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FEASIBILITY OF USING THE VESSEL MONITORING SYSTEM IN SIERRA LEONE TO MONITOR AND ASSESS THE INDUSTRIAL FISHERY

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ABSTRACT

In Sierra Leone Vessel Monitoring System (VMS) is only used to monitor in real time as a role in the enforcement of fishery regulations. The paper looks at the possibility of using this system to assess the industrial fisheries of Sierra Leone in evaluating the quality of VMS data collected to ascertain: 1. whether it can be combined with logbook data for mapping fishing effort by vessel, 2. describe the spatial distribution of fishing effort, and 3. map the catch of the main target species. The R programming language was used to analyse VMS data provided by AST marine via the Ministry of Fisheries and Marine Resources (MFMR) and the logbook data from the Sierra Leone Industrial Fisheries database (SLIFDAS). This paper represents the first attempt to link VMS and logbook data to evaluate the potential to map fishing effort and catch. In this study the evaluation of the level of coincidence between VMS data classified as fishing, using speed thresholds for individual vessels and the presence of entries in the logbook database gives a mixed result. On one hand, it is evident that there is a fair amount of overlap between the VMS and logbook data, meaning that for a vessel there is at least one VMS record classified as fishing in dates in which fishing activity was reported in the logbooks, with some vessels having a relatively high degree of coincidence through the entire period. On the other hand, there are several problematic patterns, vessels reporting fishing activities in the period June 2017 to May 2018, for which there is no VMS data classified as fishing. The VMS classified as fishing was used to map the relative fishing effort by category and those of the logbook were used to map the relative catch. VMS data have the potential to improve fisheries management and serve as a baseline to validate logbook positions and provide estimate of fishing effort by mapping of the catch. Lack of clarity in VMS coverage and inconsistencies in the logbook database introduce difficulties in combing the VMS and logbook data leading to limiting data sets. Personnel should be trained in modern methods of data management and analysis.

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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
USSR	Union of Soviet Socialist Republic
GCLME	Guinea Current Large Marine Ecosystem
ISFM	Institutional Support to Fisheries Management
RV	Research Vessel
Yr.	Year
MT	Metric ton (1,000kg)
Dr	Doctor
Nm	Nautical miles

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1 INTRODUCTION

1.1 Geographical setting

Sierra Leone lies between 7°N and 10°N latitude and 10°W and 14°W longitude on the west coast of Africa (Fig.1). The country covers a total area of about 72,325 km^2 and is bordered on the north and east by the Republic of Guinea, and on the south by Liberia. The coastline is about 560 mm long. In addition to the mainland, Sierra Leone also includes the offshore Banana, Turtle and Sherbro Islands, as well as other islets. The coastline has extensive mangrove swamps and a few estuaries and rivers that are navigable for short distances (Jalloh, 2010). Sierra Leone has two distinct seasons the rainy season starting from May – October and the dry season from November to April, each season lasting about six months. Temperature varies from 25ºC to 34ºC with mean values around 26°C, although it could be as low as 16 ºC (Blinker, 2006).The continental shelf off Sierra Leone is relatively narrow in the south of the country, where the 100 m isobath is only approximately 25 km off the coastline. The shelf expands towards the northwest where the distance between the coastline and the 100 m isobath can reach 130 km. The oceanographic conditions in Sierra Leone waters are characterized by a stable, shallow thermocline lying at mid-shelf and affecting the distribution of fish. Seasonal changes are due to the monsoonal wet season, which is characterised by high river discharge, reduced surface water salinities, lowered surface radiation and a decrease in mixed layer temperatures (Ssentongo & Ansa-Emmin, 1986) (Longhurst, 1983).

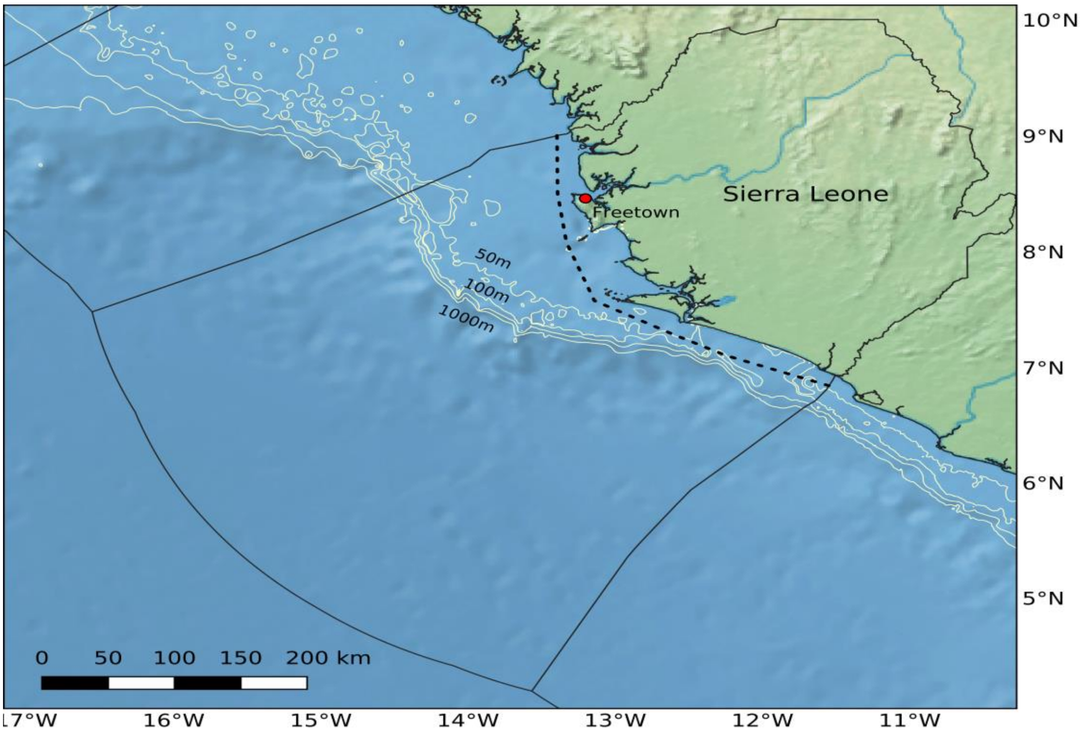

Figure 1 Map of Sierra Leone's Exclusive Economic Zone (EEZ). The dotted line indicates the IEZ (Inshore Exclusion Zone), where industrial fishing vessels are not allowed to operate,(Marine Regions, 2018)

1.2 Overview of Fisheries in Sierra Leone

Fisheries play a significant role in the national economy and food security of Sierra Leone. They contribute about 10% of the Gross Domestic Product (GDP) and are the most important economic activity along the coastline of the country. Fish is the largest source of animal protein for the majority of Sierra Leoneans, supplying about 80% of total animal protein consumption. Over 600,000 people are directly or indirectly employed in the fisheries sector (MFMR, 2017). Fisheries in Sierra Leone comprises three sub-sectors: the artisanal fishery, the industrial fishery, and the inland fishery and aquaculture.

A number of surveys have been carried out in the territorial waters of Sierra Leone supported by the European Union of Institutional Support to Fisheries Management (ISFM). Between 1982 and 2017 the biomass estimates for demersal species ranged between 105,000 mt in 1982 and 170,000 mt in 2009, and for pelagic species between 513,400 mt in 1982 and 116,138 mt in 2017 (Baio & Sei, 2017).

1.2.1 *Artisanal fishery*

The artisanal fishery is a small-scale fishery characterised by diverse fishing gears and crafts and is a major activity in 530 fishing landing sites in the coastal districts of Western Area, Port Loko, Kambia, Moyamba, Bonthe and Pujehun. This fishery is comprised of a variety of dugout and planked canoes which employs a diverse range of fishing gears. The total number of fishing crafts in the artisanal fisheries has increased from about 6,000 in 1974 to about 10,000 currently (MFMR, 2009). It creates direct employment for about 30,000 fishermen. Estimated 250,000 additional jobs are provided by ancillary activities like fish processing, marketing, boat-building and engineering, with women playing major roles in the fish distribution channels.

In the Fisheries and Aquaculture Act of 2017 part IV,18(1) it is stated that the Inshore Exclusion Zone (6nm off the coast) is reserved for artisanal and recreational fisheries (Gazette & Government, 2018).The artisanal fishery operates in estuaries and coastal waters extending from the shoreline to a depth between 15 m to 45 m. The most common species in this sector includes small pelagic species such as clupeids, including herring (*Sardinella* spp.) and bonga (*Ethmalosa fimbriata*) which constitute about 60% of the artisanal fisheries catch (Jalloh, 2010). Historically, the majority of fishers (44% full-time, 50% part-time) operated in the richer fishing grounds to the North, where larger vessels were also more commonly found including 71 % of the national inventory of 3–5 man canoes and 44% of Ghana's (canoes with more than 10 man canoes and provided with ice box) boats were located here (Thorpe et al., 2009).

1.2.2 *Industrial fishery*

The industrial fishery operates in the Exclusive Economic zone (EEZ) which extends to 200nm from the shoreline, and it is comprised of a multinational fleet that includes shrimp trawlers, purse seiners, canoe support vessels, mother ships and carriers. The main target in the industrial fishery includes species of the families Sciaenidae (*Pseudotolithus senegalensis)*, Haemulidae (*Pomadasys jubelini*), Sparidae (*Sparus caeruleostictus*, *Pagellus belloti*, *Dentex canariensis*), Polynemidae (*Galeiodes decadactylus*), and Lutjanidae (*Lutjanus goreensis*) which are included in the demersal stocks (Ssentongo & Ansa-Emmin, 1986). The pelagic stocks mostly constitute the clupeids (*Sardinella maderensis, Ethmalosa fimbriata, Illisha africana, Sardinella aurita) Caranx hippos* etc. The fishery also targets some shellfish resources which are dominated by crustaceans (shrimps, crabs and Lobsters), cephalopods (cuttlefish) and molluscs (gastropods and bivalves).

This sub sector is highly export-oriented, and the fleet ownership is mostly foreign. Principally, the fleet comprises shrimp and finfish demersal trawlers. Historically, Sierra Leone's industrial fisheries date from 1955 when Italian companies introduced trawlers into local waters. Fishing effort gradually increased thereafter until a series of fishing agreements with the USSR allowed a large Soviet fleet of trawlers, purse seiners and factory vessels to enter national waters (Thorpe et al., 2009). Since 1981 the Ministry of Fisheries and Marine Resources (MFMR) has systematically recorded changes in industrial fishing effort. The industrial fishing fleet consists mainly of demersal trawlers, shrimp trawlers, canoe support vessels and purse seiners belonging to various nationalities including Chinese, Korean, Russian, Greek, Italian, Spanish. Table 1 below gives a summary of the Sierra Leone Industrial Fleet composition as published in the Ministry of Fisheries and Marine Resources' website in the media section.

Table 1 Sierra Leone Industrial Fleet composition, November 2017 (mfmr.gov.sl, 2018)

Vessel Type	Number of Vessels	Country of origin
Demersal Fish Trawler	52	China, San Marina, South Korea, Guinea
Tuna Purse Seiner	44	Spain, Panama, Italy, France, Curacao, El Salvador, Belize, Cape Verde, Senegal, Guatemala
Midwater Trawler	19	China, Russia, Saint Kitts and Nevis
Shrimp Trawler	11	Italy, China
Supply Vessel	6	France, Spain, Senegal
Cephalopod Trawler	3	Italy
Tuna Longliner	1	Chinese Taipei (Taiwan)
Carrier Vessel	12	Spain, Panama, China, Comoros

The size of the shrimp trawlers has not changed significantly over time which is generally between 75-200 GRT whilst that of the finfish trawlers is between 100-300 GRT. Tuna purse seiners or long-liners operating in Sierra Leone waters have GRTs between 1000-3000 GRT and this is similar to fishing carrier vessels that transport fish to other countries (FAO, 2008).

1.2.3 *Inland Fishery and Aquaculture*

This fishery operates in rivers, a few lakes, floodplains, and swamps. It has great potential for development (MFMR, 2008) .The most cultivated species are the Nile tilapia (*Oreochromis niloticus*) and the African catfish (*Clarias* spp.)(FAO, 2008).

1.3 **Vessel Monitoring Systems (VMS)**

VMS are satellite-based monitoring systems in which vessels are equipped with a transmitter that transmits information on the vessel identification, position, speed and bearing at regular intervals. The information is received by a station on land and stored in a database, which can also consolidate other information about vessels and operators (e.g. vessel characteristics, contact information, licenses and registries), making this information available to managers

(FAO, 2018). VMS are increasingly required for fishing fleets worldwide, and represent a source of data complementary of that obtained from other sources like logbooks.

The reliability of VMS transmissions (also known as pings) is high, although the interval between transmissions is relatively large (usually 30-120 minutes) due to the cost of satellite communication, which limits the spatial resolution of the resulting data (Gerritsen & Lordan, 2011). The timing of transmission is unknown to the fishers to prevent any potential illicit activities between recordings (Vakily J.M, 1995). VMS are mostly used to track the positions of vessels for safety purposes and to monitor compliance with fishery closures and other fishing regulations.

However, there are many other possible applications of integrated VMS and logbook datasets, particularly in a mixed-fisheries context. Management of mixed fisheries can be particularly challenging, but it may be assisted using integrated VMS and logbook data in many ways. Supplemental to their utility for law enforcement, VMS data have been used to estimate and map fishing effort and catch, validate logbook data and delineate habitats impacted by fishing (Bastardie, Nielsen, Ulrich, Egekvist, & Degel, 2010):

(i) more accurate catch per unit effort (CPUE) estimates can be provided by considering changes in fishing locations for fleets that may switch between target species;

(ii) the intended target species of each trip may be identified by comparing the spatial distribution of effort and CPUE data, allowing trips to be characterised more accurately;

(iii) distribution maps of catches of vulnerable species can be used to identify areas for potential fisheries closure and to monitor their effectiveness;

(iv) Vessel tracks representing the movement of individual vessels can be obtained.

(v) sampling locations can be compared with the distribution of catches or effort to investigate whether the samples are representative of the catches or effort of a fleet.

1.4 VMS in Sierra Leone

In Sierra Leone, a Vessel Monitoring System (VMS) was introduced in 2011 (Kargbo, 2018), to monitor the position and activities of licensed fishing vessels. The current system was donated by the government of the Isle of Man in 2013. The installation of VMS transponders on-board fishing vessels is a pre-condition to obtain a license and presently there is VMS coverage on licensed industrial fishing vessels in Sierra Leone (MFMR, 2017).

Monitoring the activity of vessels through the VMS is done in real time, on a 24 hour 7 day basis, at the MFMR radio and the Joint Maritime Committee (JMC) operations room (MFMR, 2017). The data collected by the VMS system is retained off-site by the VMS provider and can be obtained on request.

1.5 Structure of the existing data collection system in Sierra Leone

The management of fisheries resources in Sierra Leone is based on the collection and analysis of statistical data, market data and biological data from both the industrial and artisanal fisheries. The Ministry of Fisheries and Marine Resources (MFMR) has placed field-based monitoring activities involving field officers such as fisheries outstation managers, enumerators and dock observers at different fishing areas in Sierra Lone to support the data collection effort.

Within the technical wing of the MFMR there are two units that manage the activities of the industrial fisheries in terms of data collection and compliance with the Fisheries act of 2017: The Monitoring Control and Surveillance unit (MCS) and the Statistics Research and Policy (SRP) unit. These units work in partnership with each other as SRP is responsible for collecting logbook data, while MCS assigns observers on board fishing vessels and installs VMS transponders on fishing vessels.

For monitoring activities, fisheries observers are placed on licensed industrial vessels throughout the year as stated in part V section 29(3) 'The Director of Fisheries may require as a condition of a license issued under this Act that the operator of a fishing vessel comply with any requirement that may be imposed pursuant to the observer program'. They collect and record catch data on logbooks. In addition, they send daily catch and effort data to the SRP through the radio officer at the MFMR. A database program (the Industrial Fishery Database System-IFDAS) is used to analyse catch and effort data. There are also dock observers at major landing sites that collect catch landings for the SRP. The collection of statistical data is continuous throughout the license period of every fishing vessel.

1.5.1 *Logbooks*

This type of data has been used in the industrial fisheries to monitor catch levels and fishing activities, providing a low-cost alternative to increased monitoring and enforcement. The data often includes latitude and longitude coordinates of fishing activities, depth levels, total catch and catch composition. Logbook data has been used as sources of fisheries data in many instances for scientific research when independent data is not available. This type of data is called fisheries-dependent data, whereas scientific research represents fisheries-independent methods such as surveys (Bastardie et al., 2010).

According to the Fisheries and Aquaculture Act of 2017 part IV section 17(1) 'The operator of a licensed or authorised vessel, or of Reporting such other fishing vessel licensed under this Act, shall maintain logbooks and make such reports relating to fishing or related activities at such times, containing such information and in such formats as may be prescribed or as the Director of Fisheries may require'. In Sierra Leone logbook dataset are compiled in the IFDAS so that each fishery has a complete data of all the fishing locations for a given time period. The IFDAS system is an highly integrated fisheries management tool and covers the following important aspects of fisheries management: registration of fishing vessels with the MFMR, licensing of fishing vessels, catch recording and summary reports (monthly/annual) (Vakily J.M, 1995). It also contains the species categories, effort, hauling time and fishing coordinates. Fisheries observers record catch and effort data on industrial fishing vessels and send daily catch reports to the Ministry of Fisheries where it is recorded in the database.

1.6 Rationale

Currently in Sierra Leone the VMS is only used to monitor in real-time the activity of fishing vessels at sea. To this day the historical VMS data collected by the VMS provider has not been analysed for any purpose, in part due to lack of institutional and human resources. The database in operation (IFDAS) only contains the logbook data, while the VMS data is retained off-site by the VMS provider and can only be accessed through a data request.

This is a missed opportunity, as VMS data can provide a wealth of information that can be used, for example, to map the main fishing grounds of vessels, visualise the track of individual vessels or to verify whether the vessels follow Fisheries laws and regulations such as avoiding fishing activities within the Inshore Exclusion Zone (IEZ).

In addition, if data from the VMS is combined with logbook data, additional inferences are possible, including mapping the catch-per-unit-effort (CPUE) of the main species by the different fleets. The knowledge gained from such research will contribute to the management of fisheries in terms of decision making on policies and laws governing the fisheries, including in relation to illegal, unreported and unregulated fishing (IUU).

Vessel position data as reported by the logbook data can be verified and potentially updated by referencing them against VMS data. Currently this cannot be done in near real time because the data is stored off-line by the VMS provider and can only be accessed on request. Nevertheless, it is possible to retrospectively compare the reported positions with VMS data to evaluate possible biases and errors.

Data collection on logbook and VMS is a continuous process and knowledge gained on the effective use of such information in a developing nation such as Sierra Leone will contribute to the collective effort of nation building and to the empowerment of people in the fisheries sector. It is also worth noting that in this age of data quest and information management, it is necessary to have an effective analysis of data on a continuous basis to make informed decisions.

1.7 Objectives

The aim of the research is to evaluate the use of VMS data for purposes of monitoring and assessing industrial fisheries in Sierra Leone. We aim to:

- Evaluate the quality of the VMS data collected in Sierra Leone.
- Explore the feasibility of combining VMS data with logbook data for mapping fishing effort by vessel.
- Describe the spatial distribution of fishing effort.
- Map the catch of the main target species.

2 METHODOLOGY

2.1 Data sources

The VMS data from vessels licensed to fish in Sierra Leone's EEZ are stored off-site by AST Marine, which is the current VMS provider for Sierra Leone. At this time there is no arrangement for fishery managers in Sierra Leone to directly access or download the data, and therefore the data needs to be requested from the service provider before any analysis can be carried out. For this project we utilised a total of seven files provided by AST Marine to the MFMR. These files contained VMS data between September 2016 and November 2018. Permission to proceed with the analysis of the Vessel monitoring was given by the Director of Fisheries (MFMR).

Each file contained a table where each row corresponded to a single transmission from a single vessel, and the columns included the transponder identification number, the date and time of transmission, the date and time when the signal was received by the system, the position of the vessel as latitude and longitude (in decimal degrees), the vessel speed (in meters per second), plus some additional technical information. After standardising the format, the seven files were merged into a single dataset. Records originating from Sierra Leone waters were identified performing a spatial overlap with the boundaries of the EEZ. EEZ coordinates were obtained from Marine regions website.(Marine Regions, 2018).

The data obtained from AST Marine included the identification code for the VMS transducer, but did not include the vessel identification. Because transducers can be moved from one vessel to another (for example when a vessel has its license revoked). It is possible that records with the same transponder identification number originated from different vessels. Therefore, it is necessary to associate each VMS record with a particular vessel, and it is also required to link the VMS data to other data sources (e.g. logbooks). Personnel from the Joint Maritime Committee (JMC), who are responsible the installation and maintenance of VMS transponders, provided a list of the vessels where each transducer has been in operation, but did not provide the dates when transducers were moved among vessels.

Logbook data for the period October 2015 to June 2018 was extracted from the IFDAS in collaboration with Mr. Alpha Turay, the database developer. The logbook data contained information such as the company name, vessel category, fishing date, vessel names and international radio call sign, species group and names, discard, longitude and latitude, and the number of hauls. The logbook data was prepared by standardising the variables such as names and categories. In the raw data, number of observations (number of rows) was 331, 169. The logbook data was provided as a single long table where each row corresponded to a single species or species group captured in a tow by a vessel. In this format there is unnecessary repetition of data. In a database, logbook data are normally stored as two tables, one table containing all the information associated with each fishing event (for trawlers this would be individual tows) and a catch composition table listing the species caught and amount caught. After standardising the variables such as vessel names and categories, the raw data table was thus divided into two tables: A setting (tow) table and a catch by species table.

In order to associate the VMS and the logbook datasets it is necessary to create a key or identifier using data present in both tables. EEZ coordinates were obtained from Marine regions website (Marine Regions, 2018).

2.1.1 *Identification of VMS records associated to fishing activities*

In normal conditions, vessels equipped with VMS transmit information at regular intervals regardless of whether the vessel is fishing or not. Therefore, a critical step in the use of VMS data to map fishing effort is to identify which records originated at time intervals when the vessel was fishing. This is usually done using speed criteria, i.e. selecting a range of speeds that can be connected to fishing activities. VMS data usually includes instantaneous speed (i.e. the speed of the vessel at the time of the transmission). Speed can also be derived from the distance and time between records. In many cases, if we plot a histogram or a density curve of the speed of a vessel, we see a bimodal distribution where modes can be related to different activities: lower speeds are usually associated with fishing, while higher speeds originate when the vessel is steaming or moving between fishing grounds. Analysis was carried out by grouping vessels into three categories, based on their fishing gear and target species: demersal, midwater and shrimp. A small number of vessels were included in multiple categories.

An initial examination revealed that there was significant variation in the speed profiles in vessels in the same category. Therefore, speed criteria were selected for each vessel individually by visually examining their speed profile.

2.1.2 *Association of VMS and logbook data*

Preliminary data analysis was carried out both in the VMS and logbook datasets in order to describe basic properties of both datasets and to identify possible gaps in coverage. For each vessel, the potential association between VMS and logbook data was explored by evaluating the presence of VMS records classified as fishing in dates where the logbook database indicated that fishing activity took place. We restricted the analysis to data obtained between May 2017 and June 2018. This was done to obtain a full year of data for both the VMS and logbook data while at the same time minimizing the probability that the transponders were moved between vessels.

2.1.3 *Mapping fishing effort and catch*

Fishing effort was defined as the number of VMS records classified as fishing per cell, computed in a regular grid with a spatial resolution of 1/100 of an arc-degree and with an extent large enough to encompass the EEZ of Sierra Leone. A map was produced showing the overall distribution of fishing effort using all VMS records classified as fishing regardless of whether they were associated with a logbook entry. We also produced maps of fishing effort by vessel category, in order to compare the spatial distribution of effort among vessels using different fishing gears.

In order to demonstrate how VMS data can be used to map the distribution of species or species groups, we mapped the catch of the main species groups reported in the logbook database. This was done first by obtaining the total catch of each species group by each vessel and each day. Next, those catch values were assigned to the VMS records classified as fishing from the corresponding vessel and date. Distribution maps were produced by adding the total catch in each cell of a regular grid with a spatial resolution of 1/100 of an arc-degree and with an extent large enough to encompass the EEZ of Sierra Leone. In order to compare the distribution of the catch among groups, all maps were standardised to a scale between 0 and 1. All analysis was carried out using the R statistical language (R Core Team, 2018).

3 RESULTS

3.1 Vessel Monitoring system Data

The total number of VMS records in the data provided by AST marine is 2,185,902, from which a total of 1,904,166 points were located within the EEZ of Sierra Leone. Figure 2 shows the number of VMS records per month in the raw dataset. It is observed from the figure that the number of VMS records increased between October 2016 and October 2017 and fluctuated thereafter with no clear trend. This increase is likely reflecting the increase of licensed vessels with VMS transponders as compared to the latter period.

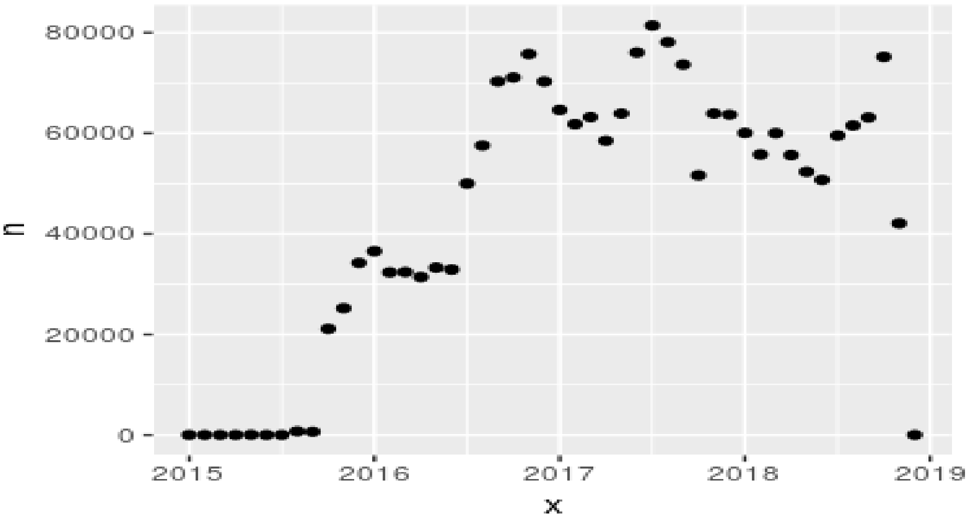

Figure 2 Number of VMS record per month of raw data on the raw dataset obtained from VMS provider.

The frequency of VMS transmissions was analysed by vessel category. The total number of VMS records in vessels from the demersal category between June 2017 and May 2018 was 772,258 from which a total of 683,459 were from within Sierra Leone EEZ. Most of the vessels had >21 pings per day, for example vessel numbers 3,16 and 40 (Figure 3). This is the expected pattern, given that VMS transponders are supposed to send a transmission once per hour. On the other hand, in some vessels the frequency of transmission is much lower. For example, vessels 37 and 38 transmitted less than 15 pings per day, and sometimes less than 10 pings per day, and vessel 22 transmitted less than 5 pings during large intervals. It is also evident in this graph that for some vessels there are gaps or periods where VMS data is not existent, which could be associated to malfunctioning transducer or errors in the data storage and retrieval. The graph also shows that the database includes some vessels with very few VMS transmissions.

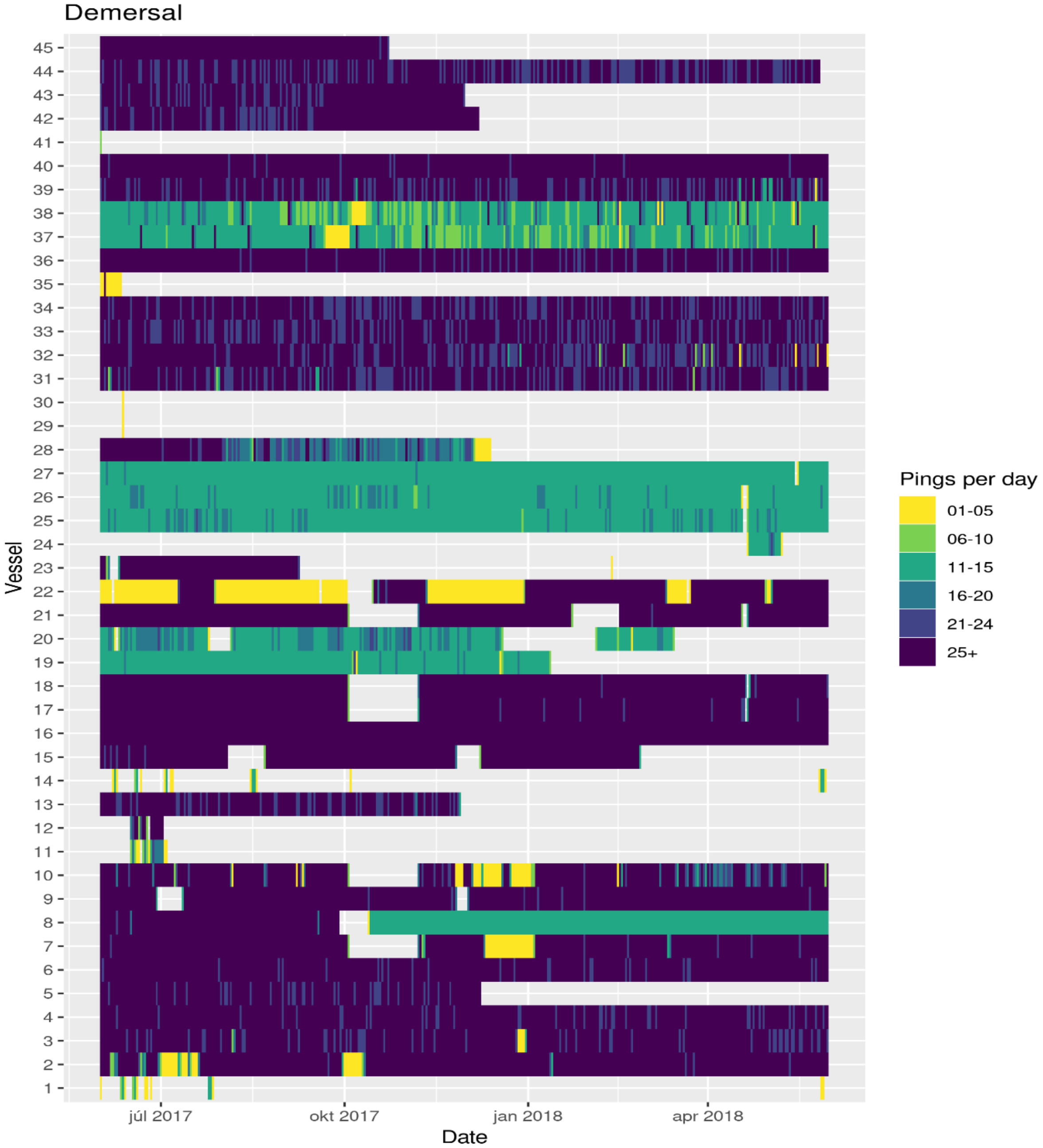

Figure 3 Number of VMS transmissions per day by demersal trawlers in the period between June 2017 and May 2018

There were only 13 vessels in the midwater vessels category (Figure 4) and from these six vessels (e.g. vessels 2. 3 and 10) showed relatively low (<15) number of pings per day. The shrimp included 18 vessels (Figure 5). Most of the vessels in this category had >21 pings per day. There was a gap in the data over several vessels (vessels 11-18) for the period October-December 2017, which was likely due to an error in data storage or retrieval. One vessel (vessel 8) had a consistently low ping rate of <10 pings per day.

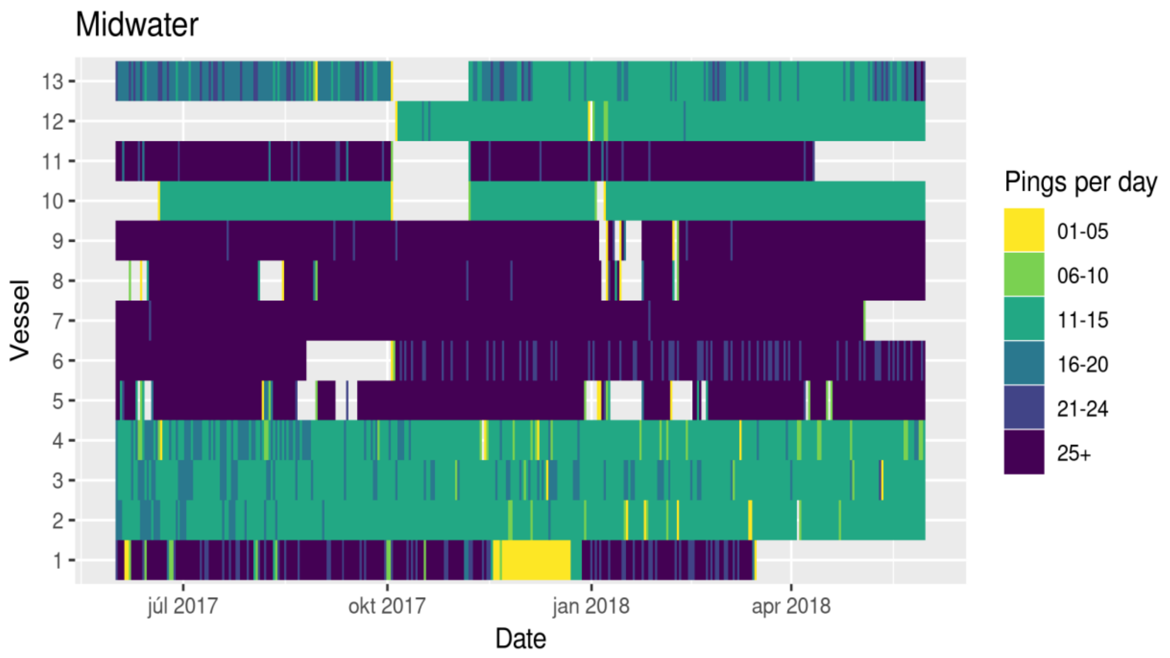

Figure 4 Number of VMS transmissions per day by midwater trawlers in the period between June 2017 and May 2018.

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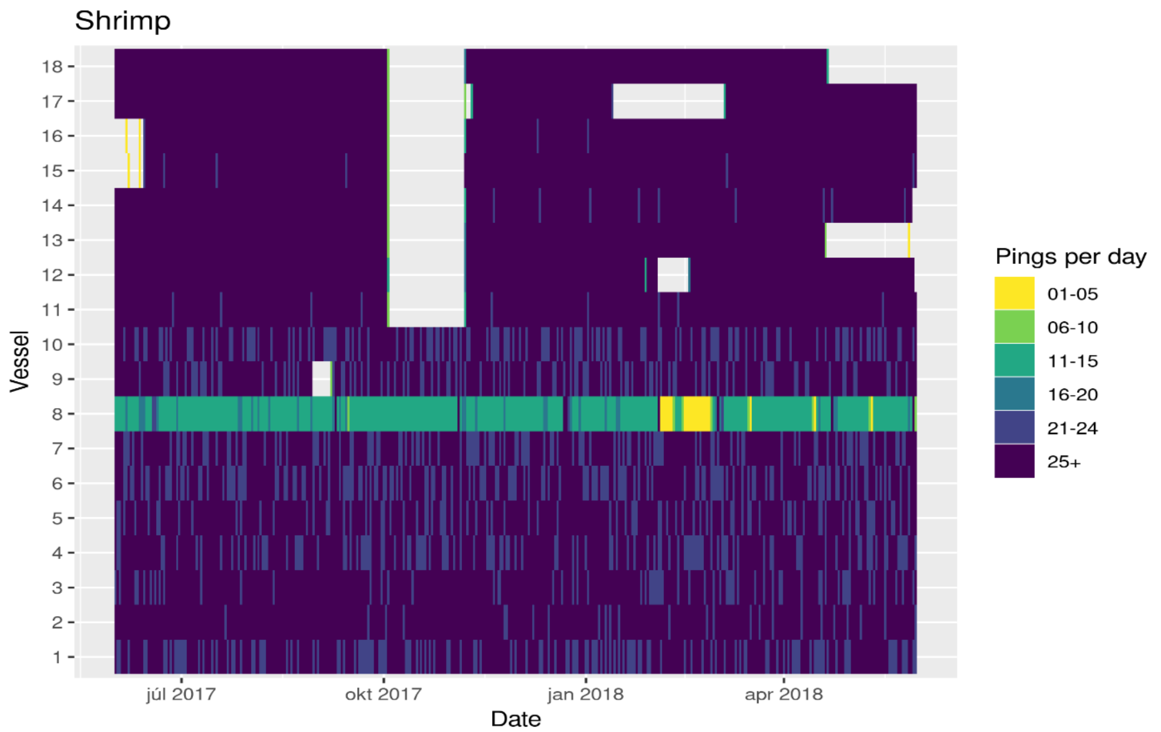

Figure 5 Number of VMS transmissions per day by shrimp trawlers in the period between June 2017 and May 2018.

3.2 Analysis of Vessel Speed

The average density distribution of vessel speed in each category, and the density distribution of the speed of individual vessels are shown in figure 6. The NA on figure 6 shows the speed profile of vessels not assigned to any vessel category. Midwater trawlers normally fish at a faster speed as compared to vessels in other categories such as shrimp trawlers. The individual speed profiles shown were used to assign fishing criteria for each vessel, the range criterion based on where the ascending slope started, and descending slope ended.

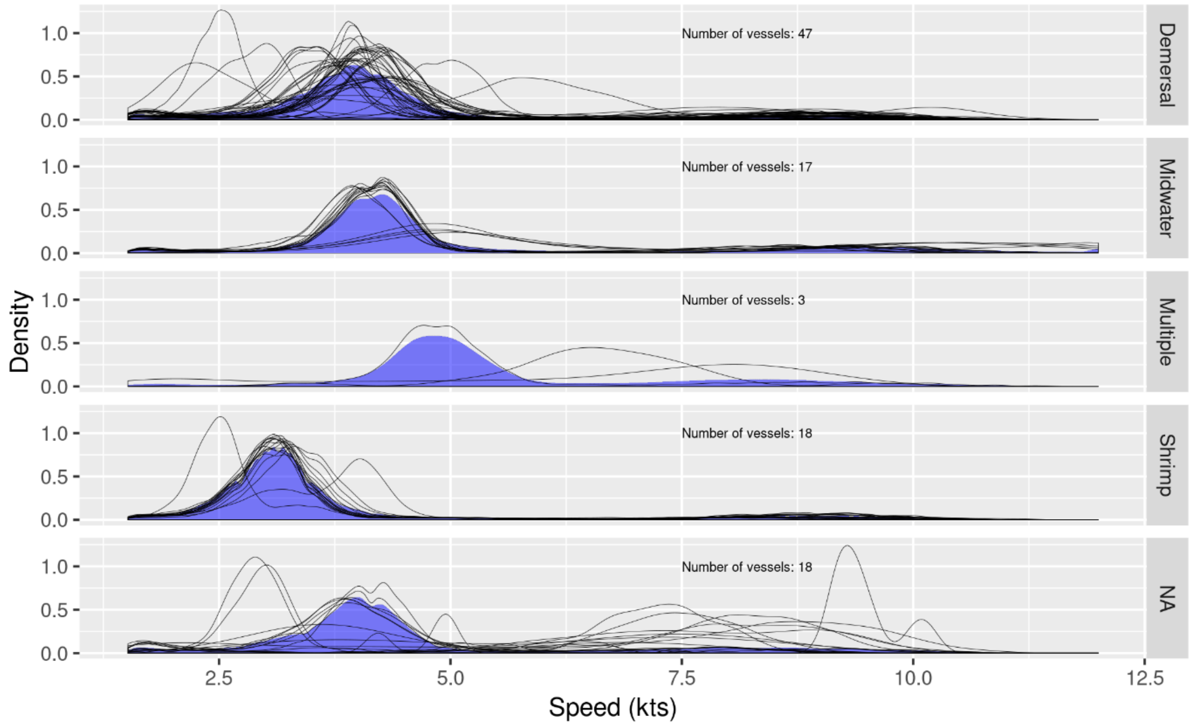

Figure 6. Density distribution of vessel speed by category obtained from VMS data.

The blue curve shows the mean distribution in each vessel category, while the back lines show the distributions for individual vessels. The NA shows the speed profile of vessels not assigned to any category.

3.3 Analysis of Logbook Data

In the period between June 2017 to May 2018 July 2017 the logbook database included records from 54 vessels. In general, demersal trawlers reported a low number of hauls per day (Figure 7) Only a few vessels reported several hauls per day such as vessels 39, 53 and 54.

Figure 7 Number of hauls per day registered in the logbook database by demersal trawlers.

The logbook data included 21 vessels in the midwater category. It is observed in figure 8 that vessels 17-21 reported a very low number of hauls, and this is likely due to errors in the database (potentially wrong dates).

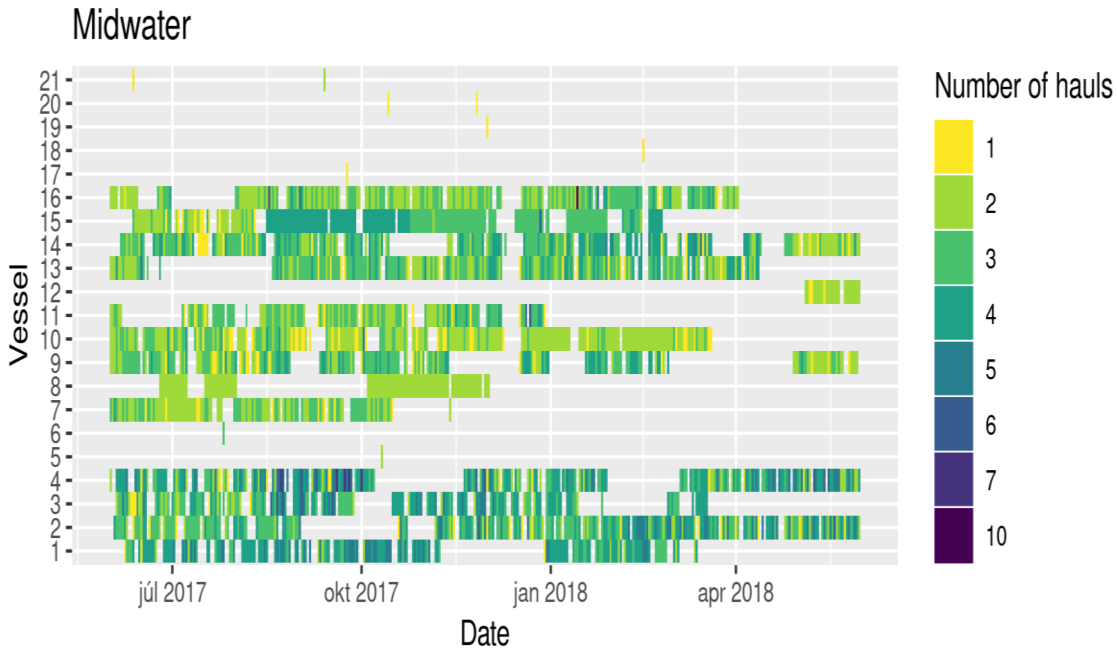

Figure 8 Number of hauls registered in Logbook database by midwater trawlers.

Shrimp trawlers reported more hauls per day than vessels in other categories (Figure 9). From the 21 vessels in this category most reported >5 hauls per day.

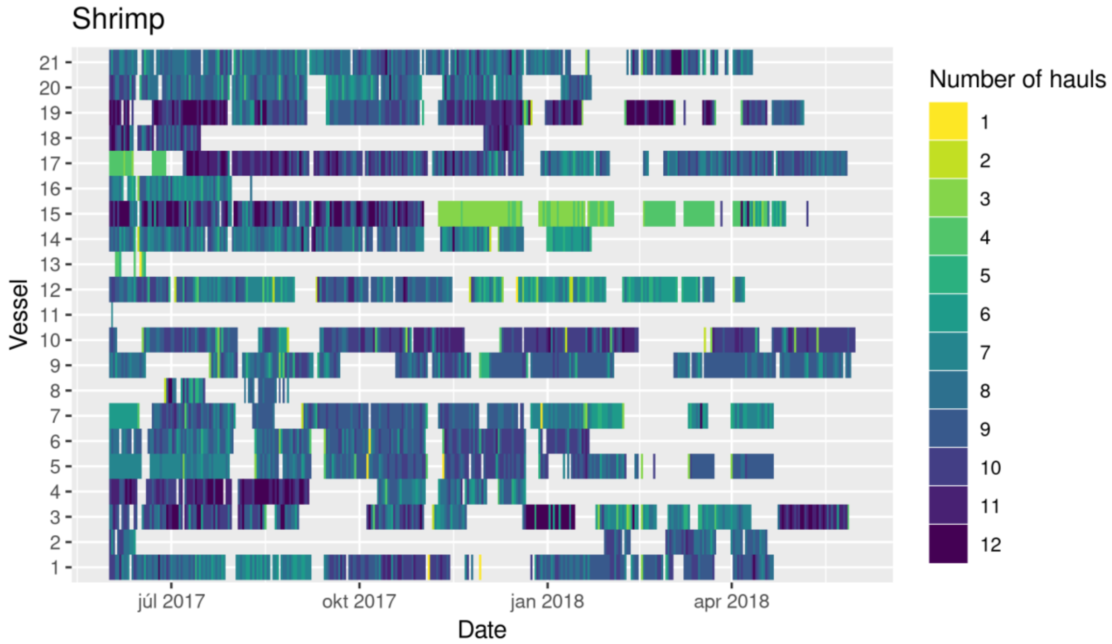

Figure 9 Number of hauls registered in logbook database by shrimp trawlers.

3.4 Exploratory Analysis of Logbook and VMS data

The coincidence of VMS and logbook data was evaluated by date and vessel by comparing the presence of VMS data classified as fishing and the presence of logbook entries. The expectation was that on days where fishing activity was reported in the logbook database there would be at least one VMS record in which the vessel was moving with the speed range considered indicative of fishing activities. Results for demersal, midwater and shrimp trawlers are shown in Figures 10, 11 and 12 respectively. The plot only shows the available data during the period June 2017 to May 2018, a period over which migration of transponders were likely at minimum.

Some patterns are evident when compared to both the logbook and VMS datasets (Figures 10, 11 and 12). First, the number of overlaps is not total, and there are logbook entries not associated with VMS data, and VMS data not associated with any logbook entry. Nevertheless, for many vessels the degree of overlap is quite high and consists of a combination of days with both logbook reports and VMS data within fishing speeds in the same day, with days where the vessel was moving at speed classified as fishing, but no fishing activity was reported in the logbook. Examples of these patterns include, demersal trawlers number 41 and 42, or midwater trawler number 2. Secondly, a number of vessels including at least eight demersal trawlers (e.g. vessels 17 and 23) and one midwater trawler have been reporting fishing activity but there is no VMS data associated with these vessels. Third, some vessels show acceptable overlap in the early part of the period analysed, but do not have logbook entries in the later part. Examples include midwater trawler number 7, and shrimp trawler number 14. These patterns may be due to recent logbook records not having been entered into the database yet.

Figure 10. Co-occurrence of VMS data and Logbook entries by date (Demersal vessels)

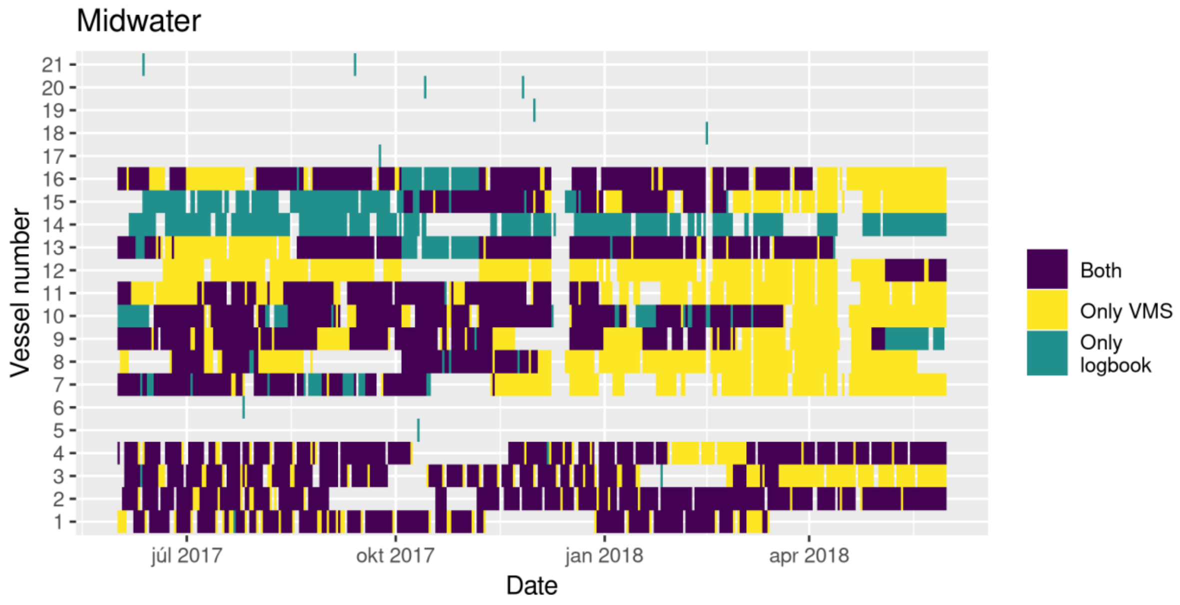

Figure 11. Co-occurrence of VMS data and Logbook entries by date (Midwater vessels)

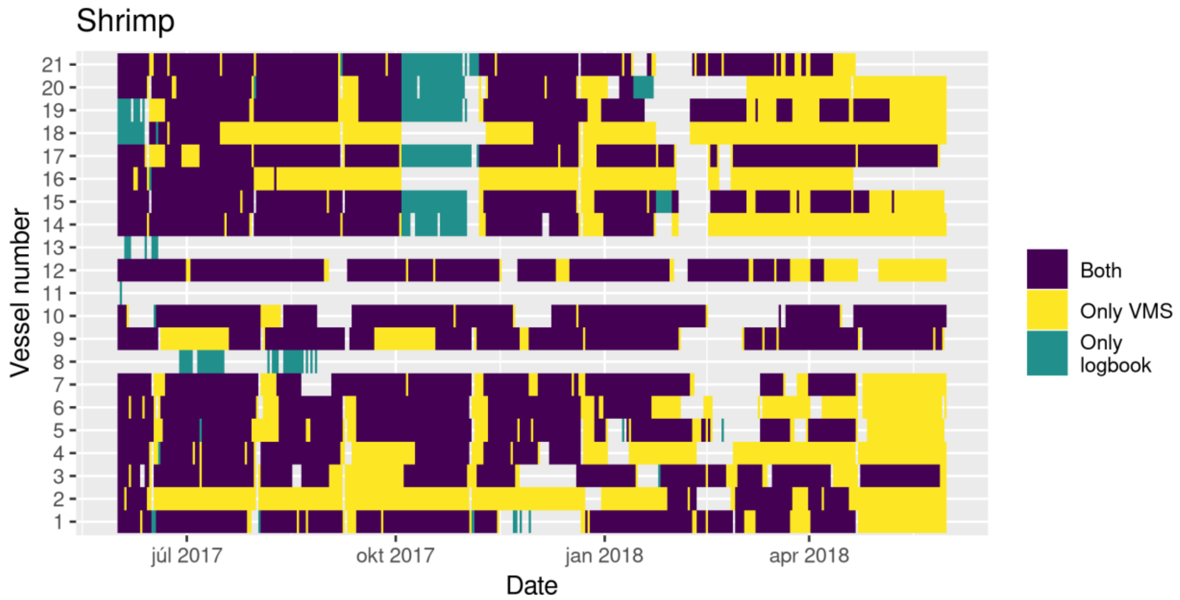

Figure 12. Co-occurrence of VMS data and Logbook entries by date (Shrimp vessels)

3.5 Fishing Effort

The map in figure 12 shows the distribution of fishing effort using VMS records that have been classified as fishing within the limited data timeline of June 2017 and May 2018. It is observed that there are more concentrated records on the south west of the map, as the continental shelf is relatively narrow on the south and starts expanding toward the north. Most of the fishing activity is concentrated towards the south west and north due to the upwelling on the north which has high nutrient content

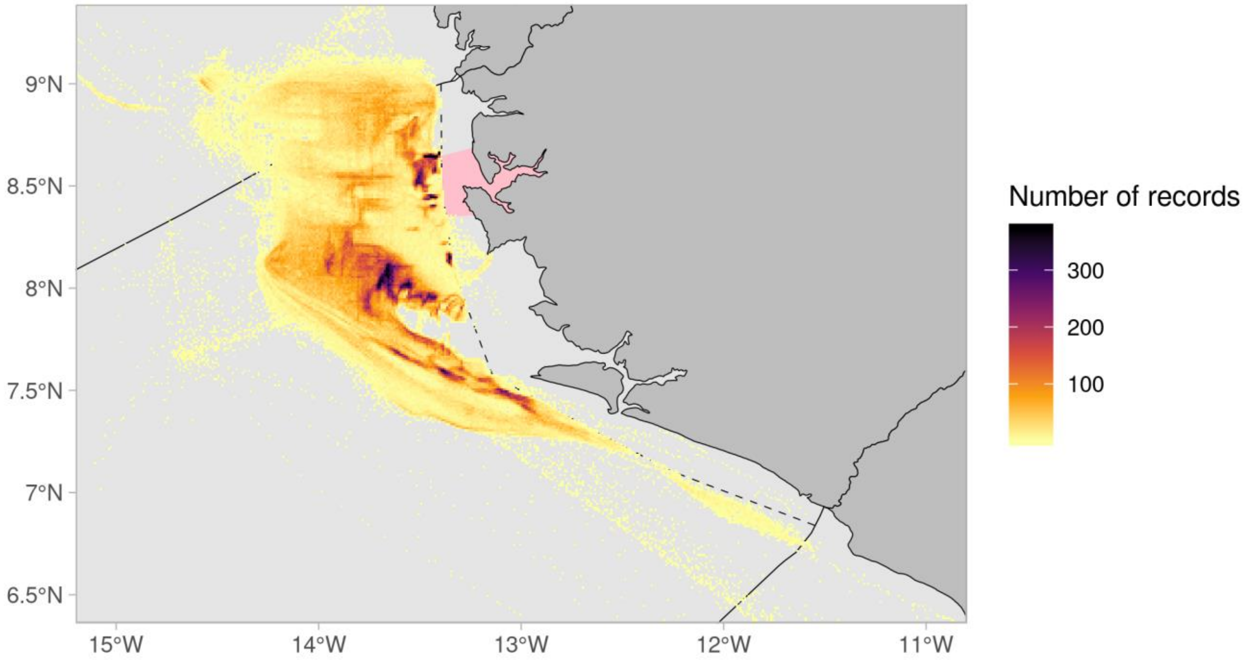

Figure 13. Map of fishing effort, defined as number of VMS records classified as fishing per cell in a regular grid with a spatial resolution of 0.05 degree.

3.6 Distribution of Relative Fishing effort

Maps of relative fishing effort were produced, where the fishing effort from each vessel category was standardised into a scale between 0 and 1 to allow a comparison of their spatial distribution (Figure 14). The dark areas show where effort is close to the highest effort for that category. The maps show differences in the spatial distribution of fishing effort among vessels of different categories. Fishing effort by demersal and midwater trawlers is more widely distributed than shrimp trawlers or vessels using multiple gears.

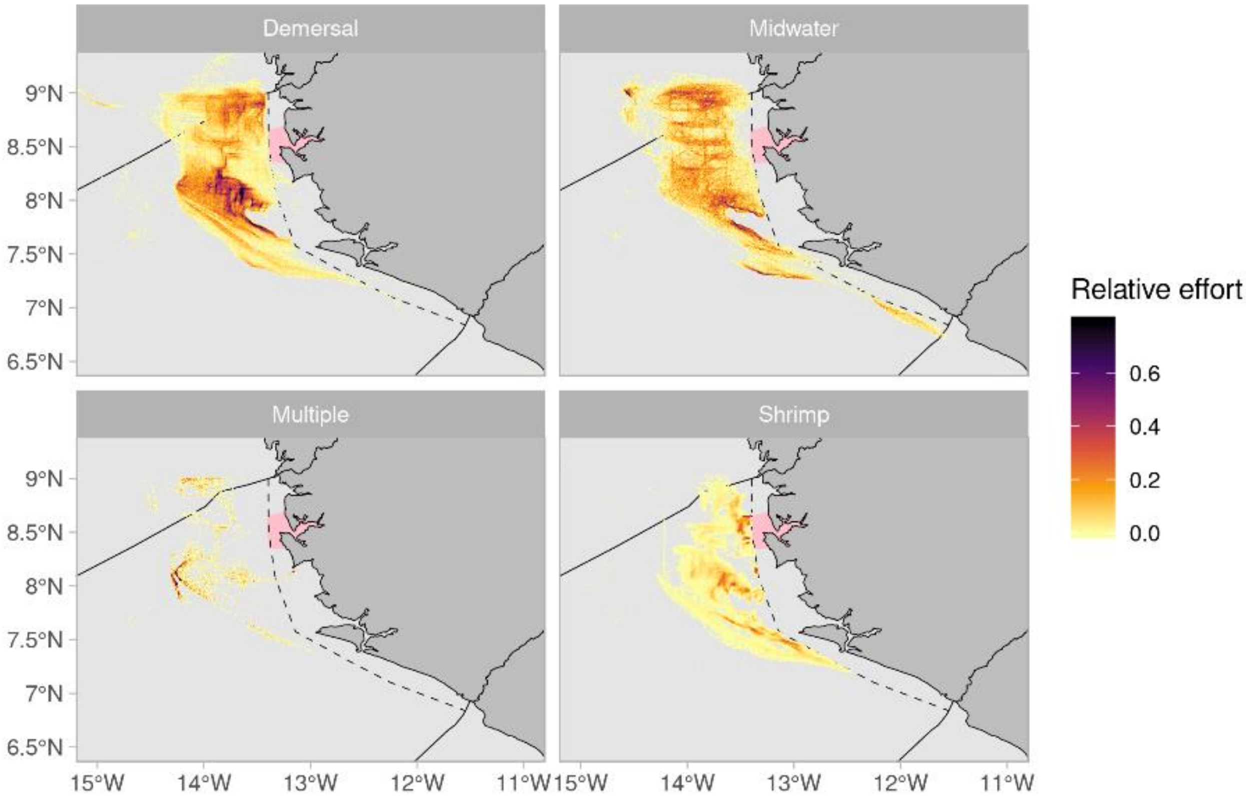

Figure 14 Map of Relative Fishing effort by vessel category

3.7 Relative catch

As a demonstration, we combined VMS and logbook data to map the distribution of the catch of the main target species (Figure 15).

The map shows that the distribution of the catch of demersal species, and the reported discard is distributed relatively evenly in the shelf. The catch of pelagic species and cephalopods on the other hand had more skewed distributions and were concentrated in a particular location. Sharks and rays have dispersed distributions between the north and south of the continental shelf.

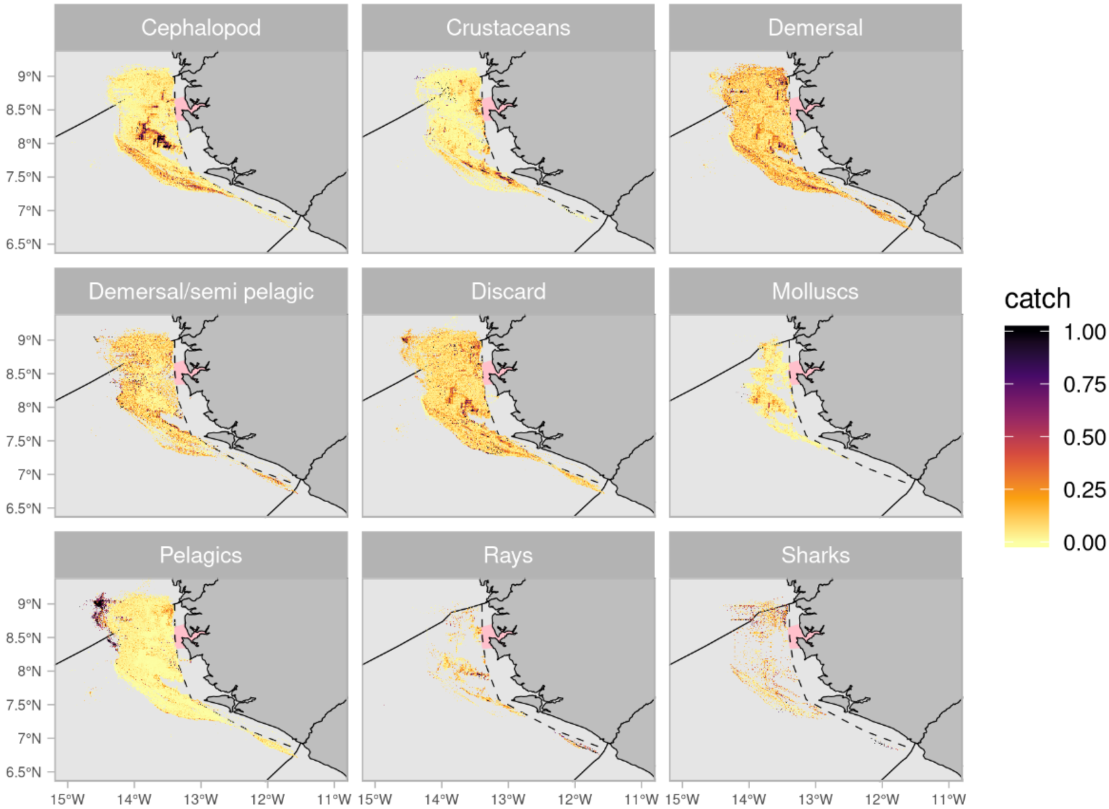

Figure 15 Relative Catch of the main target species defined as the number of VMS records from hauls where each species was reported.

Values were standardised as a 0-1 scale to allow comparison of the distribution among groups.

4 DISCUSSION

4.1 Exploratory analysis of VMS data

To this date the VMS has been used in Sierra Leone to monitor the position of fishing vessels in real time. Even though the use of VMS data in Sierra Leone started in some form in 2011, and the current system has been in operation since 2013, this work represents the first time the VMS data collected has been compiled and analysed retrospectively. In addition, this is the first attempt ever made to link VMS and logbook data in Sierra Leone and to evaluate the potential use to map fishing effort and catch.

The analysis of VMS data collected revealed that there are limitations and inconsistencies in the data which seriously restrict its usefulness for fishery management purposes. Our analysis concentrated on the period between June 2017 and May 2018, but it is likely that the issues observed are representative. In the first place, several transponders emitted signals at lower temporal frequencies than expected. Figures 3, 4, and 5 showed the number of pings per day for individual vessels. If VMS transponders are sending a transmission once every hour as they are supposed to, it is expected that the average number of pings per day should be 24. This was observed for many vessels, but not for all. From the 46 vessels in the “demersal” category that were transmitting for a significant period, 10 of them (27.8%) had ping rates of 15 per day or less. Six of the 13 vessels (46.2%) had similarly low ping rates. The situation was better among shrimp trawlers, where only one of the 18 vessels (5.5%) had low ping rates. In most cases, vessels displayed with low ping rates for extended periods, which highlights the necessity for the VMS data to be examined on a regular basis to ensure that transmissions are occurring as expected.

Low ping rates are problematic for several reasons. In the first place, if the interval between pings is lower than the average duration of a fishing event (e.g. a trawl or a net cast), then fishing effort estimates derived from VMS data will be biased because there will be cases when transmission occurs before and after, but not during a fishing event. Low ping rates also reduce the spatial resolution (i.e. the amount of detail) that can be obtained when producing maps derived from VMS data, which is problematic when evaluating compliance with fishing regulations like closed areas or when comparing the distribution of effort and catch with features like depth contours, oceanic fronts, etc. Hourly ping rates are very commonly used in developed (Bastardie et al., 2010) and developing (Joo, Bertrand, Chaigneau, & Ñiquen, 2011),(Walker, Gaertner, Gaspar, & Bez, 2010) nations. Although hourly ping rates have been considered too low and more frequent ping rates (one ping per 20-30 minutes) have been suggested to improve the quality of fishing effort estimates (Deng et al., 2005),(Lambert et al., 2012), this is usually not carried out because of the cost of the satellite transmissions. Therefore, a one-hour ping rate should be considered the minimum acceptable, and efforts should be made to ensure that the transponders are emitting at that rate.

Several vessels showed gaps in the temporal coverage of VMS transmissions. Occasional gaps may be due to a malfunctioning transducer or some other technical issue but may also indicate tampering when the gap coincides with the presence of “reefer” vessels in the area or when multiple vessels stop transmitting at the same time. One potential example can be seen in vessels 5, 8 and 9 from the “midwater” category, all of which show coincident temporal gaps in January 2018. On the other hand, several vessels show a gap in the coverage for the entire month of October 2017, including six demersal trawlers, three midwater trawlers, and eight shrimp trawlers. In this case, it is likely that the gap is due to a mistake in the data extraction or a problem in the database when the data is stored. A number of transponders were included in the database but had a very low total number of transmissions. The status of these vessels should be evaluated to assess if they still have valid fishing licences or if they have moved away from the EEZ of Sierra Leone.

The lack of a clear record of the dates when transponders were moved among vessels is problematic. Whereas when using the VMS system to track the position of vessels in real time it is only necessary to know in which vessel each transponder is currently located, when analysing VMS data retrospectively it is essential to know also when a transponder was moved from one vessel to another. Without this information it is not possible to reconstruct a time series of data for all vessels. Clear records should be kept of the dates when transponders enter into operation, are moved between vessels, or are removed from vessels, in order to allow researchers to unequivocally assign the VMS transmission to the vessel from which it originated.

4.2 Exploratory analysis of Logbook data

It was observed in the Logbooks and license lists that there were some mismatches in data organisation such as inconsistency in categorical variables, file names, dates format that were not in line with ISO 8601 standards, empty cells, multiple data in a sheet, and highlighting in Excel worksheets. All these were solved in the final analysis with only a fraction of the data which was used to derive the different figures of species and vessel categories.

It was also observed that there is some inconsistency in the data arrangement with observations and variables. Such examples include different spellings for vessel names, no standard date format used, inconsistency in vessel category (e.g. a vessel having different categories, for example switching from midwater to demersal). Only the dataset from July 2017 to April 2018 was used, the reason being that during this period transponder migration in the VMS data used were considered minimal. The number of hauls registered in the logbook database by vessel and days was used to give a holistic view of the status of the logbook data as shown in figures 7, 8 and 9. Hauls in this context means the number of times the fishing gear was pulled from the water at a certain date as recorded in the logbook database.

4.3 Association between VMS and logbook data

In an ideal situation, most or all fishing activity will be reflected both in the VMS data as VMS records classified as fishing, and in the logbook as registrations of tows or other fishing events, and both sources of data should show a high level of coincidence. In this study we evaluated the level of coincidence or overlap between VMS data classified as fishing using speed thresholds for individual vessels, and the presence of entries in the logbook dataset. The comparison, done by vessel and date, is shown in figures 10, 11 and 12. The results are mixed. On the one hand, it is evident that there is a fair amount of overlap between the VMS and logbook data, meaning that for a particular vessel there is at least one VMS record classified as fishing in dates in which fishing activity was reported in the logbooks, with some vessels having a relatively high degree of coincidence through the entire period. On the other hand, there are several problematic patterns. First, there are vessels that are reporting fishing activities in the period June 2017 – May 2018 but for which there is no VMS data classified as fishing, including eleven (11) vessels in the demersal category and one (1) vessel in the midwater category. Given that having a functioning VMS system is a pre-requisite for obtaining the fishing licence, it is puzzling that there is no VMS data for these vessels. Second, there are vessels that have VMS records classified as fishing for large periods, but for which there are no logbook entries. This in part could be because some data may not have been entered in the logbook database, in cases later in the study period, or cases of mismatch between the VMS and logbook databases due to inconsistencies in vessel names. It is also possible that some of these records represent cases in which a vessel engaged in fishing activities without reporting data for the logbook.

4.4 Fishing effort exploration

The data found in VMS was used to plot a map in figure 14 of the relative fishing effort defined as number of VMS records classified as fishing and a distribution of the fishing effort by vessel category. Data from the logbook were used to plot a map as shown on figure 15 referred to as a relative catch. These plots only show the possible outcome of using the VMS and logbook datasets. It was observed that there were more pings associated with demersal as compared to vessels in the midwater and shrimp category with the reason being that there are more licensed demersal vessels than the other categories.

5 RECOMMENDATION AND CONCLUSION

The VMS already has a role in the enforcement of fishery regulations in Sierra Leone, providing in real time to the authorities the location of vessels suspected of having committed infringements and enabling inspectors on patrol vessels to carry out the necessary investigations at sea. But in addition, the data collected by the VMS has the potential to greatly improve the management of the industrial fisheries in Sierra Leone, by serving as a baseline to validate the positions reported in the logbooks, by providing independent estimates of fishing effort, and by allowing the mapping of effort and catch.

Nevertheless, the irregularity in ping rates, gaps in VMS coverage, and lack of clarity in the information about dates of transfers of transducers, seriously limit the usability of VMS data for fishery management purposes. In addition, inconsistencies in the logbook database introduce additional difficulties when combining VMS and logbook data. Following are a set of recommendations to solve some of these issues.

1. Nowadays, fishery managers in Sierra Leone do not have direct access to the VMS data collected by vessels operating in national waters. VMS data needs to be requested from the service provider, and it is usually delivered albeit with some delay. As an immediate solution it is necessary to arrange with the service provider that the VMS data is delivered regularly, for example once per month. A better solution would be for the data to be stored in a cloud-based service which could be automatically downloaded into a database maintained by personnel of the Ministry of Fisheries and Marine Resources.

2. The quality of the VMS data needs to be monitored in a continuous base, in cooperation with personnel from the JMC. Gaps in VMS coverage and changes in ping rate should promptly be identified so measures can be taken to ensure the quality and integrity of the data.

3. There was a significant degree of mismatch in the information from both the logbook and VMS data which needs to be solved by synchronising the logbook database with the license list, the VMS transponder list, and the VMS data itself. It is therefore necessary to have all data in a centralised database hence avoiding having different portions of the data stored and managed by different agencies. Work needs to be done to merge the data and have a comprehensive, high-quality data structure that allows the integration of VMS and logbook data.

4. The VMS and logbook data must be analysed jointly in a continuous basis to verify the integrity of the logbooks reported. In particular, the spatial position of the hauls reported in the logbook should be compared with the position of the VMS transmission. Cases when there are

discrepancies between the actual position of the vessel derived from the VMS and the reported positions of hauls should be investigated.

5. Fisheries officers and data entry personnel should be trained on how to maintain the proper data structure such as recording information, data entry format and interpreting data on a regular basis. This is necessary to minimise the errors observed during the data cleaning process.

6. The AIS (Automatic Identification System) data should be stored and analysed. The AIS is a system independent from the VMS and is based on radio transmissions and usually has a higher transmission frequency that the VMS. The position of fishing and other vessels is also monitored in real time at the JMC using the AIS. The AIS allows for vessel tracks from individual vessels to be downloaded for a period of up to 90 days, although the system does not provide the option to download the data from multiple vessels in bulk. Nevertheless, it would be possible to regularly download the data from individual vessels in order to compile a database like the VMS. Then VMS and AIS data could be joined to increase the temporal resolution of data and provide positions for vessels without a functioning VMS transponder (for example reefer vessels).

8. The use of the electronic logbooks should be explored, allowing fisheries observers to record and transmit the information digitally using a tablet or smartphone. It has the benefit of making the process of gathering and transmitting logbook data more accurate, and less costly, and would allow a much more rapid analysis of the data

9. Efforts should be made to train personnel in modern methods of data management and analysis, using 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.

Given that the authorities in Sierra Leone are considering upgrading the current VMS system with a new service provider, it is of great importance that these recommendations are considered to ensure that the maximum benefit can be obtained from this data. Given the financial cost that maintaining a functioning VMS represents for the government of Sierra Leone, and the potential uses and benefits from VMS data, it will be a missed opportunity if we do not ensure that the data collected by the VMS is of the highest quality possible.

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