found to be highly abundant in Princess Town, followed by Abokwe Island located in the Western Region of Ghana. Lessios et al. (1999), in a phylogeography study of the *Eucidaris sp*. confirmed the presence of *Eucidaris tribuloides* in Ghana through genetic markings. Similarly, *Echinometra lucunter* was found to occur at Nyanyano and La and one unidentified species were found at Nyanyano and Tema. *E. lucunter* resembled *Arbacia lixula* with its' coloration. However, blunt spines were the most distinctive feature of *E. lucunter* as shown in Figure 7.

The present of *E. lucunter* in this study affirms species observation by Gauld & Buchanan (1959). *E. lucunter* was first described as present in

Ghana by Gauld & Buchanan (1959), the study indicated the species dominance within the lithothamnia zone of rocky beaches at Cape Coast, Elmina and Accra. According to Gauld & Buchanan (1959), the association of *E. lucunter* and *Arbacia lixula* within the lithothamnia zone considering dominance were inversely related. Further, high numbers of *Echinometra lucunter* was found in spherical pits within rocky ridges.

Species Composition

A total of 2,042 sea urchin specimens were sampled over the study period. Nyanyano recorded the highest species composition, with the occurrence of all four sampled species at the station. However, the highest species abundance was recorded at Tema. Among the stations, several factors could have accounted for the variations in species composition and abundance encountered such as diving efficiency, habitat geomorphology, nature of the species and sampling technique. According to Micheli et al. (2005), recruitment variability, availability of shelters, food subsidies, hydrographic conditions and substrate topography are major drivers that influenced the assemblage of marine species within a particular ecosystem.

From the study, Nyanyano with the high species occurrence could be attributed to the wide geomorphological features of the coast. This included the type of rocks, food availability, and other hydrographic parameters like temperature (28.385 ± 1.504 ºC) and tidal influx that were tolerable by diversity of sea urchin species within the area. The level of exploitation at Nyanyano could be considered moderately low which had minimal impact on the species abundance within the area. Also, the topography of the station could have influence sampling at wider tidal zones that have an impact on composition. At Tema, *E. lucunter* was not encountered, reasons could be associated with overfishing of the species within the area. *E. lucunter* is noted to inhabit exposed rocky pits which could have made them vulnerable to sea urchin harvesters and other predators. In Tema, another possible effect of the disappearance of *E. lucunter* could be attributed to high sea-level rise. Sea level rise could also influence the sheltering of patchy rocky substratum limiting habitat space for the species.

Echinometra lucunter strives well on an exposed rocky substratum as documented by and Gauld & Buchanan, (1959) and McPherson, (1969). However, the influx of tidal influence could impact its composition and abundance in an ecosystem. At La, two species (*A. lixula* and *E. lucunter*) were found to occur the area. This could be attributed to the wide variation in rocky substratum that co-existence of both species. The absence of *E. tribuloides* could be associated with the sampling area considered which was mainly within the rocky intertidal sections, limiting capture to species only habiting in such areas.

The remaining stations had only *A. lixula* which had high tolerance to varying conditions. Anthropogenic activities such as pollution, overfishing, human encroachment, and construction of sea defence as seen in Axim, Dixcove, Mumford, and Iture could also influence the abundance and composition of sea urchin communities at the locations. Regardless of the presence of other urchins, *A. lixula* resulted in a large reduction in bare rock surface area and a considerable change in algal assemblages, suggesting that this species plays a critical role in sustaining the barren condition (Gianguzza, & Bonaviri, 2013). In the Mediterranean Sea, for example, algal cover increased by 40 – 50% in regions where the sea urchin *Arbacia lixula* was eradicated, whereas it never exceeded 10% in control patches (Bulleri et al., 2002).

Size Structure

In fisheries, the size structure is considered the most utilized evaluation tool in assessing species population dynamics. At any one time, the size structure of a sea urchin population can be considered a snapshot that displays the complex relationship between the recruitment, mortality and growth. As a result, length-frequency information provide vital insight into the changes occurring in the urchin populations and aid in the identification of issues such as species size-class strength inconsistencies, poor growth, or high mortality according to Neumann & Allen (2007). The result from the study shows that the *Arbacia lixula* size range was between 5.8 mm – 85.8 mm and a modal class of 45 – 50 mm for all sampled stations. Comparatively, this support findings of *Arbacia lixula* size ranged from 15 mm to 60 mm in test diameter (TD) in the Mediterranean Sea (Elmasry et al, 2015).

Along the sampling stations, *Arbacia lixula* exerted dominance among the sampled species. The distribution of *Arbacia lixula* was wide homogenous, this indicates the high prevalence of the species within the coastline of Ghana. Nungua and Nyanyano presented larger size specimens while samples in Tema were relatively smaller than the others as shown in Figure 10. This may be a result of overexploitation, topography, nature of species, and hydrographic conditions. In Tema, the socio-economic data obtained, coupled with samples collected indicated that the large sizes were overexploited leaving the smaller sizes. Large sizes of *Arbacia lixula* at Tema are of high commercial value.

Also, the coastline of Tema was categorized as a high urbanized coastal area of which activities could induce high organic loads into the coastal shores.

According to Chiarelli (2019), urchins are highly susceptible to pollution-causing the loss of spines of individual species leading to increased mortality. This could also account for their smaller sizes. Again, tidal influx could probably influence the juveniles of *Arbacia lixula* to drift and anchored onto the coastline at Tema. Also, Nyanyano recorded the largest size for *Arbacia lixula* sampled during the study period. However, the failure for the study to be carried out a yearlong sampling limited the generalization of the largest size of sea urchin occurring within the coastline of Ghana. The removal of *Arbacia lixula* was considered episodic since harvesting was based on demand.

The number of harvesters within Nyanyano was substantially lower than all areas where *Arbacia lixula* were harvested in Ghana. The major economic activity, fishing usually targets finfishes and occasionally some shellfishes as well. The gears used in fishing in this area were mostly targeted to finfishes. Also, minimal anthropogenic activities were impacting the ecosystem within the intertidal area of Nyanyano. In areas where smaller *Arbacia lixula* sizes were sampled, harvesting of the species was only at the subsistence level. These stations included Cape coast, Axim, and Dixcove which may probably be as a result of low food availability, intraspecific competition for space, and habitat modifications influence community assemblage affecting food availability.

Eucidaris tribuloides from the study had size ranges for test diameter as 24.7 mm – 47.7 mm and a modal class of 40 mm – 45 mm as shown in

Figure 8. In the habitats off south-eastern Florida, the test-diameter of *Eucidaris tribuloides* range from 8 mm to 39 mm (McPherson, 1968). Test diameter of 19 mm to 23 mm of *E. tribuloides* was also found in the San Blas Islands of Panama (Shulman, 1990). *E. tribuloides* rarely exceed 30mm in test diameter (Lessios, Kessing, Robertson & Paulay, 1999), though the maximum recorded size is 130 mm (Hendler, Miller, Pawson, & Kier, 1995). However, the maximum and minimum sizes of *E. tribuloides* obtained from the study were within the normal size ranges as compared with the aforementioned research. *Eucidaris tribuloides* occurred at Nyanyano and Tema, its absence in other stations could perhaps be as a result of unfavourable environmental conditions.

Also, the lowest and highest test diameter for *Echinometra lucunter* was 47 mm – 58.3 mm with a bimodal class of 45 mm – 50 mm and 50 mm – 55 mm. Similarly, the test diameter of *E. lucunter* was 25 mm –70 mm at Cox's Bay (Ebert, Russell, Gamba & Bodnar, 2008). McPherson (1968) recorded a range between 20 mm – 70mm of *E. lucunter* in south-eastern Florida, even though, the sizes obtained during the study were smaller compared with sizes in Cox's Bay. Ascribe reasons could be attributed to overfishing, diseases, and predations since coastal dwellers harvest or consume black sea urchins in Ghana regardless of the nature, type, or kind of the species harvested. The habitat preference of *E. lucunter* makes it naturally vulnerable to predation and overexploitation.

The test diameter ranges for unidentified species were 21.8 mm – 31.8 mm with a modal class between 20 mm – 25 mm. Generally, the relative size obtained for the unidentified species was smaller across the sampled area compared to the other species sampled in this study.

Test Height-Diameter Relationship

In this study, sea urchin was observed to grow radially symmetrical. *A. lixula* specimens collected had test diameter growing faster to the test height as shown in Figure 11. Generally, test height to the test diameter ratio for *A. lixula* assumed 1:2 relationship which gives evidence to the plumpness of the organism. This also meant that *A. lixula* was increasing more widely or broader than any increase in height. The observation may probably be due to taxa adaptation features. *A. lixula* is mainly composed of the roe or gonad which is the core edible part of the organism. The relationship between the height and test diameter suggests the creation of space that enhances gonadal development (Conor, 1972). This grants advantage for early maturation at relatively smaller size ranges. The coefficient of determination (r) provides the degree of predictability of the test diameter to test height. The coefficient of determination (r) for *A. lixula* was 0.95. For *E. tribuloides*, the test diameter to test height ratio assumed a 3: 2 relationships. *E. tribuloides* was more elliptical and have the test height increasing more closer to the test diameter. The coefficient of determination (r) for *E. tribuloides* was 0.82. In this study, *E. lucunter* and the unidentified species assumed a test diameter to test height ratio similar to *A. lixula*.

Again, the ratios of the shell height- shell diameter of *A. lixula* sampled across the stations showed significant variation among the stations (Figure 15). This was probably due to environmental limitations. According to De Zoysa, Jinadasa, Edirisinghe, & Jayasinghe (2018) and Rahman et al. (2012)

the feeding habit and environmental conditions had significant influence on the growth pattern between the test height and test diameter of urchins within a particular area. From this study, *A. lixula* at Nyanyano recorded the highest percentage mean ratio (53%) and lowest at Axim (48%). This probably indicated the degree of the species wellbeing which were affected by environmental stressors within the area corroborating with the impact imposed by the activity within the stations (Table 1). For *Eucidaris tribuloides, Echinometra lucunter* and the unidentified species, although no significant variation occurred for the ratio between test height and test diameter among the sampled stations, similar inference on *A. lixula* could be used. The percentage ratio for *Echinometra lucunter* and the unidentified species around 50%, similar to *A. lixula* depict a 1:2 relationship which gives evidence to the plumpness of the organism (Appendix A). Further, the calculated ratio between the shell height- shell diameter of the urchins affirms the growth rate adduced from the slope (b) of the regression line (Figure 14).

Diameter-Weight Relationships

Generally, in fish biology, the relationship between length and weight is used to make inferences about the well-being of the organism. The change in body size and biomass are used mostly to define the growth of organism. However, the change in biomass present a more suited indicator of growth to change in body size due to constant changes in water and food intake. In this study, the relationship between the test diameter and weight assumed a significant linear relationship at all the sampled stations which was in contrast with reports by De Zoysa, Jinadasa, Edirisinghe, & Jayasingh (2018) and Rahman et al. (2012) which considered the relationship on a logarithmic scale.

The study followed Tomšić et al. (2010) which consider the relationship without log transformation of the parameters. However, in the study by Tomšić et al. (2010), the diameter – weight relationship of *Paracentrotus lividus* was considered between the test diameter and body weight with the spines. The spines of sampled specimens were removed in this study since trauma or stress causes breakages of the sea urchin spines resulting in an irregular growth pattern according to Ebert (1986).

Considering the test diameter-weight relationships of sea urchins, the growth rate of the organism was defined by the slope (b) of the fitted regression line. Thus, the higher the slope value indicate a higher growth rate. *A. lixula* at Nyanyano had the highest growth rate (b = 2.13) than the other sampled stations as shown in Table 4 and Figure 12. This might probably be due to the faster growth rate assumed by juveniles resulting from higher metabolic activity. There is a possibility of ontogenic changes that could have occurred among the specimens collected. The lowest growth rate was recorded at Dixcove (b=0.95) as shown in Table 4 and Figure 12. However, the difference in the slope values among stations suggested possible environmental limitations and adaptation of species than ontogenic or post-metamorphic changes.

Similarly, the weight of the urchin was more of a relationship between the shell, roe and the coelomic fluid. Exposure to stress induce the species to shed off fluid which could have affected the weight. For *E. tribuloides* the growth rate between the body weight and test diameter was b= 1.16 as shown Table 5 and Figure 13. The growth rate of *E. tribuloides* at Nyanyano was relatively slower than *A. lixula* at Nyanyano, Mumford and Iture. This is could probably be due to the dominance of *A. lixula* population that might have reduce the availability of food in the habitat and hence reducing the growth rate of *E. tribuloides.*

Socioeconomic Assessments of the Ghanaian Sea Urchin Fishery

Gender role in sea urchin fishery in Ghana

Ghanaian shellfish value status of the respective stakeholders that makes it effective (Adzraku, 2017). Although, the above account did not include sea urchins, the role of urchin value chain in Ghana is also influence by gender, age and educational level. In this study, Ghanaian sea urchin fishery is highly influenced by the sex and age. In this current study, the proportion of females in the urchin fishery constitute about 28.2% and dominant male contributing about 71.8%. Despite, some shellfish fishery especially the oyster fishery in Ghana was with about 97% female as described by Osei, Yankson and Obodai (2020), this contradicted with the current studies.

The harvesting of sea urchins was engaged by both male and female in Ghana. The harvesting of sea urchins exited in two forms namely; diving and handpicking. The advantage of this methods employed in the sea urchin fishery to the other shellfish and finfish fishery was that, it was simple to use. Thus, it involves less capital and resource. Also, the methods required using simple tools such as locally made metallic rod and knives in exploiting the sea urchins. It is not labour intensive and the species was easily accessible since they can be found at the intertidal areas. The sea urchin hand pickers were mainly dominated by women whiles diving were dominated by men.

The segregation of roles by this type of harvester was due to the methods and energy used in harvesting the sea urchin. Diving for sea urchin in Ghana were done by most men and children within the age group of 13 – 40 years. The women in sea urchin fishery either uses the handpicking technique or most often prefer to purchase from the men fresh for home keeps or commercialization. According to Nayer (2009), diving was done by most men with women and adolescents engaged as "breakers" to assist in the breaking and cooking of the urchin roe before marketing.

Education level and occupation of harvesters in sea urchin fishery

Considering the educational level of participants, the sea urchin fishery was engaged by people with a wide level of education, some having formal education within the highest level of tertiary as shown in (Figure 17). However, more than 40% of participants had attained basic formal education to a level of Junior High School (JHS). This is in contrast with the level of education by people within the oyster fishery in Ghana where about 76% were not educated (Osei, Yankson, & Obodai, 2020) this suggest the sea urchin was exploited by individuals who had a fair idea of the economic prospect and the impact that excessive exploitation could impose sustainability of the urchin fishery. Even though the finfish trade is well documented to be dominated by people of less formal education, the level of education by the sea urchin harvesters and traders indicated the active participation of the youth within the communities, reflecting the age bracket obtained in this study (20 – 40 years).

Within the fishing community majority of the youth are fishing crew members, unemployed youth and student with no substantive secure assets in the community. The sea urchin trade then provides a supplementary source of livelihood for the actors. The sea urchin fishery was most done on the subsistence level with few commercial activities. The people involved in the sea urchin fishery were mainly unemployed youth and some fishermen, this was in contrast to the urchin fishery in Califonia, Malaysia and Babardos where the fishery was their main occupation. The age group coupled with the level of education projects a high acceptance for the sector to be formalized and a positive response for any form of innovative training that could enhance development of the sector whiles ensuring the right use of the resource.

Sea urchin value chain

The urchin fishery in Ghana is mainly done at the subsistence level with few communities namely: Nyanyano, Tema, Teshie and La who are engaged in the commercialization of the resource. By proportion, Tema represented the area with most sea urchin fishery activity. This is due to the wide market space the community enjoys as an urbanized dominated coastal community. According to Todd et al. (2019), increased urbanization leads to an increase in the labour force and in the level of consumption of various products, putting a huge strain on crucial marine resources. In Ghana, urchin fishery comprises of three main groups which includes divers and collectors, breakers and vendors which is similar to reports on the sea urchin fishery in California (Kato, 1972), Grenada (Nayar et al., 2009) and Barbados (Pena et al., 2010). According to the harvesters, two edible sea urchins occurred in Ghana’s waters namely the white and black sea urchin. Most often the black urchins were predominantly harvested. Processing of sea urchin involves three main processes; roasting, boiling and unprocessed sea urchin. The majority of the sea urchins are retailed, rather than wholesaled. The value chain within the sea urchin trade was mostly made up of harvesters and seller with most of the harvesters doubling as sea urchin sellers.

The retailing of sea urchins was noted to be highly patronized by the inhabitants and fringe communities. From the harvesters, sea urchins are sold all year long however, majority of the harvesters identified peaking harvest from October to January. This might be due to several factors such as spawning, migratory season for the species or likely the occurrence of an upwelling event that could increase productivity within the intertidal regions. From the survey, it was identified that the only edible part of the sea urchin in Ghana was the eggs or roe similar with the widely consumed part of the urchin internationally (Parvez et al., 2016; Rahman et al., 2012). Per account, sea urchin eggs are mostly used as replacement for eggs in locally prepared stews, 'taken-on-the-go' with bread or kenkey.

Management of urchin fishery in Ghana

In understanding the knowledge of respondents on the possibility of any regulatory body within the sector, 100% of the respondents indicated no knowledge of a regulatory body responsible for the fishery. However, harvesters observed localized days of restrictions to sea and ban on fishing during festive seasons. At Dixcove, Axim, Iture, La and Tema, the sea urchin is locally perceived to be the 'eye of the sea', this myth was backed by the seemly raises in sea level during sampling within those communities. In Tema, most of the urchins harvested were smaller sizes which the respondents attributed to likelihood of overfishing of the larger sizes due to competition. This they account had led to the force migration of harvesters to explore areas outsider their locality such as La, Teshie and Nyanyano waters.

Market value of urchin sales in Ghana

According to Parvez et al. (2016), many coastal countries valued highly the urchin fishery resource. The sales of sea urchin roe provide substantial economic returns that sustain livelihoods for coastal dwellers (Nayar, 2009). In Ghana, the sea urchins are harvested mainly on subsistence as complementary protein source within most coastal households. However, the few commercializing the resource at Tema, Teshie, La and Nyanyano, trade in the freshly harvested urchins, boiled or roasted within the communities. Prices were set by the individual harvester based on the quantity and sizes of the capture. This may probably be associated with the absence of formalized groups or institution within the fishery.

This study attempted to document the average market prices and per day sales of sea urchins in Ghana as shown in Table 15. The per day sales of fresh sea urchins comprising small and larger sized urchins ranged from USD 1.32 to 5.72 and roasted ranged from USD 1.32 to 8.22. The increase in price of roasted urchins to the sale of the fresh were as a result of compensation cost for the source of fuel used in processing the resource. According to the respondents, the main driver influencing more harvesters into the trade was in relation to the zero-cost required for capture of the sea urchins, thus alleviating some financial burdens on the harvesters.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study's summary, conclusions, and suggestions are presented in this chapter. It outlines the study's principal findings, draws implications from them, and gives recommendations for long-term management of the fisheries resource.

Summary

The study sought to assess the sea urchin fishery, analysed the state of the sea urchin in Ghanaian waters in order to provide the biological information needed for proper fisheries resource management. The assessment specifically focused on:

1. Occurrence and distribution along Ghana's coastline
2. Assessment of the diversity of sea urchin species in the coastal waters of Ghana.
3. Assessment of the diversity and growth of the sea urchin fishery along the coastline of Ghana.
4. Provision of information on the demography of fisherfolk, knowledge perception of the urchins, assess exploitation, economic importance of the sea and profitability are presented.

Data was collected over a six-month period along Ghana's coast, specifically from four (4) designated rocky beaches and spot sampling in six (6) settlements. To meet the study's objectives, standard methods and procedures for assessing the occurrence and distribution, structural variations and sea urchin fishery were strictly followed. Samples were identified into taxa, and further examinations were made to address the set objectives.

Conclusions

The study provides information on assessing the existence of sea urchin fishery in Ghana. It provides overview on occurrence, distribution and assess the socioeconomic importance of sea urchins among sampling stations in Ghana from the period of November 2020 to April 2021. The following are some of the conclusions reached:

1. Sea urchins occurs in Ghana's rocky beaches from the east coast to the west coast.
2. Four species of sea urchin species were obtained from the study which includes *Arbacia lixula, Eucidaris tribuloides*, *Echinometra lucunter* and a new unidentified species.
3. It was observed that the test height and test diameter relationships between *Arbacia lixula, and Eucidaris tribuloides* attained a ratio of 1:2 and 3:2 respectively. *Echinometra lucunter* and a new unidentified species assumed the same ratio as 1:2 similar to *Arbacia lixula*
4. *A. lixula* was increasing more widely or broader than any increase in height. However, *Eucidaris tribuloides* was more elliptical and have the test height increasing more closer to the test diameter
5. The diameter-weight relationship of *Arbacia lixula* and *Eucidaris tribuloides* for all sampled station assumed linear function.
6. The size *Arbacia lixula* (5.8 mm to 85.8 mm), *Eucidaris tribuloides (*24.7 mm to 47.7 mm), *Echinometra lucunter (*47 mm to 58.3 mm) and unidentified species (21.8 mm to 31.8 mm) respectively.

7. From the socioecological data, coastal dwellers are exploiting all species of black sea urchins regardless of the type of species under exploitation which had led to the vulnerability of some species such as *Echinometra lucunter*
8. From the study, sea urchins are mostly exploited at the subsistence level and few commercial hooking businesses are their only marketing strategy used in the retailing the species.
9. The edible sea urchin fisheries in Ghana includes *Arbacia lixula* (black sea urchin) and *Echinometra lucunter* (sea raster) as obtained from the study.
10. The were no regulatory body ensuring the sustainable utilization of the sea urchins at all sampled stations.

Recommendations

1. There is the need for capacity building on value addition to the sea urchin fishery.
2. Studies on the exploitation rate and density of the sea urchin should be conducted.
3. Further studies such as DNA sequencing, histology and proximate composition are needed.
4. Further studies should be made on the new species to genetically identify the family or class it belongs.
5. Stock assessment on the sea urchin density and abundance along the coastline requires to be investigated.

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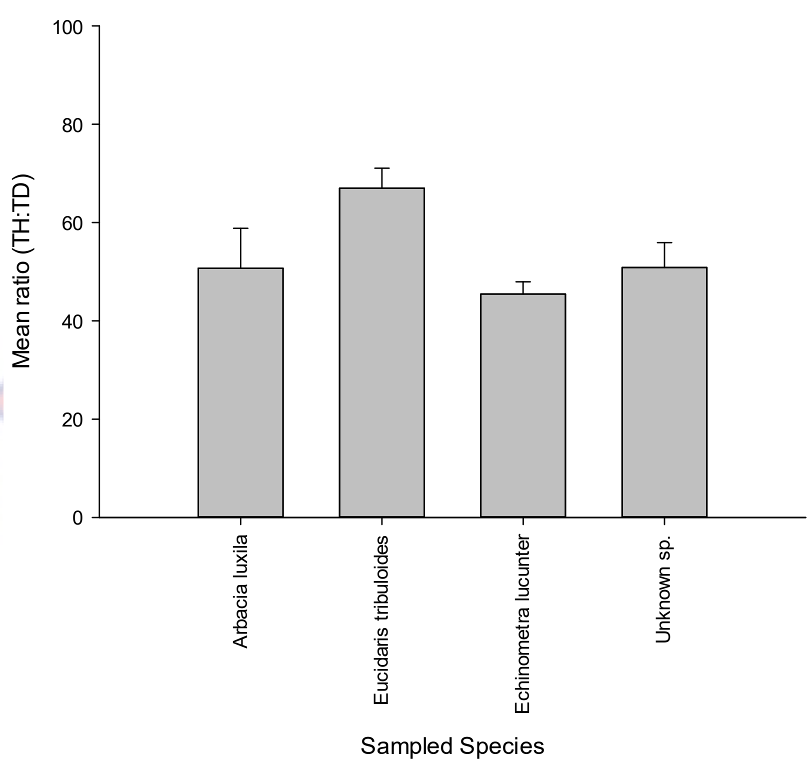
APPENDICES

Appendix A: Mean ratio of the test height to test diameter of sampled sea urchin species

Species	Mean R
Arbacia lixula	50.72 ± 0.08
Eucidaris tribuloides	67.01 ± 0.04
Echinometra lucunter	45.48 ± 0.02
Unidentified sp.	50.87 ± 0.05



Appendix B: Mean ratio of the test height to test diameter of sampled sea urchin species

Appendix C: Mean Variation of Test Height (TH): Test Diameter (TD) Ratio of Sea Urchins sampled along the Coastline of Ghana.

	Arbacia lixula		*Eucidaris tribuloides*		*Echinometra lucunter*		Unidentified species	
Stations	% (N)	sd	%(N)	Sd	%(N)	sd	%(N)	sd
Tema	50 (555)	0.06[bcd]	67 (8)	0.07[a]	-	-	50 (6)	0.05[a]
Nungua	51 (81)	0.09[abcd]	-	-	-	-	-	-
La	52 (174)	0.07[ad]	-	-	56(3)	0.06[a]	-	-
Teshie	52 (222)	0.09[ad]	-	-	-	-	-	-
Nyanyano	53 (379)	0.07[ad]	67 (50)	0.04[a]	44(5)	0.03[a]	52 (3)	0.07[a]
Mumford	49 (86)	0.04[bc]	-	-	-	-	-	-
C. Coast	50 (155)	0.08[bcd]	-	-	-	-	-	-
Iture	50 (200)	0.05[bcd]	-	-	-	-	-	-
Dixcove	50 (36)	0.03[bcd]	-	-	-	-	-	-
Axim	48 (48)	0.03[bc]	-	-	-	-	-	-

Where stations with similar occurring letters are not significantly different

Appendix D: Interview Guide for the Socioeconomic Assessment of the Sea urchin Fishery in Ghana

UNIVERSITY OF CAPE COAST

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES

SOCIOECONOMIC ASSESSMENT OF SEA URCHIN FISHERY IN GHANA

CONSENT

I am Juliet Afrah Obeng, an MPhil Fisheries Science student with the Department of Fisheries and Aquatic Sciences at the University of Cape Coast, Ghana. I do wish to request for your support in completing this questionnaire on "A study of sea urchin populations along the coast of Ghana with a note on its fishery". This research seeks to obtain information on the occurrence, distribution, and diversity of sea urchins along the coast of Ghana. It also seeks to evaluate the growth parameters and some aspect of the sea urchin fishery in Ghana thereby contributing to the conservation and sustainable utilization of resources in the Ghanaian waters. Results of the study would provide appropriate information for conservation of the species and sustenance of the sea urchin fishery in the country. This questionnaire is meant to elucidate the knowledge and awareness level of coastal dwellers on the sea urchins and their fishery.

This questionnaire is mainly for academic purpose and your responses would remain anonymous and confidential, neither would they be disclosed to a third party for any other use.

You are not expected to respond to the sections that you feel uncomfortable to answer or have no knowledge about. There are six (6) sections in all, Please, you would need between 20 – 30 minutes to complete this questionnaire.

Do you accept to partake in this interview? ☐

Demographic Data of Respondents

1. Name of respondent……………………………………….

2. Age of Respondent ☐< 12☐13 – 19 ☐20- 40 ☐ >41

3. Gender ☐ Male☐ Female ☐Not mentioned

4. What is your level of Education?

None ☐Primary ☐ JHS ☐SHS ☐ O' Level ☐Tertiary ☐

5. What is your primary occupation? …………………………………………..

6. What is your secondary occupation if any? ………………………………...

7. Residence……………………………………………………….

8. Citizenship ☐ Native ☐ Foreign

Occurrence of sea urchin

9. Do you know about the sea urchins?

Photos of different species of Sea urchin is shown to the participant.

☐ Yes ☐No

10. Do sea urchins occur in the coastal waters of your locality?

☐ Yes ☐No

11. If yes, what name do you call it in your local dialect?

……………………………..

12. Are there different kinds of sea urchins you know?

☐ Yes ☐No

13. How many?.......................................

14. What is the difference between them?

☐ Body color ☐ Body shape ☐ Spine length ☐ Gonad color

15. Which areas do you think sea urchins can be found aside where you are currently?..

Dietary importance of Sea Urchin

16. Do you eat sea urchins?

☐ Yes ☐ No

17. If No, why?...

18. If Yes which part of the sea urchin do you eat? ……………………………..

19. How do you process sea urchins for consumption?

☐ Boiling ☐ Frying ☐ Roasting

Exploitation of Sea Urchin

20. Do you harvest the sea urchins?

☐ Yes ☐ No

21. How do you harvest them?...

22. When do you collect sea urchins? ………………………………………..

23. Which type do you usually encounter during harvesting?..........................

24. Are all the different types edible?

☐ Yes ☐ No

25. In which months do you harvest the highest number of sea urchins?...

26. What equipment do you use for collecting sea urchins?..............................

27. Which group of people harvest the sea urchin?

☐ Men ☐ Women ☐ Children ☐ Any

Economic importance of Sea Urchin

28. Do you sell the sea urchin harvested?

29. How much do you price the sea urchin you sell?...

☐ Yes ☐ No

30. How many sea urchins do you sell in a day? ....

31. How much income do you get from days sells? ……………………….

32. Do you export the sea urchin?

☐ Yes ☐ No

33. If Yes, to which countries do you export the sea urchins?………………

34. Who are your buyers?..

35. Do you have any competitors also harvesting the sea urchin?

☐ Yes ☐ No

36. If Yes, who are your competitors? ……………………………………

37. On a scale of 1 to 10, what is the level of exploitation by your competitors in the sea urchin fishery? ………………………………..

38. Do the fishermen also sell their catch?

☐ Yes ☐ No

Sea urchin management

39. Do you know that the eggs eaten are babies of sea urchin?

☐ Yes ☐ No

40. Do you know any organization that is regulating the exploitation of the sea urchin?

☐ Yes ☐ No

41. If yes, name of organization and address?..

42. Do you have personal measures for sea urchin conservation?.....................

43. Do you have any other comment to add to this questionnaire?....................