RE-ANALYSIS OF HORSE MACKEREL (*TRACHURUS SPP*) ABUNDANCE AND GEOGRAPHICAL DISTRIBUTION IN RELATION TO ENVIRONMENTAL EFFECTS, USING ACOUSTIC DATA FROM A SCIENTIFIC SURVEY CONDUCTED BY RV DR. FRIDTJOF NANSEN IN 2014

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ABSTRACT

Horse mackerel (*Trachurus spp*) is one of the major commercial fish species in Angola. Its abundance and distribution are not only affected by the fishery, other factors also have an effect. In this study geographical distribution, the effect of using a different target strength coefficient (72 dB versus 65.2 dB) on abundance estimates, and environmental effects on *T. trecae*, both on presence/absence and abundance, distribution were explored. Only one-year survey data was used; therefore, it should be taken into consideration when interpreting the results. *T. trecae* showed a wide geographical distribution surprisingly with more presences in higher salinity areas (35.7 – 36.0 ppt) and higher abundance over a narrow range of dissolved oxygen (2.0 – 4.0 mgL^{-1}). There was no difference in geographical distribution between immature and mature individuals. Temperature is normally used to describe the distribution of pelagic species, surprisingly for this study, no significant influence on neither presence nor abundance of *T. trecae* was noticed. The use of a target strength coefficient value of 65.2 dB instead of the currently used value of 72 dB, resulted in a 79% decline in estimated biomass. This emphasizes the need of *in-situ* measurements of *T. trecae* target strength in Angolan waters.

Keywords: *Trachurus spp*, *T. trecae*, abundance estimates, geographical distribution environmental effect, target strength, presence/absence.

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1. INTRODUCTION

Angola is located on the southwest coast of Africa, between Namibia and the Democratic Republic of Congo, and is home to about 26 million people (INE, 2014). The country has a coastline of 1650 km and a continental shelf that is 51000 km^2 (República de Angola, 2013). The commercial value of marine fisheries in Angola is only approximately 4 % of the annual Gross Domestic Product (GDP). However, fish is a national staple food as it supplies 60% of animal protein consumed annually by the Angolan population (Angelini & Vaz-Velho, 2011; Chilamba, 2016). Sustainability of fisheries in Angola is therefore vital for the food security of the nation.

Horse mackerel is the most important species as it constitutes 24% of the total annual catch and it is the most popular species for human consumption (INIP, 2014). There are two horse mackerel species (*Trachurus spp*), that is, Cunene horse mackerel (*Trachurus trecae*) and Cape horse mackerel (*Trachurus capensis*) which are managed as one stock. The fishery began in the late 1940s and has been managed using total allowable catch (TAC) since 1995, which is established by scientific stock assessment. Bi-annual scientific surveys measure stock size using hydroacoustics and simultaneously measure environmental conditions.

Understanding how the physical environment influences geographical distribution of fish stock is important and provides auxiliary information for stock assessment and fisheries management. Limited knowledge is available on how environmental variables influence horse mackerel geographical distribution in the Angolan Exclusive Economic Zone (EEZ). Therefore, this study explores how ambient temperature, salinity, dissolved oxygen and fluorescence influence geographical distribution of horse mackerel using information from a Nansen scientific survey conducted in winter 2014.

Hydroacoustic methods utilize *in-situ* information on species specific target strength (TS) to convert backscatter into fish numbers. TS has not been measured for horse mackerel in Angolan waters, instead herring TS is used. One of the aims of the present study is to explore how different TS values influence horse mackerel stock biomass estimates. This is done to facilitate understanding the importance of measuring *in-situ* horse mackerel target strength in Angolan waters.

1.1 Problem statement

There is limited knowledge on how the physical environment influences stock size, mediated via recruitment, survival, and changes in geographical distribution. Given the data at hand, the first step is to understand how environmental variables influence geographical distribution of horse mackerel. Such analysis identifies which environmental conditions horse mackerel prefer to occupy and which conditions they avoid.

Target strength (*TS*) is a key variable when converting acoustic backscatter to an abundance index, however, the variable has never been measured *in-situ* for *Trachurus spp.*, in Angolan waters. In the Angolan biomass estimates of horse mackerel, a TS from the Norwegian spring-spawning herring has been used with a constant of 72 dB (target strength (dB) = 20log(length) – 72 dB; Foote, 1987). A study in Namibian waters resulted in *Trachurus capensis* target strength equation with constant of 65.2 dB (Axelsen, *et al*., 2003). A higher constant in the target strength equation, results in a higher stock index. In the wake of these findings there is

a need to compare the abundance estimate indexes resulting from the use of the two-different constants, to reveal to what extent different target strength influences the stock index calculations.

1.2 Objectives

The project has two objectives: (1) to understand how the physical environment influences geographical distribution of the two horse mackerel stocks at different life history stages (immature versus mature fish) during a period of small stock size; and (2) to estimate how the survey abundance index calculations are affected by different target strength values to convert backscatter (S_A-values) into number of fish.

1.2.1 Specific objectives

a) To examine stock structure of the two horse mackerel species, and the geographical distribution;

b) To observe the influence of physical environment (water temperature, salinity, dissolved oxygen, and fluorescence) on horse mackerel geographical distribution;

c) To compare how two different target strength values 72 dB and 65.2 dB influence estimated mackerel biomass.

2 ANGOLAN FISHERIES

Annual fish catches in Angola were estimated approximately 350 thousand tons in 2014 with an estimated value of 950 USD million (Chilamba, 2016). The five most prized fish species are: croakers *(Atractoscion aequidens;* USD 5 per kg), cod (*Brotula barbata*; USD 4.25 per kg), horse mackerel *(Trachurus spp;* USD 4 per kg), dentex *(Dentex spp;* USD 4 per kg) and African moonfish *(Selene dorsalis;* USD 3.75 per kg) (Chilamba, 2016). Fishing is mostly done by two different fleets; industrial fleet and semi-industrial fleet (Table 1) (COFREPECHE, 2013; INIP, 2014; Baião, 2015; MinPescas, 2015; Chilamba, 2016)**.**

Table 1. Two main pelagic fishing fleet.

Identifiers	**Industrial**	**Semi-industrial**
Vessel Length (m)	> 45	10 - 45
Fishing gear	Pelagic and Bottom Trawl	Purse seine
Proportion to annual catch*	36%	54%
Fishing zones (NM) **	10	4 < 10

* 2014 ** distance from the coast line

2.1 The horse mackerel fishery

Horse mackerel fishery is one of the main fisheries in Angola due to its importance both economically and as a source of animal proteins with national consumption of 19 kg per person per year (Chilamba, 2016). Due to higher national demand for fish but limited supply, market prices have increased from USD 2.5 per kg in the early 2000s to USD 4 per kg in 2016. The fishery began in the late 1940s, but catch numbers are only available since the late 1970s. The annual catch declined by a factor of ten, from 600 thousand tons to 72 thousand tons, from the late 1970s until 2015 (Figure 2) (Luyeye, 1995; Chilamba, 2016). In 2015, horse mackerel

catch was 24 % of the total fish catch in Angola (MinPescas, 2014). The fishery operates in three provinces that are located adjacent to the major horse mackerel distribution areas: Namibe, Benguela and Luanda (Figure.1).

Figure 1. Horse mackerel fishery in red circles. Source: Chilamba, 2016.

The fishery has experienced various changes during the last five decades. Fleet composition changed from semi-industrial to industrial, semi-industrial and artisanal. In the 70s, the fleet was mainly composed of small vessels of 40-50 gross rate tonnage (GRT) and an estimate of 700 thousand boats that resulted in high fishing effort, but this effort reduced by almost 70% in the late 1970s, thus resulting in a decline of the catches (ITC, 2003). The number of people employed by the fishing industry decreased by 80% from the 60s to the 1990s, due to the closure of processing plants which used to employ the majority of people in the fishery industry (ITC, 2003).

Total Allowable Catch (TAC) was introduced as a fisheries management tool in 1995. From 1995 to 2016, the annual TAC fluctuated from 17 thousand tonnes to 85 thousand tonnes with an average of 60 thousand tonnes (INIP, 2016; INIP, 2017), figure 2. Fish processing and storage methods have advanced with improved technology resulting in greater product quality (ITC, 2003; Chilamba, 2016).

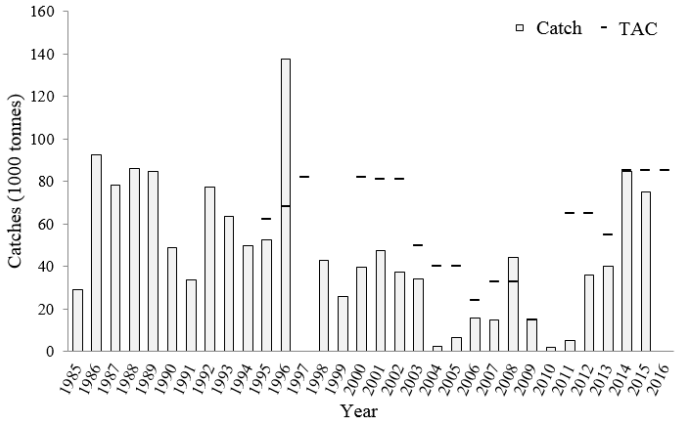

Figure 2. Horse mackerel catches and recommended total allowable catches in Angolan EEZ from 1985 to 2016 (source: INIP, 2016).

2.2 Ecology of horse mackerel

Two horse mackerel species are found in Angolan waters, Cunene horse mackerel (*Trachurus trecae*) and Cape horse mackerel (*Trachurus capensis*) (Figure 3.)

Scientific names: *Trachurus capensis*
Local names: Carapau do Cabo

Trachurus trecae
Carapau do Cunene

Figure 3. Scientific and local names for horse mackerel species.

Cunene horse mackerel is a benthopelagic species that occurs in coastal waters at depths between 0-50 m and in deeper shelf waters at depths up to 500 m. The species has a spatial distribution from southern Angola extending to the northern border of Guinea-Bissau (latitude from 35°N to 19°S; FAO, 2017). Cunene horse mackerel juveniles occupy the southern part of the distribution range in colder waters which are nutrient rich compared to the north (INIP, 2017). Adults are more abundant in the northern part with the highest abundance recorded in the central part of Angola (latitude from 9°S-13°S) at depths from 20 m to 100 m. Cunene horse mackerel are usually located in temperatures ranging from 15°C to 22°C (FAO, 2017). Limited information is available on seasonal migration pattern of the species, spawning location, and spawning season. It is believed that *T. trecae* like other *Trachurus* species, spawns throughout the year with peaks from May to August which coincides with the fishing closing season (Ndjaula, *et al*., 2013; INIP, 2014). Its density is higher off the north and central coast of Angola compared to the south coast (Vaz-Velho *et al.*, 2006). Cunene horse mackerel recruits to the fisheries at the age of three which corresponds to 25 cm fish (Vaz-Velho, *et* al, 2006; INIP, 2016), maximum age reported is of 10 years.

Cape horse mackerel is distributed from southern Angola to the south-eastern coast of South Africa (latitude from 16°S to 35.5°S). This more southward distribution compared to Cunene

horse mackerel is explained by different temperature preferences between the two horse mackerel species (Ekau & Verheye, 2005; Geist, et al., 2015). Cape horse mackerel prefers the colder temperatures of the Benguela current which range from 14°C to 17°C (Konchina, 1986; Naish *et al.,* 1991). Cape horse mackerel has a maximum age of 10 years that corresponds to 51 cm. The age considered to be recruiting to fisheries is 2.5 years that corresponds to 19-21 cm fish length (Krakstad, *et al*., 2001; Mundjulu, 2009). The juveniles are considered pelagic since they occur mainly within 100m from the surface. The adults occupy deeper waters with a maximum depth of approximately 500m and are considered demersal (Namwandi, 2002; Axelsen *et al.*, 2003). In contrast Cunene horse mackerel is an extensively studied and documented species. It has a spawning period running throughout the year reaching a peak between December and March (Wysokinski, 1985; Ndjaula *et al.,* 2013). The main spawning area is located between latitudes 17°S and 19°S with some seasonal variability in density between summer and winter (Ndjaula *et al.,* 2013). Their highest densities are registered during summer in the months of February and March (Ekau & Verheye, 2005; Geist, et al., 2015).

2.3 Environmental influence

Fish geographical distribution is influenced by a myriad of factors, including physical parameters, biotic interactions, dispersal ability, and life history traits (Pearson & Dawson, 2003; Araujo & Pearson, 2005). Importance of different factors varies between species, ecosystems, season and areas.

In the Namibian waters, horse mackerel spawn sporadically during spring while in summer they spawn intensely and widespread (Kreiner, *et al.,* 2015). Due to a general warming in the Benguela region, a shift in spawning location of pelagic species to more southern areas, has been noticed in the 2000s in comparison to 1980s (Kreiner, *et al.,* 2011). For many pelagic species, different life history stages occupy different geographical areas with limited spatial overlap (Geist, *et al*., 2015).

2.4 The physical environment

Two surface currents dominate the continental shelf of Angola: the Angola Current (AC) which is a southward flowing warm tropical current (15°C - 32°C), and the Benguela current (BC) which is a northward flowing cold-water current (8°C - 17°C).

The AC is related to that of a continuous poleward current, being stronger in summer and weaker in winter (Kopte, et al., 2017).

The front where the water masses meet is called the Angola-Benguela Front Zone (ABFZ), situated between latitudes 14°S – 16°S. In some years, intrusions of warm saline water from the AC displaces off the ABFZ southward to at least 23°S (Vaz-Velho & Barros, 2010). Shifts in the ABFZ influence the biological productivity of the Angolan shelf ecosystem and productivity declines when the front is displaced southward (Ekau & Verheye, 2005). This occurs as cold nutrient-rich waters are displaced off the Angolan shelf, which reduces coastal upwelling (INIP, 2014). Reduced coastal upwelling has negative effects on nutrient concentrations, limiting phytoplankton production, which is the basis of the marine food chain, sustaining large pelagic biomass (Gyory, *et al.,* 2004; Ekau & Verheye, 2005; INIP, 2006).

Salinity concentrations differ both longitudinally as well as latitudinally, whereby close to the coast and in the northern region lower concentrations are observed and higher concentrations

observed offshore as well as in the southern region (Loick, *et al*., 2005). Salinity concentrations range from 35.4 to 36.3ppt (Korsbrekke, *et al*., 2014).

Lastly, the oxygen minimum zones (OMZs) are common in the Angolan waters (Loick, *et al*., 2005), with some zones having dissolved oxygen (DO) < 0.5 mg L^{-1} and a few areas having DO 5 mg L^{-1}. Near the ABFZ oxygen concentrations is reported with minimum as low as 0.2 mg L^{-1} but that does not impede the survival of organisms, although they are richly abundant south of the ABFZ (Postel, *et al*., 2007).

2.5 Horse mackerel fishery management in Angola

Although the two horse mackerel species can be separately estimated by their respective biomass indexes, the management is done as one stock due to the fact that fishermen can seldom distinguish between the species (Angelini & Vaz-Velho, 2011, INIP, 2016), thus the TAC advice for both species is combined.

Horse mackerel is a transboundary fish species (fished by 7 countries) that splits into several stocks distributed along the west coast of Africa. The Cape horse mackerel stock occurring in the Angolan waters is the same stock as occurs in the Namibian waters thus joint management efforts are necessary to manage the fishery sustainably. A regional commission called Benguela Current Commission (BCC) consisting of the countries South Africa, Namibia and Angola, with support from FAO, initiated and implement the Small Pelagic Fisheries Management Plan (Cofrepeche, 2013). The management plan emphasizes the fisheries sector's role in bringing forth national fundamental objectives of fighting hunger and poverty within the concept of sustainable development. Although there is a regional commission, each country also has its specific management measures in respect to their specific stock component of horse mackerel.

As for Angola, the management of horse mackerel is grounded on a compatible institutional, legal and regulatory framework, through the Angolan Fisheries Law (Lei n.° 6-A/04). Such law embeds in it all management and conservation policies for all aquatic living resources. TAC is the main management tool used in fisheries management. The amount given per year depends on the scientific information (scientific survey and catch data information). The other methods used to manage the horse mackerel fishery in Angola include; input control and technical restriction, output control, and time/area restriction (Table 2). It is worth mentioning that all other measures, that is, effort and area restrictions, are dependent on the stipulated TAC, hence making it the main management measure.

Table 2. Resume of management measure for Small pelagic fishery

	Command and Control
Input control and Technical restrictions	Licensed purse seiners: 90 vessels 84 vessels with a GRT ≤ 250 and hold capacity ≤ 120m^3 6 vessels with: 250<GRT>800 t Minimum mesh size: 25-30 mm Minimum landing size: 18 mm (Decree n.° 109/05) Restriction on net size Prohibition of beach seine Prohibition of pelagic trawl
Output control	TAC set primarily based on scientific recommendations Landings should take place at specified ports Prohibition on unauthorized transhipment
Times and area restrictions	Closed season from May-August Closed areas: Estuaries and bays Purse seiners should operate beyond 4 NM Trawlers should operate beyond 10 NM

All fishermen must provide statistical information about their catches to the Angolan authorities. Heavy fines are applied to vessel captains who do not comply with the measures stipulated and companies can have their licenses suspended depending on the gravity of non-compliance. To have feasible scientific information, fishermen and their companies are obliged to give a biological sample to fisheries scientists.

The National Fisheries Research Institute (INIP) is responsible for providing scientific information on the state of the resources and propose TACs to the Ministry of Fisheries. This is done through:

a) National Program on Biological Sampling;

b) Research Surveys

The National Program on Biological Sampling is conducted mainly on commercial catches. This program was started by INIP in 2001 in Benguela province and later extended to Luanda and Namibe provinces which are the three main commercial fishing provinces (Figure 1). With the main objective of obtaining data that enable better understanding of the dynamics of the fleet and study the biology of the main species that are caught on different fleets. From samples collected, length is measured (cm), condition factors are determined and gonadosomatic index (GSI) recorded. Since, the two different fleets use different fishing gear, purse-seine and trawl, such data shows the catchability of the gears (see figure 4). These results, combined with survey data, serve as the basis for report writing of the state of the stock and propose recommendation for management on the basis of the best available scientific information.

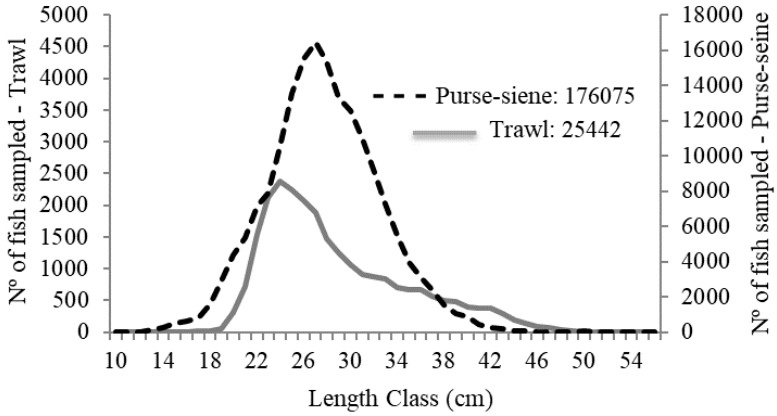

Figure 4. Length frequency of *Trachurus trecae* captured by purse-seine and trawl from 2005 to 2015. (source: INIP 2014 report on the National Biological sampling program).

2.6 Horse mackerel scientific research in Angola

Bi-annual scientific research surveys have been conducted since 1985 in the Angola EEZ, annually. These surveys are part of the Dr. Fridtjof Nansen Research Programme, which is conducted and planned under agreements between the government of Angola, FAO's Department of Fisheries and the Institute of Marine Research (IMR), Norway[1]. Its execution is the responsibility of the IMR-Bergen in cooperation with the Instituto Nacional de Investigação Pesqueira of the Ministry of Fisheries of Angola and FAO (Korsbrekke *et al.*, 2014). The survey on biology, ecology and population dynamics of main pelagic and semi-pelagic fish species and monitoring of the physical environment and measure the plankton abundance. The target fish species are: horse mackerel, *Sardinella aurita, S. maderensis, Sardinops ocellata, Decapterus rhonchus, Selene dorsalis, Chloroscombrus chrysurus* as well as *Brachydeuterus auritus.*

2.7 Fisheries acoustics a research tool for horse mackerel

Fisheries hydroacoustics is a field of acoustics that uses sounds underwater to measure distribution and amount of various organisms in the water column (Simmonds & MacLennan, 1992). This is a standardized scientific method widely used to measure abundance and distribution of pelagic and semi-pelagic fish species. Acoustic measurements provide abundance indices for routine stock management all over the world (ICES, 1999). For fish, 38 kHz frequency is generally used, this has the power to penetrate to a maximum depth of 500 m (Simmonds & MacLennan, 2005).

The method works by using an echo-sounder, which transmits sound waves to the water through a transducer, that is mounted to the keel of the vessel, if the sound hits on an object, it reflects back to the echo-sounder (Simmonds & MacLennan, 2005). The intensity of the reflection at which the sound hits the fish, depends on swimbladder size, shape and compression, state of maturity, fat content, and tilt angle of the individual (Simmonds & MacLennan, 2005).

The acoustic method measures the distribution of organisms over large spatial scales both day and night without disturbing the fish. It gives a two-dimensional view of the distribution of fish

[1] Sponsored by the Norwegian Agency for Development Assistance (NORAD), The Food and Agriculture Organization (FAO) of the United Nations, and the United Nations Development Programme (UNDP).

in the water column and estimates the absolute abundance with relatively two variances even with sporadic populations. However, this method alone does neither do species identification, nor population size structure. The Biological sample is necessary to allocate backscatter to species and for echo integration, that is the conversion of reflected energy into the number of specimen (Simmonds & MacLennan, 1990) (Figure 5).

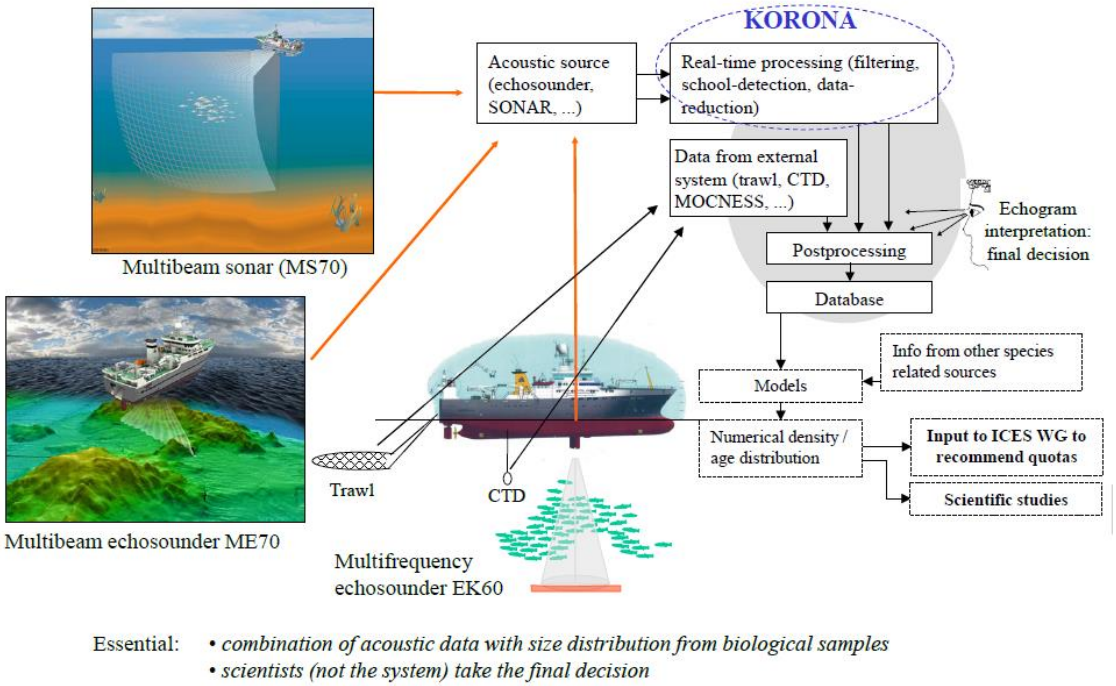

Figure 5. Schematic diagram of various components used when estimating fish abundance using acoustic methods. Source: Korneliussen LSSS meeting in Luanda, Angola "*General fishery acoustics"*.

Visual display of acoustic data is called an echogram (figure 6). A team of experienced scientists interprets the echogram, on a computer screen using a specifically designed software, and manually allocates backscatter to species or species groups utilizing shape of scatter, strength of scatter, and species composition from biological sampling (Korneliussen, et al., 2006).

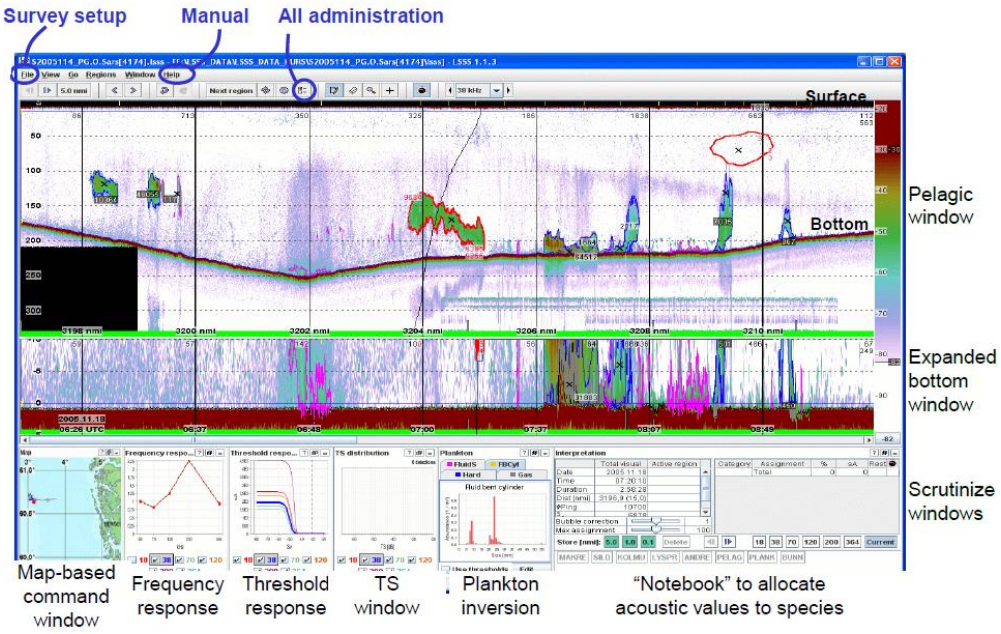

Figure 6. An echogram displayed using the LSSS software, illustrating how acoustic data have been allocated to schools of different fish species (red and blue encircled areas). The echogram displays 15 nm of survey transect and the vertical dimension has the range of 300 m below the vessel. Source: Korneliussen LSSS meeting in Luanda, Angola "*Processing acoustic ecosystem data with Large Scale Survey System"*.

The echogram analysis results in nautical area scattering coefficient (S_A) per unit area (Simmonds & MacLennan, 1992). For each species, the target strength (TS) equation is used to convert the scattering coefficient to the number of the specimen. TS corresponds to resolved single-fish echoes, and its equation relates average acoustic backscatter of species to length, whereby the length distribution of the species is found from the biological samples (Korneliussen, 2004). To deduce quantitative information about fish targets, such as number per unit volume, the value of target strength appropriate to those fish that contribute to the received signal must be known.

3 METHODOLOGY

3.1 Area of Study

The study area is the Angolan EEZ, between Congo river (latitude 6°S) and Cunene river mouth (17.15°S) (Fig.7).

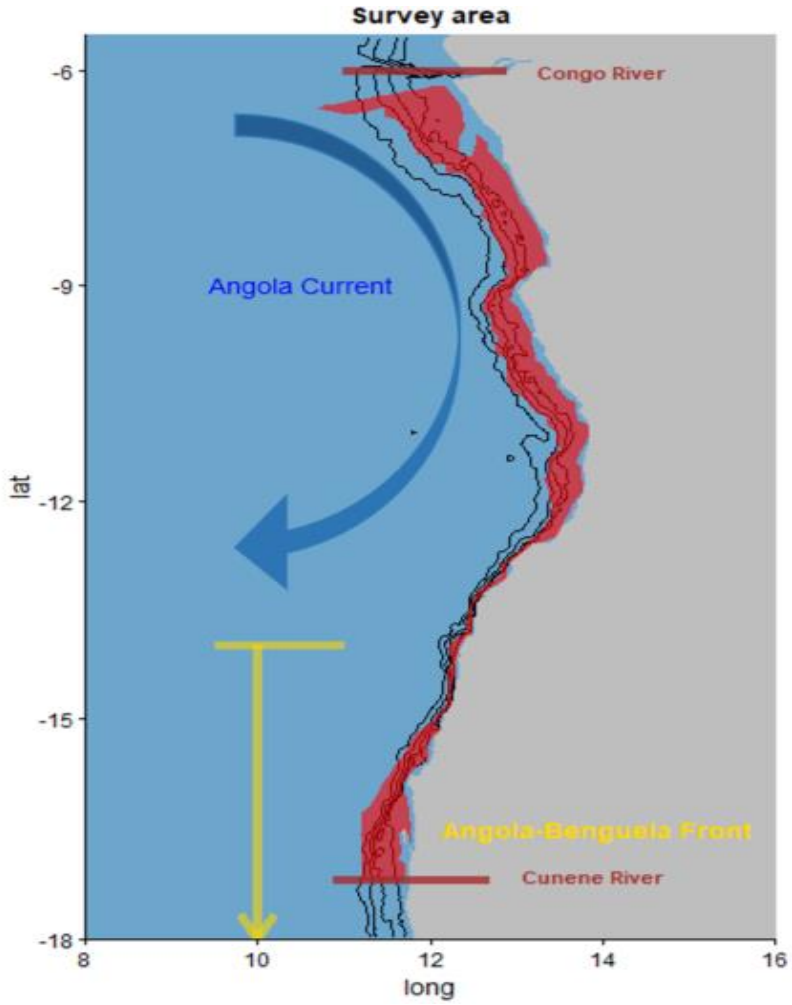

Figure 7. Survey area (red shadow area) with Angola's northern and southern EEZ limits (brown horizontal lines), the Angola current (blue arrow), range of the Angola-Benguela front (yellow horizontal line is maximum northward boundary), and depth contours (100 m, 200 m, 500 m and 1000 m).

3.2 Survey design

The survey design was based on predefined transects and trawl stations which were semi-randomly distributed on transects running perpendicular to the coast following the Nansen survey protocol (Korsbrekke, *et al.*, 2014). Transects are parallel and perpendicular to the coast, with the distance between transects ranging from 5 to 20 NM. (Figure 8.) The data used in this project was collected onboard of the Norwegian survey vessel *Dr. Fridtjof Nansen* during the pelagic Survey that took place in the winter of 2014 from 16 June to 17 July. The survey was aimed at estimating the abundance of pelagic fish using the acoustic method. (Table 3.)

Table 3. Sampling effort for the survey, acoustic recordings, biological trawl sampling and environmental measurements.

Type of data	Number of Samples
Survey effort: acoustic transects	4005 NM
Demersal and Pelagic trawls	75 stations
Conductivity, temperature and depth instrument (CTD).	287 stations

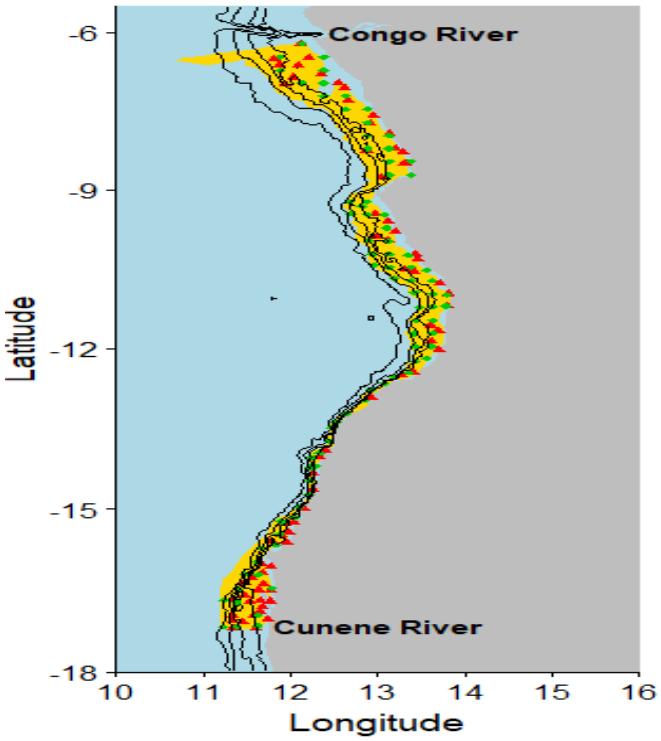

Figure 8. The survey area (yellow shaded area) with the depth contour lines (100 m, 200 m, 500 m and 1000 m), CTD stations (red filled triangles) and trawl stations (green filled triangles).

3.2.1 Acoustic equipment

The data were recorded from the water column by a Simrad ER60 scientific echo sounder equipped with keel-mounted transducers at nominal operating frequencies of 18, 38, 120 and 200 kHz, but backscatter was only analysed at 38 kHz as this information is used in stock assessment (Korsbrekke, *et al.*, 2014). All transducers were calibrated prior to the survey. The bottom channel was set at 10 m above the bottom with a 0.5 m bottom offset, pulse length set at medium (1,024ms), bandwidth of 2.43kHz, a 2-way beam angle of -20.6dB.

3.2.2 Acoustic energy allocation to species

A software Large Scale Survey System (LSSS, version 1.5) was used to scrutinize the acoustic data. This includes identifying echo traces from fish and to allocate the integrated acoustic values (S_A values (m^2/NM^2)) to a predetermined set of species. Species allocation was done on the basis of established echogram features and from species composition of trawl catches. For carangids (*Trachurus spp.*, included) and associated species, an overall average length of 23 cm and a condition factor of 0.88 was applied. That was done because there was such great variety of species in the group and it was therefore not possible to obtain an accurate estimate of the different species. However, an estimate of the group size was knownand an average length was applied to convert the allocated acoustic energy to biomass of fish.

Only data collected using the 38kHz transducer were analysed. The acoustic values per species were binned into 5 NM horizontal bins along the survey transect.

The data was stored in ListCompactScatter format at 5 NM distance for later use in the calculation of biomass and abundance estimates.

3.2.3 Survey area

The survey area was set as a closed polygon map by drawing a line between adjacent transects western ends and eastern ends, using the software program OpenCPN version 4.8.0 and later imported into R as a gpx file to set up limits to the survey area that was used in the r coding when calculating horse mackerel stock size. The survey area was split into boxes (10 minutes, 112 boxes) and horse mackerel biomass per box was calculated.

3.2.4 Calculations of fish biomass

In the Nansen survey, horse mackerel biomass is calculated in two steps using two different software (Korsbrekke, *et al*., 2014). First, a software called "NansisMapTool (version 1.7) is used to split the survey area *ad hoc* into three different sub-areas based on fish density and to calculate average fish density per species, and length distribution per species, per sub-area. This provides fish density per species per sub-area. The second step is done by using excel sheets, where the total number of fish and biomass is calculated per sub-area and summed to get total number and biomass.

In the current report, a script was written in R (R Core Team, 2017) to calculate horse mackerel biomass and numbers from S_A values, (see the script in Appendix. 6). In the R-script, the survey area is not split into sub-areas based on the density of fish. Instead, the survey area is split into a grid of equally sized cells where each cell is 10 minutes in latitude by 10 minutes in longitude. Biomass and abundance are calculated for each cell and the sum of all cells give the total biomass and abundance. In analysis of the environmental effects, each cell is one value. Separation of the two horse mackerel species is also included in the script.

There is a notable difference in the approach used from designing the survey area to calculating biomass estimates between the two reports (table 4).

Table 4. Differences in the biomass calculation approach.

Nansen Survey Report	**Current Study**
NansisMaptool	OpenCPN
Sub-areas	Per grid cell of 10 minutes lat. and long.
Excel sheet is used to sum up sub-area results	R script is used to sum the grid cell results

3.3 Biological sampling

Trawling was carried out only in areas where acoustic responses were positive to confirm with biological sampling. Gisund Super two-panel bottom trawl net was towed at a constant speed of 3.0 knots for about 30 minutes. The outer lining of the cod-end mesh size was 20 mm while the inner-net was 10 mm. The catch was identified to species, weighted and specimen counted. For very large catches > 250 kg, a subsample ~30% of the catch was taken and processed instead of the whole catch. For each species, various biological variables were measured for a subsample of the specimen (table 5). The total catch of the survey was 9104 kg, of which 22% was horse mackerel. A total of 36 fish species were identified in the survey, composed of both demersal and pelagic species. From the 75 stations trawled 70 stations had horse mackerel, thus making 80% of the total trawl stations.

Table 5. Processing of trawl catches

Name of sampling	Definition
Catch	Species name, total weight and number of individuals
Length frequency	Length measurements of all or up to 100 individuals of a given species
Individual	Weight, sex and maturity stages are determined. The number of individuals sampled is decided by a leading scientist
Stomach	Stomachs collected from the individual sampled fish (in addition to length measurements).

3.3.1 Biological Sampling

Biological sampling is the study of each specimen such as sex, maturity, gonad weight, stomach content, and otolith. The form for biological observations was also marked with identifiers like: station number, vessel, species and length of the specimen were included. A total of 70 stations were sampled resulting in 6904 horse mackerel measured and weighted. The fish total length was measured to the nearest 1 cm, and weighted to a nearest 1 g. The weight and number of length samples, number of fish that were individually sampled was recorded at all times. The data was digitally recorded to the database 'Nansis' inbuilt in the Nansen vessel.

3.3.2 Environmental parameters

The environmental data consists of vertical hydrological profiles collected by a CTD equipment in four depth strata: 0-20 m, 20-50 m, 50-100 m, 100-200 m. At each CTD station, temperature, salinity, dissolved oxygen and fluorescence were measured at five different depths (Table 6). In total 1370 measurements conducted at 287 CDT stations.

Table 6. Number of environmental observations per depth bin.

Depth (m)	5	15	25	50	75	100	Total
Measurements	280	277	241	216	197	159	1370

3.4 Acoustic Data Analysis

The following target strength (TS) function was applied to convert s_A-values (mean integrator value for a given area) to number of fish by category (Foote 1980). This TS function was used because TS is not known for horse mackerel, and this target strength is generally used for fish species with swim-bladder for acoustic surveys in European waters (Foote 1980) hence its adoption:

$$TS = 20 \log L - 72 \text{ dB} \quad (1)$$

or in the form

$$C_F = 1.26 \cdot 10^6 \cdot L^{-2} \quad (2)$$

$$N_i = A \cdot s_A \cdot \frac{p_i}{\sum_{i=1}^{n} \frac{p_i}{C_{Fi}}} \quad (3)$$

where L is the total length and C_F is the reciprocal back scattering strength (fish conversion factor). To split and convert the allocated s_A-values (m^2/NM^2) to fish densities (number per length group per NM^2) the following formula is used

where: N_i = number of fish in length group i

A = area (NM^2) of fish concentration

s_A = mean integrator value (echo density) in area A (m^2/NM^2)

p_i = proportion of fish in length group i in samples from the area

C_{Fi} = fish conversion factor for length group i

3.4.1 Horse mackerel Abundance Estimates

To obtain the total number of fish a summation of the number per length group (N_i):

$$N = \sum_{i=1}^{n} N_i \tag{4}$$

The length distribution of a given species within an area was computed by addition of the length frequencies obtained in the trawl samples within the area. In the case of co-occurrence of target species, the s_A value was split in accordance with length distribution and catch rate in numbers in the trawl catches.

3.4.2 Biomass Estimate of horse mackerel

Biomass per length group (B_i) was estimated by applying measured weights by length (W_i) through the length-weight relationship, multiplied with number of fish in the same length group (N_i). The total biomass in each box was obtained by summing the biomass of each length group:

$$B = \sum_{i=1}^{n} N_i \overline{W}_i \tag{5}$$

The number and biomass per length group in each concentration were then added to obtain total.

For better and efficient way to estimate abundance and biomass in the future, a R-script is being developed to best fit the species specificities as well as the demarked area of study.

3.5 Statistical Analysis

Generalized additive models (GAM) were used to investigate the multivariable relationship between environmental variables and horse mackerel distribution as such model can capture nonlinear relationships (Hastie and Tibshirani, 1990). Geographical location was included as co-variates to account for its effects. Horse mackerel density was analysed using the model:

$$log10D_{i,(\lambda,\,\phi)} = a + s_{1(\lambda,\,\phi)} + g_1[Temp_{i,(\lambda,\,\phi)}] + g_2[Sal_{i,(\lambda,\,\phi)}] + g_3[Oxy_{i,(\lambda,\,\phi)}] + g_4[Chl_{i,(\lambda,\,\phi)}] + e_{i,(\lambda,\,\phi),} \tag{6}$$

where λ is longitude, ϕ is latitude at station i, a is the model intercept, s and $g_{1\text{-}3}$ are smoothing functions for the influence of location and environment on mackerel density (D), and $e_{i,(\lambda,\,\phi)}$ is the error term. Stations missing either temperature, salinity or dissolved oxygen recordings were excluded from analysis and were log transformed to reduce skewness of data before analysis.

The parsimony principle was used to select the best model from all possible combinations of explanatory variables by selecting the model with the lowest Akaike Information Criterion (AIC) (Burnham and Anderson, 2002). If the AIC difference between competing models was < 3 (Burnham & Anderson, 2002), analysis of variance was used to compare the nested models, accepting the simpler one if the models were not statistically different ($p < 0.05$). All statistical analyses were done using R (version 3.4.3). The "mgcv" package (version_1.8-23; Wood, 2006) was used for GAMs. Correlation of explanatory variables was explored using pairwise scatterplots and by calculating correlation coefficients. For all possible subsets of models, the maximum correlation coefficient was 0.95 and showed a positive relationship between oxygen and chlorophyll.a and a negative relationship for temperature and salinity (Appendix 2).

4 RESULTS

4.1 Nautical area scattering

Results from the Nansen survey in winter in the Angolan EEZ measured higher horse mackerel densities at latitudes south of 15°S compared to latitudes north of 15°S (Figure 9).

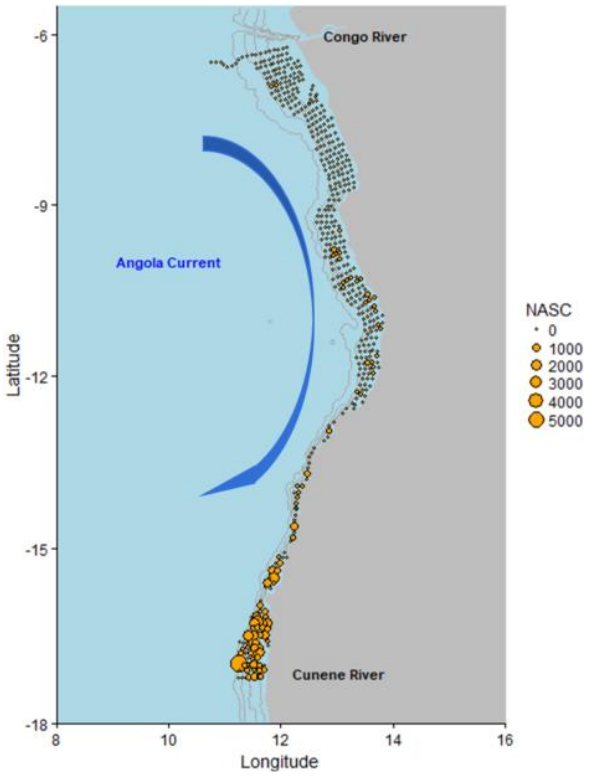

Figure 9. Acoustic backscattering strength (yellow filled circles), for the two horse mackerel species, aggregated into 5 nautical mile bins along the survey track from the Nansen survey in winter 2014.

4.2 Horse mackerel Abundance Estimates & relative proportion of species

Horse mackerel total biomass of both species was estimated 314 223 tones. Proportion of immature fish was 66.1% and 33.9% were mature. The contribution of the two species to the total biomass differed by approximately a factor of five. Cunene horse mackerel biomass was 84% of total biomass and Cape horse mackerel was 16%.

Horse mackerel length distribution, combined for both species, show that 19 cm length fish contributed the most to the total biomass estimate with about 10%, and fish < 9 cm contributed the least with less than 0.1% altogether (Figure 10). Length class that contributed the most to the total biomass per species varied by a few cm. Cunene horse mackerel was larger, length ranged from 15 to 48 cm, and Cape horse mackerel ranged in length from 15 to 27 cm.

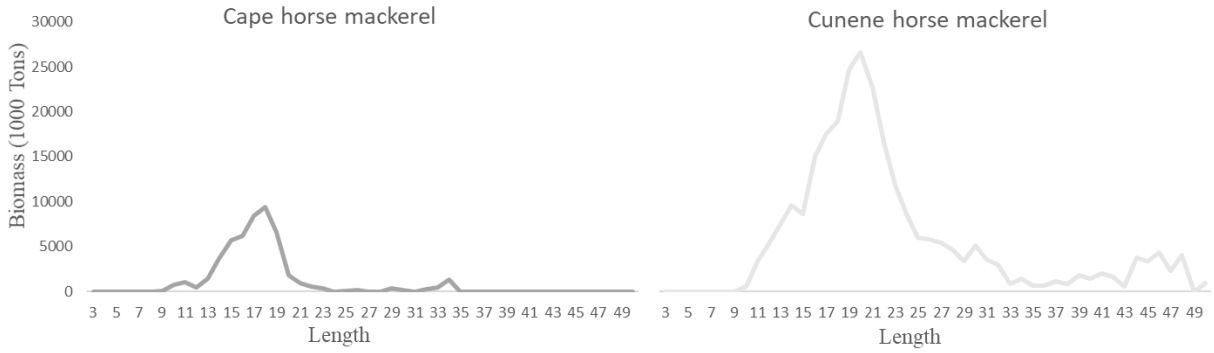

Figure 10. Biomass estimate per length class of Cape horse mackerel and Cunene horse mackerel from the Nansen survey in winter 2014.

4.3 Length Frequency of both horse mackerel species

The mean length for both species combined was 26.5 cm. Separated by species, Cunene horse mackerel was bigger with the mean length of 27 cm than Cape horse mackerel mean length of 19 cm (Figure 11).

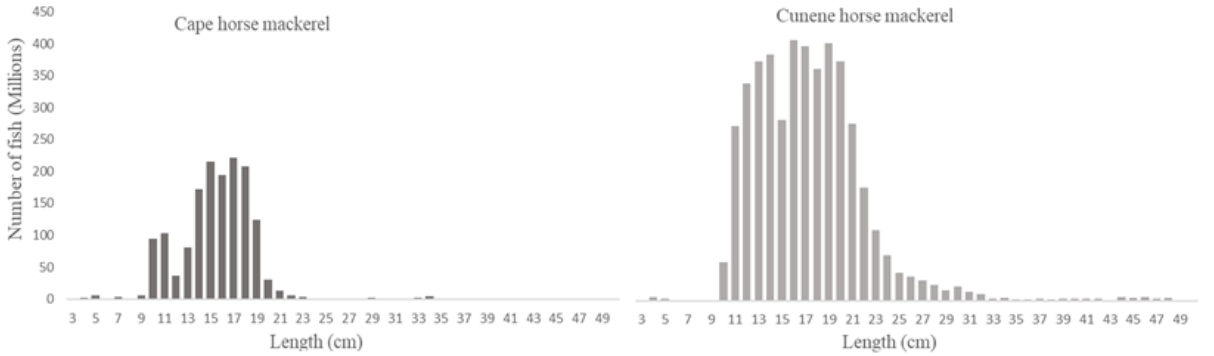

Figure 11. Length frequency distribution of Cape horse mackerel and Cunene horse mackerel from the Nansen survey in winter 2014.

4.4 Target strength value influence on estimated mackerel biomass.

The difference in the constant value used in the TS equation had large effects on estimated biomass. By decreasing the constant by 6.8, from 72 to 65.2, the estimated biomass, in the Nansen survey in winter 2014, declined by 79% (Table 7).

Table 7. Abundance and biomass estimates from two different constant values used in the target strength equation. The standard constant is *in-situ* target strength of herring, and the *in-situ* constant was estimated from *in-situ* measurement on horse mackerel in Namibian waters.

TS constant	Back-scattering coefficient (dB)	Abundance Estimate (Millions)	Biomass Estimate (Tonnes)
Standard	72	6210	314223
In-situ	65.2	1306	66102

4.5 Environmental parameters

During the winter survey in 2014, the temperature declined with greater depth in the water column from 25.8 ℃ at 5 m depth to 17.3 ℃ at 100 m depth. There was a small decline in salinity with depth, from 35.1 to 36.3 ppt. Oxygen ranged from $0.5*10^{-3}$ to 6.3 mg L^{-1}, and chlorophyll a varying from $0.3*10^{-5}$ to 6.2 µgL^{-1} (Table 8).

Table 8. Summary of environmental parameters from the Nansen 2014 winter survey.

Parameters	Statistics	Depth (m)						Average
		5	15	25	50	75	100	
Temperature (℃)	Mean	19.82	19.04	18.08	16.85	16.04	15.35	18.47
	StDev	2.92	2.56	1.97	1.38	1.12	0.95	1.84
	Min	13.84	13.58	13.5	13.58	13.25	13.09	13.9
	Max	25.74	24.42	22.75	19.86	18.2	17.25	22
Salinity (ppt])	Mean	35.77	35.8	35.78	35.72	35.66	35.59	35.78
	StDev	0.17	0.16	0.16	0.15	0.13	0.11	0.14
	Min	35.22	35.35	35.35	35.35	35.33	35.31	35.34
	Max	36.26	36.26	36.25	36.06	35.9	35.8	36
Oxygen (mg L^{-1})	Mean	4.23	3.71	2.98	1.76	1.10	0.72	2.83
	StDev	0.89	1.01	1.02	1.04	0.95	0.81	0.75
	Min	1.378	0.00099	0.0008	0.00069	0.00069	0.0005	0.8975
	Max	6.339	5.427	5.084	4.103	3.786	3.024	4.2207
Chlorophyll.a (µgL^{-1})	Mean	0.73	0.52	0.02	0.07	0.03	0.00	0.32
	StDev	1.07	0.91	0.59	0.31	0.18	0.00	0.50
	Min	5.60E-05	8.30E-05	0.00012	0.00008	4.20E-05	3.80E-05	0.00014
	Max	5.54	6.21	3.02	2.08	1.54	0.00	2.47

4.6 Environmental influences on horse mackerel distribution

Immature and mature horse mackerel were present in the same cells within the spatial grid used to calculate biomass by maturity, hence it sufficed to run the GAM analysis for presence once for total biomass irrelevant of maturity stage. The best-fitting model for horse mackerel presence included only salinity which had positive effect and explained 60.3 % of the variance (Table 9: Figure 1a, b).

Table 9. GAM fits comparison and selection (1a) for the effects of temperature (tem), salinity (sal), oxygen (oxy) and chlorophyll.a (chlo) accounting for effects of location on the presence of Cunene horse mackerel measured in the Nansen survey in winter 2014. Best model according to the parsimony principle displayed in bold and its parameters (1b).

1a. Model		ΔAIC	Deviance explained (%)
Presence ~ s(lon, lat) + s(tem) + s(sal) + s(oxy) + s(log(chlo))		0.4	65.9
Presence ~ s(lon, lat) + s(tem) + s(sal) + s(oxy)		0	64.7
Presence ~ s(lon, lat) + s(tem) + s(sal)		0.9	61.5
Presence ~ s(lon, lat) + s(tem)		7	59.3
Presence ~ s(lon, lat) + s(sal)		**2.4**	**60.3**
Presence ~ s(lon, lat) + s(oxy)		6.2	60.8
Presence ~ s(lon, lat) + s(log(chlo))		7.8	58.2
1b. Parameters	estimated	standard error	p-value
Intercept	-1.1289	0.9981	0.0283

*family is bionomial; link function is logit; number of sampling boxes = 193

ΔAIC = AIC – minAIC

Environmental influences on horse mackerel abundance were analysed separately for immature and mature individuals as abundance of the different maturity stages varied within spatial grid cells. The best model for immature Cunene horse mackerel included oxygen which had a positive effect as density increased with increasing oxygen to approximately 2 mg L^{-1} and then plateaued with minor fluctuation at higher oxygen levels (Table 10, Figure 2 a, b). In areas south of 15°S, showed a high abundance of cunene horse mackerel in waters with oxygen levels 3.5 to 4.5 mg L^{-1} (Figure 13). The best model explained 66.9% of the total deviance.

Table 10. GAM fits comparison and selection (2a) for the effects of temperature (tem), salinity (sal), oxygen (oxy) and chlorophyll.a (chlo) accounting for effects abundance (M. abun) of Cunene horse mackerel measured in the Nansen survey in winter 2014. Best model according to the parsimony principle displayed in bold and its parameters (2b).

2a. Model		ΔAIC	Deviance explained (%)
log(M.abun) ~ s(lon, lat) + s(tem) + s(sal) + s(oxy) + s(log(chlo))		0	69.2
log(M.abun) ~ s(lon, lat) + s(tem) + s(sal) + s(oxy)		1.5	67.8
log(M.abun) ~ s(lon, lat) + s(tem) + s(sal)		24.5	45.6
log(M.abun) ~ s(lon, lat) + s(tem)		23	45.1
log(M.abun) ~ s(lon, lat) + s(sal)		22.6	45.5
log(M.abun) ~ s(lon, lat) + s(oxy)		**1.4**	**66.9**
log(M.abun) ~ s(lon, lat) + s(log(chlo))		20.9	45.8
2b. Parameters	estimated	standard error	p-value
Intercept	13.6355	0.1578	0.00073

*family is gaussian; link function is identity; number of sampling boxes = 78

ΔAIC = AIC – minAIC

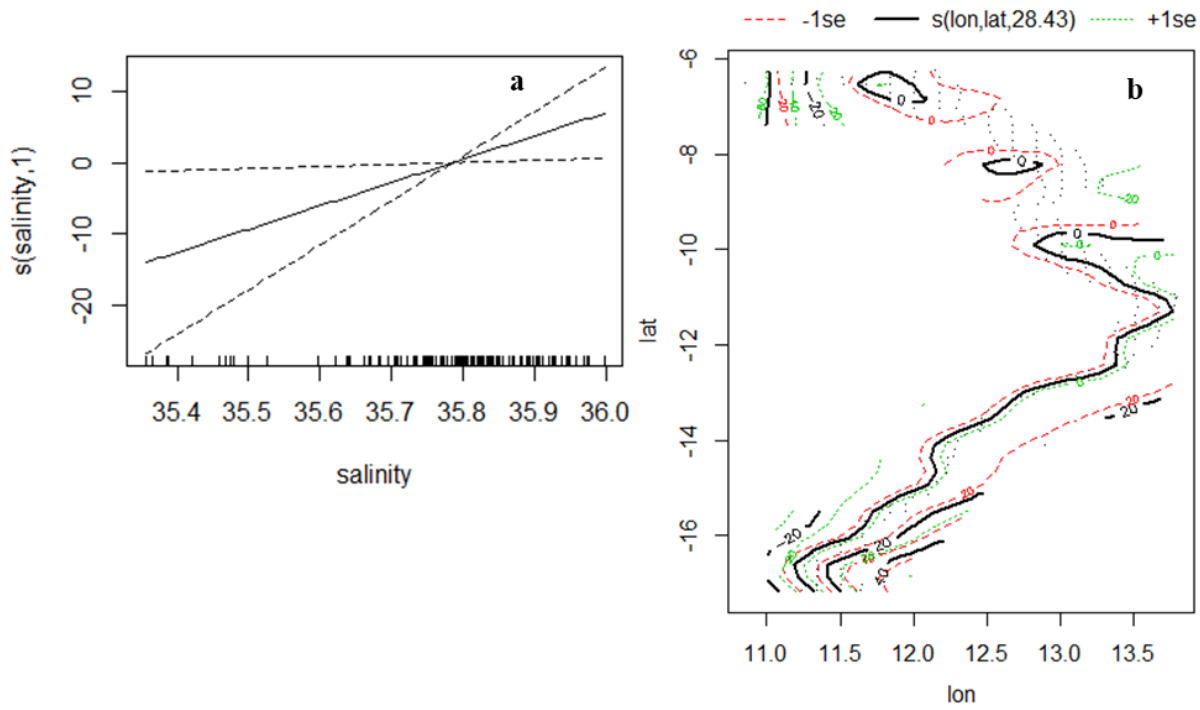

Figure 12. GAM smoothing effects of salinity on the presence/absence of cunene horse mackerel, the y-axis represents the relative importance of the covariate and x-axis represents the observations (**a**). Dashed lines are the 95% confidence intervals of the mean prediction. Bivariate smooth of spatial effects on the presence/absence of cunene horse mackerel in contour plot over the survey area, and sampling points in dots (**b**).

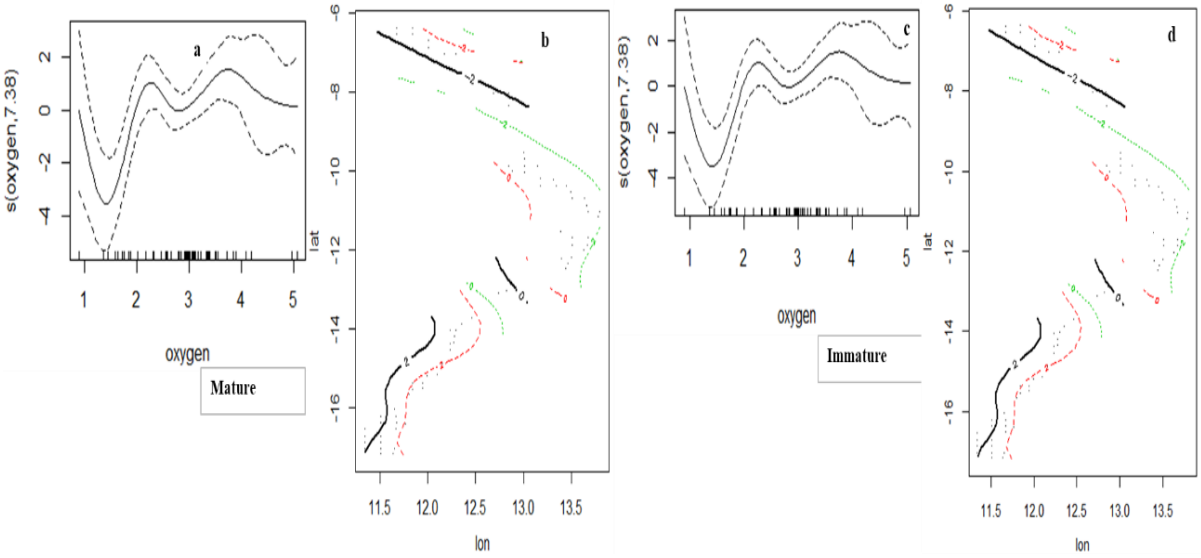

Figure 13. (**a & c**) GAM smoothing curve effects of oxygen on geographical distribution of mature (**a)** and immature (**c**) cunene horse mackerel. The y-axis represents the relative importance of the covariate and x-axis represents the observations. Dashed lines are the 95% confidence intervals of the mean predictions. Bivariate smooth of the spatial effects on the abundance of cunene horse mackerel in contour plot over the survey area, and sampling points in dots for mature (**b**) and immature (**d**) fish.

Environmental effects on the distribution of cape mackerel could not be tested due to limited data (n = 4).

4.7 Horse mackerel Distribution

Horse mackerel was present in 78 of 193 spatial grid cells distributed throughout the entire studied area (Figure 14). Its presence is indicated by shaded plum circles. The biomass distribution varied with temperature as such, the northern parts from latitude > 10 °S had highest temperatures (≥ 22°C) coupled with low biomass distribution while south of 15°S latitude had temperatures < 18°C, and highest biomass distribution. However, temperature did not have significant effects on horse mackerel distribution.

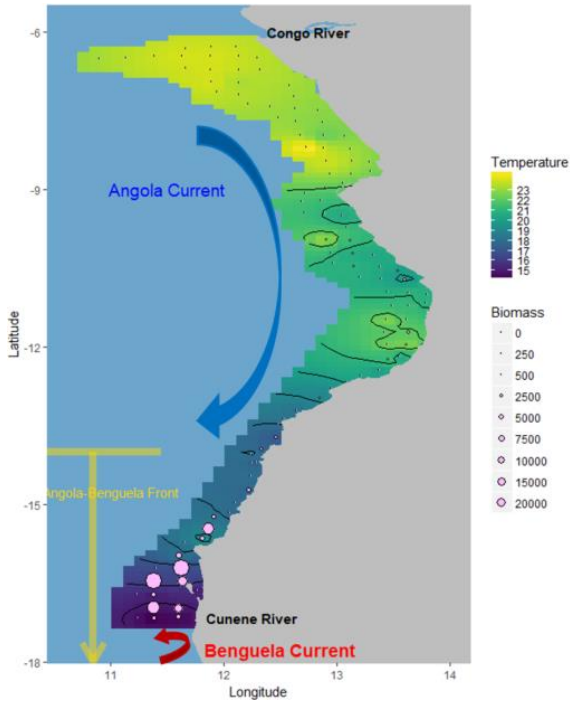

Figure 14. Horse mackerel biomass (ton) in the studied area in relation to temperature (°C).

Horse mackerel biomass distribution in relations to oxygen, presented highest biomass (>10000 tons) in the southern part (latitude > -15°S) with oxygen concentration levels between 3.5 – 5.0 mg L^{-1}. The northern part of the study area (-6 – -10°S) had a limited oxygen concentration range of 4.5 mg L^{-1} and low biomass concentration. The central region (between < -15 and ≥ -10°S) had the lowest biomass with varied oxygen concentrations, the lowest (< 2 mg L^{-1}) and also the highest oxygen concentration (> 6.5 mg L^{-1}) (Figure 15).

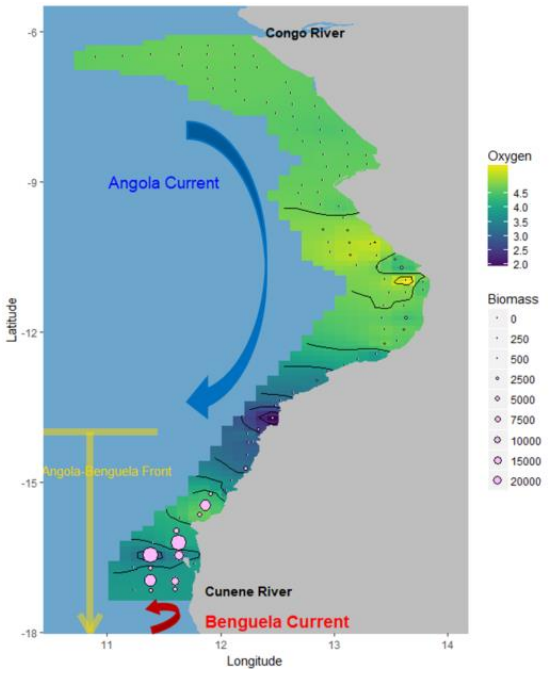

Figure 15. Horse mackerel biomass (ton) in the studied area in relation to oxygen (mg L^{-1}). Display of horse mackerel biomass in boxes where fish was present (plum filled circles).

5 DISCUSSION

The study aimed at determining the abundance and distribution of horse mackerel (both species), based on environmental effects using acoustic data. This was conducted using R script developed using the GAMs model to correlate environmental variables to the presence and abundance of Cunene horse mackerel. It has become a common practice by scientist to calculate fish biomass from acoustic data by developing a R-script that is then used repeatedly.

5.1 Horse mackerel Abundance Estimates

The overall biomass estimate was at 314 223 tons which is 3% less than the estimates from the survey report 322 610 tons (Korsbrekke, *et al*., 2014). The slight difference may be due to different methods used to calculate the biomass (Table 4). The calculation method is discussed in the methodology under calculation of fish biomass.

The relative abundance proportions of species, Cunene horse mackerel 84% and 16% tons for Cape horse mackerel. This species proportion split showed a huge disparity from the ones obtained on the survey report. The proportion of species on the survey was of 58% for Cunene horse mackerel and 42% for Cape horse mackerel (Korsbrekke, *et al*., 2014). The disparity noticed on the species proportion split, can be associated to the approaches taken when assigning the survey area. The Survey report had its survey area separated into 3 different regions, consequently calculations were done per region. Whereas, for the current report, the survey area was considered as 1 but split into grids, thus calculations were done per grid before summing them for the whole survey area. Therefore, further exercises of this nature should be taken to best understand such disparity in the species proportion split.

5.2 Environmental effects on geographical distribution of Cunene horse mackerel

Interpreting the results for environmental effects on Cunene horse mackerel distribution must be done with caution as data from only one survey that was conducted during winter was used in the analysis.

Surprisingly, distribution of mature and immature Cunene horse mackerel had a perfect overlap in the spatial grid used, that is, each cell with immature fish present also had mature fish. Therefore, environmental effects on fish distribution were the same for mature and immature individuals. Interestingly, different environmental variables influenced horse mackerel presence and density. These effects between fish presence and fish density is common (Zwolinski, *et al*., 2010). Presence increased with increasing salinity whereas density increased with increasing oxygen. Salinity is highest in the northern part of the Angolan EEZ and declines southward. Due to survey area shape, there is a higher number of grid cells in the north part of the EEZ compared to the southern part, see Figure 12. Many of the grid cells in the north have horse mackerel present, hence this latitudinal gradient in a number of grid cells could inflate the effects of salinity. The current study is the first to explore the environmental effects on distribution of Cunene horse mackerel. A future study using a larger dataset is recommended to confirm the effect of salinity on Cunene horse mackerel presence to confirm that salinity has significant effects on presence of the species.

This study, showed that, abundance of Cunene horse mackerel differed with respect to area and its distribution seemed to be affected positively by oxygen concentration. The highest abundance was in the south, from latitude 15°S to 17°S, and coincided with the Angola Benguela Front Zone (ABFZ). ABFZ is a high productivity area where horse mackerel aggregate to spawn (Gyory, *et al.*, 2004; Ekau & Verheye, 2005; Ndjaula *et al.*, 2013; Reference for productivity at the ABFZ front). It appears that both immature and mature horse mackerel was located in high densities in the south. Immature fish is frequently found in higher densities in the south compared to the north (INIP, 2017). Mature fish also aggregate in the south during the peak spawning season which is from May to August (Ndjaula, Krakstad, & Kjesbu, 2013; INIP, 2014). The data used in the current analysis were collected in June and July which coincides with peak spawning which could explain high abundance of mature fish in the south.

The temperature variable did not indicate a significant influence on presence and density of horse mackerel. That was surprising as horse mackerel distribution is frequently described in relation to temperature. As such, previous studies done in the ABFZ show that horse mackerel flourished in relatively colder waters compared to warmer waters, for spawning and for juvenile growth (Oliver & Barange, 1990). Due to the continuous experience of warmer waters in the Angola upwelling systems than the average, has resulted in the abundance distribution shift to the south were the Benguela current effects are noticeable during winter (Hagen, *et al*., 2001, H-Ch, et al., 2004). Latitude and longitude had significant effect on both the presence/absence and on the abundance distribution of cunene horse mackerel. Bivariate smooth of spatial effect proved to impact on presence/absence and distribution of larval and early juvenile cod (Jonasson, *et al*., 2009).

It is possible that the observed salinity and oxygen effects do not directly influence Cunene horse mackerel presence and distribution but are correlated to other variables which directly influence horse mackerel distribution such as prey abundance or location of appropriate

spawning habitat. A study involving a larger dataset (several years) is needed to further explore environmental effects on Cunene horse mackerel density during winter.

5.3 Effects of target strength coefficients on biomass estimate

Cunene horse mackerel biomass estimates, using target strength measured for the same species in Namibia EEZ, suggests that the current use of herring target strength severely over estimates biomass. A decline by 79% in the estimate by using 65.2 dB coefficient instead of 72 dB (table 7). The severe effects of small changes to coefficients in the target strength equation emphasizes the need for *in-situ* measurement of Cunene horse mackerel in the Angolan EEZ. If Cunene target strength in Angolan EEZ is similar to the *in-situ* values from Namibia EEZ, then the Cunene horse mackerel stock is currently overestimated. Overestimated stock size could explain why the fishing industry does not capture the allocated TAC in most years, (Figure 2).

6 CONCLUSIONS AND RECOMMENDATIONS

Horse mackerel abundance and distribution is not only affected by the fishery, but also by environmental condition. Target strength coefficient is vital in the converting acoustics estimates to abundance indexes. Therefore, recommendation are as follows:

- Using the r-script developed in the current report to calculate horse mackerel biomass.
- Repeat the analysis done for environmental effects on Cunene horse mackerel distribution for every year in the Nansen survey time series to get a better understanding of how environmental factors affect their distribution and presence in the Angolan EEZ.
- Conduct *in-situ* measurements of Cunene horse mackerel target strength in the Angolan EEZ.
- Make scientific data easily available to scientist for research purposes.

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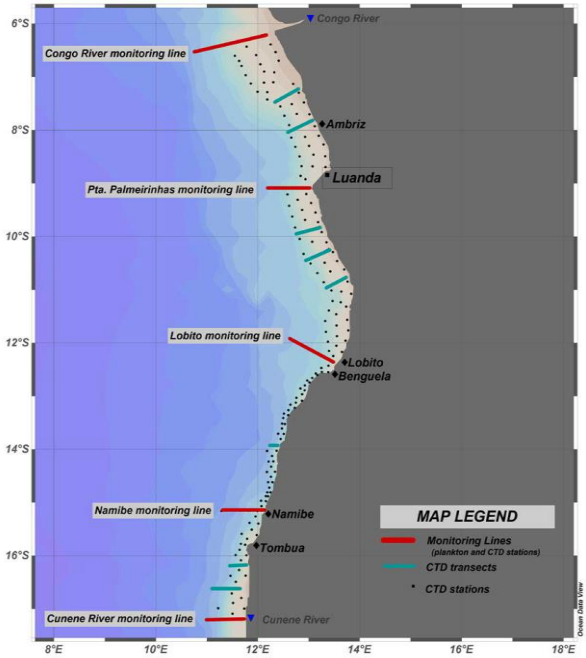
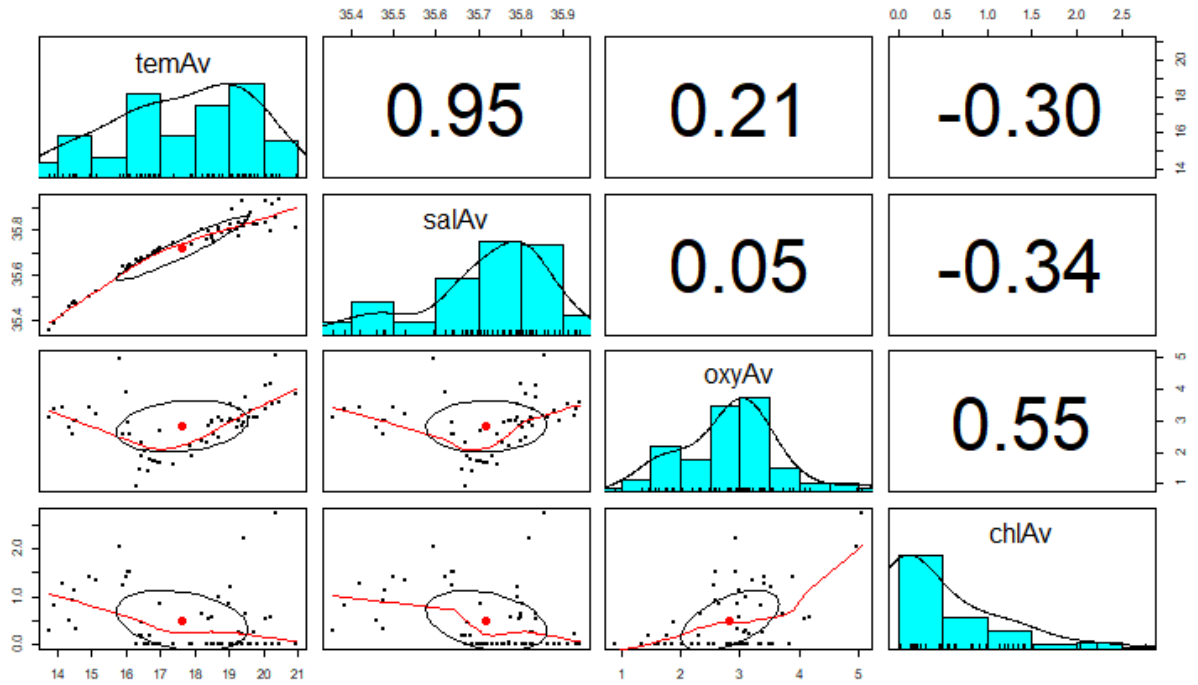
8 APPENDICES

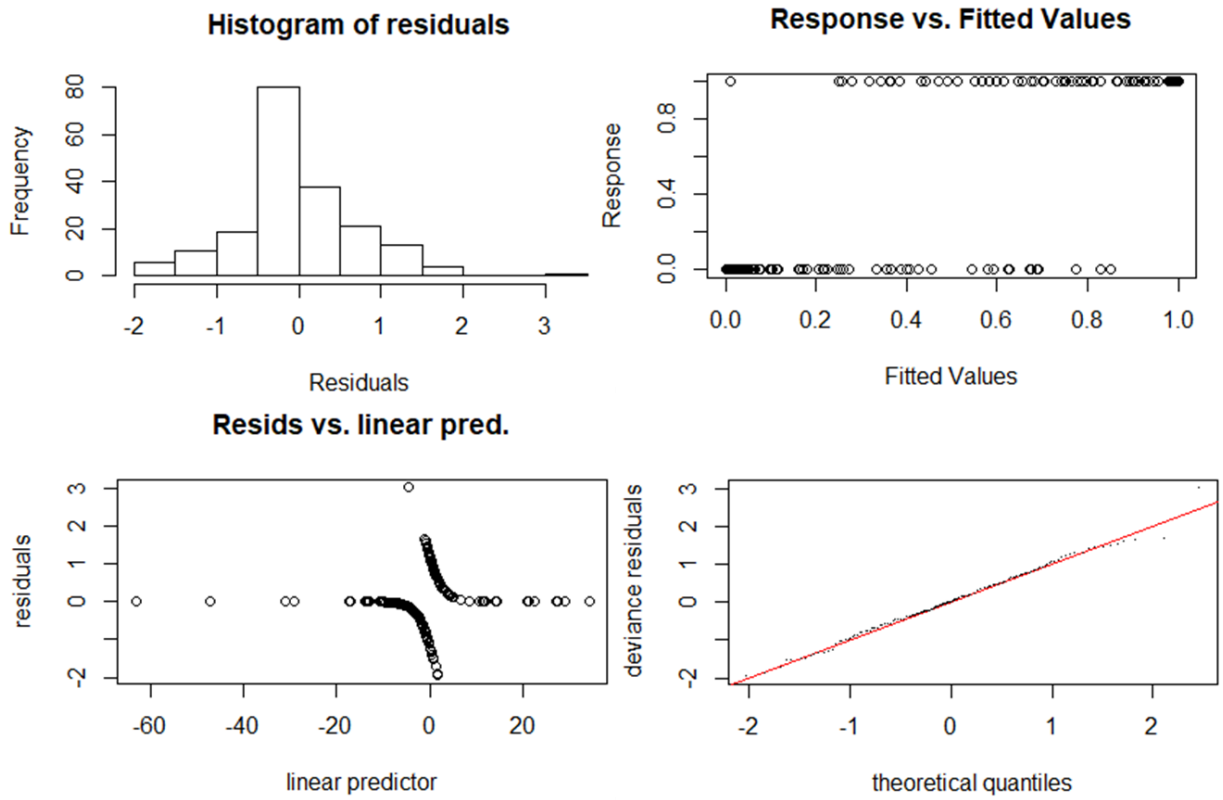
Appendix 1. CTD monitoring lines and transects along the coast. Source: 2014 Winter Survey Report.



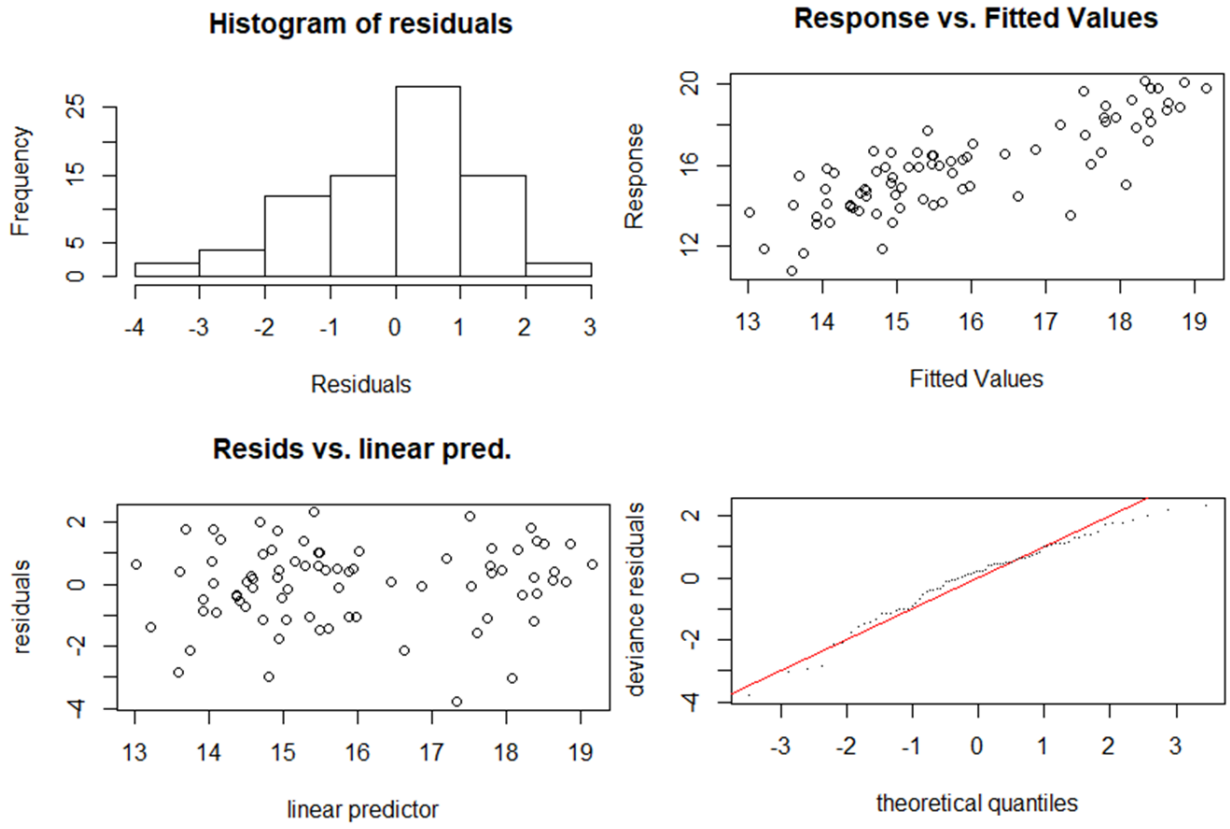
Appendix 2. Correlation plot of explanatory variables. The values within the boxes are the correlation coefficients.



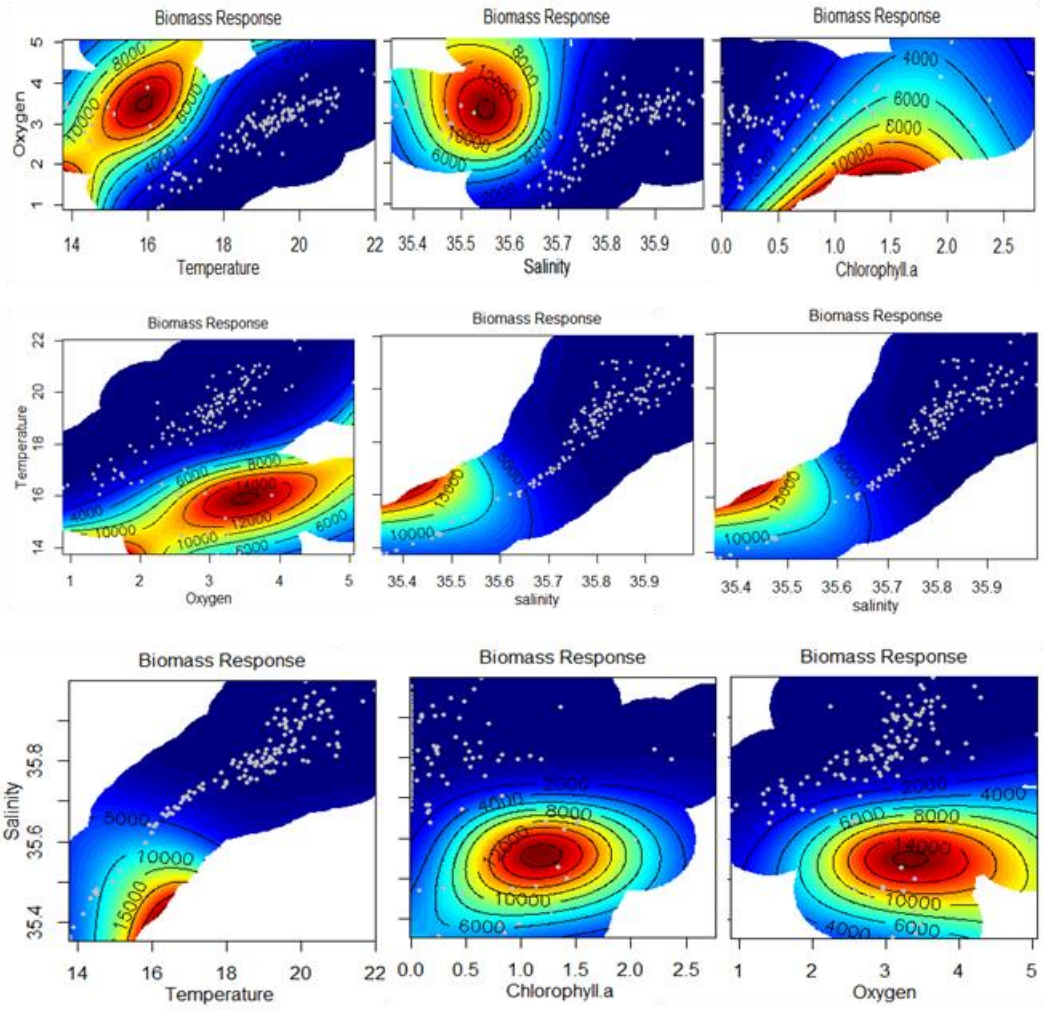
Appendix 3. Residuals plots for presence/absence of horse mackerel from the best GAM model. Salinity was the term for the best model.



Appendix 4. Residuals plots for biomass of horse mackerel from the best GAM model. Oxygen was the term for the best model.



Appendix 5. Abundance estimates response to environmental variables correlations



Appendix 6. R-script for biomass/abundance estimates

Biomass Estimates

```
library(XLConnect)

library(geo)

library(plyr)

source("boxgrid9c.R", encoding="unknown")
source("biomass7.R",encoding="unknown")
# Import NASC data.
wb <- loadWorkbook("/Users/UNUFTP/OneDrive/UNU-FTP 2017/Project/R/StockAss/2014405_5NMI.xlsx"); nasc <- rea
dWorksheet(wb,sheet=1)
nasc$NASC <- nasc$Horse
# Define survey boundaries.
# export nasc data to gpx format, then import it to OpenCPN.
library(rgdal)

library(rgeos)
```

```
library(plotKML)

# Make SpatialLinesDataFrame from nasc:
nasc.spdf <- SpatialPointsDataFrame(coords=nasc[,c("lon","lat")],data=nasc,proj4string =CRS("+proj=longlat + ellps=W
GS84"))
coord<-as.data.frame(coordinates(nasc[,c("lon","lat")]))
lin<-Line(coord)
lin1<-Lines(list(lin), ID="track")
lin2<-SpatialLines(list(lin1))
df<-data.frame(len=sapply(1:length(lin2), function(i) gLength(lin2[i,])))
rownames(df)<-sapply(1:length(lin2), function(i) lin2@lines[[i]]@ID)
lin3<-SpatialLinesDataFrame(lin2, data=df)
proj4string(lin3)<-CRS("+proj=longlat +datum=WGS84")
names(lin3)<-"name"
# Export in GPX format:
writeOGR(lin3,
        dsn="nasctrack1.gpx", layer="tracks", driver="GPX",
        dataset_options="GPX_USE_EXTENSIONS=yes","FORCE_GPX_TRACK=T", overwrite_layer = T)
# STOP! Do not run this script further until you have finished the OpenCPN procedure.
# Then open the nasctrack.gpx in OpenCPN and draw a boundary line:
# Click "Create Route" and draw a polygon along the boundaries or extension of the survey.
# Name the new route "bb1" e.g. by double clicking the route on the map and write into "Name" field.
# In "Route & Mark manager" select the new route and choose "Export selected" and save the GPX file.
# Then continue this script:
pol1 <- readGPX("bb1.gpx")
geoplot(nasc)
pol1 <- as.data.frame(pol1$routes$bb1)#
pol1 <- rbind(pol1,pol1[1,])
##geolines(pol2$routes$boundary2,col="red")
geolines(pol1,col="red",lwd=2)

write.csv(pol1,file="poly1.csv")
p1 <- "poly1b.csv"
# Subsample nasc data within defined grid of squares.
nasc1 <- nasc#[nasc$lat < -13 & nasc$lat > -16,]
#nasc1$lat <- -nasc1$lat
#pol1$lat <- -pol1$lat
write.csv(pol1,file="poly1b2.csv")
p1 <- "poly1b2.csv"
b <- boxgrid(nasc1,latmin=10,lonmin=10,gridfile="grid.csv",dir=paste(getwd(),"/",sep=""),pol = p1)

b <- b[b$box!=0,]
b <- b[b$mnasc!="NaN",]
dev.off()

# Plot the NASC data and the grid of squares.
#pdf("bio_geo_stations1.pdf",height=6,width=10,paper="a4r")
png("nasc4.png",height=800,width=600)#
par(mar=c(0.5,0.5,0,0))
geoplot(nasc1,type="n",grid=FALSE,ylim=c(-6,-17.30), xlim=c(8,18))
gr <- read.table("grid.csv",sep=",",header=TRUE)
border1 <- "black"
geopolygon(pol1,border="blue")
for(i in b$box){
  geopolygon(gr[gr$reitn %in% b$box[b$box==i],],border=border1,col="white")
  geotext(lat=b$lat[b$box==i],lon=b$lon[b$box==i],z=round(b$box[b$box==i]))}
geosymbols(lat=nasc1$lat,lon=nasc1$lon,z=nasc1$NASC,vbars=0.5,lwd=2,col="red")#,perbars=0.5,lwd=2
geolines(lat=nasc1$lat,lon=nasc1$lon,col="grey")
dev.off()

# Import biological data
wb2 <- loadWorkbook("/Users/UNUFTP/OneDrive/UNU-FTP 2017/Project/R/StockAss/Biological analise.xls")
lf <- readWorksheet(wb2,sheet=1) #Length frequency from trawl data.
Bio <- readWorksheet(wb2,sheet=2) #Individual biological measurements.
# Summarise length frequency.
llf<- lf[lf$species=="CARTR02",]
```

```
lff<- lf[lf$species=="CARTR04",]
length(llf$station)

lf<-merge(lff,llf, all=TRUE)
names(lf)

unique(lf$species)

lf[is.na(lf)] <- 0#to replace na with zero
lengths <-  colSums(lf[,c(10:73)])
len <-  c(3:66)
freq <-  t(lengths[1:64])
freq <- aperm(freq)
freq <- data.frame(freq)
len <- data.frame(len)
lf0 <-  cbind(len, freq)
lf0<- lf0[-(49:66),]#remove the last rows with zero values

lf1 <- lf[lf$species=="CARTR02", ] # change species....
lengths <-  colSums(lf1[,c(10:73)])
len <-  c(3:66)
freq <-  t(lengths[1:64])
freq <- aperm(freq)
freq <- data.frame(freq)
len <- data.frame(len)
lf1 <-  cbind(len, freq)
lf1<- lf1[-(49:66),]#remove the last rows with zero values
mean(lf1$len)

lf2 <- lf[lf$species=="CARTR04", ] # change species....
lengths <-  colSums(lf2[,c(10:73)])
len <-  c(3:66)
freq <-  t(lengths[1:64])
freq <- aperm(freq)
freq <- data.frame(freq)
len <- data.frame(len)
lf2 <-  cbind(len, freq)
lf2<- lf2[-(49:66),]#remove the last rows with zero values
lf3 <- cbind(lf0,lf1$freq,lf2$freq)
names(lf3)<- c("length","count", "count.i", "count.m")
#Length weight relationship applied to length frequency data.
stations <- lf$station
bbb<- Bio[Bio$species=="CARTR02",]
bb<-Bio[Bio$species=="CARTR04",]
Bio<- merge(bbb,bb, all=TRUE)
Bio1 <- Bio[Bio$station  %in% stations, ]
Bio1$rlen <- round(Bio1$len)#To make group class of 1.
head(Bio1)

summary(Bio1)

plot(log(Bio1$len[Bio1$weight > 0]), log(Bio1$weight[Bio1$weight > 0]), ylab="Log of Weight", xlab= "Log of Length" )
#Define the Length key based on weight
Bio1.lm <- lm(log(weight)~ log(len), data=Bio1[Bio1$weight > 0,] )#Is the intercepts that will be used to plot the line
Bio1.lm

abline((Bio1.lm))
plot((Bio1$len), (Bio1$weight),ylab="Weight (g)", xlab= "Length (cm)")#Do the simple plot to fit the line in
lines(1:100, exp(Bio1.lm$coefficients[1]) * c(1:100)^Bio1.lm$coefficients[2] )#The defined line
mtext("Length-Weight Relationship of horse mackerel", side = 3, line = 0.5)
legend("topleft", "Weight = 4.727L^2.983")
points(lf3$len,exp(Bio1.lm$coefficients[1]) * lf3$len^Bio1.lm$coefficients[2],col="red",pch=16)
#Estimated valu for each length.
lf3$weight <- exp(Bio1.lm$coefficients[1]) * lf3$len^Bio1.lm$coefficients[2]
#Length weight relationship for Per Species#
bbb<- Bio[Bio$species=="CARTR02",]
Cartr02<-bbb[Bio$station %in% stations, ]
```

```
Cartr02$rlen<-round(Cartr02$len)
summary(Cartr02)

plot(log(Cartr02$len[Cartr02$weight > 0]), log(Cartr02$weight[Cartr02$weight > 0]), ylab="Log of Weight", xlab= "Log of Length" )#Define the Length key based on weight
Cartr02.lm <- lm(log(weight)~ log(len), data=Cartr02[Cartr02$weight > 0,] )#Is the intercepts that will be used to plot the li ne
abline((Cartr02.lm))
plot((Cartr02$len), (Cartr02$weight),ylab="Weight (g)", xlab= "Length (cm)")#Do the simple plot to fit the line in
lines(1:100, exp(Cartr02.lm$coefficients[1]) * c(1:100)^Cartr02.lm$coefficients[2] )#The defined line
mtext("Length-Weight Relationship of cunene horse mackerel", side = 3, line = 0.5)
legend("topleft", "Weight = 4.583L^2.941")
points(lf1$len,exp(Cartr02.lm$coefficients[1]) * lf1$len^Cartr02.lm$coefficients[2],col="red",pch=16)#Estimated valu for each length.
lf3$weight.i <- exp(Cartr02.lm$coefficients[1]) * lf1$len^Cartr02.lm$coefficients[2]
################################################################
bb<- Bio[Bio$species=="CARTR04",]
Cartr04<- bb[Bio$station %in% stations, ]
Cartr04$rlen<-round(Cartr04$len)
summary(Cartr04)

plot(log(Cartr04$len[Cartr04$weight > 0]), log(Cartr04$weight[Cartr04$weight > 0]), ylab="Log of Weight", xlab= "Log of Length" )#Define the Length key based on weight
Cartr04.lm <- lm(log(weight)~ log(len), data=Cartr04[Cartr04$weight > 0,] )#Is the intercepts that will be used to plot the li ne
abline((Cartr04.lm))
plot((Cartr04$len), (Cartr04$weight),ylab="Weight (g)", xlab= "Length (cm)")#Do the simple plot to fit the line in
lines(1:100, exp(Cartr04.lm$coefficients[1]) * c(1:100)^Cartr04.lm$coefficients[2] )#The defined line
points(lf2$len,exp(Cartr04.lm$coefficients[1]) * lf2$len^Cartr04.lm$coefficients[2],col="red",pch=16)#Estimated valu for each length.
mtext("Length-Weight Relationship of cape horse mackerel", side = 3, line = 0.5)
legend("topleft", "Weight = 4.759L^2.965")
lf3$weight.m <- exp(Cartr04.lm$coefficients[1]) * lf2$len^Cartr04.lm$coefficients[2]
names(lf3)<- c("length","count","count.i","count.m", "weight","weight.i", "weight.m")
lf3$part <- lf3$count/sum(lf3$count)
lf3$part.i <- lf3$count.i/sum(lf3$count)
lf3$part.m <- lf3$count.m/sum(lf3$count)
exp(Bio1.lm$coefficients[1]) * 51^Bio1.lm$coefficients[2]

sum(lf3$weight*lf3$count)

lf3 <- lf3[!is.na(lf3$weight.i),]
sum(lf3$count)

# Biomass calculation
biom <- biomass(b,teg=30,lendist=lf3,dir=getwd()) #Based on length frequency from trawl measurements. (Perhaps more c orrect)

write.csv(biom,"biom.csv")
```