grocentre.is/ftp

Final Project 2019

ESTIMATION OF THE TOTAL CATCH AND EFFORT OF THE INDUSTRIAL FISHERY IN SIERRA LEONE, 2008-2019

Sahr Patrick Sandi
Ministry of Fisheries and Marine Resources
Republic of Sierra Leone
sahrpsandi@gmial.com

Supervisor(s):

Einar Hjorleifsson
einar.hjorleifsson@hafogvatn.is
Julian Mariano Burgos
julian.burgos@hafogvatn.is
Marine Research Institute of Iceland

ABSTRACT

One of the challenges in the management of the industrial fishery in Sierra Leone is the lack of a complete historical record. This study integrated data from different sources in order to reconstruct monthly catch and effort statistics from 2008 to 2019. This was achieved by comparing the total catch by the industrial fishery by species category with vessel licencing statistics. The monthly catch and effort statistic were calculated including missing data from vessels in the license statistics. The estimated missing catches added approximately 20 percent to the total catches reported in the logbooks. Expert knowledge and published literatures were key in the result analysis. Reporting system and data management has improved in the most recent year (2019), there is though a good agreement with between the reported vessels in the license and logbook database. The overall decline in effort since 2016 in the number of vessels to about 50 percent. The result from the monthly estimated catch statistic present a large discrepancy from Sea Around Us project reconstructed catches for Sierra Leone.

This paper should be cited as:
Sandi, S. 2020. *Estimation of the total catch and effort of the industrial fishery in Sierra Leone, 2008-2019.* UNESCO GRÓ-Fisheries Training Programme, Iceland. Final project.
http://www.grocentre.is/ftp/static/fellows/document/Sahr19prf.pdf.

ACRONYMS AND ABBREVIATIONS

GDP	Gross Domestic Product
MFMR	Ministry of Fisheries and Marine Resources
EEZ	Exclusive Economic Zone
IEZ	Inshore Exclusion Zone
FAO	United Nation Food and Agricultural Organisation
MCS	Monitoring Control and Surveillance Unit
SRP	Statistics Research and Policy Unit
VMS	Vessel Monitoring System
IFDAS	Industrial Fisheries Database System
JMC	Joint Maritime Committee
MPA	Marine Protected Areas
CPUE	Catch Per Unit Effort
IUU	Illegal, Unreported and Unregulated Fishing
GRT	Gross Registered Tonnage
GoSL	Government of Sierra Leone
GCLME	Guinea Current Large Marine Ecosystem
ICCAT	International Conservation for the Commission of Atlantic Tuna
LOA	Length Overall
EU	European Commission
Yr.	Year
MT	Metric ton (1,000kg)
IMBO	Institute of Marine Biology and Oceanography
VHF	Very High Frequency
GEF	Global Environmental Fund
SAU	Sea Around Us

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

The marine fisheries sector is the most important activity along the coastline of Sierra Leone and contributes significantly to Sierra Leone's socio-economic development. Sierra Leone is a coastal nation in West Africa with a population of over 7 million people. Its Exclusive Economic Zone (EEZ) covers 205,611 km^2 and encompasses particularly rich and productive fishing grounds (Kadijatu, 2009). The fishing sector of Sierra Leone currently produces about 150,000 tonnes of fish per year with an estimated first-sale value of USD 125 million (MFMR, 2018). The sector generating Le70.9 billion ($9.6 million) in 2017 and Le94.59 billion ($11.8 million) in 2018 (MFMR, 2018), accounting for about 10% of Sierra Leone's Gross Domestic Product (GDP). The activities of fishing and processing are an important source of employment in coastal areas. Approximately 100,000 fishermen are directly engaged in artisanal fishing, and an average of 300,000 people work in the fishing industry (MFMR, 2019). Fish is the largest single source of dietary animal protein consumption in Sierra Leone, representing 80% of protein intake.

Figure 1 below outlines Sierra Leone's EEZ, where he dotted line indicates the IEZ (Inshore Exclusion Zone), where industrial fishing vessels are not allowed to operate. Depth contours indicate depth of 25, 100, 500, 1000 and 2500 m.

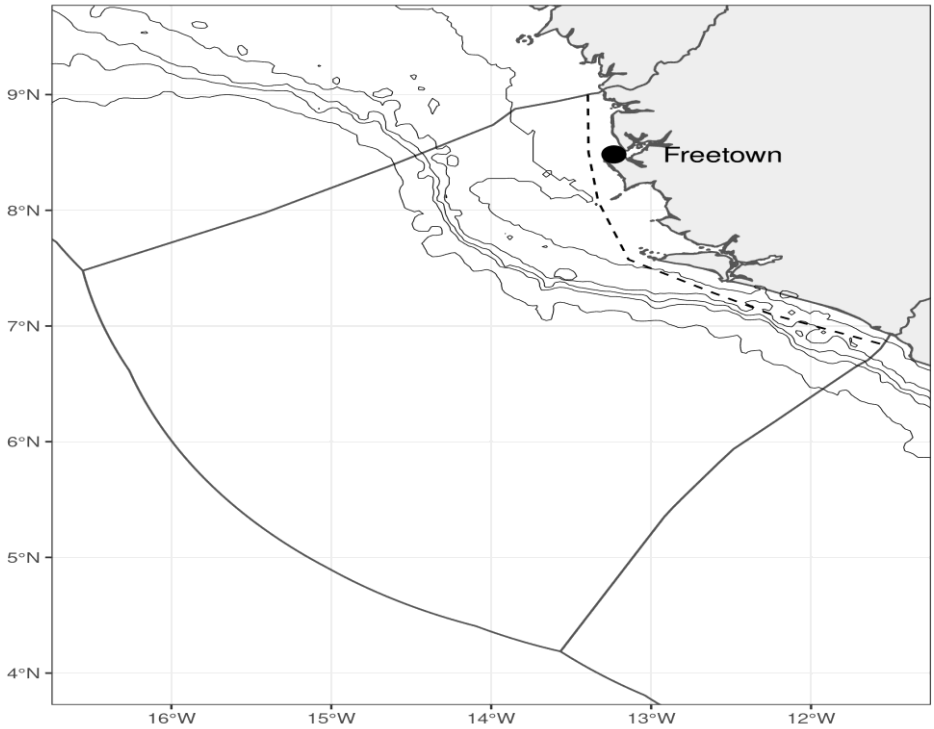

Figure 1. Map of the Sierra Leone's Exclusive Economic Zone (EEZ)

Fisheries resources, although renewable, are not infinite and need to be properly managed to be sustainable (Shui-Kai Changa, 2010). Accurate fisheries statistics are necessary to set good fisheries policies, including monitoring the input (effort) and output (catches). Modern legal frameworks for international and regional fisheries management require states to compile extensive, accurate and verifiable data on fisheries activities and their effects (SA Murawski, 2005) .The compilation of data on fishing fleets, gears, total production, landings and catches also provides information on the social, environmental, economic and biological performance of the fisheries (FAO, 2018). Given the lack of fisheries-independent data in developing countries like Sierra Leone, the management of marine resources is based on catch and effort statistics, which are only way to approximate trends in fish stocks (Seto et al. 2017).

In Sierra Leone, the management of industrial fisheries is based on the licensing of fishing vessels and the reporting of fisheries statistics, namely catch and effort, in logbooks. Vessel licences serve to control access to the fishery resources, generate statistical information for the monitoring of fishing activities and to generate revenues to the state issuing the licences. (FAO, 2018). However, there is significant variation in data collection and reporting over time, and there are also of concern in self-reported statistic from Sierra Leone (Seto et al., 2017). Inconsistencies in data collection and reporting will result in biased estimations of the annual effort and production. Nevertheless, scientists and managers within the Sierra Leone industrial fishery have shown little interest on ensuring the quality of the fisheries data collected, for example by cross-referencing with the licence registry to detect potential data gaps in logbook records.

Catch data compiled by the Food and Agriculture Organization of the United Nations (FAO) have been shown to significantly underestimate the catch in some countries including Sierra Leone (Wielgus, 2010). Data on discarded catches are not included in the FAO database as it covers only retained catches. Given that these data are often used in formulating management policy, these underestimations may lead to inaccurate and detrimental policies and management measures (Jacquet, 2010).

1.2 Overview of the Industrial fisheries sector in Sierra Leone.

The industrial fishery of Sierra Leone is conducted within 6 to 200 Nautical miles (Nm) in the continental shelf and the exclusive economic zone (EEZ). The industrial sector is strongly export-oriented, especially now when the growing demand of fish products in developed or developing countries cannot be met by fish stock in their own waters, as in the case for China, and South Korea. These markets have increased the supply with fish imported from developing countries or caught in the water of developing countries, including Sierra Leone. Historically, Sierra Leone industrial fisheries sector started in 1955, when the Italians introduced trawlers in local waters and the fishing effort gradually increased (MFMR, 2003). The main targets were species of the pelagic genus Sardinella.

Today, the industrial fisheries sector is comprised by a multinational fleet that includes shrimp trawlers, purse seiners, canoe support vessels, demersal, pelagic trawlers and carriers (Croker, 2018). Target species also include the highly migratory tuna stocks and the deep water rose shrimps which are mainly offshore, attracting high sea fishing vessels. In 2019 there were 129

industrial fishing licensed vessels (Seisay, 2019). Since the introduction of trawlers in Sierra Leone, the industrial sub-sector has been involved in joint venture agreement with owners of foreign-registered and foreign-based vessels (Andy Thrope, 2009). The flag state of industrial fishing vessels operating in Sierra Leone includes China, South Korea, Guinea, Spain, Panama, Italy, France, Cape Verde, Senegal, Russia, Comoros, San Marino and Belize (MFMR,2019).

Fishing rights are granted under licenses are based on vessel types, and fishing gear characteristics, including gross registered tonnages and vessel ownerships. For regulation and management purposes, vessels are classified into the following categories, demersal fish trawlers, shrimp and cephalopods trawlers, pelagic and mid water trawlers, carrier vessels, purse seiners and tuna long liners (Sheku Sei, 2009).

Table 1 below shows the number of vessels licensed from 2014 -2018 and the quantity of fish caught. The number of this licensed vessel peaked in 2016, after which it decreased due to precautionary measures and advice from the European Commission.

Table 1. Number of licences vessels 2014-2018 and reported catch

YEAR	NO. VESSEL	AVERAGE REPORTED CATCH PER VESSEL (tonnes)
2014	134	94,633
2015	149	180,632
2016	153	161,065
2017	134	160,699
2018	137	137,424

The Ministry of Fisheries and Marine Resources plans to conduct fish stock assessment surveys to estimate the abundance and distribution of the fish stocks and to set up a quota management system where licensing of industrial fishing vessels will be based on the quantity of fish caught by vessels instead of the size of the vessels. This is required for future management planning. It is expected that revenues will increase through the introduction of a quota management system based on the establishment of a Total Allowable Catch (MFMR, 2018).

1.3 Current framework for data collection

In Sierra Leone, the management, development and conservation of the fisheries resources of Sierra Leone is the responsibility of the Ministry of Fisheries and Marine Resources (MFMR).

1.3.1 Vessel License registry

The vessel licence register should serve as the backbone of fisheries statistics. The vessel register is not only important for the registration and processing of catch, effort and fishing activity data, but also for the purposes of taxation, payment of subsidies, issuing of licences, payment of licence fees, surveillance, enforcement of fisheries regulations, and inspection (FAO, 2018). Therefore, the creation and maintenance of a vessel register must have priority within the system to compile fishery data. In Sierra Leone a separate vessel registration system is not maintained. Instead, it is an intrinsic part of the vessel licensing system. The system

contains statistics on vessel name, company, flag state, category, call sign, gross tonnage and length.

1.3.2 Vessel licensing

All industrial vessels operating in Sierra Leone waters require a licence. Licenses are issued in accordance with section 14(1)a of the Fisheries and Aquaculture act of 2017, which states: "No person shall engage in any of the following activities without a valid license or authorization issued by the director of fisheries under this act, using a fishing vessel (national or foreign) for fishing or related activities including diving for commercial fishing purposes, commercial sport fish and recreational fish."

The licence fee is based on the reported gross registered tonnage (GRT) of the vessel (MFMR, 2018). The licensing process involves a pre-licensing inspection before industrial licenses are granted to deck semi-industrial and industrial fishing vessel after due diligence, and agreement by an inspection team under the Joint Maritime Committee (JMC) and jointly approved by the Director, Permanent Secretary and Minister.

The license document contains information including the license category, an official license number, the gross registered tonnage (GRT), length overall (LOA), landing obligations and the name of the fishing company that owns the fishing vessel. The first schedule of the fisheries and aquaculture regulation part 16(1b) set out the conditions under which the fishing vessel application form and list out the licensed period, the previous license of the fishing vessel, authorization or license granted by the flag state, year of construction of the vessel, the crew details, storage, processing capacities and detail of fishing gears. The application must accompany by a true copy of the vessel registration certificate, an international tonnage certificate, an engine manufacture certificate and a recent side on photo of the vessel to be licensed with the current name and international call sign.

An inquiry is always made on the Illegal, Unreported and Unregulated (IUU) status of a vessel during the application for a fishing license. It is imperative to do a background check about the history of compliance to ensure that the concerned fishing vessel and its potential owner have never been involved in IUU activities. When the ownership of vessel has changed, the new owner must provide enough evidence to demonstrate that the previous owner or operator has no further legal benefit or financial interest in or control of the vessel.

Up to date licence records are currently stored and managed using Excel spreadsheets. The updated vessel and licensed list are published regularly by the head of statistics research and policy units on the Ministry's website (www.mfmr.gov.sl). The data is available since 2015. The spreadsheets cover distinct periods and the report format is not uniform across different periods, and in addition the spreadsheets contain summary statistics. This makes it challenging to track and summarise changes in licensing over time as well to cross-reference vessel registrations with other fisheries data sources.

1.3.3 On-board observers (logbooks)

Industrial vessels in Sierra Leone are required to carry fishery observers, as a condition for receiving and maintaining their licences. Section 17(1) of the fisheries and Aquaculture Act of 2017 states that "the operator of a license or authorized vessel under this act, shall maintain logbooks and make such report relating to fishing or related activities at such times, containing such information and in such format as may be prescribed or as the Director of Fisheries may require." As a result, there is almost 100% observer coverage on all industrial fishing vessel licensed in Sierra Leone, except for vessels in the tuna fishery. Observers record information in logbooks, including daily records of vessel position (longitude and latitude), hours fished, number of tows, depth, total catch and species composition.

In addition, since 2018 scientific observers have been trained by the Institute of Marine Biology and Oceanography (IMBO), with the objective of obtaining more accurate statistics from each haul, including location, species identification, and biological measurements such as length, sex and maturity. About 60 scientific observers have been trained, but only 16 are deployed at any given time. The majority of the observes are not sufficiently experienced to work on-board tuna vessels (MFMR, 2019).

Fisheries observers must be aware of the vessel's fishing activities consistently and be ready to report any infraction. While they have no authority to lay charges or arrest violators, their reports can justify an arrest. It is then imperative that the observers are trained to detect violations. Observers must have comprehensive training in fisheries regulations, and must also be able to fully document any noted infractions, have a thorough understanding of fishing technology and operations, be conversant in the basics of navigation, and be able to present himself as a credible witness in a court of law (FAO, 2018). Observers are required to send daily catch reports for every vessel using a VHF radio. Catch reports are recorded in a ledger by an officer in the Joint Maritime Committee (JMC) and the Ministry's radio operational room, but sometimes due to faulty radio or bad weather this might not be possible leading to misreporting of data in case the logbook is misplaced.

The logbook data are compiled in the Sierra Leone Industrial Fishery Database (IFDAS). Until 2018, there was a large backlog of data that had not been entered into the database. Since then, a project by the Global Environmental Fund (GEF) funded the recruitment of data encoders and to this date the data entry is completed up to April 2019. Logbook data has been the key statistics to estimate the annual effort and production level in the industrial fishing sector in Sierra Leone, in the absence of fish stock assessment surveys. Logbooks are to be submitted as soon as the catch is landed in port to verify the information and send the logbook to the statistic research and policy unit of the Ministry of Fisheries and Marine Resources. However, there is delay sometimes in submitting logbooks from the observer and this may lead to misreporting.

1.4 Rationale

The reliance on incomplete national fishery statistics puts the fisheries authorities under serious risk of over-licensing, increased fishing access, underestimating the contributions of the industrial fisheries and mismanaging the marine ecosystems thereby affecting national food security. For Sierra Leone fisheries to maintain a sustainable exploitation of the marine

resources, there is the necessity to evaluate, develop and implement a system to collect reliable fisheries statistics from logbook and vessel licence data. Therefore, this study will seeks to integrate the data from vessel license and logbook data in order to create the most accurate representation of the activity of Sierra Leone's industrial fishery over the past decade, assessing the accuracy of these data sources, and providing recommendations for an efficient data management system that ensures a level of integrity in the data.

1.5 Research objective

This project aims to estimate the total catch of the industrial fishery within the Sierra Leone Exclusive Economic Zone (EEZ) from 2008 to 2019, using data from logbooks and the licence registry. The goal of this reconstruction is to provide better estimates of catch and effort statistics from the industrial sector, in other to inform policy and management decisions.

Specifically, this work aims to:

- Estimate the monthly catch and effort of the industrial logbooks data using a correction factor to calculate for missing logbook records.
- Estimate the catch per unit effort (CPUE) of pelagic, shrimp and demersal fisheries over time.
- Use logbook data to analyse the composition of the catch by species groups.
- Compare estimates of the total catch by year with the statistics from the Sea Around Us (SAU) project.
- Use recent scientific logbook data to describe the fleet patterns, including tow duration, number of hauls, catch per tow, and spatial distribution of fishing effort, catch and catch per unit effort.

2 METHODS

2.1 Data sources

The data sources for this research were logbook (2008-2019), and the fishing vessel license records (2008-2020).

2.1.1 Logbook data

The logbook data was extracted from the Sierra Leone Industrial Fishery Database (IFDAS) in collaboration with Mr. Alpha Turay, the database developer. The dataset included two types of data: a) aggregated data (2008 - mid 2018) containing daily summary statistics for each vessel and fishing day, and b) itemized data (2018 onward) containing records of individual tows.

Both datasets contain the following information:

- Vessel parameters, such as vessel name, call-sign, company name, port of registration, size and license category
- Tow activity, such as date, time, location and haul duration. For the aggregated daily data, the approximate median daily position, numbers of hauls and the total daily effort.

For the itemized data, information on individual hauls, including the start and end time and position of hauls.
- Detailed catch statistics by species or group of species, either daily statistics (in the aggregated data) or statistics by tow (in the itemized data).

Although the underlying structure of the IFDAS database conforms to the above structure, the data were delivered in a flat file format, where each row corresponds to a single species or species group captured in a day or an individual tow by a vessel. Hence statistics such as vessel parameters, tow activity (including effort) and daily summary statistics of major species grouping are unnecessarily repeated. Such structure of the data makes any data-processing cumbersome and can easily lead to errors in the calculation downstream. The format was hence restructured into a relational database such that each row constitutes a single observation. This restructuring resulted in the raw flat files separated into two principal tables which were used in further analyses:

- An effort table: A table that contains all the information associate with a single day of vessel operation.
- A catch table: A catch composition table listing the species caught and amount caught within a single day of operation.
- A unique key was created that provides a link of the data records in the two tables.
- A major challenge was the standardization of the information in the database, which were entered with varying degrees of quality. For example, we encountered five different spellings for what is suspected to be the same vessel: “JIUYUAN 811”, “Jui Yuan 811”, “JIUYUAN811”, “JUI YUAN 811” and “JIU YUAN 811”. Since the original source data (i.e. the physical logbooks) were not available in this study, expert judgement was used to correct obvious entry typos where possible. The focus was on standardizing and correcting vessel names and license category in order to facilitate cross-referencing with the license data, but other variable (e.g. company names and species grouping) were also corrected. The main types of errors corrected were:
- Removals of extra spaces, either at the end or within a variable name.
- The addition of spaces, for example between vessel name and vessel number.
- Removal of non-alphabetical or non-numerical characters (“-”, "_“,”(“,”line-return", etc.).

In addition, character values were all made upper case. These changes were done programmatically within R this facilitating any future review of the correction process done in this analysis.

Once the data had been cleaned, the two logbook data sources were merged. Because the data sources overlap to some extent in 2018, replicate data from the same vessel on the same fishing date were identified. For those vessels, only the itemized data were used in subsequent analysis.

2.1.2 License data

The license data were compiled from two different sources:
Recent license records: A total of 17 different PDF files and Excel sheets retrieved from the MFMR statistic unit and from the website of the Ministry of Fisheries and Marine Resources

on 4/12/2019. The PDF files contain records for the year 2014-2020. PDF files were signed and approved by the head of statistic unit and the Director of fisheries. These PDF files were converted into Excel sheets through an online application called smallpdf.com (https://smallpdf.com/).

The West-Africa regional license database: an Excel file with a compilation of information in reports and publications covering the years from 2008 to 2014.

Each row in both data sources represents a record of the license period for a given vessel. Each pdf or excel file is a snapshot of the vessels that are licensed at the date when the document was generated. Hence the same license can appear in multiple documents. The information available in each document is variable, but most often includes the following: vessel name, call sign, fishing company, flag state, license category, gross registered tonnage, length overall and duration of fishing license. In addition, it includes the license number, vessel International Maritime Organization number, vessel MMSI number, observer status and VMS status. In many cases two values are stored within the same variable (e.g. call-sign, MMSI and IMO numbers) and the values entered may not correspond to the variable name. This was likely an artefact caused by the conversion of the PDF files into Excel.

All the sheets were imported into R and merged into a single table. The data cleaning process was similar to what was done for the logbooks, with the addition that values were in the wrong variable columns were allocated to the right variable. Particular attention was made on the syntax of the vessel name and license category corresponded to the same information in the logbooks. Following this any duplication of license period for a vessel was removed.

A daily vessel license table was generated from license period table based on vessel name and license category. In cases where vessels had two different license categories on the same date only one license category was retained.

2.2 Estimates of total monthly catch and effort

The common variable in the logbook and license statistics are days, in the former case fishing days and in the latter case license days. All vessels operating in Sierra Leone waters are required to have a fishing license. If a complete census of the license record is available, but there is an incomplete historical logbook record, it would be possible to use the ratio of license days versus fishing days over a period where both records are considered accurate as a correction factor for a period where logbook records are suspected to be incomplete. This would provide the best estimates of catch and effort over time.

Preliminary investigation of the two data sources using time and vessel name indicate that both the license and the logbook records are incomplete. In other words, some vessels were found in the logbook data over given time period (month) that were not in the license data and vice versa. The original approach described above was hence modified in the following way: If a record of a vessel on a given date was in the logbook data but not in the license data, those vessels were added to the license data and the number of license days assumed to be the number of days for the date in question.

For vessels that were in the license registry but there was no logbook data available, following procedure was applied for each vessel category: the average proportion of license days where fishing was reported was estimated by vessel category from monthly estimates of license and fishing days during the years 2017 and 2018. The assumption was that during this time period both the license and logbooks are reasonably accurate. Monthly estimates of average daily catch and effort were computed from the reported logbook data.

The monthly catch and effort data where then calculated by the following equations:

Catch = License days x proportion days used as fishing x average daily catch
Effort = License days x proportion days used as fishing x average daily effort

These corrected statistics were then added to the reported catch and effort in the logbook database.

3 RESULTS AND DISCUSSION

3.1 License statistics

The reconstructed license time series (Figure 2 and 3) span the time period from 2008 to 2019. As indicated the data come from three disparate sources:

- Sierra Leone national license statistics
- West-Africa regional license database
- Vessels in the logbooks but with no registered licence

The non-uniform format of the reporting, as well as the assumptions used to derive the statistics from these data sources may result in unknown bias in the statistics presented. They are however considered to represent the minimum estimates of vessels and license days.

The correction of the reported records in the Regional and National-based statistics with the information of vessels in the logbook records in any given month indicated that relative to the vessel record in the logbooks there is an underestimation in the license records in the period prior to mid-2015 and some missing records in the license database thereafter. In the most recent year (2019) there is good agreement between the reported vessels in the license and logbook database.

The license in the shrimp fishery over time show the greatest stability, the number of licensed vessels per month being in the range of 10 to 20, with the exception being year 2009. There are indications in decline in number of licenses from 2009 to mid-2013. The period from the second quarter of 2013 to the second quarter of 2015 show very few reported licenses.

The license statistics from demersal fish vessels showed two distinct periods (Figure 2). In the first period, between 2008 to 2014, the license statistics indicated similar number of licensed vessels and fishing days as observed in the shrimp fisheries, peaking in 2009 with just over 30 vessels and 1000 days license, and gradually declining to less than 10 vessels and 250 days around mid-2014. In the subsequent period there was an almost four-fold increase in vessels

and fishing days that reached a peak in the first half of 2016. From then onwards there has been an approximately 50% declined in licensed vessels and days.

The license statistics of the mid-water fish vessels shows a similar overall pattern as the demersal vessels, except for an almost absence of licenses prior to mid-2014, except for a brief interlude of some 5 vessels in 2011. A peak in the license records is observed in mid-2015. The decline licenses in the mid-water fishery in recent years is similar as was observed in the demersal vessels.

The general pattern after the peak period for the mid-water and demersal vessels has shown a gradual reduction in the number of fishing vessels and license days issued for all vessel categories over the past years. From 2017 to 2019 there has been around a 50% decrease in demersal and mid-water vessel licenses. This may be attributed to management measure to reduce the effort, based on advice from the EU in 2016.

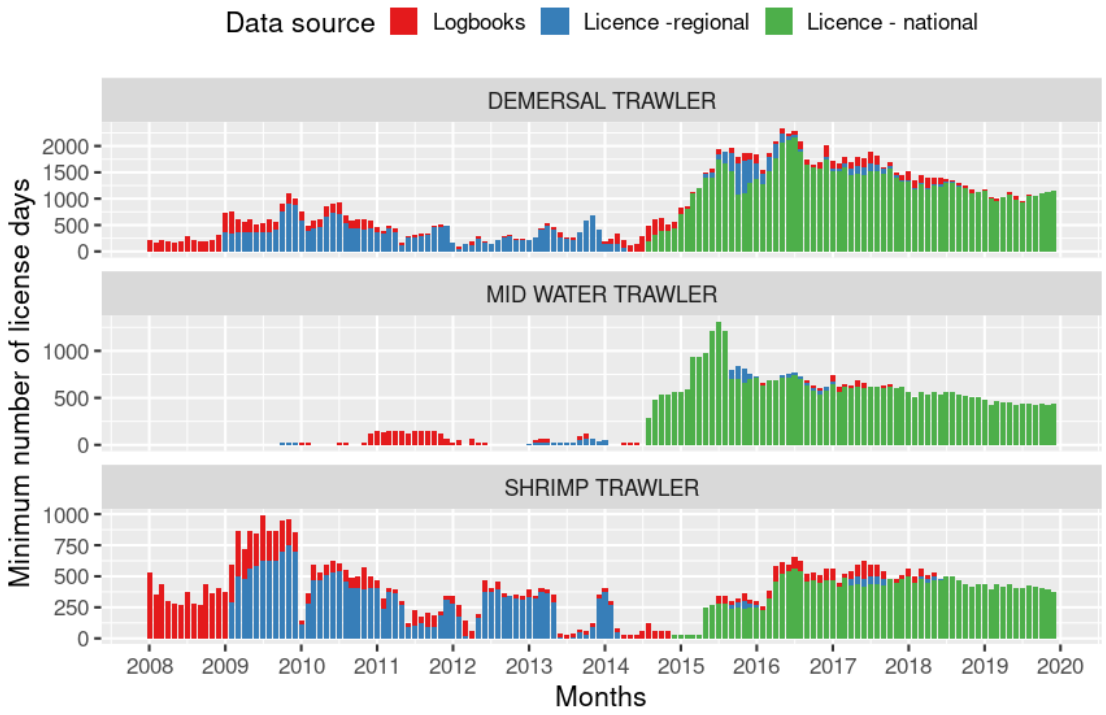

Figure 2. Reconstructed estimates of the minimum number of license days per month by vessel category

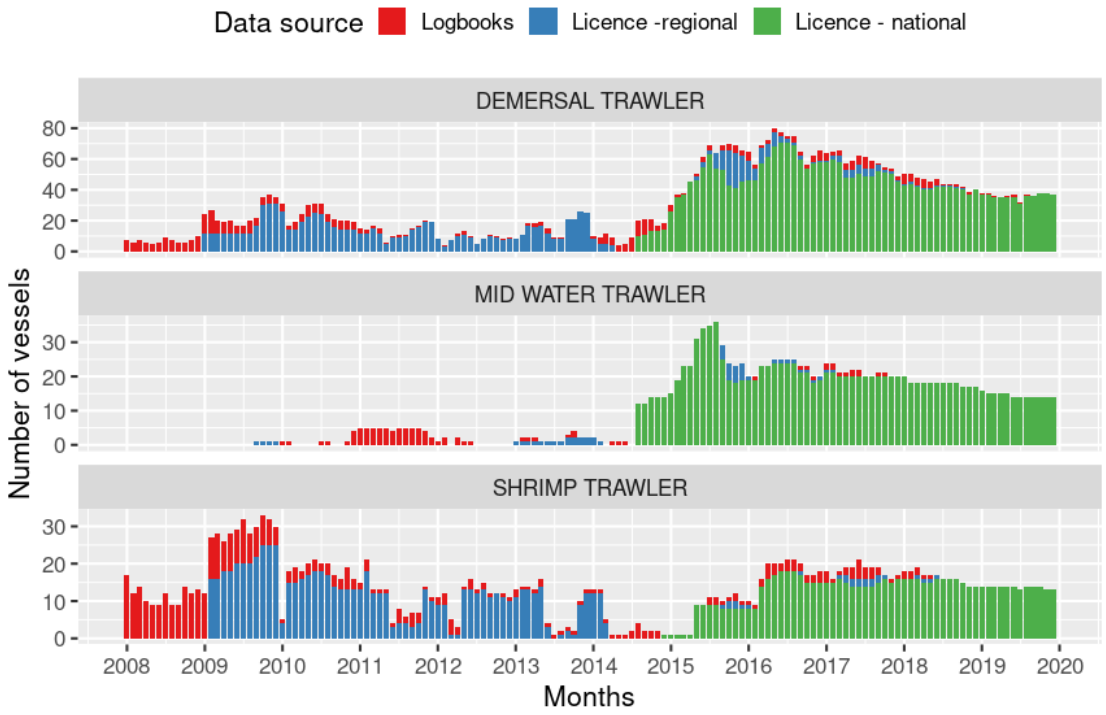

Figure 3. Reconstructed estimates of the minimum number of vessels per month by vessel category

3.2 Estimates of total catch and effort

The mean proportion of license days fished was estimated using the monthly logbook statistics in 2017 and 2018, a period when the licence statistics are considered most accurate. Results showed that shrimp vessels used around 63% of the issued license days, while for the demersal and mid-water vessels around 50% of the issued license days were reported as fishing days (Table 2).

Table 2. Mean proportion of license days fished in 2017 and 2018 by vessel category

Vessel category	Proportion of fishing days used
Demersal	0.48
Pelagic	0.52
Shrimp	0.63

These proportions were the basis for calculating the monthly catch and effort statistics of vessels that were in the license database but not in the logbook database. The data sources are the logbook records and license from vessel in the regional database. Prior to 2014, a significant proportion of the reconstructed catch and effort are based on raising of those statistics with the regional license database, sometimes being much larger than 50% (Figure 4). In general, since 2014 there has been a good agreement between the vessels in the licence and logbook databases. In general, during this later period the correcting factor was lower than 10%, although occasionally reached up to 25% of the catches.

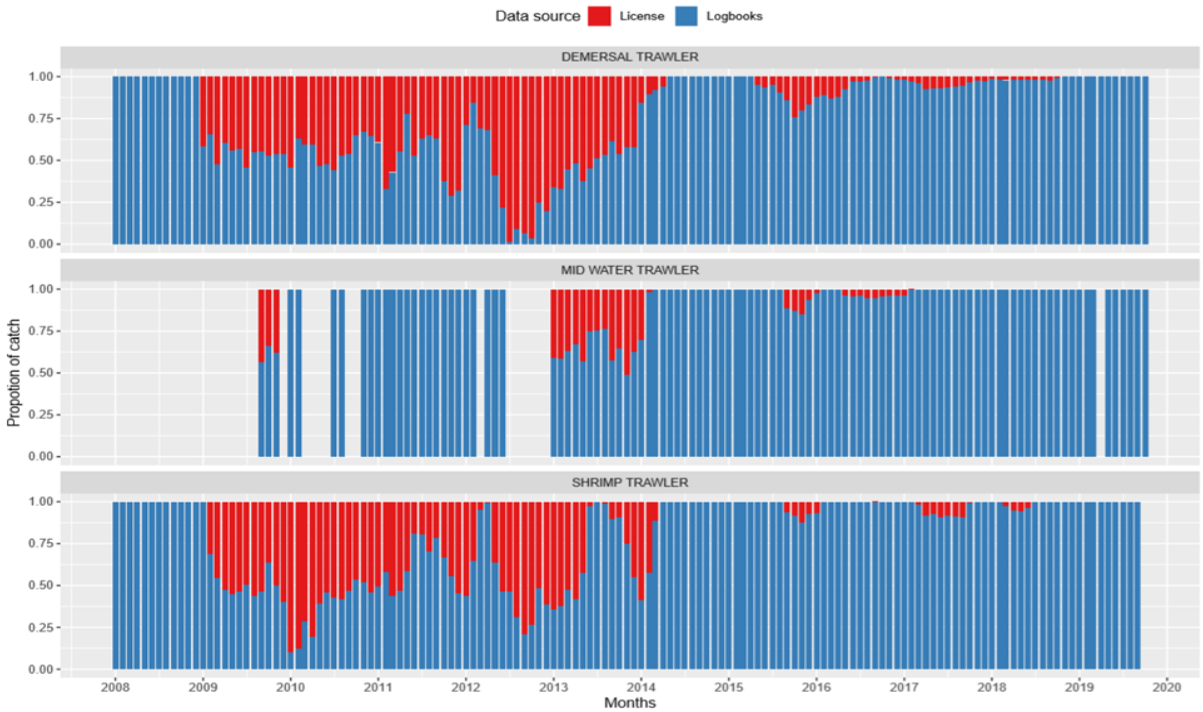

Figure 4. Estimated proportion of the total reconstructed catch by vessel category

The corrected statistics provided a minimum monthly estimate of catch and effort by vessel category (Figure 5 and 6). In general, the catch and effort in the shrimp fishery (Figure 5 and 6) have been relatively stable over the entire time period from 2008 to 2018, with monthly catches being in the range of 500 to 1000 tonnes and effort in the range of 3000 to 8000 tow hours per month. In the demersal fishery, monthly catches increased from around 1000 tonnes in 2008 to a peak around 4000-5000 tonnes in 2009 and 2010. This was followed by a decline in the next few years, reaching minimum in 2012, both because of a reduction in effort and catch per unit effort (Figure 7). Both effort and catches increased after that reaching a peak in late 2015 to mid-2017. Both effort and catches have declined since then the catches being less around or less than 3000 tonnes a month at present.

In the case of midwater fishery, catches increased sharply with increasing effort after 2013 catches reaching a peak of just under 4000 tonnes per month in late 2015. From then on, both effort and catches have declined, catches being around 2000 tonnes a month in the latter part of 2018.

The overall decline in effort in the three fishing categories since 2016 is most likely a result of reduction in licensed vessel days, in part driven by advice from the EU. The decline in catches over the same time period is largely a reflection of that. Additionally, there has been a decrease in the size and powers of licensed fishing vessels, particularly trawlers, compared to the early 1980s and 1990s (Sheku Sei, 2009).

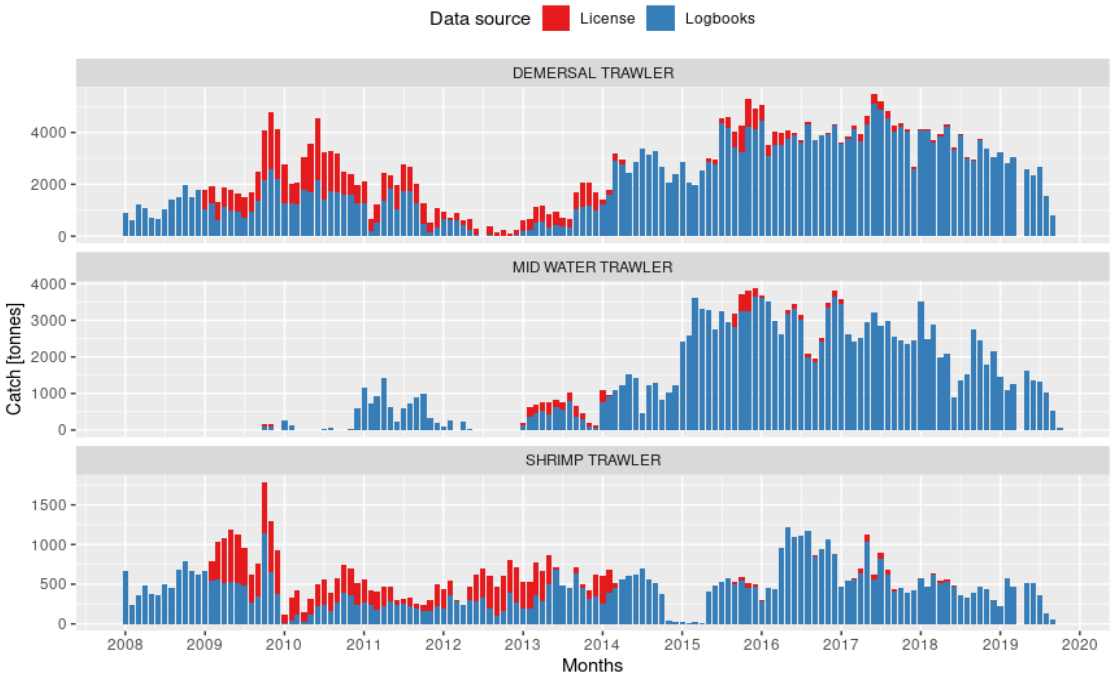

Figure 5. Reconstructed estimates of the minimum monthly catches by vessel category

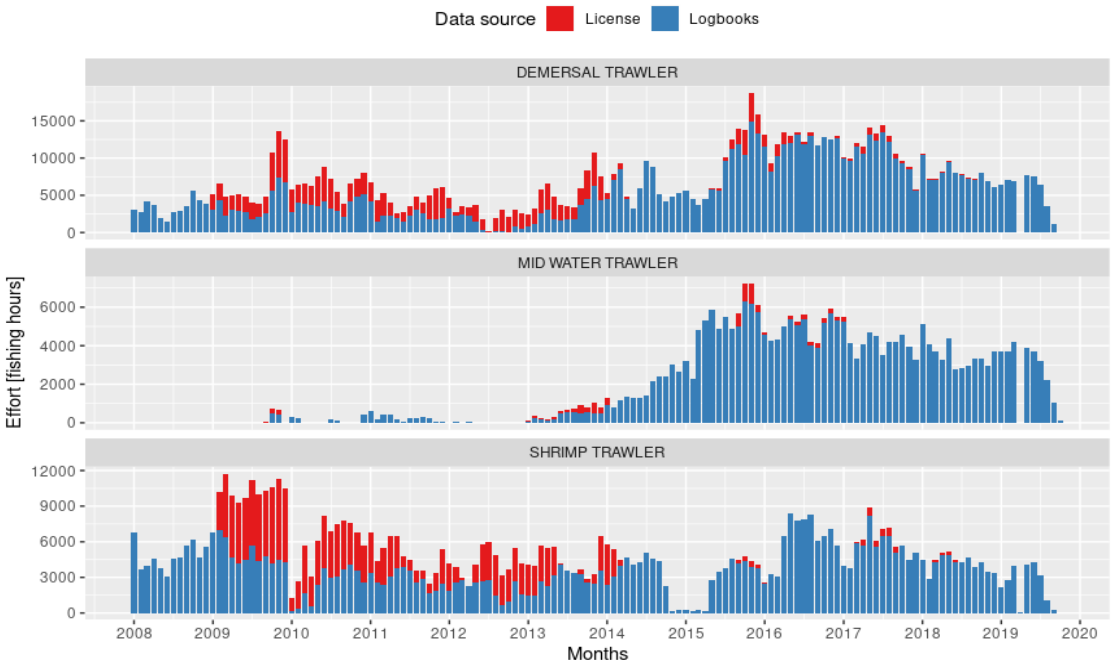

Figure 6. Reconstructed estimates of the minimum monthly effort by vessel category

Total annual catches remained generally below 50 thousand tonnes prior to 2014 but have increased in more recent years reaching a maximum of above 90 thousand tonnes in 2016 and 2017 (Table 3). The increase in the total annual catch has been driven by the increase in effort of the demersal and midwater vessels while the shrimp catches have remained relatively stable.

Table 3. Annual statistics for major species categories

Year	DEMERSAL TRAWLER	MID WATER TRAWLER	SHRIMP TRAWLER	TOTAL
2008	14.421	0.000	6.219	20.640
2009	42.163	0.000	17.852	60.015
2010	50.411	1.058	8.410	59.879
2011	30.368	8.845	6.445	45.658
2012	7.718	0.633	9.923	18.275
2013	21.367	9.515	9.616	40.497
2014	32.480	13.732	6.518	52.731
2015	47.504	40.487	4.358	92.348
2016	51.393	37.655	10.505	99.553
2017	53.790	33.123	7.710	94.623
2018	44.356	25.878	5.636	75.871

3.3 Estimating Catch Per Unit Effort (CPUE) over time

The catch per unit effort was analysed based on the two logbook data sources, the daily summary statistic and the individual tow records. Over the full time period there are little indication of a persistent decline in catch per unit effort in any of the vessel categories although there are is variable (Figure 7).

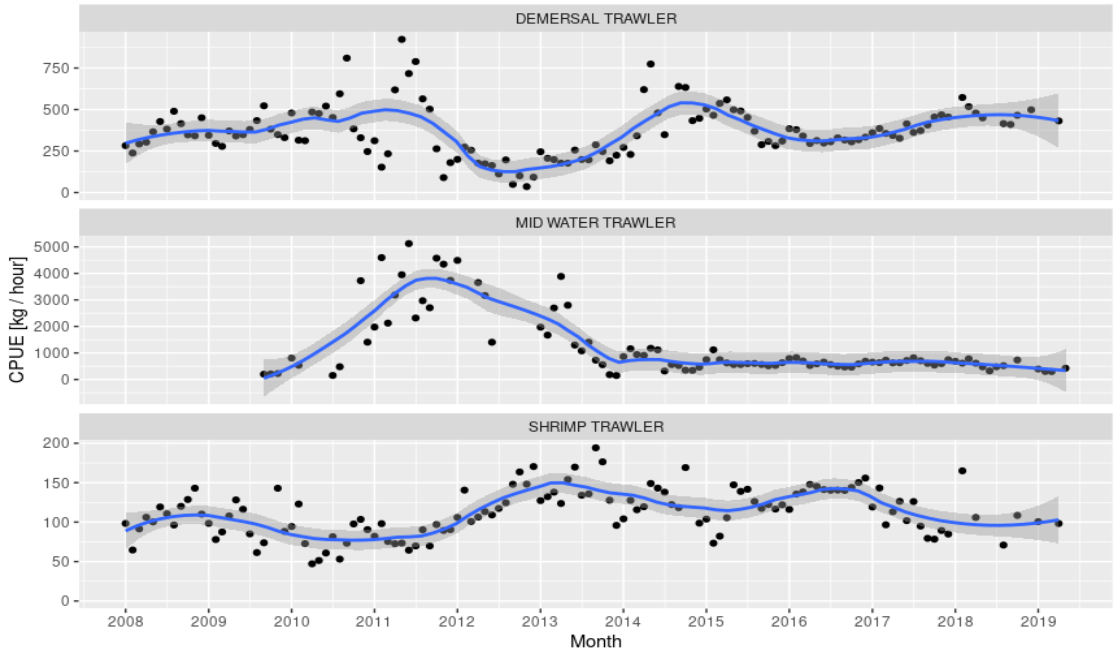

Figure 7. Monthly catch per unit effort (kg per hour) by vessel category

The catch per unit effort of the shrimp vessels has been between 75 to 150 kg per hour over the time period, a twofold difference between the maximum and the minimum. The catch rate was generally above 125-150 kg per hour from 2013 to 2016 but closer to or less than 100 kg /hour before and after that time period.

The catch per unit effort of the demersal fishing vessels has been between 125 to above 500 kg per hour over the time period, a fourfold difference between the maximum and the minimum The lowest catch rates occurred in 2012 and early 2013 coinciding with the time period of low catch and effort. The catch rates have been around 375 kg per hours since mid-2015 being similar as at the start of the time series.

The catch rate of the midwater trawlers has a range of 500 to 4000 kg per hour over the time period, an eightfold difference between the maximum and the minimum. The dynamic range observed is largest over the time period from late 2009 to late 2013, a time period coinciding with low and intermittent effort. Since then, the catch rate has been relatively stable around 350 kg per hour.

It is unclear to what extent the dynamics in the catch per unit effort reflects the dynamics of the underlying resources and to what extent a reflection of changes is vessel capacity, gear changes, change in targeting practices as well as other factors. To investigate that further one may need to try to first standardize the catch per unit effort taking such factors into account.

3.4 Composition of the catch by species group

The catch composition of major species group by vessel category showed that demersal trawlers catch a significant amount of pelagic species. The proportion has increased with time, being approximately 50% in recent years (Figure 8). The midwater trawlers also catch significant amount of demersal species, with the proportion of pelagic species decreasing with time. The dominant catch of the shrimp vessels has been demersal fish throughout the time period, with actual contribution of the shrimp (labelled crustaceans in the graph) hardly being higher than 25% of the catch as well as decreasing with time, being less than 5% recently. An increasing portion of the catch of the shrimp vessels are cephalopods, being 25% of the catch in some recent months. Overall, there has been an increase in the proportion of pelagic species in the catches. The overall trend in the monthly catches by major species groups (Figure 9) are largely a reflection of the general patterns described above. Pelagic species followed by the demersal species group dominated the catches being of the order of 2000 to 5000 tonnes per month in recent years.

Vessel categories, like midwater and demersal trawlers, were fishing on both the pelagic and midwater resources and the catch of shrimp trawlers is largely demersal fish with shrimp being only a minor proportion of the catch. This may in part be explained by the narrow water depth in Sierra Leone waters and hence little geographical separation of the demersal and the pelagic resources. Hence, management measures with respect the pelagic and the demersal fish may not be possible based on vessel category alone.

Figure 8. Catch proportion for major species groups by vessel category

Figure 9. Catch of major species groups by month by vessel category

In 2017, the herring Sardinella species constituted approximately 50% of the total catch yielding some above10,000 thousand tonnes. The catch of other species was generally less than 100 tonnes, the number of species groups which reported catches greater than 100 tonnes were 36 in 2017 (Figure 10). The figure only shows species where the annual catch was greater than 100 tonnes

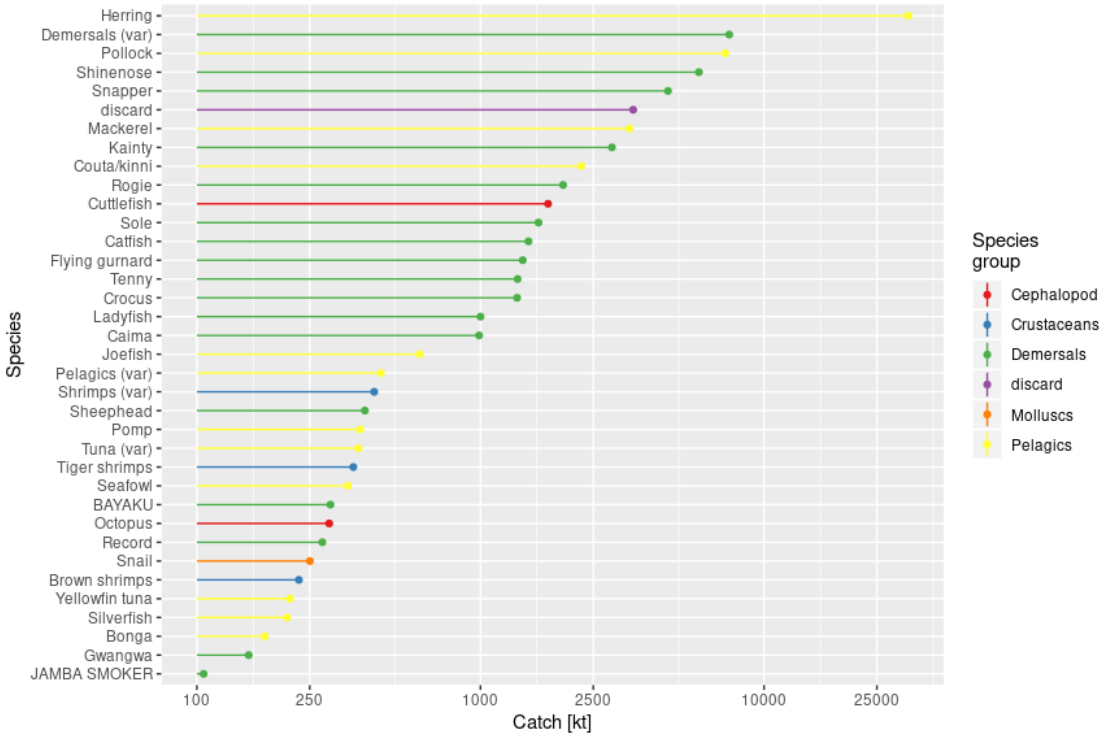

Figure 10. The catch in 2017 ranked by species or species groups.

3.5 Comparison of estimated catches from logbooks and statistics from Sea Around Us

This comparison presents a brief overview of the Sierra Leone industrial estimated logbook catch statistic and the Sea Around Us project reconstructed catch for Sierra Leone. Sea Around Us (SAU) used reconstructed global catch data that combine officially reported landings data with comprehensive estimates of unreported landings and discards. SAU provides what is claimed by some fisheries scientist to be better estimates of catches than what is reported by FAO. For most countries, the baseline data are the statistics reported by member countries to FAO (Zeller, 2015). SAU data provides a split of the catch data between subsistence, artisanal and industrial catches. The trends of catches for these different sectors are provided below, both in terms of absolute numbers as relative proportions. In Figure 10 below, the red lines are Sea Around Us industrial catch data and the black lines are this project's estimates based on logbook reports.

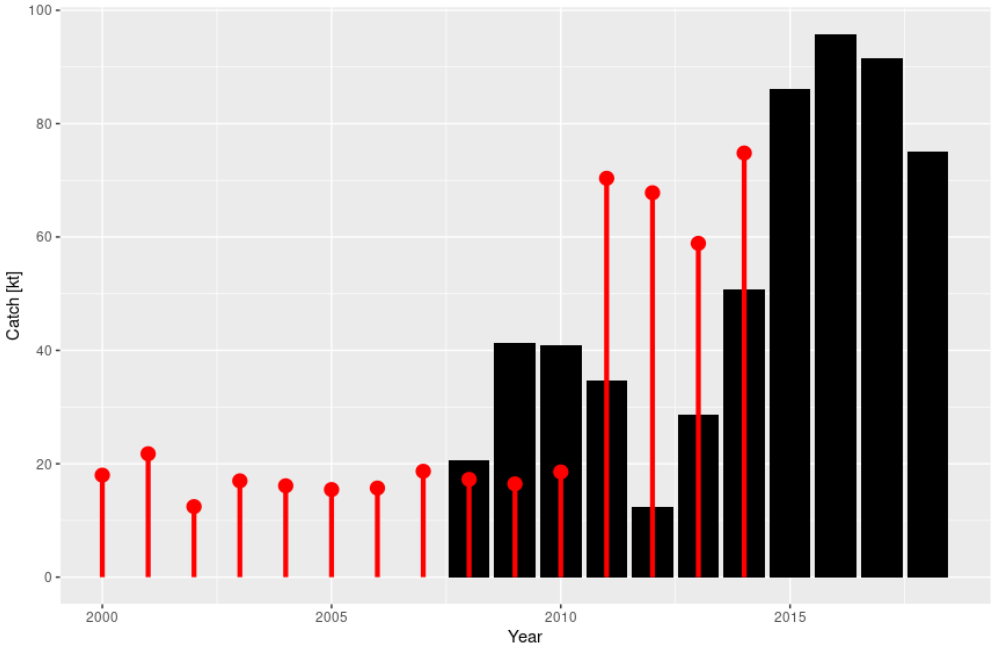

Figure 10. Reconstructed catches compared to the catch data supplied to the SAU, 2000–2014

For the years 2008 to 2010 the estimates from the Logbooks are higher than that obtained from SAU. The SAU estimates are higher for the years 2011 to 2014 being around 60 to 75 thousand tonnes while the logbook catches are lower and much more variable between years. It is of interest that SAU reports that large proportion of the industrial catch from 2011 to 2014 are from domestic vessels.

Many national datasets do not necessarily include catches by national distant-water fleets fishing and/or landing catches elsewhere. The FAO catches by nationality are dictated by the flag of the fishing vessel, unless the wording of chartering and joint operation contracts indicates otherwise.

These estimated logbook catches have fewer assumptions in the reconstruction process, and utilise more recent logbook data, which was not available for the Sea Around Us project reconstruction. Using underestimated reported landings data collated by FAO FishStat, the most widely used time-series data on global fisheries catch landings, does not account for IUU catches and contributed by all member countries.

This comparison is a step towards the evaluation of the landing reports and SAU catch reconstruction. It also an opportunity for Sierra Leone improve their historical data. However, the Sea Around Us welcomes any engagement with countries that wish to consider or review reconstruction in the context of their national data improvements. This research seeks to explore this opportunity based on the discrepancies noted from both sets of statistics. SAU and FAO could use the knowledge and information from this research to improve the compilation of landings data in the future.

3.6 Spatial Distribution

The spatial distribution of catches in tonnes, effort in hours, and catch per unit effort (CPUE) in tonnes per hour were computed from the recent logbook data, where the recording is based on individual tows. The spatial distribution analysis was done by gridding the haul positions as registered in the logbooks at a resolution of 0.05 degrees of latitude and longitude.

The resulting maps of catch, effort, and CPUE show differences in the behaviour of the different fishing fleets. The demersal trawling effort was more concentrated towards the north west of the continental shelf, further from the inshore exclusive zones (Figure 11). Compared to the demersal trawlers, fishing effort for midwater trawlers seems more evenly distributed on the continental shelf. In the case of shrimp trawlers, the effort was concentrated in shallow depths near the Inshore Exclusive Zone and the shelf (less than 25m). Maps showing the distribution of total catch (Figure 12) showed similar patterns. Finally, maps of catch per unit effort (Figure 13) did not show any clear spatial trends. CPUE in demersal trawlers appears to be slightly higher at water depths less than 50 m. CPUE from mid-water trawlers show relatively high values (>2 ton/hr) in a small region on the Guinea EEZ. It is not known what the explanation for this.

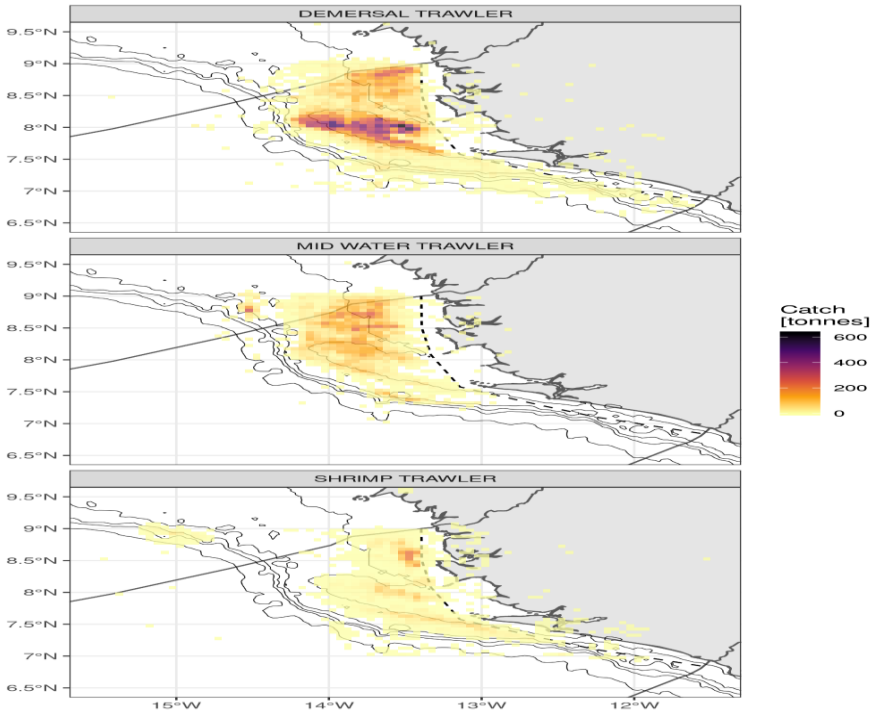

Figure 11. Distribution of the total catch (tonnes) within the Sierra Leone EEZ

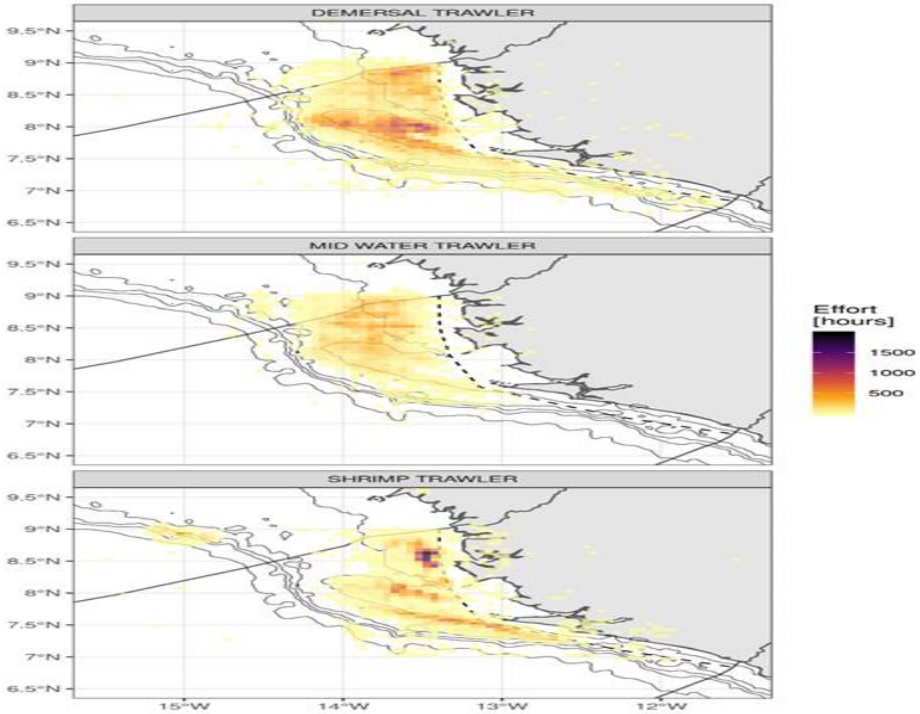

Figure 12. Distribution of the total effort (hours) within the Sierra Leone EEZ

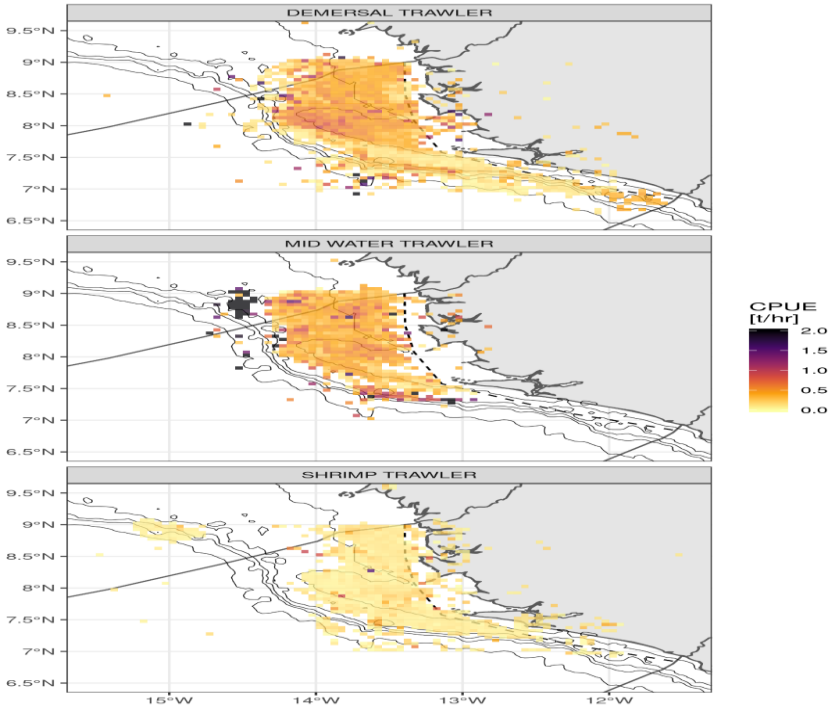

Figure 13. Distribution of the catch per unit effort (CPUE) in tonnes per hour within the Sierra Leone EEZ

4 CONCLUSION

Fisheries management in Sierra Leone is hindered by a lack of reliable data and historical records (Katherine Seto D. B., 2015). This study was an attempt to integrate the license data and the logbook data sources in order to create a better estimate of the catch and effort by the industrial fishery in Sierra Leone over the past decade. Hopefully this information contributes to the management Sierra Leone's industrial marine resources.

This research recognized that fairly good progress has been made in the collection of fishery statistics. Nevertheless, there are still a large degree information mismatch between the logbook and licenses, showing lack of standardization on parameters like vessel name, GRT, callsign, etc. This makes difficult to cross-reference both data sources.

The main outcome of the reconstruction of the reported catches and effort for Sierra Leone industrial fisheries is that there was a large amount of missing records, especially before the expansion of the data collection on board industrial vessels and the introduction of the Vessel Monitoring System in 2011 (Sheku Sei, 2009). The observed discrepancy between the reported and reconstructed records in this report is mainly due to missing logbooks, weak methods of data management, inaccurate data entry, as noted in the data cleaning method section, and lax enforcement especially between 2008 and 2015 when our results showed multiple missing records in both logbook and license data.

In the description of the species composition of the catch, it was observed that fish from the pelagic genus Sardinella spp accounted for the largest proportion, with over 50,000 tonnes. The dominance of Sardinella spp, is a relatively recent phenomenon. The historical records show that initially the demersal species accounted for over than 50% of the total catch, while pelagic species were less than 25%. These proportions have almost reversed in the latest years of observations. Discards for total catches have declined to almost zero.

However, despite all the challenges noted in this research, there are positive signs for the industrial sector. The catch per unit effort observed overtime for the different species category appears to show no sign of recent decline at current effort.

This has been complimented by the expansion of the vessel monitoring system coverage and onboard observes to collect biological and scientific information from the daily activities of the industrial fishing vessels. The reduction in the number of license vessel of shrimps and demersal fishery was a precautionary measure as fleet limitation of 20 fishing vessel for which was proposed under a dual scheme of demersal fish and shrimp licenses with restricted to night hours, from 6pm to 6am to minimize bycatch (Sheku Sei, 2009) and advice from the European Union on the management of the marine resources.

5 RECOMMENDATIONS

Following there are a set of recommendations to solve some of the challenges of missing and data management.

The license record should be incorporated into IFDAS. This will serve as quality control check, as the other information in the database will be cross-referenced to the licence information. There is a need to update the inventory of all data sources and the inventory of all industrial fishing vessels, indicating nationality of vessel, type of vessel, horsepower, overall length, GRT as well as characteristics of the fishing gear.

The logbook entry by the scientific observers showed more accuracy and the resulting data is more suitable for a detailed analysis. The Ministry of Fisheries and Marine Resources should improve the coverage of scientific observers on boards industrial fishing vessel.

The logbook records should be recorded as the individual tow records rather than daily summary statistics.

Fisheries officers and data entry personnel should be trained on how to maintain proper data integrity when recording information. The format of the data should be standardized. In addition, the integrity of the data should be verified by cross-referencing it with other sources of information. For example, the haul locations reported should be compared with the vessel positions from VMS data.

Effort should be made to train personnel in modern methods of data management and analysis, using the use of open source software like the R programming language, in order to increase the capacity of Sierra Leone to independently extract the maximum amount of information from the data collected.

ACKNOWLEDGEMENT

First, I would like to thank Allah for blessing me with many opportunities and abilities. My main source of strength lies in you, and I know that if it was not for you, I would not be where I am today. Thank you.

I wish to express gratitude to my supervisors Einar Hjorleifsson and Julian Mariano Burgos for their constant support and encouragement motivated me to rise to the challenge of this research work, as well as inspiring me to achieve high standards. Thank you for challenging me to think critically and explore the richness of stock analysis and using R language.

I would like to specifically thank the Honourable Minister, Deputy Minster and the Permanent Secretary for their support throughout this study and staff of the Ministry of Fisheries and Marine Resources Kadijatu Jalloh, Josephus Mamie, Lahia D. Sesay, Ivory Mae Coker, Mamoud Mansaray, Alpha Turay, Hindolo Momoh, Mohamed Kamara, Shaka Kargbo and Sallieu Sankoh who shared their knowledge and expertise for this study.

I would also like to express my deepest appreciation to the entire UNESCO-GRO FTP team in Iceland especially the Director and Deputy Director for providing the facility to realise this study, and to all lecturers of the stock assessment specialization for their technical support. A special thank you to the UNESCO-GRO FTP 2020 fellows for a wonderful year of friendship, encouragement and memorable times.

On a more personal note, I need to thank my parents for always being a major source of strength and encouragement. The same thanks go to my fiancée Fatmata Davies, whose understanding and patient nature supported me throughout my research project.

REFERENCES

Andy Thorpe, D. W. (2009). *Fisheries and failing states: The case of Serra Leone*. www.elservier.com/locale/marpol.

Arthur E (Bah, 2019). Neiland1, S. C. (2016). *Assessing the Potential Contribution of Fisheries to Economic Development —The Case of Post-Ebola Sierra Leone*. Freetown.

Coker, I. (2018). *Feasibility of using the vessel monitoring system in Sierra Leone to monitor and assess the industrial fishery*. United Nations University Fisheries Training Programme. Iceland. unuftp.is

FAO. (2009). Fishing Vessel Monitoring System-Limitation. http://www.fao.org/fishery/topic/18100/en.

FAO. (2010). *Marine fishery resources of Sierra Leone: a review of exploited fish stocks*. Rome: http://www.fao.org/3/R9003E/R9003E00.htm#TOC.

FAO. (2018). *Data collection methods*. http://www.fao.org/3/X8923E07.htm.

FAO. (2018). *Observer program operations manual*. Rome: www.fao.org.

FAO. (2019). *Fishing vessel monitoring center*. http://www.fao.org/fishery/topic/18110/en.

Garibaldi, L. (2012). *The FAO global capture production database: A six-decade effort to catch the trend*. Marine Policy.

Heymans, J. J. (2004). *Structure and Dynamics of the marine ecosystem off Sierra Leone for three period,1964,1978,1990*.

Jacquet, J. H. (2010). *Few data but many fish: marine small-scale fisheries catch for Mozambique and Tanzania*. African Journal of Marine Science 32(2): 197-206.

Kadijatu J. (2009). *The Economic potential and feasibility of a landing site investment in the artisanal small pelagic fishery of Sierra Leone*. United Nations University Fisheries Training Programme. Iceland. unuftp.is

Katherine Seto, I. T. (2015). *Colonialism, conflict, and fish: a reconstruction of marine fisheries catches for Sierra Leone, 1950-2010*.

Katherine Seto, J. M. (2017). *War, Fish and foreign fleets, the marine catches of Sierra Leone 1950-2015*.

Mamoud Mansaray, I. C. (2019). *Monthly local discharge report*. MFMR Statistics unit.

MFMR. (2003). Fisheries framework and policy development.

MFMR. (2018). National Plan of Action to deter IUU fishing. Freetown.

MFMR. (2018). Poverty reduction strategy paper IV.

MFMR. (2019). License list.

MFMR. (2019). Provision into the country yearbook of Sierra Leone 2017. Freetown: www.mfmr.gov.sl.

MFMR. (2019). Service charter. Freetown: www.mfmr.gov.sl.

SA Murawski, S. W. (2005). *Effort distribution and catch patterns adjacent to temperate MPAs*. ICES Journal of Marine Science, 62 (6) (2005), pp. 1150-1167.

Seisay, L. (2019). License list report. www.mfmr.gov.sl.

Sheku Sei, A. B. (2009). *Fisheries management in data deficient industrial fisheries of Sierra Leone: Input controls and ecological risk assessment*. Freetown: Ministry of Fisheries and Marine Resources.

Shui-Kai Changa, K.-Y. L.-H. (2010). *Distant water fisheries development and vessel monitoring system implementation in Taiwan − History and driving forces*. Marine Policy, 34(3): 541-548.

Wielgus, J. D.-H. (2010). *Estimation of fisheries removals and primary economic impact of the small-scale and industrial marine fisheries in Colombia*. Marine Policy 34: 506-513.

Zeller, D. P. (2015). *The catch reconstruction database contains the entirety of the catch reconstruction information by year, fishing nation, taxon name, catch total, fishing sector, catch type, reporting status, input information source and spatial area of catch, for example*. Sea Around Us (www.seaaroundus.org). University of British Columbia.

Appendix - Proportion of species group composition.

Table 4 showing annual proportion of species group composition for different species categories

Spp. group	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cephalopod	0.02	0.01	0.00	0.00	0.03	0.01	0.01	0.01	0.04	0.02	0.03	0.03
Crustaceans	0.05	0.05	0.03	0.03	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.02
Demersal	0.58	0.64	0.65	0.47	0.65	0.57	0.57	0.45	0.45	0.38	0.43	0.55
Pelagic	0.20	0.15	0.19	0.41	0.20	0.34	0.36	0.49	0.45	0.54	0.52	0.40
Discard	0.10	0.14	0.12	0.09	0.05	0.05	0.03	0.03	0.03	0.04	0.01	NA

Table 5 showing proportion of species group composition for the shrimp category

Spp. group	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cephalopod	0.06	0.03	0.02	0.02	0.06	0.02	0.07	0.05	0.13	0.13	0.14
Crustaceans	0.17	0.16	0.25	0.22	0.10	0.09	0.10	0.13	0.07	0.10	0.09
Demersal	0.65	0.59	0.56	0.63	0.75	0.80	0.70	0.66	0.61	0.62	0.69
Pelagic	0.03	0.05	0.02	0.02	0.20	0.02	0.05	0.06	0.11	0.07	0.05
Discard	0.09	0.18	0.15	0.08	0.06	0.06	0.07	0.07	0.05	0.07	0.02

Table 6 showing proportion of species group composition for the mid-water category

Spp. group	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cephalopod	0.00	NA	NA	NA	NA	0.01	0.01	0.01	0.01	0.01	0.01
Crustaceans	0.01	0.00	NA	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
Demersal	0.84	0.06	0.05	NA	0.09	0.27	0.28	0.26	0.25	0.25	0.28
Pelagic	0.10	0.83	0.84	0.96	0.90	0.70	0.69	0.70	0.72	0.70	0.70
Discard	0.05	0.11	0.11	0.04	0.01	0.02	0.02	0.02	0.03	0.01	0.01

Table 7 showing proportion of species group composition for the demersal category

spgroup	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cephalopod	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.02	0.02
Crustaceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Demersal	0.57	0.65	0.69	0.74	0.69	0.73	0.68	0.59	0.56	0.43	0.49
Pelagics	0.28	0.20	0.17	0.18	0.23	0.21	0.27	0.35	0.34	0.49	0.46
Discard	0.11	0.12	0.12	0.07	0.04	0.06	0.03	0.03	0.04	0.04	0.01