POPULATION PARAMETERS, GENETIC DIFFERENTIATION AND SOCIO-ECONOMICS OF *SARDINELLA AURITA* (VALENCIENNES 1847) AND *PSEUDOTOLITHUS SENEGALENSIS* (VALENCIENNES 1833) IN SOUTH COAST, LIBERIA

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DECLARATION AND APPROVAL

I, NATHANIEL DECIUS LEESOLEE declare that this thesis is my original work and to the best of my knowledge has not been presented or submitted as proposed work of study or examined for the award of degree in any university.

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DEDICATION

I dedicate this thesis to my family especially my mother, who through her tireless effort has ensured that I become the man I am today! Thanks Mom and I love you more.

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LIST OF ABBREVIATIONS

EEZ	-	Exclusive economic zone
MSY	-	Maximum sustainable yield
IUU	-	Illegal, unreported and unregulated
HP	-	Horse power
IEZ	-	Inshore exclusive zone
vBGF	-	von Bertalanffy growth function
ML	-	Maximum likelihood
RAxML	-	Randomized Axelerated Maximum Likelihood
MUSCLE	-	Multiple Sequence Comparison by Log-Expectation
MEGA	-	Molecular Evolutionary Genetics Analysis
ELEFAN	-	Electron Length Frequency
FAO	-	Food Agriculture Organization
FiSAT	-	FAO and ICLARM Stock Assessment TOOLS
ICLARM	-	International Centre for Living Aquatic Resources Management
LFDA	-	Length frequency Distribution Analysis
SLCA	-	Shepard Length Composition Analysis
LRD	-	Liberian Dollar
DNA	-	Deoxyribonucleic acid
NCBI	-	National Center for Biotechnology Information
Y’/R	-	Relative Yield per Recruit
B’/R	-	Biomass per Recruit

ABSTRACT

Fish is a source of protein to over 20 million people. This contribute to food security and poverty alleviation in coastal communities of the world leading to overexploitation in most fisheries in Africa. This study investigated growth, mortality parameters and exploitation rate of *Sardinella aurita* and *Pseudotolithus senegalensis*. The analysis were based on 2,270 specimens of *S. aurita* and 1,711 specimens of *P. senegalensis* collected between December 2016 and May 2017 nearshore waters off Liberia. Genetic differentiation and socio-economic status of the two fish species were also determined.

The growth parameters and performance index estimated based on von Bertalanffy model gave the asymptotic length $L\infty$ of *S. aurita* which ranged between 34.50 to 36.00 cm, growth coefficient K at 0.50 to 1.18 year^{-1}, theoretical age at length zero t_o between 0.502 and 0.895 year^{-1} and performance index **Ø'** from 2.77 to 3.18 year^{-1}. *Pesudotolithus senegalensis* asymptotic length varied between $L\infty$ 52.99 to 60.00 cm, K 0.50 to 1.03, t_o 0.551 to 0.88 and **Ø'** 3.13 to3.52 year^{-1} at Montserrado (Gbanjor, West Point and King Gray & ELWA) and Marshall respectively. The slope *b* of the length-weight relationship were 1.89 to 1.97 and 2.3 to 2.8 in Montserrado and Marshall. Estimates of total, natural and fishing mortality for *S. aurita* and *P. senegalensis* were found between 6.36 to 9.61 and 1.50 to 6.11 year^{-1}; 1.38 to 1.87 and 0.9 to 1.51 year^{-1} and 4.98 to 7.74 and 0.54 to 4.60 year^{-1} at Montserrado and Marshall. The high value of exploitation (0.75 to 0.81) ratio of *S aurita* and *P. senegalensis* at Gbanjor, West Point, King Gray & ELWA and Marshall indicated that these species were harvested at a higher level than the optimum fishing mortality but (0.36) for *P. senegalensis* at King Gray & ELWA was lower than the optimum fishing mortality. Analysis of yield per recruit suggested that *S. aurita* and *P. senegalensis* stocks in the two fisheries needs regulatory measures for sustainable management.

Sardinella aurita and *Pseudotolithus senegalensis* revealed inter-species variations of genetic diversity using four molecular markers from 12 taxa obtained from National Center for Biotechnology Information. Phylogeny reconstruction using the selected markers (16s, COI, Cytb and Rag-1) revealed distance relationship between *S. aurita* and *P. senegalensis*. The fascinating result from this analysis is the well supported monophyly for *S. aurita* and *H. jaguana* in trees using 16s, COI, and Rag-1 genes.

An average rate of 36 – 52 fishermen accounted for 48 – 68 % of the daily catch. Gill nets contribute (80%) of the fisheries. The highest catches recorded for *S. aurita* and *P. senegalensis* were in January and February at Montserrado and Marshall while the lowest catches were in April and May.

The stocks of *S. aurita* and *P. senegalensis* nearshore off Montserrado and Marshall were found to be over-exploited. This study provides relevant information to monitor stocks over time in areas sensitive to fishing pressure, size-limit regulation of fishing gear mesh size and time-limit regulation of restricting fishing during spawning seasons in nursery areas for sustainability.

CHAPTER ONE

1.0 INTRODUCTION

Over 20 million people depend on fish as an essential resource providing animal protein which contributes to food security and poverty alleviation in coastal areas of the world (FAO, 2014). Artisanal fisheries provide more than half of the world's fish harvest (FAO 2011; FAO 2008). As such policy makers are required to provide strategies of minimizing the catch for sustainability and preserve the marine resource environment. Globally, more so in the developing world, the fisheries sector depend on the artisanal fisheries (Hoggarth et al. 2006; FAO 2008) which are characterized by small-scale fishermen that operate within the inshore waters. These fishermen use multi-gear to target multispecies using traditional fishing methods. Generally, the artisanal fisheries consist of full time and part-time fishers.

The Liberian marine fishery is exploited all through the year. The effort in which multi-gears are used to target multi-species is complicated due to the use of a variety of fishing techniques and methods by fishermen within the same fishery hence affecting the fishery resources in many ways (Allendorf et al., 2008). Primarily the effects of demography on target fish stocks (Beverton, Raymond, & Sidney, 1958) shrinks the abundance and biomass (Hutchings & Myers, 1994), shorten growth (i.e. morphology and age) (Boukal et al., 2008; Poos et al., 2011), and changed the geographical distribution (Overholtz & Link, 2007). The second effect describes traits expression via phenotypic plasticity. Decrease in abundance often lead to increase per capital of stock and earlier species development reduced age at growth (Allendorf et al., 2008; Engelhard & Heino, 2004). As such regulatory management on fish stock is important.

Conventionally, the fisheries management systems are designed for single-species in which the same group of fishermen target single-species. Moreover, management of single-species and gear types is difficult within the same fisheries (Hoggarth et al., 2006). Numerous studies (Cochrane et al. 2011; Roberts et al. 2005; NOAA 2014; Armfield 2008; Mosquera et al. 2000; Hoggarth & Aeron-thomas 1998) suggest the importance of marine reserves and closure of a part of the fishery in order to increase the fishery stocks.

The marine fisheries in Liberia include both the industrial and artisanal sectors. The artisanal fisheries target multi-species use canoes from shore to the inshore exclusive zone. The industrial fishery operates trawling vessels in the exclusive economic zone and target specific species (BNF, 2014; Kebe et al., 2009; Pesca & Paises, 2004; USAID, 2016). Moreover, the increased exploitation of fishery resources requires monitoring the level of fishing effort within each fishery sector and the amount of fish stocks that can be economically harvested without leading to depletion of the resource. These results provides relevant information for sustainability and compliance to fisheries strategies in Liberia such as size-limit regulation by gradually increasing fishing gear mesh size and time-limit regulation by restricting fishing during the spawning seasons and in nursery areas. The plan to monitor stocks over time needs to be made, especially in areas under fishing pressure.

1.1 Problem statement

Globally, over-fishing is considered a major socio-economic and environmental problem that reduces the biodiversity and affects the ecosystem. Liberia inshore fishery is exploited all through the year deploying various fleets. However, many inshore fisheries are being over-exploited and some are at or approaching maximum sustainable yield (MSY), while the offshore waters are often considered under exploited because there are no reliable data to support or disprove this supposition. The artisanal fishermen use wide range of fishing methods that target multispecies and multi-gear fishing activities usually follow the distribution of fish patterns leading to over-fishing and causing ecological imbalances within the ecosystem. Normally, conventional fisheries management design requires methods for single-species fisheries that allow the same group of fishermen to target a single species.

1.3 Justification

The inshore fishery in Liberia is exploited throughout the year by artisanal fishers deploying various fleets using multi-gear to target multi-species and consequently showing signs of over-exploitation (Belhabib et al., 2013; BNF, 2014; Kebe et al., 2009; Pesca & Paises, 2004; USAID, 2016). The marine fishery in Liberia has struggled with huge amount of illegal, unreported and unregulated catches in absence of monitoring during the civil conflicts which approximate to US$ 75 million annually. These conflicts have had a strong impact on fisheries and food security

(Belhabib et al., 2013; BNF, 2014; Kebe et al., 2009). Over-fishing causes ecological imbalances within the ecosystem where fish stocks are reduced below acceptable levels which lead to gradual reduction in biodiversity and endangering certain populations especially threatened species thus affecting the natural resources. Increasing evidence has proven that over-fishing has strong reversing selection of changing life-history traits (Olsen, Heupel, Simpfendorfer, & Moland, 2012), physiology, behaviors and morphology of target fish species (Laugen et al., 2014). Moreover, stocks that are over-exploited are due to evolve over time (Allendorf et al., 2008; Darimont et al., 2009). Increased fishing activities cause wider genetic variation among species (Dunlop et al., 2009; Enberg et al., 2010; Jørgensen et al., 2009; Kuparinen et al., 2010; Mollet et al., 2013).

The artisanal fisheries remain the largest source of fish for domestic consumption. The knowledge of fish abundance, distribution patterns and its impact on the artisanal fisheries predominantly in tropical countries still remains undeveloped (Belhabib et al., 2016). It is interesting to note that not only space, food, predators and temperature that limit fish stocks but also the number of new young fish that grow to enter fishing grounds. The communities along the coastal areas of Montserrado and Marshall rely on these resources for their livelihood (Belhabib et al., 2013; BNF, 2014; NFDS et al., 2013). However, it is important that comprehensive growth analysis, evolution of species population dynamics, species distribution patterns, robust fishery surveys and socio-economic study form part of data collection for all subsectors in order to formulate sound management policies for management and compliance purposes. Therefore, it is imperative to conduct comprehensive studies to determine the status of these resources due to the daily exploitation of fish stocks and ascertain the long-term economic benefits through management strategies.

1.4 Aims of the study

1.4.1 General Objective of the study

To conduct a growth assessment and genetic differentiation of *Sardinella aurita* and *Pseudotolithus senegalensis* and study the socio-economic status of the two selected fish stocks in relation to their sustainable exploitation in Montserrado and Marshall in Liberia.

1.4.2 Specific Objectives of the study

- **a.** To determine the growth parameters, mortality and exploitation rates and the relative yield per recruit (Y'/R) and average biomass per recruit (B/R) of *Sardinella aurita* and *Pseudotolithus senegalensis* in Montserrado and Marshall.
- **b.** To evaluate the genetic differentiation of *Sardinella aurita* and *Pseudotolithus senegalensis*.
- **c.** To establish the socio-economic status of *Sardinella aurita* and *Pseudotolithus senegalensis* fish species in Montserrado and Marshall.

1.4.3 Hypothesis

The artisanal fishery of Montserrado and Marshall are over exploited by the use of multi-gears in the fishery.

CHAPTER TWO

2.0 LITERATURE REVIEW

Within our global communities, artisanal fisheries provide animal protein, contribute to food security and poverty alleviation (FAO, 2014). Approximately 60% of the total marine catches of domestic fish landed in Liberia come from the artisanal fisheries (BNF, 2014; Pesca & Paises, 2004). The marine small-scale fisheries support up to 33,000 full-time fishers and fish processors (BNF, 2014; NFDS et al., 2013). The artisanal fisheries exploited by the indigenous kru fishermen, Fanti and Popoh fishermen migrating from neighboring countries of Benin, Ghana and Côte d'Ivoire are currently the major contributors in the subsector. The Fanti and Popoh fishermen own and operate larger motorized fishing canoes and use sophisticated fishing gears and fishing methods. They dominate the artisanal fishery by providing about 40% of artisanal landings and previous estimates suggest that before the war in Liberia, they provided approximately 90% of the country's artisanal landings (Belhabib et al., 2016; BNF, 2014; Kebe et al., 2009; Pesca & Paises, 2004)

The Liberian marine fisheries was established in 1950 and have struggled with strong inconsistencies in the fisheries catch data and multi-species fishing activities up to present (Belhabib et al., 2013; BNF, 2014; Kebe et al., 2009). However, specific inshore fisheries are over-exploited and at or nearing to MSY. Over-fishing is a leading problem in the marine fisheries and cause reduction within the ecosystem and biodiversity. Moreover, the present trends and the future prospects for global fisheries remain controversial (Worm et al., 2009). The fishermen in marine fisheries exploits the inshore waters using multiple fishing gears for targeting multispecies thereby exerting pressure on the inshore waters leading to over-fishing (Belhabib et al., 2016; BNF, 2014; NFDS et al., 2013). More than 60% of the total marine fish landings in Liberia come from the inshore waters, shallow coastal waters and estuaries (BNF, 2014; Kebe et al., 2009). About 80% population of Liberia depend on fish as a mean of protein and as potential contributor to poverty alleviation and food security (Belhabib et al., 2013).

In Liberia trawling and use of large-scale gears are unfavorable within the inshore exclusive zone. The main gears used in the marine small-scale fisheries are ring nets, drift nets, set nets, gill nets, cast nets, beach seine traps, hooks and longlines (BNF, 2014; Kebe et al., 2009; NFDS et al., 2013; Pesca & Paises, 2004). The artisanal fleets include the indigenous dugout canoes propelled by oars or sail and have a capacity for 1 – 3 people. They are about 7m and some powered by 9.9HP outboard engines, using mainly hooks, long lines and gillnets. The Fanti and Popoh migrants from neighboring countries of Ghana and Togo operates larger canoes about 12 – 25m, powered with 25 – 45 HP outboard engines and a crew of 6 – 10 people. They use variety of fishing gears such as purse seine and ring net to catch small pelagic fish. Larger gears are used in distinct seasons for different species. These migrates contribute about 40% artisanal landings in Liberia. Main gunus of fish exploited in Liberia by artisanal fishermen such as *Sardinella, Cybium, Pseudololithus, Sphyraena, Chloroscombrus, Caranx, Trichiurus,Galeoides decadactylus, Cyanoglossue, Arius* spp. (Ariddae), *Ethmalosa*, *Drepane Africana* (Drepanidae), *Vomer, Cynoglossus* spp (Cynoglossidae), *Ilisha africana*, *Pentanemus quinquarius* (Polynemidae), *Dentex, Parapenaeus atlantica* and *Lutjanus* spp and *Ethmalosa fimbriata* (Clupeidae) (BNF, 2014; Kebe et al., 2009). The seasonal catches of these species are obtained throughout the year.

The global marine resources of many countries have reached exploitation level that is beyond sustainability in regard to the importance of humanity survival, which put marine biodiversity into greater danger leading to fisheries depletion (FAO / DANIDA, 1998). Many countries in West Africa stocks have been underreported with an average rate of 200% to 300% by FAO data reported on their consent. The artisanal sectors is currently the main Liberian domestic fishery which catches contribute to the local population and is 66% alone larger than the data (337,900 t) reported to FAO by Liberia (Belhabib et al., 2013).

The marine fishery in Liberia include both the industrial and artisanal sectors that utilizes different technology of fishing gears, methods and deploy various fleets (BNF, 2014; Kebe et al., 2009; NFDS et al., 2013). The artisanal fisheries which target multi-species operate canoes in estuaries and extend from the shoreline to a distance within the six nautical miles. On the other hand, the industrial fishing fishery mainly operates trawling vessels in the Exclusive Economic Zone and either target shrimp or finfish (Belhabib et al., 2013; BNF, 2014; Kebe et al., 2009; NFDS et al., 2013).

Generally, during prediction of national food supply, fish is excluded and yet it serves as a major source of food besides providing livelihood for many people around the world (FAO, 2011). Too much fishing efforts result into over-fishing and depletion of fish stocks which threaten food security in many natural's fisheries sector in the world (Hutchings & Myers, 1994). However, exploitation of fishery resources requires knowledge of monitoring the level of fishing effort within each fishery sector and the amount of fish stocks that can be economically harvested without leading to depletion of the resource. Artisanal fishing catch are sold at various landing sites. However, the biological, evolution information and data needed for conventional fisheries and compliance purposes are expensive and difficult to mine due to limited resources and lack of facilities. A comprehensive catch assessment, length frequency distribution analysis of growth and mortality modeling and the genetic differentiation of commercial fish stocks are required for management advice.

2.1 Distribution of *Sardinella aurita:*

Sardinella aurita is widely distributed and its population occurs in a wider depth ranging from inshore waters to the shelf edge. It has an estimated generation of four years and a rapid growth. It is over-exploited as commercial stock mostly in eastern Atlantic region (mainly Venezuela and Florida) (A. Tsikliras, 2005; A. C. Tsikliras & Antonopoulou, 2006). Due to high exploitation along the Gulf of Mexico off Florida, population has differed overtime and slows to static ricochet. In 1995, catches decreased after inshore purse-seining was banned by the U.S. government and commercial fisheries adhered to set quotas. The species population was considered stable in the Mediterranean after fishing efforts notably decreased in the 1970s (Mustac & Sinovcic, 2012; A. Tsikliras, 2005). The species is over-exploited off West Africa. And report of catches over the previous 10 years (2000 – 2010) has differed indicating a decrease as high as 36% regarding the standard reference point used (Bureau & Resources, 1999). Further evidence of over-exploitation in this region show notable increased in effort, juveniles harvest and decrease in the standard size of adult fish. Recommendations since 2007 have been made to decrease fishing effort but have not been adhered to. This species has short-life span and the population is known for rapid growth, but it population is receptive to natural difference due to environmental factors such as over-exploitation. This species is widely exploited and marketed as fresh or canned fish and is largely used as baitfish outside West Africa. As such, *Sardinella aurita* is listed as last essential species. Enforcing catch limits, decreasing effort, and recording catch data in West African fisheries is strongly imperative. The routine study of managing the exploitation of this wide spread species is important towards rebuilding and monitoring population (Bureau & Resources, 1999; Mustac & Sinovcic, 2012; A. C. Tsikliras & Antonopoulou, 2006). *Sardinella aurita* occurs along the coastal shelf of Liberia. The species prefer a minimum temperature of 24 ^{0}C waters and spawning is mostly all through the year but the maximum peak of reproduction is mostly during the dry season for Liberia and Côte d'Ivoire.

2.2 Distribution of *Pseudotolithus senegalensis* (Cassava croaker):

Pseudotolithus senegalensis found widely distributed in the east Atlantic along Morocco to Namibia, and along Cape Verde Islands (Abimbola, 2016; Longhurst, 1969). It is the most common sciaenid species in the region. A trawl surveys reported 70% of sciaenid biomass from the RV Fridjoff Nansen. A numerous surveys from 1999 – 2006 report 37% decrease in mixed scriaenid biomass. This species is primarily found in shallow waters to a depth of 60 m. It is found within the trawling depths of 25 to 75 m. It preserved exiting conditions was estimated at least 30% to 63% higher (in relation to surveyed biomass) during the last ten years. This species is listed as endangered species since it population has been threatened due to the decrease in the mid-1990s and effort is gradually increasing (Nunoo, F. & Nascimento, 2015). The species spawn between November and March in waters of 22 to 25 ^{0}C in the Gulf of Guinea. It is both fished by artisanal and industrial fleets using longlines, beach-seines, gillnets and bottom trawls.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Areas

The study was conducted in Montserrado and Marshall which are located on the coast in the north western region of Liberia. Liberia is a sub-Saharan West African country that is found at 4˚N and 6˚N and 7˚W and 9˚26'W. It is bordered by Sierra Leone at the West, North by Guinea and to the East by Côte d'Ivoire (Belhabib et al., 2013) as well as the Atlantic Ocean. The Liberian coastline is approximately 579km long that extends from Cape Palmas in a northwest direction bordering Côte d'Ivoire and Robertsport to the border with Sierra Leone that lies in the Gulf of Guinea, eastern central Atlantic region. The continental shelf is approximately 34 km in width and the fishing area is 186322.2 km^2 within the EEZ. Montserrado and Marshall are located on the coast in the north western region of Liberia, bordered by three counties and the Atlantic Ocean. The Atlantic Ocean border is further to the south, while Bong County lies on the northern border. Bomi County is to the west and Margibi County make up the eastern border. From the Shebro fishing grounds to the border of Sierra Leone along the west and within the Cavalla River Basin to Côte d'Ivoire border make up the fishing areas.

Montserrado is a coastal county that lies along the south coast of Liberia. Within Montserrado data was collected from four landing sites which includes: Banjor fishing community at N06.40077˚; W010.81179˚, West Point has two fishing communities; New West Point known as Dosa field at N06.32860˚; W010.80779˚ and Fanti Town at N06.33071˚; W010.80492˚ and lastly, King Gray fishing community at N06.13831˚; W010.38174˚ whereas ELWA fishing community found at N06.23355˚ and W010.69365˚ a few miles away from King Gray. Marshall lower Margibi has two adjacent fishing communities namely Fanti Town at N06.13833˚; W010.38171˚ and Kru Town at N06.25944˚; W010.40457˚ these landing sites are found along the south cost of Liberia.

Within each lowland on the coast are grown palm trees, mangrove trees, savanna grasslands and tropical forest covering the interior hills and valleys which add nutrients into the flowing rivers St. Paul, Mesurado, Du and Po that empty into the Atlantic Ocean and enhance fish stocks (Belhabib et al., 2013; BNF, 2014; Kebe et al., 2009; Pesca & Paises, 2004).

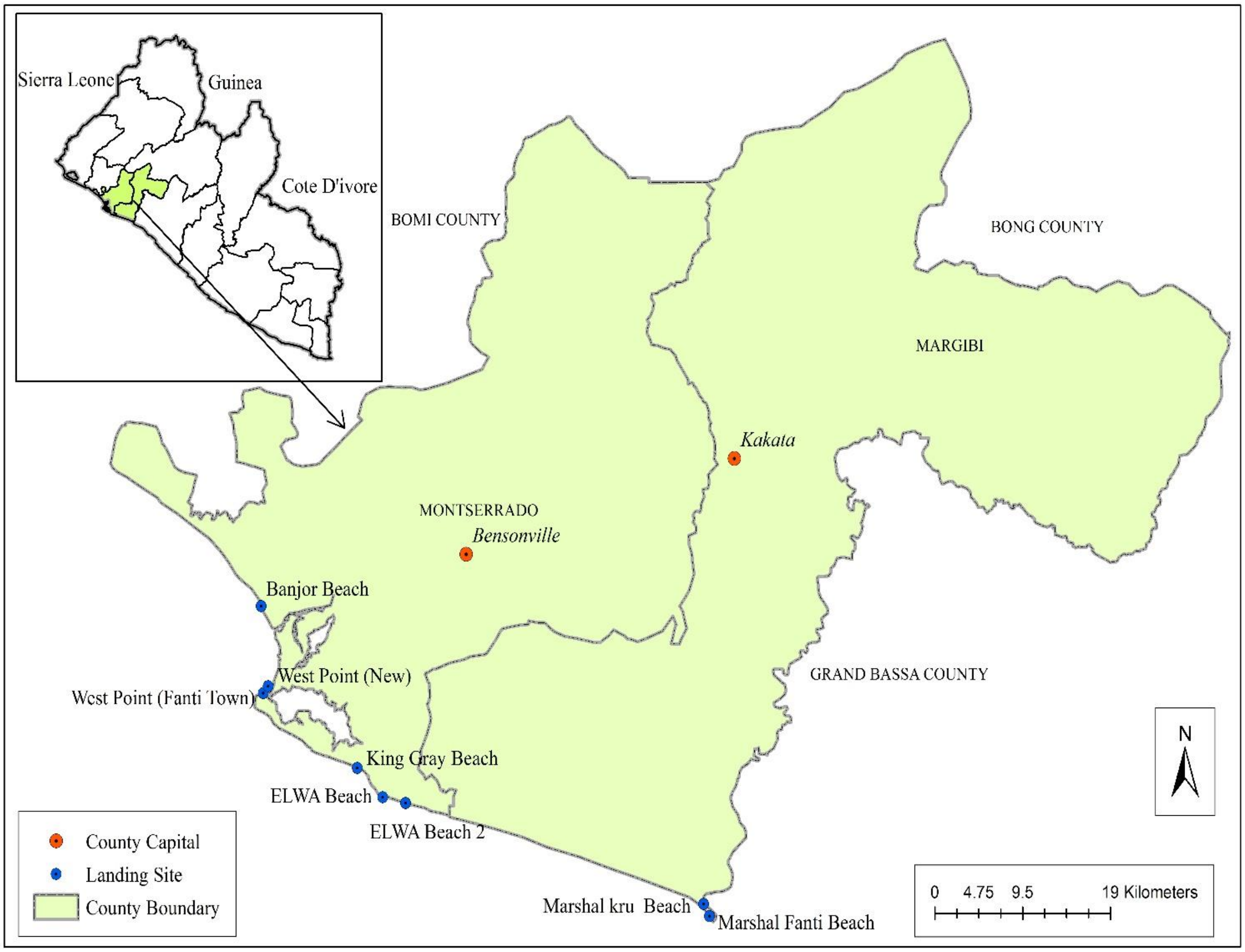

Figure 3.1: Coastal zone of Liberia, showing the sampling/landing site of *Sardinella aurita* and *Pseudotolithus senegalensis* for Montserrado and Marshall-Lower Margibi

3.2 Sample collection and measurement

To determine growth parameters and mortality rates of *Sardinella aurita* and *Pseudotolithus senegalensis* (Plate 3.1), their length and weight measurements were taken. Fish specimens were taken from the population sub-samples from artisanal fishers and middle men during landing their catches at each landing site for domestic consumption and local marketing in Montserrado and Marshall from December 2016 to May 2017. Most artisanal fishermen are Kru and Fanti. Kru is one of the 16 tribes of Liberia. They are indigenous fishermen and Fanti fishers migrated from Ghana and settle in Liberia. Fishing gear used to catch these species were gillnets used as drift nets or set nets with mesh sizes ranging between 40 and 50 mm along with hooks and longlines. Both *Sardinella aurita* and *Pseudotolithus senegalensis* were sampled in Montserrado and Marshall and length and weight parameters were measured. Total length was measured using the fish measuring board while wet weights in grams were recorded using Chatillon precision scales. The total length (Lt) of each specimen was measured from the tip of the anterior region of the mouth to the tip of the caudal fin in centimeters and measured to the nearest 0.1 cm. Each landing site was sampled for two successive days per month throughout the sampling period. During each month, the two-day sampling period was randomized. Each landing site was randomly selected on the basis of their fishing activity and huge catches within the month per day.

a) Sardinella aurita

b) Pseudotolithus senegalensis

Plate 3.1: *Sardinella aurita* and *Pseudotolithus senegalensis* sample and measurement

3.3 Data analysis

3.3.1 Growth assessment

An algorithm based program, Fish Stock Assessment Tools (FiSAT) (Hoggarth et al., 2006; Roomian & Jamili, 2011) was used for analysis in this study. A quantitative analysis of the population dynamics of two important commercial fish species in Montserrado and Marshall was conducted. The combination involved the elucidation of length-weight relationships and the parameters estimation of growth, mortality and recruitment pattern analysis. Length frequency data was accumulated for six (6) months for both *Sardinella aurita* and *Pseudotolithus senegalensis* within the two subsectors.

3.3.2 Length-weight relationship

The length-weight relation was computed with respect to (Le Cren, 1951) using the formula:

$$\mathbf{W = a\ L^b}$$

Where: W is the weight (g), L is the total length (cm), *a* is the intercept and *b* is the slop.

The intercept **"*a*"** was tested if significantly different from zero while the slope **"*b*"** was tested against the expected value of Isometric relationship "3". The t-text was used at $\alpha = 0.05$.

3.3.2.1 Test of Isometry

The Isometry test (significant difference from 3 i.e. growth change in morphological size and change in shape) was established for the two selected commercial species Sardinella aurita and Pseudotolithus senegalensis. The isometric growth possibility was tested according to Pauly (1985) by a statistic calculation, t^ using the equation: $t\hat{} = [(SD_X/SD_Y)\ (b\text{-}3/{*}(1\text{-}r^2)]{*}(n\text{-}2)$

Where: SD_x is the standard deviation of $\log_{10}$ of lengths,

SD_Y is the standard deviation of $\log_{10}$ of weights

n is the number of fish used in the analysis

and r^2 is the co-efficient of determination.

The statistic t^ is significantly different from 3 if its value is greater than the tabulated value of t (in the t-tables) at n-2 degrees of freedom.

3.3.3 Growth parameters models: Length

The growth parameters of *Sardinella aurita* and *Pseudotolithus senegalensi*s within the two subsectors were described by the von Bertalanffy growth function (vBGF) (Sparre & Venema, 1998a) using the ELEFAN 1 model in FiSAT II, calculated using these equations:

$$L_t = L_\infty * (1-exp^{-K(t-t0)})$$

Where Lt is the length (cm) at time t, L_∞ is the asymptotic or maximum average length recorded, K is the Brody growth coefficient, and t_0 is the initial condition parameter when the hypothetical age at size zero.

Both populations maximum length, estimated were set as the preliminary values of the asymptotic length which followed (Calandra et al., 2016). Given the estimated maximum length as initial estimate of $L\infty$, the preliminary values of K was obtained using monthly catches with length data at 1 cm intervals by length frequency analysis using FiSAT II in ELEFAN 1 (Pauly & Froese, 1996) and Shepherd's length composition analysis (SLCA) (Arreguin-sanchez, 1995) respectively. The response surface analyses of ELEFAN and SLCA were then used to search for optimal combination of $L\infty$ and K (Arreguin-sanchez, 1995; Gulland, 1987; Pauly & Froese, 1996). These estimation procedures were completed using FiSAT software (Hoggarth et al., 2006). The theoretical age at length zero (t_o) was estimated using the Pauly's empirical equation:

$$\mathbf{Log(-t_o) = -0.392 - 0.275\ log(L\infty) - 1.038\ log(K)}$$

The inverse von Bertalanffy growth equation was used to find the lengths of the fish at various ages. The fitting of the best growth curve was based on ELEFAN 1, which allows the fitted curve through the maximum number of peaks of the length-frequency distribution.

3.3.4 Growth performance index, (***Ø′***)

The estimates of the asymptotic length (L∞) and the growth coefficient (K) were used for the Growth performance index (***Ø′***) calculation (in terms of length) of the fish species using the reliability of growth parameters according to (Pauly, 1985) method comparing different fits.

$$\boldsymbol{\varnothing' = \log(K) + 2\log(L\infty)}$$

The index showed the population structures of *Sardinella aurita* and *Pseudotolithus senegalensis* growth in both Montserrado and Marshall. The index is an Explained Sum of Peaks (ESP) which is a chi-square procedure that explain the best growth curve using the ratio of observed peaks to the expected peaks. The higher index, the better is the fitted growth curve.

3.3.5 Mortality parameters of two commercially important exploited species

The total instantaneous mortality (Z) was estimated via the length-converted catch curve model based on the length frequency distribution (Hoggarth et al., 2006; Smith et al., 1998), given the estimated value of the vBGF parameters using the ELEFAN 1 program within FiSAT II. Total mortality (Z) was derived from length-frequency data of the two selected fish species caught in all gear from both Montserrado and Marshall through the linearized length-converted catch curves procedure. The natural instantaneous mortality (M) coefficient was estimated using Pauly's equation (Pauly, 1985) at a mean annual surface temperature (T) 27.4 ºC (for both Montserrado and Marshall) from the length-frequency data from all four landing sites.

$$\mathbf{Log}(\boldsymbol{M}) = \mathbf{-\ 0.0066 - 0.279log}(\boldsymbol{L}\infty) + \mathbf{0.6543log}(\boldsymbol{K}) + \mathbf{0.4634log}(\boldsymbol{T})$$

Where: L∞ is maximum average or asymptotic recorded length of fish (cm), K is instantaneous rate of growth (vBGF) and T is the average water temperature where fish live, (i. e. 27.4^{0}C) in this study for both fisheries.

3.3.6 Fishing Mortality

The instantaneous fishing mortality was determined by common substraction (***F***): ***F = Z – M*** showed the difference between the total mortality (***Z***) and natural mortality (***M***). The coefficient of catchability (q) was derived from standardized effort and fishing mortality (F = qE). To derive length at first capture (Lc_{50}), gear specific selection parameters were derived probability of capture at length from the catch curves. The first fully recruited length class was taken as the cut-off point in the analysis (Kumar et al., 2014; Mohite & Biradar, 2001). Parameter $\boldsymbol{L_{c50}}$ is the length at which 50% probability at capture. The estimated exploitation ratios (***E***) shows the result between the fishing mortality and the total mortality using the Beverton and Holt's equation $\boldsymbol{E = F/Z}$ within the two subsectors. With respect to (Beverton & Holt, 1957). The value of exploitation rate (E) and probability of capture for each length class analysis was also calculated.

3.3.7 Recruitment pattern of two commercially important species

Recruitment for both subsectors was considered to be the addition of new fish species to catchable population by growth. The reconstructed seasonal percentage recruitment patterns of *Sardinella aurita* and *Pseudotolithus senegalensis* were established using the recruitment pattern option in the FiSAT program (Hoggarth et al., 2006) and in relation with (Kumar et al., 2014; Roomian & Jamili, 2011). The analysis entailed back-projecting with a track defined by the VBGF coefficients showing length frequency of all data onto a one-year time scale. This back-projecting of the frequency is done at each length-class of every data set to the zero time axes using the estimated growth curve and then accumulating those frequencies falling in the same time interval.

3.3.8 Estimation of relative yield and biomass per recruit of *S. aurita* and *P. senegalensis*

The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) of *S. aurita* and *P. senegalensis* were estimated in regard to (Beverton & Holt, 1957) using the Knife-edge selection. From the analysis, the maximum allowable limit of exploitation (E_{max}) giving maximum relative yield-per-recruit was estimated. The exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per-recruit is 10% as well as the exploitation rate corresponding ($E_{0.5}$) to 50% of the unexploited relative biomass per-recruit were estimated (Gulland, 1987).

3.4 Genetic differentiation of *Sardinella aurita* and *Pseudotolithus senegalensis*

3.4.1 Sequence retrieval of selected molecular markers

This study used four selected molecular markers along a wide genome distribution of bony fish examined. Sequences of nuclear and mitochondrial DNA markers including 16s ribosomal RNA (16s rRNA), mitochondrial Cytochrome oxidase subunit I (COI), Cytochrome b (Cytb) and recombination activating protein 1 (Rag-1) were subsequently obtained for 10 bony fish species. Plus two outgroups including one tetrapod species (*Pseudis paradoxa*) and chondrichthyan (*Carcharondon carcharias*) retrieved to infer genetic differences between *S. aurita* and *P. senegalensis*. These molecular markers are often used to enhance the productivity of the fisheries and fish industries to meet the increasing demand of the stocks. The molecular markers are identified through DNA testing regardless the age, environmental challenges and developmental stages experienced by an organism. The application of 16s rRNA, Cytb, COI and Rag-1 markers have enabled investigations in rapid progress of genetic inbreeding and variability, species and strain identification, construction of top resolution genetic linkage maps for fisheries and parentage assignment (Thomas et al., 2014). The diversity of fish was shown using a phylogenetic data matrix using a total of 12 species classification. Details of the retrieved sequenced were summarized of the four molecular markers retrieved from NCBI/GenBank using the link http://www.ncbi.nlm.nih.gov/. Taxonomy database was selected and family name of species was search.

3.4.2 Sequence alignment and phylogenetic analysis

The multiple sequence alignment was analyzed using MUSCLE v3.8.3 (Edgar, 2004) within SeaView v4 (Gouy et al., 2010). The marker sequences from all 12 species were aligned individually. The aligned sequences were edited using Jalview (Clamp et al., 2004) to understand the genetic differentiation of *S. aurita* and *P. senegalesnsis* and functional groups of related bony fish species. The aligned sequences were analyzed under Maximum Likelihood (ML) using RAxMLv8.2.10 (Silvestro & Michalak 2012). Substitution was done using the GTRGAMMA model with 1000 bootstraps for each dataset set to run independently. The data was examined by visually checking and analyzing each gene tree within Fig Tree v1.4.3 (Lemey et al., 2010) algorithm. In addition to individual gene trees, a concatenated tree was reconstructed to validate the results obtained from singular gene trees. Individual marker sequences were concatenated and the datasets were assembled and analyzed under Maximum Likelihood using a combination of (16s, COI, Cytb and Rag-1) by partition Finder using the default setting.

The supporting ML nodal was evaluated through fast bootstrapping algorithm of RAxML v8.2.10 using 1000 replicates as employed in the GTRGAMMA model. The gathering of gene trees were established for bipartitions occurrences of the best tree. The bootstrap and optimal trees search was placed to run separately. A comparative slight value of k was selected randomly as a result of computational restriction to investigate the susceptibility of other nodes. The comprehensive search parameters was independently set for every two hits for the optimal current score. A strict consensus of four equally optimal trees was computed. Bootstrap search methods was set to each marker reserving only one tree per replicate (i.e. 1000 replicates). The bipartition frequencies bootstrap was drawn on the consensus tree (Betancur-R. et al., 2013).

3.4.3 Calculation of genetic distances of *Sardinella aurita* and *Pseudotolithus senegalensis*

Pairwise genetic distances analysis was inferred from MEGA v6.0 (Tamura, et al., 2013) using 16s RNA, COI, Cytb and Rag-1 gene sequences. The best-fitted nucleotide substitution model, namely the Kimura's (1980) 2- parameter model and proportions of nucleotide difference (p-distances) were estimated for all pairwise comparison using the four selected markers (Thomas et al., 2014). Sequence divergences of mitochondrial and nuclear sequences among ten bony fish species and two outgroup (*C. carcharias* and *P. paradoxa*) were checked by plotting the Kimura -2- parameter against the proportions of nucleotide difference (p-distances) described by Nei, (1978). The two statistical procedures were employed to determine the distribution of sequence divergence which significantly differed among the two species. The calculated genetic variability within and between *S. aurita* and *P. senegalensis* did not show close relationship of the two species. *S. aurita* and *P. senegalensis* were not identified as monophyletic pairs in the pairwise distance analysis except for three genes (16s, COI, and Rag-1) where *S. aurita* and *H. jaguana* paired out of the 10 bony fish species.

3.5 Socio-economics and Demography

3.5.1 Demography and selection of study area

The socio-economic study was carried out along the two fisheries at seven landing sites (Gbanjor Beach, West Point (Kru and Fanti) Beach, King Gray Beach, ELWA Beach, and Marshall (kru and Fanti) Beach from December 2016 to May 2017 in Montserrado and Marshall respectively. The fishing sites were selected because of their huge fishing activity and largely commercial fish species exploited from these landing sites. During the study king Gray and ELWA fishing communities were joined as one fishing community *Pseudotolithus senegalensis* was only fish and landed with other mix fish in ELWA whereas King gray fish both target species (i.e. *Sardinellla aurita* and *Pseudotolithus senegalensis*) along with other mix fish. Besides the both landing sites are just mile away from each other whereas Marshall (Fanti and Kru) landing sites were on the same beach and vary in terms of species landed. Marshall Kru beach mainly catch and land *Sardinella aurita* and other mix fishon a low scale while Marshall Fanti land both target species (i.e. *Sardinella aurita* and *Pseudotolithus senegalensis*) and other mix fish on large scare. A survey was conducted to study two commercially exploited fish species in nearshore waters between Montserrado and Marshall.

3.5.2 Selection of target group and sample size

The selected target group was composed of fishermen who were involved in fishing permanently (as their primary income source) and partially (as their secondary income source) for their livelihood. The targeted group was chosen to understand the economic status of the two fisheries and their fishing activity. The data were systemically collected from 25 fishermen based on their vessel type and horse power selected from each community that is solely involved in fishing within the two subsectors.

3.5.3 Design and formulation of questionnaire for data collection

A detail questionnaire (Appendix 1) was used to collect the relevant data related to the socio-economic status of the fishermen and the two fish species. A systematic sampling design was carried out within each landing sites where every fishing site was established by the sample size. Where population of fishermen was found to be low a random selection from list of fishers' canoes (paddle and outboard engines) was selected on their catch status. Data were collected using two methods: (a) primary data collection and (b) secondary data collection. Primary data collected through field survey at all landing sites of the two subsector (Marshall and Montserrado). Interview and cross check interview methods were used and time required for each interview was about 15 minutes. After recording, data was cross checked. Secondary data were collected from the Bureau of National fisheries (BNF), from various books, reports, journals and thesis. The survey covered fishers' demography and livelihood activities, resource perceptions and income, conditions of fishing activities, age structure, marital status, gender, religion, family size and type, education status, target species (i.e. *Sardinella aurita* and *Pseudotolithus senegalensis*), fishermen monthly cost and monthly income. For estimating the catch and incomes, an average of 21 fishing day to day per month was used. The bio-economic model for fisherman costs was estimated based on the results obtained from fishers' surveys at each landing site within the two fisheries.

3.5.4 Monthly cost calculation for Montserrado and Marshall per fisher

A modest calculation was used to perform the average costs of fisher per month at the landing sites. Calculating the monthly cost for every gear type (Plate 3.2) for each fishing site, include modest formula was used.

$$P/Rr * N + Rc = Tc$$

Where: ***P*** = price, ***Rr*** = replacement rate, ***N*** = number per sites and ***Rc*** = repair costs, which amount for total cost (Tc).

To determine the costs for each fisher, the overall monthly cost was divided by the total number of fishers within the landing sites.

Plate 3.2: Fishermen fishing gear repair

CHAPTER FOUR

4.0 RESULTS

4.1 Growth assessment

4.1.1 Samples of *Sardinella aurita* and *Pseudotolithus senegalensis*

Data on fish landings from December 2016 to May 2017presented in Table 4.1 and 4.2

	Gbanjor		West Point (Kru & Fanti)		King Gray/ ELWA		Marshall (Kru & Fanti)	
Month/ year	No. of fish	Length freq. (cm)	No. of fish	Length freq. (cm)	No. of fish	Length freq. (cm)	No. of fish	Length freq. cm
Dec - 2016	106	20 – 31	102	20 – 30	64	19 – 30	98	19 – 29
Jan - 2017	118	17 – 30	127	19 – 28	133	20 – 29	132	19 – 29
Feb - 2017	109	19 – 29	120	22 – 29	105	19 – 30	139	19 – 30
Mar - 2017	116	18 – 29	91	21 – 29	115	17 – 28	104	18 – 29
Apr - 2017	26	19 – 27	45	25 – 29	83	18 – 29	56	20 – 28
May - 2017	57	17 – 24	70	19 – 27	56	23 – 28	98	19 - 28
Total	**532**		**555**		**556**		**627**	

Table 4.1: Sampled *Sardinella aurita* from Montserrado and Marshall Fisheries

	Gbanjor		West Point (Kru & Fanti)		King Gray/ ELWA		Marshall (Kru & Fanti)	
Month/ year	No. of fish	Length freq. (cm)	No. of fish	Length freq. (cm)	No. of fish	Length freq. (cm)	No. of fish	Length freq. cm
Dec - 2016	88	32 – 49	54	31 – 47	53	31 – 49	47	34 – 50
Jan - 2017	81	30 – 50	80	28 – 48	66	32 – 50	104	32 – 49
Feb - 2017	96	29 – 47	99	28 – 50	103	28 – 49	90	29 – 50
Mar - 2017	80	29 – 50	62	29 – 48	52	28 – 49	96	28 – 50
Apr - 2017	72	32 – 51	59	28 – 49	48	30 – 50	94	31 – 50
May - 2017	44	30 – 49	44	28 – 46	49	32 – 50	49	30 - 49
Total	**461**		**399**		**371**		**480**	

Table 4.2: Sampled *Pseudotolithus senegalensis* from Montserrado and Marshall Fisheries

4.1.2 Length frequency distributions of *S. aurita* and *P. senegalensis* at the landing sites

4.1.2.1 Length frequency distribution at Gbanjor.

The length frequency distribution is shown by Table 4.3. Most sardines at Gbanjor were in the range of 20 to 27 cm, 17, 18, 30 and 31 were smaller and 25, 23, 26 and 24 larger giving an overall normal distribution curve. The length frequently caught by artisanal fishermen were 20 cm to 27 cm with frequencies ranging between 40 and 77. *Sardinella aurita* was mostly caught at length 25 cm with a frequency of 77, followed by 23 cm, 26 cm and 24 cm at length with a frequency of 73, 60 and 59 respectively. Length 17, 18 and 28 to 31 cm were few.

Total Length (cm)	Dec – 2016	Jan - 2017	Feb - 2017	Mar - 2017	Apr - 2017	May -2017	Total Frequency
17		3				3	6
18		1		1		4	6
19		9	1	1	1	21	33
20	9	13	1	2	3	12	40
21	7	14	6	7		11	45
22	8	7	19	6	4	4	48
23	3	16	31	21	2		73
24	8	8	12	24	5	2	59
25	11	14	16	29	7		77
26	16	15	12	14	3		60
27	22	7	10	6	1		46
28	13	7		3			23
29	5	3	1	2			11
30	3	1					4
31	1						1
Total	**106**	**118**	**109**	**116**	**26**	**57**	**532**

Table 4.3: Gbanjor, Monthly length-frequency distribution for *Sardineslla aurita*.

The length measurements of *P. senegalensis* during the sampling ranged from 29 to 51 cm (Table 4.4). Lengths 32 cm to 46 cm were frequently caught by artisanal fishermen at this sampling site. Their frequency vary from 17 to 48. The most frequent length exploited by artisanal fishermen at Gbanjor is 40 cm for *P. senegalensis.* December 2016 to February 2017 had high catches. From March to May 2017 there was a decrease and May 2017 had the least sample size.

Total Length (cm)	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	Total Frequency
29			1	2			3
30		1	3	1		1	6
31		3	2	1		1	7
32	1	5	6	3	3	1	18
33	1	5	10	5	2	1	24
34	3	5	9	2	1	2	22
35	4	4	9	4	4	2	27
36	2	5	12	2	3	4	28
37	4	8	7	2	3	6	30
38	4	7	7	4	3	4	29
39	7	8	4	7	7	2	35
40	10	2	10	11	10	5	48
41	12	1	5	10	6	4	38
42	11	9	6	7	2		35
43	10	3	2	5	4	7	31
44	3	4		3	5	2	17
45	6	3	1	4	2	1	17
46	3	3		3	4		13
47	1		2	1	2		6
48	3	1		1	3		8
49	3	1		1	2	1	8
50		3		1	4		8
51					2		2
Total	**88**	**81**	**96**	**80**	**72**	**44**	**461**

Table 4.4: Gbanjor monthly length-frequency distribution of *Pseudotolithus senegalensis*

4.1.2.1 Length frequency distributions at West Point (Fanti and Kru) Beach

During the sampling period *S. aurita* exploited by artisanal from West point ranged from 19 to 30 cm (Table 4.5). The most frequent length ranged from 22 cm to 28 cm. The highest frequencies ranged between 43 and 105. The highest frequency of length caught was 26 cm, 25 cm followed by 27 cm.

Total Length (cm)	Dec – 2016	Jan – 2017	Feb – 2017	Mar - 2017	Apr- 2017	May- 2017	Total Frequency
19		6				1	7
20	1	10				3	14
21	3	26		1		9	39
22	8	19	8	1		7	43
23	21	10	11	5		11	58
24	21	9	14	6		12	62
25	16	12	26	13	6	14	87
26	16	19	32	15	13	10	105
27	9	12	15	24	16	3	79
28	2	4	9	19	9		43
29	3		5	7	1		16
30	2						2
Total	**102**	**127**	**120**	**91**	**45**	**70**	**555**

Table 4.5: West Point beach, monthly length-frequency distribution of *Sardinella aurita*

Total length for *P. senegalensis* ranged between 28 and 50 cm at West Point sampling site (Table 4.6). During the sampling period lengths 32 to 46 cm were most frequently caught at varying frequencies from 10 to 38. The length exploited by artisanal fishermen was 40 cm with frequency of 38 followed by 35 cm with a 37 frequency. Length 47 to 50 cm were very few.

Total Length (cm)	Dec – 2016	Jan – 2017	Feb – 2017	Mar - 2017	Apr- 2017	May- 2017	Total Frequency
28		3	1		2	1	7
29		1		1		4	6
30		1		1		3	5
31	3	2		2	1	1	9
32	3	2			2	3	10
33	5	1		5	2	6	19
34	6	2	2	3	3	2	18
35	11	9	5	3	4	5	37
36	6	12	5	3	4	2	32
37	4	8	6	4	3	2	27
38	3	7	4	4	5	7	30
39	4	5	5	6	5	2	27
40	1	10	7	8	9	3	38
41	2	4	7	7	2		22
42	2	5	15	3	1	1	27
43	1	1	11	6	2		21
44		4	6	2	8		20
45	1	2	4	2	1	2	12
46	1		7		1	1	10
47	1		4	1	1		7
48		1	5	1	2		9
49			2		1		3
50			3				3
Total	**54**	**80**	**99**	**62**	**59**	**45**	**399**

Table 4.6: West Point beach monthly length-frequency distribution of *Pseudotolithus senegalensis*

4.1.2.3 Length frequency distributions at King Gray and ELWA Beach

King Gray has three sizes of *Sardinella aurita* exploited by fishermen (Table 4.7). Length 22 cm with a frequency of 69, 24 cm with a frequency 86 and 26 cm with a frequency of 87. During the sampling period the length frequently exploited ranged from 21 to 27 cm and their frequencies vary from 53 to 87 respectively.

Total Length (cm)	Dec – 2016	Jan – 2017	Feb - 2017	Mar - 2017	Apr - 2017	May-2017	Total Frequency
17				1			1
18				1	2		3
19	1		1	2	9		13
20	3	4	5	7	7		26
21	15	25	5	4	4		53
22	16	31	14	8			69
23	2	16	6	25	3	3	55
24	7	27	13	25	9	5	86
25	2	12	16	19	3	16	68
26	6	11	26	13	15	16	87
27	4	6	16	9	13	11	59
28	5		1	1	15	5	27
29	2	1	1		3		7
30	1		1				2
Total	**64**	**133**	**105**	**115**	**83**	**56**	**556**

Table 4.7: King Gray fishing community monthly length-frequency distribution of *Sardinella aurita*

During sampling period at King Gray and ELWA fishing community, length 28 cm was the smallest and 50 cm as the maximum length recorded for *P. senegalensis* (Table 4.8). Lengths 31 to 45 cm and 48 to 49 cm were frequently caught during the sampling period. Among these length 40 cm became the most exploited length within King Gray and ELWA fishing sites with highest frequency of 34. The month of February 2017 had the highest catch and follow by January 2017 respectively.

Total Length (cm)	Dec – 2016	Jan – 2017	Feb – 2017	Mar - 2017	Apr – 2017	May-2017	Total Frequency
28			2	1			3
29			1	1			2
30			2	2	1		5
31	3		7	1			11
32	2	1	7	4	2	1	17
33	5		10	3			18
34	2	2	6	1	4		15
35	2	2	2	1	2	1	15
36	5	7	4	5		4	25
37	3	2	3	2	2	2	14
38	2	6	7	4	7	1	27
39	5	5	6	3	6	5	30
40	1	3	11	4	6	4	34
41	2	5	3	2	2	8	22
42	2	11	6	2	3	4	28
43	1	4	9	1	1	7	23
44	2	2	6	4	1	3	18
45	1	4	4	3	4	4	20
46	3	2	1		2	1	9
47	3	3	1	1		1	9
48	1	3	2		3	2	11
49	3	3	3	2	1		12
50		1			1	1	3
Total	**53**	**66**	**103**	**52**	**48**	**49**	**371**

Table 4.8: King Gray and ELWA fishing community monthly length-frequency distribution of *Pseudotolithus senegalensis*

4.1.2.4 Length frequency distribution at Marshall - lower Margibi

Marshall had three fish landing sites namely Marshall-Kru beach, Marshall-Fanti beach and Marshall Boy’s Town fishing community. Two fish landing sites were selected (Marshall-Fanti beach and Marshall-Kru beach). These two landing sites vary in terms of species composition, Marshall-Kru beach mainly land *Sardinella* and other mixed fish on a lower scale while Marshall-Fanti site landed both *Sardinella, Pseudotolithus* and other mixed fish on a larger scale. As such the landing sites were joined as one landing site during this study. *Sardinella aurita* landing at Marshall is shown by Table 4.9. The length recorded from Marshall (Fanti & Kru) beach ranges from 18 to 30 cm. Length 26 cm had the highest frequency of 103 followed by 25 cm with frequency of 86. The lengths showing the exploitation of *S. aurita* range between 20 and 28 cm and their frequencies vary between 32 and 103.

Total Length (cm)	Dec – 2016	Jan – 2017	Feb – 2017	Mar - 2017	Apr-2017	May - 2017	Total Frequency
18				1			1
19	2	2	1	1		4	10
20	5	1	1	2	1	17	32
21	16	16	1	1		29	63
22	18	20	6	6		24	74
23	11	16	4	14	4	6	55
24	8	20	9	14	12	4	67
25	9	20	20	22	11	4	86
26	18	18	34	13	14	6	103
27	7	1	32	16	8	3	72
28	3	7	17	12	6	1	46
29	1	1	12	2			16
30			2				2
Total	**98**	**132**	**139**	**104**	**56**	**98**	**627**

Table 4.9: Marshall (Kru & Fanti) beach monthly length-frequency distribution of *Sardinella aurita*

Pseudotolithus senegalensis smallest length recorded was 28 cm and the largest length was 51 cm (Table 4.10). Length 31 to 48 cm and 50 cm were frequently caught and their frequencies varied between 10 and 52. The most exploited length was 40 cm with the highest frequency of 52. Marshall had most of the largest lengths recorded.

Total Length (cm)	Dec – 2016	Jan - 2017	Feb – 2017	Mar - 2017	Apr - 2017	May - 2017	Total Frequency
28				1			1
29			1	4			5
30			1	5		1	7
31			1	10	1	1	13
32		2	2	8	3	1	16
33		8	3	9	2	2	24
34	3	5	4	1	4	5	27
35	4	4	4	5	1	1	19
36	2	7	3	1	6	6	30
37	1	10	3	4	5	5	28
38	2	5	5	4	5	1	22
39	1	16	2	2	5	1	27
40	4	15	13	7	8	5	52
41	4	8	6	5	5	5	33
42	4	14	5	3	11	4	41
43	5	3	4	5	11	1	29
44	4	3	5	5	3	1	21
45	1	2	2	1	10	2	18
46	3		6	2	4	2	17
47	3	1	5	1	4	2	16
48	3		7	1	1	1	13
49	1	1	1		3	2	8
50	2		5	2	1		10
51			2		1		3
Total	**47**	**104**	**90**	**96**	**94**	**49**	**480**

Table 4.10: Marshall-Fanti beach monthly length-frequency distribution of *Pseudotolithus senegalensis*

4.1.3 Length-weight relationship in *S. aurita* and *P. senegalensis*

4.1.3.1 *S. aurita* and *P. senegalensis* length-weight relationship at Gbanjor

A total of 532 *S. aurita* from Gbanjor was used in this analysis. Figure 4.2 shows the length-weight relationship for *S. aurita*. The length and weight ranged between 17 cm weighing 120g and 31 cm weighing 310g. The calculated mean length and weight were 23.64 cm and 192g respectively, while the regression line fitted for length on weight at Log W = 1.9748 Log TL-0.4385. The exponential value at 1.9748 shows that length increases with increase in weight (negative allometric growth)

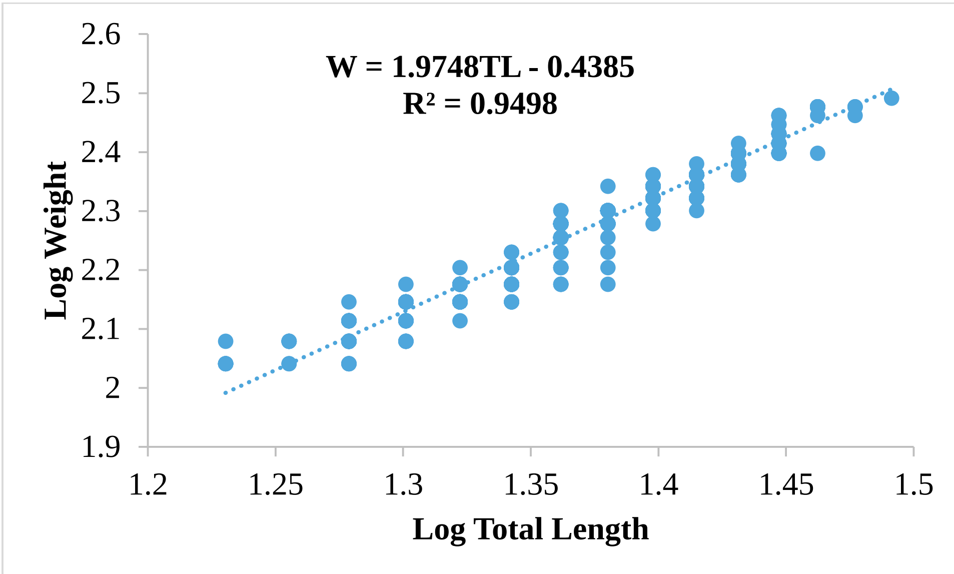

Figure 4.2: Length-Weight relationship for *S. aurita* in Gbanjor

A total of 461 *P. senegalensis* from Gbanjor was used in this analysis. Figure 4.3 shows the length the length-weight relationship. The specimen length and weight ranged between 29 cm weighing 280g and 51 cm weighing 1250g. The calculated mean length and weight were 39.29 cm and 599.80g respectively, while the regression line fitted for length on weight was Log W = 2.7706 Log TL -1.6565. The exponential value of 2.7706 shows that length increases with increase in weight (negative allometric growth).

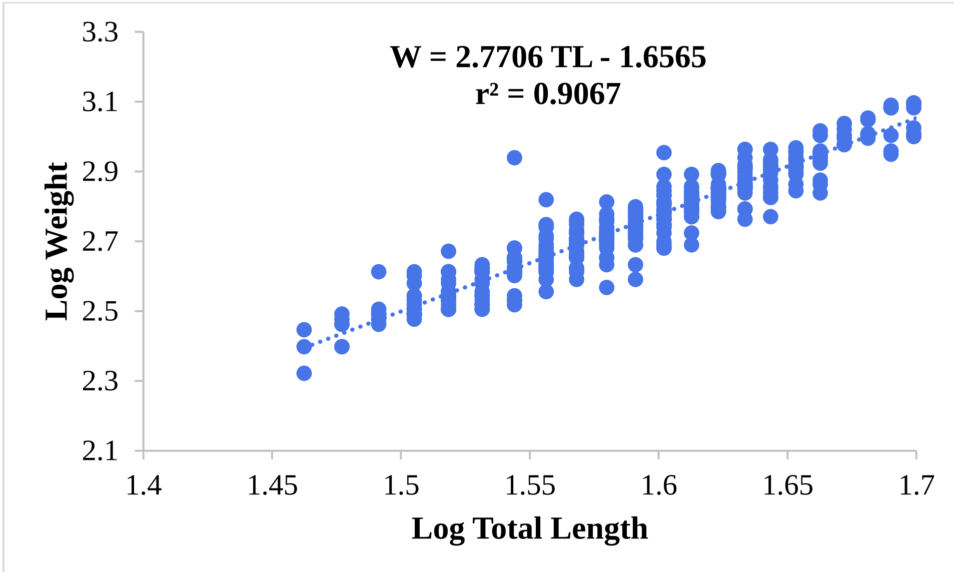

Figure 4.3: Length-Weight relationship for *P. senegalensis* at Gbanjor

4.1.3.2 *S. aurita* and *P. senegalensis* length-weight relationship at West Point

A total of 555 *S. aurita* from West Point Fanti Town was analyzed. Figure 4.4 shows the length-weight relationship. The specimen length and weight ranged between 19 cm weighing 130g and 30 cm weighing 300g. The calculated mean length and weight were 24.80 cm and 207. 41g respectively, while the regression line fitted for length and weight at Log W = 1.9359 Log TL - 0.3868. The exponential value at 1.9359 shows that length increase with increase in weight (negative allometric growth).

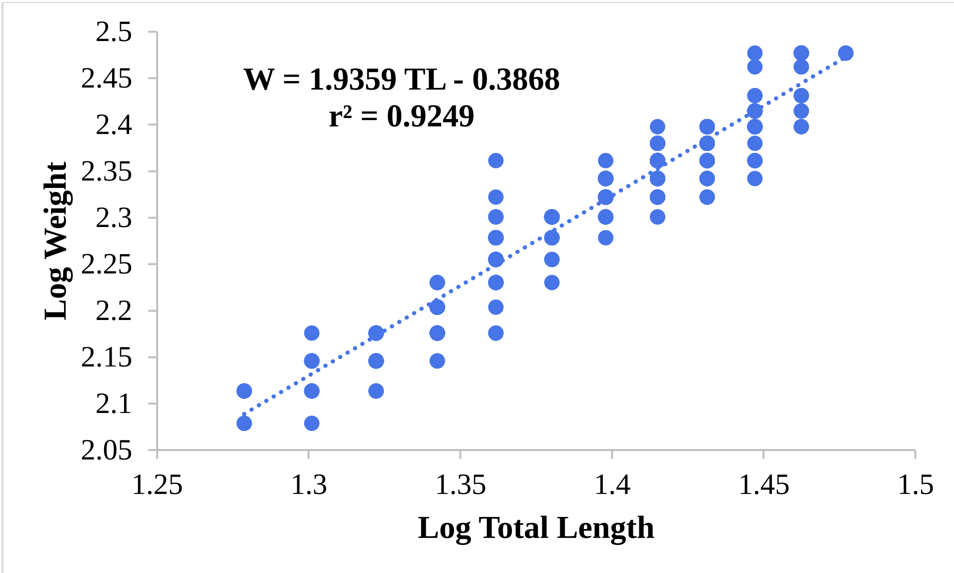

Figure 4.4: Length-Weight relationship for *S. aurita* at West Point.

A total of 399 *P. senegalensis* from West Point Kru Town were analyzed. Figure 4.5 shows the length-weight relationship. The specimen length and weight ranged between 28 cm weighing 300g and 50 cm weighing 1030g. The calculated mean length and weight were 38.6 cm and 583g respectively, while the regression line fitted for length on weight was Log W = 2.4459 Log TL - 1.1286. The exponential value of 2.4459 shows that length increases with weight (negative allometric growth).

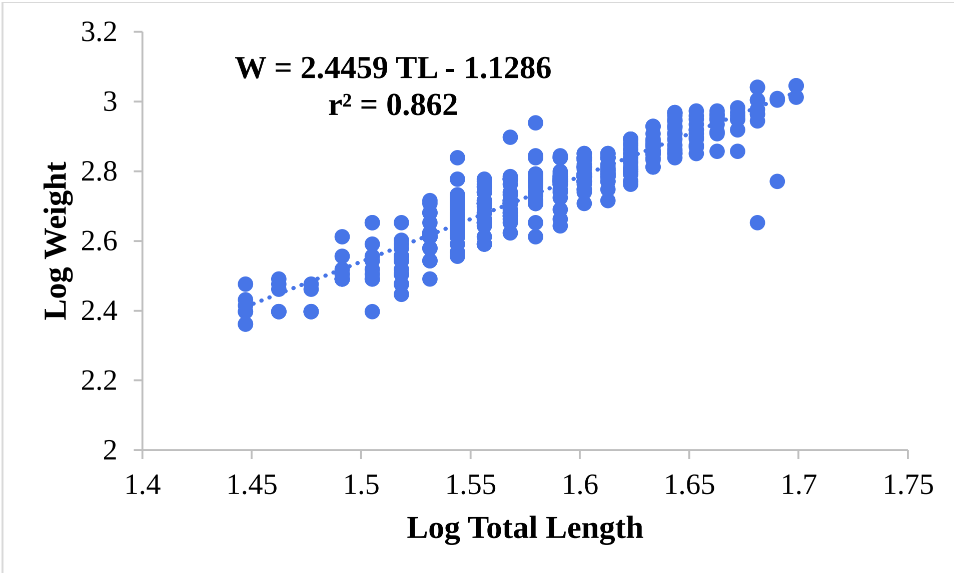

Figure 4.5: Length-Weight relationship for *P. senegalensis* at West Point

4.1.3.3 *S. aurita* and *P. senegalensis* length-weight relationship at King Gray and ELWA

A total of 556 *S. aurita* data collected from King Gray was used in this analysis. Figure 4.6 shows the length-weight relationship. The specimen length and weight ranged between 17 cm weighing 150g and 30 cm weighing 240g. The calculated mean length and weight were 24 cm and 196g respectively while the regression line fitted for length on weight at Log W = 1.8897 Log TL - 0.3233. The exponential value at 1.8897 shows that length increase with increase in weight (allometric growth).

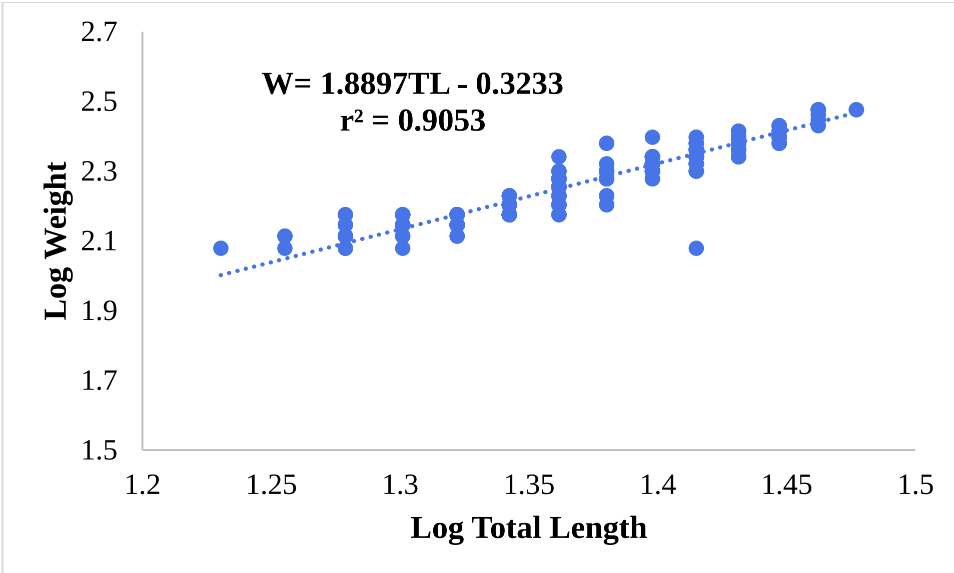

Figure 4.6: Length-Weight relationship for *S. aurita* at King Gray

A total of 371 *P. senegalensis* from King Gray and ELWA was used in this analysis. Figure 4.7 shows the length-weight relationship. The specimen length and weight ranged between 28 cm weighing 290g and 50 cm weighing 1250g. The calculated mean length and weight were 39.5 cm and 620.6g respectively, while the regression line fitted for length on weight was Log W = 2.4991 Log TL = -1.2121. The exponential value of 2.4991 shows that length increases with increase in Weight (negative allometric growth).

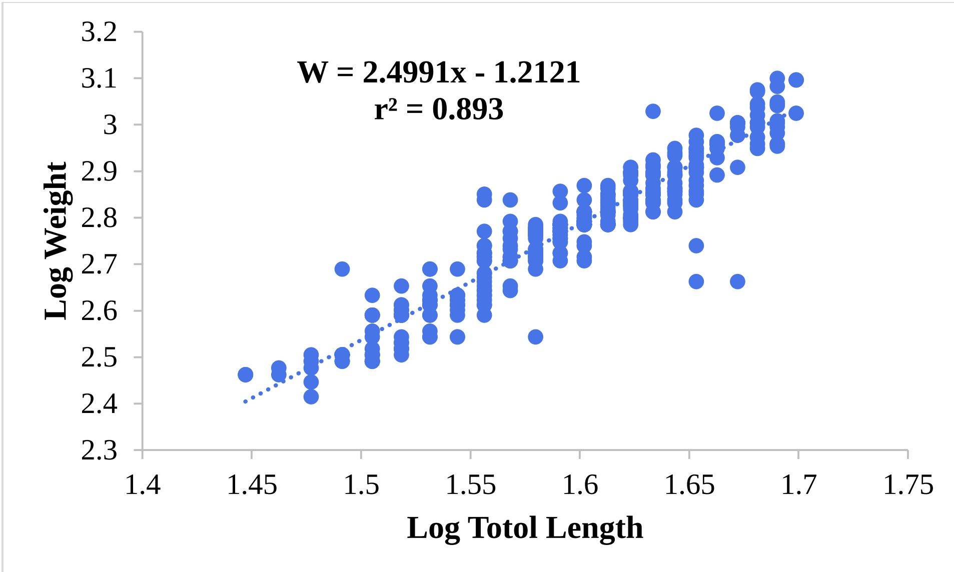

Figure 4.7: Length-Weight relationship for *P. senegalensis* at King Gray & ELWA

4.1.3.4 *S. aurita* and *P. senegalensis* length-weight relationship at Marshall

A total of 627 *S. aurita* from Marshall Fanti and Kru Town were analyzed. Figure 4.8 shows the length-weight relationship. The specimen length and weight ranged between 18 cm weighing 110g and 30 cm weighing 300g. The calculated mean length and weight were 24.3 cm and 199.3g respectively, while the regression line fitted for length and weight at Log W = 1.9698 Log TL - 0.34362. The exponential value at 1.9698 shows that length increase with increase in weight (negative allometric growth).

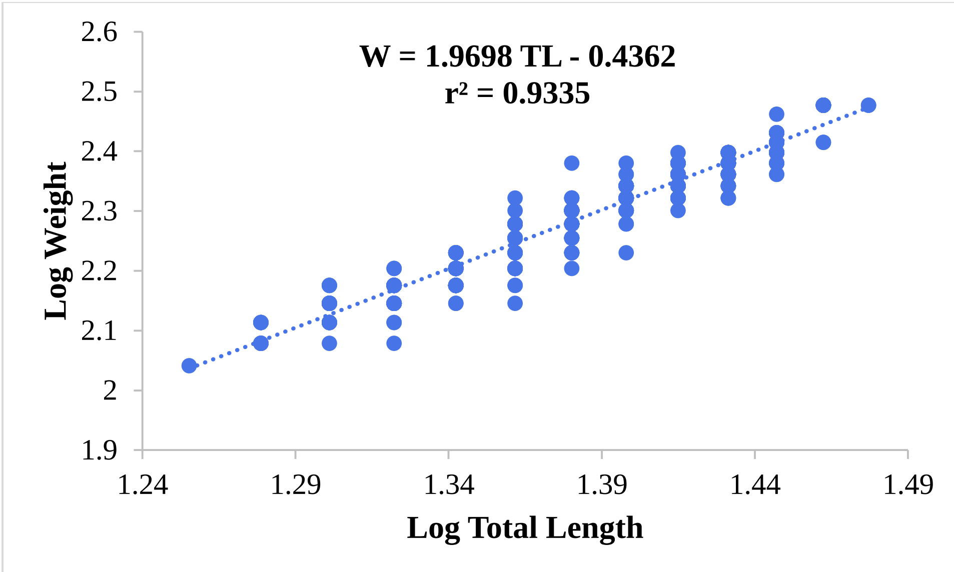

Figure 4.8: Length-Weight relationship for *S. aurita* in Marshall

A total of 480 *P. senegalensis* from Marshall Fanti Town was used in this analysis. Figure 4.9 shows the length-weight relationship. The specimen length and weight ranged between 28 cm weighing 230g and 51 cm weighing 1270g. The calculated mean length and weight were 39.62 cm and 613.02 respectively, while the regression line fitted for length on weight was Log W = 2.2862 Log TL = -0.8809. The exponential value of 2.4991 shows that length increases with increase in Weight (negative allometric growth).

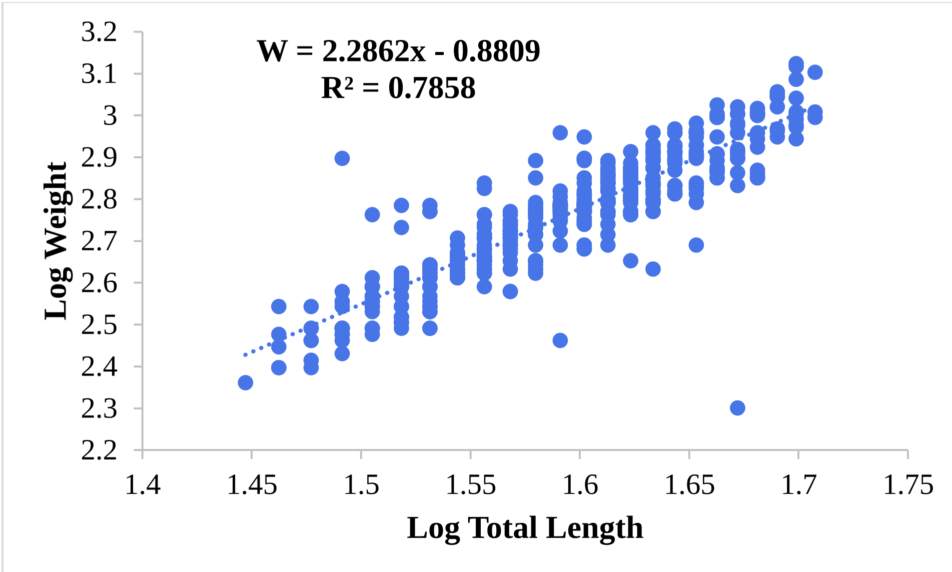

Figure 4.9: Length-Weight relationship for P. senegalensis in Marshall

4.2 Fish Stock Assessment

4.2.1 Growth parameters (L∞, K, t_o) and performance index, Ø' for *S. aurita* and *P. senegalensis*

Estimation of the growth parameters (**L∞, K, t_o**) from length frequency data shows the length frequency distribution with the superimposed growth curve output for the six successive months from FiSAT analysis for both *S. aurita* and *P. senegalensis* in Figure 4.10 to 4.17 for Montserrado and Marshall.

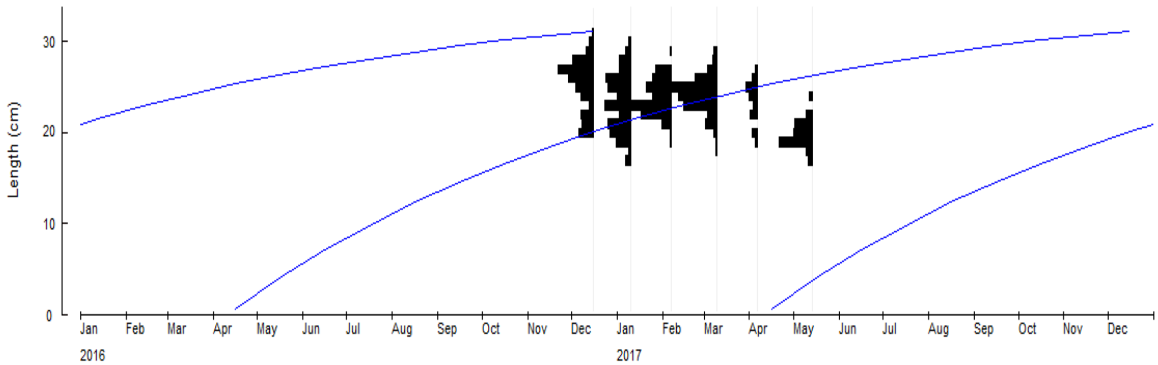

Figure 4.10: length frequency distribution output from FiSAT with superimposed growth curves for *S. aurita* at Gbanjor's nearshore waters.

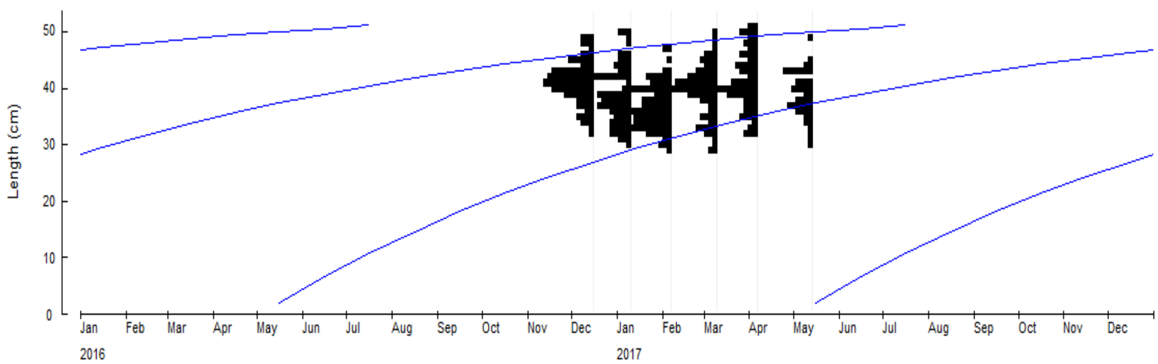

Figure 4.11: length frequency distribution output from FiSAT with superimposed growth curves for *P. senegalensis* at Gbanjor's nearshore waters.

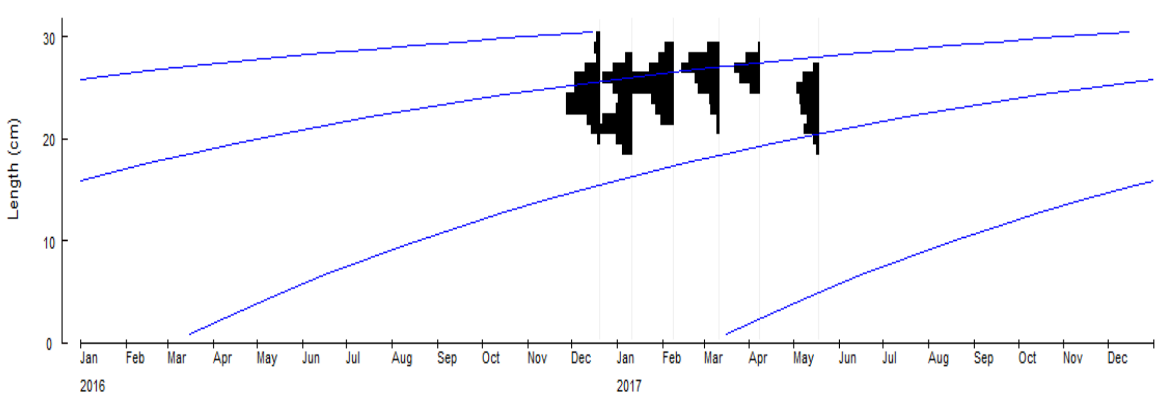

Figure 4.12: length frequency distribution output from FiSAT with superimposed growth curves for *S. aurita* at West Point's nearshore waters.

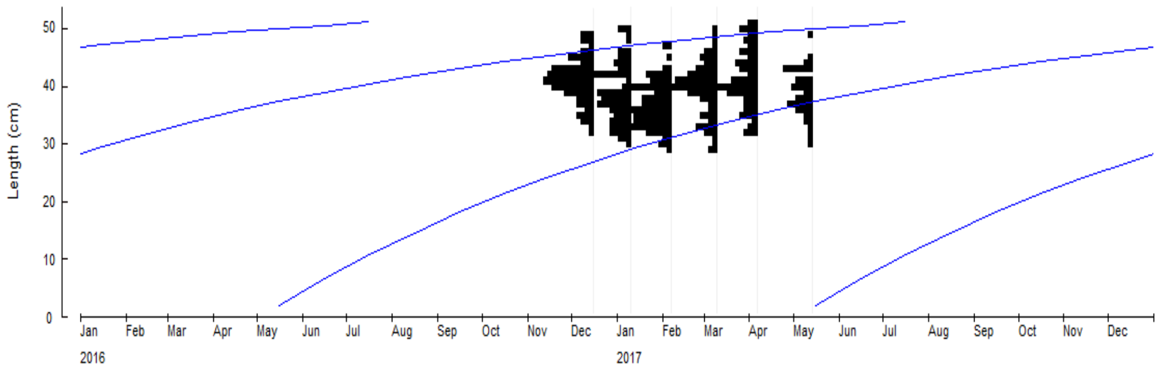

Figure 4.13: length frequency distribution output from FiSAT with superimposed growth curves for *P. senegalensis* at West Point's nearshore waters.

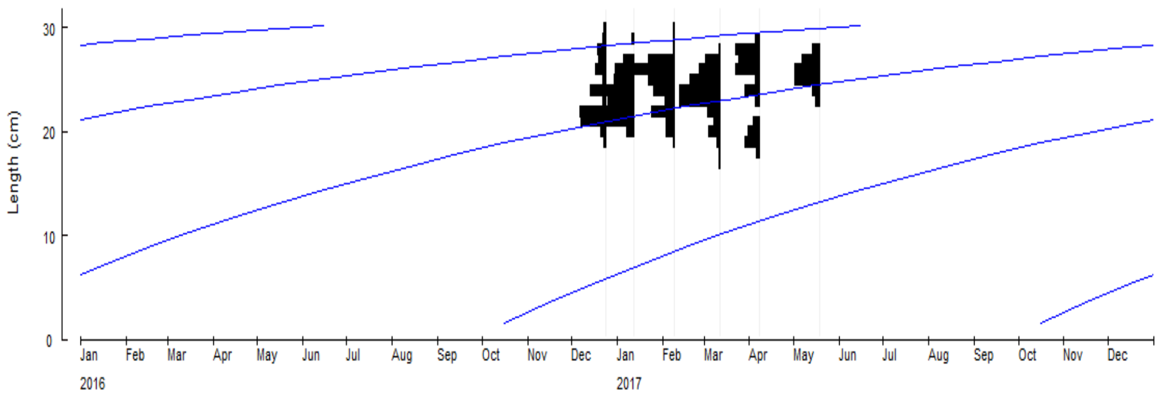

Figure 4.14: length frequency distribution output from FiSAT with superimposed growth curves for *S. aurita* at King Gray's nearshore waters.

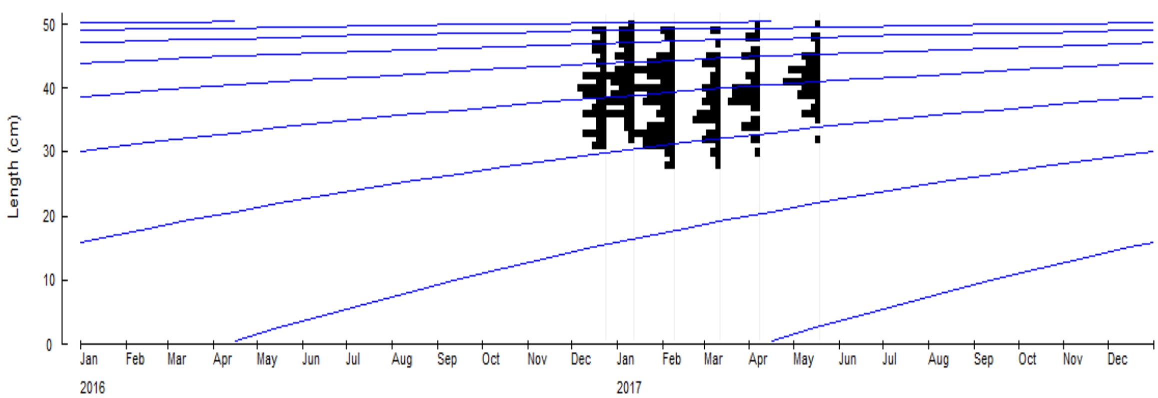

Figure 4.15: length frequency distribution output from FiSAT with superimposed growth curves for *P. senegalensis* at King Gray & ELWA's nearshore waters.

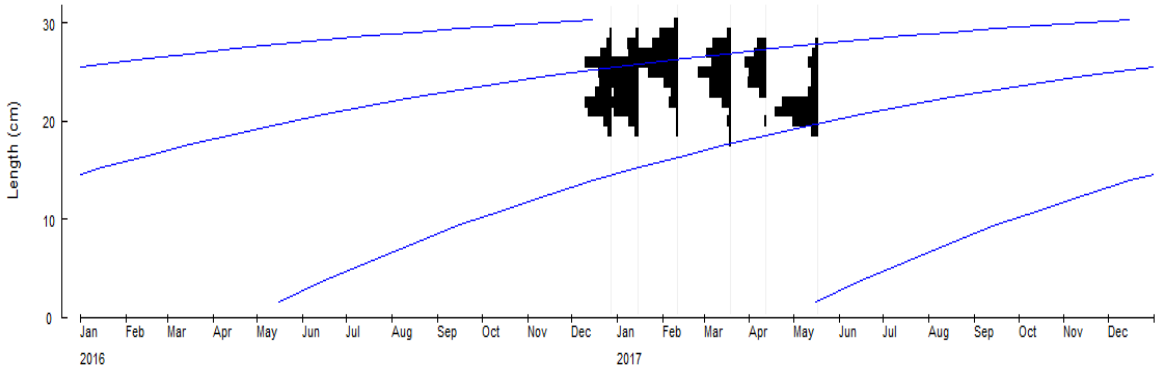

Figure 4.16: length frequency distribution output from FiSAT with superimposed growth curves for *S. aurita* at Marshall's nearshore waters.

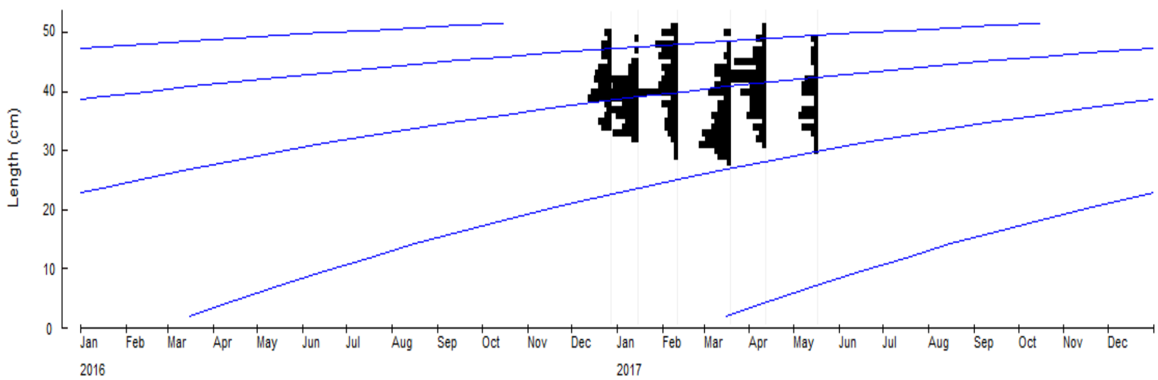

Figure 4.17: length frequency distribution output from FiSAT with superimposed growth curves for *P. senegalensis* at Marshall's nearshore waters.

Sardinella aurita coefficient of the seasonal von Bertalanffy growth function (vBGF) L∞, K (yr^{-1}) and **Ø'** were 36.00, 1.18 and 3.18 at Gbanjor; 35.00, 0.73 and 2.95 at West Point; 35.00, 0.73 and 2.95 at King Gray in Montserrado and 34.50, 0.50 and 2.77 Marshall Fanti and Kru respectively. These results were significantly lower for Marshall ($p<0.05$) than for fish specimens from the other three landing sites (Gbanjor, West Point and King Gray). There were a significant difference observed in the growth parameters for *S. aurita* specimens between Gbanjor, West Point and King gray for *S. aurita*, whereas West Point and King Gray had no significant difference in respect to their growth parameters (Table 4.11 and Figure 4.10, 4.12 and 4.14). The methods of sampling or the combination of data varies in some cases with the fit of von Bertalanffy equation (Parker & Larkin, 1959), closeness of 't_0' e.g. for *S. aurita* (0.895) Gbanjor, (0.675) West Point, (0.675) King Gray in Montserrado. (0.502) Marshall Fanti and Kru in Marshall (Table 4.11). The asymptotic length, L∞ for *S. aurita* (36.00) in Gbanjor was higher than for West Point (35.00), King Gray (35.00) in Montserrado and (34.50) in Marshall. Both King Gray and West Point was (35.00) and Marshall was the smallest (34.50).

Table 4.11: Growth parameters at Montserrado and Marshall

Study areas		Species	L- max	L ∞	K (yr^{-1})	Lc (50%)	t_0	**Ø'**
Montserrado	Gbanjor	*Sardinella aurita*	31	36.00	1.18	26.64	0.895	3.18
		Pseudotolithus senegalensis	51	57.00	1.03	50.00	0.888	3.52
	West Point (Kru & Fanti)	*Sardinella aurita*	30	35.00	0.73	27.68	0.675	2.95
		Pseudotolithus senegalensis	50	60.00	0.58	45.75	0.635	3.32
	King Gray & ELWA	*Sardinella aurita*	30	35.00	0.73	26.14	0.675	2.95
		Pseudotolithus senegalensis	50	52.00	0.50	48.87	0.551	3.13
Marshall - Lower Margibi	Marshall (Fanti & Kru)	*Sardinella aurita*	30	34.5	0.50	27.63	0.502	2.77
		Pseudotolithus senegalensis	51	58.5	0.58	45.83	0.632	3.30

Pseudotolithus senegalensis co-efficient of the seasonal von Bertalanffy growth function (vBGF) L∞, K (yr^{-1}) and **Ø'** were 57.00, 1.03 and 3.52 at Gbanjor; 60.00, 0.58 and 3.32 at West Point and 52.00, 0.50 and 3.13 King Gray & ELWA in Montserrado. For Marshall Kru and Fanti were 58.50, 0.58 and 3.30 respectively for Marshall (Table 4.11). There were slight differences observed in the growth parameters for *P. senegalensis* fish specimens between Montserrado and Marshall Fisheries (Figure 4.11 to 4.17). Also for *P. senegalensis* (0.888) Gbanjor, (0.635) West Point, (0.551) King Gray & ELWA in Montserrado and (0.632) Marshall Kru and Fanti in Marshall (Table 8) described their growth patterns with the use of von Bertalanffy growth model. *P. senegalensis* (52.00) in King Gray & ELWA was lower than for West Point (60.00) and (57.00) Gbanjor in Montserrado and (58.50) in Marshall. The length (Lc) at which 50% of all the fish encountering the gear are retained was slightly the same for Gbanjor (26.64) and 26.14) King Gray and higher in West Point (27.68) in Montserrado.

The length at which 50% of all the fish encountering the gear are retained was fairly high for Marshall (27.63) compared to Montserrado for two sites (Gbanjor and King Gray) for *S. aurita* (Table 4.11). *P. senegalesis* length at which 50% encountering the gear are retained was fairly higher for Gbanjor (50.00) compared to the two sites in Montserrado (West Point and King Gray & ELWA) and Marshall. Marshall has the same (L_c) as one of the site in Montserrado, West Point (Table 4.11). Gbanjor had the highest growth performance index, **Ø'** for all species with *S. aurita* having the highest **Ø'** value of 3.18 and *P. senegalensis* (3.52) as compared to West Point, King Gray & ELWA and Marshall (Table 4.11). The $L\infty$ and K estimates from ELEFAN 1 preliminary runs did not differ much when amplitude of growth oscillation (C) (Daniel Pauly, 1985) was zero or non-zero. Therefore, C was equally determined t_o 0. Only the best sets of $L\infty$ and K values at Maximum Rn values for different sets of length-frequencies were obtained.

4.2.2 Growth and mortality parameters (M, F and Z) and exploitation (E) ratios of two commercially important species in Montserrado and Marshall

Estimation of growth and mortality parameters (M, F and Z) for *S. aurita* and *P. senegalensis* from length frequency data for December 2016 to May 2017 presented in Figure 4.18 to 4.25 at Montserrado (Gbanjor, West Point and King Gray & ELWA) and Marshall (Fanti and Kru) Town.

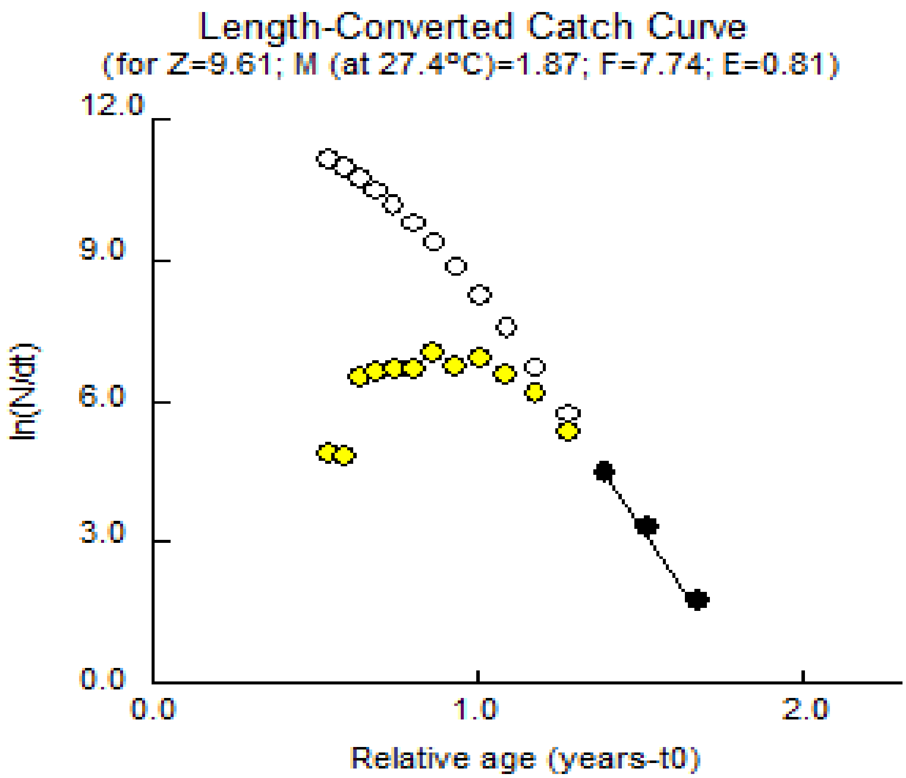

Figure 4.18: FiSAT output of linearized length-converted catch curve for unsexed *S. aurita* at Gbanjor's nearshore waters

Gbanjor landing site shows the linearized length-converted catch curve which enabled estimation of an average annual instantaneous total mortality rate Z, as 9.61 yr^{-1}. The estimated instantaneous fishing mortality rate F = 7.74 yr^{-1}, is beyond the estimated natural mortality rate (M) of 1.87 yr^{-1} and could reflect an overexploitation of the fish stock within Gbanjor fishing community (Figure 4.18).

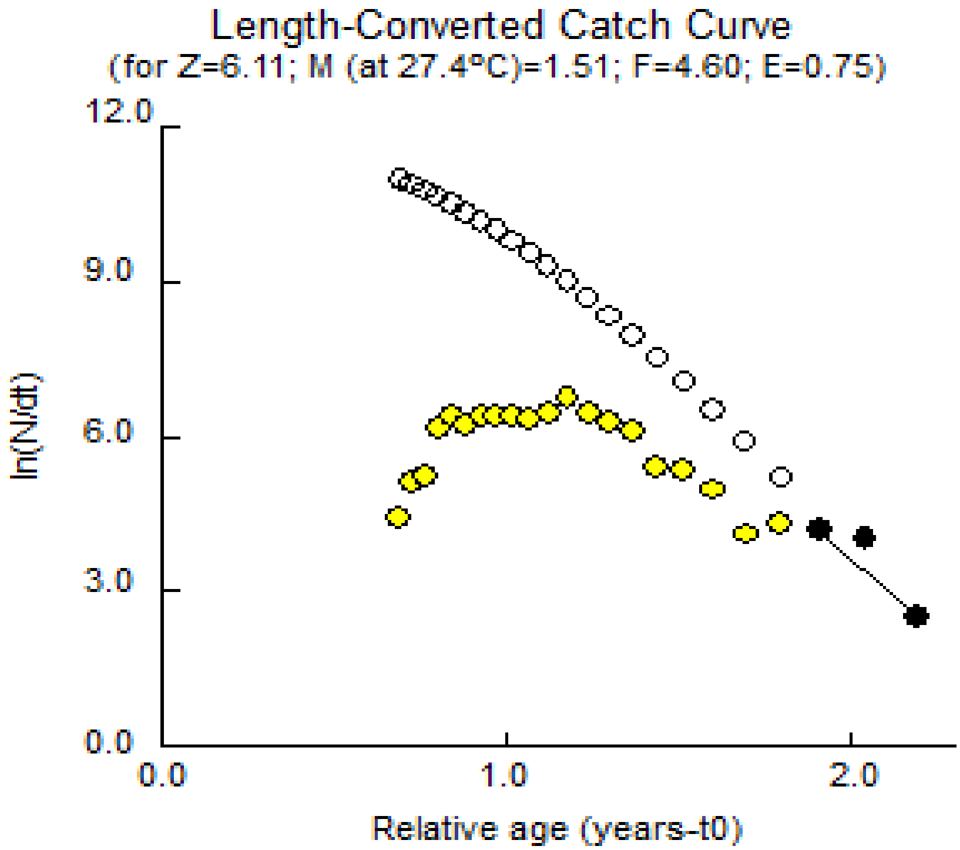

Figure 4.19: FiSAT output of linearized length-converted catch curve for unsexed *P. senegalensis* at Gbanjor's nearshore waters.

Gbanjor landing site shows the linearized length-converted catch curve for *P. senegalensis* which enabled estimation of the average annual instantaneous total mortality rate Z, as 6.11 yr^{-1}. The estimated instantaneous fishing mortality rate F = 4.60 yr^{-1}, which double the estimated natural mortality rate (M) of 1.51 yr^{-1} and could reflect an overexploitation of the fish stock within Gbanjor fishing community (Figure 4.19).

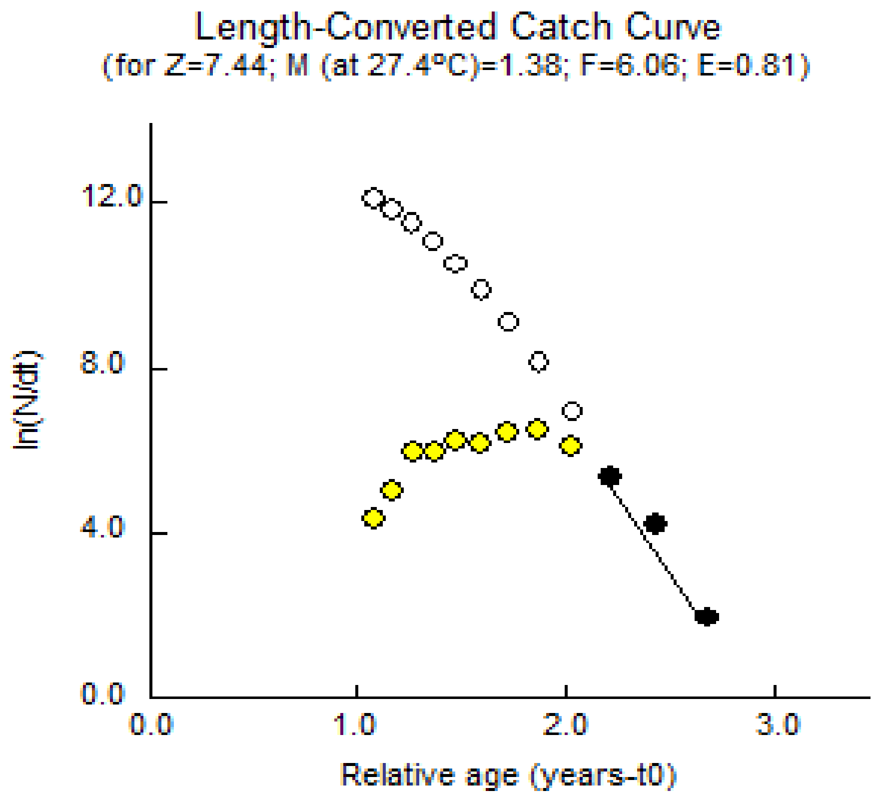

Figure 4.20: FiSAT output of linearized length-converted catch curve for unsexed *S. aurita* at West Point's nearshore waters.

West Point-Fanti beach shows the linearized length-converted catch curve for *S. aurita* which established the average annual instantaneous total mortality rate Z, as 7.44 yr^{-1}. The estimated instantaneous fishing mortality rate F = 6.06 yr^{-1}, double five times the estimated natural mortality rate (M) of 1.38 yr^{-1} and could reflect an overexploitation of the fish stock within West Point-Fanti fishing community (Figure 4.20).

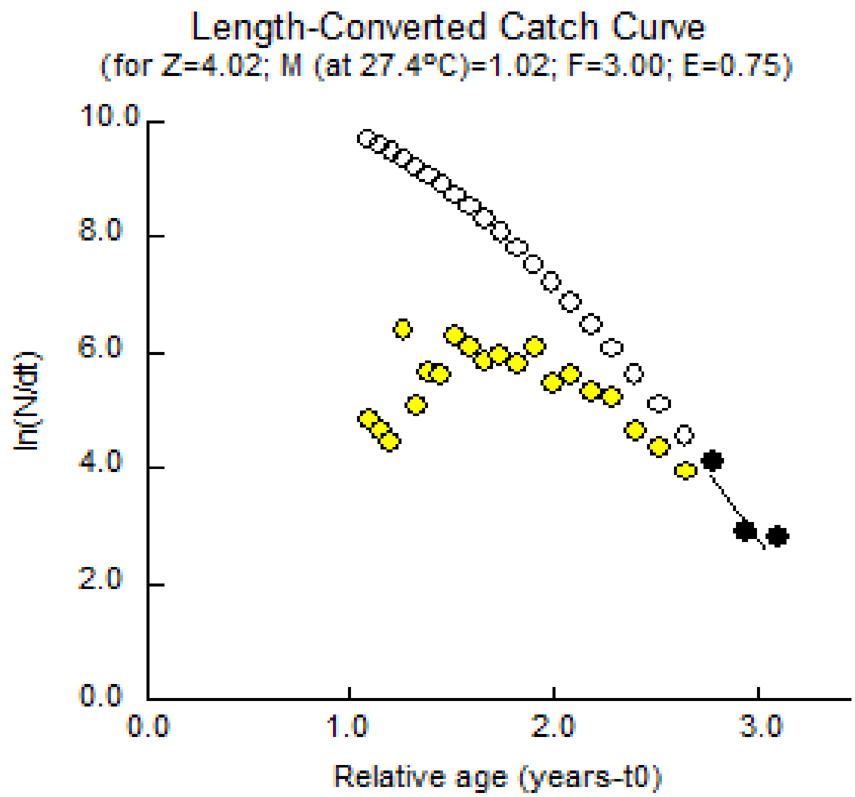

Figure 4.21: FiSAT output of linearized length-converted catch curve for unsexed *P. senegalensis* at West Point's nearshore waters.

West Point-Kru landing site shows the linearized length-converted catch curve for *P. senegalensis* which enabled estimation of the average annual instantaneous total mortality rate Z, as 4.02 yr^{-1}. The estimated instantaneous fishing mortality rate F = 3.00 yr^{-1}, is double the estimated natural mortality rate (M) of 1.02 yr^{-1} and could reflect an overexploitation rate of the fish stock within West Point fishing community (Figure 4.21).

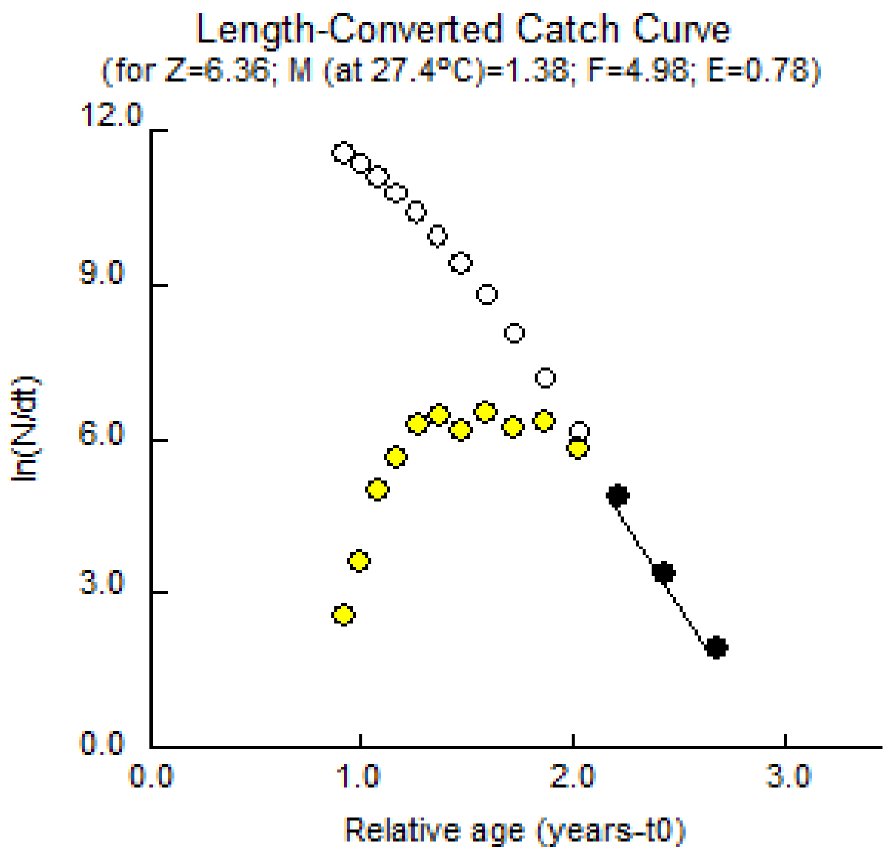

Figure 4.22: FiSAT output of linearized length-converted catch curve for unsexed *S. aurita* at King Gray's nearshore waters.

King Gray shows the linearized length-converted catch curve for *S. aurita* which established the average annual instantaneous total mortality rate Z, as 6.36 yr^{-1}. The estimated instantaneous fishing mortality rate F = 4.98 yr^{-1}, triple the estimated rate of natural mortality (M) of 1.38 yr^{-1} and could reflect an overexploitation of the fish stock within King Gray fishing community (Figure 4.22).

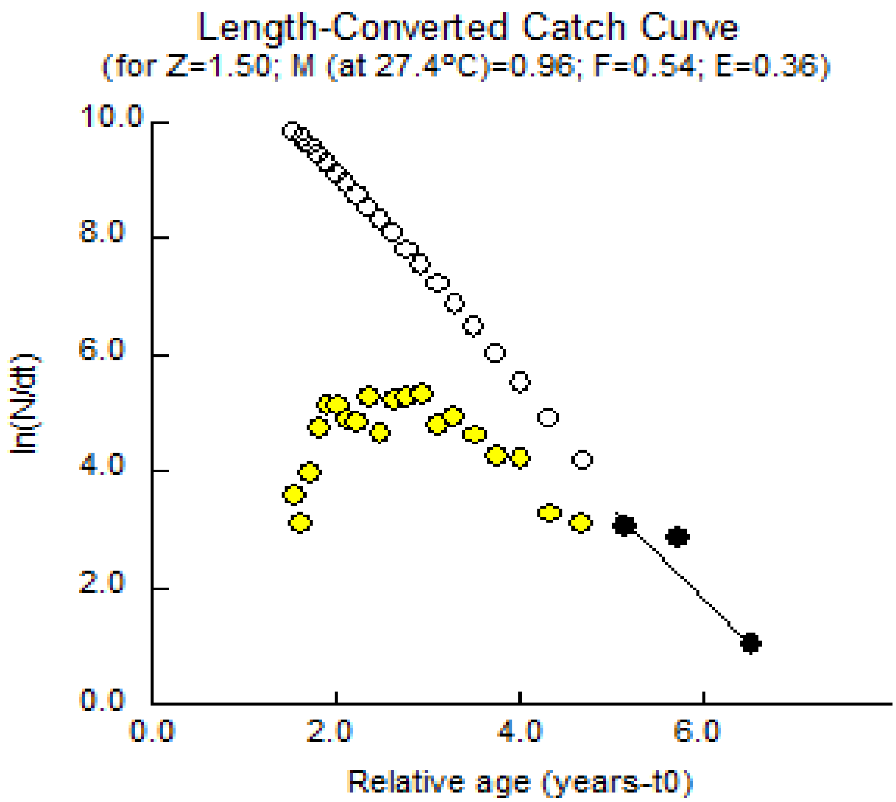

Figure 4.23: FiSAT output of linearized length-converted catch curve for unsexed *P. senegalensis* at King Grat & ELWA's nearshore waters.

King Gray and ELWA landing sites shows the linearized length-converted catch curve for *P. senegalensis* which enabled estimation of the average annual instantaneous total mortality rate Z, as 1.50 yr^{-1}. The estimated instantaneous fishing mortality rate F = 0.54 yr^{-1}, is less than the estimated natural mortality rate (M) of 0.96 yr^{-1} and could reflect no overexploitation of the fish stock (Figure 4.23).

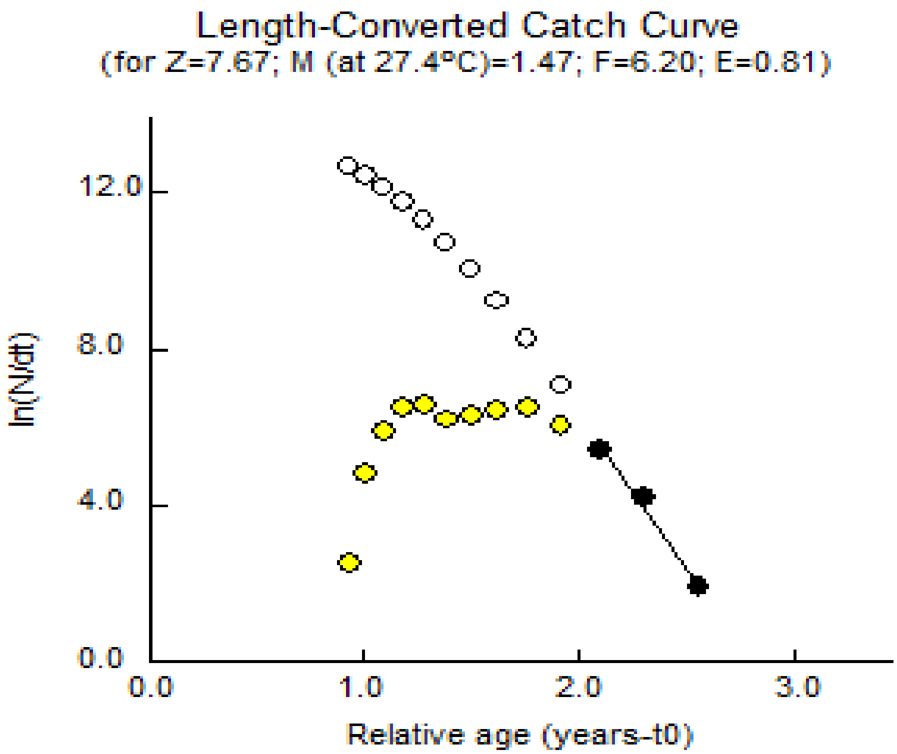

Figure 4.24: FiSAT output of linearized length-converted catch curve for unsexed *S. aurita* at Mrashall's nearshore waters.

Marshall Kru and Fanti landing sites shows the linearized length-converted catch curve for *S. auriat* which established the average annual instantaneous total mortality rate Z, 7.67 yr^{-1}. The estimated instantaneous fishing mortality rate F = 6.20 yr^{-1}, which double five times the estimated rate of natural mortality (M) of 1.47 yr^{-1} reflect an overexploitation of the fish stock within Marshall fishing community (figure 4.24).

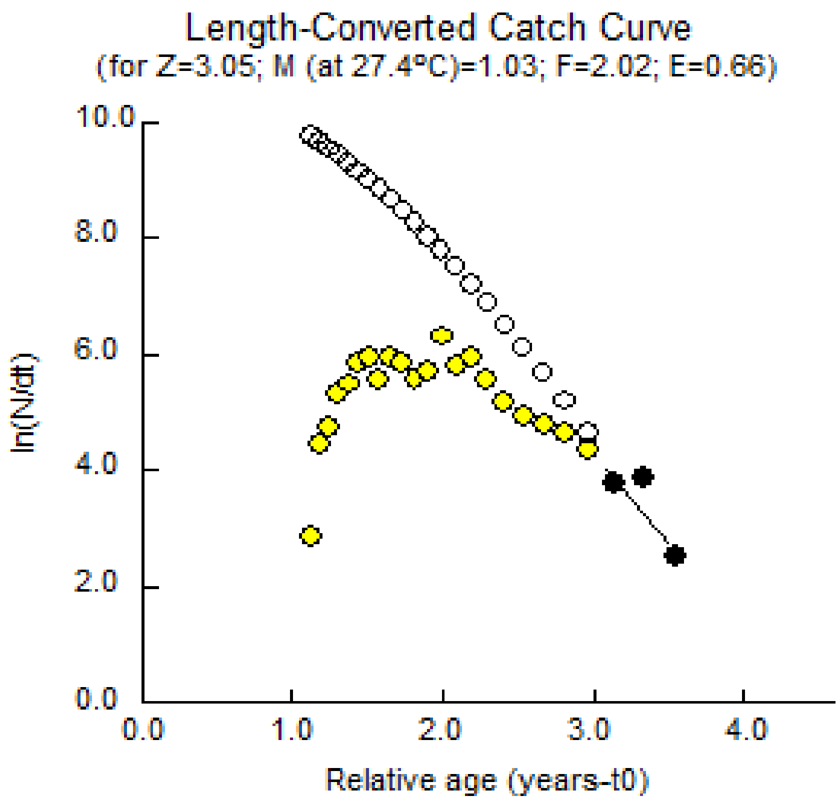

Figure 4.25: FiSAT output of linearized length-converted catch curve for unsexed *P. senegalensis* at Marshall's nearshore waters.

Marshall-Fanti landing site shows the linearized length-converted catch curve for *P. senegalensis* which enabled estimation of the average annual instantaneous total mortality rate Z, as 3.05 yr^{-1}. The estimated instantaneous fishing mortality rate F = 2.02 yr^{-1}, is slightly beyond the estimated natural mortality rate (M) of 1.03 yr^{-1} and could reflect a little overexploitation of the fish stock (Figure 4.25).

Both Marshall and Montserrado landing sites were observed to have high E values for *S. aurita* and *P. senegalensis* (Table 4.12 and Figure 4.18 to 4.25). Both species were equally overly exploited at all the landing sites, except for King Gray & ELWA which had a lower exploitation rate for *P. senegalensis* but a high E value on *S. aurita*. ANOVA revealed that there was never a significant difference found between Montserrado and Marshall Fish (P>0.05).

Table 4.12: Mortality levels and exploitation ratios for *S. aurita* and *P. senegalensis*

				Mortalities		Exploitation ratios	
Study area		species	N	M	Z	F	E = F/Z
	Gbanjor	*Sardinella aurita*	532	1.87	9.61	7.74	0.81
Montserrado		*Pseudotoithus senegalensis*	461	1.51	6.11	4.60	0.75
	West Point	*Sardinella aurita*	555	1.38	7.44	6.06	0.81
		Pseudotoithus senegalensis	399	1.02	4.02	3.00	0.75
	King Gray/	*Sardinella aurita*	556	1.38	6.36	4.98	078
	ELWA	*Pseudotoithus senegalensis*	371	0.96	1.50	0.54	0.36
Marshall-							
Lower Margibi	Marshall	*Sardinella aurita*	627	1.47	7.67	6.20	0.81
	(Fanti & Kru)	*Pseudotoithus senegalensis*	480	1.03	3.05	2.02	0.66

N = number of *S. aurita* and *P. senegalensis* caught, Z = Corresponding estimates of instantaneous total mortality rate, M = natural mortality rate, F = fishing mortality rate and E = exploitation ratio

Catches in Montserrado and Marshall represent 39.8% of the total estimated stock for the selected commercial fish species. These exploitation percentages for the resource remain high within the two fisheries. A significant relationship between total stocks and fishing pressure shows that catches are higher in certain habitats and for certain species. *P. senegalensis* and *S. aurita* were at a higher ratio within Marshall and Montserrado. West Point and Marshall-Fanti exploited *P. senegalensis* on the ratio while Gbanjor exploitation of *P. senegalensis* and *S. aurita* varied between West Point and King Gray & ELWA in Montserrado and Marshall respectively.

4.2.3 Recruitment patterns of *Sardinella aurita* and *Pseudotolithus senegalensis* for Montserrado and Marshall

4.2.3.1 *Sardinella aurita* recruitment pattern at landing sites

Figures 4.26 to 4.29 shows recruitment pattern of unsexed *S. aurita*, based on pooled length-frequency data for Gbanjor, West Point and King Gray in Montserrado and Marshall Kru and Fanti beach in Marshall from December 2016 and May 2017. Relatively six months data were used to estimate monthly recruitment pattern using ELEFAN 1 extant in FiSAT II software (Hoggarth et al., 2006).

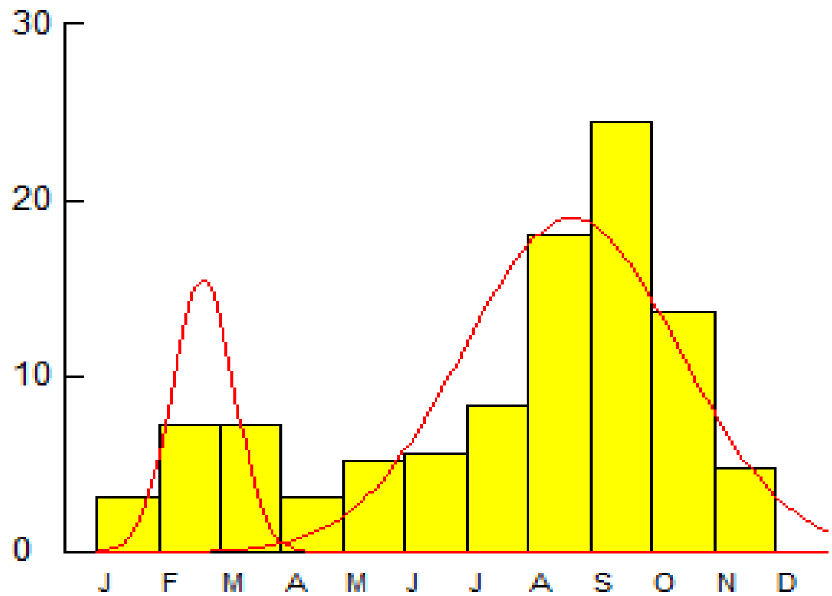

Figure 4.26. Recruitment patterns of unsexed *S. aurita* based on pooled length-frequency data at Gbanjor from December 2016 and May 2017 estimated using FiSAT II.

Gbanjor recruitment pattern showed that *S. aurita* was recruited in the fishery continuously throughout the year with the peaks from August and September. The highest recruitment was observed in the month of September (23.22%) whereas the lowest recruitment was observed in January and April. The mid-point of the lower length class (17 cm) in the sampled data was used as a length at recruitment (Figure 4.26)

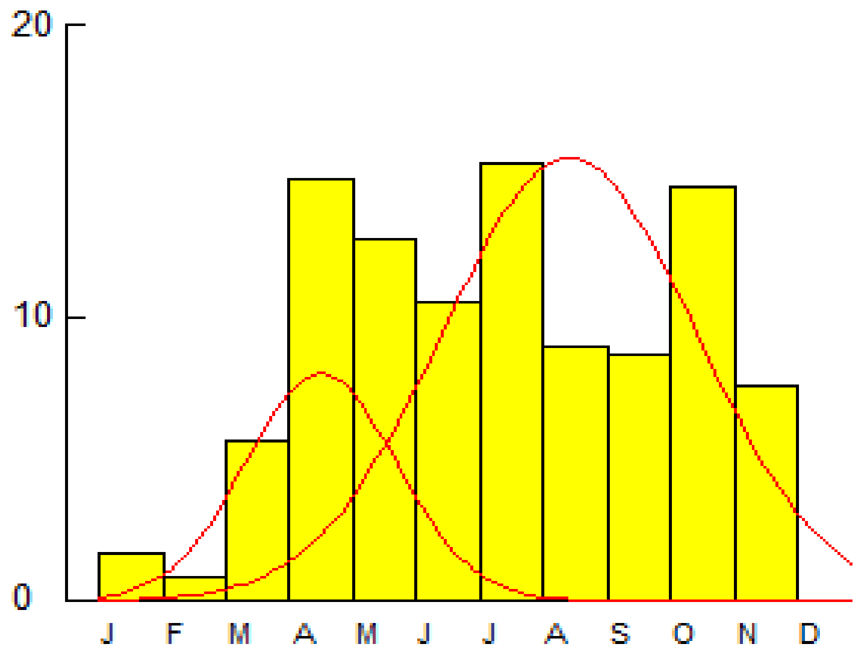

Figure 4.27. Recruitment patterns of unsexed *S. aurita* based on pooled length-frequency data at West Point-Fanti from December 2016 and May 2017 estimated using FiSAT II.

West Point-Fanti beach recruitment pattern showed that *S. aurita* was recruited in the fishery continuously throughout the year with the peaks from April, July and October. The highest recruitment was observed in July (13.91%) whereas the lowest recruitment was observed in February. The mid-point of the lower length class (19 cm) in the sampled data was used as a length at recruitment (Figure 4.27).

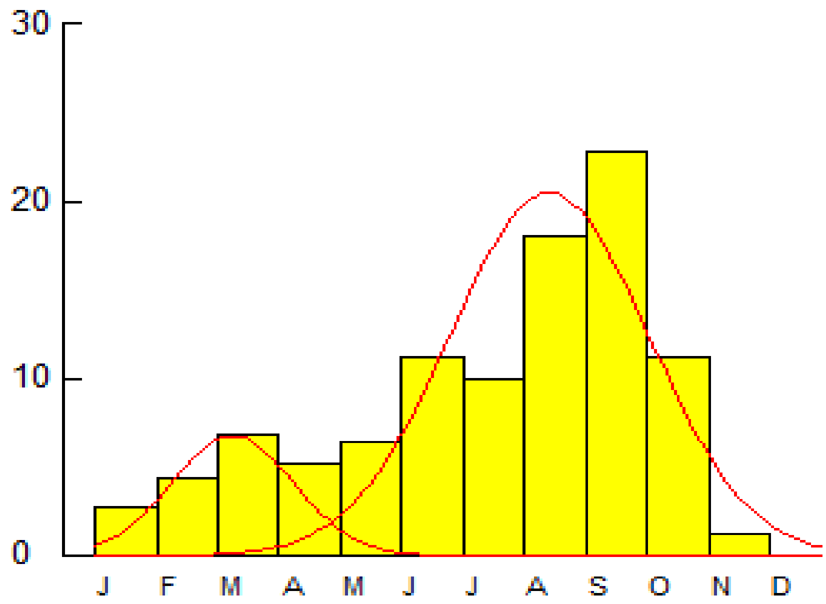

Figure 4.28: Recruitment patterns of unsexed *S. aurita* based on pooled length-frequency data at King Gray from December 2016 and May 2017 estimated using FiSAT II.

King Gray and ELWA recruitment pattern showed that *S. aurita* was recruited in the fishery continuously throughout the year with the peaks from August and September (Figure 4.28). The highest recruitment was observed in the month of September (25.32%) whereas the lowest recruitment was observed in November. The mid-point of the lower length class (17 cm) in the sampled data was used as a length at recruitment.

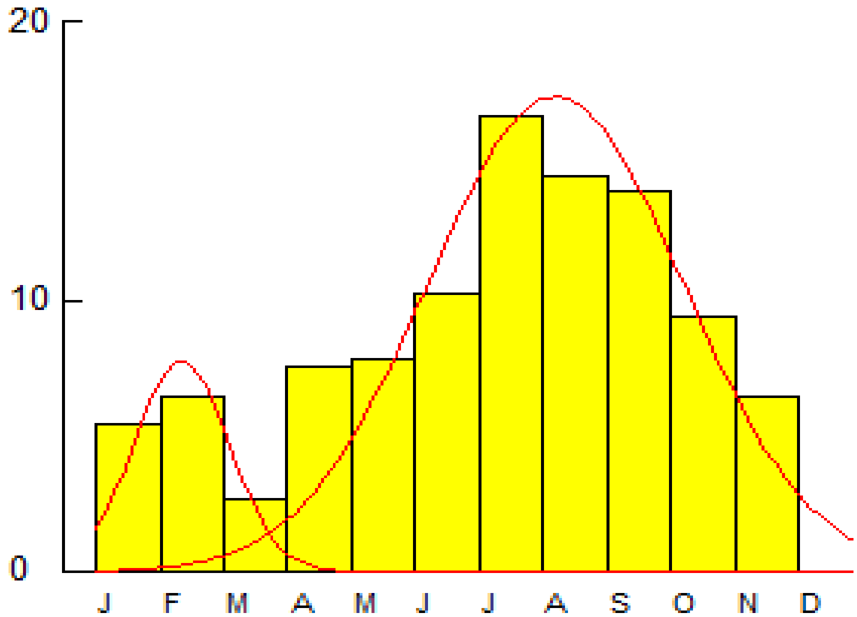

Figure 4.29: Recruitment patterns of unsexed *S. aurita* based on pooled length-frequency data at Marshall (Fanti & Kru) from December 2016 and May 2017 estimated using FiSAT II.

The recruitment pattern of Marshall showed that *S. aurita* was recruited in the fishery continuously throughout the year with the peaks between July and September. The highest recruitment was observed in the month of July (15.88%) whereas the lowest recruitment was observed in March. The mid-point of the lower length class (18 cm) in the sampled data was used as a length at recruitment (Figure 4.29).

4.2.3.2 *Sardinella aurita* recruitment pattern at landing sites

Figures 4.30 to 4.33 shows recruitment pattern of unsexed *P. senegalensis*, based on pooled length-frequency data for Gbanjor, West Point and King Gray & ELWA in Montserrado and Marshall Kru and Fanti beach in Marshall from December 2016 and May 2017.

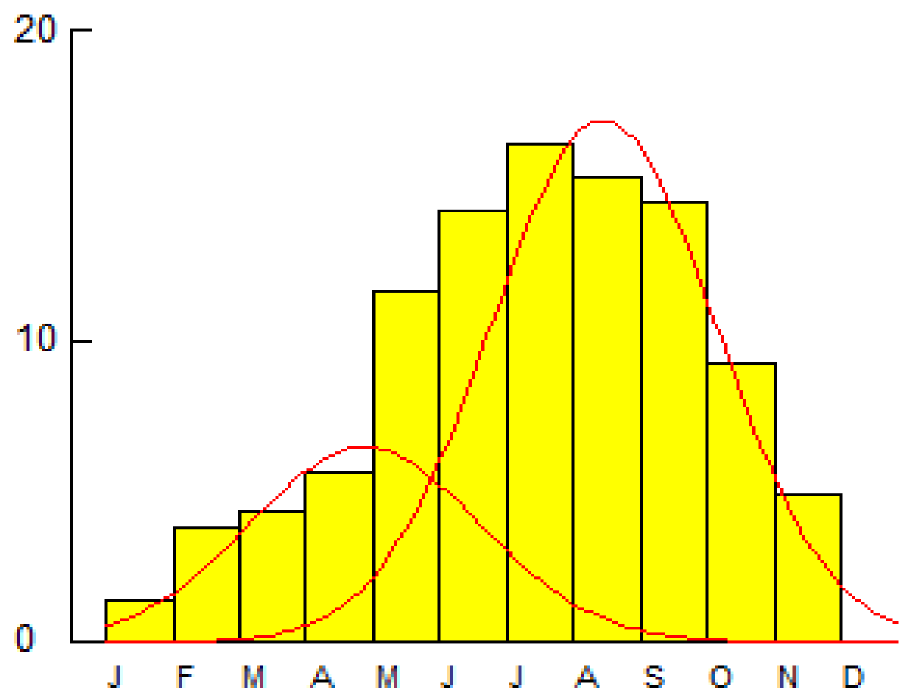

Figure 4.30: Recruitment patterns of unsexed *P. senegalensis* based on pooled length-frequency data at Gbanjor from December 2016 and May 2017 estimated using FiSAT II.

The recruitment pattern at Gbanjor (Figure 4.30) showed *P. senegalensis* high recruitment occurring throughout the year between June and September. The highest recruitment was observed in the month of July (16%) whereas the lowest recruitment was observed in January. The mid-point of the lower length class (29 cm) in the sampled data was used as a length at recruitment. The recruitment patterns were decomposed using NORMSEP and fitted with up to two Gaussian generated (i.e. group 1 and group 2) output by groups of starting estimated (in months) for all landing sites within Montserrado and Marshall.

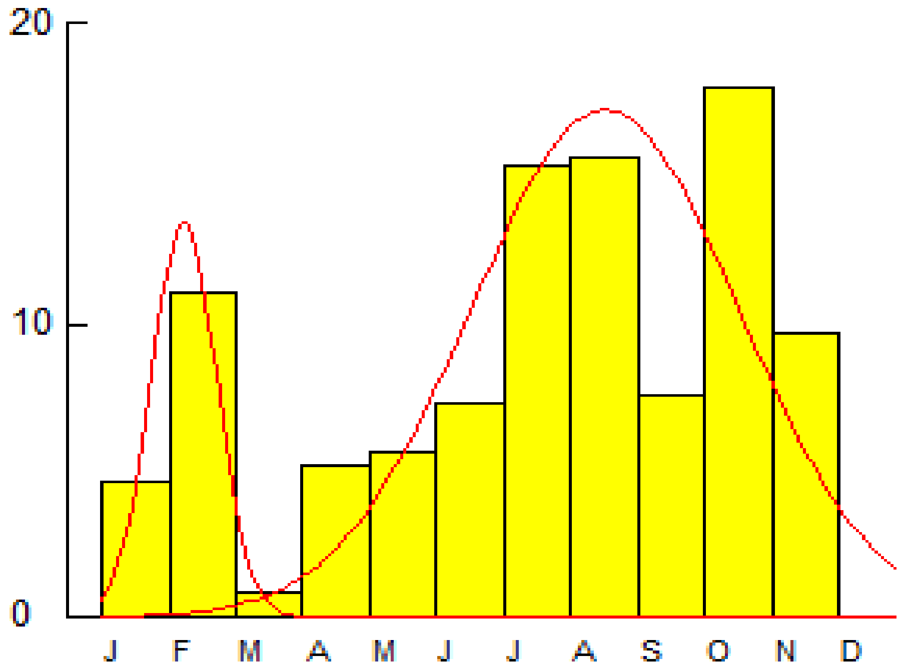

Figure 4.31: Recruitment patterns of unsexed *P. senegalensis* based on pooled length-frequency data at West Point-Kru from December 2016 and May 2017 estimated using FiSAT II.

West Point recruitment pattern showed that *P. senegalensis* was recruited in the fishery continuously throughout the year with high recruitment between July, August and October. The highest recruitment was observed in the month of October (24.03%) whereas the lowest recruitment was observed in March. The mid-point of the lower length class (28 cm) in the sampled data was used as a length at recruitment (Figure 4.31).

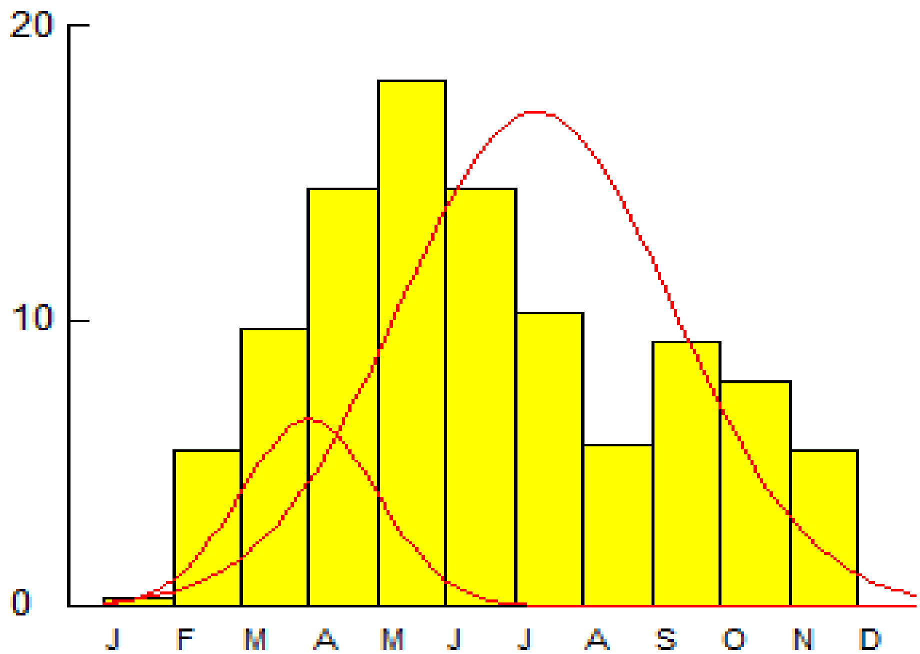

Figure 4.32: Recruitment patterns of unsexed *P. senegalensis* based on pooled length-frequency data at King Gray and ELWA from December 2016 and May 2017 estimated using FiSAT II.

King Gray & ELWA recruitment pattern (Figure 4.32) showed that *P. senegalensis* was recruited in the fishery continuously throughout the year with high recruitment between April, May and June. The highest recruitment was observed in the month of May (15.76%) whereas the lowest recruitment was observed in January. The mid-point of the lower length class (28 cm) in the sampled data was used as a length at recruitment.

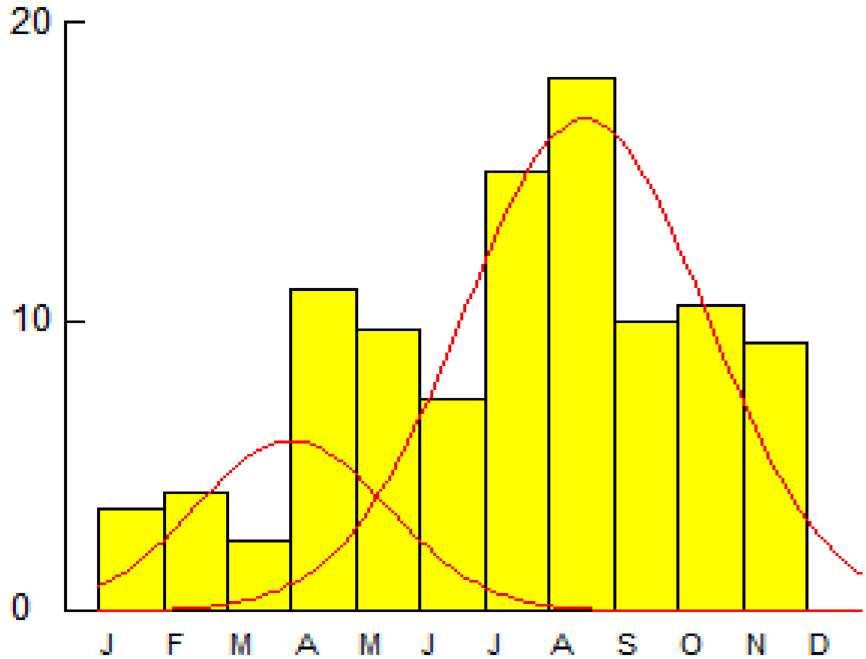

Figure 4.33: Recruitment patterns of unsexed *P. senegalensis* based on pooled length-frequency data at Marshall from December 2016 and May 2017 estimated using FiSAT II.

Marshall's recruitment pattern (Figure 4.33) showed that *P. senegalensis* was recruited in the fishery continuously throughout the year with high recruitment ranging from July and August. The highest recruitment was observed in the month of August (19.11%) whereas the lowest recruitment was observed in March. The mid-point of the lower length class (28 cm) in the sampled data was used as a length at recruitment.

4.2.4 Probability of capture and length at first capture (Lc or $L_{50\%}$) of *Sardinella aurita* and *Pseudotolithus senegalensis* for Montserrado and Marshall

The length distribution of probability of capture and the length at which 50% of all the fish encountering the gear are retained from all four landing sites (Gbanjor, West Point, King Gray & ELWA and Marshall) are shown in Figure 4.34 to 4.41 for *S. aurita* and *P. senegalensis*.

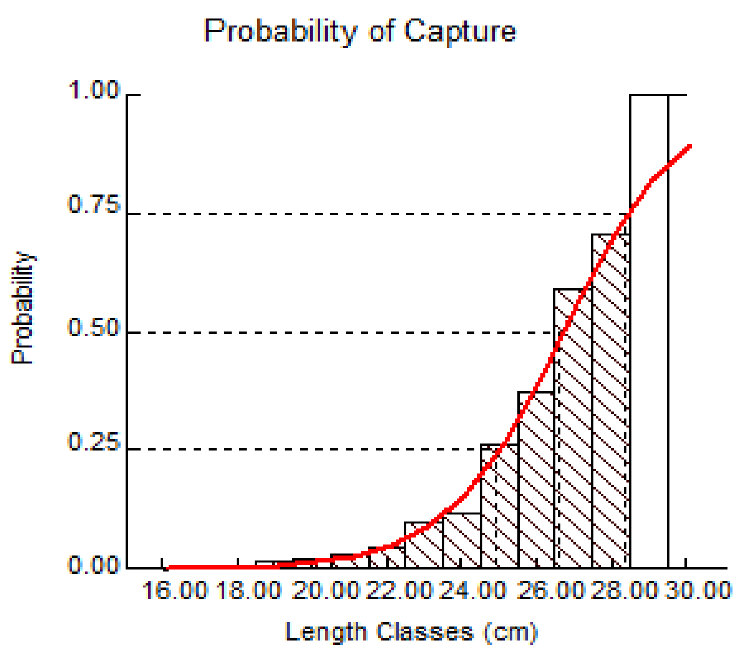

Figure 4.34: FiSAT output of probability of capture and length at first capture *S. aurita* at Gbanjor

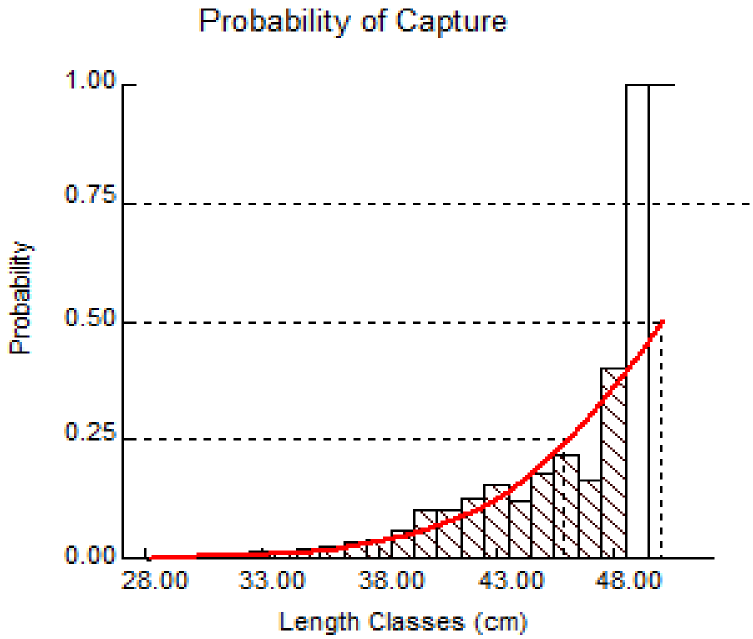

Figure 4.35: FiSAT output of probability of capture and length at first capture *P. senegalensis* at Gbanjor

Gbanjor shows the probability of length at which 50% of all the fish encountering the gear are retained for *S. aurita* was 26.64 cm whereas the lengths at which 25% and 75% of the fish capture were 24.91 cm and 28.37 cm respectively. The length at which 50% of all the fish encountering the gear are retained for *P. senegalensis* was 50.00 cm whereas the lengths at which 25% and 75% of the fish are capture were 45.89 cm and 54.10 cm in Gbanjor fishing community (Figure 4.34 and 4.35).

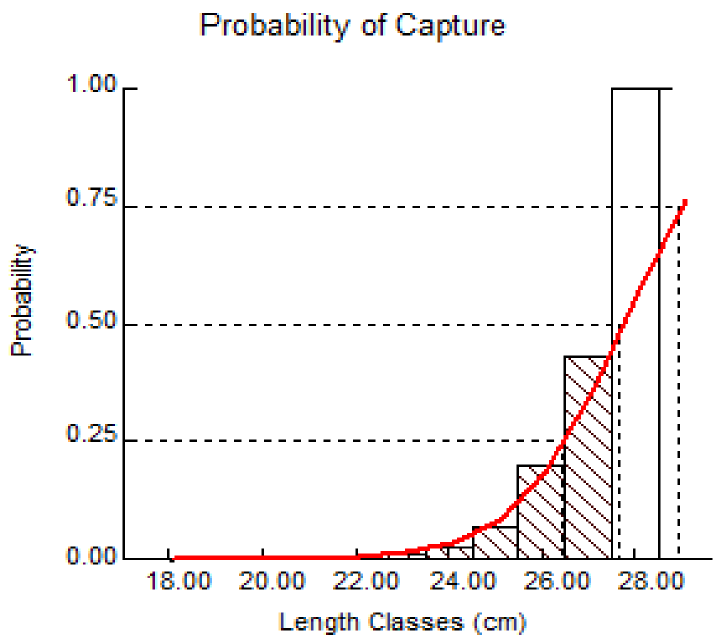

Figure 4.36: FiSAT output of probability of capture and length at first capture *S. aurita* at West Point

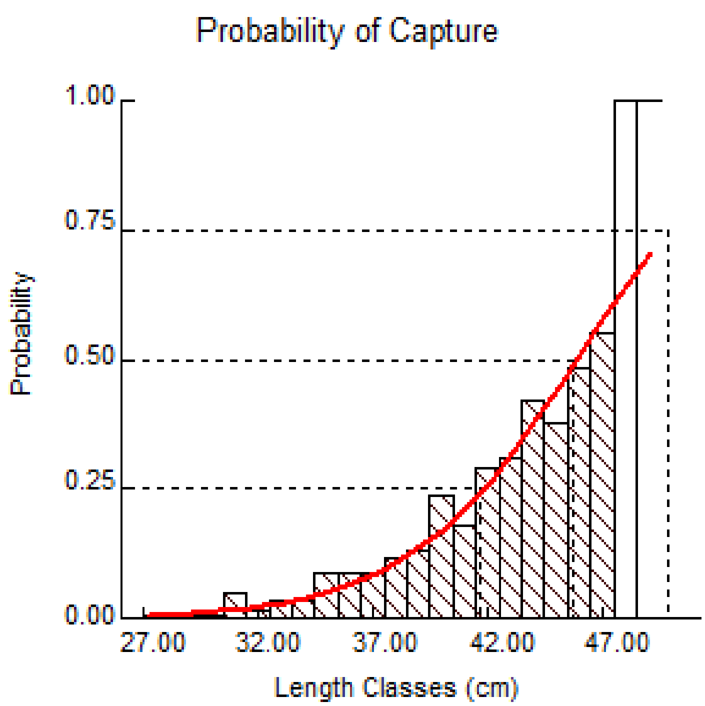

Figure 4.37: FiSAT output of probability of capture and length at first capture *P. senegalensis at* West Point

West Point (Fanti and Kru) fishing sites shows the probability of length at which 50% of all the fish encountering the gear are retained for *S. aurita* was 27.68 cm whereas the lengths at which 25% and 75% of the fish capture were 26.44 cm and 28.92 cm respectively. The length at which 50% of all the fish encountering the gear are retained for *P. senegalensis* was 45.75 cm whereas the lengths at which 25% and 75% of the fish are capture were 41.66 cm and 49.84 cm in West Point fishing community (Figure 4.36 and 4.37).

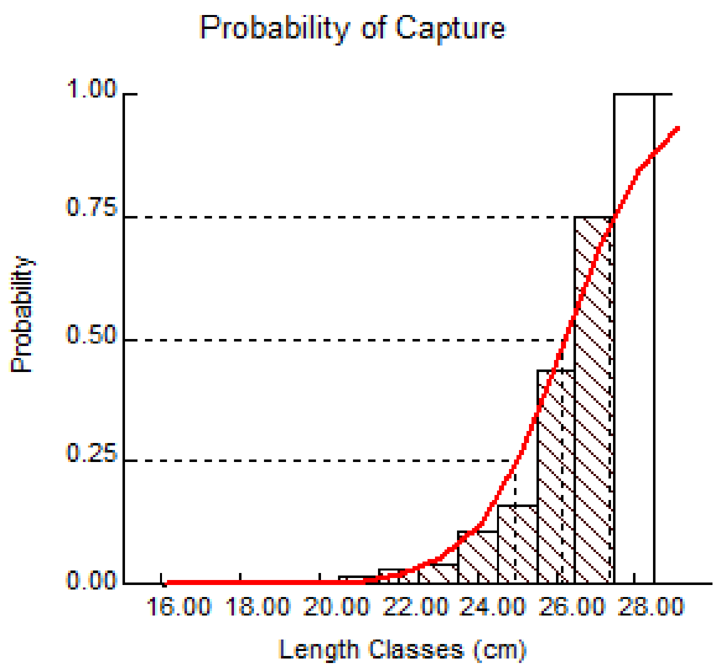

Figure 4.38: FiSAT output of probability of capture and length at first capture *S. aurita* at King Gray

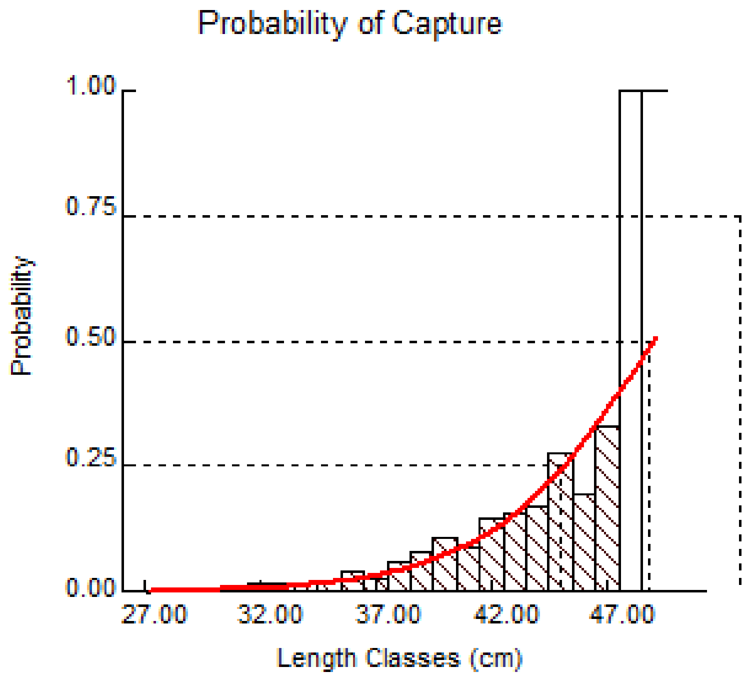

Figure 4.39: FiSAT output of probability of capture and length at first capture *P. senegalensis* at King Gray and ELWA

King Gray and ELWA fishing sites shows the probability of length at which 50% of all the fish encountering the gear are retained for *S. aurita* was 26.14 cm whereas the lengths at which 25% and 75% of the fish capture were 24.94 cm and 27.35 cm respectively. The length at which 50% of all the fish encountering the gear are retained for *P. senegalensis* was 48.87 cm whereas the lengths at which 25% and 75% of the fish are capture were 44.95 cm and 52.79 cm in King gray and ELWA fishing community (Figure 4.38 and 4.39).

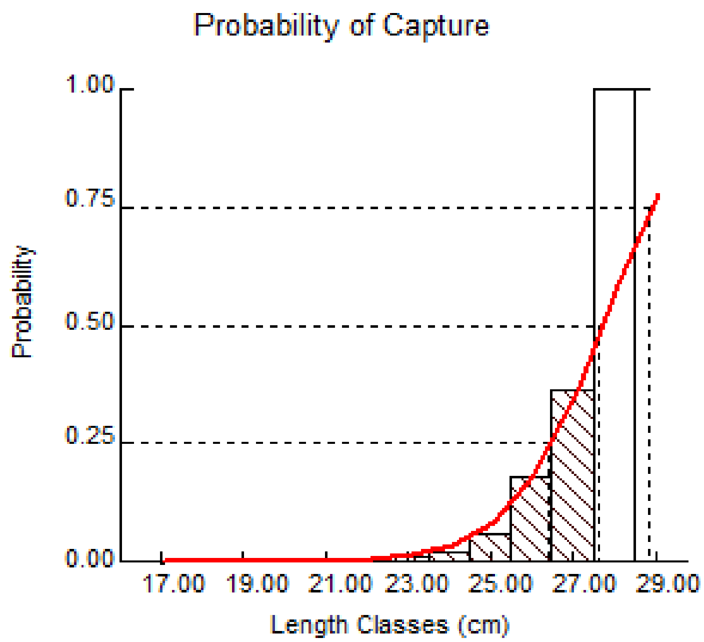

Figure 4.40: FiSAT output of probability of capture and length at first capture *S. aurita* at Marshall

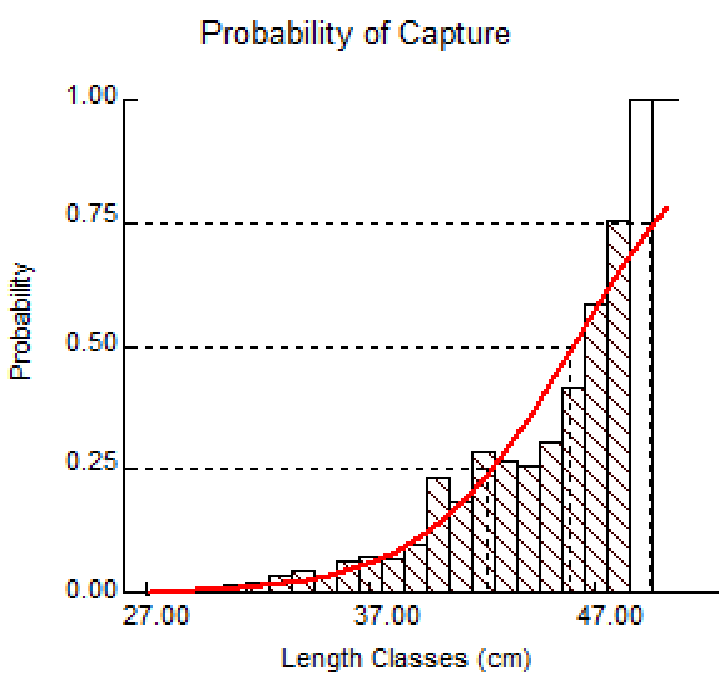

Figure 4.41: FiSAT output of probability of capture and length at first capture *P. senegalensis* at Marshall

Marshall (Fanti and Kru) fishing sites shows the probability of length at which 50% of all the fish encountering the gear are retained for *S. aurita* was 27.63 cm whereas the lengths at which 25% and 75% of the fish capture were 26.43 cm and 28.83 cm respectively. The length at which 50% of all the fish encountering the gear are retained for *P. senegalensis* was 45.83 cm whereas the lengths at which 25% and 75% of the fish are capture were 42.19 cm and 49.46 cm in King gray and ELWA fishing community (Figure 4.40 and 4.41).

4.2.5 Relative yield per recruit (Y'/R) for *Sardinella aurita* and *Pseudotolithus senegalensis* in Montserrado and Marshall

4.2.5.1 Yield per recruit for *Sardinella aurita*

Yield and biomass per recruit (Y/R, B/R) for *Sardinella aurita* in function of the fishing mortality rate (F). F_{max} = value of F that gives the maximum possible yield per recruit from a cohort during its life from a drived exploitation pattern are shown for Gbanjor, West Point, King Gray and Marshall (Figure 4.42 and 4.45).

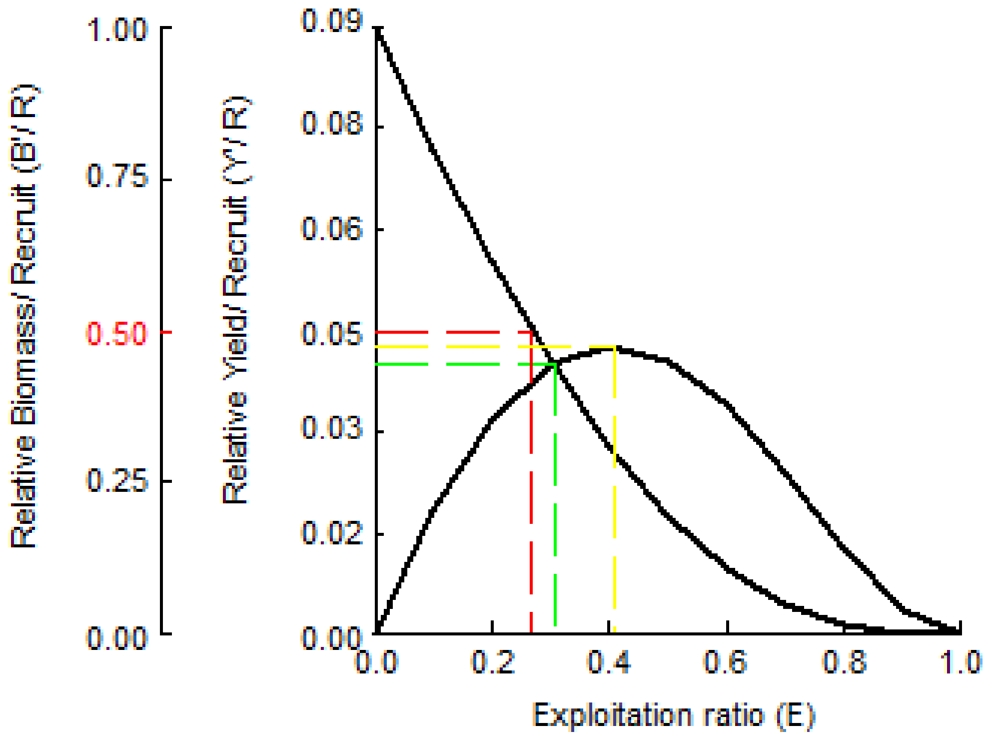

Figure 4.42: *Sardinella aurita* relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at Gbanjor along the coastal waters of Liberia

Gbanjor relative Y'/R and B'/R analysis for *S. aurita* were estimated using Lc/L∞ = 36.00 and M/K = 1.18 as input for knife-edge selection procedure (Figure 4.42). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.42. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.31 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.27.

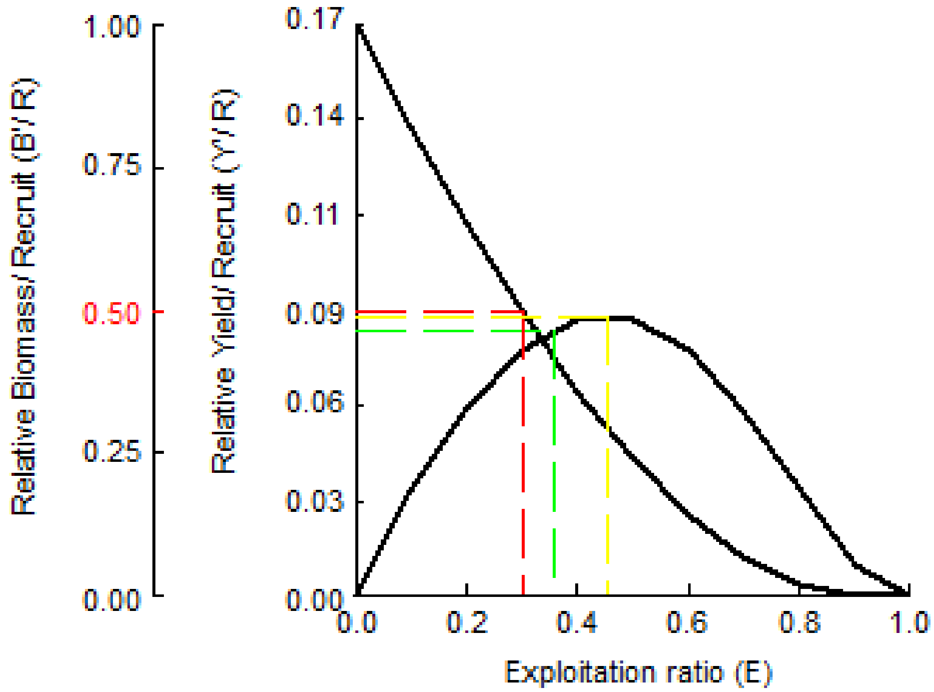

Figure 4.43: ***Sardinella aurita*** **relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at West Point along the coastal waters of Liberia**

West Point Fanti beach relative Y'/R and B'/R analysis for *S. aurita* were estimated using Lc/L∞ = 35.00 and M/K = 0.73 as input for knife-edge selection procedure (Figure 4.43). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.45. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.36 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.30.

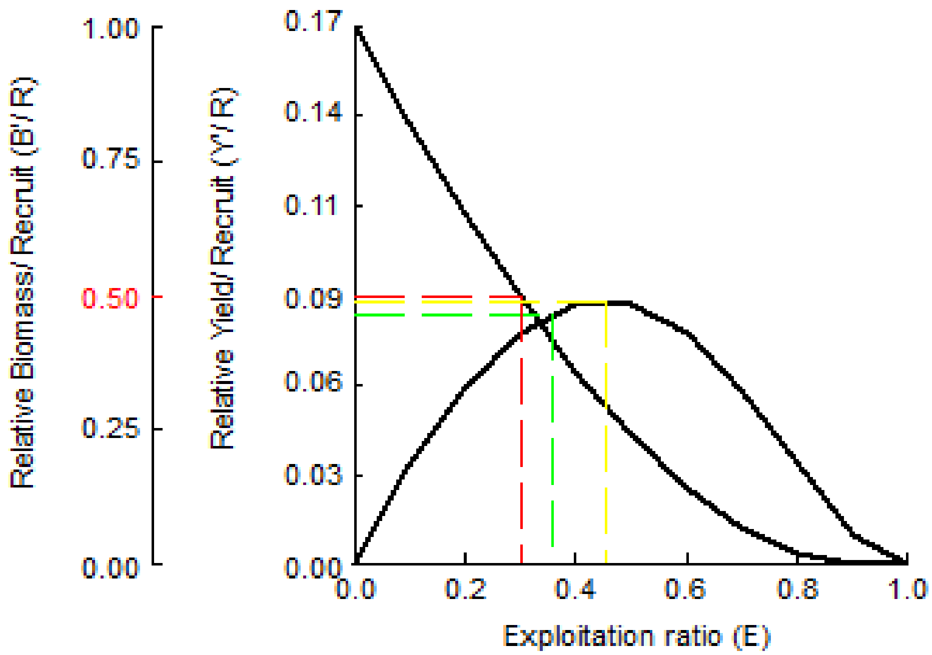

Figure 4.44: ***Sardinella aurita*** **relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at King Gray along the coastal waters of Liberia**

King Gray relative Y'/R and B'/R analysis for *S. aurita* were estimated using $L_c/L\infty$ = 35.00 and M/K = 0.73 as input for knife-edge selection procedure (Figure 4.44). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.45. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.36 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.30.

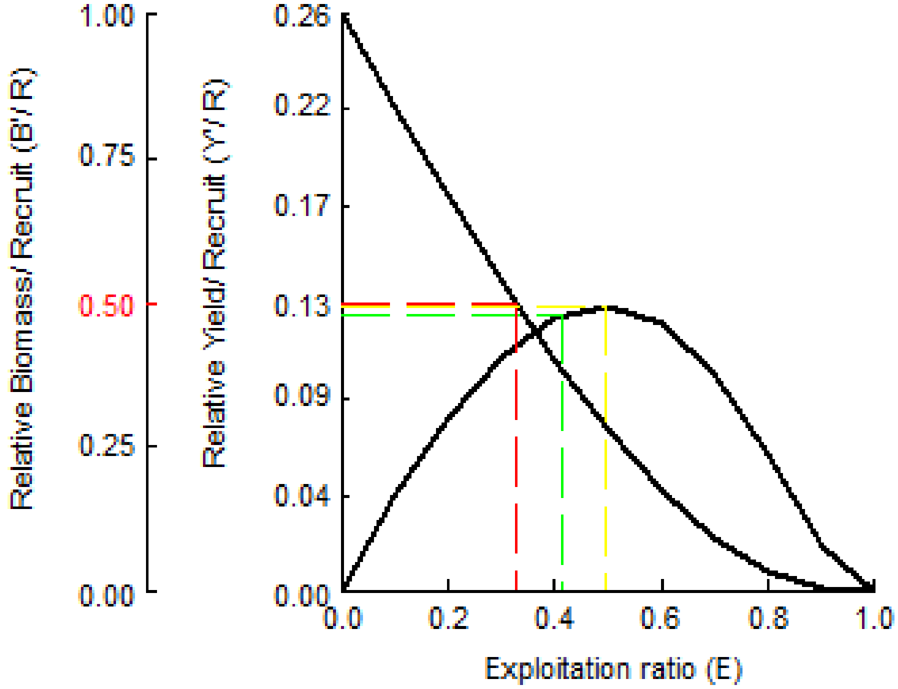

Figure 4.45: ***Sardinella aurita*** **relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at Marshall along the coastal waters of Liberia**

Marshall (Fanti and Kru) beach relative Y'/R and B'/R analysis for *S. aurita* were estimated using $L_c/L\infty$ = 34.50 and M/K = 0.50 as input for knife-edge selection procedure (Figure 4.45). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.49. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.42 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.33.

4.2.5.2 Yield per recruit for *Pseudotolithus senegalensis*

Yield and biomass per recruit (Y/R, B/R) for *P. senegalensis* in function of the fishing mortality rate (F). F_{max} = value of F that gives the maximum possible yield per recruit from a cohort during its life from a drived exploitation pattern are shown for Gbanjor, West Point, King Gray & ELWA and Marshall (Figure 4.46 and 4.49).

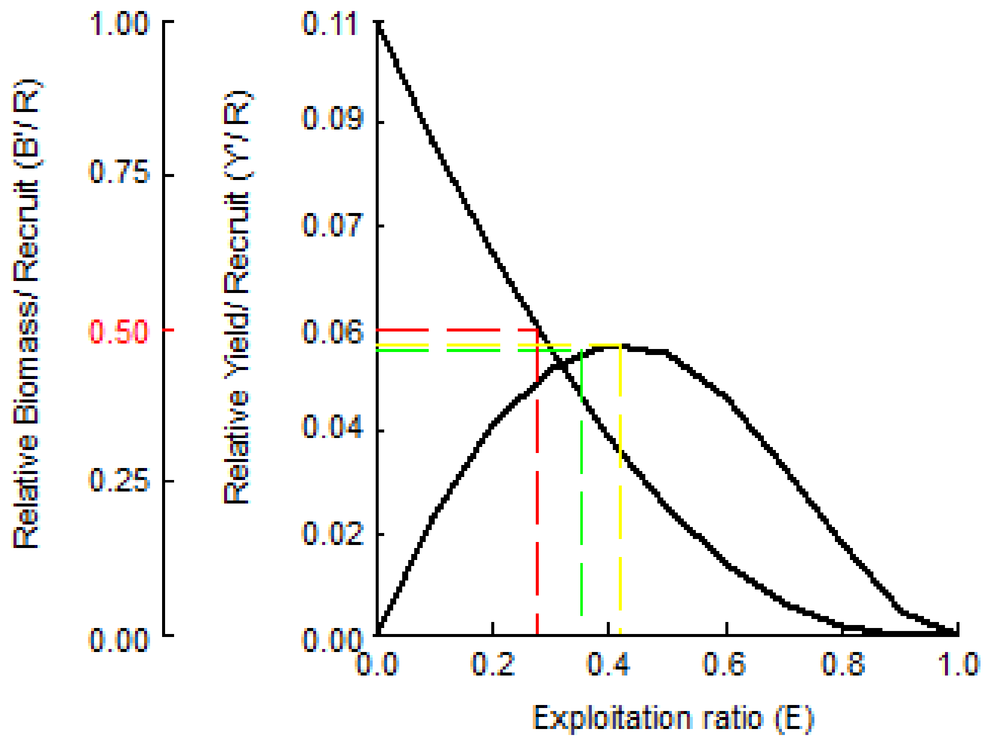

Figure 4.46: *Pseudotolithus senegalensis* relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at Gbanjor along the coastal waters of Liberia

Gbanjor relative Y'/R and B'/R analysis for *P. senegalensis* were estimated using $L_c/L\infty$ = 57.00 and M/K = 1.03 as input for knife-edge selection procedure (Figure 4.46). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.42. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.35 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.28.

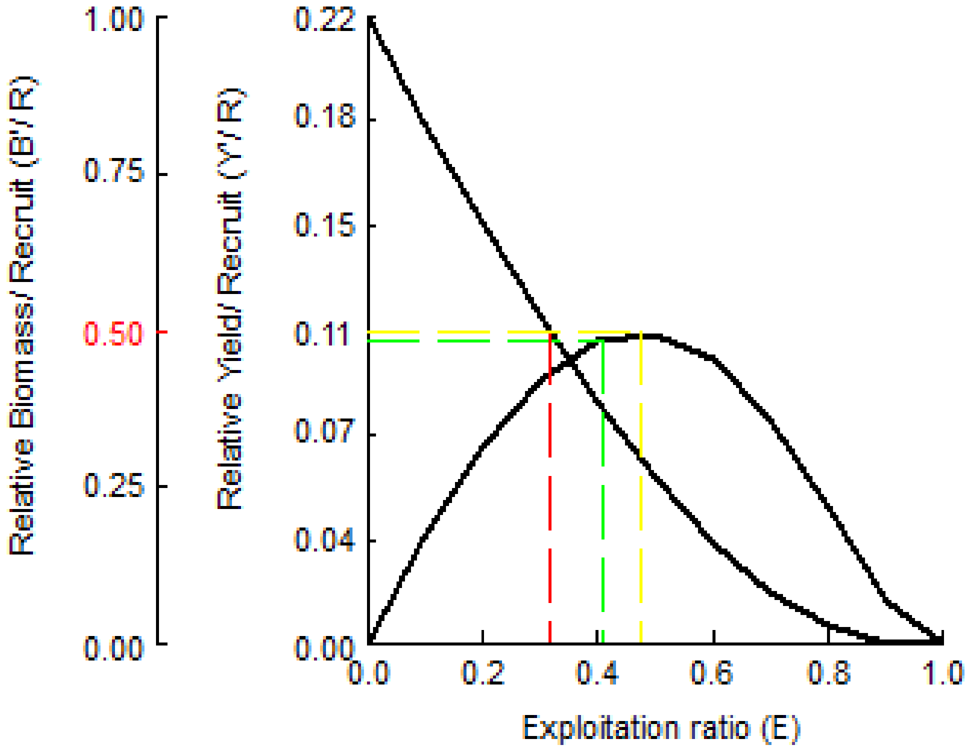

Figure 4.47: *Pseudotolithus senegalensis* relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at West Point along the coastal waters of Liberia

West Point Kru beach relative Y'/R and B'/R analysis for *P. senegalensis* were estimated using $L_c/L\infty$ = 60.00 and M/K = 0.58 as input for knife-edge selection procedure (Figure 4.47). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.48. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.41 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.32.

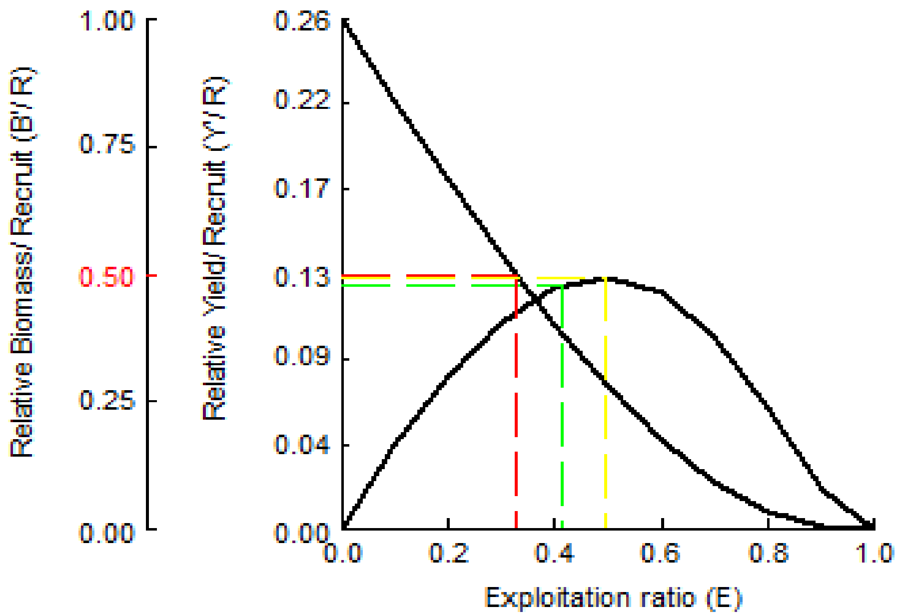

Figure 4.48: *Pseudotolithus senegalensis* relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at King Gray & ELWA along the coastal waters of Liberia

King Gray and ELWA relative Y'/R and B'/R analysis for *P. senegalensis* were estimated using $L_c/L\infty$ = 52.00 and M/K = 0.50 as input for knife-edge selection procedure (Figure 4.48). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.49. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.42 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.33.

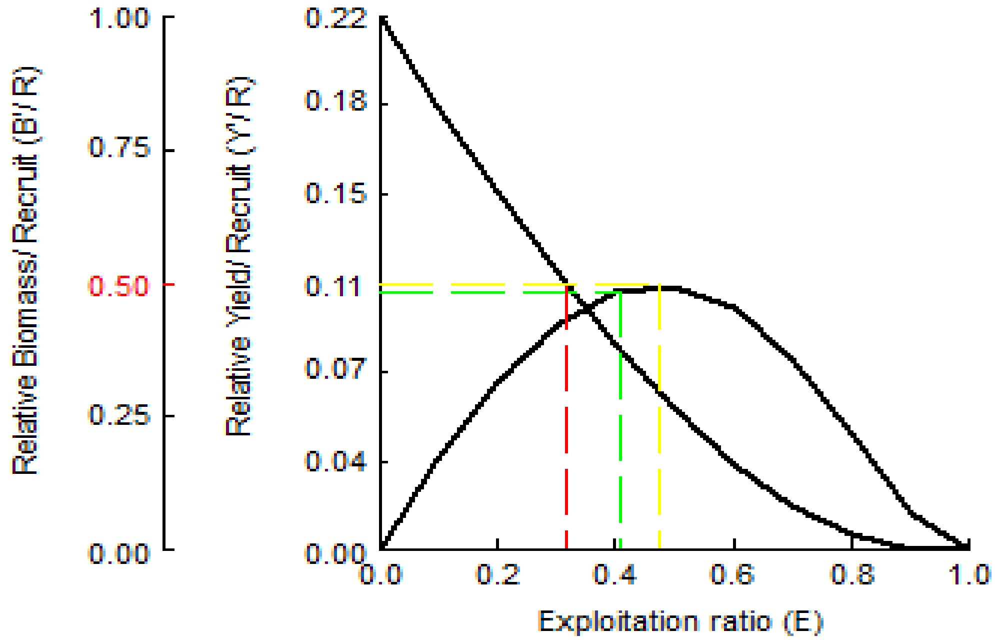

Figure 4.49: ***Pseudotolithus senegalensis*** **relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at Marshall along the coastal waters of Liberia**

Marshall Fant beach relative Y'/R and B'/R analysis for *P. senegalensis* were estimated using $L_c/L\infty$ = 58.50 and M/K = 0.58 as input for knife-edge selection procedure (Figure 4.49). The maximum allowable limit of exploitation level (E-max) that gives the maximum allowable limit relative Y'/R was 0.48. The exploitation level ($E_{0.1}$) at which the marginal increases in relative yield per recruits is 10% of its value at E=10 was 0.41 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.32.

The average monthly figure for 2017 for *S. aurita* was estimated at 1.09 tonnes for Gbanjor, 2.58 tonnes for West Point and King Gray as 1.79 tonnes in Montserrado. The Marshall Fishery yield was estimated at 9.02 tonnes/month-1 during the period of study. *P. senegalensis* Catches for Montserrado and Marshall average monthly figure for 2017 was estimated at 4.86 tonnes for Gbanjor, 0.53 tonnes for West Point and King Gray as 5.49 tonnes in Montserrado. The Marshall Fishery yield was estimated at 6.29 tonnes/month-1 during the period of study.

4.3 Genetic differentiation of *Sardinella aurita* and *Pseudotolithus senegalensis*

4.3.1 Sequence retrieval

Four selected nuclear and mitochondria DNA such as 16s ribosomal RNA, Cytochrome oxidase subunit I (COI), Cytochrome b (Cytb) and recombination activating protein 1 (Rag-1) were subsequently retrieved from NCBI for ten bony fish species plus two outgroup (tetrapod and chondrichthyan) species. Details of the sequences are summarized in Table 4.13. Majority of the sequences (give a fraction) were found to be a partial sequences. These molecular markers were used to infer genetic differentiation of *P. senegalensis* and *S. aurita*.

Table 4.13: Molecular markers for 10 bony fish species plus one tetrapod (*Pseudis paradoxa*) and one chondrichthyan (*Carcharondon carcharias*) species

Sequence_ID	Gene name/ Description	Sequence Length (bp)	Species	Type	Remarks
KP722769.1	Cytochrome oxidase subunit 1 (COI)	654	*Pseudotolithus Senegalensis*	Mitochondrial	partial cds
DQ197987.1	cytochrome b (Cytb)	1,141	*Pseudotolithus Senegalensis*	Mitochondrial	complete cds
KP722951.1	recombination activating protein 1 (Rag-1)	1,472	*Pseudotolithus Senegalensis*	Exon 3	partial cds
KR056175.1	16S ribosomal RNA	583	*Sardinella aurita*	Mitochondrial	partial sequence
KM538516.1	cytochrome oxidase subunit 1 (COI)	663	*Sardinella aurita*	Mitochondrial	partial cds
EU552619.1	cytochrome b (Cytb)	1,149	*Sardinella aurita*	Mitochondrial	Partial
DQ912104.1	recombination activating protein 1 (Rag-1)	1,491	*Sardinella aurita*	Exon 3	Partial
DQ912069.1	16S ribosomal RNA	1,315	*Brevoortia tyrannus*	Mitochondrial	partial sequence
FJ194939.1	cytochrome c oxidase subunit I (COI)	459	*Brevoortia tyrannus*	Mitochondrial	partial sequence
EU552614.1	cytochrome b (Cytb)	1,148	*Brevoortia tyrannus*	Mitochondrial	partial sequence
DQ912106.1	recombination activating	1,491	*Brevoortia tyrannus*	Exon 3	partial sequence

	protein 1 (Rag-1)				
DQ532863.1	16S large subunit ribosomal RNA	543	*Dentex dentex*	Mitochondrial	partial sequence
KJ012329.1	cytochrome oxidase subunit 1 (COI)	655	*Dentex dentex*	Mitochondrial	partial
EF392579.1	cytochrome b (Cytb)	1,141	*Dentex dentex*	Mitochondrial	Complete
KT883716.1	recombination activating protein 1 (Rag-1)	1,428	*Dentex dentex*	Exon 3	Partial
DQ912078.1	16S ribosomal RNA	1,313	*Clupea harengus*	Mitochondrial	partial sequence
JF693778.1	cytochrome oxidase subunit I (COI)	730	*Clupea harengus*	Mitochondrial	partial sequence
AF472580.1	cytochrome b (Cytb)	1,141	*Clupea harengus*	Mitochondrial	Complete
DQ912114.1	recombination activating protein 1 (Rag-1)		*Clupea harengus*	exon 3	partial sequence
JQ939010.1	16S ribosomal RNA	1,206	*Trichiurus lepturus*	Mitochondrial	partial sequence
EU263823.1	cytochrome oxidase subunit I (COI) haplotype 5	944	*Trichiurus lepturus*	Mitochondrial	Partial
DQ364155.1	cytochrome b (Cytb) clone 1	1,141	*Trichiurus lepturus*	Mitochondrial	complete
EU167903.1	recombination-activating protein 1 (Rag-1)	1,428	*Trichiurus lepturus*	Exon 3	partial
JQ939036.1	16S ribosomal RNA	1,199	*Sphyraena barracuda*	Mitochondrial	partial sequence
EU263790.1	cytochrome oxidase subunit I (COI)	944	*Sphyraena barracuda*	Mitochondrial	Partial
JQ088717.1	cytochrome b (Cytb)	629	*Sphyraena barracuda*	Mitochondrial	Partial
JQ938282.1	recombination activating protein 1 (Rag-1)	1,296	*Sphyraena barracuda*	DNA linear	Partial
DQ874727.1	16S ribosomal RNA	626	*Acanthocybium solandri*	Mitochondrial	partial sequence
DQ835838.1	cytochrome oxidase subunit I (COI)	998	*Acanthocybium solandri*	Mitochondrial	Partial
DQ197922.1	cytochrome b (Cytb)	1,141	*Acanthocybium solandri*	Mitochondrial	Complete

KP866741.1	RAG1 (Rag-1) mRNA	856	*Acanthocybium solandri*	mRNA linear	Partial
DQ912086.1	16S ribosomal RNA	1,318	*Harengula jaguana*	Mitochondrial	partial sequence
GU225329.1	cytochrome oxidase subunit 1 (COI)	652	*Harengula jaguana*	Mitochondrial	partial sequence
EU552617.1	cytochrome b (Cytb)	1,144	*Harengula jaguana*	Mitochondrial	partial sequence
DQ912122.1	recombination activating protein 1 (Rag-1)	1,491	*Harengula jaguana*	exon 3	partial sequence
AB679225.1	16S ribosomal RNA	570	*Beryx decadactylus*	Mitochondrial	partial sequence
EF609296.1	cytochrome oxidase subunit 1 (COI)	655	*Beryx decadactylus*	Mitochondrial	partial
DQ197929.1	cytochrome b (Cytb)	1,141	*Beryx decadactylus*	Mitochondrial	complete
JX189798.1	recombinase activating protein 1 (Rag-1)	1,332	*Beryx decadactylus*	exon 3	Partial
KP149394.1	16S ribosomal RNA	569	*Pseudis paradoxa* (frog)	Mitochondrial	partial sequence
KP149190.1	cytochrome oxidase subunit 1 (COI)	658	*Pseudis paradoxa* (frog)	Mitochondrial	partial sequence
AY549417.1	cytochrome b (Cytb)	385	*Pseudis paradoxa* (frog)	Mitochondrial	partial sequence
AY323773.1	Rag-1	1,559	*Pseudis paradoxa* (frog)		partial sequence
AY836586.2	16S ribosomal RNA	510	*Carcharodon carcharias* (shark)	Mitochondrial	partial sequence
DQ108328.1	cytochrome oxidase subunit 1 (COI)	655	*Carcharodon carcharias* (shark)	Mitochondrial	partial sequence
L08031.1	cytochrome b (Cytb)	1,146	*Carcharodon carcharias* (shark)	Mitochondrial	Complete
AF135482.1	recombination-activating protein Rag-1	1497	*Carcharodon carcharias* (shark)		Partial

Table 4.14: Sequence divergences of mitochondrial and nuclear sequences among ten bony fish species and two outgroup (*C. carcharias* and *P. paradoxa*)

	1	2	3	4	5	6	7	8	9	10	11	12
S. aurita		0.223	0.235	0.217	0.231	0.299	0.166	0.218	0.141	0.316	0.229	0.254
P. senegallus	0.266		0.160	0.156	0.288	0.277	0.227	0.156	0.224	0.295	0.177	0.198
A. solandri	0.284	0.182		0.175	0.313	0.284	0.246	0.167	0.250	0.310	0.158	0.145
B.decadactylus	0.259	0.177	0.200		0.284	0.275	0.219	0.167	0.216	0.288	0.180	0.202
B. tyrannus	0.280	0.367	0.410	0.361		0.365	0.227	0.284	0.222	0.384	0.291	0.322
C. carcharias	0.388	0.350	0.361	0.347	0.510		0.315	0.274	0.301	0.268	0.290	0.286
C. harengus	0.190	0.273	0.300	0.263	0.272	0.417		0.217	0.165	0.309	0.235	0.261
D. dentex	0.259	0.177	0.192	0.190	0.360	0.346	0.258		0.225	0.288	0.162	0.187
H. jaguana	0.159	0.268	0.306	0.258	0.267	0.391	0.189	0.270		0.314	0.233	0.270
P. paradoxa	0.417	0.379	0.405	0.367	0.547	0.335	0.402	0.366	0.410		0.304	0.321
S. barracuda	0.277	0.205	0.179	0.207	0.372	0.373	0.286	0.185	0.282	0.393		0.180
T. lepturus	0.313	0.233	0.163	0.237	0.426	0.364	0.324	0.217	0.340	0.425	0.208	

Values above the diagonal show proportions of nucleotide difference (p-distances) and below the diagonal are gamma distances with Kimura -2- parameter model.

4.3.2 Phylogenetic analysis

Present investigation revealed inter-species variations between *S. aurita* and *P. senegalensis*. Here, we tested for genetic diversity within *S. aurita* and *P. senegalensis* using four molecular markers for nuclear and mitochondrial genes from 12 taxa obtained from NCBI. Deep genetic divergence and subsequent clustering was consistent across both mitochondria and nuclear markers. The increased resolution, of 16s, COI, Cytb and Rag-1 dataset was able to reject the hypothesis regarding *S. aurita* and *P. senegalensis* close phylogenetic. Consistent across examined genetic distances calculated, gene regions for both mitochondrial and nuclear gene regions exhibited divergence comparable to species-level differentiation for *S. aurita* and *P. senegalensis* (Table 4.14). The outcome from this analysis show the well supported monophyly (Figures 4.50, 4.51 and 4.53) of *S. aurita* and *H. jaguana* in trees using 16s, COI, and Rag-1. Also, the analysis of the final concatenated sequences tree demonstrate substantial phylogenetic utility of 16s, COI, Cytb and

Rag-1 genes. The analysis in this investigation revealed clear weakness of the partial Cytb dataset. The final concatenated alignments included four markers 16s, COI, Cytb and Rag-1 from 12 taxa, the average presence of data (number of sequences per taxon) across the alignments was 100% for the dataset. The main phylogenetic hypothesis of *S. aurita* and *P. senegalensis* is summarized in figure 4.54, which a deep genetic divergence and subsequent clustering was consistent across both mitochondria and markers. Figures 4.51 – 4.54 did not provides congruence among alternative analyses (Concatenation and gene trees) for *S. aurita* and *P. senegalensis* but for *S. aurita* and *H. jaguana* which provides further hypothesis in ichthyology. Figure 4.51 – 4.53, the concatenated tree Figure 4.54 and Table 4.14 compares the results of divergence times estimated for major groups (*S. aurita* and *P. senegalensis*) with those obtained from (10 bony fish and two outgroups) multi-locus.

Maximum-likelihood analysis of 16s, COI, Cytb and Rag-1 sequences showed distance genetic relationship of *S. aurita* and *P. senegalensis* (Figure 4.50 – 4.53). Clustering for all markers did not exhibit monophyletic (group of organisms descending from a common evolutionary ancestor or ancestral group which do not share with any other group) clades for *S. aurita* and *P. senegalensis* but exhibited for *S. aurita* and *H. jaguana* clades with high bootstrap support. Rather, nuclear and mitochondria DNA sequences of 16s, COI and Rag-1 genes revealed congruence close relationship between *S. aurita* and *H. jaguana* (Figure 4.50, 4.51 and 4.53).

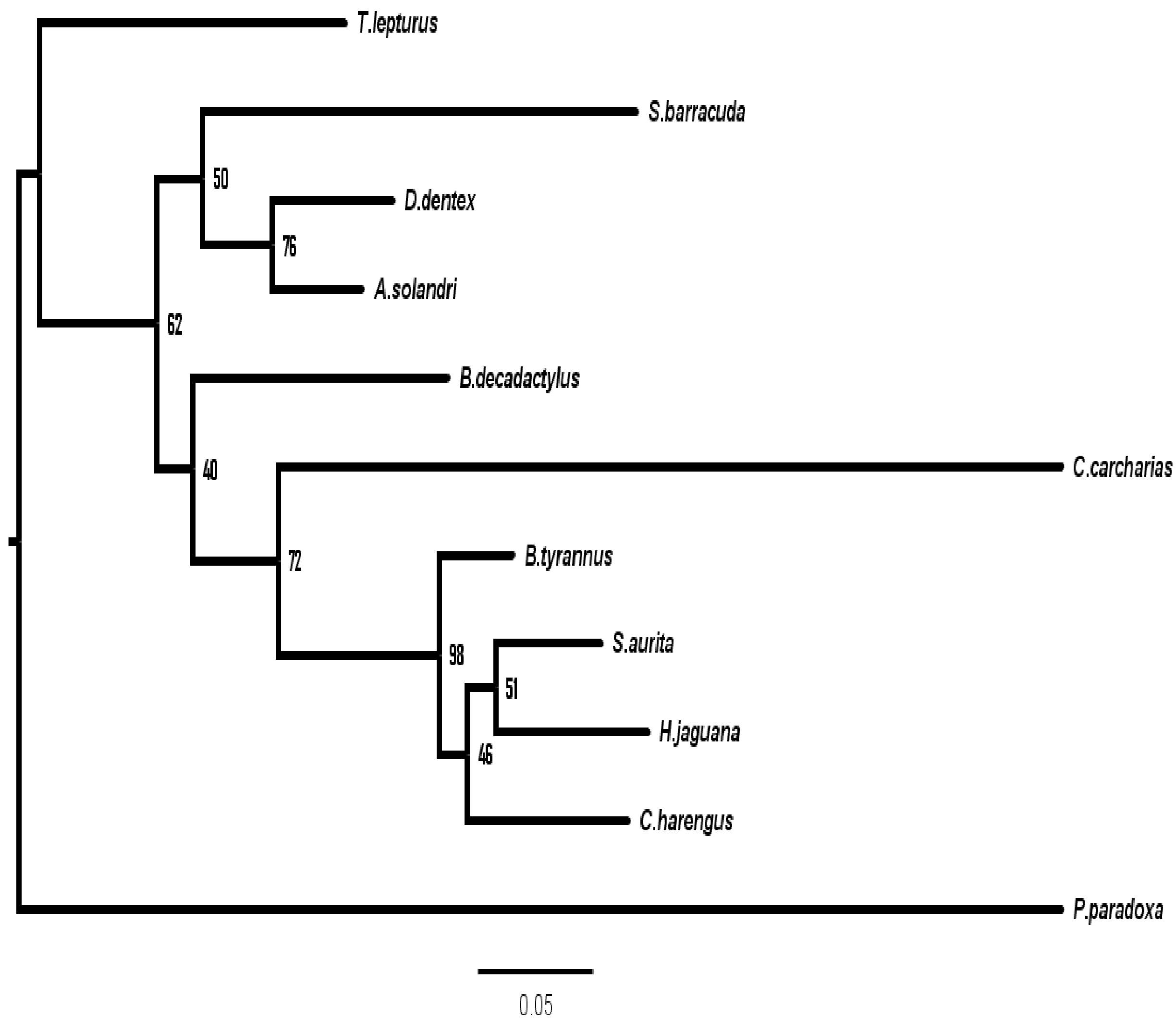

Figure 4.50: Phylogeny of 16s ribosomal RNA sequences.

Maximum Likelihood (ML) tree inferred using 16s mitochondrial conserved region of eleven species (*S. aurita, B. tyrannus, D. dentex, C. harengus, T. lepturus, S. barracuda, A. solandri, H. jaguana*, *B. decadactylus, P. paradoxa* and *C. carcharias*) missing (*P. senegalensis*). Sequence alignment was performed using MUSCLE v3.8.31 and phylogeny relationship was inferred using RAxML v8.2.10 with the best fitted GTRGAMMA model and 1,000 bootstraps iterations.

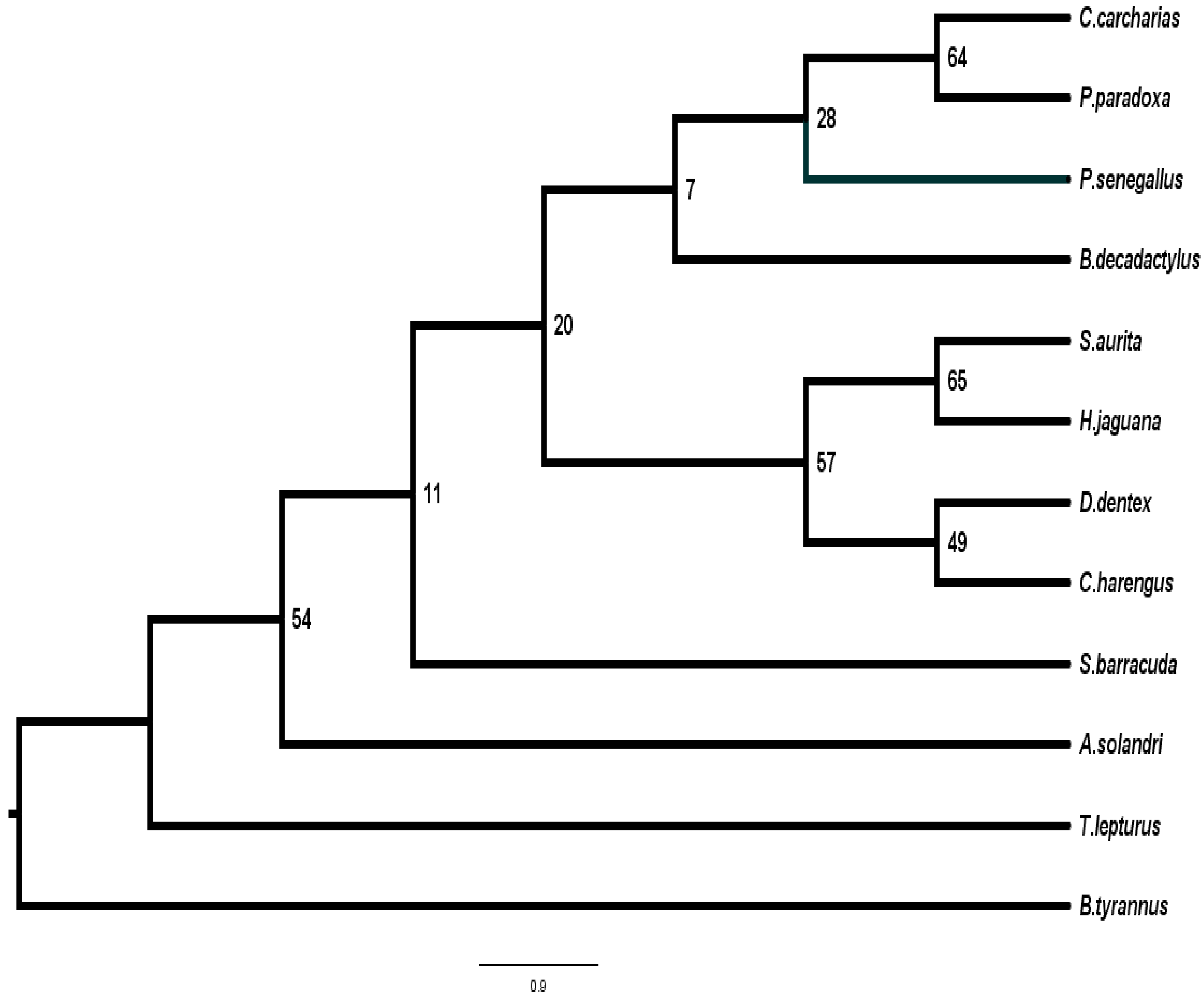

Figure 4.51: Phylogeny of cytochrome oxidase subunit 1 (COI) sequences.

Maximum Likelihood (ML) tree generated from COI mitochondrial conserved region of 12 species (*S. aurita, B. tyrannus, D. dentex, P. senegalensis, C. harengus, T. lepturus, S. barracuda, A. solandri, H. jaguana, B. decadactylus, P. paradoxa* and *C. carcharias*). Sequence alignment was performed using MUSCLE v3.8.31 and phylogeny relationship was inferred using RAxML v8.2.10 with the best fitted GTRGAMMA model and with 1,000 bootstraps iterations.

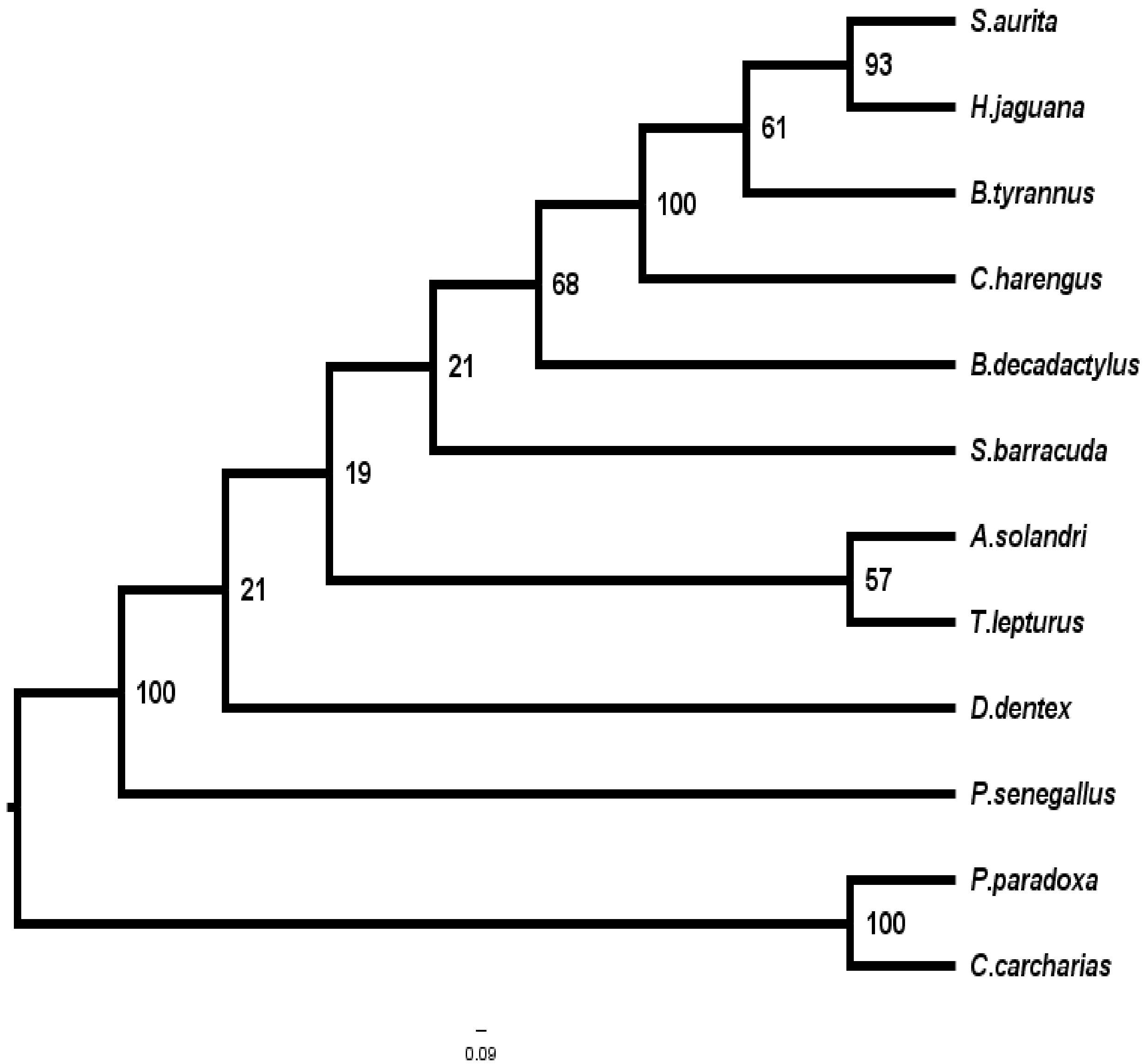

Figure 4.52: Phylogeny of recombination-activating protein (Rag-1) sequences.

Maximum Likelihood (ML) tree generated from Rag-1 nuclear DNA conserved region of 12 species (*S. aurita, B. tyrannus, D. dentex, P. senegalensis, C. harengus, T. lepturus, S. barracuda, A. solandri, H. jaguana, B. decadactylus, P. paradoxa* and *C. carcharias*). Sequence alignment was performed using MUSCLE v3.8.31 and phylogeny relationship was inferred using RAxML v8.2.10 with the best fitted GTRGAMMA model and with 1,000 bootstraps iterations.

None of the phylogenetic trees revealed *S. aurita* and *P. senegalensis* to be sister species. Consistent across both examined nuclear gene regions and genetic distances calculated for mitochondria exhibited divergence comparability to *S. aurita* and *P. senegalensis* differentiation (Table 4.14). Maximum-Likelihood analysis of 16s, mitochondrial control region sequences could not depict the relationship of *S. aurita* and *P. senegalensis* (Figure 4.50) due to the absence of the 16s sequence of *P. senegalensis* in the NCBI database and limited funding. However, the available 16s sequences revealed a strong clustering of *S. aurita* and *H. jaguana* suggesting they emerged from the same ancestor (Figure 4.50). Analysis of Cytochrome oxidase subunit 1 (COI) sequences revealed similar clustering for *S. aurita* and *H. jaguana*. *Pseudotolithus senegalensis* was found in a monophyletic group with *C. carcharias* and *P. paradoxa* (Figure 4.51). Clustering for both markers 16s and COI exhibited monophyletic clades with high bootstrap support for *S. aurita* and *H. jaguana* (Figure 4.50 and 4.51). The Maximum-Likelihood analysis of Cytochrome b (cytb) sequences of the 12 species did not support the relationship of the two species *S. aurita* and *P. senegalensis* rather did show *S. aurita* cluster with *H. jaguana*. Cytochrome b (Cytb) sequence supported the relationship of *S. aurita* and *C. harengus* as paired cluster whereas *P. senegalensis* and *S. barracuda* found a paired clustered (Figure 4.51). The Maximum-Likelihood analysis of recombination-activating protein (rag-1) sequences support the relationship of *S. aurita* and *H. jaguana* with a high bootstrap. *Pseudotolithus senegalensis* differed greatly with the marker analysis that found a paraphyletic (group of organisms descending from a common evolutionary ancestor or ancestral group which does not include all the descendant groups) group with *D. dentex, T. leptanus* and *A. solardri* (Figure 4.52).

Maximum-Likelihood analysis of combined 16s, COI, Cytb and Rag-1 sequence support the existence of the two species *S. aurita* and *H. jaguana* with high bootstrap. *P. senegalensis* and *D. dentex* formed a clustered with a low bootstrap (Figure 4.54). Clustering for the three makes exhibited monophyletic clades with high bootstrap support for *S. aurita* and *H. jaguana*. In addition, the nuclear DNA and mitochondrial sequences of the four markers revealed a deep divergence between *S. aurita* and *P. senegalensis* (Figure 4.51 – 4.53). None of the phylogenetic analysis indicated that the two species initially identified as *S. aurita* and *P. senegalensis* are ancestral group or did evolve from the common ancestor. Consistent across examined gene regions, genetic distances for both mitochondrial and nuclear gene regions exhibited divergence incomparable to species-level differentiation of *S. aurita* and *P. senegalensis* (Figure 4.51 – 4.53 and 4.54).

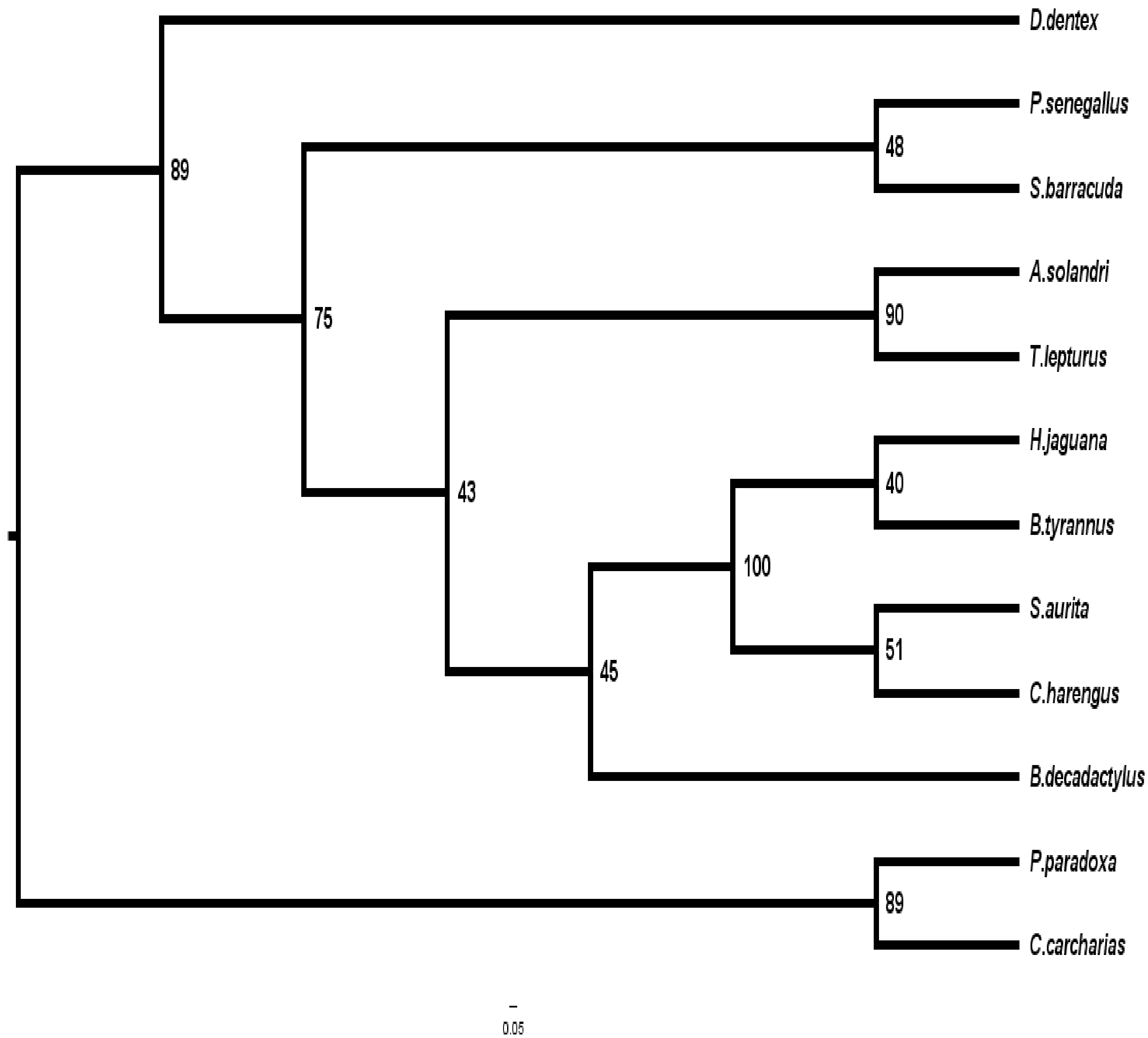

Figure 4.53: Phylogeny of cytochrome b (Cytb) sequences.

Maximum Likelihood (ML) tree generated from Cytb mitochondrial conserved region of 12 species (*S. aurita, B. tyrannus, D. dentex, P. senegalensis, C. harengus, T. lepturus, S. barracuda, A. solandri, H. jaguana, B. decadactylus, P. paradoxa* and *C. carcharias*). Sequence alignment was performed using MUSCLE v3.8.31 and phylogeny relationship was inferred using RAxML v8.2.10 with the best fitted GTRGAMMA model and with 1,000 bootstraps iterations.

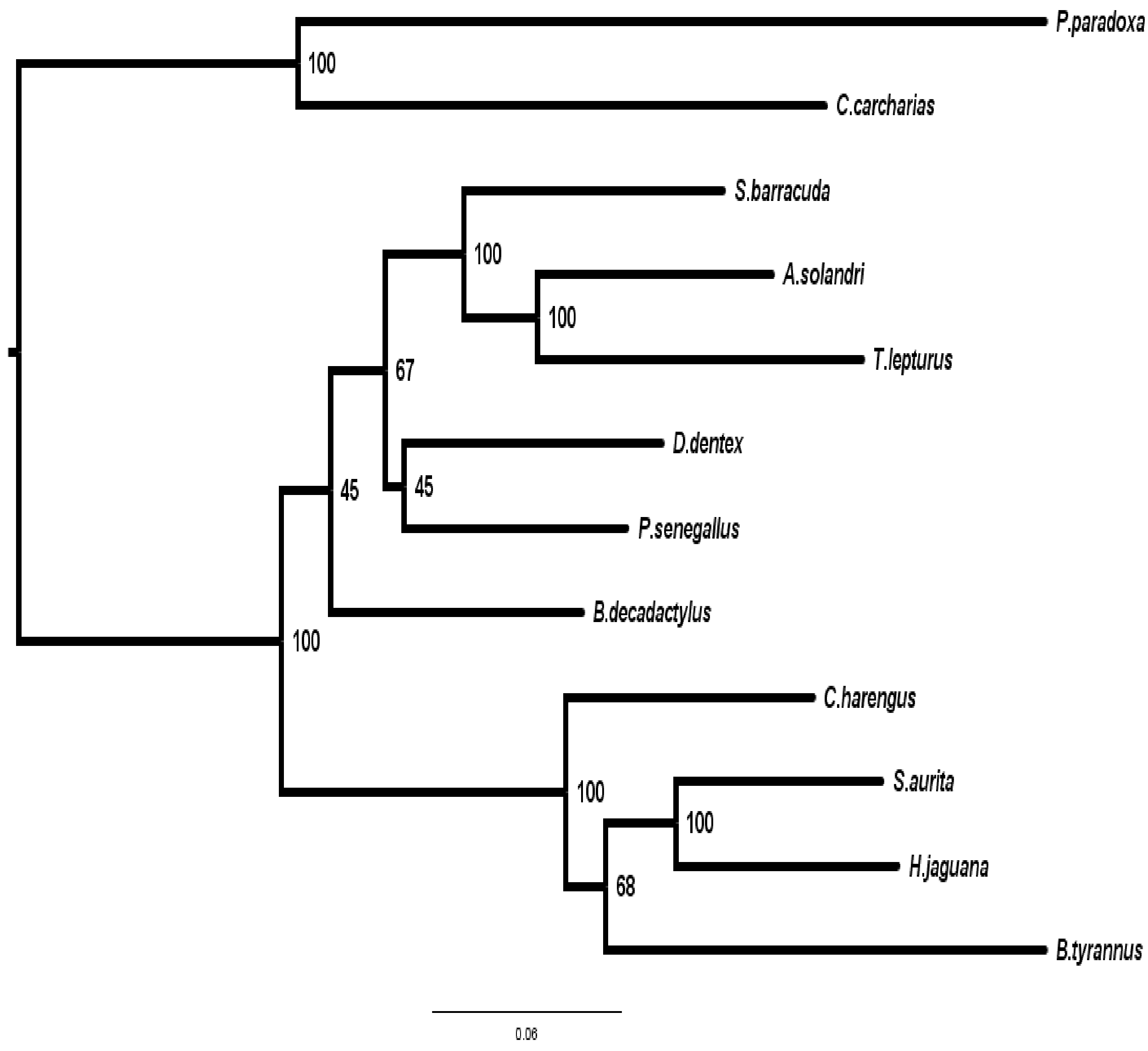

Figure 4.54: Phylogeny of combined dataset 16s, COI, Cytb and Rag-1 sequences.

Maximum Likelihood (ML) tree generated from both mitochondrial and nuclear DNA conserved regions of 12 taxa (*S. aurita, B. tyrannus, D. dentex, P. senegalensis, C. harengus, T. lepturus, S. barracuda, A. solandri, H. jaguana, B. decadactylus, P. paradoxa* and *C. carcharias*) inferred deep genetic divergence relationship of *S.aurita* and *P. senegalensis*. Sequence alignment was performed using MUSCLE v3.8.31 and phylogeny relationship was inferred using RAxML v8.2.10 with the best fitted GTRGAMMA model and with 1,000 bootstraps iterations.

4.4 Socio-economic and Demography of fishermen in Montserrado and Marshall

The socio-economic and livelihood status for fishermen in Montserrado and Marshall are presented in terms of

1. **Demography:** number of fishermen and vessels per fishing community
2. **Natural capital:** aquatic resource perceptions and income
3. **Human capital:** Age distribution, gender profile, family size and type, marital status, fisherman origin, educational status and dropout of school going children
4. **Fishing program:** Type(s) of gear used, type of fishing vessel, number of crew per vessel, duration of fishing activity, fishing grounds/locations of fishing, target species, total weight of catch, Conditions of fishing activity, number of fishermen/vessels catch these species in the fishing location at the same time of fishing, do they catch the same amount every day and average amount of catch described on a daily fishing trip
5. **Fishermen's sales/income in Liberian dollars and USD:** fisherman's sale price and dealer/middlemen sale price
6. **Fish species caught:** specific *Sardinella aurita* and *Pseudotolithus senegalensis*
7. **Socio-economics status:** Fishing gear price, fishing gear replacement rate, fishing gear repair costs and others

4.4.1 Demography

Montserrado has seven (7) fishing communities that are permanently involved with fishing activity (i.e. Gbanjor, point-four, West Point, (kru and Fanti), King Gray, ELWA and Kpekor), whereas Marshall has three (3) fishing communities such as Marshall Kru, Marshall Fanti and Marshall Boy's Town. Among the seven (7) fishing sites four were randomly chosen (i.e. Gbanjor, West Point (Kru and Fanti), King Gray and ELWA) but King Gray and ELWA were joined as one fishing site during the study because of their catchability and proximity. This made Montsorrado to have three (3) landing sites during the survey (Gbanjor, West Point, (kru and Fanti), King Gray and ELWA). Two were selected from Marshall and later became one due to the target species landing (Marshal-Kru and Marshall-Fanti). The number of active registered canoes and fishermen are shown in Table 4.15.

The number of fishermen and vessels per fishing community identified in Gbanjor, West Point (Fanti and Kru) which constitute the largest populated fishing community in Montserrado, King Gray and ELWA fishing communities as well as Marshall Kru and Marshall Fanti's beach are shown in (Table 4.15). These landing sites were selected from both subsectors Marshall and Monsterrado.

Table 4.15: Name of landing sites, active registered canoes and number of fishermen in Montserrado and Marshall - Lower Margibi

County	Landing site	Total canoes 2010	Decommission Canoes	New Reg Canoes	Total active canoes	No. of Fishermen
Montserrado	301 Gbanjor	59	20	14	53	78
	302 Point-Four	132	64	57	125	306
	303 West Point	429	None	4	433	849
	304 Bernard Beach	123	None	3	126	89
	305 King Gray	78	58	30	50	198
	306 ELWA Beach	103	None	9	112	166
	Kpekor	47	None	21	68	130
Sub-Total		**971**	**142**	**138**	**967**	**1816**
Marshall – Lower Margibi	401 Ben's Town	4	3	10	11	2
	402 Floko Town	4	Sea erosion			11
	403 Kpakpacon	7	5	13	15	18
	Marshall Kru	51	36	10	25	77
	Marshall Fanti	17	None	21	38	20
	Marshall Boy's Town	13	None	10	23	27
Sub-Total		**96**	**44**	**64**	**112**	**155**

(Source: Bureau of National fisheries, Montserrsdo)

4.4.2 Natural capital (Aquatic resource - water body and fish resource) and perceptions

The fishermen of the two subsectors are largely dependent of fishing along the coastline of Liberia waters, especially Montserrado and Marshall. Different species exploited by artisanal fishers in nearshore along the coastline of Liberia include *Sphyraena, Caranx, Sardinella*, *Ethmalosa*, *Pseudotolithus, Cybium, Trichiurus, Chloroscombrus, Vomer, Ilish africana, Dentex, Cyanoglossus, Galeoides decadactylus, Pentanemus quinquarius and Drepane Africana*, *Panulirus, Sanquerus* etc.

4.5 Human capital

4.5.1 Age distribution

In this study the age of fishermen was classified into three groups such as young (15 – 30 yrs), middle-aged (31 – 45 yrs) and old (46 – 70 yrs or above). The results showed that majority (52%) of the fishermen were young, 40% were middle aged and 8% were old in Gbanjor. On the other hand, a majority 60% of the fishermen was middle aged, other was 28% young age and 12% was old aged group at West Point. Within King Gray and ELWA majority (48%) was middle aged, 44% were young and 8% was old aged. At Marshall 48% majority of fishermen was middle aged, 36% old aged and 16% were young (Table 4.16).

4.5.2 Gender profile (sex status)

The survey was conducted in the four fishing communities among the fishers of whom all of the fishers in Gbanjor, West point and Marshall were male (100%) whereas King Gray and ELWA had 96% male and 4% female in the fishing activity (Table 4.16).

4.5.3 Religion status

In the study it was observed that majority 96% of fishermen were Christian in Gbanjor, West Point and King Gray & ELWA and 4% were Muslim in Gbanjor, West Point and King Gray % ELWA respectively. In Marshall all (100%) fishermen were Christian (Table 4.16).

Table 4.16: History of Fishermen

		Gbanjor		West Point (Fanti & Kru)		King gray and ELWA		Marshall (Fanti & Kru)	
Human Capital	Pattern	Number of respondent	%	Number of respondent	%	Number of respondent	%	Number of respondent	%
Age distribution	Young (15 - 30 yrs)	13	52	7	28	11	44	4	16
	Middle (31-45 yrs)	10	40	15	60	12	48	12	48
	Old (46 yrs or above)	2	8	3	12	2	8	9	36
Gender profile	Male	25	100	25	100	24	96	25	100
	Female	0	0	0	0	1	4	0	0
Religion	Christian	24	96	24	96	24	96	25	100
	Muslim	1	4	1	4	1	4	0	0
Marital status	Married	11	44	14	56	11	44	21	84
	Unmarried	14	56	11	44	14	56	4	16
Family size (person)	Small (1 – 4)	17	68	15	60	16	64	11	44
	Medium (5 – 7)	6	24	5	20	6	24	8	32
	Large (8 and above)	1	4	2	8	0	0	5	20
	No family	1	4	3	12	3	12	1	4
Family type	Nuclear	11	44	15	60	11	44	21	84
	Joint	14	56	10	40	14	56	4	16
Educational status	No education	14	56	12	48	4	16	16	64
	Primary level (up to class 5)	5	20	3	12	2	8	4	16
	Junior High	3	12	5	20	12	48	1	4
	Senior High	0	0	2	8	1	24	3	12
	Graduate	3	12	3	12	1	4	1	4
Dropout level of fisher's children	Not going school children	2	8	3	12	2	8	2	8
	School going children	23	92	22	88	23	92	23	92

4.5.4 Marital status

In the survey, it was found that majority 84% of the fishermen were married in Marshall, 56% in West Point and 44% in both Gbanjor and King Gray & ELWA. Majority 56% of fishermen were unmarried in both Gbanjor and King Gray & ELWA and few 44% and 16% were unmarried in West Point and Marshall (Table 4.16).

4.5.5 Family size

In this study the family size of the fishermen were divided into three categories on the basis of the number of family members. The results showed about 68% families were small (1 – 4 persons), 24% families were medium (5 – 7 persons), 4% families were large (8 person and above) and 4% did have a family in Gbanjor. West Point had about 60% families were small (1 – 4 persons), 20% families were medium (5 – 7 persons), 12% had no family and 8% families were large (8 persons and above), 64% families were small (1 – 4 persons), 24% families were medium (5 – 7 persons), 12% fishermen had no family and there were no large family member in King Gray and ELWA respectively. And Marshall had about 44% families were small (1 – 4 persons), 32% families were medium (5 – 7 persons), 20% families were large (8 person and above) and 4% fishermen did not have a family (Table 4.16).

4.5.6 Family type

In rural and urban Liberia, normally families are classified into two types such as (1) Nuclear family (parents and children): married couples with children or consist of the member of two generations and (2) Joint family: a group of people related by blood and/or by law meaning the number of three or more generations. The results showed that Gbanjor and King Gray and ELWA had 56% fishermen families were classified as joint and 44% families were nuclear. 60% fishermen families were nuclear and 40% families were jointed within West Point respectively. And finally, Marshall had 84% fishermen families were nuclear and 16% families were jointed (Table 4.16).

4.5.7 Educational status

In the study areas it was found that 64%, 56%, 48% and 16% fishermen had no education in Marshall, Gbanjor, West Point and King Gray and ELWA respectively. Few fishermen 20%, 16%, 12% and 8% only had primary level education (up to class 5) in Gbanjor, Marshall, West Point and King Gray and ELWA. 48%, 20%, 12% and 4% fishermen had junior high education (class 6 - 9) in (King Gray and ELWA, West Point, Gbanjor and Marshall). King Gray and ELWA, Marshall and West Point had 24%, 12% and 8% senior high education (class 10 – 12), whereas Gbanjor had no formed of senior high education among fishermen. And finally, fishermen in Gbanjor and West Point had 12% and 4% for both Marshall and King Gray & ELWA diploma certificate (Table 4.16).

4.5.8 Dropout level of school going children of fishermen

The study results showed that 12% for West Point and 8% for Gbanjor, King Gray and ELWA and Marshall had no school going or dropout children, whereas 92% for Gbanjor, King Gray and ELWA and Marshall and 88% for West Point had school going children. Few 12% fishermen had dropout school going in West Point and 8% fishermen in Gbanjor, Marshall and King Gray & ELWA had the least dropout school going children (Table 4.16).

4.6 Fishery

Within the Montserrado and Marshall Fisheries there were three types of gears used by fishers namely gill net, drift net, hook and long lines. Approximately 92%, 76%, 60% and 56% of the fishers used gill net in King Gray & ELWA, Gbanjor, West Point and Marshall respectively. Drift net was used at 40%, 36%, 20% and 4% in West Point, Marshall, Gbanjor and King Gray & ELWA respectively. This net is mostly used by the 25 and 40 HP outboard engine canoe. The least of all gears used was hooks and longlines by fishermen at 4% both in Gbanjor and King Gray & ELWA and at 8% in Marshall (Table 4.17).

Table 4.17: Components of fishing along Liberia South Coast

		Gbanjor		West Point		King Gray & ELWA		Marshall	
		Number	%	Number	%	Number	%	Number	%
Gear type used	hooks & longlines	1	4	0	0	1	4	2	8
	Drift net	5	20	10	40	1	4	9	36
	Gill net	19	76	15	60	23	92	14	56
Fishing vessel type	paddle canoe	15	60	12	48	20	80	9	36
	9.9 HP	0	0	1	4	0	0	0	0
	15 HP	5	20	0	0	5	20	8	32
	18HP	1	4	0	0	0	0	0	0
	25 HP	4	16	1	4	0	0	0	0
	40 HP	0	0	11	44	0	0	8	32
No. of crew per vessel	1 - 2 person	20	80	9	36	18	72	13	52
	3 - 5 person	5	20	9	36	7	28	11	44
	6 person and above	0	0	7	28	0	0	1	4
Fishing duration	4 - 9 hours	13	52	22	88	24	96	12	48
	10 hours and above	12	48	3	12	1	4	13	52
Fishing grounds/ locations	Nearshore	18	72	23	92	19	76	13	52
	nearshore & deepsea	7	28	2	8	6	24	12	48
Target species	Sardines & mix fish	4	16	12	48	2	8	7	28
	Pseudotolithus pp & mix fish	15	60	12	48	13	52	13	52
	Sardines, *Pseudotolithus pp* & mix fish	6	24	1	4	10	40	5	20
Average amount of catch described	½ - 2 bag	17	68	13	52	17	68	13	52
	3 bags and above	8	32	12	48	8	32	12	48

The fishing vessel types ranged from paddle canoe to outboard engines with different capacities, (9.9 HP, 15 HP, 18 HP, 25 HP and 40 HP) used by fishermen (Table 4.17). Approximately 80% in King Gray & ELWA, 60% in Gbanjor, 48% in West Point and 36% in Marshall used paddle canoe. 44% of fishermen used 40 HP in West Point and 32% in Marshall. 32% of fishermen used 15 HP in Marshall 20% in both Gbanjor and King Gray and ELWA. 16% of fishermen in Gbanjor used 25 HP and 4% in West Point, whereas 4 % of fishermen in West Point used 9.9 HP and 4% of fishermen in Gbanjor used 18 HP (Table 4.17).

The number of crew per vessel was divided into three categories small (1 – 2 people), medium (3 – 5 people) and large (6 people and above) on the basis of vessel type. The result showed about 80% Gbanjor, 72% King Gray & ELWA, 52% Marshall and 36% West Point crew were small. The crew was medium at 44% Marshall, 36% West Point, 28% King Gray & ELWA and 20% Gbanjor and were large at 28% West Point and 4% Marshall (Table 4.17). Most paddle canoe had small crew while medium crew used 9.9, 15 and 18 HP canoes and the larger crew (6 person and above) used 25 and 40 HP outboard engines. The Fanti fishers normally used the larger motorized canoes whereas the Kru used the dugout canoes.

Fishing duration was classified into two categories i.e., 4 – 9 hours and ≥10 hours. The majority, approximately 96% in King Gray & ELWA, 88% in West Point, 52% in Gbanjor and 48% in Marshall fished within 4 – 9 hours and other 52% in Marshall, 48% in Gbanjor, 12% in West Point and 4% in King Gray & ELWA fished within ≥10 hours. In Liberia, fishing grounds are normally nearshore and deep sea. The study showed that 72% of fishermen in Gbanjor, 92% in West Point, 76% in King Gray & ELWA and 52% in Marshall fished within nearshore waters of Liberia, while 48% of fishermen in Marshall, 28% in Gbanjor, 24% in King Gray & ELWA and 8% in West Point fished both nearshore and deep sea depending on fish vessel.

The fisheries of Liberia are multi-species using variety of fishing gears. The study focused on Sardines and cassava fish species specifically *S. aurita* and *P. senegalensis* as target species which were selected due to their market demand and high frequency of catches. The result showed that majority 60% in Gbanjor, 52% in both Marshall and King Gray & ELWA and 48% in West Point fished for *Pseudotolithus* and mixed fish; other include 48% in West Point, 28% in Marshall, 16%

in Gbanjor and 8% in King Gray fished for sardines and mixed fish and finally, 40% fishermen in King Gray & ELWA, 24% in Gbanjor, 20% in Marshall and 4% in West Point fished for sardines, *pseudotolithus* and mixed fish along the coastal waters of Liberia (Table 4.17).

Interestingly, fishermen in both Marshall and Montserrado never caught the same species each fishing trip. This was due to the visibility and pattern of fish species. In the study the average amount of catch described was classified into two groups such as small catch (½ - 2 bags) and large catch (3 bags and above). The majority 68% both Gbanjor and King Gray & ELWA and 52% both West Point and Marshall fishers average amount of catch described were small (½ - 2 bags). Other 48% in both Marshall and West Point and 32% in both Gbanjor and King Gray and ELWA fishermen average amount of catch described were large (3 bags and above) (Table 4.17). The average catch by paddle canoe is (½ - 2 bags) and motorized canoe average catch is 3 bags and above).

4.6.1 Distribution of fishing effort within the two subsectors (Marshall and Montserrado)

Table 4.18 shows the number of fishing crafts by type and total number of active fishermen at the landing sites at both Montserrado and Marshall. Montserrado had higher number of fishermen and fishing vessels than Marshall due to the many landing sites in Montserrado.

Montserrado has seven fishing communities that are permanently involved in fishing activity. Among the seven fishing sites four were randomly selected including Gbanjor, West Point, King Gray and ELWA. King Gray and ELWA were joined as one fishing site due to the similarity in fish landings and closeness. Marshall had three landing sites within Lower Margibi but two were chosen namely Marshall Kru and Marshall Fanti. These two landing sites differ in terms of fish landings. Marshall-Kru beach mainly land *Sardinella* and other mixed fish species in small numbers while Marshall-Fanti landing site landed both *Sardinella, Pseudotolithus* and other mixed fish species in large numbers. Therefore, the two landing sites were joined as one landing site during this study Table 4.18.

The dug-out canoes were the most commonly used by fishermen in Montserrado but less used by fishermen in Marshall. Approximately 60% fishermen used outboard engine boats ranging from (9.9, 15, 18, 25 and 40 HP). The most widely used are the 15 HP and 40 HP by mostly Fanti fishers. Although fish landing were variable from month to month (Table 4.1 and 4.2) there appeared to be no significant pattern in most fish catches in South coast, Liberia. Especially *Sardinella* and *Pseudotolithus* which were found to be declining steadily and periodically.

Table 4.18: Total number of boats by type and number of fishermen per landing beach in the south coast of Liberia, Montserrado and Marshall 2017.

County	Landing site	Dug-out canoes	Engine boats					Total vessels	Total fishermen
			9.9 HP	15 HP	18 HP	25 HP	40 HP		
Montserrado	Gbanjor	26	3	11	4	5	4	53	78
	West Point	135	12	20	16	108	143	433	849
	King Gray	33	1	10	2	1	3	50	198
	ELWA Beach	41	6	20	9	12	24	112	166
Sub-Total		**235**	**22**	**61**	**31**	**126**	**174**	**648**	**1291**
Marshall-Lower margibi	Marshall Kru	25	0	0	0	0	0	25	77
	Marshall Fanti	0	2	18	4	2	12	38	20
Sub-Total		**25**	**2**	**18**	**4**	**2**	**12**	**63**	**97**

4.7 Economic status of Montserrado and Marshall Fisheries

Table 4.19 shows an illustration cost calculation per month (in LRD) for fishermen at different landing sites in Montserrado (Gbanjor, West Point and King Gray & ELWA) and Marshall (Marshall Fanti and Kru). The main objective of this component was to assess the economic status of the Montserrado and Marshall Fisheries. The scope of analysis included a socio-economic profiling of coastal fishing communities/populations shown in Table 4.19, fishermen operational dynamics analysis and a bio-economic model. The surplus production model mainly forced on assessing the issue of economic overfishing (i.e. the effort exerted on the fish species that dissipates resource rent from the coastal fishery).

Table 4.19: Estimated cost calculation per month (in Liberian Dollar-LRD) for fishermen at landing sites Gbanjor, West Point, King Gray & ELWA and Marshall.

Gear	Fishing Gear Cost (FGC)	Average Initial Price (P)	Replacement rate per month (Rr)	Number per site (N)	Repair costs (RC)	No. of Fishermen	Total costs (TC)	Others expenditure
Hook	150	400	2	3	0	3	600	200
Longline	200	600	2	3	0	3	900	200
Gill net 1 ½ Inch/finger	4,800	21,450	71	13	3,500	13	7,427.46	3,500
Gill net - 2 Inches/finger	5,600	22,000	152	22	3,500	22	6,684.21	3,500
Gill net 3 - 4 Inches/finger	7,200 - 12,000	24,000	173	27	4,000	27	7,745.66	4,500
Drift net - 6 Inches/finger	28,000 - 32,000	42,000	291	25	6,600	25	10,496.91	8,000

Most fishers in Liberia used either a small wooden dugout canoe costing LRD 32,000 - 40,000 (USD 400 – 500) used for 5 to 6 years without engine. Others used a bigger and larger dugout canoe, mainly the Fanti fishermen from Ghana costing about LRD 104,000 – 640,000 used for 10 – 12 years both with engines that ranges from 9.9 Horse Power, 15 HP, 18 HP, 25 HP and 40 HP. The cost of these outboard engines are 9.9 HP US$ 2,400 – 2,600; 15 HP US$ 2,800 – 3,400; 18 HP 3,200 – 3,600; 25 HP 3,500 – 3,750 and 40 HP US $ 4,400 – 4,800. The price vary with the model, e.g. Touko and Yamaha are used for about 3 years. An inventory of the costs of gear indicated that hook and longline were the cheapest gears (Table 4.19). A hook cost LRD 150 to 400 while a longline cost about LRD 200 to 600. However, Kru fishermen used hooks and longlines for fishing as to reduce the costs of buying and making nets. One boat can deployed about 24 – 30 hooks along with longlines.

Gill nets and drift nets are the most expensive fishing gears and hence constitute a major investment in the fisheries. On average, they cost gill net 1 ½ inch/finger LRD 4,800 – 21,450, gill net 2 inches/finger LRD 5,600 – 22,000, gill net 3 – 4 inches/finger LRD 7,200 – 24,000 and drift net 6 inches/finger 28,000 – 42,000 respectively. The gears can be used up to 3 – 4 years, especially when well maintained and regularly repaired. The maintenance costs on average ranges from LRD 1,500 – 3,500 and 4,500 – 6,600 per month depending on severity of the damage to the net and repaired takes about 2 days of labour on average (Table 4.19).

Table 4.19 shows the units and values for the used variables. It is noted that many fishermen use more than one type of gear in the artisanal fisheries. A representative cost per gear was calculated and a cost per month for the two subsector's fishery. This was estimated at some LRD 1,440 and 14,400 per fisher-month with a range between LRD 40 – 80 and 500 – 700 per fisher per month. The gross income is the result of the amount of fish caught and the price for the catch that a fishermen receives. Fisherman and dealer fish price data were generated for both Marshall and Montserrado fisheries (Table 4.20).

For the three sites of Montserrado (Gbanjor, West Point and King Gray & ELWA) and two sites in Marshall (Marshall Fanti and Kru), the average monthly catch and the catch composition per-fisher in the first half of 2017, was multiplied with the average price per fish category in 2017 (taken as the midpoint estimate between the value per season) to arrive at the gross income per day for a fisher at Montserrado and Marshall of LRD 3,500 – 6,000 for paddle canoe, LRD 12,450 – 18,450 for 9.9 HP, 15 HP and 18 HP motorized canoe and LRD 24,200 – 43,200 for 25 HP and 40 HP respectively. Note that fish taken for personal consumption and that which was landed elsewhere does not count. Multiplying this figure with the average number of trips per month (24), and deducting the average costs of fishing per month (8,400 for paddle canoe, 84,000 for 9.9 HP, 15 HP and 18 HP motorized canoe and 192,000 for 25 HP and 40 HP motorized canoe), net monthly income is LRD 75,600 – 135,600 for paddle canoe, LRD 214,800 – 358,800 for 9.9 HP, 15 HP and 18 HP motorized canoe and LRD 388,800 – 844,800 for 25 HP and 40 HP motorized canoe for both Montserrado and Marshall fishermen. From these calculations it is concluded that gross annual income per fisherman varies between US$ 945 – 1,695 for paddle canoe, US$ 2,685 – 4,485 for 9.9 HP, 15 HP and 18 HP motorized canoe and US$ 4,860 – 10,560 for 25 HP and 40 HP motorized canoe.

A calculation that takes into account the estimated total amount of fish landed per category and the average price paid to the fishers gives an estimate of the annual total gross income of all fishermen combined at Montserrado gives as US$ 59,925 for paddle canoe; US$ 33,300 for 9.9 HP, 15 HP and 18 HP motorized canoe and US$ 56,400 for 25 HP and 40 HP motorized canoe. At Marshall US$ 3,712.5 for paddle canoe; US$ 16,200 for 9.9 HP, 15 HP and 18 HP motorized canoe and US$ 25,800 for 25 HP and 40 HP motorized canoe (at a rate LRD 80 = 1USD). If we use fish prices of Montserrado (Table 4.21) to estimate incomes of fishers at other sites, a fishermen at Marshall has a net income of LRD 2,750 for paddle canoe, LRD 13,500 for 9.9, 15 and 18 HP motorized canoe and LRD 21,500 for 25 and 40 HP motorized canoe and fisherman at Montserrado has a net income of LRD 8,500 for paddle canoe, LRD 18,500 for 9.9, 15 and 18 HP motorized and LRD 23,500 for 25 and 40 HP motorized canoe per day. This translates to the equivalent of USD 34.38, 168.75 and 268.75 for paddle canoe, motorized canoe (9.9, 15 and 18 HP) and motorized canoe (25 and 40 HP) for Marshall and USD 106.25, 231.25 and 293.75 for paddle canoe, motorized 9.9, 15 and 18 HP canoe and motorized 25 and 40 HP canoe. However, mean family numbers in both areas/communities is between one and four constituting small families translating to 1 USD per person a day for the poorest. This illustrates the success of the fishermen and suggests that fishers can put more money aside for investments and other economic ventures.

4.7.1 Fishermen's sales/income and dealer/middlemen sale price (Liberian dollars)

At all landing sites fish prices vary with respect to species, the most valuable were Catfish, Snapper, Grouper, Cassava fish, Cavalla, Butter nose, Mackerel, Barracuda, Atlantic bigeye, Silver fish, Lobber and Shark (Table 4.20). There was a significantly higher price for dealer prices (i.e. 15 – 25% more than fishermen price) in all landing sites, which was similar in both Marshall and Montserrado. Fish prices also vary with season where fish is more expensive during some period in dry season and rainy season both Montserrado and Marshall due the difference in availability of fish (Table 4.1, 4.2 and 4.20). The total value of the commercial landings must therefore be calculated from the values that the dealers calculate when they sell their fish to consumers or middlemen, which is slightly higher than the price paid to fishers by ≥20%. The fishing communities at the landing sites indicated that middlemen paid a higher price of about US$ 2.5

per part/bunch of fish, especially with preferred groups of *Arius*, *Dentex* and *Pagrus*, *Lutjanus*, *Pseudotolithus*, *Caranx* and *Alectis*, *Galeoides*, *Sphyraenaand Panulirus* which apparently also exhibit some slight seasonal price fluctuations (Table 4.20).

On an annual basis, an extrapolation from the data collection shows that total catch per landing site increases and decreases and catch per fisher also decreases and increases in month due to the availability of fish and the weather and hydrodynamic condition. The estimate for fishing hooks, longlines, gillnets and driftnets was based on the responses of fisher to questions on how much one costs. However, personal observation confirmed that majority of fishermen repaired their own nets and pay approximately, LRD 1,500 – 6,600 for threads, ropes, corks, led and contribute to food. Only two sites depicted use of 40 HP in Marshall and Monsterrado while 15 HP is widely used in the two fisheries.

Table 4.20: Fish prices per part/bunch in LRD for 2016 – 2017 at four major landing sites in Montserrado and Marshall from fishermen and dealers (exchange rate: 1 USD to 80 LRD)

		Marshall		Montserrado					
		Marshall		Gbanjor		West Point		King Gray & ELWA	
Family	Local name	Fishermen	Dealer	Fishermen	Dealer	Fishermen	Dealer	Fishermen	Dealer
Arius pp.	Catfish	500 – 800	1000	500 – 800	1000	500 – 800	1000	500 - 800	1000
Ethmalosa pp	Bonga	50	80	50	80	50	80	50	80
Sardinella pp	Bonny	40	80	40	80	40	80	40	80
Ilisha pp	Gbapleh	200	250	200	250	200	250	200	250
Dentex/Pagrus pp	Snapper	200 – 500	1,000	200 – 500	1,000	200 – 500	1,000	200 - 500	1,000
Lutjanus pp	Grouper	800	1,500	1,000	1,500	1,500	1,600	1,500	1,600
Pseudotolithus pp	Cassava fish	500 – 600	700	500 - 600	700	500 - 600	700	500 - 600	700
Caranx/Alectis pp	Cavalla	1,000	1,500	750	1000	700 - 800	1,000	700 - 800	1,000
Chloroscombrus pp	Pojoe	100	200	100	200	100	200	100	200
Istiophorus pp	Napleh	1,500	2,000	1,500	2,000	1,500	2,000	1,500	2,000
Galeoides pp	Butternose	200 – 500	1,000	200 - 500	1,000	200	1,000	200 - 500	1,000
Euthynnus pp	Blood fish	200	250	250	300	200	250	200	250
Scomberomorus pp	Mackerel	500	700	500	750	500	700	500	700
Sphyraena pp	Barracuda	500	750	500	750	500	750	500	750
Coryphaena pp	Forbor	600	1,000	500	1,000	600	1,000	600	1000
Priacanthus pp	Atlantic bigeye	1,000	2,000	1000	1,500	1,000	2,000	1,000	2,000
Psettodes pp	Sole fish	200	350	300	350	200	350	200	250
Trichiurus pp	Silver fish	1000	1,200	1000	1500	1,000	1,500	900	1,200
Panulirus pp	Lobster	2,000	2,500	2,000	2,500	2,000	2,500	2,000	2,500
Parapenaeopsis pp	Crew fish	100	200	100	200	100	200	100	200
Sanquerus pp	Crab	250	400	250	400	250	400	250	400
Rhizoprionodon pp	Shark	5,000	8,000	5,000	8,000	5,000	8,000	5,000	8,000
Dasyatis pp	Stinger	175	200	175	200	175	200	175	200
Gymnura pp	Sea bat	500	1,000	500	1,000	500	1,000	500	1,000

CHAPTER FIVE

5 DISCUSSION

5.1 Samples of *S. aurita* and *P. senegalensis*

A total of 2,270 of *Sardinella aurita* and 1,711 of *Pseudotolithus senegalensis* were sampled at Gbanjor, West Point, King Gray & ELWA in Montserrado and Marshall along the Liberian south coast from December 2016 to May 2017. *Sardinella aurita* appear abundant in May, June and July within the Northeastern Mediterranean (A. C. Tsikliras & Antonopoulou, 2006) suggesting most mature individuals are caught during July with high frequency. Between January and March, the number of *S. aurita* was high at all sampling sites both Montserrado and Marshall but lower between April and May. This differed with the previous studied in Northeastern Mediterranean. January to March seem to be the period when *S. aurita* is abundant in the fisheries. The overall length frequency ranged from 17 to 31 cm which indicate that *S. aurita* is exploited at a medium size. The highest catches recorded was in January and February for *P. senegalensis* at Montserrado and Marshall. This result is similar with (Sossoukpe, et al., 2013) indicated that the abundant of *P. senegalensis* occurs during the warm season from February – May in Benin. There was decline in the landing of *Pseudotolithus senegalensis* in May at all landing sites due to the seasonal changes with respect to high tide. This coincided with introduction of gillnets, hooks and long lines used within the fishing period. Set net or drifting method for gillnets within the four landing sites contributed about 80% of the artisanal catches of the two subsectors. Hooks and long lines were used by few fishers. The outboard engine canoes had more catch then the paddle canoes. The length of *P. senegalensis* ranged between 28 and 51 cm. During April and May 2017 catch decreased in the four landing sites for *S. aurita* and *P. senegalensis* could be attributed to high tide.

The highest catches recorded was in January and February for *S. aurita* and February for *P. senegalensis* at Montserrado and Marshall in January. The lowest catches was recorded in April and May for both species in the two fisheries. The general increase in catches and value from December 2016 to March 2017 in subsequent months could be attributed to the weather and good tide of the ocean. During this period the majority of the gears deployed constitute mainly gill nets and drift nets especially for *Sardinella*, *Pseudotolithus* and other mixed fish species. The high price of fish during this period could be attributed to the demand of fish compared to catch after April.

5.2 Length-weight relationship in *S. aurita* and *P. senegalensis*

Previous studies published values of the growth coefficient *b* varied between areas 2.977 (Omogoriola et al., 2011) in Nigeria; 3.21 (Calvin 1990) in Cameroon; 3.02 (Sidibé, 2003) in Guinea and 2.67 – 2.91 for site 1 and 2 (Sossoukpe et al., 2013) in Benin for *S. aurita*. In previous published values of (*b*) a negative allometric growth for *S. aurita* was observed (95% CI was 2.724 – 2.767) (Mehanna & Salem, 2011) in Egypt and 3.064 – 3.086 (Tsikliras, 2005) in Greece indicate positive allometric growth. *Sardinella aurita* growth coefficient *b* of length-weight relationship from this study suggest that *S. aurita* show negative allometric growth irrespective of the environment. The estimated *b* include Gbanjor 1.94, West Point 1.94, King Gray 1.89 for Montserrado and 1.97 for Marshall. The growth coefficient *b* of *P. senegalensis* length-weight relationship generally lies between 2.5 and 3.5 and the relation is isometric when it is equal to 3 reported for most aquatic organisms (Le Cren, 1951). In this study, the estimated *b* varies between Montserrado and Marshall such as Gbanjor was 2.77, West Point at 2.45 and King Gray & ELWA was 2.50 which was not significantly different from the isometric value along with Marshall which was 2.29. The present study growth coefficient *b* are much smaller than the previous published values. The reasons for the variation of *b* in the different regions are suggested to be due to seasonal fluctuations in the environmental fishing parameters, physiological conditions of the fish at the time of fishing activity, gonadal development, sex and nutritional conditions in the environment of fish (Biswas, 1993). The value of "*b*" in the length-weight relationship should be exactly "3" if the growth is isometric. This cube law relationship is hardly expected as most of the species change their shape due to sex, maturity and season. These differences in the values of asymptotic weight could be attributed to differences in productivity.

Montserrado showed a higher range of specimens and lower values in length size (TL, cm) and Marshall had a lower range of specimens but a higher values in length size (TL, cm) frequencies for the two species. For instance, *S. aurita* had a size range of 17 – 31 cm at Gbanjor, 19 – 30 cm at West Point, 17 – 30 cm at King Gray and 18 – 30 cm at Marshall whereas *P. senegensis* ranged from 29 – 51 cm in Gbanjor, 28 – 50 cm in West Point and 28 – 50 cm in both King Gray & ELWA and Marshall respectively. No difference were found between West Point, King Gray & ELWA and Marshall in total length for *P. senegalensis*, only Gbanjor differed slightly from the three landing sites. There was no difference in total length for *S. aurita* between Montserrado and Marshall. The lack of significant difference in total length between fish specimens from Montserrado and Marshall could be due to the fact that fishermen fished within the same fishing ground and therefore fish from the two fisheries could be referred to as the same stock. Since the growth exponent '*b*' of *S. aurita* and *P. sengalensis* species did differ significantly from the expected value of 3, it can therefore be the species in both Marshall and Montserrado conform to negative isometric growth. However, the overriding fact here is that the Montserrado and Marshall fish is under extreme fishing pressure. This is highly supported by the significant variations from isometric growth in *S. aurita* and *P. senegalensis* specimens compared with those of Marshall and Montserrado. It is more practically easier to use lengths than weights in field situations, which can be converted into weights later using regression equations (McClanahan & Kaunda-Arara, 1996). Differences in length-weight and condition in fishes are usually due to condition factor, for instance they could be in good condition during spawning and low condition after spawning.

5.3 Fish Stock Assessment

5.3.1 Growth parameters and performance index, Ø' for *S. aurita* and *P. senegalensis*

Growth parameters of the von Bertalanffy growth model for *S. aurita* and *P. senegalensis* were estimated for both Montserrado and Marshall. *Sardinella aurita* L_∞ obtained from Montserrado fishing communities (i.e. Gbanjor, West Point and King Gray & ELWA) in this study were 36, 35 and 35 cm and 34.5 cm for Marshall. They were slightly different from 31.32 cm (Gaamour et al., 2001) in Tunisia and far greater than 26 cm by (El-Maghraby et al., 1970) in Alexandra, Egypt, 28.37 cm (Desoukt & Agouz, 2012) in El-Arish, North Sinai, Egypt, 25.83 cm (Salem et al. 2010) in El-Arish, Egypt, 25.58 cm (Mehanna & Salem, 2011) in El-Arish, Egypt, and 24.9 cm (Tsikliras, 2005) in Greece waters, suggesting that the stock is relatively exploited at medium size in Liberia.

However, the K values for Montserrado fishing communities were (1.18, 0.73 and 0.73 yr^{-1}) were much higher than 0.53 yr^{-1} (El-Maghraby et al., 1970) in Alexandria, Egypt, 0.55 yr^{-1} (Mehanna & Salem, 2011) in El-Arish, 0.51 yr^{-1} (A. Tsikliras, 2005) in Greece, 0.30 yr^{-1} (Salem et al. 2010) in El-Arish, 0.24 yr^{-1} (Gaamour et al., 2001) in Tunisia and 0.23 yr^{-1} (Desoukt & Agouz, 2012) in El-Arish, North Sinai, Egypt. Marshall was 0.50 yr^{-1} slightly different from 0.55 yr^{-1} (Mehanna & Salem, 2011) in El-Arish, 0.53 yr^{-1} (El-Maghraby et al., 1970) in Alexandria, Egypt and 0.51 yr^{-1} (Tsikliras, 2005) but greater than 0.24 yr^{-1} (Gaamour et al., 2001) in Tunisia, 0.23 yr^{-1} (Desoukt & Agouz, 2012) in El-Arish, North Sinai, Egypt and 0.30 yr^{-1} (Salem et al. 2010) in El-Arish. These values showed a much difference among in various geographic locations especially Mediterranean waters and the Atlantic waters for the same species and are due to variations in environmental conditions, fishing methods, sampling techniques and computations. The growth parameters estimated are biologically reasonable because the growth performance index (**Ø')** of *S. aurita* were in the range of 2.27 – 2.77 reported by these authors which was regarded as showing low growth. This low growth rates in these regions might have been induced by changes in physical and chemical characteristic of the waters (Ofori et al., 2002). In this study, the **Ø'** estimated for *S. aurita* for Montserrado and Marshall fishing communities were 3.18, 2.95, 2.95 and 2.77. These results showed that there are slightly higher growth rate in this species in Liberia.

Pseudotolithus senegalensis $L\infty$ obtained from Montserrado fishing communities (i.e. Gbanjor, West Point, King Gray and ELWA) and Marshall in this study were 57, 60, 52 and 58.5 cm were less than 61.4 cm recorded in Cameroon waters (Calvin, 1990), 60.8 cm in Guinean waters (Sidibé, 2003), but greater than 51.4 cm in Benin waters (Sossoukpe et al., 2013). This suggests that the stock is relatively exploited at medium size since larger specimens of 100 cm (TL) have been recorded by (Sidibé, 2003). However, the K values in this study for Montserrado and Marshall were 1.03, 0.58, 0.50 and 0.58 yr^{-1} are higher than 0.20 yr^{-1} recorded by Calvin (1990), 0.24 yr^{-1} by Sossoukpe et al. (2013) and 0.35 yr^{-1} Sidibé (2003) respectively. According to (Hernández et al., 1998), the differences among various geographic locations for the same species are due to variations in environmental conditions, fishing methods, sampling techniques and computations. The growth parameters estimated are biologically reasonable because the growth performance index (**Ø')** of *P. senegalensis* were in the range of 2.75 – 3.11 recorded by these authors. The correlated parametric values adjust themselves to provide a similar growth pattern represented by

Ø' (Sparre & Venema, 1998b). According to Baijot & Moreau (1997) the **Ø'** mean values for some essential fish species (e.g. *Pseudotolithus spp*) in Africa were between 2.65 and 3.32 which are reflected as low growth. Previous study by Sossoukpe et al. (2013) reported that **Ø'** of *P. senegalensis* in the nearshore waters of Benin at 2.75, which also was regarded as showing low growth. This low growth rates in these regions might have been induced by changes in physical and chemical characteristic of the waters (Ofori et al., 2002). In this study, the **Ø'** estimated for *P. senegalensis* at Montserrado and Marshall (Gbanjor, West Point, King Gray and ELWA and Marshall-Fanti) fishing communities were 3.52, 3.32, 3.13 and 3.30 respectively. These results suggest that there a slight increase in this species growth rate in Liberia. This slight increased might be due to best fisheries practices in the region and favorable environmental conditions.

5.3.2 Mortality levels and Exploitation ratios of two commercially important species

The computed annual total (Z), natural (M) and fishing (F) mortality rates for *S. aurita* in Montserrado fishing communities were Gbanjor 9.61, 1.87 and 7.74 yr^{-1}. The rate of exploitation (E) was estimated at 0.81; West Point were 7.44, 1.38 and 6.06 yr^{-1}. The exploitation (E) was estimated at 0.81; King Gray were 6.36, 1.38 and 4.98 $year^{-1}$. The rate of exploitation (E) was estimated at 0.78 and Marshall (Marshall Fanti & Kru) were 7.67, 1.47 and 6.20 yr^{-1}. The rate of exploitation (E) was estimated as 0.81 respectively. These results indicate overfishing of *S. aurita* stock and are heavily exploited in the Liberia waters along Montserrado and Marshall. This assumption is based on (Gulland, 1987) which stated that optimized suitable yield is when F = M (i.e., when E is more than 0.50, the stock is generally considered to be overfished). Another more recent proposed lower optimum F (Pauly, 1985) that equals to 0.4 M. The present study, F values were higher than the two values given by (Gulland, 1987; Pauly, 1985) suggesting that the stock of *S. aurita* in Liberia waters in heavily exploited. The estimated annual mortality rates Z, M and F and exploitation (E) rate for (Gbanjor, West Point-Kru and Marshall-Fanti) fishing communities showed that within Montserrado and Marshall the stock of *S. aurita* is heavily exploited. Recent study (Mehanna & Salem, 2011) in El-Arish waters with estimated annual mortality rates Z = 2.53, M = 0.64 and F = 1.89 and exploitation (E) rate as 0.75 also indicate the stock of *S. aurita* in El-Arish waters been heavily exploited. The variation in natural mortality can be explained as a natural phenomenon which is controlled by density dependent factors (i.e. food availability, disease, predation and migration) which varies within same species in different locations.

The estimated annual total (Z), natural (M) and Fishing (F) mortality rates for *P. senegalensis* at Montserrado fishing communities were Gbanjor 6.11, 1.51, and 4.60 yr^{-1}; West Point were 4.02, 1.02 and 3.00 yr^{-1}. The rate of exploitation (E) for both Gbanjor and West Point were 0.75; King Gray & ELWA were 1.50, 0.96 and 0.54 yr^{-1}. The exploitation (E) was estimated at 0.36 and Marshall (Marshall Fanti and Kru) were 3.05, 1.03 and 2.02 yr^{-1}. The rate of exploitation (E) was estimated as 0.66 respectively. Estimated total and natural mortality rates 0.91 and 0.49 yr^{-1} reported by (Sossoukpe et al., 2013) in the Benin waters and 1.20 and 0.97 $year^{-1}$ in the Guinean waters (Sidibé, 2003) were lower than the estimated total and natural mortality rates of (Gbanjor, West Point-Kru and Marshall-Fanti) fishing communities in Liberia. Whereas King Gray & ELWA 1.50 and 0.96 yr^{-1} was slightly different from (Sidibé, 2003) at 1.20 yr^{-1} and 0.97 yr^{-1} respectively. However, the total mortality of Gbanjor at 6.11 yr^{-1}, West Point-Kru 4.02 yr^{-1} and Marshall-Fanti at 3.05 yr^{-1} were higher than those of (Sossoukpe et al., 2013) at 0.91 yr^{-1} in Benin and (Sidibé, 2003) at 1.20 yr^{-1} in Guinea waters respectively. King Gray and ELWA (1.50 yr^{-1}) was slightly close to those of Guinean (1.20 yr^{-1}) and Côte d'Ivoire (1.07 yr^{-1}) waters.

The variation in natural mortality can be explained as a natural phenomenon which is controlled by density dependent factors (availability of food, disease, predation and migration) and also density independent factors such as (temperature, salinity, current regimes, climate change etc.) which varies within same species in different locations. The rate of exploitation (E) estimated in this study for Montserrado and Marshall fishing communities were (0.75, 0.75, 0.36 and 0.66) which indicate overfishing during the study period. This assumption is based on (Gulland, 1987; Pauly, 1985) which states that E = 0.50 stock is considered to be overfished when a lower optimum value of F equals to 0.4M. The current fishing mortality was higher than both the target reference point ($F_{0.1}$) and the limit reference point (F_{max}), indicated that the stock of *P. senegalensis* is heavily exploited in the Liberia waters.

Since the F values for the selected species is far way higher than the E -10 value, when considering overall fishing presence on both fisheries, stocks seem far threatened and it is possible to significantly monitor the fishing effort and introduce fishing season within the fisheries of Liberia. However, it must be considered that, on a larger scale, some specific nearshore and geographical locations already sustain a significant amount fishing activity. The high values for Z also suggest that further investigations are needed to monitor the demographic evolution and increase over-fishing. The inshore waters off Liberia for instance, is subject to a higher fishing pressure, which mainly occurs on and around nearshore. For each one of exploited fish species, the maximum sustainable catch may also represent about 15.2% of the estimated total stock (i.e. E-10). The average annual instantaneous total mortality rate of *S. aurita* Z at 6.36 to 9.61 year^{-1}. The estimated fishing mortality rate F at 6.06 to 7.74 year^{-1} which is far above the estimated natural mortality (M) of 1.38 to 1.87 year^{-1} and the exploitation rate was 0.78 to 81. For *P. senegalensis* Z at 3.05 to 6.11 year^{-1}. The estimated fishing mortality F was 2.02 to 4.60 year^{-1}, greater than the estimated natural mortality (M) 1.02 to 1.51 year^{-1} and the exploitation rate was 0.66 to 0.75 reflecting an overexploitation of the two fish stock within Gbanjor, West Point and Marshall fishing communities.

5.3.3 Recruitment patterns of *Sardinella aurita* and *Pseudotolithus senegalensis* for Montserrado and Marshall

According to the monthly variation of the GSI and the maturation stages of the fish, the spawning of round *Sardinella aurita* in the Northern Aegean occurs once every summer from May to July (Tsikliras & Antonopoulou, 2006). However, this result varied with the spawning season of *Sardinella aurita* between the two studied areas suggesting to temperature differences. During the study Gbanjor recruitment pattern showed that *S. aurita* was recruited in the fishery throughout the year with peaks from August and September. The highest recruitment was observed in September (23.22%) and the lowest observed in January and April. The mid-point of the lower length class (17 cm) in the sampled data was used as a length at recruitment. West Point-Fanti showed *S. aurita* was recruited throughout the year with peaks from April, July and October. The highest recruitment was observed in July (13.91%) and the lowest observed in February. For King Gray & ELWA showed that *S. aurita* was recruited throughout the year with two peaks from August and September. The highest recruitment was observed in September (25.32%) and the lowest observed in November. Marshall showed that *S. aurita* was recruited continuously in the fishery throughout the year with peaks between July and September. The highest recruitment was observed in July (15.88%) and the lowest was observed in March. The recruitment pattern of the species was confined to a specific period during the year in July or September, conforming mature individuals were caught only during July and September. Similar to (Tsikliras & Antonopoulou, 2006) reported that the spawning season of the species was of specific period during the year in May or June, indicating most of the sexually mature individuals were caught only during May, June and July but 36.7% and 24.5% in July

The spawning frequency for *P. senegalensis* showed continuous recruitment throughout the year with peaks between June and September. The highest recruitment was observed in July (16.01%) and the lowest recruitment observed in January. West Point showed that *P. senegalensis* was recruited in the fishery throughout the year with three distinct peaks from July, August and October. The highest recruitment was observed in October (24.03%) and the lowest observed in March. The King Gray recruitment pattern showed that *P. senegalensis* was recruited throughout the year with peaks from April, May and June. The highest recruitment was observed in April (15.76%) and the lowest was observed in January. Marshall showed that *P. senegalensis* was recruited continuously throughout the year with the peaks from July and April in the fishery. The highest recruitment was observed in August (19.11%) and the lowest observed in March. The mid-point of the lower length class (28.00 cm) in the sampled data was used as a length at recruitment. Similar results were reported for *P. senegalensis* (Sossoukpe et al. 2013c) suggested two spawning season per year in March and October, the first occurring during the warm season in Benin from February – May and the second including the minor warm season in November. This confirm the result of Sossoukpe et al. (2013) the *P. senegalensis* in Benin spawn mainly during the warm season in waters where temperature equal to 27.7 ^{o}C or high.

5.3.4 Relative yield per recruit (Y'/R)

Generally, the relative yield per recruit (Y'/R) model was use to assess growth of overfishing. The model estimates the Y/R for various fisheries activities such as fishing mortality and fish size, which suggest policies and describes current usage of stock to enhance the yield. The Y'/R depends on the exploitation pattern and natural mortality, which increases with fishing mortality up to a point where the maximum sustainable yield is obtained. Beyond this point overfishing occurs and population collapses according to (Cadima, 2003). The model of Beverton & Holt (1957) revised by (Gulland, 1987) was applied to estimate *S. aurita* yield per recruit in Marshall and Montserrado nearshore waters. The results also indicated that, at the present level of fishing mortality coefficient (F) 7.74, 6.06, 4.98 and 6.20 year^{-1} for Gbanjor, West Point, King Gray and Marshall. Natural mortality coefficient (M) were 1.87 at Gbanjor, 1.38 both West Point and King Gray at Montserrado and 1.47 at Marshall. The current fishing mortality of *S. aurita* was higher than the target reference point ($F_{0.1}$) and limit reference point (F_{max}), indicating excessive fishing pressure on the stock in both Montserrado and Marshall. This mean the current level of fishing mortality is higher than that which gives the maximum yield per recruit, which is an indication of overfishing. This result greatly differed from El-Arish waters in Egypt where the fishing mortality coefficient (F = 1.89) and Natural mortality coefficient (M = 0.64) reported by (Mehanna & Salem, 2011). The current exploitation rate (E) was estimated as 0.81 for both Gbanjor and West Point, 0.78 at King Gray in Montserrado and Marshall at 0.81 for *S. auriat* greater than those from (Mehanna &

Salem, 2011) reported as E = 0.75 in El-Arish waters and (Desoukt & Agouz, 2012) at 0.60 from the North Sinai Coast. The maximum relative yield per recruit was obtained at E = 0.42, Gbanjor, E = 0.45 both West Point and King Gray for *S. aurita.* The current exploitation rate were lower than both the exploitation rate (E0.1) at which the marginal increase in relative yield-per-recruit is 10% at (0.31) for Gbanjor and (0.36) at both West Point and King Gary in Montserrado and (0.42) Marshall for S. aurita. The exploitation ratio corresponding (E0.5) to 50% of the unexploited relative biomass per-recruit (0.27) at Gbanjor, (0.30) both West Point and King Gray and (0.33) at Marshall for *S. aurita*.

The current exploitation rate for *P. senegalensis* (E) 0.75 for both Gbanjor and West Point and 0.36 for King Gray & ELWA at Montserrado and 0.66 at Marshall. These results less than 0.82 – 0.91 obtained from Benin by (Sossoukpe et, 2013). *P. senegalensis* fishing mortality was higher than the optimum level of exploitation estimated by the Beverton and Holt's method at Gbanjor, West Point and Marshall, indicating excessive fishing pressure on the stock but at King gray & ELWA smaller than the target reference point ($F_{0.1}$) and limit reference point (F_{max}), indicating no fishing pressure on the stock. According to Gulland (1987) the optimum exploitation ratio E_{opt} = 0.5, indicate the stocks of these species is over exploited. The maximum relative yield per recruit was obtained for *P. senegalensis* at E = 0.42 Gbnjor, E = 0.48 West Point and 0.49 King Gray & ELWA at Montserrado and 0.48 Marshall. The current exploitation rate were lower than both the exploitation rate (E0.1) at which the marginal increase in relative yield-per-recruit is 10% at (0.35) Gbanjor, (0.41) at West Point, (0.42) at King Gray & ELWA and (0.41) at Marshall for *P. senegalensis*. The exploitation ratio corresponding (E0.5) to 50% of the unexploited relative biomass per-recruit for *P. senegalensis* at (0.28) Gbanjor, (0.32) at both West Point and Marshall and (0.33) at King Gray & ELWA revealed that the fishery is underexploited in terms of relative yield-per-recruit.

5.4 Genetic differentiation of *Sardinella aurita* and *Pseudotolithus senegalensis*

Several detections of cryptic species have been based on prior observations of subtle behavioral, biological, morphological intra-species variations and etc (Bickford et al., 2007). However, the genetic differentiation of species does not necessary complement the phenotypic and genotypic divergence (Knowlton, 1993), as evident in the lack of congruence between genetics and distinctive morphological characters (Carolan et al., 2012; Knowlton, 1993). Morphological variations are randomly shared among genetically distinct lineages within a cryptic species complex, in extreme cases (Hebert et al., 2004; Thomas et al., 2014). Which help to avoid drawback of morphological species restriction (Mallet, 1995). Cryptic species recognized through genetic clustering can then be strengthened by support from additional biological traits.

In *S. aurita* and *P. senegalensis*, molecular evidence from both mitochondrial and nuclear DNA markers showed that they strongly differed from each other genetically. A lack of corresponding monophyly in *S. aurita* and *P. senegalensis* showed that the two lineages are different and are not sister species. In addition, the 22.2 and 26.6% genetic distances between *S. aurita* and *P. senegalensis* calculated using p-distances and Kimura 2-parameter model showed comparable species-level difference. In some pairs, genetic distances for the four markers distinguish closely related species (e.g. *S. aurita* and *H. jaguana*). It is also interesting to note that *S. aurita* and *P. senegalensis* do not have shared haplotypes and polymorphic in the four mitochondrial and nuclear markers. Consistent patterns in the four genetic markers demonstrated a lack of gene flow between the two bony fish species. *S. aurita* is widely distributed in a wider depth ranging from inshore waters to the shelf edge, in eastern Atlantic region, Gulf of Mexico off Florida, Mediterranean Sea, West Africa and the Atlantic Ocean region, whereas *P. senegalensis* is widely found in the east Atlantic along Morocco to Namibia, and along Cape Verde Island. Such allopatric distribution has been reported to occur in other cryptic species (Brown et al., 2007; Ross et al., 2010). In addition, the two clades did not exhibit the same clustering for all markers Figure 4.28 – 4.31). Likewise, a lack of shared monophyly in *S. aurita* and *P. senegalensis* showed that the two lineages are different and are not ancestral species. *S. aurita* and *H. jaguana* were paraphyletic with each other, a phylogenetic pattern that commonly occurs among cryptic species, descendants of a common ancestor (Funk & Omland, 2003; Shaffer & Thomson, 2007). In some pairs, genetic distances for 16s rRNA, COI and RAG-1 exceed levels typically distinguishing closely-related species (Lavoué et al., 2003). It is also fascinating to note that *S. aurita* and *P. senegalensis* do not have shared haplotypes in the conserved COI, Cytb, RAG-1 and polymorphic mitochondrial control region (Figure 4.29 – 4.31). Consistent patterns in all four inherited genetic markers demonstrate a lack of gene flow between the two species *S. aurita* and *P. senegalensis*. Such patterns lied within the framework of the general species concept for two unique species (1). Hence, the genetic information from both mitochondrial and nuclear DNA presents solid evidence for the two biologically distinct species.

Discrete morphometric variations in head shape characterized *S. gibbosa* species (Thomas et al., 2014). Multivariate analysis of head measurements discovered clustering similar to the genetic clades of which comparable clustering due to head shape differences have characterized sub-species within a sardine (Silva, 2003; Thomas et al., 2014). A result confirmed by molecular evidence from mitochondrial data (Thomas et al., 2014). Morphological variances between closely related sardines are often categorized by slight difference in measurements or meristic counts, resulting in an obscure and often controversial taxonomic status (Thomas et al., 2014). For instance, the ancestral sardine species such as *sardinella tawilis, Sardinella gibbosa* and *sardinella hualiensis* share diagnostic characters; which exclude habitat preference and differed only in head length and lower gillraker count (Thomas et al., 2014). However, inter-species morphological variations in sardines are often presumed to be an artifact of localized adaptations to environment, due to a lock of support from significant genetic different between morphological form (Grant et al., 2010; Thomas et al., 2014). In addition, the morphological difference between *S. aurita* and *P. senegalensis* complements genetic divergence (Figure 4.28 – 4.31), and this is not a simple localized ecological adaptation. Morphological and Genetic combined data revealed a concealed diversity in a common and commercially distinct sardine. The findings of *S. aurita* and *P. senegalensis* expand the preceding investigations on the biology, ecology and morphology of *S. gibbosa* that suggested to a cryptic diversity (Okera, 1974; Thomas et al., 2014). A previous study discovered a new fish species in the northern Philippines (Thomas et al., 2014) which include sardine outside its earlier known distribution that suggests the region harbors undocumented and unique fauna (Willette et al., 2011). Such a pattern presents the possibility that *Sardinella gibbosa* clades 2 suggest a new species (Thomas et al., 2014). However, *H. jaguana* might be previously documented synonyms of *S. aurita*. Moreover, further scrutiny of type specimens is necessary for validation. In addition, the findings in this study demonstrate that a combination of both morphological and genetic data is essential to assess diversity in taxonomically ambiguous sardines and *P. senegalesis*. Hence, a strong evidence of two ecologically similar, but generally and morphologically distinct species warrents appreciate management strategies for separate sardine fisheries and closure of fishing ground for species recruitment purposes.

5.5 Socio-economic and demography

In the present study, it is noted that Montserrado has the largest number of fishermen and active registered fishing canoes (Gbanjor, 78 fishermen and 53 canoes, West Point, 849 fishermen and 433 canoes and 198 fishermen and 50 canoes in King Gray & ELWA) and Marshall has about (Marshall-Kru, 77 fishermen and 25 canoes and Marshall-Fanti, 20 fishermen and 38 canoes). These communities were selected based on their dependence of fishing fish for their survival.

From the study it was observed that majority of the fishermen 60%, 48% and 48% were middle aged (31 – 45 yrs) in West Point, Marshall and King Gray & ELWA. Whereas other 44%, 36% and 28% were young aged (15 – 30 yrs) in King Gray & ELWA, Marshall and West Point and 16%, 12% and 8% were old aged (46 yrs and above) in Marshall, West Point and King Gray & ELWA. Similar to (Ahmed et al., 2005; Ali, Hossain, Hasan, & Bashar, 2008) reported that in coastal region 66% and 70% fishermen were less than 40 years old and (Reza et al., 2015) around Atrai and Kankra Rivers in Dinajpur District also reported that 48% fishermen was less than 40 years old, respectively. Only Gbanjor result showed that majority (52%) of fishermen was young aged (15 – 30 yrs), other 40% was middle aged (31 – 43 yrs) and 8% old aged (46 yrs and above) group. Fishing is ancient but a profitable profession which attracts younger and middle aged people of fishing community to adopt the profession.

During the study it was found that only males were involved in fishing activity and females are housewives and caretakers. Mazumder et al. (2014) reported that 94% of male and 6% female were fishers in Jelepara, Chittagong district. This result is different from the present study unlike King

Gray & ELWA 96% male fishers and 4% female fishers. Reza et al. (2015) also reported 100% of male fishers around Atrai and Kankra Rivers in Dinajpur district.

Religion play a keen role in human capital, social and cultural life of people and can act as a notable constraint or social change of a particular area. In the study it was found that the majority of the fishermen were Christian (96%) in Gbanjor, West Point and King Gray & ELWA. Marshall had a full 100% of Christian fishermen. This result greatly differed from previous studies (Kamruzzaman & Hakim, 2016) reported 65.7% fishermen were Muslim in Dhaleshwari River central Bangladesh and (Reza et al., 2015) 84% of fishermen were Muslim around Atrai, Kankra Rivers at Dinajpur District in Bangladesh, respectively. Banerjee et al. (2014) reported that majority 96% of fishermen were Hindu at Kaligonj in Shenidah district, Bangladesh and 16% Reza et al. (2015) in Chirirbandar Upazila under Dinajpur District.. Present study greatly differed from previous studied and more or less similar results have been observed from place to place.

According to Reza et al. (2015) 56% families were medium, 40% small and 4% large in Dinajpur District which is quite different from present study. Other studies (Banerjee et al. 2014) at Kaligonj in Shenidah district, Bangladesh reported an average family size 50% and (Ali et al., 2008) reported a large family size of 94% fishermen. It was also interesting to note among the fishing communities both Gbanjor and Marshall had 4% of fishermen who live alone and 12% in both West Point and King Gray & ELWA respectively.

The results showed about 68%, 60%, 64% and 44% families were small in the four fishing communities at Gbanjor, West Point, King Gray & ELWA and Marshall respectively. 24% families were medium for both Gbanjor and King Gray & ELWA, 20% families were in West Point and about 20%, 8% and 4% families were large (8 person and above) in Marshall, West Point and Gbanjor. In the survey, it was found in two fishing communities (Marshall and West Point) that majority 84% and 56% fishermen were married and few were unmarried 16% and 44% respectively. Previous studies on socio-economic condition of fishermen (Ali et al., 2008) in Jelepara under Pahartoli of Chittagong district in Bangladesh and (Reza et al., 2015) in Dinajpur District reported that 84% and 88% fishermen were married and the rest 32% and 12% were unmarried similar to present study. It was also found that majority 56% of fishermen in both

Gbanjor and King Gray & ELWA were unmarried while few were married, this differed with previous studies.

The present study showed that Gbanjor and King Gray & ELWA majority 56% fishermen had joint and 44% nuclear families which is similar to passed studied (Reza et al., 2015) reported that 36% fishermen had joint and 64% had nuclear families in Dinajpur District. 60% fishermen had nuclear and 40% joint families within West Point and finally, Marshall's fishermen had 84% nuclear and 16% joint families. However, (Ali et al., 2008) reported that majority 64% of fishermen were interested to live alone, only 36% like to live in a joint family. This is slightly similar to the findings of the present study.

It is interesting to note that there is a strong relationship between education and social status. The higher the population is educated the better is the livelihood opportunities. It was observed from the study areas that 64%, 56%, 48% and 16% fishermen had no education in Marshall, Gbanjor, West Point and King Gray & ELWA. 20%, 16%, 12% and 8% had only primary education (up to class 5) in Gbanjor, Marshall, West Point and King Gray & ELWA. (Reza et al., 2015) reported slightly the same at 44% fishermen had no education, 36% fishermen could only sign their names and 20% had primary education level (up to class 5) similar to present study. It was also found that 48%, 20%, 12% and 4% fishermen had junior high education (class 6 – 9) in King Gray & ELWA, West Point, Gbanjor and Marshall respectively. King Gray & EWLA, Marshall and West Point fishermen had 24%, 12% and 8% senior high education (class 10 – 12). And finally, fishermen in Gbanjor and West Point had 12% and at both Marshall and King Gray & ELWA have 4% diploma certificate. Previous studies (Ali et al., 2008) in Jelepara under Pahartoli of Chittagong district, Bangladesh found that among the fishermen 52.5% were illiterate, 22.5% educated up to secondary level and 2.5% educated up to SSC (Staff Selection Commission – Combined Higher Secondary) level. These results are closely related with the present study.

5.5.1 Economic status of Montserrado and Marshall Fisheries

Eighty percent (80%) of fisher folk in these areas depend on fishing for their income, although the women often do some other business, which provide income. The driving force in changes on prices is perhaps due to the nature of the markets, forces of supply and demand at a given time with surplus and scarcity of fish. However, climate is a major factor in determining fish stocks dynamism and therefore plays an important role. The highest price for shark are > LRD 5,000 to 8,000 wholesale from fishermen to middlemen who then sell at 20% profits. Among the fish groups, cassava fish and bony fish at > LRD 500 – 700 and 40 – 80 respectively. Prices did not differ significantly for fish in Montserrado and Marshall ($P>0.05$). Generally, prices were the same in both fisheries areas. This could be due to more effort employed during this period and availability of most fish species during this period in the two fisheries.

Both Montserrado and Marshall Fisheries are important to the local economy and the sustainability of the fisher folk. The artisanal fishery is the most important source of dietary protein. There is a potential conflict of interest between the artisanal fisher folk and the trawler vessel (industrial vessel), and the local fishers who see as a disadvantage of their fishing gear being destroyed by the industrial vessel. Simultaneously, alternative economic activities are a necessity, because high pressure is put on the fish stock by fishers for their survival since the fishing communities fully depend on fish for their survival.

5.5.2 Fishery

Most of the artisanal fishing effort is restricted to six nautical miles nearshore of the Liberia waters (BNF, 2014) and fish within nearshore are most likely source of vigil fish that may migrate into the inshore waters. Some landing sites have shown strong seasonality in pelagic and demersal fish catch (BNF, 2014) but sardines and cassava fish catches are more stable in these areas. Within the two fishing areas majority 92%, 76%, 60% and 56% of the fishers used gill net in King Gray & ELWA, Gbanjor, West Point and Marshall respectively. Drift net was used on a lower scale at

40%, 36%, 20% and 4% in West Point, Marshall, Gbanjor and King Gray & ELWA which is mostly used by 25 and 40 HP outboard engine canoe. The least of all gears used was hooks and longlines by fishermen, 4% both Gbanjor and King Gray & ELWA and 8% in Marshall. Mostly used by paddle canoe fishers. Most of these gill nets (called monofilament nets) are band from the fisheries due to their destruction to the fisheries resource (BNF, 2014).

Majority of fishermen used paddle canoe with 1 -2 crew within the two fishery but fewer used motorized canoe with 3 – 5 crew and 6 crew and above. Majority of Fanti fishers are owner of motorized canoe and the paddle cones are owned by Liberian fishers. Kru fishers are the dominant user of dug-out canoe. The Fanti fishers contribute to about 40% of artisanal fish landed (BNF, 2014). Fishermen fishing duration are normally 4 – 9 hours due to their catchability. In Liberia fisheries, fishing grounds/locations are normally nearshore and deep sea. The study showed that majority of fishers fished within nearshore waters of Liberia, while few of the fisher fished deep sea depending on fish pattern or target species.

The fisheries of Liberia allowed fishers to fished multi-species using variety of fishing gears. The study focused on sardines and cassava fish meanly *S. aurita* and *P. senegalensis*. The result showed that majority of the fishers fished for sardines, cassava fish and mixed fish along the coastal waters of Liberia. Interestingly, fishermen in both Marshall and Montserrado did not catch the same quantities of fish during daily fishing trip. This was due to the visibility and pattern of fish species. In the study the average amount of catch described was classified into two groups such as small catch (½ - 2 bags) and large catch (3 bags and above). The majority 68% both Gbanjor and King Gray & ELWA and 52% both West Point and Marshall fishers average amount of catch described were small (½ - 2 bags). Other 48% in both Marshall and West Point and 32% in both Gbanjor and King Gray and ELWA fishermen average amount of catch described were large (3 bags and above). The average catch by paddle canoe is (½ - 2 bags) and motorized canoe average catch is 3 bags and above).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

6.1.1 Growth Parameters of *Sardinella aurita* and *Pseudotolithus senegalensis*

Between January and March, the number of *S. aurita* was high at all sampling sites both Montserrado and Marshall whereas the highest catches recorded for *P. senegalensis* was in January and February. The lowest catches were observed in April and may for both species in the two fisheries. Gill nets contributed about 80% of the artisanal catches. Hooks and long lines were used by few fishers. The outboard engine canoes had more catches than the paddle canoes. Decreased in catches for *S. aurita* and *P. senegalensis* could be attributed to high tide. The overall length frequency distribution for *S. aurita* and *P. senegalensis* indicated that both species were exploited at a medium size at Gbanjor, West Point, King Gray & ELWA and Marshall respectively. The slope *b* of the length-weight relationship conformed to negative isometric growth for both species in Montserrado and Marshall.

6.1.2 Mortality and exploitation

These results from the four landing sites indicated overfishing of *S. aurita* and *P. senegalensiss* stocks in the Liberia waters along Montserrado and Marshall. The exploitation (E) rate estimated in Montserrado and Marshall fishing communities suggest overfishing during the study period. The current fishing mortality was higher than both the target reference point ($F_{0.1}$) and the limit reference point (F_{max}), indicated excessive fishing pressure on both stocks in the Liberia waters. The linearized length-converted catch curve shows the instantaneous fishing mortality rate were beyond the estimated natural mortality rate at Gbanjor, West Point, King Gray and Marshall for both *S. aurita* and *P. senegalensis* reflect an overexploitation of the fish stock in Montserrado and

Marshall. King gray & ELWA fishing mortality was less than the estimated natural mortality rate suggesting below exploitation for only *P. senegalensis*.

The high value of exploitation (0.75 to 0.81) ratio for *S aurita* and *P. senegalensis* at Gbanjor, West Point, King Gray & ELWA and Marshal indicated that these species were harvested at a higher level than the optimum fishing mortality. The exploitation ratio corresponding (E0.5) to 50% of the unexploited relative biomass per recruit for *S aurita* and *P. senegalensis* at Gbanjor, both West Point and Marshall and King Gray & ELWA revealed that the fishery is underexploited in terms of yield per recruit.

6.1.3 Phylogenetic of *Sardinella aurita* and *Pseudotolithus senegalensis*

Inter-species variability was revealed between *Sardinella aurita* and *Pseudotolithus senegalensis* through phylogenetic analysis of the nuclear and mitochondrial DNA markers and their final concatenated alignments included four markers. Comparison was done within 12 taxa including 10 bony fish and two outgroup species.

The combined markers 16s, COI, Cytb and Rag-1 dataset did not support the hypothesis regarding *S. aurita* and *P. senegalensis* close phylogenetic relationship. Instead the analysis generated a well-supported monophyly of *S. aurita* and *H. jaguana* in trees using 16s rRNA, COI and Rag-1 genes. Despite the lack of a clear morphological apomorphy between *S. aurita* and *H. jaguana*, instinctive pre-cladistics approaches initially recognized that *S. aurita* and *H. jaguana* are of natural group. None of the phylogenetic tree supported *S. aurita* and *P. senegalensis* as sister species.

6.1.4 Montserrado and Marshall Fisheries

Fishermen of the two subsectors are largely dependent of the fishing along the Liberia waters, especially Montserrado and Marshall. The age distribution of fishermen was classified into three groups young (15 – 30 yrs), Middle-aged (31 – 45 yrs) and old-aged (46 yrs and above). Majority 60% was middle aged. Fishermen in Gbanjor, West Point and Marshall were all male. King Gray & ELWA had 96% male and 4% female fishers. Majority 96% fishermen were Christian in Gbanjor, West Point and king Gray & ELWA and only 4% were Muslim. Marshall had (100%)

Christian fishermen. Majority 44 – 84% fishermen were married in all four landing sites and few were unmarried. About 44 – 68% fishermen families were small (1 – 4 person) in all the landing sites. Majority 60 – 80% fishermen families were Nuclear in West Point and Marshall while 56% were Joint in Gbanjor and King Gray & ELAW. Majority 48 – 64% of fishermen had no form of education, 8 – 20% had primary level education (up to class 5), 20 – 40% had Junior High education (class 6 – 9), 8 – 24% had senior high education (class 10 – 12 and Finally 4 – 12% had diploma certificate at all landing sites. Results showed that 88 – 92% fishermen had all school going children but 8 – 12% had dropout school going children.

Three types of fishing gears used by fishers: gillnets, driftnets, hooks and longlines. 92% fishermen use gillnets in the fishery followed by drift nets. Vessel types ranged from paddle canoe to outboard engines (9.9, 15, 18, 25 and 40 HP). 32 to 44% fishers use outboard engine and 48 – 44% used paddle canoes. Number of crew per vessel was divided into three small (1 – 2 person), medium (3 – 5 person) and large (6 person and above) on the basis of vessel type. Majority of the crew were small followed by medium. Fishing duration was about 9 hours and is nearshore or deep sea depending on the pattern of fish. Data from the Bureau of National Fisheries (BNF) indicated that 25% of fishermen registered new canoes every year into the fisheries. The dugout canoes were the most commonly used by fishers in Montserrado but less used in Marshall. Approximately 60% fishers used outboard engine boats. The most widely used are the 15 and 40 HP by mostly Fanti fishers. Fish landings were variable from month to month, there appears to be no significant patternin most fish catches in south coast, Liberia.

6.1.5 Socio-economic status of fishermen at Montserrado and Marshall

Most fishers in Liberia used either a small wooden dugout canoes costing LRD 32,000 – 40,000 (USD 400 – 500) used for 5 to 6 years without engine. Other used a bigger and larger dugout canoe, mainly the fanti fishermen costing about LRD 104,000 – 640,000 used for 10 – 12 years with engines ranging from 9.9 to 40 HP. Gillnets and driftnets are the most expensive fishing gears and hence constitute a major investment in the fisheries. On average, they cost gillnet 1 ½ inch LRD 4,800 – 21,450; 2 inches 5,600 – 22,000; 3 – 4 inches 7,200 – 24,000 and driftnets 6 inches 28,000 – 42,000 respectively. The gear can be used up to 3 – 4 years especially when well maintained and regularly repaired. The maintenance costs on average ranges from LRD 1,500 –

3,500 and 4,500 – 6,600 per month depending on severity of the damage to the net and repaired takes about 2 days of labour on average.

Average monthly catch and catch composition per-fisher in the first half of 2017 to arrive at the gross income per day for a fisher at Montserrado and Marshall. LRD 3,500 – 6,000 paddle canoe, 12,450 – 18,450 9.9 to 18 HP and 24,200 – 43,200 25 and 40 HP. Multiplying this figure with the average number of trips per month (24) and deducting the average costs of fishing per month to derived at the net monthly income. The prices of Sardines and *pseudotolithus* increased between April and May when catches decreased. It was revealed that the socio-economic and livelihood status of the fishermen during the study was considered good. Fishermen earn good income from fishing that enable them to invest.

6.2 RECOMMENDATIONS

Results of this study suggest that top two of the commercial fish in Montserrado and Marshall Fisheries are overexploited. To improve this situation the following management measures should be considered: (1) Introduction of a closed season into the fisheries to allow for recruitment and recuperation of fish stocks, (2) Regulatory management of gears and illegal fishing methods such as smaller mesh sizes, (3) monitor the fisheries by enforcing the fisheries policy, (4) Cryptic species identification for fisheries conservation and sustainable management and (5) provision of loan to small scale fishers.

Increase in catches, with respect to more fishing effort deploy, together with the illustrated economic success of the fishery, make it clear that these coastal communities need other forms of economic support to sustain their livelihoods which put more pressure on fish stock and in most cases lead to overfishing. Subsistence fishing is currently the major alternative which is not enough to support the livelihoods of these people. Further, the agricultural sector needs to be diverse towards large-scale to include the Inland fisheries and aquaculture to develop appropriate industries for the same since water is the major resource available in these areas. If Liberia's fish habitats become further degraded in the years following poor resource use, overexploitation, poverty and consequently, the need for alternative support will become increasingly important. There is a strong need for institutional targeting directed towards promotion and capacity strengthening of artisanal fishermen, community-based organizations as a medium of formation for development purposes and sustainability of the fisheries.

Some fishing practices in these areas may promote indirect conservation of fish stocks and should be considered in fishing management plans. The rotation on the fish species harvested further reinforced within Marshall and Montserrado influenced fishing seasons to reduce over-exploitation of certain target species. There exists a Fisheries and Aquaculture Policy frame work that is being or can be applied in managing the fisheries. The Bureau of National Fisheris (BNF) through the fisheries policy BNF (2014) could impose the following policy measures in the course of fisheries management.

i) Declaration of closed seasons in designated areas for recruitment purposes, species of fish or methods of fishing, e.g. West Point from May to September.

ii) Declaration on the limits of fishing gear, including mesh sizes of nets that may be used for fishing ranging between 40 and 50 mm.

iii) Limitations on the amount, size, age, species or composition of species of the fish that may be caught, landed or traded.

iv) Regulate the landings of fish and provide statistics for the management of fish landing areas.

However, these measures are more effective in the management of fisheries in these areas, whereas, there exist generally a lack of compliance by fisher folk despite them being aware of the existing laws that govern these fisheries. About 85% of fishermen have a general understanding of these policy measures. The major constraints have been the inadequate capacity and personnel to monitor the fisheries by the Bureau of National Fisheries. Take for instance the recent efforts of the structural adjustments programs implemented by the West African Regional Fisheries Program (WARFP) that led to the effective monitoring and surveillance in these regions and the transitional period of awarding the second phase of the contracts by Word Bank, the patrol boat and airplane were not effective due to lack of support. Without the means for effective monitoring and surveillance in place fish stocks will continue to be over-exploited. The government should also review its budgeting allocations to Fisheries department, as the current allocations are inadequate considering the amount of revenue the sector generates.

Subsistence fishing catches must be assessed, given their demonstrated importance, given that this study just give a glimpse of the fish population at a given moment in time. The plan to monitor stocks over time needs to be made, especially in areas most sensitive to fishing pressure, in order to study longer-term trends. The analysis of fishing pressure and current stocks would allow monitoring of exploitation levels of populations and their possible impacts on the resource. This should help prepare for the possible implementation of management measures and compliance purposes aimed at preservation and sustainability of the resource. It would be advisable to re-direct part of the fishing effort toward groups of species and biotopes (e.g. Rivers) that are less exploited.

This would allow Inland fisheries to expand into new potential markets. Finally, the methods and techniques for fishing should be investigated to see if they are technically and economically viable.

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APPENDIX

Appendix 1: Artisanal fisheries catch and socio-economic status questionnaire

1. General information

1.1 Name of respondent: __________________________ Fishery (Mont./Marsh.):__________________________
1.2 Gender:______________________________________ Age: ____
1.3 Marital status:_________________________________ Family members: ______________________________
1.4 Religion______________________________________ Education status: ______________________________
1.5 Where are you originally from____________________ How long have you live in Liberia________________

2. Fishing program
2.1 Type(s) of gear used? ____
2.2 Type of fishing vessel? ____
2.3 Number of crew per vessel? ____
2.4 Duration of fishing activity? ____
2.5 Fishing grounds/locations of fishing? ____
2.6 Number of fishing vessels and fishermen per fishing ground? _____________________________________
2.7 Target species? ____
2.8 Total weight of catch (kg)? ____
2.9 Weather and hydrodynamic condition? ____
2.10 Others relevant background information about the catch/fishery: e.g. how many fishermen/vessels catch these species in the fishing location at the same time of fishing?
____
2.11 Do you catch the same numbers every day? ____
2.12 If yes, then what is the quantity? ____
2.13 If no, then describe the average amount every day that you catch? ___________________________

3. Fishermen's sales/income (Liberian dollars)
3.1 Fishermen's sale price: ____
3.2 Dears/middlemen sale price: ____

4. Fish species caught
4.1 Specific*
Sardinella aurita: ____
Pseudotolithus senegalensis: ____
*Growth parameters(L statistics) will be recorded on a separate sheet

5. Socio-economics status
5.1 Fishing gear price: ____
5.2 Fishing gear replacement rate: ____
5.3 Fishing gear repair costs: ____
5.4 Others: ____

Name of contact person for catch (in case it differs from the respondent): ____________________
Landing beach: ____

1. Montserrado
2. Marshall