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STOCK ASSESSMENT AND THE INFLUENCE OF ENVIRONMENTAL PARAMETERS ON THE DISTRIBUTION OF MACKEREL SCAD (*DECAPTERUS MACARELLUS*) IN CABO VERDE WATERS.

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ABSTRACT

Makerel scad is one of the most important small pelagic fisheries in Cape Verdean waters, having enormous social and economic importance, and is used as bait and food and in the canning industry. INDP official landing data recorded between 1989 to 2015 indicate that mackerel scad made up almost 40 % of Cabe Verdean total catches at the peak of its fishery in 1997 and 1998. After this peak the catch decreased significantly, especially in the last six years, representing only 6.6 % of landings in 2015 or 642 tonnes. The main goal of this study was to assess if the fluctuations and recent decline in mackerel scad catch in Cape Verdeans waters are caused by harvesting or by changes in environmental parameters. The data analysed was provided by reconstructed catch data during the time frame 1950 to 2014 from the research initiative Sea Around Us, official landing and effort data from INDP in the period from 1989 to 2015, biological data from INDP in the period 1989 to 2018, and sea surface temperature and chlorophyll-*a* from satellite observation. The growth parameters K and $L\infty$, the recruitment pattern and the total mortality were computed in the software FISAT II, the biomass was estimated by the Shaefer model using the Sea Around Us reconstructed catch data and CPUE data from INDP for both fleet, and simple linear regression was applied to see the correlation between the catch data and environmental parameters. The growth parameters computed from FISAT II indicate $L\infty = 40.6$ cm, $K = 0.450$ year^{-1}, $Z = 3.23$ year^{-1}, $F = 2.31$ year^{-1}, $M = 0.92$ year^{-1}. The biomass estimated by the Shaefer model indicate an MSY of 5,619 tonnes using the Sea Around Us catch and artisanal CPUE from INDP, and 5,686 tonnes using the Sea Around Us catch and industrial CPUE from INDP. The correlation between catch and environmental parameters, showed an $R^2 = 0.043$ when catch is correlated with sea surface temperature, and $R^2 = 0.21$ when catch is correlated with chlorophyll-*a*. There are indicators that the stock is declining, but not conclusive, hence the fishing effort should be reduced until more information is known. The stock did not show strong links to environmental factors, further studies and improved sampling procedures are recommended to get more information on the stock.

Keywords: mackerel scad, environmental factors, biomass, growth parameters, decline

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LIST OF ACRONYMS

BMSY	Biomass that Produce Maximum Sustainable Yield
CC	Canary Current
CCLME	Canary Current Large Marine Ecosystem
CPUE	Catch Per Unit Effort
CUC	Canary Upwelling Current
CVC	Cape Verde Current
CVFZ	Cape Verde Frontal Zone
dPUC	deep Poleward Undercurrent
EEZ	Economic Exclusive Zone
FAO	Food and Agriculture Organization
FL	Fork Length
FMSY	Fishing Effort to Produce Maximum Sustainable Yield
GDP	Gross domestic product
INDP	Instituto Nacional Desenvolvimento das Pescas
MC	Mauritania Current
MSY	Maximum Sustainable Yield
NACW	North Atlantic Central Water
nCVC	northern Cape Verde Current
NEC	North Equatorial Current
NECC	North Equatorial Counter Current
NORAD	Norwegian Agency for International Development
PUC	Poleward Undercurrent
RV	Research Vessel
SACW	South Atlantic Central Water
SL	Standard Length
SST	Sea Surface Temperature
TL	Total Length

1 INTRODUCTION

Fisheries are one of the most important economic activities in Cabo Verde, employing 8,600 people who represent 4 % of the economically active population, (Carvalho, 2017). Fisheries products in 2014 amounted to 40 % of exports from Cape Verde, (FAO, 2016), representing 0.8 % of Gross Domestic Product (GDP). The fisheries in Cabo Verde have a social and economic impact, providing animal protein for the population, with annual consumption per capita of around 11.9 kg (FAO, 2016).

The fisheries are divided into two components: artisanal and industrial and both operate inside Cape Verdean waters. The artisanal fleet can only operate inside a three nautical mile perimeter from the shore. For reasons of safety, it is illegal for the fleet to go out further.

In 2012, the artisanal fleet was composed of 1,239 open boats with overall lengths ranging from 3.5 to 6.5 meters (figure 1). The boats operate with different gears, handline, purse seine, gillnet, beach seine, and dive, but the most common is the hand line, used by 80% of boats. The artisanal purse seine fleet is composed of 15 boats (INDP, 2012), and in 2012 they reported catches of around 288 tonnes representing 6.7 % of the total landing made by the whole artisanal fleet (INDP, 2013).

The industrial fishery is composed of 90 vessels with overall lengths ranging from 7 to 17 meters, the main gear is purse seine (figure 1), (INDP, 2012), operating around all the archipelago´s fishing grounds. The total catch declared by the industrial fleet in 2015 was 9,694 tonnes (INDP, unpublished data).

Figure 1: Examples of artisanal boats on the left and industrial boats on the right.

The artisanal and industrial purse seiners target the small pelagic. The catches are a combination of mackerel scad, blackspot picarel and bigeye scad. Following the high decline of mackerel scad catches since 2010, the semi-industrial and industrial fleet have focused their attention on frigate tuna, particularly since 2012.

The mackerel scad (figure 2) has a wide geographical distribution around the tropical seas, except for the Gulf of Mexico where it is unknown. It is a marine pelagic-neritic species, found at depths from 0 to 400 m but is most abundant from 40 to 200 m depth. Juvenile of the mackerel live inshore waters in sheltered areas where they later are recruited into the adult schools. The mackerel scad is found in large schools. It feeds predominantly on small fish, zooplankton and crustaceans in the water column and is active during day and night (Ramlochan, 2016).

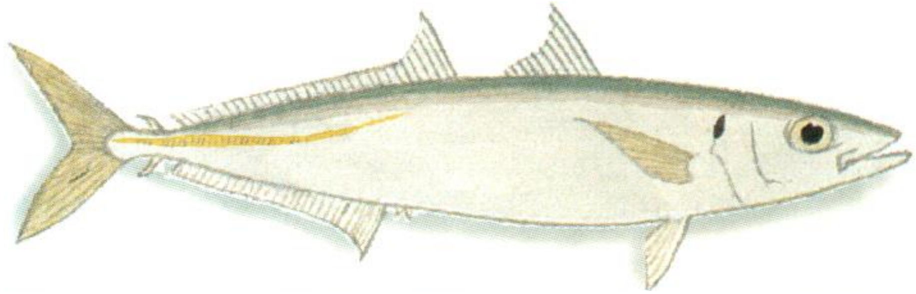

Figure 2: The mackerel scad (D. macarellus), (Curvier 1833)

The mackerel scad fishery is vital for the Cape Verdean economy (Trindade Santos *et al*. 2013). Official landing data from INDP during the period from 1989 to 2015 indicate that mackerel scad made up almost 40 % of Cabe Verdean total catches at the peak of its fishery in 1997 and 1998. After this peak the catch has decreased significantly, especially in the last six years, representing only 6.6 % of the landing in 2015 an amount of 642 tonnes. However, data from the project Sea Around Us during the period from 1950 to 2014 denote that the catch of mackerel scad is two to three times bigger than the official reported data (Sea Around Us, 2019). The is because the project Sea Around Us, reconstructed the catch based on official landing data, but also estimated unreported catch and major discard (figure 3).

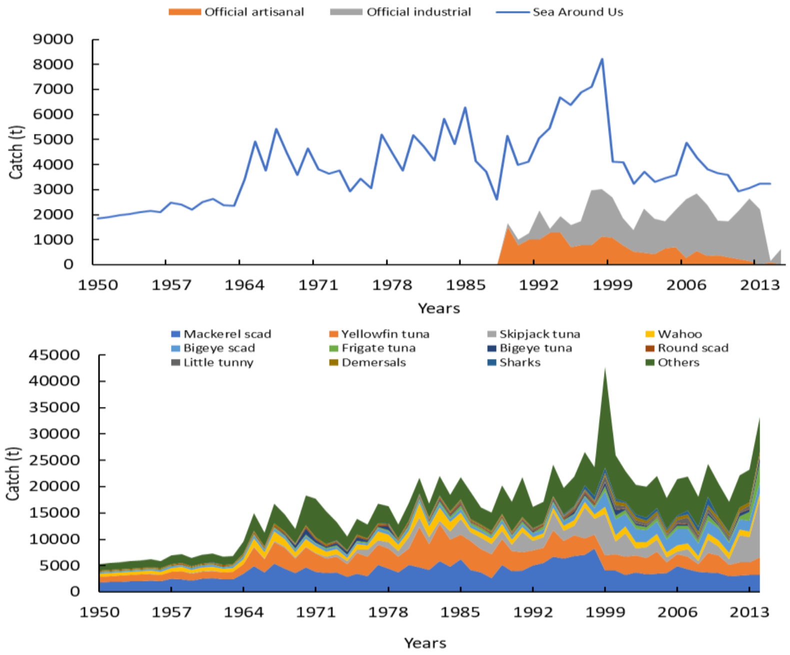

Figure 3. Upper panel Total catch data of mackerel scad in Cabo Verde waters by INDP (divided into official artisanal catch data and official industrial data) and The Sea Around Us project. (The Sea Around Us project data included discards and IUU data, while INDP records landed fish data), bottom panel major group catch estimated by the project Sea Around Us.

Several reasons might cause the fluctuation and decrease in the catch of the mackerel scad in Cabo Verde waters, one of them could be the distribution pattern off the shelf or potential migration of pelagic fish to or from the island population. Environmental factors like sea surface temperature and chlorophyll might also play an essential role in the migration of the mackerel scad.

Another potential cause could be overfishing. Increased landings during the 90s with the peak of harvesting in 1997 can be explained with the introduction of 20 new purse seiners of 11 meters length targeting small pelagic especially the mackerel scad (Fonseca, 2000), (Trindade Santos, *et al*. 2013).

According to Almada (1997), the increase in the mackerel scad landing during the 90s was caused by the partial interruption of the local tuna fleet and by two Japanese freezing vessels which have been buying mackerel scad caught from the local fleet for bait. However, after the year 2000 with the opening of a fishery canning plant, the demand for mackerel scad increased. These changes in the fishing effort could be one of the possible reasons for the increase in the catch during those years.

1.1 Research objective

The mackerel scad fisheries are among the most important fisheries in Cabo Verde; it has economic and social importance for the Cape Verdeans. Mackerel scad has long been harvested for domestic consumption, and later for the canning industry in the country. Sharp fluctuations in the catch have been noted, especially in the past six years when the catch has declined. Addressing this issue is urgent.

The overall objective of the study is to assess if the fluctuations and recent decline of the mackerel scad catch in Cape Verdean waters are could be caused by harvesting or by environmental changes that can affect the distribution of the species. The main objectives are to:

- Analyse the landing data in order to construct total and spatial catch per unit effort (CPUE) time series, for the artisanal and industrial fleet.
- Assess possible impact of chlorophyll-a and sea surface temperature on the mackerel scad abundance.
- Estimate stock size and fishing mortality based CPUE and length frequency distribution.

1.2 Study area

The study area is the ocean surrounding the Republic of Cabo Verde, which is situated 650 km from the coast of Africa at 15°N and is composed of ten islands of volcanic origin (figure. 4). The total territorial area is 4,033 km^2, with a coastline of 965 km. The islands rise from a depth of at least 3,000 m and the insular platform where depths are less than 200 m, covering an area of 5,934 km^{2,} and the exclusive economic zone (EEZ) covers an area of 78,940 km^2.

The climate on the archipelago is warm with the temperature ranging from an average of 22 ºC during the cold season (December to March) to 27 ºC in the warm season (April to November). The wind is mainly northeasterly, except during the cold season when the winds are predominantly easterly.

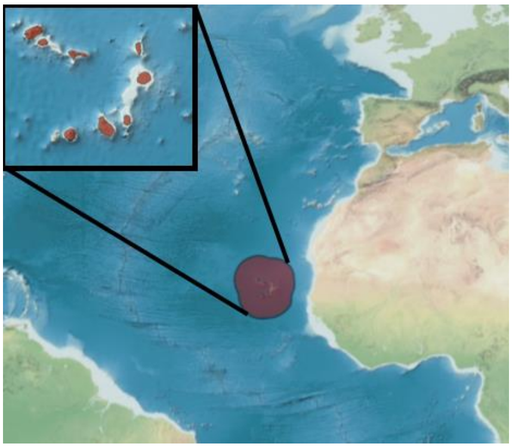

Figure 4. Location of the Republic of Cabo Verde

2 LITERATURE REVIEW

2.1 Biology

Mackerel scad has an elongated and cylindrical body. The ventral part of the fish has a black colour and dorsal is bluish to green. The common length is around 30 cm total length, with the maximum recorded length reaching 46 cm total length. There is no difference in growth between male and females, (Prado & Bearez, 2004).

The mackerel scad occupies an intermediate position in the marine ecosystem, feeds predominantly on small fish and macroplanktonic crustaceans in the water column. The scad is prey for wahoo, skipjack, yellowfin tuna, bigeye tuna and dolphin fish (Weng & Sibert, 2000). Active during day and night, the scad's preferred temperature is from 13 to 28 °C (Froese & Pauly, 2018) (Ramlochan, 2016).

Shiraishy *et al*.(2010) studied mackerel scad in Japanese waters. They analysed otolith, gonads, and length. The results indicate that maximum age is around eight years with spawning occurring from April to July. They mature at two years of age, at an average size of 25.8 cm fork length.

Mackerel scad spawning occurs in April to August in Hawaiian waters, and they need sunlight for their spawning. They mature at 18 months, where their standard length is 24.5cm (Clarke & Privitera, 1995).

2.2 Global fishery

The genus *Decapterus* support major fisheries around the world (figure 5) and is especially caught in the Pacific, where it is used as bait and food. China leads the world catch followed by Indonesia and the Philippines (Froese & Pauly, 2018).

The most significant fishery of the genus *Decapterus* is in the East China Sea, where the total annual catch was more than 20,000 tonnes in the 80s and 90s. After 1998 the annual catch decreased to 10,000 tonnes, and in 2006 was only 7,000 tonnes (Shiraishy *et al*. 2010).

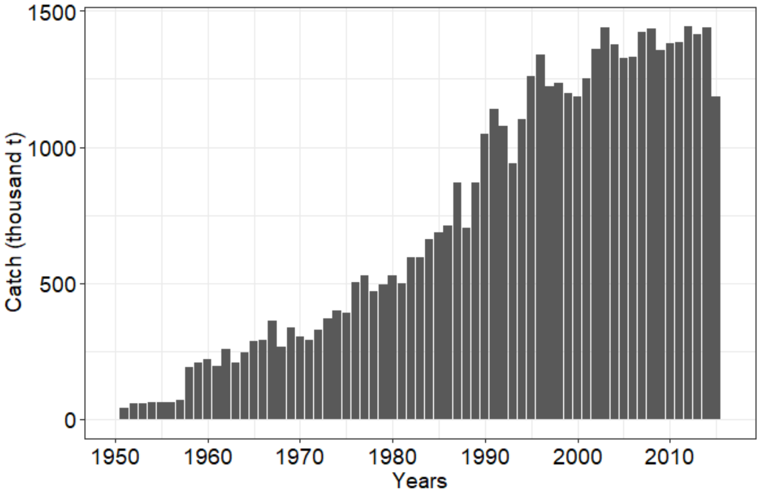

Figure 5. Global catch of *Decapterus spp*. source of data FAO

2.3 Cabo Verde

In the past 30 years, some surveys have been conducted to estimate the biomass of the fish around Cabo Verde.

In 1982 the fishery research vessel (RV) Dr Fridtjof Nansen belonging to the Norwegian Agency for International Development (NORAD) together with FAO, conducted a survey investigation of the fishery resources in the Cape Verdean waters. The survey comprised: 17 bottom trawl stations, 17 pelagic trawl stations, eight longline stations, and 27 hydrographical stations. The total fish biomass was estimated at 100,000 tonnes, of which half were pelagic species mainly mackerel scad (Decapterus macarellus), and round scad (*Decapterus punctatus*) (NORAD and FAO, 1982).

In 1984 the Icelandic RV Fengur conducted a survey but only for the demersal fish and estimated the biomass at around 43,000 tonnes. Pelagic fish were also observed but estimated to be far less representative than the demersal fishes, at around 10% of the total catch (Magnusson, 1984).

In 1988 another survey was conducted for demersal fish by the RV Fengur. The estimated total biomass index for all commercial fish was 14,700 tonnes. The results indicated low biomass of commercial fishes in the waters of Cabo Verde, and at this time they did not estimate any biomass for the pelagic fishes (Pálsson, 1988).

In 1997 the Portuguese RV Capricornio conducted a cruise to estimate the abundance of the small pelagic around Cabo Verde using eco-integration and the estimated abundance for the *Decapterus spp*. was 14,715 tonnes. However, the result was an underestimation because it was not possible to cover the entire distribution area of the mackerel in the coastal areas (IPIMAR and INDP, 1997).

The last survey made in the Cape Verdean waters was in 2011 by the fishery RV Dr Fridtjof Nansen. The survey was done for demersal and pelagic fish, and the catches of pelagic species were generally low. The abundance of pelagic fish was evaluated to be 3,000 tonnes.

Decapterus macarellus species was found, but it was not the most commonly caught pelagic species (FAO-NORAD, 2011).

The mackerel scad stock has been assessed on several occasions in Cabo Verde. The most important assessments were made by, Almada (1997); Stobberup (2005); Stobberup and Erzini (2006); DeAlteris (2012) and Trindade Santos (2013).

In 1997, Almada estimated the growth parameters, the proportion of age-groups, and the mean length of age-groups was estimated using the distribution method by MacDonald and Pitcher. The following growth parameters were estimated $L\infty$ = 30.1 cm fork length; K = 0.34 year^{-1}, and t_0= 0.11year, at that time the catch was around 3,000 tonnes, the estimated Maximum Sustainable Yield (MSY) was around 5,000 - 6,000 tonnes (Almada, 1997).

Stobberup (2005) evaluated the small pelagic resources using dynamic biomass models, but it was not possible to evaluate the mackerel scad specifically due to difficulties in obtaining a reliable abundance estimate for this species alone.

The most recent studies were made in 2006 and 2012. Those made in 2006 were based on a Bayesian approach to dynamic biomass modelling. The results of the model indicate that the stock was being exploited sustainably, with the total catch during that period being around 2,100 tonnes and was half of the estimated MSY of 4,700 tonnes (Stobberup & Erzini, 2006). The last assessment for this small pelagic was made in 2012; the results of the study show one MSY to approximately 2,500 tonnes. It suggests that to attain this MSY the stock needs to be rebuilt to BMSY, and according to the analysis made overfishing has occurred, caused by the harvest over the last 30 years (DeAlteris, 2012).

2.4 Oceanographic description of Cabo Verde

Cabo Verde islands are part of the Canary Current Large Marine Ecosystem (CCLME), limited to the south by the North Equatorial Counter-Current (NECC), and to the north by the North Equatorial Current (NEC), (Lazaro *et al*. 2005).

The CCLME is a major upwelling region off the northwest coast of Africa. It is influenced by the Canary Current that flows from north to south between 30ºN – 10ºN and offshore to 20ºW. Global warming and the consequent rise of sea surface temperature effect the fish stock in the CCLME. Sea surface temperature and upwelling intensity are strongly linked and are believed to effect the spatial distribution and abundance of fish in the CCLME (Cury & Roy, 1991).

The Canary Current reaches the archipelago with a speed of 10 to 15 cm s^{-1}. When it approaches the islands, the water mass produces complex hydrodynamic effects related to the topography, morphology of the coast, the geographic position of the islands and the nature and the extension of the insular platforms. Its velocity also increases, generating cyclonic and anticyclonic eddies south of the islands (Medina, 2008).

The Cabo Verde Islands are located in an oceanographic region called the Cape Verde Basin, which is bounded by the northeastern corner of the eastern tropical North Atlantic Ocean, approximately between Cape Vert (14°45′N), Cape Blanc (20°46′N) and the Cabo Verde Islands (Figure 6, right). According to Stramma *et al*. (2005), the region is under the influence of two major water masses, the North Atlantic Central Water

(NACW), and the South Atlantic Central Water (SACW). The transition between these two water masses is made south of the parallel 20º N (Hernandez-Guerra *et al*. 2001), the junction of these two water masses generate the Cape Verde Frontal Zone (CVFZ) (figure 6, left panel).

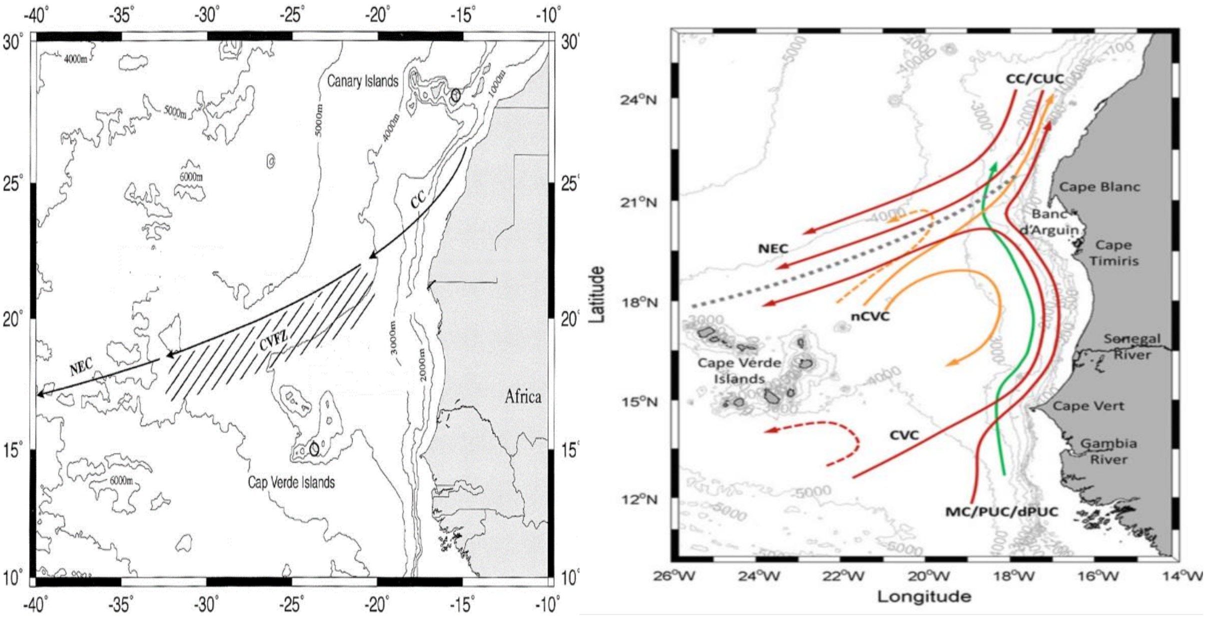

Figure 6 Right panel mapping illustrating the Cape Verde Frontal Zone, adapted from Vangriesheim *et al*. (2003). Left panel adapted from Pelegrí *et al*. (2017) represents the crossroad between subtropical (northern origin) and tropical (southern origin) waters in the eastern boundary of the North Atlantic Ocean. The coloured lines illustrate the major pathways for upper central (red, 100–300 m), lower central (orange, 300 – 600 m), and intermediate (green, 600–1000 m) waters, with dashed lines representing weaker summer pathways (Canary Current CC; Canary Upwelling Current CUC; North Equatorial Current NEC; Cape Verde Current CVC; northern Cape Verde Current nCVC; Mauritania Current MC; Poleward Undercurrent PUC; deep Poleward Undercurrent dPUC).

In this region the filaments from the eutrophic upwelling along the coast of West Africa, play an essential role in transporting phytoplankton, nutrients, organic matter and fish larvae onto the interior oligotrophic subtropical gyre, contributing in this way to the enrichment of this zone (Valdés & Déniz-González, 2015).

Another phenomena that occurs in this region during wintertime are the eddies. According to Schütte, Brandt, & Karstensen (2016) the eddies are major transport agents between coastal waters and the open ocean in the eastern tropical North Atlantic. The eddies are generated along the coast of Mauritania and propagate westwards towards the region of Cabo Verde Islands. The eddies maintain a conservative ecosystem, keeping the properties for several months.

During the westward propagation of the eddies from the west coast of Africa, the oxygen concentration is found to decrease, to a concentration less than 40 µmol kg-1 (Schütte *et al*. 2016). These depleted oxygen eddies are known as dead zones. It is critical to understand the effect of these eddies in fisheries in countries like Cabo Verde during the westward propagation.

Although Cabo Verde is part of the CCLME, the waters around the Cape Verdeans Archipelago are oligotrophic, with less primary production than the upwelling region off the west coast of Africa. This is caused by the distance between the archipelago and the African continent.

However, the Cabo Verde islands receive some water filaments from the upwelling region through the propagation of eddies, which may cause an increase of primary productivity. Water filaments are cold water tongues with their origin in coastal upwelling zones which spread to open ocean, preserving their properties.

2.5 Environmental effects on fisheries

Many studies indicate the effects of environmental factors on the distribution of small pelagic. Meteorological and oceanographic factors influence the distribution of the earliest life stages such as eggs and larvae, which have an impact on the recruitment for the next years (Ruiz *et al*. 2006), (Ruiz *et al*. 2013).

Climate change causes changes in the global oceans, such as sea level rise, an increase in ocean temperature, and ocean acidification (Cheung, Ota, & Swartz, 2014). There is evidence that climate variability can affect marine fisheries productivity by alteration of oceanic conditions, like ocean currents, water temperature, and coastal upwelling. Those changes in the ocean conditions affect primary productivity, species distribution, community, and food web structure (Cheung, *et al*. 2010).

In the tropical islands, there are some marine ecosystems such as coral reefs, seagrass communities that are important for the availability of some fish species. The availability, abundance, and resilience of fish can be affected drastically in these ecosystems by changes in the water temperature as well as by the effect of higher carbon dioxide concentrations (UNFCCC, 2005).

Other studies show that temperature is one of the critical environmental factors. It can interact with food availability and affect the metabolic process because each species has an optimum temperature and food level that results in maximum growth (Morgan, Rideout, & Colbourne, 2010).

Chassot *et al*. (2010) tested the relationship among marine primary production and fisheries harvesting over the world's Large Marine Ecosystems based on environmental data from satellite and annual catch data including all quantities landed for food and animal feed, from the project Sea Around Us and FAO. They realised that primary production limits average and maximum fisheries catch across the world at the Large Marine Ecosystems scale over both short and long timescales.

Along the Moroccan coastal area, studies showed that the migration of the sardine is related to the seasonal dynamic of the upwelling in the region. The intensity of the sardine migration appears to be associated with the strength of the upwelling. The highest catches are recorded when the upwelling is strong (Álvarez-Salgado *et al*., 2004).

In the case of Senegal, the abundance of the sardinella stock seems to be related to the interannual variations of the wind-driven upwelling index (Álvarez-Salgado *et al*., 2004).

3 MATERIAL AND METHODS

3.1 Data source

3.1.1 Landing and effort data

The official available statistical catch data used in this work are from 1989 to 2015 for the artisanal and industrial fleet from the National Institute of Fisheries Development (INDP). The data available from both fisheries are total landing and fishing effort.

For longer time series reconstructed catch data was used from 1950 to 2014 from the Sea Around Us project, the data combines official published data and reconstructed estimates of unreported data, including major discards, estimated by Trindade Santos, *et al.* (2013). This makes the Sea Around Us numbers higher than the official data from INDP.

The official data collection for the artisanal fleet is based on systematic sampling (Shimura, 1984). Cabo Verde has 97 landing sites for the artisanal fleet, and 17 of those landing sites are regularly being sampled according to their importance with regards to a number of boats, gear, and volume, which is equivalent to 18% of the total coverage, representing more than 50% of the total catch.

According to a pre-established calendar, the catch and effort are sampled for seven days each month. Sampling days are chosen every four days from a randomly selected first day, making sure that all weekdays will be covered, except weekends and holidays. Calculations and extrapolations are made to estimate the landing and fishery effort for the whole archipelago. The effort for the artisanal fisheries is defined as the number of trips. The average CPUE is given as kg/trip.

The landing and effort data are collected from industrial fishing vessels in Sal, São Vicente, and Santiago Islands harbour. Besides, canning industry data were also collected for the analysis. The effort is measured in day trips and numbers of vessels. Average CPUE is recorded in kg/day trip.

From 1989 – 1995 the effort is aggregated by year and gear, but available for artisanal and industrial fisheries separately. From 1996 - 2015 the effort is aggregated by months by gear and island for artisanal and industrial fisheries.

3.1.2 Biological data

Length frequency data has been collected since 1988. It was not possible to sample all months of each year, due to the absence of the catch in some months (table 1).

From 2005 to the present biological samples have been taken twice per month, and the goal is to collect 150 specimens per month. Samples are taken randomly from the fish market in the city of Mindelo and then analysed in INDP fish laboratory, where the fork length is measured, the total weight, the weight of gonad, and the weight of the liver from each.

Determination of the sex and maturity stage is made macroscopically. Seven stages of maturity are being used: immature (I), resting (II), maturing (III), pre-spawning (IV), spawning (V), spent (VI), gonads regression (VII) (Fonatana & Le Guen, 1969).

Table 1: Total numbers of length frequency samples per month and year

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1988	60	60	60	60	60	60	32	60					**452**
1989	30	28	30	60			19			30	30	30	**257**
1990			30	30	30	30	30	30	30	31	30	30	**301**
1991		30	30	16									**76**
1993	30	31	60	90	60		60	60	92	90	84	87	**744**
1994	60	60	60	60	60	120	120	60	90		60	60	**810**
1995	130	60	34	60	60		58	60	60	60		60	**642**
1996	283	50	202	150	150		100	10	151	179			**1275**
1997	150	150	150		150		75	74	150	75	75	78	**1127**
1998	75	65	75	75	75	75	75	75	78	75	75	75	**893**
1999	74		75	75	75		75						**374**
2000	150	151	152	151	219	146	145	75	75		145	75	**1484**
2001		145	144	75	75	144	146			75	75	141	**1020**
2002		70	145	76	74		74	75	75	75	75	74	**813**
2003	75	75	75	75	75	75	75	151	75	75	72	76	**974**
2004				75	149	75	150	151	75	75	203	150	**1103**
2005	150	150	150	150	75	150	150	150	150	227	150	75	**1727**
2006	143	150	140	150	150		151	150	150	75	153	75	**1487**
2007	150	150	150	150	150	150	150	150	150	150	150	75	**1725**
2008	150	150	76	150	75	188	180			75			**1044**
2009	36	150	145	150	150	150	150			150	150	150	**1381**
2010	150	150	150	75	75	145	150			150	150	75	**1270**
2011	75	149	150	141	150	75	150	75		150	100		**1215**
2012	148	150	150	150	75	150	150			150	147	150	**1420**
2013	150	75	75	75	75	75	150			75	75	150	**975**
2014		75	75		150		75			75	75		**525**
2015	75	150	75		130	75	125			75	75	75	**855**
2016	75		75						75		75	75	**375**
2017			75	75	75	75			75	75	75		**525**
2018	150	150	150	224	75	150							**899**
Total	**2569**	**2624**	**2958**	**2618**	**2717**	**2108**	**2815**	**1406**	**1551**	**2267**	**2299**	**1836**	**27768**

3.1.3 Environmental parameters

Remote sensing data were used to estimate the sea surface temperature (SST) and chlorophyll-a. The data were derived from a frame provided by Marine Copernicus (http://marine.copernicus.eu/), for the Cabo Verde region.

The SST was estimated with the NEMOv3.1 ocean model, with a monthly mean temporal resolution and a spatial resolution of ¼ degree horizontal, covering the 1993 – 2015 period. The assimilated observations are along-track satellite from SST and in situ profiles of temperature from the CORA4 database (Marine Copernicus, 2019).

The chlorophyll-a is from ocean satellite observation, based on a multi-sensors/algorithms approach, with a space-time interpolation called L4 what means cloud free, taken during the daylight. The spatial resolution is 4 km, with a monthly temporal resolution. Covering the period from 1997 to 2015 (Marine Copernicus, 2019).

3.2 Data analysis

3.2.1 Growth parameters estimation

The growth parameters were estimated for the Von Bertalanffy equation.

$$L_t = L_\infty[1 - e^{(-K(t-t_0))}]$$

Where L_t is the length at age t, $L\infty$ is the asymptotic length the fish reach if they grow indefinitely, K is the growth coefficient, and t_0.

The hypothetical age (in years) the fish would have had at zero length (t_0) was estimated by Pauly's empirical equation. Where $L\infty$ and K are the growth parameters from the Von Bertalanffy function (Froese & Pauly in FishBase, 2018).

$$log(-t_0) = 0.3922 - 0.2752\, log(L_\infty) - 1.038\, log(K)$$

Estimation of the growth parameters $L\infty$ and K were found from length frequency distribution in catches using the Von Bertalanffy equation in Shepherd's model routine of the FISAT II software (FAO, 2006).

From the biological data weight and length measures are available from 1988 to 2018, a total of 27,766 specimens, the relationship is a way to predict weight at a given length.

$$W = aL^b$$

Where W is weight in grams, a and b are parameters of the function and L is the fork length in centimetres, the above equation can be linearised with a logarithmic.

$$Log\ W = Log\ a + b\ Log\ L$$

The length at first maturity (L_m) was estimated by fitting a logistic curve to the relationship between the proportion mature and length (Jennings, Kaiser, & Reynolds, 2001).

$$P = 1/(1 + e^{(-r(L-Lmat))})$$

Where P is the proportion mature, r is a constant, L is the length and L_{mat} is the length of the mature specimens in the samples.

Age at first maturity (t_m) was estimated from the length of the first maturity, using the inverse of the von Bertalanffy growth function, t_m is the average age at which fish of a given population mature for the first time (Froese & Pauly, FishBase, 2018).

$$t_m = t_0 - ln(1 - L_m / L_\infty)/K$$

The life span (t_{max}), was estimated following Taylor (1959). It is defined as the maximum age a fish or population can attain. It is calculated using the K parameter obtained from the Von Bertalanffy growth function (Froese & Pauly in FishBase, 2018).

$$t_{max} = t_0 + 3/K$$

The total mortality (Z), was estimated by the length converted catch curve in FISAT II, with the Von Bertalanffy parameters K, $L\infty$.

Total mortality was estimated from the slope of a catch curve with a negative slop given by the following equation.

$$ln\frac{N_i}{\Delta t_i} = a + b * t_i$$

Where N_i is the number of fish in length class i, Δt_i is the time needed for the fish to grow through length class i, t_i is the age (or the relative age, computed with $t_0 = 0$) corresponding to the midlength of class i, and where b is the regression slope and a is the intercept.

The Fishing mortality (F) was obtained from the equation $Z = F + M$, thus $F = Z - M$.

Where Z is the total mortality, F is the fishing mortality, and M is the natural mortality.

The natural mortality (M) was estimated by Pauly's empirical formula, calculated using the Von Bertalanffy parameters K, $L\infty$ and T is the annual mean of the water temperature (°C).

$$log(M) = -0.0066 - 0.279log(L\infty) + 0.6543log(K) + 0.463log(T)$$

The L_{opt} is the length class with the highest biomass in an unfished population. It is the length class where a fishery would obtain the maximum yield if it caught fish of only this size. The L_{opt} were adapted from Beverton's, (1992) formula, where is estimated using Von Bertalanffy parameter K and the natural mortality M (Froese & Pauly, 2018).

$$L_{opt} = L_{\infty} * (3/(3 + M/K))$$

The recruitment patterns were estimated in the software FISAT II, using length frequency data, the inputs are growth parameters from Von Bertalanffy equation K, $L\infty$ and t_0 (FAO, 2006).

3.2.2 *Biomass estimation*

The approach used to assess mackerel scad in Cabo Verde waters was the Shaefer model.

The model attempts to estimate the biomass level and have as output the maximum sustainable yield (MSY). The assumption that catch per unit effort is linearly related to population biomass because population biomass linearly decreases with effort (Haddon, 2011).

$$N_{(t)} = N_{(t-1)} + rN_{(t-1)}(1 - N_{(t-1)}/Ks) - C$$

where N_t is the stock biomass at time t, $N_{(t-1)}$ is the stock biomass in the year before, r is the population growth rate, and Ks is the maximum population size for growth to be positive.

The use of the catch per unit effort (CPUE) as an index of abundance is based in a relationship used in quantitative fisheries analysis (Maunder, et al., 2006) by the following equation.

$$C_t = qE_tB_t$$

where C_t is catch at time t, E_t is the effort at time t, B_t is biomass at time t, and q catchability coefficient, the equation can be reorganised to show the relationship between CPUE and abundance.

$$\frac{C_t}{E_t} = qB_t$$

The catch to be used to fit the Shaefer model will be the reconstructed catch from the project Sea Around Us This is because the model needs a historical time series catch to run properly.

The Sea Around Us, catch data are assumed to be two times higher than the official reported catch data from INDP.

MSY is obtained from the Schaefer model by the following formula.

$$MSY = \frac{(Ks * r)}{4}$$

The equation gives the biomass that produces the maximum sustainable yield (BMSY).

$$B_{MSY} = \frac{Ks}{2}$$

F_{MSY} is fishing effort or level of exploitation required to produce MSY is given by the following equation

$$F_{MSY} = \frac{r}{2}$$

Where Ks and r are obtained from the Schaefer equation.

3.2.3 Environmental data analysis

The anomaly was calculated for SST and chlorophyll-a.

The anomalies and seasonalities were calculated based on the average of each parameter and determine how the annual value deviates from this average, by the following equation.

$$A = a - \bar{a}$$

Where A is the anomaly, a is the annual average of the parameters and $\bar{a}$ is the average of the parameters during the time set. SST was calculated for the time period from 1993 to 2015 and chlorophyll-a from 1997 to 2015.

4 RESULTS

4.1 Growth parameters

The relationship between total weight (W) and the fork length (FL) were given by the equation $W = 0.00869L^{3.11}$, whit a $R^2 = 0.95$, $b = 3.11$ and $a = 0.00869$, which is growing over age (figure 7).

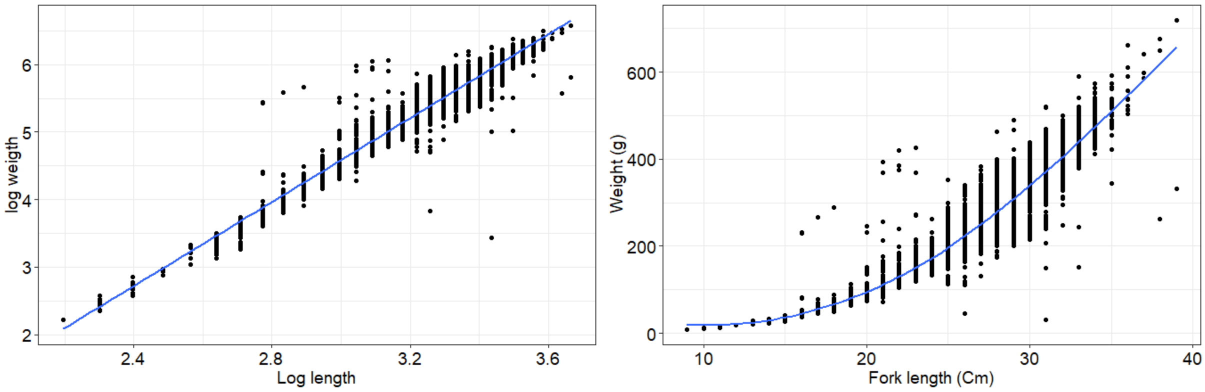

Figure 7: The log-transformed *W/FL* relationship in the left and the *W/FL* curve relationship on the right.

The length and age of the first maturity are commonly used as a fisheries management measure, to determine the minimum landing size. In this study, the L_{50} was estimated at 20.3 cm *FL* from the logistic curve for both sexes (figure 8), and the estimated T_m was 1.2 year.

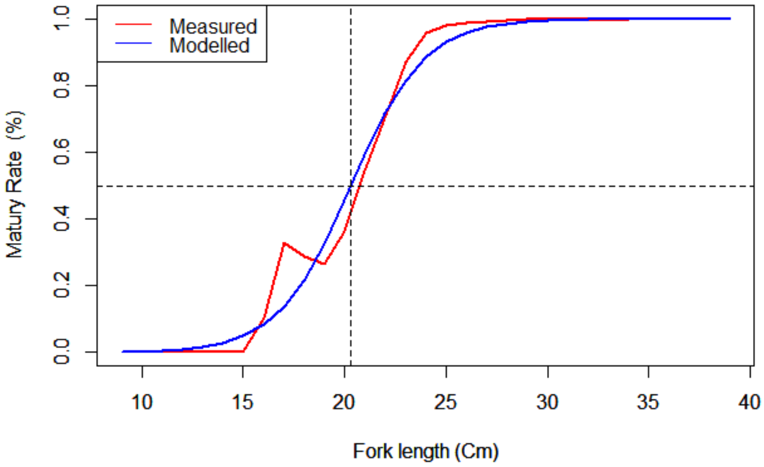

Figure 8: Maturity at length for mackerel scad

The growth parameters were estimated from Shepherd's model in FISAT II using the Von Bertalanffy growth equation. Where the asymptotic length ($L\infty$) was 40.6 cm of fork length, and the growth coefficient was 0.45 year^{-1}. For the estimation of t_0 was made with the Pauly empirical formula and t_0 was -0.34 year (table 2).

The maximum age of Cape Verdean mackerel scad was estimated from Taylor's formula, and t_{max} was 6.3 years. The l_{opt} which is the length class with the highest biomass in an unfished population was estimated to be 24.1 cm (table 2).

The length converted catch curve has been plotted in FISAT II. It gave total instantaneous mortality as 3.23 year^{-1} (figure 9) and natural mortality as 0.92 year^{-1}. Natural mortality has been obtained from the Pauly empirical formula. The fishing mortality has been calculated as 2.31 year^{-1} (table 2), which is the difference between total mortality and natural mortality.

Table 2. Growth parameters estimated for mackerel scad

L_∞ (cm)	40.6
K ($year^{-1}$)	0.450
t_0 (year)	-0.34
Z ($year^{-1}$)	3.23
M ($year^{-1}$)	0.92
F ($year^{-1}$)	2.31
L_{50} (cm)	20.3
t_m (year)	1.2
t_{max} (year)	6.3
L_{opt} (cm)	24.1
a	0.00869
b	3.11

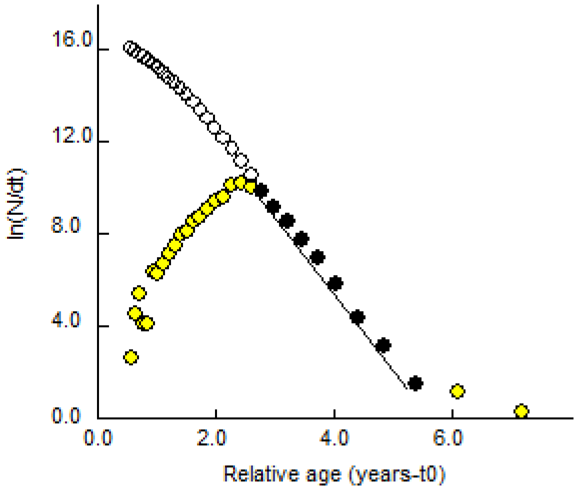

Figure 9. Length converted catch curve for estimate the total mortality for mackerel scad in Cabo Verde.

The recruitment was obtained as a percentage from the length frequency data in FISAT II (figure 10). The result shows that recruitment occurs at all times of the year except for January and February. The maximum recruitment peak was found in July, corresponding to 15.45 %.

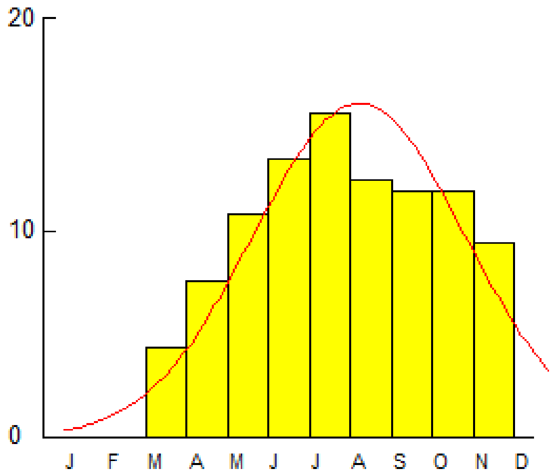

Figure 10. Recruitment pattern of mackerel scad in Cabo Verde waters

4.2 Catch per unit effort (CPUE) and effort

4.2.1 Artisanal fleet

CPUE for the artisanal purse seiners fleet was calculated using days at sea as the unit for effort from 1989 to 2012. For the artisanal fleet, the total CPUE show two peaks one in 1993 and another in 2005, and effort decreased over the years, (figure 11, top left) this could be one indication that the artisanal fishermen in Cabo Verde stopped targeting the mackerel scad and moved to another fishery.

CPUE were also calculated for the most important islands where they catch the mackerel scad. For the Santo Antão Island (figure 11, top right), The CPUE and the effort fluctuate over the years. The most significant fluctuation was observed in 1993.

For the São Vicente Island (figure 11, bottom left), CPUE along the years is almost constant, except for the year 2005 where a high CPUE was observed, in relation to effort over the years it has been reduced, and from 2005 significant changes was not observed.

In Sal Island (figure 11, bottom right), the CPUE and effort data were available from the year 1998 to 2012. The result shows a clear fluctuation between the CPUE and effort. The highest CPUE was obtained in the year 1999.

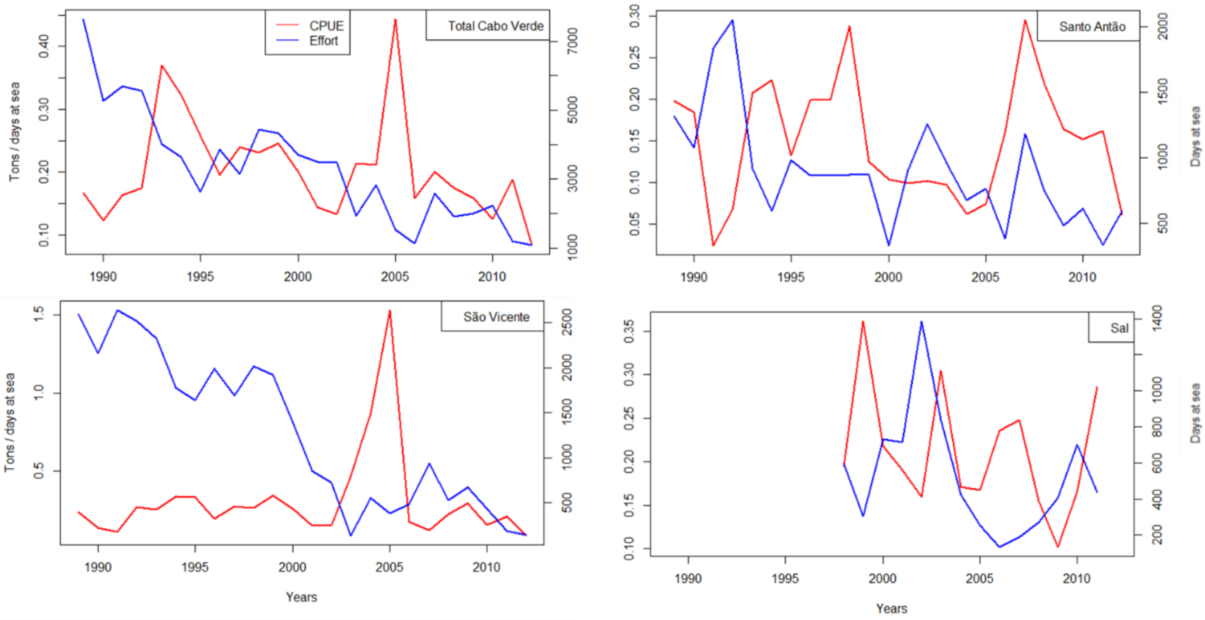

Figure 11. CPUE and Effort for the artisanal fleet. Left top total for all Cabo Verde, top right Santo Antão island, bottom left São Vicente island, bottom right Sal island.

4.2.2 *Industrial fleet*

CPUE for the industrial purse seiners fleet was calculated using days at sea as the unit for effort, but there is only data available from 2001 to 2012.

Analysing the CPUE from the all industrial fleet (figure 12, top left), it shows an inverse relationship between the effort and CPUE, in the years 2005 and 2006 with the lowest effort registered the maximum CPUE.

The data was also analysed by region, Santo Antão Island (figure 12, top right), the CPUE increased from 2002, reaching a maximum in 2007, after that the CPUE decreased accompanied by an increase in the effort.

For the São Vicente island (figure 12, middle left), from 2001 to 2004 there was no change in the effort and CPUE, the CPUE reach the maximum value in 2005 with a low effort, after 2005 the CPUE starts to decrease and effort increases.

Sal island (figure 12, middle right); the maximum CPUE was observed in the year 2005 and 2006, after this the CPUE dropped down while the effort increased registering the maximum in 2012.

São Nicolau island (figure 12, bottom left), here the highest CPUE was observed, and it was registered in the years 2005 and 2006 with a low effort.

Santiago Island (figure 12 bottom, right) the maximum CPUE was in 2005 and 2006 accompanied by a low effort after the CPUE decreased and effort increased attaining the maximum in 2008.

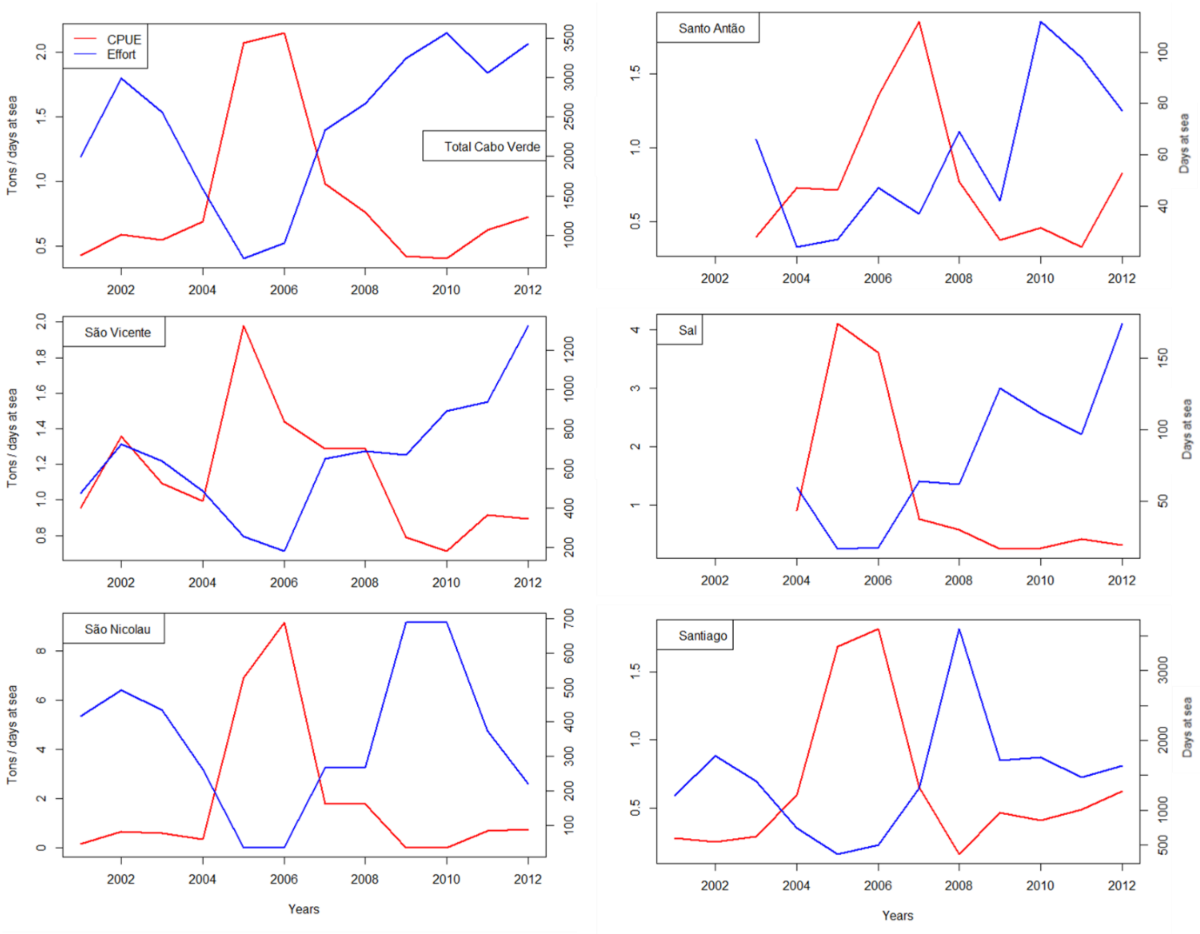

Figure 12. CPUE and effort for the industrial fleet. Top left total Cabo Verde, top right Santo Antão island, middle left São Vicente island, middle right Sal island, bottom left São Nicolau island, bottom right Santiago island.

4.3 Biomass estimation

The biomass was estimated by the Schaefer model, with the assumption that catch per unit effort is linearly related to population biomass because population biomass linearly decreases with effort.

The Shaefer model was applied for industrial and artisanal fleet. To support the Shaefer model, reconstructed unreported data, including discards from the project Sea Around Us, were used to estimate the fishable biomass during the period 1950 to 2014. Besides, official CPUE data from INDP for both fleets available from 1989 to 2012, were used for estimating the biomass index (figure 13).

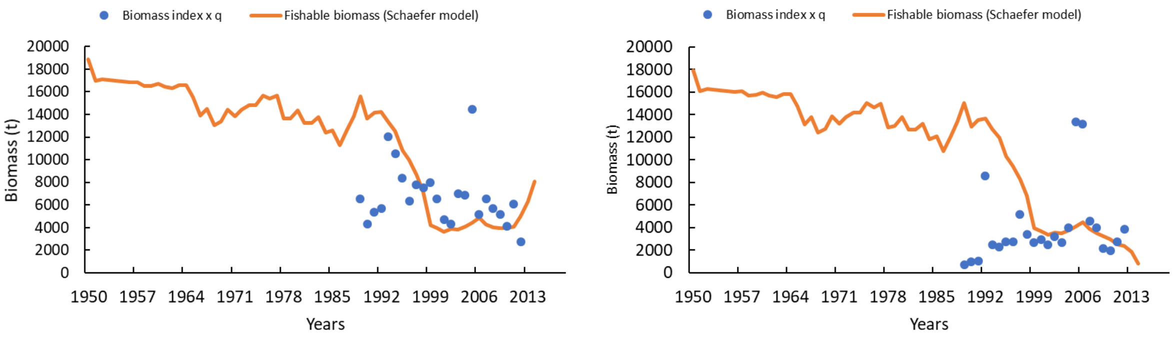

Figure 13. Biomass estimation using catch data from the project Sea Around Us and CPUE as a biomass index from INDP, Left panel using artisanal CPUE, right panel using industrial CPUE.

The results for the Schaefer model using the artisanal CPUE for the mackerel, suggest that the carrying capacity is about 18,840 tonnes, the population growth rate is 1.2 year^{-1}, The MSY is 5,619 tonnes, and B_{MSY} is around 9,420 tonnes, and the F_{MSY} is 0.6.

Using the CPUE from the industrial fleet, the results do not deviate much from the results with the artisanal CPUE, that the carrying capacity is about 17,932 tonnes, the population growth rate is 1.3 year^{-1}, The MSY is approximately 5,686 tonnes and B_{MSY} is around 8,966 tonnes and the F_{MSY} is 0.63 (table 3).

Table 3. Biomass parameters estimated by the Schaefer model, based on catch data from the Sea Around Us project and INDP CPUE data for the industrial and artisanal fleet.

	Ks (tonnes)	r (year^{-1})	BMSY (tonnes)	F_{MSY}	MSY (tonnes)
Artisanal	18,840	1.2	9,420	0.60	5,619
Industrial	17,932	1.3	8,966	0.63	5,686

4.4 Environmental factors

4.4.1 Temperature

The SST data analysed have monthly mean temporal resolution and a spatial resolution of ¼ degree horizontal, covering the 1993 – 2015 period.

The average monthly and annual temperature anomalies have been calculated from the satellite data for the Cabo Verde region over the period from 1993 to 2015. The average temperature during this time was 24.7 ºC, the southern part of the region is warmer with temperature around 25 ºC, and the northern part is colder with the temperature around 24 ºC, and with a region in the northeast where it reaches 23 ºC (figure 14).

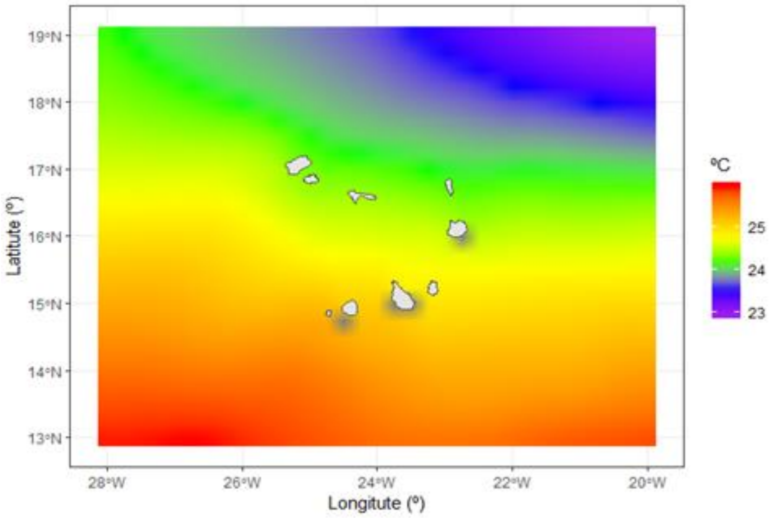

Figure 14. Average SST in Cabo Verde for the period from 1993 to 2015

The SST shows an interannual variability, the coldest year was 1994 that deviated -1.26 ºC from the average temperature, and the warmest year was 2010 with a deviation of 1.1 ºC from the average temperature (figure 15, top). From the monthly average temperature, it is possible to calculate the SST seasonality, where the data shows a cold season from January to June where the coldest months are February and March, and a warm season from July to December where the warmest months were September and October (figure 15, bottom).

In order to relate the environmental factors and the INDP official landing data, simple linear regression to determine the R^2 value was applied. The linear regression applied between SST, and CPUE shows that the relationship is not significant with an $R^2 = 0.043$, which can be interpreted as the SST does not have much influence on the catch during this period (figure 16).

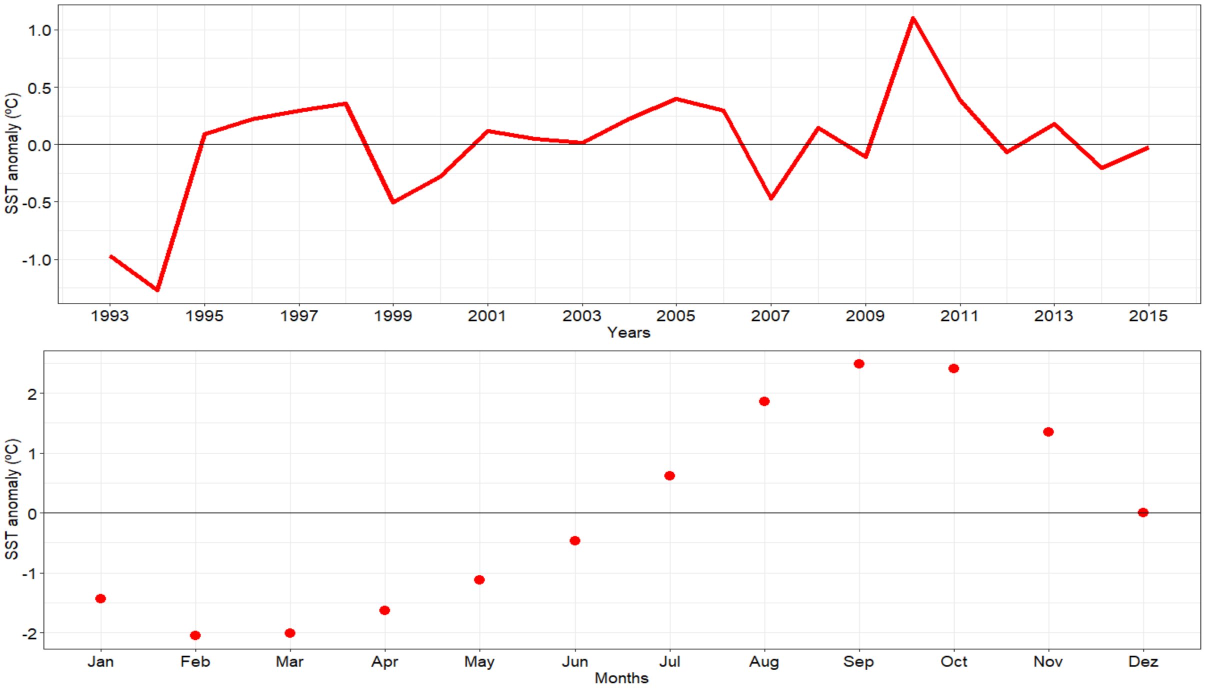

Figure 15. SST anomalies. Top panel annual SST anomaly, bottom panel monthly SST anomaly, during the period from 1993 to 2015.

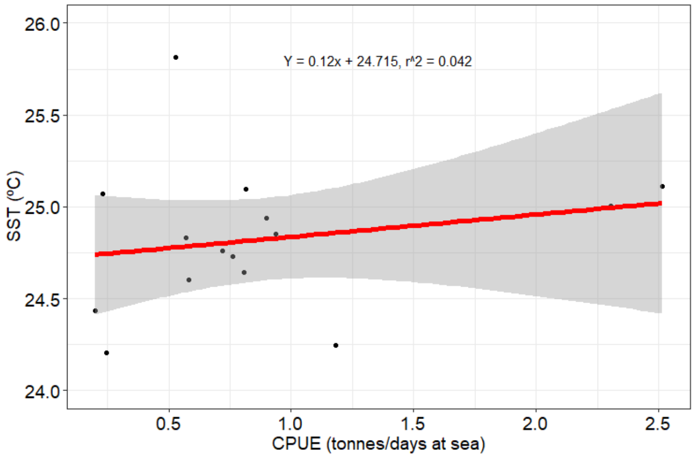

Figure 16. Linear regression between CPUE and SST, the grey shadow is the 95% confidence region for the regression fit.

4.4.2 Chlorophyll-a

The chlorophyll-a is a photosynthetic pigment present in the phytoplankton, the concentration of chlorophyll-a in the oceans allows to estimate the quantity of phytoplankton and therefore the biological activity. It is an indicator of the primary production in the oceans, that is the base of trophic level in the marine food web. Change in the concentration of chlorophyll-a will affect all higher trophic levels, from zooplankton to fish, marine mammals and seabirds.

The chlorophyll-a can be estimated from ocean satellite observation, based on a multi-sensors/algorithms approach, with a space-time interpolation called L4 which means cloud free. The spatial resolution is 4 km, with a monthly temporal resolution covering the period from 1997 to 2015

For the chlorophyll-a, the average monthly and annual anomalies have been calculated for the period between 1997 to 2015. The average chlorophyll-a during the time period was 0.14 mg m^{-3}, The highest productive area in the region is between the longitude 20°W to 24°W, In the western part of the region, the waters have a much lower concentration of chlorophyll-a (figure 17).

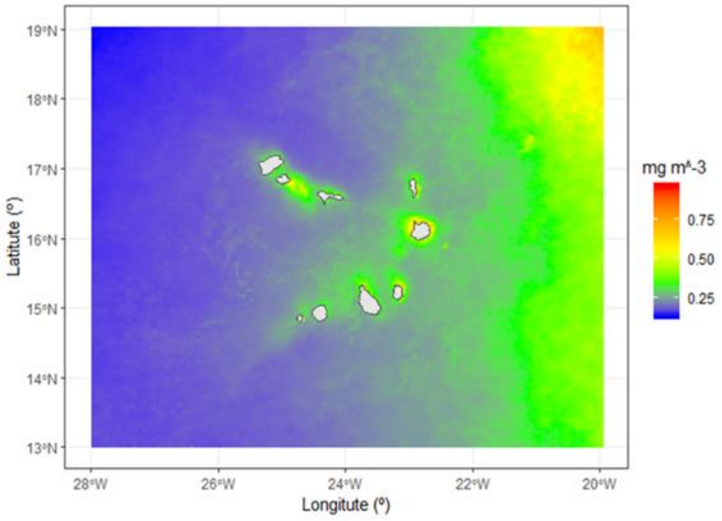

Figure 17. Average chlorophyll-*a* for the period between 1997 to 2015

The chlorophyll also demonstrates inter-annual variability, with the annual mean concentration being highest in 1998 and 1999 (figure 18, top). The monthly average calculated in order to determine the chlorophyl seasonalities in Cabo Verde waters, it shows that there is a peak of production from November to February, and a season with less production from March to October (figure 18, bottom).

The linear regression applied to see the relation between chlorophyll and the CPUE also did not show a significant correlation, with an $R^2 = 0.21$ (figure 19).

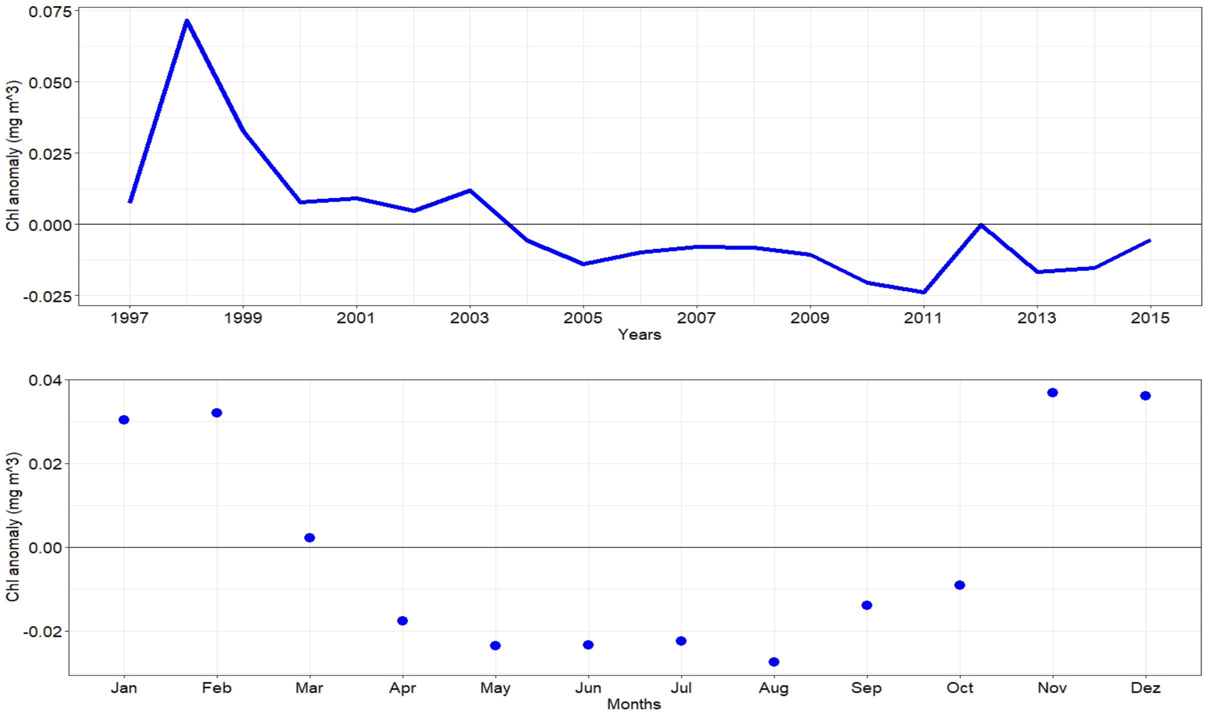

Figure 18. Chlorophyll-*a* anomalies. Top panel annual chlorophyll-*a* anomaly, bottom panel monthly chlorophyll-*a* anomaly, from the period 1997 to 2015.

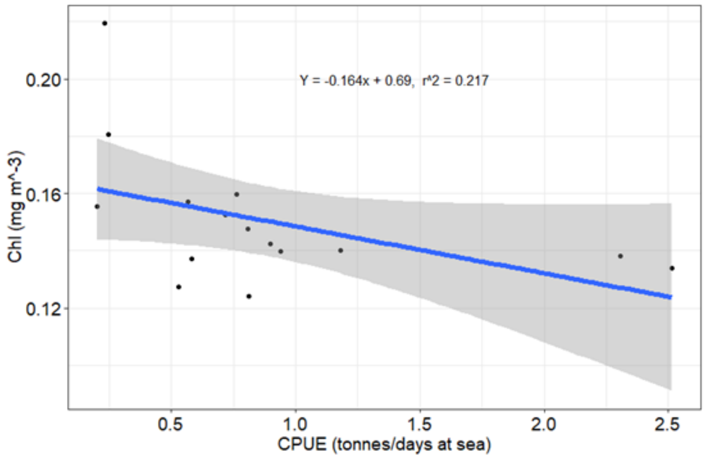

Figure 19. Linear regression between CPUE and chlorophyll-*a*, the grey shadow is the grey shadow is the 95% confidence region for the regression fit.

5 DISCUSSION

5.1 Growth parameters

The relationship between weight and length is a valuable tool used in fishery assessment, it can be used to predict weight when only length is available. In this study, *a* value obtained was 0.00869 and the *b* was 3.11, which shows positive allometric growth because the b value is higher than 3 (Morey et al., 2017). A previous study was carried out with the same species in Cabo Verdean waters, Magnuson (1984), Almada (1997), Tariche & Martins (2009) found similar values of *a* and *b*.

Table 4. Weight-Length parameters found for different studies for mackerel scad in Cabo Verde

Author	*a*	*b*	Number of specimens
Magnuson (1984)	0.00783	3.140	190
Almada (1997)	0.0070	3.170	4762
Tariche & Martins (2009)	0.0070	3.169	
This study	0.00869	3.11	27768

The length at first maturity was estimated for both gender and was 20.30 cm *FL*. Almada (1997) also estimated the L_{50} and was 21.8 cm *FL*. The difference is small, but this might indicate that the mackerel scad is maturing earlier now or growing faster. Almada, (1997) recorded an annual average temperature of 24.1 ºC, and in this study showed an annual average temperature of 24.7 ºC, indicating a slightly increase in the temperature of the water in Cabo Verde, which can explain the differences in the L_{50}.

Other studies around the world show different L_{50} for the mackerel species, according to Shiraishy et al. (2010) in the Japanese waters the mackerel scad matures at 25.8 cm *LF*, and according to Clarke & Privitera (1995), in the Hawaiian water, the L_{50} is 24.5 cm standard length. This can be explained by the difference in water temperature in these regions, the main reason is due to changes in the water temperature which can affect the size of first maturation.

The values obtained for *K* and $L\infty$ in this present study, were higher than the values estimated by Almada, (1997). Both studies used samples taken from commercial fisheries.

Majority of samples analysed by Almada, (1997) were between 23 and 27 cm, in this study majority of samples analysed were between 25 to 30 cm, giving little information about the real length distribution population of scad mackerel in Cabo Verde waters (appendix 1).

The mackerel scad growth parameters values depend on the region and habitat (table 5). One of the reasons for the different values of growth parameters could be related to the gear selectivity used in those different regions. Another reason could be related to the geographical areas, that can determine differences in $L\infty$ value, once the growth can be affected by factors such as food availability and population density, and k value is determined by the genetic or physiology of the species (Beverton & Holt, 1957).

Table 5. Estimated growth parameters for mackerel scad in other regions of the world

$L\infty$ (cm)	Length type	K (years^{-1})	Country
24.3	TL	1.8	Philippines
31.4	TL	0.28	Taiwan
41.2	FL	0.8	Sri Lanka

30.1	FL	0.34	Cabo Verde
40.6	FL	0.45	This study

The t_0, t_m and t_{max} observed in this study were respectively -0.34 year, 1.2 years, and t_{max} 6.3 years. There was only one study where it was estimated the t_0 in Cabo Verde waters, the t_0 estimated by Almada, (1997) was 0.11year, which is higher than t_0 obtained in this study, this difference can be explained because of the different method used for estimate the value.

There are no previous studies on t_m and t_{max} in Cabo Verde waters. But estimates are available for other water. In Hawaiian waters, the t_m was estimated to be 1.6 years according to (Clarke & Privitera, 1995), and for the Japanese waters the t_m is two years, and the t_{max} was estimated to be eight years (Shiraishy, et al., 2010). In Hawaiian and Japanese waters Otoliths were used for estimate the growth parameters and in this study, the growth parameters were based in the length frequency distribution.

The natural mortality obtained in this study was 0.92 years^{-1}, estimated by Pauly method. Almada, (1997) also estimated the natural mortality for the mackerel scad in Cabo Verde waters from two different methods, on that study it was found $M = 0.64$ year^{-1} by Pauly method, and $M = 0.43$ year^{-1} by Tanaka method. Observing just the mortality estimated by Pauly method, there is a difference between this study and Almada, (1997). This is because of the different value of K and $L\infty$ obtained on this study and the Almada (1997).

In this study the fishing mortality observed was higher than the natural mortality, which means they are harvesting intensively putting the stock at risk. In order to provide a maximum sustainable yield, the fishing mortality should be 15 to 35 % lower than the natural mortality (Hilborn, 2010).

Recruitment is commonly defined as the number of new generation of fish added to the fisheries. In this study found that the mackerel scad is recruited almost through the whole year except for January and February where the percentage of recruitment is zero, the recruitment pattern is high from May to December with the highest peak occurring in July.

Unfortunately, because of the narrow length distribution between 25 to 30 cm (appendix 1), it was not possible to analyse the size of the recruitment cohorts each year or if any of the years had a failure in the recruitment which could put the stock at risk.

5.2 Biomass estimation

The MSY observed to be needed was estimated from Sea Around Us data, and it can be assumed that the catch from the Sea Around Us is two times higher than the official landing catch from INDP.

The Shaefer model takes as an assumption that CPUE can be an indication of biomass. The results of this study showed a discrepancy when estimating the biomass index based in the CPUE. The model does not show a very good correlation between the fishable biomass and the biomass index. Because of this weak correlation, the estimated biomass of mackerel scad in this study might not reflect the real biomass in Cabo Verde waters. This weak correlation might be caused by errors in the effort data collection, another reason could be that the assumption from the Shaefer model that the CPUE is proportional to the biomass is not applicable for the data analysed in this work.

In 2005 and 2006, lowest level of fishing effort was recorded in all regions of Cape Verde, while it produced highest level of CUPE in that period. As far as is known, there were no changes in the active fishing fleets or even in the gear that might justify this high CPUE during the years 2005 and 2006. Because an increase of the active fishing vessels would increase the effort as well, and during those years the effort was low, the second hypothesis and the more plausible one is that there was a mistake during the data collection or during the estimation of the effort.

In this study, the MSY were estimated separately for artisanal and industrial fleet, for artisanal the MSY was 5,619, for industrial the MSY was 5,686. The estimated MSY for artisanal and industrial values are almost the same.

The previous study estimated the MSY for the mackerel scad. Almada (1997) estimated the MSY around 5,000 – 6,000 tones. Stobberup & Erzini (2006) estimated MSY as 4,700 tonnes per year. This results from Stobberup & Erzini (2006) and Almada (1997) indicate that the stock was being exploited sustainably. In 2012, biomass estimation was made by DeAlteris (2012) and he defined the MSY to be 2, 500 tonnes.

5.3 Environmental factors

The average SST on this study was 24.7 ºC, similar results of 24 ºC were found by Almada, (1992).

The northern part of the archipelago is influenced by the Canary Current and is, therefore, colder than the southern part which is influenced by the warm North Equatorial Counter Current (figure 14) (Lazaro et al. 2005).

The SST fluctuation in this study showed two patterns, in the Cabo Verdeans waters with a colder period from January to June, and a warmer period from July to December, which coincides with studies done in this area (Diankha *et al*., 2013).

The linear regression between annual SST and CPUE of mackerel scad in Cabo Verde region showed a negative correlation. This correlation is not significant and it shows probably limited influence of the SST on the abundance of mackerel scad for Cabo Verde waters. Short time series data for CPUE and SST might be one of the reasons for the weak correlation.

This study does not show a significant relationship between SST and abundance of mackerel scad, however, is well known that the small pelagic are short-lived species, between three to seven years, making their biological characteristics highly sensitive to any change in the environment. Environmental changes influence the distribution of the earliest life stages such as eggs and larvae, which has an impact on the recruitment for the next years (Ruiz *et al*., 2013).

In Cabo Verde waters there are no studies concerning the chlorophyll-a, estimation of the primary production or upwelling areas.

The average chlorophyll-a found in this study was 0.14 mg m^{-3} when compared to Senegalese waters which are the closest neighbouring country where the average of chlorophyll-a is 1.06 mg m^{-3} (Diankha *et al*. 2013), it can be said that the water surrounding the Cabo Verde Islands are oligotrophic.

The chlorophyll -a fluctuation in this study showed two patterns, in the Cape Verdean waters with increased productivity in the months from November to February and less productivity in the months from March to October, these patterns can be explained by the strength of the wind during the months from November to February where the mixed layer is more homogeneous, and probably bring a flux of nutrients from below to the surface layer.

The eastern part of the archipelago and around the islands the concentration of chlorophyll-a is higher than in the western part. This can be due to the fact that the eastern part of the archipelago is closer to the rich upwelling system along the West Coast of Africa, wherein during the Westwards propagation of eddies and waters filaments generated in the coastal upwelling system can reach the eastern part of the Islands (Schütte *et al*. 2016).

The linear regression between chlorophyll-a and landing of mackerel scad in Cabo Verde region showed a negative correlation, although this correlation is not significant, showing that there might be a weak influence of the chlorophyll-a on the abundance of mackerel scad for Cabo Verde waters. This weak influence can be explained because of the short time series data for chlorophyll-a and CPUE data analysed on the study.

The environmental parameters showed a very week correlation between SST, chlorophyll-a and abundance of the mackerel scad. However, it was noticeable that chlorophyll-a relate stronger to the catch than the SST. The could be because the phytoplankton is an indicator of the primary production in the oceans and is the base of trophic level in the marine food web, which is the base of the food for the small pelagics.

6 CONCLUSION AND RECOMMENDATION

There are indicators that the stock is declining but not very conclusive, hence the fishing effort should be reduced until more information is known. The stock did not show a strong link to environmental factors Further studies and improved sampling procedures are recommended to get more information on the stock.

- Update the effort and landing data from 2012 to recent years.
- Design a new scheme for collecting biological data, making sure that the data are collected randomly in order to cover all length sizes found in the market, also conduct surveys to collect all sizes samples to better understand the real size and length distribution of the stock.
- Design a new scheme for collecting the landing data and effort and increase the number of landing sites covered in order to have a complete data compilation.
- Know and assess possible reproduction and recruitment area of mackerel scad in Cabo Verde and make an oceanographic characterisation of these areas.
- Understand the sea currents around the islands and the effects of the currents in fish larvae dispersion.
- Study to quantify the primary productivity and identify possible upwelling areas around the islands.
- Implementation of a laboratory for study of otoliths reading to better understand recruitment strength.

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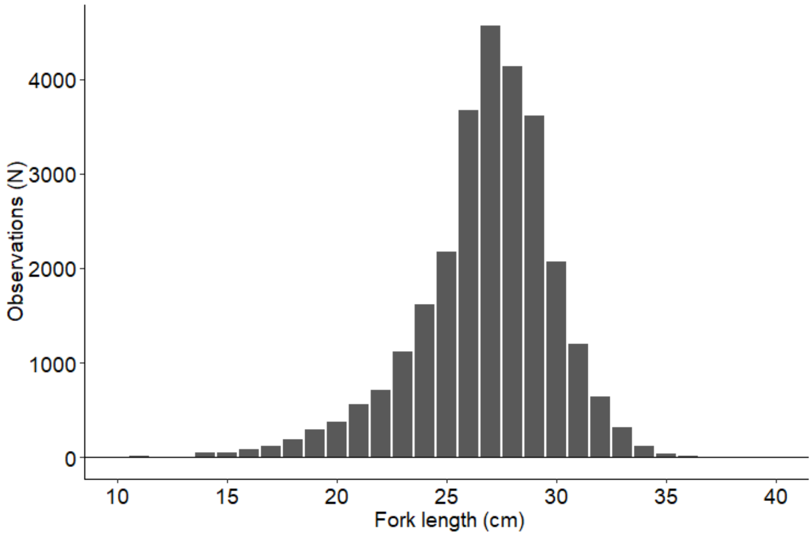
8 APPENDIX



Appendix 1. Mackerel scad length frequency obtained from the commercial fisheries (N=27762) from 1988 to 2018