ASSESSMENT OF BYCATCH SPECIES IN THE NAMIBIAN HAKE - DIRECTED BOTTOM TRAWL FISHERY (1997-2014)

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ABSTRACT

One of the main problems faced by fisheries management, is how to manage and mitigate bycatch caught during commercial fishing. The Namibian hake-directed bottom trawl fishery has been an important component of the Namibian fishing industry for decades. Due to the low selectivity of the bottom trawling method, bycatch has been a common feature of this hake-directed fishery. This study examines the spatial distribution of bycatch; monthly and inter-annual variations in the bycatch catch per unit effort (CPUE) (kg/hr); and factors that influence bycatch catch rate of Namibian hake bottom trawl bycatch species. The specific objectives were: to assess the spatial distribution of the bycatch species in the hake-directed bottom trawl fishery; to assess monthly variations of hake bycatch species/ species groups based on catch rate data that spans over 18 years; to assess inter-annual variations of hake bycatch species'/ species groups, catch rate over a period of 18 years and to identify and assess the relative importance of factors (latitude, month and year) that best explain the variation in catch rates of hake bottom trawl bycatch species. Data were extracted from the database: Fisheries Information Management System (FIMS) at Namibia's Ministry of Fisheries and Marine Resources, where all commercial information is captured and stored by scientists. The data extracted and used in the study was from 1997-2014. The study covered the whole fishing grounds within the Namibian Economic Exclusive Zone (EEZ), from the Kunene River to the Orange River. Data analysis methods used in this study included: mapping and density plots; Hierarchical Cluster Analysis (HCA); Multidimensional Scaling (MDS); Similarity Percentage (SIMPER) and Analysis of similarity (ANOSIM) to tackle the following objectives: spatial distribution of bycatch and monthly variations of the Namibian hake bottom

trawl bycatch species. These analyses are used to find natural groupings and to give statistical significance in groups. In addition, Generalized Additive Models (GAMs) analyses are used for: monthly and inter-annual variations in the bycatch catch per unit effort (CPUE) (kg/hr); and for the significance of factors that influence bycatch catch rates of Namibian hake bottom trawl bycatch species. These analyses are done by incorporating various factors (latitude, month and year) that may have had an influence on bycatch. In this study twenty-four species are recorded as bycatch in the hake-fishery, with a combined catch amounting to about 9120.90 metric tons for the period 1997-2014. Among all bycatch species, the species that had the highest total catch rate was ribbonfish (*Trachipterus trachypterus),* while blacktail (*Diplodus capensis*) was the species with the lowest catch rates in the study period. Most bycatch species were caught along the entire Namibian coast, with some species having higher catch rates in the Northern (17°S - 20°59'59" S), Central (21°S - 24°59'59") and the majority in Southern regions southern (25°S - 29°59'59"). Blacktail (*Diplodus capensis*) and silver kob (*Argyrosomus inodorous)* were only encountered in the Northern parts of Namibia while, yellowfin tuna (*Thunnus albacores*) was only caught in Northern and Central Namibia. Three major bycatch assemblages/groups were identified along latitudes. The three bycatch groups were mostly distributed at around 29°S (A), 22°S (B) and 17°S (C). Kingklip *(Genypterus capensis),* west coast sole (*Austroglossus microlepsis),* species belonging to the family *Raja* (Skates) and large-eye dentex (*Dentex macrophthalmus*) were the species that contributed most to the dissimilarity in groups for spatial distribution for A, B and C respectively. Variations in monthly CPUE were observed in all bycatch species. Some species had noticeable variations in the trends increasing /decreasing. CPUE was explained by various factors: latitude; month and year that had an influence on it. This was done for all bycatch species. The

common factor that influenced the CPUE of most species was latitude while month and year had the least influence on CPUEs of species. Overall, this study shows that bycatch varies considerably between different species. It also shows that hake fishing has the potential to negatively influence the functioning of the Benguela ecosystem on the basis of the number of species that it has an influence on. Bycatch management measures will, therefore, need to be species-specific in order to tackle specific factors that may have an influence on the different bycatch species. Each species has an influence on the structure and function of food web and the ecosystem at large.

CONFERENCE PROCEEDINGS

1. GL Mbaimbai, SK Mafwila, JA Iitembu, (2017). Assessment of bycatch from the Namibian hake - directed bottom trawl fishery. Presented at the Research and Innovation Day, 28 -29 September 2018.University of Namibia, Henties Bay, Namibia.

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ANOSIM…….	Analysis of similarity
Av.Abund……..	Average Abundance
Av.Diss…….	Average Dissimilarity
BCLME …….....	Benguela Current Large Marine Ecosystem
Contrib%.....	Contribution percentage to the dissimilarity
Cum%.....	Cumulative percentage to the dissimilarity
Diss/SD……...	Dissimilarity Standard Deviation
EEZ…….....	Exclusive Economic Zone
FIMS	Fisheries Information Management System
FOA……...	Fisheries Observer Agency
GRT……	Gross Registered Tonnage
HCA……	Hierarchical Cluster Analysis
MDS……	Multidimensional Scaling
MFMR…….	Ministry of Fisheries and Marine Resources
NatMIRC…….	National Marine Information and Research Centre
SIMPER……	Similarity Percentage
TAC……	Total Allowable Catch
VIF…….	Variance Inflation Factor

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God bless you all!!

Dedication

This work is dedicated to my parents for the good work they started by sending me to school in 1999. I shall always remember the sacrifices you made throughout my studies. May the good Lord bless you abundantly. To God, all the Glory is due to Thee.

Declaration

I, Mbaimbai Greg Limbo hereby declare that this work is the product of my own research efforts, undertaken under the supervision of (Dr. SK Mafwila and Dr. JA Iitembu) and has not been presented elsewhere for the award of a degree or certificate. All sources have been duly and appropriately acknowledged.

Signature

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Date

08/04/2021

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CHAPTER ONE

1. INTRODUCTION

1.1Background

The marine environment of Namibia falls within the Benguela Current system. The Benguela Current System is one of the four major upwelling systems in the world (Kirkman et al. 2016). Upwelling systems are highly productive, supporting multiple fishery industries (Kirkman et al. 2016). Namibian commercial fisheries are dominated by three species: hake (*Merluccius capensis* and *Merluccius paradoxus*); horse mackerel (*Trachurus capensis*) and pilchard (*Sardinops ocellatus)* (Lange 2003), with hake being the most dominant in terms of value (Wilhelm et al.2015). Hake species are caught by bottom trawling off the Namibian coast (NatMIRC 2007). This method is however, not selective and many species apart from hake are caught during the fishing process. The non-specific nature of many fishing gears has an influence not only on their target species but on many other species referred to as bycatch (Hall et al. 2000). Bycatch is defined as the catching of species that are not targeted (Hall et al. 2000).

Bottom trawling is one of the most destructive ways to catch fish and is responsible for up to half of all unwanted fish and marine life worldwide (Kelleher 2005). This type of fishing method indiscriminately catches every life and object it encounters. According to Van der Westhuizen (2001), in trawling catches there are many other fish species caught as bycatch.

Bycatch from commercial fishing has contributed to overfishing and the dramatic drop of fish populations around the world (Hall et al. 2000). Demersal species often co-

occur in species-rich assemblages (Hofstede et al. 2010), though broad spatial segregation patterns exist among certain species, bycatch is common in targeted fisheries (Gerritsen et al. 2012). Alaska spotlight article (1996), also noted that bycatch is one of the most crucial symptoms of poor fisheries management, which substantially reduces the net economic benefits generated by commercial fisheries.

Bycatch has been a persistent problem for decades, specifically because there is a lack of comprehensive understanding of bycatch rates across species and with few exceptions, there is a lack of data on demographic responses to bycatch or the in-situ effectiveness of existing mitigation measures (Soykan et al. 2008). The effective management of living marine resources depends on understanding the population dynamics of target and bycatch species and their related ecosystem processes (Nashima 2009). Understanding how the hake bottom trawl fishery influences bycatch is therefore essential for the assessment and sustainable management of Namibian fish stocks.

1.2 Problem statement

Fisheries research and surveys traditionally, have been driven by the need to manage stocks of target species, while research efforts have always been placed on understanding the biology of target fish species (MFMR 2001). This has resulted in a poor understanding of hake-directed bottom trawl bycatch species. Poor understanding of a resource may lead to poor management and thus ultimate depletion of resources. Although the hake-directed fishery in Namibia is managed through various measures such as restrictions on fishing at depths shallower than 200m (imposed on all commercial fishing vessel operating within Namibian water), these

measures are still not enough to deter bycatch or reduce it. One of the contributing factors is the lack of knowledge on how bycatch species composition varies spatially, temporally and among different fishing operations, as well as the factors that influence catch rates of bycatch. This knowledge is crucial for the identification of effects that the hake bottom trawl fishery has on stock abundance and vital rates of other species (bycatch).

1.3 Objectives

The main objective of this study was to assess the bycatch species in the Namibian hake directed bottom trawl fishery using their catch rates (Catch per Unit Effort (CPUE)) from commercial data from 1997 to 2014. The specific objectives were:

1. To assess the spatial distribution of the bycatch species in the hake-directed bottom trawl fishery from 1997 to 2014.

2. To assess monthly variations of hake bycatch species/ species groups based on catch rate data that spans over 18 years (1997 to 2014).

3. To assess inter-annual variations of hake bycatch species'/ species groups, catch rate over a period of 18 years (1997 to 2014).

4. To identify and assess the relative importance of factors that best explain the variation in catch rates of hake bottom trawl bycatch species.

1.4 Significance of the study

The hake fishery in Namibia is well-established and can be divided into two fisheries using: the bottom trawl and the long-line fishing methods respectively. The former is less selective than the latter. There is limited published work on demersal bycatch in Namibia and also, the spatio-temporal variations of bycatch species in the hake fishery are still not well understood. Thus, investigations into the catch dynamics of the demersal bycatch is imperative in our understanding of the inherent factors that influence bycatch catch rates. Understanding the spatio-temporal variations of hake bycatch species will be helpful for effective management strategies in the hake-directed fishery for identified bycatch species and for better conservation of marine resources i.e. this can be done by developing and implementing an ecosystem approach to fisheries and thus bringing attention to the potential ecosystem effects of bycatch in the Namibian hake directed bottom trawl fishery. The potential ecosystem effects are to be identified in order to give recommendations and alternatives to address bycatch in the Namibian hake directed bottom trawl fishery. Although it is difficult to completely avoid bycatch, knowledge on bycatch is still crucial for its reduction.

CHAPTER TWO

2. Literature Review

2.1 Demersal fish assemblages in Namibia

Supported by the high productivity of the Benguela upwelling ecosystem, abundant fish stocks characterize Namibian waters (Bianchi et al. 2001). Fish resources in upwelling systems are typically high in biomass and relatively low in diversity compared to non-upwelling environments (Bianchi et al. 2001). However, Namibian fish stocks have traditionally supported intensive fishing activities (Bianchi et al. 2001). Unlike other fishing nations, Namibia's fisheries have not originated from local small-scale subsistence fisheries, but the country's marine resources have always been subject to foreign industrial-style exploitation (Bianchi et al. 2001). As from the 1960s, the shelf and upper slope demersal assemblages of Namibia were subject to heavy fishing by bottom trawlers (Bianchi et al. 2001). The shallower-water hake *Merluccius capensis* and *M. paradoxus* were the major components of the catch (Bianchi et al. 2001). Prior to independence, there were about 300 vessels operating in the Namibian waters (Hamukuaya 1999). When Namibia gained independence in 1990, the state restructured the fisheries sector, aiming to direct the flow of benefits toward Namibians. By 1991 the number of vessels reduced to about 55 (Hamukuaya 1999). The Fishing pressure remained well below earlier levels throughout the 1990s, although there has since been a steady increase in the number of vessels operating in Namibian waters (Hamukuaya 1999).

It is reasonable to assume that the heavy fishing effort of bottom trawlers before and after independence have an influence on the marine environment, particularly on fish community structure (Bianchi et al. 2001). Fishing may influence community

diversity, size composition and the life history traits of component species (Mafwila 2017). In a study carried out by Mafwila (2017) on the community structure of demersal fish assemblages off the Benguela System, the study depicted that demersal fish assemblages in the Benguela are spatially distinct. According to Bianchi et al. (2001), change in distribution and relative abundance of species in the assemblage is a direct effect of fishing. Efforts have recently been made by various authors to evaluate the extent to which fishing affects nontarget species or more generally, community structure (Mafwila 2011; Bianchi et al. 2001). Kaiser and de Groot (2000); Jennings and Kaiser (1998), reviewed several aspects of the effects of fishing on non-target species and habitats. They further alluded that there was a notable increase in the catch rates of both target and non-target species for the slope assemblage. Macpherson and Gordoa (1996), analyzed biomass spectra in the fish assemblages of the shelf and upper slope off Namibia over a three-year period (1987– 1990). The study by Macpherson and Gordoa (1996), covered the area from south of Walvis Bay to the Orange River, they related the patterns they observed to zonal productivity. They then concluded that there were no appreciable differences between northern and southern upper slope assemblages, which they stated were subject to higher and lower levels of fishing intensity respectively. These results were, however, consistent with the study by Payne et al (2001), showing some homeostatic properties of the slope communities in terms of relative abundance across size-classes.

2.2 The Namibian Hake Fishery

The Namibian demersal trawl fishery targets hake in deep waters (Maurihungirire 2002). Hake is the most valuable of Namibia's commercial fisheries (Wilhelm et al.2015). Three species of hake are found in the Namibian Exclusive Economic Zone

(EEZ), this includes the *Merluccius polli* (Benguela hake), which is confined to the far Northern areas of the Namibian EEZ and makes up a small portion of the catch (Manning 2005). The main target species are shallower-water hake (*Merluccius capensis*) and deep-water hake, (*Merluccius paradoxus)*. The two species of hake, *M. capensis* and *M. paradoxus* are the most important fish species in terms of value and job generation in Namibia (Paterson et al. 2013). The two commercially exploited species of hake off Namibia (*M. capensis* and *M. paradoxus)*, have always been assessed and managed as a single stock (Kathena et al. 2016). Both species are found from close inshore to depths of 900 m off the coast of southern Africa (Manning 2005). The two hake species overlap at certain depths and for this reason commercial landings have not been separated by species (Gordoa et al. 2000). However, one of the main characteristics that separate the two species is depth distribution (BCLME 2011). Within the confines of the Namibian coast, hakes are distributed on the shelf and upper slope (Inada 1981). *M. capensis* occurs, at a depth of about 100m to 450m while *M. paradoxus* extends from 300 to 1000 m bottom depth, but most are caught at 300–500m bottom depth (Burmeiste 2001; Manning P 2005). There is some evidence suggesting that the difference in depth relates to preferred temperature with *M. paradoxus* preferring deeper cold water between 4 – 7° C and *M. capensis* preferring shallower warmer water between 7 – 13°C (BCLME 2011). The latitudinal and depth distribution differences between *M. capensis* and *M. paradoxus* may therefore depend on their preferred temperature ranges (Macpherson and Duarte 1991). *M. paradoxus* is found along the entire Namibian slope with a change in distribution at approximately 25°S, north of this latitude it is found only on the lower part of the slope (Macpherson et al. 1985). *M. capensis* lives along the entire shelf and upper slope off Namibia (Gordoa et al. 1995). Geographically *M. capensis* occupies shallower water and more

Northerly area than *M. paradoxus* (Burmeister 2001), although, *M. paradoxus* is also observed in shallow water but only south of Luderitz (Johnsen and Kathena 2012). Variations in temperature and oxygen conditions are also believed to influence hake distribution and availability, particularly in Namibia (Johnsen and Kathena 2012). Species-specific distribution differences within-species juveniles and adults also occur and could result from differences in low-oxygen tolerance levels (Wilhelm et al. 2015). *M. paradoxus* prefer more oxygenated water (Wilhelm et al. 2015). Dissolved Oxygen (DO) levels increase from north to south in Namibia (Wilhelm et al. 2015). According to Wilhelm et al. (2015), adults require higher oxygen concentrations than juveniles and DO levels generally increase with bottom depth. For both species small individuals are found in shallower water compared to large fish (between 25m-100m isobaths), during their first year before migrating to deeper water (Manning P.2005). Both *M. capensis* and *M. paradoxus* have, at least three defined spawning grounds: at 20°S in Namibia; 32°S and 27°E off the south coast of South Africa at depths ranging from 50m to 450m (Jansen et al. 2015). Then again, the spawning areas in Namibia appear to have shifted southward in the late 1970s, as a response to disturbances emanating from fishing pressure and environmental changes (Wilhelm et al. 2015).

In Namibia, monitoring of fishing operation in the hake fishery is done by fisheries observers (FOA 2007). Fisheries observers ensure that harvesting operations are conducted within the legal and administrative framework of the Marine Resources Legislation (The Marine Resources Act of 2000), (FOA 2007). Observers are further tasked with the responsibility to collect biological and scientific data, which is used as input variables in stock assessment models for the hake fishery (FOA 2007). The hake fishery off Namibia has been using bottom trawl (otter trawling) as the main fishing gear for decades (Mafwila 2011). The potential harm triggered by bottom trawling has

been documented by many authors (Sanchez et al. 2007; Mafwila 2011; Gillespie 2013).

2.3 Bycatch

The main factor that threatens marine fish biodiversity globally is fishing (Hiddink et al. 2008). Bycatch has always been a big problem in fisheries. Although concern about bycatch in commercial and recreational fisheries can be found in the scientific literature from the mid-1970s, it became the most critical fisheries issue in the 1990s (Costa et al. 2008). Given the overfished state of many of the world's important fish stocks, there has been great interest in documenting and finding solutions to the economic, political, and ecological implications of bycatch (Costa et al. 2008). The worldwide interest has given rise to a significant number of publications on bycatch and the factors that lead to its occurrence (e.g. Costa et al. 2008; Pinedo and Polacheck 2004). According to Pinedo and Polacheck (2004), most often bycatch occurs when bycatch species have the same feeding grounds as the target species or caught while migrating across regions. Various studies have also shown that bycatch varies considerably between different species, vessels, fleets, and also varies temporally (e.g. Catchpole and Gray 2010) and spatially (e.g. Rochet et al. 2002). However, many factors may influence bycatch or its distribution. Any type of fishing gear has some effect on the target species but the effect of catching large quantities of bycatch is prob greater on the bycatch species because it is usually unregulated and its demographic effects are unknown (Stobutzki et al. 2001).

When trying to understand the indirect effects of fishing, it is important to consider the effects that fishing activities such as trawling may have on bycatch. Bottom trawls and dredges are known to cause considerable damage to marine habitats and the species

within them (Davies et al. 2009), because of the disturbance of benthic communities and removal of bycatch species (Mafwila 2011). Consequently, this may lead to an increase in opportunistic feeding by fish species, which may result in aggregations of these species in recently trawled areas (Kaiser and Spencer 1994). Attraction to these recently trawled areas may increase the chances of being caught by subsequent passes of the fishing gear (Bradshaw et al. 2000) and thus increasing the number of bycatch incidents. Other studies have also shown that the removal of species from the ecosystem via bottom trawl bycatch may affect ecosystem stability and productivity by potentially altering species composition and diversity, altering the structure and function of food webs (trophic systems) (Mafwila 2011).

It is also believed that environmental variability can directly affect the species composition and abundance of fish species (Hampton et al. 2003; Mafwila 2011). According to Sakko (1998), within the Benguela system, there are changes that occur continuously with regard to physical, chemical and biological conditions, and these vary both in time and space. The changing conditions of the Benguela ecosystem result in a diversity of marine habitats, characterized by dynamic processes which can cause remarkable changes in the distribution of fish species (Gordoa et al. 2006). These changing conditions, in turn, may influence the distribution of fish, indicating that the catch composition of fish species can fluctuate highly and significant catch of bycatch species could be made. These environmental variables are thus believed to be accountable for bycatch in trawl nets (Hampton et al. 2003; Mafwila 2011).

2.4 Bottom trawling

According to Kirkman et al. (2015), marine ecosystems, in general, are characterised by changes in their structure or function over time. Examples include effects of eutrophication associated with pollution and effects on communities due to removal of target or bycatch species through fishing and modification of habitat in the case of demersal trawl fishing (Kirkman et al. 2015).

Bottom trawls (Otter trawl) are primarily utilised in the harvesting of hake in Namibian waters (Van der Westhuizen 2001). Bottom trawling has been considered as an essential method for bulk fishing by large self-fishing vessels (Gabriel et al. 2005). Otter trawling, which has increased quickly since the 1980s is a method of fishing where a mobile fishing gear, is towed behind a moving vessel (Gabriel et al. 2005). It involves towing a cone-shaped net across the sea bed (Gabriel et al. 2005). To secure contact with the seabed, the nets are typically weighted by chains or cables with heavy discs or rollers to enable the trawl to fish over the rough seabed of rocks, boulder or corals (Gillespie 2013). The introduction of modern vessels like commercial bottom trawlers, made fishing to become an operation of massive harvesting with no discrimination (Gillespie 2013). Modern trawls allow fishing to occur in areas that were previously inaccessible due to improved technology, and they can penetrate depths as great as two kilometres and such trawling is estimated to scour nearly 1.5 billion hectares of continental shelf habitat each year internationally (Gillespie 2013). According to Mafwila (2011), bottom-trawling is one of the most widespread sources of physical disturbance to the continental shelf substrates throughout the world. The combination of large size and weight designed to disturb the bottom, makes the mobile gear a significant threat to many benthic ecosystems. It has been demonstrated that bottom trawls and dredges can dramatically alter the ocean floor and cause major

changes in biological communities (Mafwila 2011). Trawling is also known as a method that has implication in the large-scale decline of a several deep-sea species, which are often slow-growing or late maturing and can only sustain low exploitation rates (Gillespie 2013). According to Saila (1983), the greatest level of bycatch is produced by demersal trawl fisheries, as they are less selective when compared to other fisheries. Extracted data from over 800 published records by Alverson *et al.* (1994) has revealed that trawl fisheries accounted for most of the records of by-catches (996) followed by drift nets and gill nets (232), line fisheries (150), pot (830) and purse seine (82) fisheries. In addition to that, bottom-trawling has a direct influence on the target species; bycatch and the marine ecosystem as a whole (Sanchez et al. 2007). All in all, bottom trawling is widely considered to have the greatest effect on marine ecosystems of any fishing gear used (Stobutzki et al. 2001), because it is a detrimental gear in the sense that it is active and non-selective.

2.5 Fishery bycatch management and solutions to bycatch

Bycatch has received a great deal of scientific attention, their minimization being a goal of marine fisheries management (Powers 2006). Different fisheries around the world tackle the bycatch problem in various ways, such as using cleaner gears, implementing bycatch limits or closing areas (migratory paths) in certain times of the year, especially in areas where bycatch is historically high or even restricting the extent to which certain gears may be used (Keledjian et al. 2014). In fisheries with bycatch management measures, literature has indicated that management of bycatch often fails because of compliance (e.g. Davies et al. 2009), thus monitoring and control is of great importance in management. Some parts of the world have implemented bycatch quotas and bycatch taxes to discourage bycatch incidents (Keledjian et al. 2014).

In Namibia, fisheries are governed by laws and regulations such as “The Marine Resources Act of 2000”, which is supported by the 2001 Regulation No. 241 (Government Gazette 2000). The regulations govern the granting of rights, allocation of quotas, and licensing of activities in the fishery sector (Chiripanhura and Teweldemedhin 2016). They also govern the non-commercial exploitation of marine resources (e.g. recreational activities), conservation measures (e.g. control of trawling activities and measurement of meshes) and determine the fishing seasons for various species (Chiripanhura and Teweldemedhin 2016). In addition to that, trawling is not allowed at depths shallower than 200 m to protect juvenile hake and horse mackerel that normally occur in relatively shallow water (Van Zyl 2019). Apart from depth restrictions and cod-end mesh-size limitations in hake and monkfish fisheries, experiments with bar-sorter grids are being carried out to establish whether better selection can be achieved with alternative gear (Van Zyl 2019). Furthermore, the regulations outline the compliance and control measures provided for under the Act, as well as applicable offences and penalties (Chiripanhura and Teweldemedhin 2016). Other controls in place include: restrictions on bycatch; protected areas and closed seasons (closed season in the month of October, implemented in 2006 due to stock uncertainty), to enable successful recruitment of stocks (David 2012).

In the Namibian hake fishery, landed bycatch species with commercial value incur a bycatch fee (MFMR 2007). Bycatch fees are applied to deter right holders from targeting species other than those for which they have been issued a quota. This is a unique feature of the Namibian fisheries management system that is not seen in many other countries (MFMR 2007), although there has been no assessment of the effectiveness of these as bycatch deterrence measures to date.

The majority of fisheries management approaches are single-species oriented. Single species total allowable catch (TAC) management, predominantly applies to situations where a single fleet targets a single stock (Hilborn and Walters 1992). Where multiple species are caught by various fleets, single species TACs often fail to achieve targeted levels of fishing mortality (Ulrich et al. 2011). Technical interactions (multiple species caught in the same fishery) and fleet diversity serve to invalidate the assumption that once a single species TAC is exhausted, fishing will cease on that species (Lordan and Minto 2014). As an outcome, many fisheries have resulted in a mixed TAC allocation, which is seen as a solution to bycatch (Lordan and Minto 2014).

Traditional fishing gears deployed over a mixed-species assemblage may be relatively unselective as to which species and size class is caught (Lordan and Minto 2014). Gear technology has however, made considerable gains in gear selectivity with the focus on reducing bycatch (Lordan and Minto 2014). Gear changes used to increase the specificity of trawls include: mesh size modifications; square mesh panels; separator grids and cutaway headlines (Keledjian et al. 2014). Research to develop more selective fishing gear is ongoing and includes innovative new designs such as Turtle Excluder Devices, fish escape devices (FEDs) (e.g. square mesh panels) and other methods that allow bycatch species to find their way out of a trap or net (Keledjian et al. 2014). Managing Namibian fish resources requires managers to deal with uncertainties brought about by the highly variable Benguela ecosystem. The only way that risk levels in managing resources can be reduced is to be conservative in harvesting (Van Zyl 2000).

CHAPTER THREE

3. Materials and Methods

3.1 Study Area

The study area was within the Exclusive Economic Zone (200 nautical miles) of Namibia, from the Kunene River mouth (17°S) in the north, to the Orange River mouth (29°S) in the South. It covered the Namibian hake-directed bottom trawling fishing grounds in waters deeper than 200 m. For this study, the coast of Namibia was divided into Northern (17°S - 20°59’59”), Central (21°S - 24°59’59”) and Southern (25°S - 29°59’59”) sub-regions (Mafwila 2011) (Figure1).

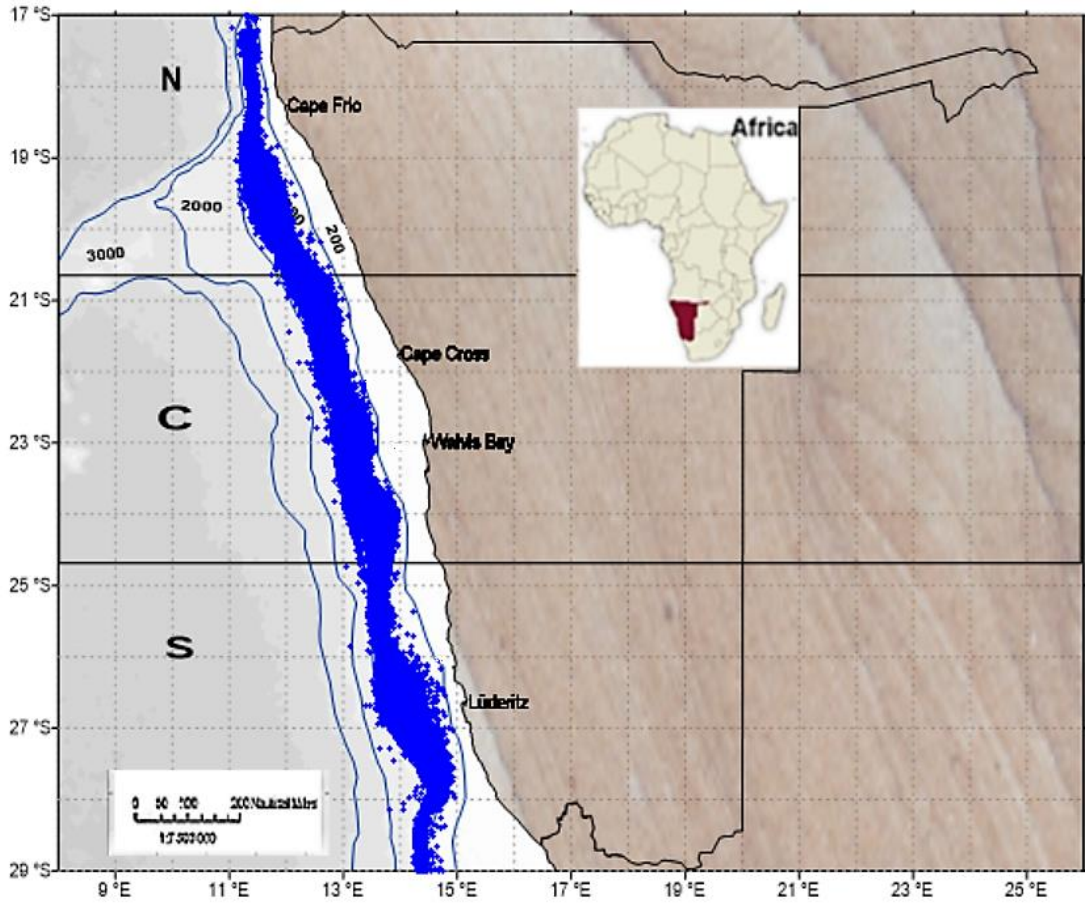


Figure 1: Distribution of some individual trawls covered by the hake bottom-trawl fishery off Namibia. (1997- 2014). One dot (blue dot) represents one trawl and the contour lines represent depth. The lines and letters indicate the areas according to sub-regions.

3.2 Field data collection

The data used in the study were collected by Namibia's Ministry of Fisheries and Marine Resources, through Captains/commercial skippers who are tasked to collect biological and scientific data during fishing operations. They are required to complete log-sheets/forms with captured information such as: position; catch; time of trawling and depth. All species caught are recorded and allocated species codes for identification purposes, such codes are used to differentiate each species from the rest. However, misidentification of species may occur and this may lead to anomalies in data distribution. Since information is recorded by captains in product forms, a convention factor table is used to convert different products forms to whole fish. Each species has their own convention factors, with some species recorded as whole, since they are not processed into different product forms. Species recorded as whole have a convention factor of 1 (one) and do not require convention and are extracted as recorded by the Captain. The number of trawls per day are then averaged together and one trawl is used to represent the catch of the day. The data is then entered and stored in the Fisheries Information Management System (FIMS) at the Ministry of Fisheries and Marine Resources (NatMIRC). The Fisheries Information Management System is a database, where all commercial information is captured and stored by scientists. This database is updated annually. Products are linked to an averaged trawl of the day to represent position since the form does not make provision for each product to be linked to each position.

Data were then extracted through Access database by creating queries, which linked different tables together and extracted different required variables. These are not samples, the Captain record everything that is caught and thus data extracted are absolute.

The data covered the period from 1997 to 2014. The study looked at twenty-two fish species. In addition to the fish species, squids (molluscs) were also part of this study. In totality the study looked at twenty-three (23) bycatch species in the hake-directed bottom trawl fishery. However, some species were pooled by genus and some by family. Species pulled by the family in which they belong were: *Macrouridae* and those pulled by *genus* were: *Raja species; Thunnus Species and Epigonus species*. There was also another category of species "other species", this was not part of the study as the species in this category could not be placed into the category: species; genus and family and thus did form part of the study.

Prior to data analyses, the data were cleaned to correct errors such as incorrectly recorded fishing position and wrongly spelt species names. Errors that could not be verified and corrected were removed from the analyses (528 errors out of 495497 records were removed; leaving a total of 494969 records). Records for the month of October were removed as no fishing took place in October from 2006, because it is closed season for the hake fishery (24397 records out of 494969, leaving a total of

470572records). The removal of October in the analysis was done in order to have consistency for the whole study period (1997-2014).

The catch per unit effort (CPUE) of each bycatch species was calculated for each individual record as catch (kg) / effort (hours).

The spatial catch rates of the commercial bottom trawl data (trawl intensity), were plotted into maps to visualize spatial distributions of the bycatch species. Mapping was done with **Surfer**® 9.0 from **Golden Software**, **LLC** (www.**goldensoftware**.com) (Surfer 9. 2010). Density distribution plots of bycatch were also done to show the

spatial catch rates for each bycatch species; this was done in R software (R Development Core Team 2010).

3.3 Statistical Analysis

Hierarchical Cluster Analysis (HCA) with similarity profile (SIMPROF) test (group average) employing the Bray-Curtis similarity index (Field et al. 1982) was performed on the hake directed bottom trawl fishery data using the multivariate techniques in PRIMER v6: Cluster and multidimensional scaling (MDS) analysis (Clarke and Warwick 2001).

Prior to the HCA and MDS analyses, a fourth-root transformation ($x \rightarrow x^{(1/4)}$) was applied to the CPUE data in PRIMER v6 (Pre-treatment of the data) to avoid overemphasis of the most abundant bycatch species and thus reducing the skewness of the data (Field et al. 1982, Clarke and Warwick 2001). Most data sets benefit by one or more data transformations. The reasons for transforming data can be grouped into statistical and ecological reasons: Statistically, it improves assumptions of normality, linearity, homogeneity of variance and makes units of attributes comparable when measured on different scales; Ecologically it makes distance measures work better and reduce the effect of total quantity (sample unit totals) to put the focus on relative quantities. In addition, it equalizes (or otherwise alter) the relative importance of common and rare species. For assemblage data, fourth-root transformation reduces the dominant contribution of abundant species to Bray-Curtis similarities (Field et al. 1982, Clarke and Warwick 2001). Transformations were done just after the data were imported into the software (PRIMER v6). After the fourth-root transformation, a resemblance matrix using the Bray-Curtis similarity index was constructed. Bray-Curtis similarities index between any two sampling stations qualifies the degree of

similarity in species composition. It also determines the contributions to the average similarity within a group.

The Hierarchical Cluster Analysis (HCA) with SIMPROF test was performed after the resemblance matrix. Hierarchical Cluster analysis (or classification) aims to find natural groupings of samples such that samples within a group are more similar to each other, generally, than samples in different group/ samples (Clarke and Warwick 2001). Cluster analysis is used in the present context in the following way; Cluster analysis of the species similarity matrix is used to define species assemblages, i.e. groups of species that tend to co-occur in a parallel manner across sites (Latitudinal distributions) and months. The output is a dendrogram, i.e. tree diagram, displaying the grouping of samples (usually) into successively smaller numbers of groups/clusters, of ever-larger sizes, as the threshold level of similarity at which two groups are considered to merge into one is steadily decreased (or the dissimilarity/ distance increased). These usually take a similarity matrix as their starting point and successively fuse the samples into groups and the groups into larger groups, starting with the highest mutual similarities then gradually lowering the similarity level at which groups are formed. The process ends with a single group containing all samples (Clarke and Warwick 2001). This classification method has been developed by ecologists and is in use, both in terrestrial and marine studies.

The SIMPROF (similarity profile) test incorporates a series of permutation tests, looking for statistically significant evidence of genuine groups in samples which are *a* priori unstructured (e.g. single samples from each of a number of sites). When the SIMPROF test is done, tests are performed, at every node of the completed

dendrogram, that the group being sub-divided has 'significant' internal structure (e.g. that samples in that group appear to show evidence of multivariate pattern). The test results are displayed by a colour convention on the dendrogram plot (samples connected by red lines cannot be significantly differentiated) and test statistics are given in the results (Clarke and Gorley 2006).

The MDS ordination analysis was performed on the same data (CPUE data) as the cluster analysis. The purpose of the MDS is to represent the samples as points in low-dimensional space (usually 2-d or 3d) such that the relative distances apart of all points are in the same rank order as the relative disciplinaries (or distances) of the samples, as measured by an appropriate resemblance matrix (in this case the Bray-Curtis similarity index) calculated on the transformed data matrix. In an MDS, points that are close together represent samples that are very similar in community composition (or environmental variables or biomarker responses, or particle size distributions etc), and points that are far apart correspond to very different values of the variable set (Clarke and Gorley 2006). The purpose of MDS can thus be simply stated: it constructs a "map" or configuration of the samples, in a specified number of dimensions, which attempts to satisfy all the conditions imposed by the rank (dis)similarity matrix, e.g. if sample 1 has higher similarity to sample 2 than it does to sample 3 then sample 1 will be placed closer on the map to sample 2 than it is to sample 3 (Clarke and Warwick 2001).

Similarity percentage (SIMPER) analysis was done after the HCA and MDS, to show the average contribution of each species CPUE to dissimilarity (discriminating species) between groups of samples (Clarke and Warwick 2001). SIMPER analysis

examines the contribution of each species to average resemblances between sample groups and shows species which are more abundant in the groups. It explains aspects of the similarity between groups (Rees et al. 2004).

An analysis of similarity (ANOSIM), the routine was also done afterwards. Analysis of Similarity procedure allows the significance testing of data groups (Rees et al. 2004). It was used to examine the statistical significance between groups produced by the HCA and MDS. ANOSIM tests the null hypothesis that the average rank similarity between objects within a group is the same as the average rank similarity between objects between groups. ANOSIM is based on the rank similarities between samples in the similarity matrix and produces a test statistic R which can range from -1 to 1. Objects that are more dissimilar between groups than within groups will be indicated by an R statistic greater than 0. An R-value of 0 indicates that the null hypothesis is true. A level of the significance p-value is also produced for the analysis (Rees et al.2004).

Generalized Additive Models (GAMs) (Hastie and Tibshirani 1990) were used to determine factors that influence the bycatch catch rate of each species. Prior to the GAM analysis, GAM modelling was done. Physical variables such as latitude, depth, month, year and gross registered tonnage were incorporated in the analysis of catch rates (duration in hours), CPUE (kg/h), and catch data from the commercial hake bottom-trawl fishery off Namibia, (all analysis was done in *R* (R Development Core Team, 2004; Wood, 200*6, 2009*). In models like these, all the factors for input in the model should be checked for correlation, and those that are highly correlated are reviewed according to their merits in the model (Hastie and Tibshirani 1990). For

instance, one would expect depth and latitude to be often highly correlated. Correlation test is used to evaluate the association between two or more variables. There are different methods to perform correlation analysis:

(i)Pearson correlation (r), which measures a linear dependence between two variables (x and y). It's also known as a parametric correlation test because it depends on the distribution of the data. It can only be used when x and y from normal distributions.

(ii) Spearman rho, which is a rank-based correlation coefficient (non-parametric), is used when data is not normally distributed.

In this study, correlations between covariates were examined using the Spearman rank correlation (Crawley 2005). Prior to the correlation, a normality test was conducted using the Shapiro-Wilk normality test. The normality test was done to verify the normality of the data and the residuals of the best models were explored visually (visual inspection of the data normality using Q-Q plots) to detect linearity/non-linearity (Appendix xiv). The appropriate correlation test was then used (Spearman rho):

$$rho = \frac{\sum(x' - m_{x'})(y'_i - m_{y'})}{\sqrt{\sum(x' - m_{x'})^2 \sum(y' - m_{y'})^2}} \quad (1)$$

Where x'=rank(x)x'=rank(x) and y'=rank(y)

Correlations between covariates (Latitude, Month, Year, depth and GRT) were examined. The covariates for which the Spearman (rho) was not close to zero (0) and had a p value that was less than or equal to 0.05, were considered correlated. In general,

an absolute correlation coefficient of >0.7 among two or more predictors indicates the presence of multicollinearity (Molala 2019).

In addition, multicollinearity was also conducted on the data. Multicollinearity is an extreme situation, where collinearity exists between three or more variables even if no pair of variables has a particularly high correlation. This means that there is redundancy between predictor variables. In the presence of multicollinearity, the solution of the regression model becomes unstable (James et al. 2014). For a given predictor (p), multicollinearity can be assessed by computing a score called the variance inflation factor (VIF), which measures how much the variance of a regression coefficient is inflated due to multicollinearity in the model. The smallest possible value of VIF is one (absence of multicollinearity). As a rule of thumb, a VIF value that exceeds 5 or 10 indicates a problematic amount of collinearity (Gareth et al. 2014). When faced to multicollinearity, the concerned variables should be removed, since the presence of multicollinearity implies that the information that this variable provides about the response is redundant in the presence of the other variables (Gareth et al. 2014; Bruce and Peter 2017).

GAMs are non-parametric or semi-parametric generalizations of multiple linear regressions that are not restricted to specific functional relationships (e.g. linearity) or underlying statistical distributions (e.g. normality) of data (Hastie and Tibshirani 1990). GAMs have been useful in examining environmental and stock relationships that are unlikely to be linear or parametric (Maravelias and Reid 1997). With GAMs, the dependent or response variable is modelled as the additive sum of the unspecified covariate or predictor variables, and a scatterplot smoother replace the least-squares

estimates used in multiple linear regression (Hastie and Tibshirani 1990). Therefore, the general form of GAMs is based on the assumption that the mean response (μ) is related to the predictor variables ($X_1,\ldots,Xp$) by the following relationship :

$$g(\mu) = \alpha + \sum_{j=1}^{P} f_j(X_j) + \varepsilon \qquad (2)$$

where g(μ) is the link function defining the relationship between the response and the additive predictor, α the intercept term of the response when the predictors are zero (no categorical variables used), f is the smoothing function for variable j and P the maximum number of variables. The f_j is estimated in a flexible manner and each of them is a regression spline in the component X_j (Hastie et al., 2001). In the present study, the GAM model used was:

$$\log(CPUE_{ymgi}) = s(year_{yi}) + s(latitude_{ymgi}) + s(month_{mi}) + s(depth_{ymgi}) + s(GRT_{gi}) + \varepsilon_{ymgi} \qquad (3)$$

Where $\log(CPUE_{ymgi})$ is the log of the CPUE for the $year_y$, $month_m$, GRT_g , and location *i*. $s(year_{yi})$ smoothed effect for $year_y$ in location *i*. $s(latitude_{ymgi})$ smoothed effect of latitude of location *i*, for $year_y$, $month_m$, GRT_g. $s(month_{mi})$ smoothed effect of location *i*, for $month_m$. $(depth_{ymgi})$ smoothed effect of depth of location *i*, for $year_y$, $month_m$, GRT_g. $s(GRT_{gi})$ smoothed effect of GRT_g for location *i*. ε_{ymgi} is the residual error term.

GAMs were also used to make graphs for monthly variations of bycatch, indicating seasonality. The model used was:

$$\log(CPUE_{ymi}) = s(month_{mi} + bs = \text{cc}, k = 12) \quad (4)$$

In the model, *k* specifies the dimensions of the basis used for the spline, which was set to the maximum possible for Month, which is 12, the number of unique values. bs allows to specify the basis type for the smooth term; "*cc*" indicates a cyclic cubic spline, which is used for the monthly term as there should be no discontinuity between months.

All the GAM modelling was done in R software (R Development Core Team 2010). Species with very low entries were not part of the analysis in GAMs as their entries were too low to run GAMs or/and to formulate graph.

CHAPTER FOUR

4.Results

4.1 Description of Namibian hake-directed bottom trawl fishery bycatch

In this study, twenty-four (24) hake bycatch species were observed (Appendix XII) : blacktail (*Diplodus capensis*); silver kob (*Argyrosomus inodorus*); yellow fin tuna *(Thunnus albacores);* species belonging to the family Macrouridae (grenadiers); cape gurnard (*Chelidonichthys capensis);* large-eye dentex (*Dentex macrophthalmus*) *;* john dory *(Zeus faber);* West coast sole *(Austroglossus microlepis);* Grootskub-pomfret (*Taractichthys longipinnis);* horse mackerel (*Tranchurus capensis);* black oreo (*Allocyttus verrucosus*); other tunas *(Thunnus species)*; cardinal fishes (*Epigonus* spp); silver scabbardfish (*Lepidopus caudatus);* ribbonfish (*Trachipterus trachypterus);* snoek *(Thyrsites atun);* shortfin mako shark (*Isurus oxyrinchus);* skates *(Raja species);* angelfish (*Brama brama*); kingklip (*Genypterus capensis);* jacopever *(Helicolenus dachylopterus);* monkfish (*Lophius vomerinus)* and flying squid *(Todarodes sagittatus).* Among all bycatch species, the species that had the highest catch rates were *Trachipterus trachypterus* (1352.34 metric tons), while *Diplodus* capensis had lowest catch rates (0.23 metric tons) (Appendix XIII). Total catch rates of recorded bycatch in the study period amounted to about 9,121.05metric tons, with an average of about 506.725 metric tons per annum.

4.2 Model fitting, evaluation and selection

The assessment of the normality showed that all covariates exhibited a non- linear relationship (Table 1).

Table 1: Normality test for all variables (Latitude,Depth Gross registered tonnage,Year and Month) at 0.05 significant level.

Shapiro-Wilk normality test					
	LatDeg	Depth	GRT	year	month
p-value	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
W	0.91609	0.91428	0.89243	0.9553	0.93561

4.3 Correlation between variables

Weak correlations were found between all the variables (Table 2). In addition, there was no multicollinearity in the variables, all variance inflation factor values were less than five (<5) and indicated that there was no multicollinearity (Table 3).

Table 2 :Correlation between covariates (*r*ho = Spearman rank correlation coefficient, *p* = significance level for correlation). Significant results represented by the denotation *

Spearman's rank correlation			
Variables	S	p-value	rho
Depth and Latitude	1576678435	< 2.2e-16 *	0.5475927
Depth and Year	3.389e+09	0.148	0.02757099

Depth and Month	3364790353	0.07007	0.03451727
Depth and GRT	2050093215	< 2.2e-16 *	0.4117525
GRT and Month	3568336388	0.2101	-0.02388761
GRT and Year	3272085111	0.00133 *	0.06111783
GRT and Latitude	2667064724	< 2.2e-16 *	0.2347205
Latitude and Year	3575659219	0.1727	-0.0259888
Latitude and Month	3177610221	3.522e-06 *	0.08822617
Year and Month	3832798333	1.541e-07 *	-0.09977152

Table 3 : Multicollinearity between covariates (Latitude,Depth Gross registered tonnage,Year and Month). VIF values that are below 5 indicate no multilinearity.

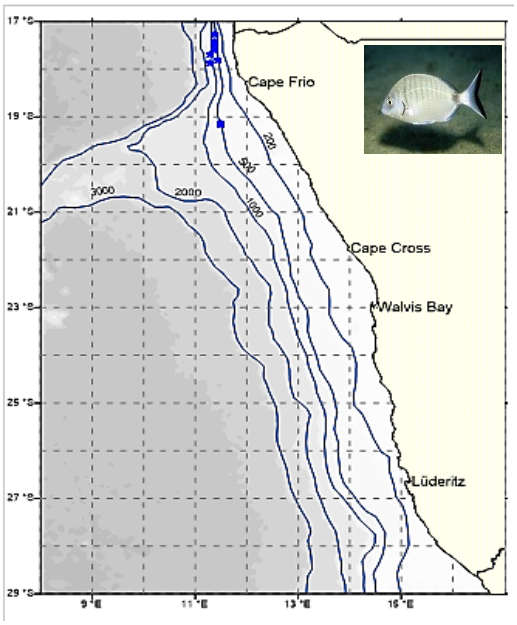
Variance Inflation Factors				
LatDeg	month	year	GRT	Depth
1.130347	1.003761	1.013236	1.110092	1.164563

4.4 Spatial distribution of hake-directed bottom trawl fishery bycatch species

Most of the hake bycatch species were encountered along the entire coast of Namibia (Appendix I and Figures 2 -13), with some species having their highest catch rates in the north : *Argyrosomus inodorus*; *Diplodus capensis;* species belonging to the family Macrouridae *; Chelidonichthys capensis; Dentex macrophthalmus; Thunnus albacores and* central ; *Tranchurus capensis*; *Austroglossus microlepis; Brama bram* and majority in the Southern parts of Namibia : *Thunnus Species; Allocyttus verrucosus, Helicolenus dachylopterus; Todarodes sagittatus; Zeus faber; Taractichthys longipinnis; Epigonus species*; *Lepidopus caudatus; Trachipterus; trachypterus;*

Thyrsites atun; Isurus oxyrinchus; Raja species; Genypterus capensis and *Lophius vomerinus* (Appendix I and Figures 2 -13). *Diplodus capensis and Argyrosomus inodorous* were only encountered in the northern parts of Namibia (Appendix I: a and b). When looking at bycatch species as a whole, most bycatch species had high catch rates at 17°S, 22°S, 27°S and 29°S (Appendix I).

a)



b)

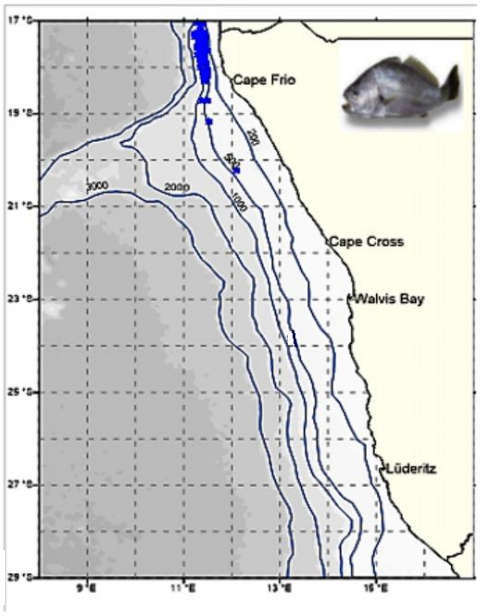
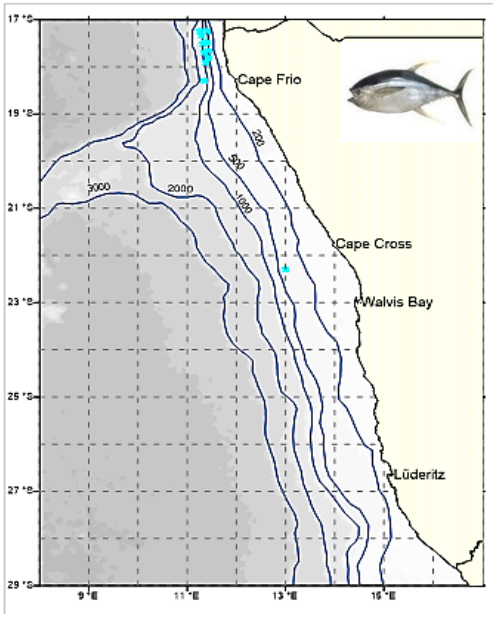


Figure 2: Maps showing the spatial distributions of blacktail (*Diplodus capensis*) (a) and (b) silver kob (A*rgyrosomus inodorus*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

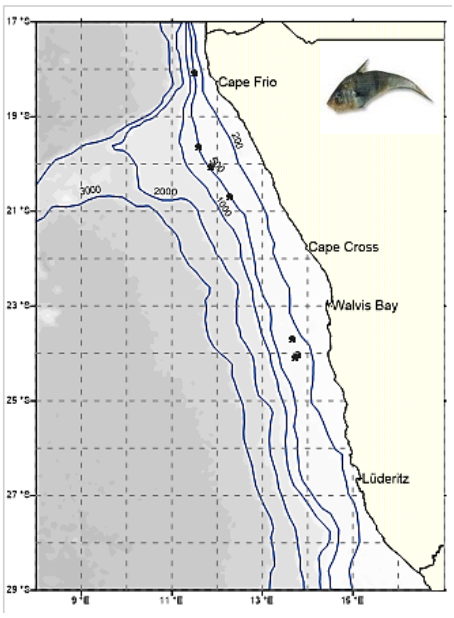
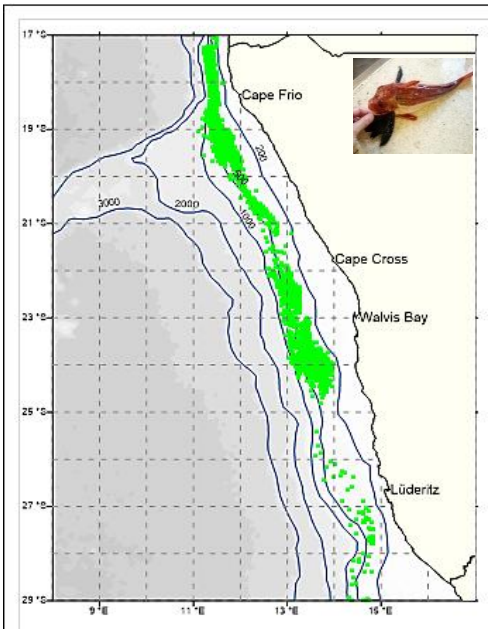


Figure 3: Maps showing the spatial distributions of yellowfin tuna (*Thunnus albacores*) (a) and (b) grenadiers (Macrouridae spp) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

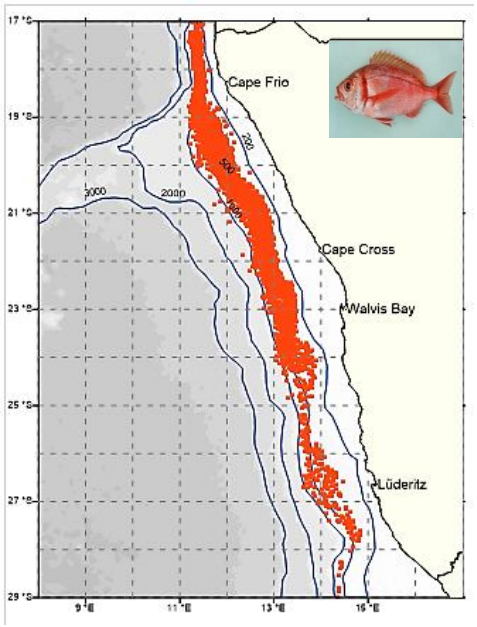
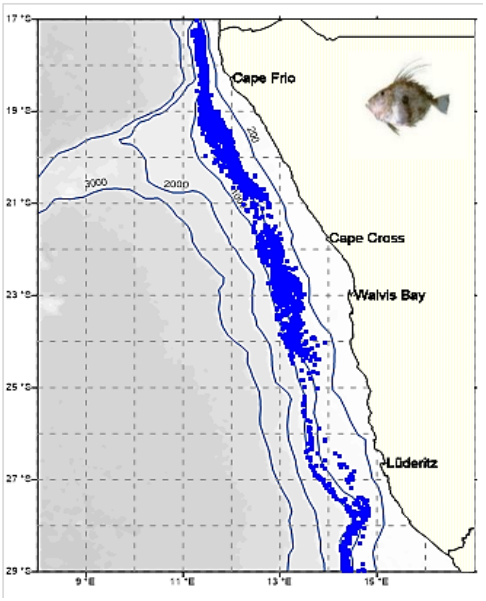


Figure 4: Maps showing the spatial distribution of cape gurnard (*Cheilidonicthys capensis*) (a) and (b) large eye dentex (*Dentex macrophthalmus*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a) 

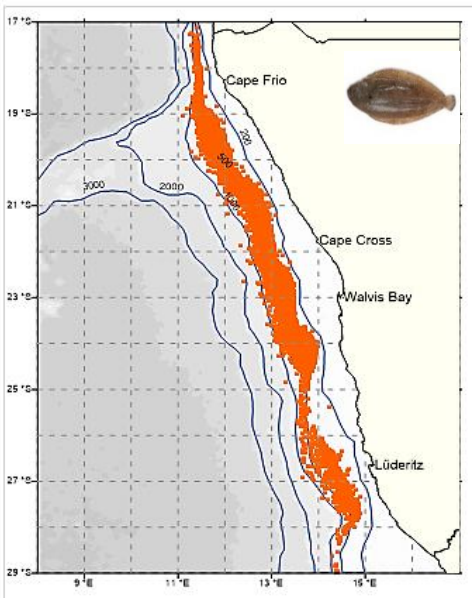
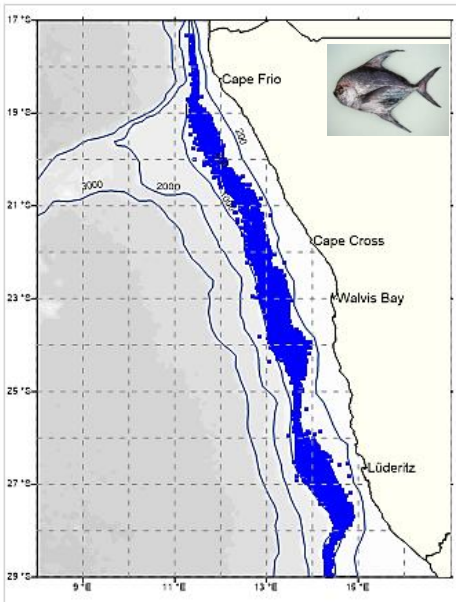
b) 

Figure 5: Maps showing the spatial distributions of john dory (*Zeus faber*) (a) and (b) west coast sole (*Austroglosus microlepsis*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a) 

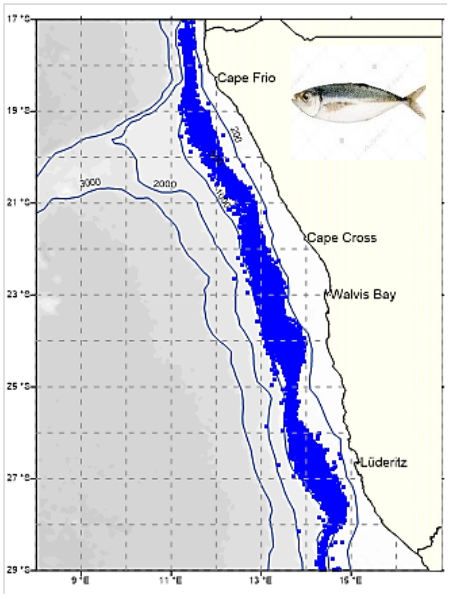
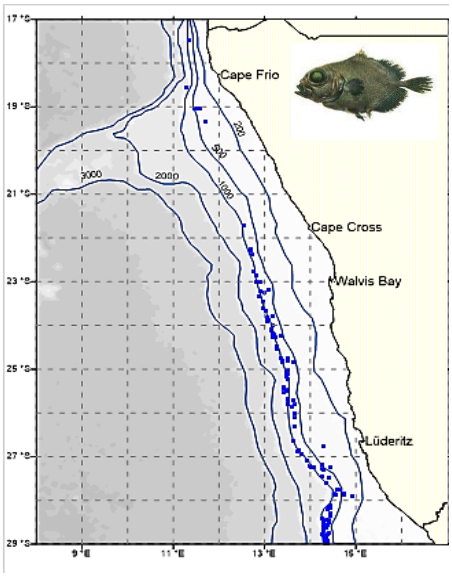
b) 

Figure 6: Maps showing the spatial distributions of Grootskub-pomfret (*Taractichthys logipinnis*) (a) and (b) Horse mackerel (*Trachurus capensis*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a) 

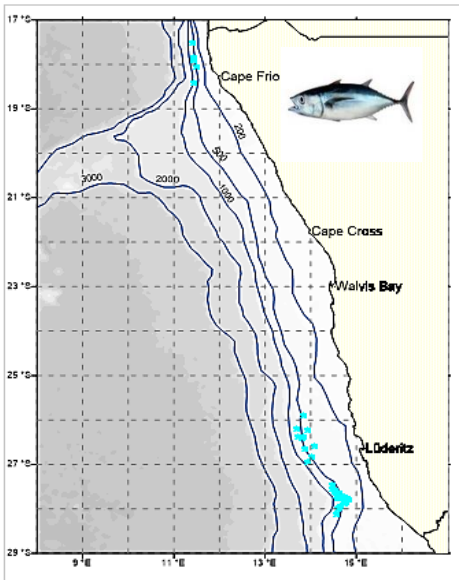
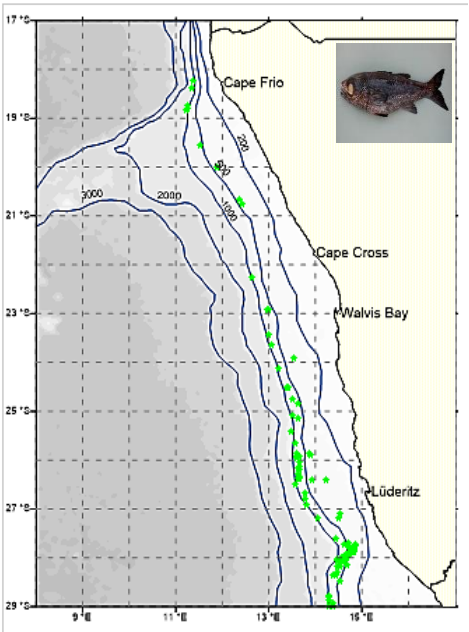
b) 

Figure 7: Maps showing the spatial distributions of black Oreo (*Allocyttus verrucosus*) and (b) Tunas (*Thunus* spp) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a) 

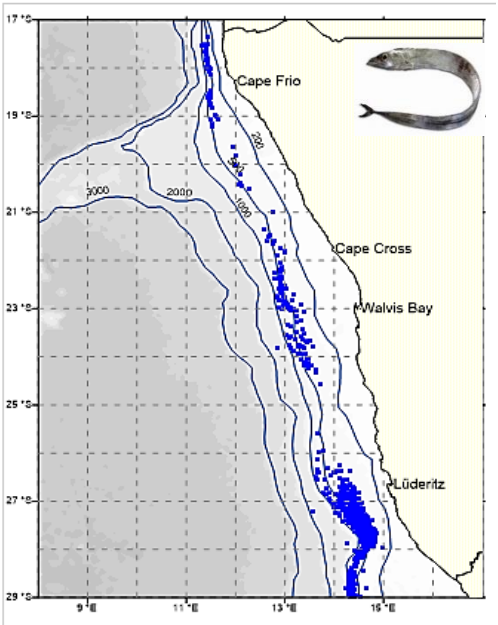
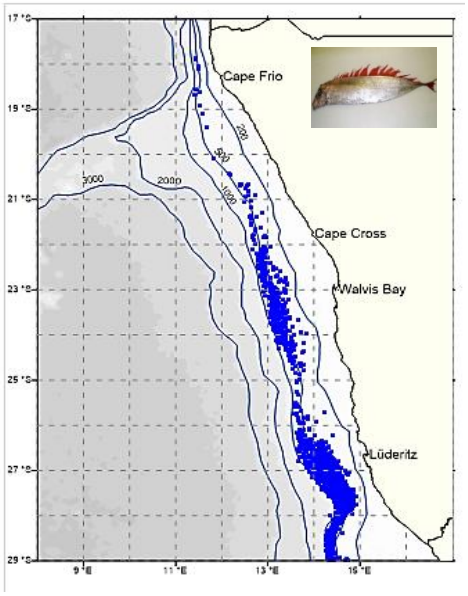
b) 

Figure 8: Maps showing the spatial distributions of cardinal fish (*Epigonus* spp) (a) and (b) scabbardfish (*Lepidotus caudatus*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

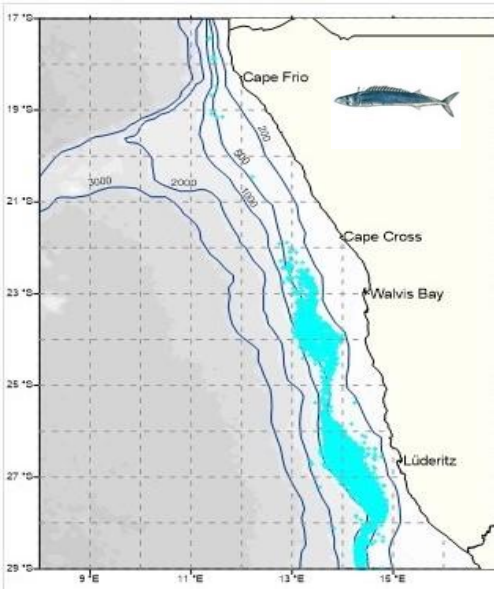
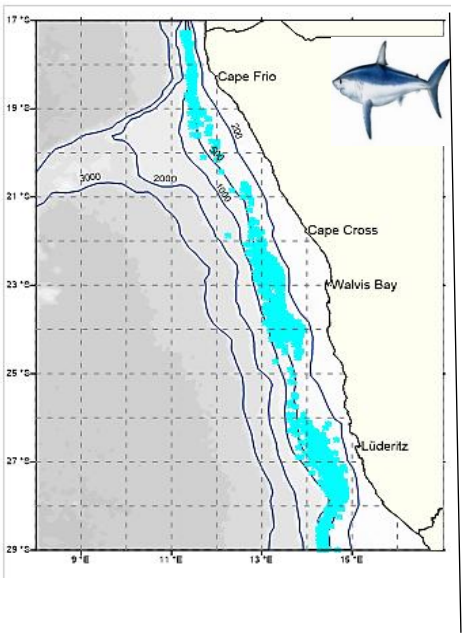


Figure 9: Maps showing the spatial distributions of ribbon fish (*Trachipterus trachypterus*) (a) and (b) *snoek (*Thyrsites atun*)* from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

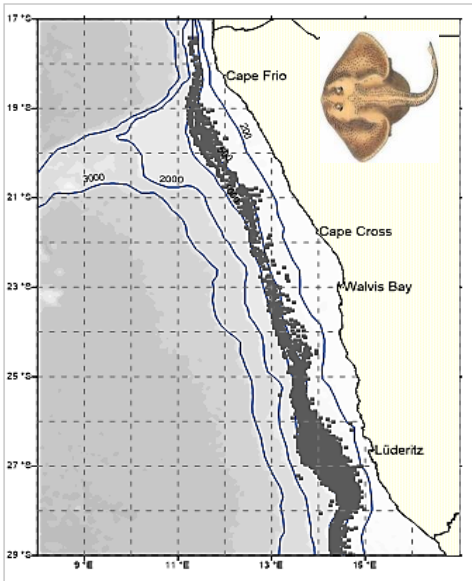
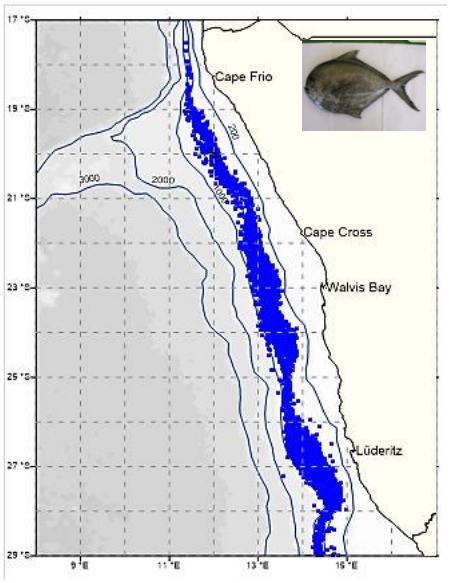


Figure 10: Maps showing the spatial distributions of mako shark (*Isurus oxyrinchus*) (a) and (b) *skates (*Raja species*)* from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

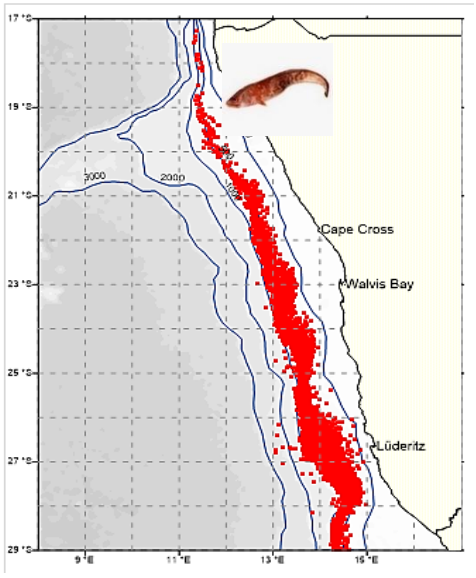
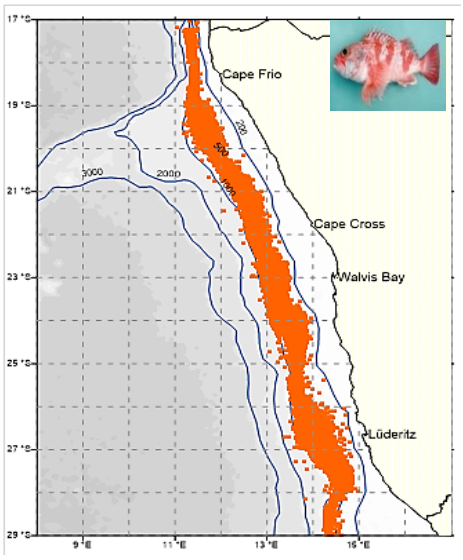


Figure 11: Maps showing the spatials distribution of angel fish (*Brama brama*) (a) and (b) kingklip (*Genypterus capensis*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

a)



b)

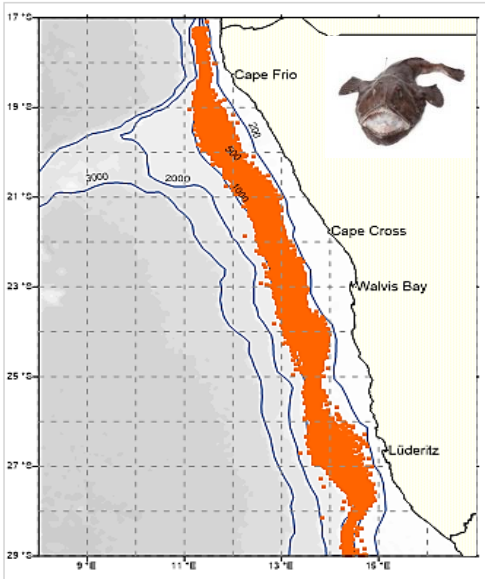


Figure 12: Maps showing the spatial distributions of) jacopever *(Helicolenus dactylopterus*) (a) and (b) monk fish *(Lophius vomerinus)* from 1997-2014. One dot represents one trawl and the contour lines represent depth.

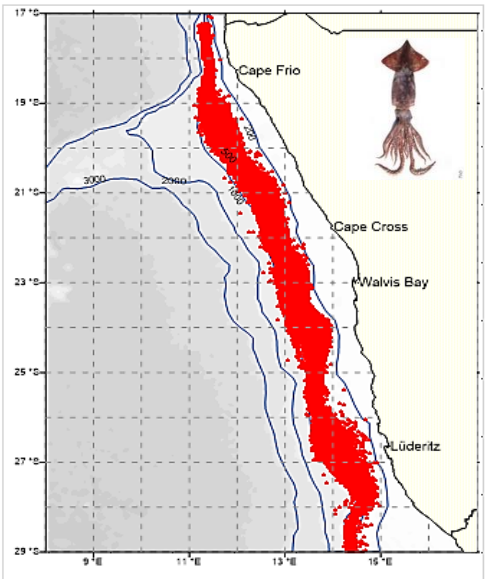
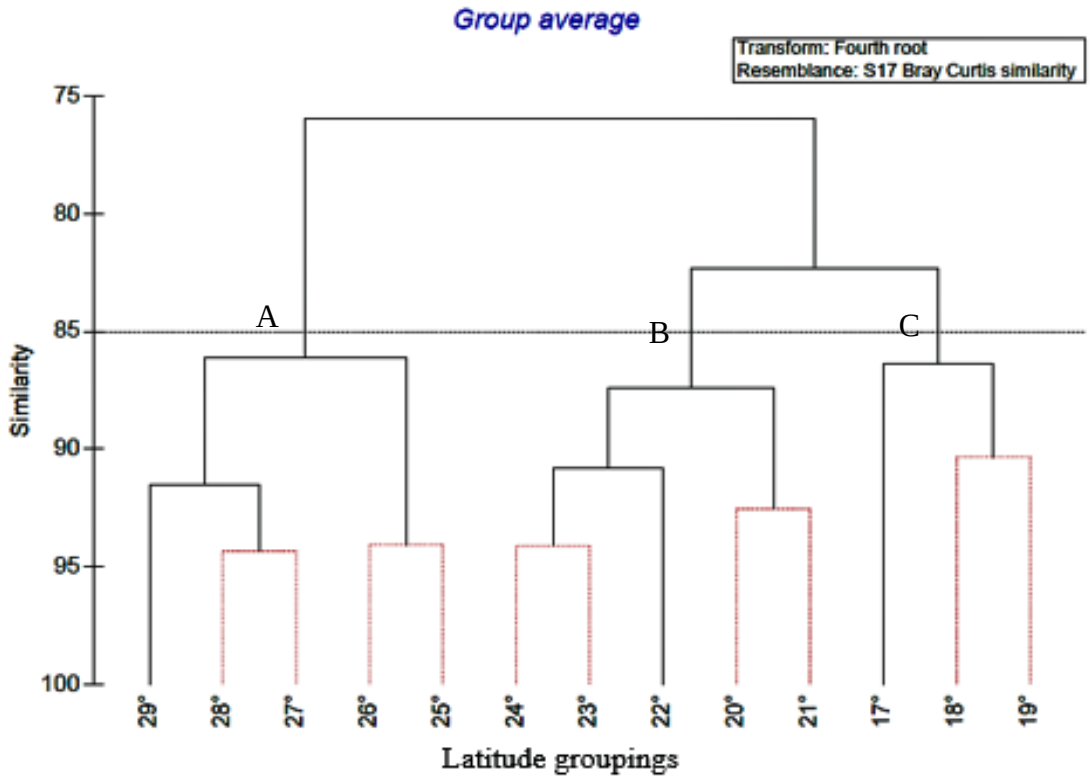


Figure 13: Maps showing the spatial distributions of) squid (*Todarodes sagittatus*) from 1997-2014. One dot represents one trawl and the contour lines represent depth.

Both the dendrogram from HCA and ordination plot from MDS (at 85% of similarity) indicated the potential existence of three assemblages structured latitudinally (A, B and C) (Figure 14). Group A species, were distributed in Southern Namibia, from 25°S to 29°S, group B was mostly distributed in Central Namibia from 20°S to 24°S, while group C was mostly distributed in northern Namibia from 17°S to 19°S (Figure 14). Group A was different from the rest of the groups, while group B and group C were not as distinct from one another, as they were from Group A (Figure 14). Within the three groups (A, B and C), 17°S, 22°S and 29°S were significantly different from the rest of the latitudes, (SIMPROF test, $P<0.05$) at 95% similarity. SIMPER results showed that *Raja species, Austroglosus microlepsis and Genypterus capensis* contributed most to the dissimilarity between Groups A and C (Table 4), while, *Dentex macrophthalmus and Genypterus capensis* contributed most to the dissimilarity between Groups A and B (Table 5). *Dentex macrophthalmus and Genypterus capensis* also contributed most

to dissimilarity between Groups C and B (Table 6). The global R statistics from ANOSIM of the assemblages (A, B and C) was 0.885, with $p < 0.05$, demonstrating that the overall difference between sites was large and statistically significant (APPENDIX II). Pairwise comparisons of the groups demonstrated a significant difference between all groups ($p < 0.05$ in all cases) (Table 7). The R values for the Groups A and B, B and C and A and C pairwise comparison were 0.908,0.75 and 1 respectively, indicating that group B and C were more similar to one another than the other two groups. Furthermore, group A showed a high level of dissimilarity between groups.



a)

b)

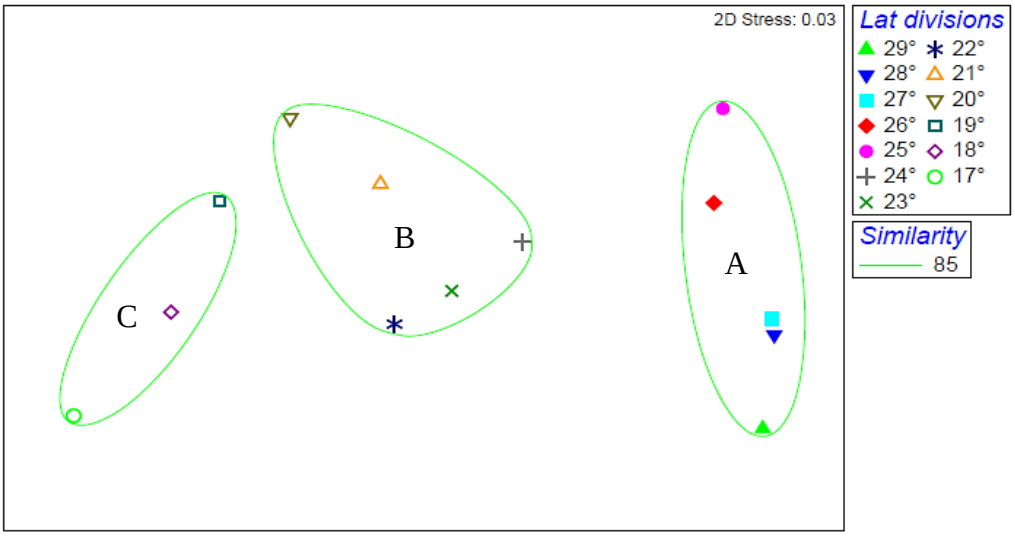


Figure 14: a) Dendrogram for hierarchical cluster analysis (HCA) (group-average linking), Dashed line represents 85% similarity; b) non-metric multidimensional scaling (MDS) ordination in two dimensions; both computed on 4th root transformed data, averaged by latitude for hake-directed bottom trawl fishery bycatch species, using Bray-Curtis resemblance matrix. Latitude groupings are shown and labelled as A, B and C.

Table 4: Average abundance of top five bycatch species in terms of latitudinal distribution in groups A and C. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

Average dissimilarity = 21.25						
Species	Group A Av.Abund	Group C Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum.%

Raja species	**7.81**	3.47	2.12	3.81	9.97	9.97
Austroglosus microlepsis	3.32	7.09	1.85	3.25	8.71	18.68
Genypterus capensis	**9.15**	5.45	1.82	2.06	8.58	27.27
Thyrsites atun	6.71	3.19	1.72	2.31	8.11	35.38
Tranchipterus trachypterus	5.61	3.03	1.32	1.63	6.21	41.59

Table 5*:* Average abundance of top five bycatch species in terms of latitudinal distribution in groups A and B. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

Average dissimilarity = 28.88						
Species	Group A Av.Abund	Group B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dentex macrophthalmus	2.70	**10.44**	3.52	14.21	12.19	12.19
Genypterus capensis	**9.15**	2.73	2.93	5.54	10.15	22.34

Chelidonicthys capensis	1.98	7.70	2.60	6.76	9.00	31.34
Thyrsites atun	6.71	1.83	2.22	5.55	7.69	39.02
Raja species	7.81	3.43	1.99	4.89	6.89	45.91

Table 6: Average abundance of top five bycatch species in terms of latitudinal distribution in groups C and B. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

Average dissimilarity = 17.70						
Species	Group C Av.Abund	Group B Av.bund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dentex macrophthalmus	5.26	**10.44**	2.49	2.56	14.06	14.06
Chelidonicthys capensis	4.51	7.70	1.55	2.80	8.73	22.79
Zeus faber	4.34	7.23	1.39	3.24	7.86	30.65
Agyrosomus inodorus	0.33	3.03	1.32	1.39	7.44	38.09

Genypterus capensis	**5.45**	2.73	1.30	2.00	7.37	45.46

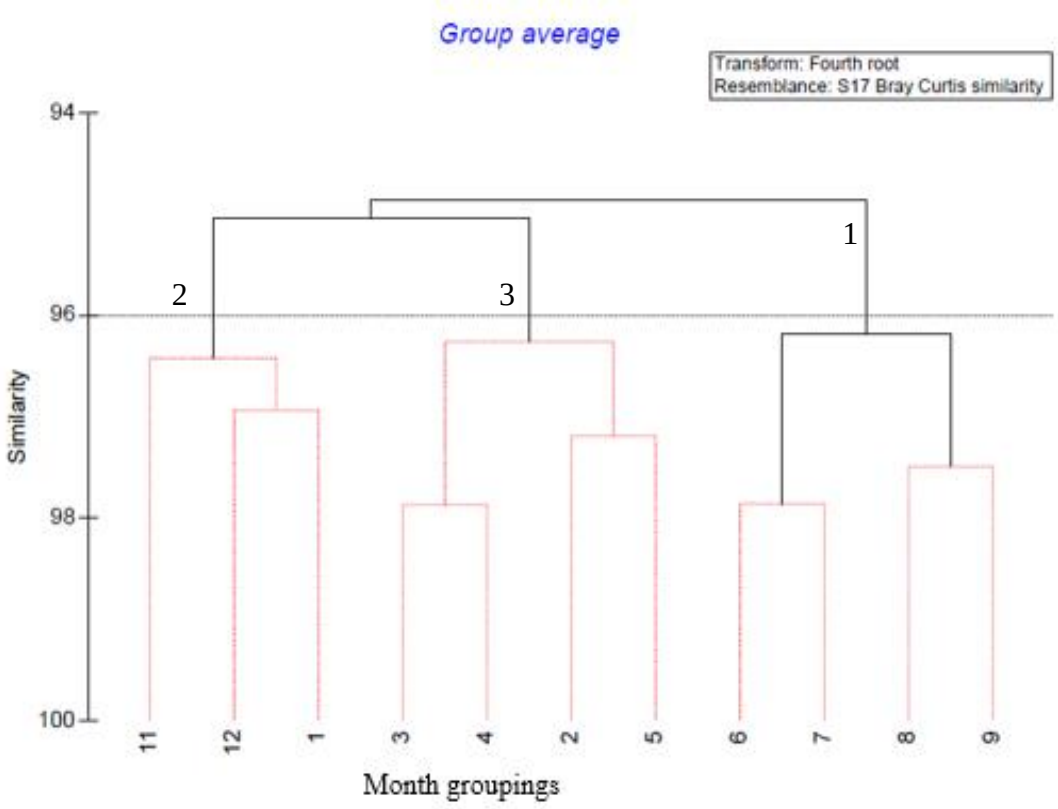
Table 7: Analysis of similarity (ANOSIM) of the three groups from the HCA and MDS in terms of latitudinal distribution. $p < 0.05$ in all cases for the pairwise comparisons.

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
a, b	0.908	0.8	126	126	1
a, c	1	1.8	56	56	1
b, c	0.754	1.8	56	56	1

4.5 Monthly variation in bycatch catch rates

In terms of monthly variation, HCA and MDS (at 96% of similarity) indicated that there is a persistent pattern (groupings) in terms of the fishing month in relation to the bycatch catch rates. Both the dendrogram from HCA and ordination plot from MDS indicated three groups. The first group (June to September) referred herein as Group 1; Group 2 (November to January) and Group 3 (February to May) (Figure 15 a and b). All the three groups are different from each other, as evidence shown in both the cluster analysis and MDS (Figure 15 a and b). All three groups were significantly different from each other, (SIMPROF test,$p<0.05$) at 96% Similarity. SIMPER results showed that *Dentex macrophthalmus* contributed most to the dissimilarity between Groups 2 and 3 (Table 8). Considering the dissimilarity between Groups 1 and 2, *Thyristes atun and Tranchipterus trachypterus* contributed most to the dissimilarity in terms of catch

rate (Table 9). In Groups 1 and 3, *Thyristes atun* and *Dentex macrophthalmus* contributed the most in the differences, (Table 10). The global R statistics from ANOSIM of the groups (1,2 and 3) was 0.88, with $p< 0.05$, demonstrating that the overall difference between groups was large and statistically significant (APPENDIX III). Pairwise comparisons of the groups demonstrated a significant difference between all groups ($p < 0.05$ in all cases) (Table 11). The R values for the groups 1 and 2, 1 and 3 and 2 and 3 pairwise comparisons were 0.833,0.854 and 0.963 respectively, indicating that all groups were dissimilar to one another. Furthermore, group 2 and 3 showed the highest level of dissimilarity between groups.



a)

b)

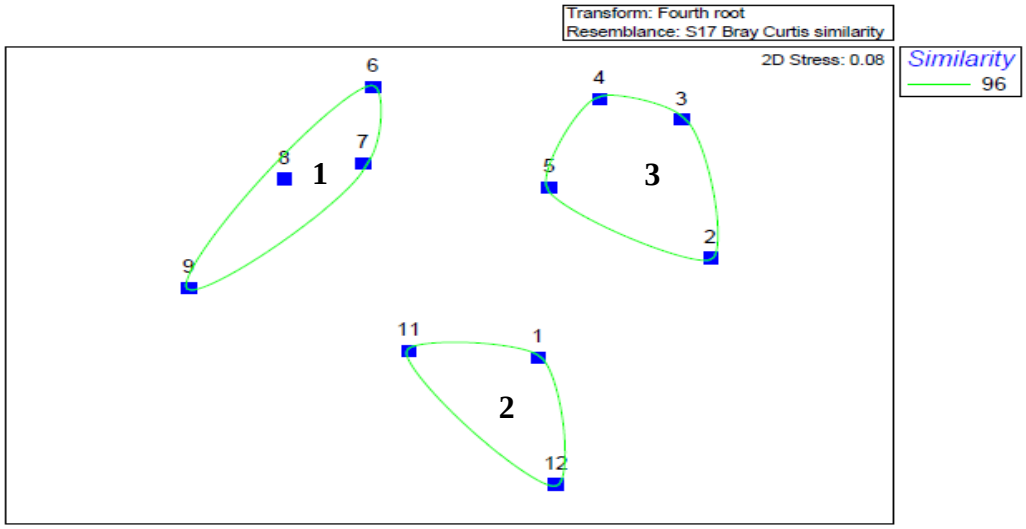


Figure 15: a) Dendrogram for hierarchical cluster analysis (HCA) (group-average linking), Dashed line represents 96% similarity; b) non-metric multidimensional scaling (MDS) ordination in two dimensions; both computed on 4th root transformed data, averaged by latitude for hake-directed bottom trawl fishery bycatch species, using Bray-Curtis resemblance matrix. Month groupings are shown and labelled as 1, 2 and 3.

Table 8: Average abundance of top five bycatch species in groups 2 and 3. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

Average dissimilarity: 15.75						
Species	Group 2 Av.Abund	Group 3 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Thunnus species	0.00	1.43	0.59	3.96	11.84	11.84

Zeus faber	4.44	5.46	0.42	3.80	8.48	20.31
Diplodus capensis	0.00	0.81	0.33	1.60	6.69	27.00
Austroglosus microlepsis	5.73	6.40	0.28	1.78	5.58	32.58
Dentex macrophthalmus	**6.18**	**6.76**	0.27	1.83	5.40	37.98

Table 9: Average abundance of top five bycatch species in groups 1 and 2. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

Average dissimilarity: 15.75						
Species	Group 1 Av.Abund	Group 2 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Thyristes atun	**6.95**	4.99	0.82	7.90	15.98	15.98
Thunnus species	1.22	0.00	0.51	1.51	9.87	25.85
Tranchipterus trachypterus	5.04	**5.99**	0.40	1.89	7.82	33.67

Chelidonicthys capensis	4.23	4.94	0.30	1.90	5.79	39.46
Zeus faber	4.17	4.44	0.24	1.76	4.74	44.20

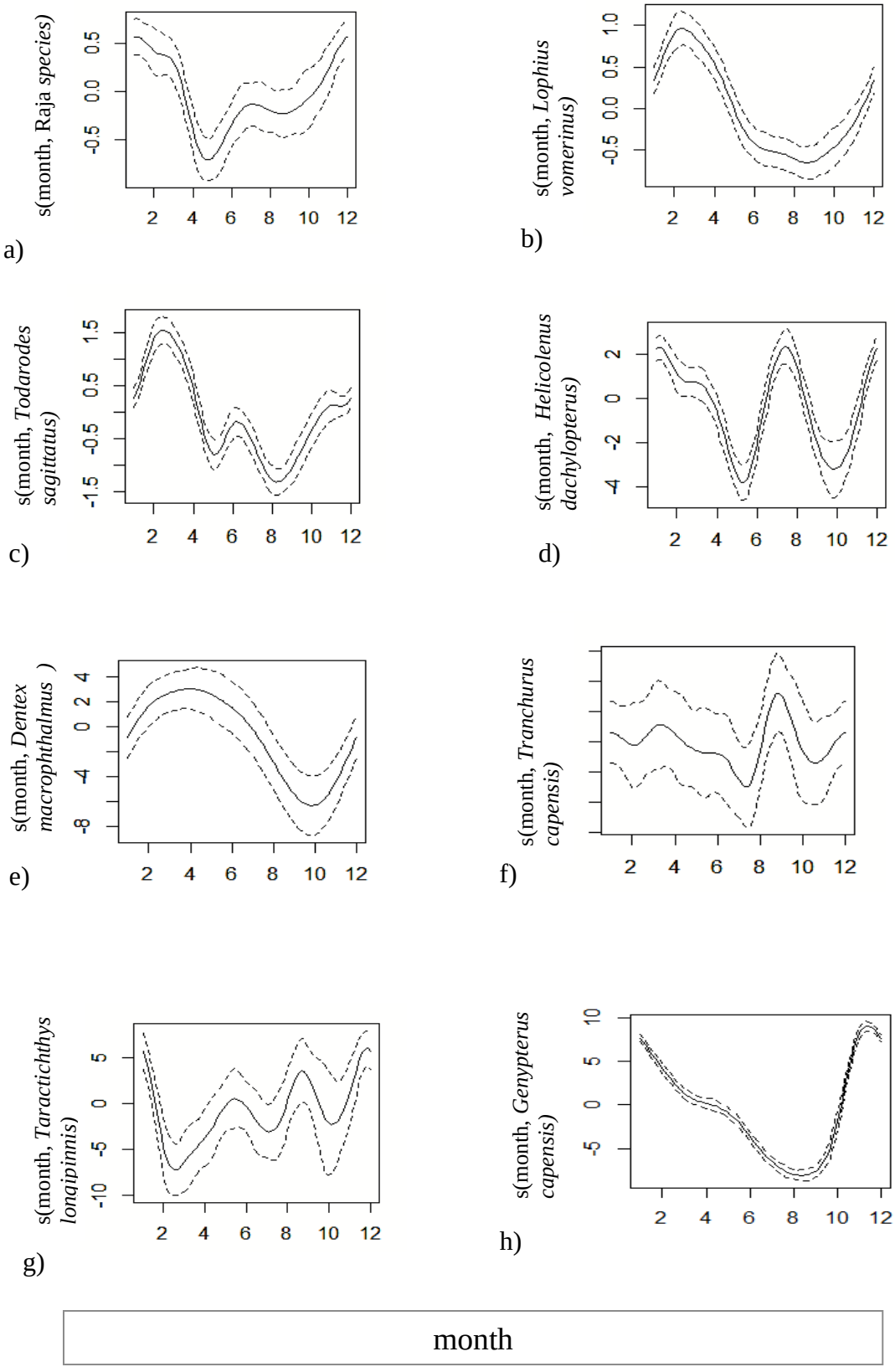
Table 10*:* Average abundance of top five bycatch species in groups 1 and 3. Species are listed in order of their contribution to the average dissimilarity between the two groups and the numbers in bold indicate species which are more abundant in that group.

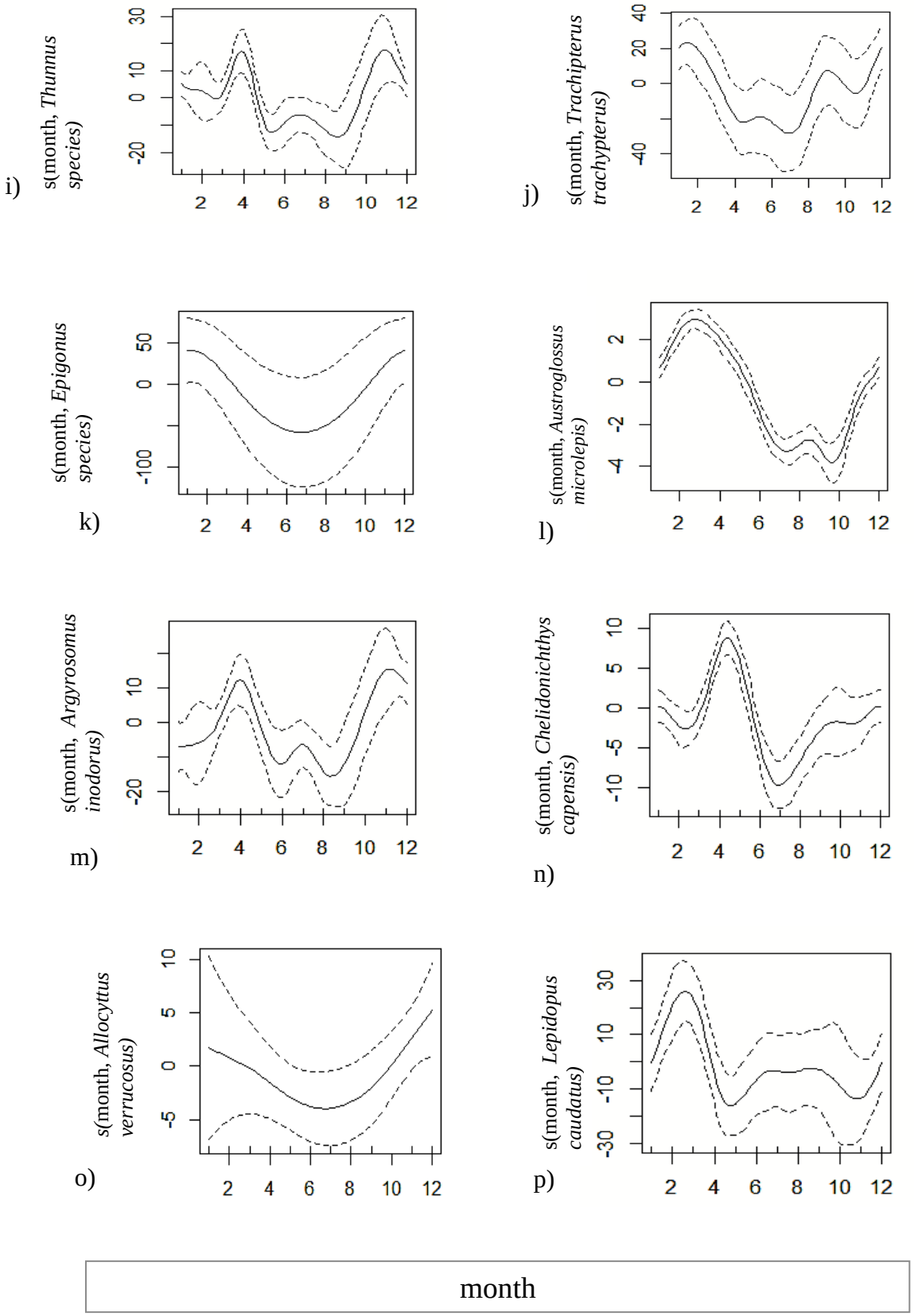
Average dissimilarity: 15.75						
Species	Group 1 Av.Abund	Group 3 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Thyristes atun	**6.95**	5.52	0.60	5.24	11.67	11.67
Zeus faber	4.17	5.46	0.54	2.06	10.52	22.19
Dentex macrophthalmus	5.78	**6.76**	0.41	2.76	7.99	30.18
Chelidonicthys capensis	4.23	5.16	0.39	3.58	7.58	37.76
Diplodus capensis	0.00	0.81	0.34	1.62	6.57	44.33

Table 11: Analysis of similarity (ANOSIM) of the three groups from the HCA and MDS. $p < 0.05$ in all cases for the pairwise comparisons

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1, 2	0.833	2.9	35	35	1
1, 3	0.854	2.9	35	35	1
2, 3	0.963	2.9	35	35	1

All bycatch species appeared to have monthly variations (Figure 16. a-t). The majority of bycatch species had high catch rates in January and December (*Raja species, Helicolenus dachylopterus, Taractichthys longipinnis, Genypterus capensis, Epigonus species* and *Trachipterus trachypterus*). Furthermore, most bycatch species had low catch rates in May and September, with five species (*Zeus faber, Lepidopus caudatus, Isurus oxyrinchus, Raja species, Helicolenus dachylopterus)* for the former and another five species (*Argyrosomus inodorus, Dentex macrophthalmus, Thunnus species, Genypterus capensis, Lophius vomerinus*) for the later. Overall monthly variations in CPUE showed a v=shaped pattern indicating that CPUE is highest at the beginning of the year and decreases towards the mid-year and increase by the end of the year (Figure 17). Overall, the month with the highest average CPUE was December and the lowest was July (Figure 17). See Appendix VIII for GAM diagnostics.


s(month, Raja species)
a)
s(month, Lophius vomerinus)
b)
s(month, Todarodes sagittatus)
c)
s(month, Helicolenus dachylopterus)
d)
s(month, Dentex macrophthalmus)
e)
s(month, Tranchurus capensis)
f)
s(month, Taractichthys longipinnis)
g)
s(month, Genypterus capensis)
h)
month


i)
s(month, Thunnus species)
-20 0 10 30
2 4 6 8 10 12
j)
s(month, Trachipterus trachypterus)
-40 0 20 40
2 4 6 8 10 12
k)
s(month, Epigonus species)
-100 0 50
2 4 6 8 10 12
l)
s(month, Austroglossus microlepis)
-4 -2 0 2
2 4 6 8 10 12
m)
s(month, Argyrosomus inodorus)
-20 0 10
2 4 6 8 10 12
n)
s(month, Chelidonichthys capensis)
-10 -5 0 5 10
2 4 6 8 10 12
o)
s(month, Allocyttus verrucosus)
-5 0 5 10
2 4 6 8 10 12
p)
s(month, Lepidopus caudatus)
-30 -10 10 30
2 4 6 8 10 12
month

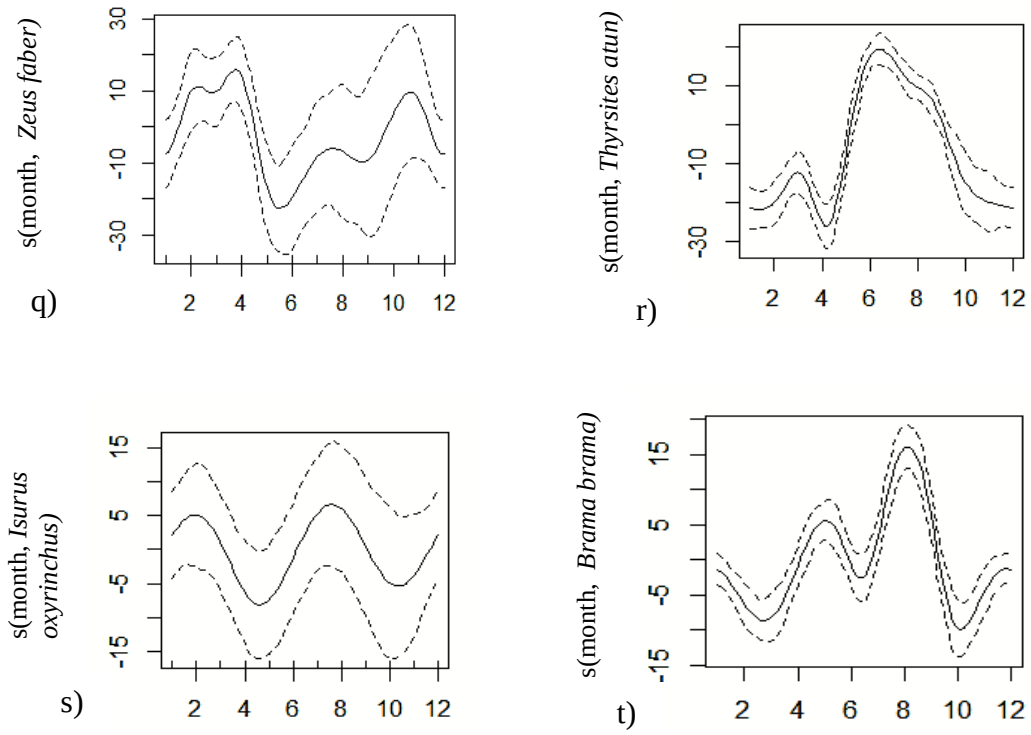
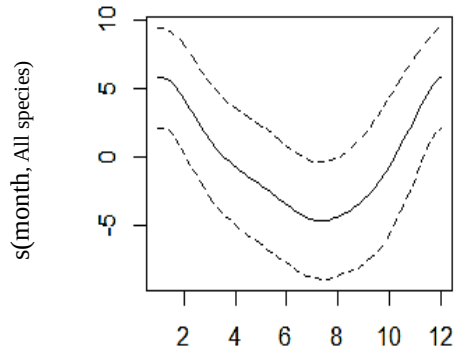


Figure 16: CPUE variability: Generalized Additive Model (GAM) smoothers of the partial effect of months on the CPUE for selected few bycatch species (a – t). Dashed lines indicate 95% confidence limits and the y-axis show the standardized value of

month

the response.

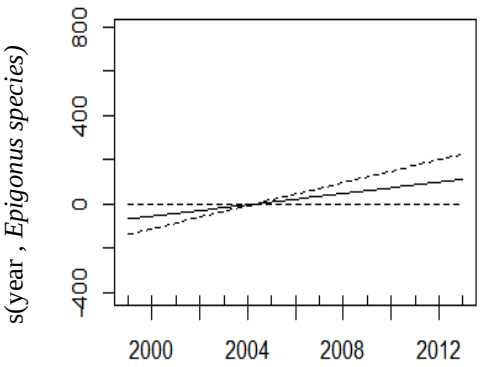


Months

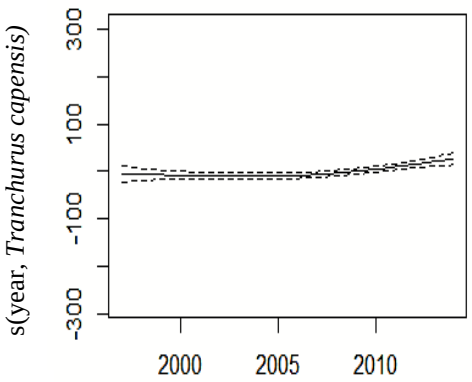
Figure 17: CPUE variability: Generalized Additive Model (GAM) smoothers of the partial effect of months on the CPUE of bycatch species as a whole. Dashed lines indicate 95% confidence limits and the y-axis show the standardized value of the response.

4.6 Inter-annual bycatch rate trends

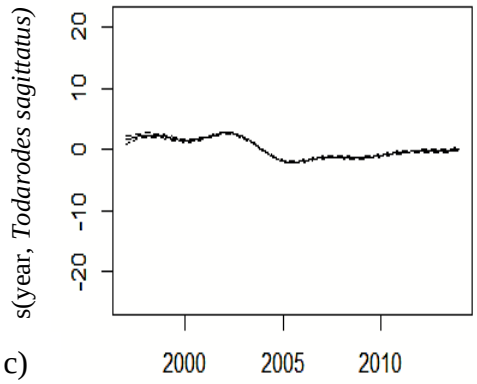
Epigonus species, *Tranchurus capensis*, *Todarodes sagittatus*, *Helicolenus dachylopterus*, *Brama brama*, *Genypterus capensis*, *Raja species*, *Austroglossus microlepis*, *Dentex macrophthalmus*, *Taractichthys longipinnis* and *Thyrsites atun* had increasing trends in CPUE (Figure 18 a-k). Among the species with increasing annual trends, *Thyrsites atun* (Figure 18 k) had more noticeable variations in the trends. *Thunnus species*, *Argyrosomus inodorus*, *Lepidopus caudatus*, *Trachipterus trachypterus*, *Isurus oxyrinchus*, *Zeus faber*, *Lophius vomerinus*, *Chelidonichthys capensis* and *Allocyttus verrucosus* had decreasing trends (Figure 18 l-t). *Allocyttus verrucosus* (Figure 18 t) had more noticeable variations in trends of CPUE among the species with decreasing trends. See Appendix IX for GAM diagnostics.



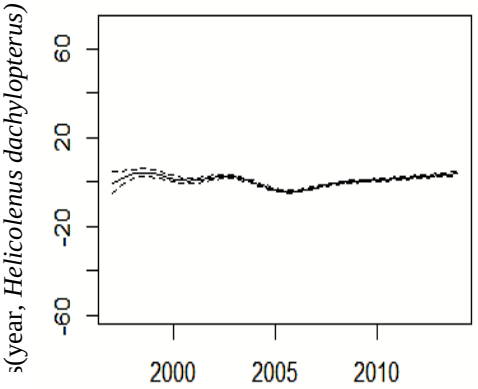
a)



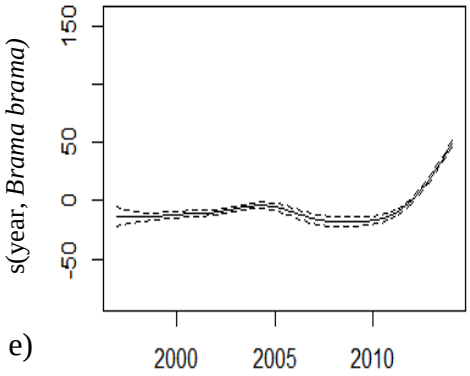
b)


s(year, Todarodes sagittatus)
20
10
0
-10
-20
2000
2005
2010

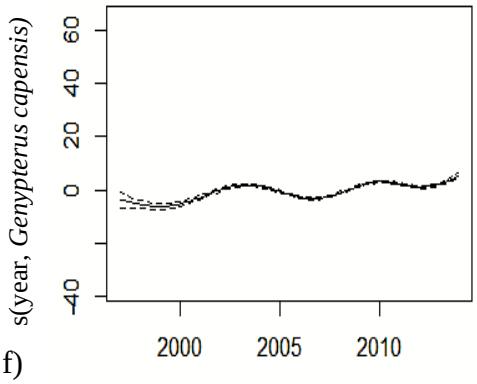
c)


s(year, Helicolenus dachylopterus)
60
20
-20
-60
2000
2005
2010

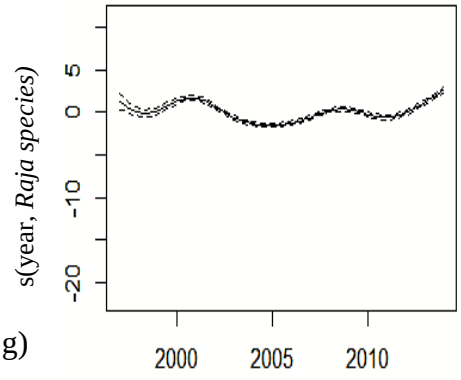
d)


s(year, Brama brama)
150
50
0
-50
2000
2005
2010

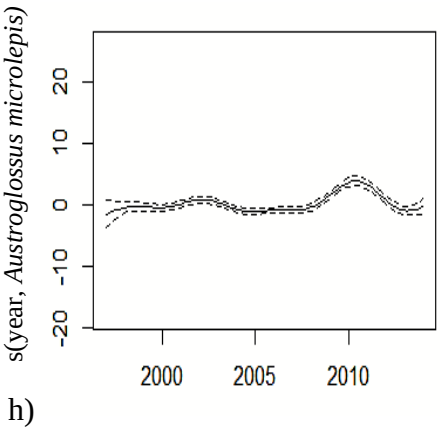
e)


s(year, Genypterus capensis)
60
40
20
0
-40
2000
2005
2010

f)

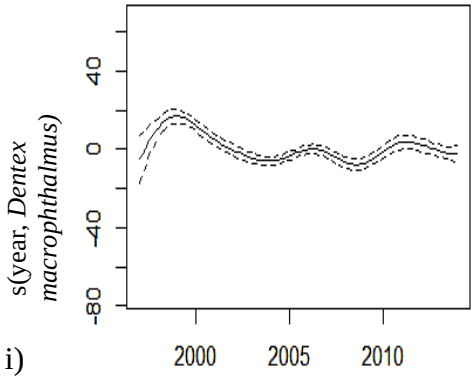

s(year, Raja species)
5
0
-10
-20
2000
2005
2010

g)

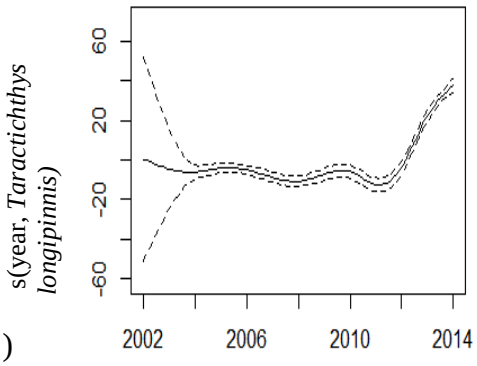

s(year, Austroglossus microlepis)
20
10
0
-10
-20
2000
2005
2010

h)

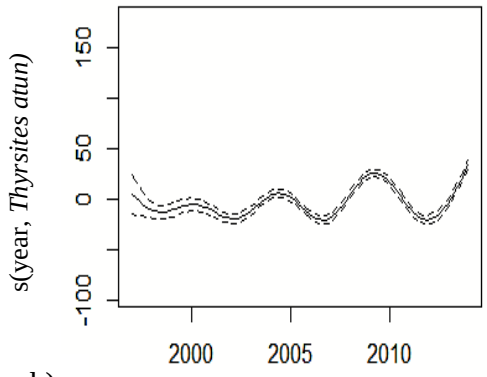
Year


s(year, Dentex macrophthalmus)
40
0
-40
-80
2000
2005
2010

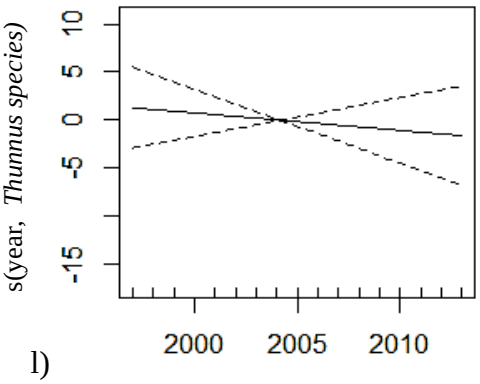
i)


s(year, Taractichthys longipinnis)
60
20
-20
-60
2002
2006
2010
2014

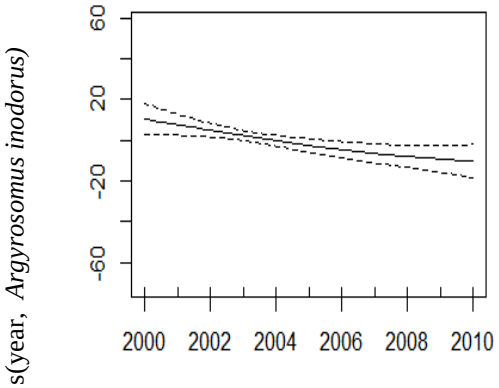
j)


s(year, Thyrsites atun)
150
50
0
-100
2000
2005
2010

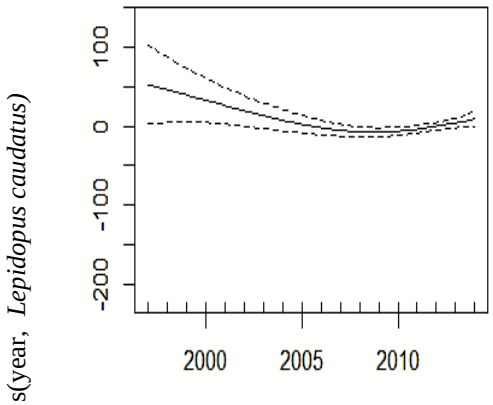
k)


s(year, Thumnus species)
10
5
0
-5
-15
2000
2005
2010

l)


s(year, Argyrosomus inodorus)
60
20
-20
-60
2000
2002
2004
2006
2008
2010

m)


s(year, Lepidopus caudatus)
100
0
-100
-200
2000
2005
2010

n)

Year

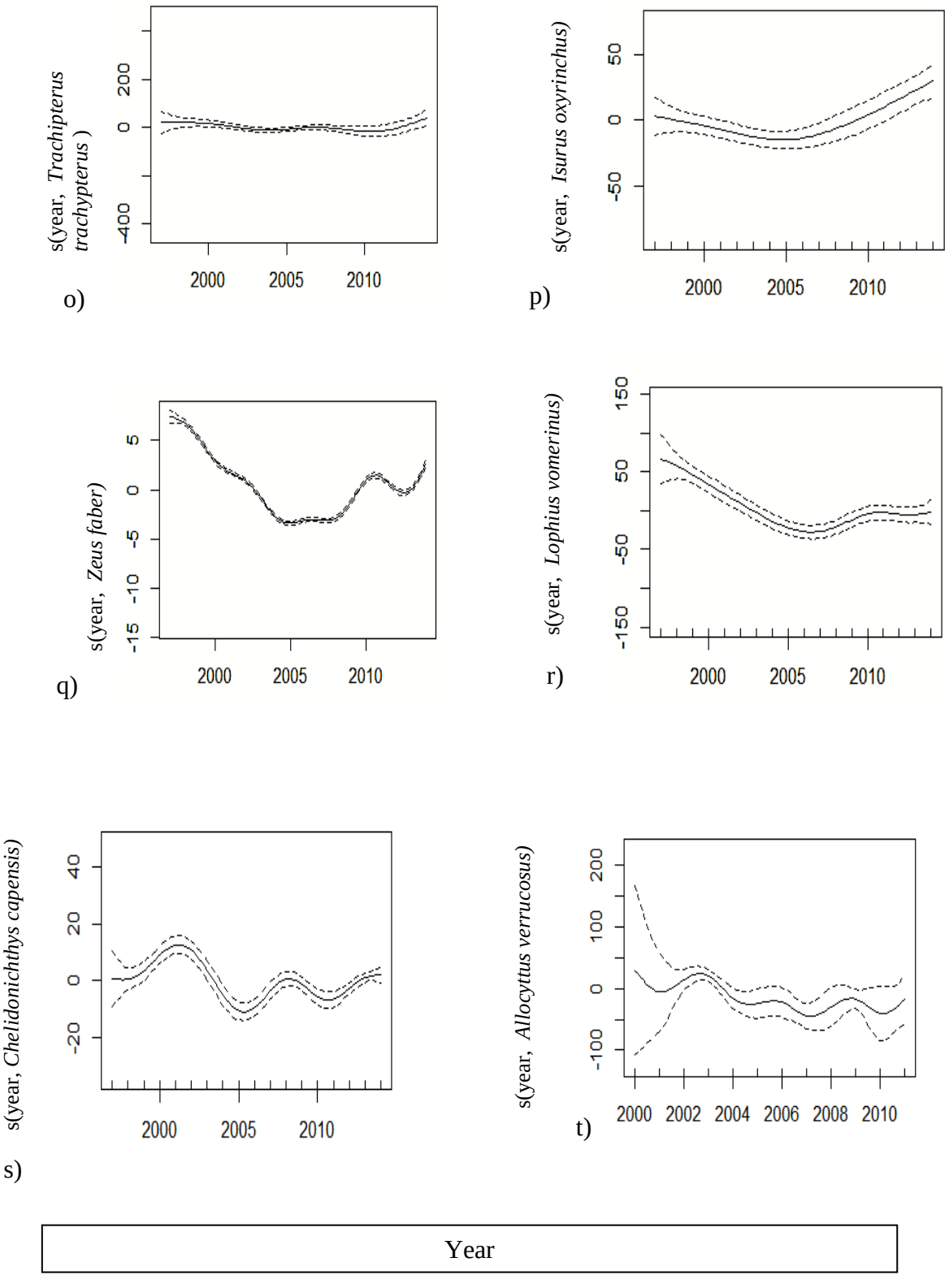


Figure 18: CPUE variability: Generalized Additive Model (GAM) smoothers of the partial effect of year on the CPUE of bycatch species (a-u). Dashed lines indicate 95% confidence limits and the y-axis show the standardized value of the response.

4.7 Influence of variables on catch per unit effort (CPUE) of bycatch species

The following variables: Latitude, Month, Year, depth and GRT employed to access the influence on catch rates, CPUE (kg/h) data from the commercial hake bottom-trawl fishery off Namibia, using Generalized Additive Models (GAMs) (Table 12; Appendix VI). The descriptor variable that influenced most hake bycatch specie's CPUE was latitude. This parameter had an influence on all species, while depth had the least influence on CPUEs of species. Overall, all the parameters had a significant influence on CPUE (Table 13; Appendix VII).

Table 12: Parameters influencing CPUE of bycatch species from GAM analysis.

Species Name	Latitude		Month		Year		Depth		GRT	
	P-value	Significance	P-value	Significance	P-value	Significance	P-value	Significance	P-value	Significance
Epigonus species	0.02254	Significant	0.00723	Significant	0.05050	Non-significant	0.97602	Non-significant	0.28703	Non-significant
Argryosomus inodorus	0.00037	Significant	0.00384	Significant	0.00579	Significant	0.23529	Non-significant	0.14166	Non-significant
Thunus Species	0.00345	Significant	0.00107	Significant	0.01288	Significant	0.11924	Non-significant	0.29426	Non-significant
Tranchurus Capensis	0.004610	Significant	0.178151	Non-significant	0.000162	Significant	0.005616	Significant	1.3e-06	Significant
Isurus oxyrinchus	0.000156	Significant	0.078999	Non-significant	1.26e-05	Significant	0.019304	Significant	0.017026	Significant
Allocyttus verrucosus	1.93e-05	Significant	9.50e-12	Significant	6.94e-06	Significant	0.246091	Non-significant	0.000455	Significant
Lepidotus caudatus	3.76e-05	Significant	0.0195	Significant	0.0149	Significant	7.17e-08	Significant	0.2838	Non-significant

Taractichthys longipinnis	< 2e-16	Significant	8.02e-14	Significant	< 2e-16	Significant	< 2e-16	Significant	4.17e-12	Significant
Brama brama	<2e-166	Significant	<2e-16	Significant	<2e-1	Significant	0.0067	Significant	<2e-16	Significant
Chelidonichthys capensis	< 2e-16	Significant	< 2e-16	Significant	< 2e-16	Significant	< 2e-16	Significant	6.97e-11	Significant
Dentex macrophthalmus	< 2e-16	Significant	8.54e-06	Significant	< 2e-16	Significant	< 2e-16	Significant	< 2e-16	Significant
Helicolenus dactylopterus	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant
Zeus faber	< 2e-16	Significant	9.79e-13	Significant	< 2e-16	Significant	< 2e-16	Significant	6.87e-14	Significant
Genypterus capensis	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant
Lophius vomerinus	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant

Raja species	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant
Thyristes atun	< 2e-16	Significant	< 2e-16	Significant	< 2e-16	Significant	8.06e-15	Significant	3.47e-08	Significant
Todarodes sagittatus	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant	<2e-16	Significant
Tranchipterus tranchipterus	<2e-16	Significant	0.000764	Significant	0.010787	Significant	< 2e-16	Significant	0.000120	Significant

13: Parameters influencing bycatch species as a whole: GAM analysis.

Species Name	Latitude		Month		Year		Depth		GRT	
All species	P-value	Significance	P-value	Significance	P-value	Significance	P-value	Significance	P-value	Significance
	7.93e-07	Significant	0.001111	Significant	4.89e-05	Significant	0.000553	Significant	0.010523	Significant

CHAPTER FIVE

5.Discussion

5.1 General discussion and description of Namibian hake bycatch.

The study examines the spatial distribution of bycatch; monthly and inter-annual variations in the bycatch catch rates and factors that influence bycatch catch rates. The above indicate the potential effects of hake fishery in Namibia on the Namibian ecosystem structure. The marine environment of Namibia falls within the Benguela Current system. The Benguela Current is one of the world's major eastern boundary current systems and is rich in pelagic and demersal fish populations (Van Zyl 2000). According to Trainer et al. (2010), these highly productive upwelling regimes support a wide diversity of marine life and account for a large portion of global fisheries production. Almost 500 species of fish are known to occur in Namibian waters, comprising of about 410 species of bony fish and 83 species of cartilaginous fish (Robertson et al. 2012). In this study, there were twenty-two fish species caught as bycatch in the hake-directed bottom trawl fishery; which is about four (4) percent of the fish species that occur in the Namibian waters. In addition to the fish species, squids (molluscs) were also part of this study. In totality the study looked at twenty-three (23) bycatch species in the hake-directed bottom trawl fishery. Among these twenty-three (23) bycatches species, about seventeen of them have commercial values. These species are: Blacktail (*Diplodus capensis*); Silver kob (*Argyrosomus inodorus*); Yellow fin tuna *(Thunnus albacores);* Cape gurnard (*Chelidonichthys capensis);* Large-eye dentex (*Dentex macrophthalmus*) *;* John dory *(Zeus faber);* West coast sole *(Austroglossus microlepis);* Grootskub-pomfret (*Taractichthys longipinnis);* Horse mackerel (*Tranchurus capensis);* Other tunas *(Thunnus species)*; Snoek *(Thyrsites atun);*

Shortfin mako shark (*Isurus oxyrinchus);* angelfish (*Brama brama*); kingklip (*Genypterus capensis)*; jacopever *(Helicolenus dachylopterus)*; Monkfish (*Lophius vomerinus)* and Flying squid *(Todarodes sagittatus).* These species make up seventy-four (74) percent of bycatch in the hake directed bottom trawl fishery while the remaining twenty-six (26) percent is made up of species belonging to: the family Macrouridae (grenadiers); Black oreo (*Allocyttus verrucosus*); Cardinal fishes (*Epigonus* spp); Silver scabbardfish (*Lepidopus caudatus)*; Ribbonfish (*Trachipterus trachypterus)* and Skates *(Raja species).*

Bycatch can potentially alter species composition, diversity, structure and function of food webs (trophic systems) (Driscoll et al. 2009; Mafwila 2011). This indicates that hake fishing may have an influence on the trophic structure of the Benguela ecosystem.

Among all bycatch species, the species that had the highest catch rates were ribbonfish (*Trachipterus trachypterus)* with a total of 1352.34 metric tons, and this is possibly linked to the fact that it occurs along the entire coast of Namibia (Heemstra and Kannemeyer 1986). *Trachipterus trachypterus* is known to feed on squids and mesopelagic fish (Heemstra and Kannemeyer 1986), which are within the distributional range of hake. According to Pinedo and Polacheck (2004) most bycatch occurs when bycatch species have the same feeding grounds as the target species or caught while migrating across regions, signifying why there may have been high catch rates in *T. trachypterus.* According to Bianchi et al. (1999) *T. trachypterus* is caught as bycatch in trawls. Bottom trawling in Namibia is permitted in waters above 200 m depth, which is within the distributional range of Ribbonfish. According to Alverson et al. (1994), the catching of bycatch species in the absence of bycatch information may lead to over-exploitation of the bycatch species as there is no information on how much is caught. In addition, there is a lack of information on *T. trachypterus* and not much has been

done on the assessment of the species; thus, the species may be at risk without the fisher's knowledge. Blacktail (*Diplodus capensis*) had the lowest catch rates (0.23 metric tons). *Diplodus capensis* is a coastal species that is usually found on rocky grounds to a depth of 50 m (Bianchi et al. 1999). It is caught mainly with line gear by shore anglers and commercially from ski-boats and rarely as bycatch in the midwater and deep-water fisheries (Bianchi et al. 1999). In Namibia, hake-directed bottom trawling fishing takes place in waters deeper than 200 m. The low catch rates of *D. capensis* may therefore, be possibly linked to the fact that it is commonly found in areas where bottom trawling is not common.

Most of the bycatch species were encountered along the entire coast of Namibia, showing that bycatch reduction measures should cover the entire hake directed bottom trawling fishing grounds (figure1). Bycatch species that might require area-specific measures include *D. capensis* and *Argyrosomus inodorus* which were only encountered in the northern parts of Namibia. Three major bycatch assemblages/groups were identified along latitudes and months, providing a potential focus for bycatch measures that can be effective for many hake bycatch species. The factor that significantly influenced most CPUE of bycatch was latitude. However different bycatch species were influenced differently by factors; one factor may significantly influence a certain group of bycatch species but may not influence the other and thus all factors need to be taken into consideration. This is also an indication that these factors need special consideration for any bycatch management strategies to be effective.

5.2 Spatial distribution of hake bycatch species

The commercial hake trawls data from 1997-2014 showed that most bycatch species were caught almost throughout the entire Namibian waters, with some species having

higher catch rates in the North, Central and majority in the Southern regions. When looking at bycatch species as a whole, the spatial catch rates of most bycatch species was concentrated at 17°S, 22°S, 27°S and 29°S. The latitudes with high catch rates may potentially be areas where hake fish may have highly influenced the populations of its bycatch species and may therefore require area-specific measures such as; Marine Protected Areas). It was observed that trawlers were active almost everywhere within the fishing grounds, except in areas which are not trawlable due to obstacles e.g. rocky ground (Mafwila 2011).

Cluster and MDS results indicated that there were three major assemblages which were consistent along the latitude (spatial distribution) in any given year at about 85% of similarity. One group (Group A-Southern Namibia) was from 25°S to 29°S and two more groups for the 20°S - 24°S, (Group B - Central Namibia) and for 17°S - 19°S (Group C-Northern Namibia). The global R statistics from ANOSIM and Pairwise comparisons of the assemblages (A, B and C) showed that the overall differences between sites were large and statistically significant (Table 7). It was also observed that group B and C were more similar to one another than the other groups. Furthermore, group A showed a high level of dissimilarity between groups (Table 7). This is consistent with the results from Mafwila (2011), who found the same demersal fish assemblages within the Namibian Economic Exclusive Zone (EEZ). This potentially provide key focus areas that can be targeted by specific measures that may be effective for most species caught as bycatch of the Namibian hake bottom trawl fisheries. However, the fact that Group A was more different from the rest of the groups may indicate uniformity in the distribution of bycatch species, which can be challenging if area bycatch management measures are to be considered. There was also an overlap in assemblages whereby the Central Namibia assemblage extended slightly into Northern

Namibia indicating similarity between Northern and Central. The Namibian marine environment is part of the BCLME (Benguela Current Large Marine Ecosystem).

The Benguela Large Marine Ecosystem is considered to cover the continental shelf between the Angola Benguela Frontal zone off northern Namibia/Southern Angola and the Agulhas retroflexion area, typically between 36 and 37°S (Boyer and Hampton 2001; Mafwila 2011; Nashima 2009). As such, it covers the west coast of South Africa, the entire Namibian coast, and part of Southern Angola, depending on the position of the Angola-Benguela front, which moves seasonally typically between 14 and 17°S (Boyer and Hampton 2001). According to Bianchi et al. (1993), upwelling intensity is not uniform in space or in time, as there are short-term and seasonal differences in the wind regime, and because of coastline and shelf topography. The major centre of upwelling off Namibia is from Lüderitz to the Orange River. Strong perennial upwelling off Lüderitz (26°S - 28°S) effectively separates the Northern from the Southern Benguela, which gives a distinction in (North and South) regions within the Namibian EEZ (Bianchi et al.1993; Boyer and Hampton 2001). According to Sakko (1998), within the Benguela system, there are variations that occur continuously with regard to physical, chemical and biological conditions (wind pressure, oxygen and temperature variations) and these also fluctuate both in time and space. The above may explain why there were three major demersal fish assemblages observed in the study as there is no uniformity in upwelling intensity as well as changing environmental conditions. This may also explain why the South (group A) was more distinct from the other two regions (B and C) in the study and may also be the reason why there was an overlap in the two regions. Moreover, this difference in the regions could affect the distribution of demersal fish species within the environment, since different fish species

prefer different conditions. According to Nashima (2009), differences in species yield might be due to differences in productivity and environmental conditions between locations. In addition, change in distribution and relative abundance of species in the assemblage is also directly influenced by fishing (Payne et al. 2001).

In terms of latitudinal grouping in A, B and C, 17°S, 22°S and 29°S, were significantly different from the rest of the latitudes, (SIMPROF test, $p<0.05$) at 95% similarity. This difference may have been instigated by the difference in catch rates of different bycatch species along the latitudes; 17°S, 22°S and 29°S (Appendix I). In addition, most species had high catch rates at these latitudes 17°S, 22°S and 29°S, and this may have been the reason why they were significantly different from the rest of the latitudes. Bottom temperature and dissolved oxygen could also have played a role in the distribution of the demersal fish; however, this type of data was not used in this study. In a study carried out by Mafwila (2017) on the community structure of demersal fish assemblages of the Benguela System; the study depicted that demersal fish assemblages in the Benguela are spatially distinct and this corresponds with the current study.

Blacktail (*Diplodus capensis)* was only caught in the Northern parts of Namibia, with highest catch rates around 17°S and lowest at 20°S. Bianchi et al. (1999) `, used data from both pelagic and demersal fishery and survey on blacktail and concluded that it occurs along the entire coast of Namibia. However, this study's findings are in contradiction with the study done by Bianchi et al. (1999), as the specie was only observed in the Northern regions. Tagging studies conducted in the De Hoop and Tsitsikamma MPAs have shown that adult blacktail is highly resident, with a mean

distance moved of only 6km (Cowley et al. 2002). The high catch rates at 17˚S may have been due to the species residing in that area as it is a highly resident specie.

Grenadiers (Macrouridae *spp)* was another species that had high catch rates in the Northern parts of Namibia, with highest catch rates at 19°S. According to Bianchi et al. (1999), there are possibly 21 species of Macrouridae from Namibia that mostly occur in the Northern parts, which agrees with the results of the present study as they were observed mostly in the Northern regions.

In the current study, nineteen species were observed along the entire coast. The West Coast sole, (*Austroglossus microlepis*), was one of the species caught along the entire coast of Namibia (Figure 5 b); (Appendix I). It is known as the only flatfish that is commercially important. They are found in waters 100−300 m deep along the entire Namibian coast and extends up to False Bay in South Africa (Mafwila 2011). Bottom trawling in Namibia is permitted in waters above 200 m depth, which is within the distributional range of these species. In the present study, these species were caught along the entire coast of Namibia, which corresponds with the study by Mafwila (2011). In addition, the West coast sole was among the species that contributed most to the dissimilarity in the groups for spatial distribution. The highest catch rates were seen at 20°S and 22°S, while the lowest was around 28°S (Appendix I). According to Bianchi et al. (1999), the Namibian waters support two distinct stocks of West Coast Sole (*Austroglossus microlepis*). The two distinct stocks of West Coast Sole: one offshore of the Orange River mouth, between 28°S and 30°S.The second stock is centered in the Walvis basin (20°S - 25°S). This species has also been encountered by hake biomass surveys along the entire Namibian coast with high abundances in the far south and central south (MFMR 2006, Unpublished data), which corresponds with the study by Bianchi et al. (1999). The highest catch rates were seen at 20°S and 22°S, and

these results partially correspond with the study by Bianchi et al. (1999) as the highest catch rates were observed in one of the areas that were specified in the study by Bianchi et al. (1999) as common areas of Sole fish and may have been the reason why the catch rates were high in that region. However, there were very low catch rates in the other area that was mentioned (28°S and 30°S), which does not correspond with the study by Bianchi et al. (1999), as the catch rates were very low in this region.

Horse mackerel (*Trachurus capensis)*, is one of the abundant pelagic species found off the coast of Namibia. In this present study, it was caught along the entire coast of Namibia, with highest catch rates at 22°S and lowest at 29°S. It was also observed that horse mackerel had very low catch rates in the Northern regions (Appendix I). Iitembu (2008) documented that horse mackerel are widely distributed along the entire Namibian coast and according to Bianchi et al. (1993), adult cape horse mackerel occur along the entire Namibian coast except for further North where catch rates are limited. The results of the present study correspond with the study by Bianchi et al. (1993) and Iitembu (2008), as latitudinal distribution of horse mackerel was along the entire coast with the low catch rates in the Northern region. In addition, horse mackerel had low catch rates in the Southern regions. Horse mackerel is known to spawn at Cape Cross (22°S) (O'Toole, 1977), signifying the increase of horse mackerel catch rates at this latitude. However, the low catch rates at 29°S can also be attributed to high numbers of seals at Wolf Bay and Atlas Bay near Lüderitz`. that feed on horse mackerel and may have led to low catch rates at that latitude.

Dentex macrophthalmus commonly known as large-eyed dentex was also caught along the entire coast of Namibia. In this present study, it was caught along the entire coast of Namibia, with highest catch rates at 19°S and lowest at 28°S. This species had high catch rates from 22° northward and very low catch rates southwards. According

to MFMR (2006), *Dentex macrophthalmus* has been encountered by hake biomass surveys from 22° S northward in Namibian water, which corresponds with the current study. According to MFMR (2018), Dentex has only been observed in the far north, starting of just south of Mowe Bay and extending further north to the border with Angola where this species is very abundant, this however does not correspond with the current study as the species was also observed in the southern regions. According to Trunov (1970), Dentex macrophthalmus is a small, commercially important sparid fish that is abundant in the deeper waters (range 50–500 m) of the Mediterranean Sea , the North-West African shelf , including the Cape Verde and Canary Islands, and the south-eastern Atlantic from the Equator to just south of Lüderitz (27°S).The study by Trunov (1970), corresponds with the current study as the species was also caught in the southern regions.

Scabbard fish (*Lepidopus caudatus*), is an important commercial fish species in the North eastern Atlantic and off Namibia and New Zealand (Nakamura and Parin 1993). In this present study this species was caught along the entire coast of Namibia, with the highest catch rates at 29°S and lowest at 19°S. According to Nakamura and Parin (1993), *Lepidopus caudatus* may occasionally be found in upwelled waters. In Namibian waters, upwelling is most intense in the southern parts of Namibia (26°S - 28°S) which may have been the reason why the catch rates were high closer to areas where upwelling is intense (29°S). The low catch rates at 19°S can be attributed to the Northern regions having a less intensity of upwelling as compared to the South.

In the current study, Snoek (*Thyrsites atun*) was caught along the entire coast of Namibia, with the highest catch rates at 27°S and lowest at 17°S. According to Boyer

and Hampton (2001), Snoek occurs along the entire length of the Namibian coast. According to Iitembu (2008), as cited in Mafwila (2011), Snoek has been recorded from 22° Southward. In the present study snoek, was observed along the entire coast of Namibia; thus, the observations do correspond with the study by Boyer and Hampton (2001). According to Crawford & de Villiers (1985), this species occurs mainly in cool upwelled waters where it is an important predator of small pelagic species. The low catch rates at 17°S and high catch rates at 27°S may be attributed to this species occurring more in cool upwelled waters, since upwelling is more intense in the South as compared to the northern regions.

Monkfish (*Lophius vomerinus*) was among the species that were caught along the entire coast of Namibia, with the highest catch rates at 22°S and lowest at 17°S and 28°S. Monk has been recorded throughout the entire Namibian waters at 100m to 700 m water depth (MFMR, 2006, Unpublished data). According to Maartens et al. (1999), the distribution of *L. vomerinus* ranges from Northern Namibia to Durban (South Africa) and thus they occur along the entire coast of Namibia, this corresponds with the results of the present study. Maartens et al. (1999) also documented that the highest densities of monkfish occur off the coast of Namibia, mainly in Central areas. The current study is in correspondence with the study by Maartens et al. (1999) as the highest catch rates were observed within the Central regions (22°S). According to BCLME 2011, two separate recruitment areas have been identified in Namibia, firstly off Walvis Bay between 23°S – 25°S, at depths between 150 and 300 m and secondly, near the Orange River (28°S - 35°S) which also explains the high catch rates around 22°S which is close to one of the recruitment areas. However, there were low catch rates observed within the second recruitment area (28°S - 35°S), and one would assume that the results would have shown high catch rates in both recruitment areas, however, this was

not the case in this study. In addition, the low catch rates at 17 °S may have been due to the species being farther away from the recruitment areas. Alternatively, spatial distributions of species may also be affected by fishing pressure (Payne et al. 2001). Thus, the low catch rates in the Northern and Southern regions may have been due to low intensity in fishing (fishing pressure).

The majority of bycatch species had their highest catch rates in the in the Southern region. This may have been due to different factors i.e. environmental factors and fishing pressure. However, environmental data were not available in the current study. According to Maunder et al. 2006, many factors can influence CPUE over time, and fisher experience is presumed to be one of them. Nevertheless, one cannot base their conclusion on this assumption, as there are many factors that influence catch rates.

5.3 Monthly variation in bycatch catch rates

In term of monthly variation, HCA and MDS (at 96% of similarity) indicated that there were three major groupings of species caught. The first group (June to September), Group 1. Two more groups were found, Group 2 (November to January) and Group 3 (February to May). These groups were, however, distinct from one another (Table 11). All three groups were significantly different from one another, (ANOSIM; SIMPROF test,$P<0.05$) at 96% Similarity. SIMPER results showed that *Dentex macrophthalmus* contributed most to the dissimilarity between Group 2 and 3. Considering the dissimilarity between Group 1 and 2, *Thyristes atun and Tranchipterus trachypterus* contributed most to the dissimilarity in order of contribution. In Group 1 and 3, *Thyristes atun* and *Dentex macrophthalmus* contributed the most in the difference. According to Gordoa et al. (2000), earlier

studies have shown that the monthly catchability of some species is related to environmental variability, catchability peaking when there is little upwelling, and dropping close to its minimum when upwelling is intense. These suggest that the fish population responds to seasonal changes and physical parameters. In the current study, all species appeared to have monthly variations. Different authors (Crawford et al. 1990; David 1989; Macpherson and Gordoa 1992) have outlined different factors that lead to increase or decrease in biomass, catch rates or availability of species during certain periods of the year. The availability of species during different months or seasons may be influenced by factors such as spawning, availability of prey and environmental factors (temperature and oxygen). In addition, different species may react differently to the mentioned factors and may therefore require seasonal measures such as; no fishing during certain times of the year (closed season). This can be used as a measure to protect bycatch species that are known to be more available at certain times of the year.

The majority of bycatch species had high catch rates in January and December. Furthermore, most bycatch species had low catch rates in May and September. This may have also led to the difference between groups as shown by the SIMPROF test and ANOSIM, as these months with high and low catch rates were in different groups (Group 2, 3 and 1 respectively).

Kingklip (*Genypterus capensis)* was one of the species that had its highest catch rates in January and December. According to Isarev (1986), *Genypterus capensis* spawning off Namibia takes place from October to December. In the current study, *G. capensis* were caught throughout the year. The monthly highest average CPUE was recorded in January and December, and the lowest was in August and September. Some researchers have also reported good *G. capensis* catch rates is associated with

spawning (Hecht 1976; Payne 1986; Roberts 1987). It has also been suggested that *G. capensis* have an apparent pre-spawning aggregation which is associated with good catch rates. Badenhorst (1988) noted that the trend in *G. capensis* catch rates on the South-East Coast in South Africa mirrored the rates made by research and commercial trawls and suggested that catch rates reflected aggregations and enhanced availability during the Kingklip spawning season. Thus, the high catch rates in January and December may have been a direct result of spawning aggregations. *G. capensis* is a predator of most of the other commercially important species in the area (e.g. hake), and this may have been the reason why it was caught in the hake bottom trawl throughout the year.

Jacopever (*Helicolenus dactylopterus)* was also one of the species with high catch rates in January and December. High catch rates were also observed in July and August. Jacopever is an opportunistic feeder and very little is excluded in its diet including juveniles of its own species. According to Van der Elst (1993), *Helicolenus dactylopterus* breeds in summer (December-February). Most species are more available during their spawning period, and the high catch rates of Jacopever in January and December may have also been due to spawning as it may have been more available during this period. *H. dactylopterus* was also among the species that were caught throughout the year. According to Davies et al. (2009), Certain types of fishing gear, such as bottom trawls, are known to cause considerable damage to marine habitats and the species within them as they lead to an increase in opportunistic feeding by fish species, which may result in aggregations of these species in recently trawled areas (Kaiser and Spencer 1994). Attraction to these recently trawled areas may increase the chances of being caught by subsequent passes of the fishing gear (Bradshaw et al. 2000), and thus this may have been a reason to why *H. dactylopterus*

also had high catch rates in July and August as it is an opportunistic feeder and possibly the reason why it was caught with hake the whole year.

Monk-fish *(Lophius vomerinus)* was one of the species with lowest catch rates in September. According to Gordoa and Macpherson (1990), *Lophius vomerinus* are non-selective predators which lure their prey by moving their illicium. These fish feed during the day (Macpherson 1985) with their most important prey being shallow-water hake (*M. capensis*) (Maartens et al. 1999) and thus this may be the reason why they are caught with hake in the hake bottom trawl fishery as they may have been found where hake is available. In the current study, monkfish were caught throughout the year. The monthly highest average CPUE was in February (summer), while the lowest was recorded in September (spring). According to Macpherson (1985), *L. vomerinus* spawn throughout the year, although at a lesser intensity in winter. Maartens and Booth (2005) noted that this species spawns throughout the year with a peak in spawning taking place in late winter and summer. According to Diaz de Atarloa (2002), maximum flatfish landings occur within the reproductive season of the flatfish species. The high catch rates in summer may be related to spawning as most species are more available during their spawning period. Macpherson and Gordoa (1992) note that the environmental factors responsible for changes in species availability are not entirely clear. In addition, changes may relate to sea surface temperature, the persistence of upwelling and concentration of dissolved oxygen at the bottom. The lowest catch rates in September may be related to environmental factors however, the environmental data was not available in the current study.

Although most species had their lowest CPUEs in September, Horse mackerel (*Tranchurus capensis)* had its highest catch rates during this month. In the current study, the monthly highest average CPUE was recorded in September, and the lowest

was in July and August. In a study carried out by Barange et al. (1998) on the South African *Tranchurus capensis*, catch rates of *T. capensis* increased in Spring. This suggested that horse mackerel move offshore in Spring to benefit from the abundant food supply as results of spring bloom (Barange et al. 1998). This may also explain why the CPUE of Horse mackerel in the current study were high in September.

Some species had high and low CPUEs neither in May, September or December. The west coast sole (*Austroglossus microlepis*) is among those species. In the current study, Sole fish were caught throughout the year. The monthly highest average CPUE was recorded in February and March while the lowest was observed in August. In a study carried out by Macpherson and Gordoa (1992), estimated biomass of *Austroglossus microlepis* based on stratified random sampling cruises between 1983 and 1990 off Namibia followed different trends in summer and in winter. It was observed that summer catch rates were more than winter catch rates in terms of biomass. Macpherson and Gordoa (1992) also noted that this difference between summer and winter values might exert important effects on estimates of biomass, which are more dependent upon the response of populations to oceanographic conditions than to the actual state of the populations. The results of the current study partially agree with the study by Macpherson and Gordoa as the highest CPUE was in February/March (Summer/Autumn months) and the lowest in August (Winter month). Maximum flatfish landings occur within the reproductive season of the flatfish species (between October and March) when the species aggregate to spawn (Diaz de Atarloa 2002). This may explain why the CPUE of *A. microlepis* was high in March and low in August.

Snoek (*Thyrsites atun)* is an important predatory fish, that occurs along the entire length of the Namibian coast (Boyer and Hampton 2001). According to Enigma (2012), as cited in Rau (2015), the availability of *Thyrsites atun* to fishers is influenced

by the distribution of their major prey species, including *sardinellas* off northern Namibia and juvenile anchovy and pilchard. Seasonal patterns of availability of *T. atun* to fishermen operating along the coast of Southern Africa have been described by several authors (Crawford et al. 1990; Griffiths 2002; Van der Elst 1993; Rau 2015), with different views on where the species spawns but in agreement with when they spawn. According to Griffiths (2002), spawning patterns have not been established for the Namibian stock, but it is likely that these fish move offshore to spawn along the shelf break during winter and spring, as has been recorded for *T. atun* off the South African west coast. According to Rau (2015), *T. atun* are found off Namibia between September and March, and they, however, move to the Western Cape of South Africa in August for spawning. Rau (2015), further added that the return migration commences before October and occurs further offshore as compared to the southerly movements. According to Van der Elst (1993), there is considerable seasonal variation in the condition of Snoek. During late winter and spring, the fish is normally in a poor state of health. Van der Elst (1993), further added that the poor health coincides with breeding season and is associated with the low oil and protein content of its flesh. Data from ichthyoplankton surveys (Griffiths in 2002) reveal that *T. atun* eggs and larvae are present throughout the Benguela system in winter/ spring, distributed as two disjoint bands separated by the Lüderitz upwelling cell. On the basis of these results, Griffiths (2002) surmises that *T. atun* spawns simultaneously in both the Northern and Southern Benguela, counter to the spawning migration hypothesis of Crawford and de Villiers (1985). In the current study, *T. atun* was caught throughout the year with high catch rates in June (winter) and the low in December, January and April (Summer). In the present study, the high catch rates of Snoek do not correspond with spawning patterns as noted by (Griffiths 2002; Van der Elst 1993; Rau 2015) that Snoek is less

abundant during winter and more available in summer due to spawning migrations. Furthermore, one would expect the highest catch rates to be in summer as literature states that they are mainly found in Namibian waters during that period. Migration patterns of juveniles and adults in Namibian waters have not been established with any certainty. Griffiths (2002) hypothesizes that the inverse relationship between catch of *Thyrsites atun* off Namibia and South Africa, which was noted by Crawford et al. (1990), is due to medium-term migrations in response to changes in prey distribution, and not to a regular seasonal migration as such. Thus, the high CPUE in June/July(winter) and low CPUE in December, January and April (summer) may have been due to migrations in response to changes in prey distribution.

Overall monthly variations in CPUE showed a v=shaped pattern indicating that CPUE is highest at the beginning of the year and decreases towards the mid-year and increase by the end of the year. This may be due to most species spawning during summer months, which are at the beginning of the year and at the end of the year. Species are more available during their spawning period (Van Overzee and Rijnsdorp 2015) and thus may have led to high catch rates.

5.4 Inter-annual bycatch rate trends

In the current study, most species had annual variations, with either positive or negative trends. The difference in trends of species can be attributed to different factors as different species respond differently to different conditions though they live in the same region. According to Pinsky and Byler (2015), fish species around the world have suffered collapses, and a key question is why some populations suffer more than others. Pinsky and Byler (2015) further added that, traditional conservation biology and evidence from terrestrial species suggest that slow-growing populations are most

at risk, but interactions between climate variability and harvest dynamics may alter or even reverse this pattern. Furthermore, it can be assumed that some species are caught more than others. Catch per-unit-effort (CPUE) data have often been used to provide information about changes in fish abundance (Swain and Sinclair 1994). Generally, it is assumed that the relationship between commercial catch rate and stock abundance is linear, CPUE being directly proportional to abundance (Hilborn and Walters 1992). Among all the species; ten had decreasing trends. The decreasing trends in bycatch species may be attributed to fishing pressure, even though we cannot neglect other possibilities, such as environmental changes. In the current study, eleven species had increasing trends. The increase in annual trends of average CPUE could be an indication of an increase in species biomass. According to Maunder et al. 2006, raw CPUE data is rarely proportional to abundance over a whole exploitation history and the entire geographic range; this is because many factors can influence CPUE (e.g. temperature, fish behaviour, searching time, area, gear used, catchability and fisher experience) to change over time. In addition, CPUE data alone generally cannot provide the information needed to assess the abundance of the species, since the relative catchability of the various species is generally unknown (Maunders et al. 2006). Thus, one cannot rely on a single factor when looking at trends. However, it is crucial that trends are carefully observed as they can be used as indicators of bycatch species populations.

In this study cape gurnard (*Chelidonichthys capensis*) was one of the species that that had a negative trend and showed large fluctuations in CPUE (fall and rise patterns) during the study period (1997- 2014). The annual trend of cape gurnard, showed a large decrease in CPUE from 2001 to 2005 and from 2008 to 2010, this decrease was also observed in the surveys conducted by the Namibian Ministry of Fisheries and

Marine Resources (MFMR 2018). In the year 2001, there was a major environmental event which took place in the Benguela region, namely a warm water event called Benguela Niño, which may have contributed to the low CPUE of bycatch species (i.e cape gurnard) in 2001. According to Monteiro et al. 2006 as cited in Mafwila 2011, warm water events are known to bring poorly oxygenated waters on the northern and central shelf, and may even penetrate much deeper to the upper slope. Mafwila (2011), further added that this could affect the distribution of demersal fish species over the continental shelf and slope, since effects of these events could be lagged, only affecting the demersal fish species at a later stage either directly, indirectly or both (Voges et al. 2002). Thus, the environment can have a large influence on catchability. For example, the 1981–1983 *El Niño* reduced catchability of yellowfin tuna to the purse-seine fisheries of the eastern Pacific Ocean (EPO) to such an extent that many vessels transferred their operations to the western Pacific (Maunders et al. 2006).

Thyrsites atun was one of the species that had a positive trend and showed large fluctuations in CPUE (fall and rise patterns) during the study period (1997- 2014). However, looking more closely at the annual trend of *T. atun*, it was observed that the year or two after a high bycatch by the hake fleet, is presided by a year with low bycatch. Therefore, one can assume that the annual level of bycatch may depend on the strength of the incoming young of the year, which are recruited a year or two later to the demersal fishery. In a study carried out by Gordoa et al. 2006, the annual trends of the bycatch species in the horse mackerel fleet showed a similar trend to the current study. Gordoa et al. 2006, therefore suggested that the annual level of bycatch may depend on the strength of the incoming young of the year. In addition to that, the increase of average CPUE can be due to efficiency that also increases when new technologies are obtained (Watters and Maunder 2001). According to Mafwila 2011,

the increase in the number of vessels in the fishery coincided with the expansion of the trawling grounds into less accessible, previously unfished areas. These efforts may be facilitated by the development of new fishing gear and navigational aids (e.g. National Research Council 1994). Different fishing pressures and to some extent, adverse environmental conditions (e.g. Benguela Niño) during the study period may have had effects on the annual variations in CPUE of bycatch species.

5.5 Influence of factors on catch per unit effort (CPUE) of bycatch species

According to Maunder et al. (2006), factors other than fish abundance are known to affect CPUE. These factors include variation in catchability among different fishing vessels, gear and methods (Petrere et al. 2010). Also, the ability of fishers to access the areas of greatest fish abundance interacts with habitat selection in fish (Harley et al. 2001). According Petrere et al. (2010) if the stock is randomly spaced this will lead to fishing effort to be randomly distributed, otherwise non-random search by the fisher, who behaves like an optimal predator. In the current study following variables; Latitude, Month, Year, depth and GRT were employed to access the influence on catch rates, CPUE (kg/h) data from the commercial hake bottom-trawl fishery off Namibia, using Generalized Additive Models (GAMs). The CPUE of *Epigonus species*, was significantly influenced by two parameters, with month being a parameter influencing the species. These species were significantly influenced by latitude and month. The *Epigonus species* was thus quite seasonal, as observed by the monthly variation in catch rates (Figure 16). One of the factors that influenced *Epigonus species was* GRT, this may have been due to the vessel size effect coming into play. Wet and freezer vessels are used in the hake bottom trawl fishery and they differ in terms of size and the amount of time they spend fishing, as well as fuel capacity which determines how

far they can steam in order to make their catch. According to Mafwila (2011), the number of vessels licensed to harvest hake fluctuates year to year, during the past few years varying from 78 to 121 vessels. However, since the number of vessels licensed to harvest hake fluctuates year by year, these figures do not reflect the actual effort used. In fact, some vessels are often licensed, but not used for harvesting (Kirchner 2010) and for this reason the CPUE of species may be affected by GRT and months. *Argryosomus inodorus* and *Thunus Species* CPUEs were influenced significantly by three parameters; Latitude, Month and Year. *Argryosomus inodorus* is localized in the north as seen in the results (Figure 2b), it is caught in small amounts in bottom trawls since it is linefish more available to inshore anglers and thus may have been significantly influenced by latitude. The CPUE of *Tranchurus Capensis, Isurus oxyrinchus, Allocyttus verrucosus* and *Lepidotus caudatus* was significantly influenced by four parameters, with latitude and year having a significant effect on the CPUEs of all species. CPUEs of the rest of the species (*Taractichthys longipinnis, Brama brama, Chelidonicthys capensis, Dentex macrophthalmus, Helicolenus dactylopterus, Zeus faber, Genypterus capensis, Lophius vomerinus, Raja species, Thyristes atun, Austroglosus microlepsis, Todarodes sagittatus* and *Tranchipterus tranchipterus*) was influenced by all the parameters. In the current study, the common parameter that influenced most species was latitude. According to Tsukahara and Sakai (2017), CPUE varies with area. According to Gordoa et al. (2006), the life history of many fish species involves changes in their distribution through the water column. Additionally, many exhibit periodic vertical migrations associated with feeding or spawning. Thus, species undertake migration either due to feeding or spawning and, in some cases, they move from one area to another and hence they change in latitudinal distribution. Namibian waters are influenced by the Benguela

upwelling system of the Southeast Atlantic. According to Sakko (1998), although the Namibian marine system is continuous, there is an unusually intense cell of upwelling off Lüderitz which effectively divides it into two parts (North and Southern Benguela). Though the system is continuous it is affected by different conditions and changes from one season to another. Various authors (Botha 1986; Millar and Field 2002; Payne 1995) have described the seasonal catchability patterns as spatial response to seasonal environmental variability. Additionally, different species prefer different water conditions and thus may be found in different areas or may change in distribution from time to time and hence the reason why latitude may have influenced CPUE most. It is also well-known that several fish species are restricted to certain seafloor depth conditions, which might be associated with their biological adaptation (Nashima 2009) and thus their depth distribution does not change much. This may possibly be a reason as to why depth had the least influence on CPUE.

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CHAPTER SIX

6.Conclusions and Recommendations

6.1 Conclusions

The study has shown that there is a spatio-temporal variation in the catch rates of most hake bycatch species. The above shows challenges and complexities that any bycatch management strategies would face. Information on the potential bycatch assemblages also shows present opportunities that will be effective for many hake fishing bycatch. The findings in this study also indicate that there are factors that influence bycatch catch rates in the hake directed bottom trawl, that should be considered for any bycatch management strategies. These factors, such as spatial differences and monthly variations, have also shown to play a role in the observed changes in fish assemblages. The same factors can also be beneficial in the implantation of management strategies (implementation of Closed season and Marine protected areas). This study highlights several trends in bycatch fish species off the Namibian coast, as well as influences on fish species by disturbances from fishing; especially bottom trawling, which negatively affects the populations of these species. It is therefore important that these trends are closely monitored by the fisheries managing authority as these trends can be used as indicators of the respective bycatch species populations. In this study, it is also confirmed that CPUE is influenced by various factors (Latitude, Month, Year, depth and GRT) and varies from one species to another. These factors are also shown to influence the trends in bycatch species. In addition, the decrease or increase in CPUE of different bycatch species varies spatially and temporally (monthly and inter-annually) and also coincide with the spawning of certain species. Overall, this study showed that there are variations in distributions and, catch rates of bycatch species in

both time and space. In addition, the study showed that these species could be grouped according to their occurrence and variation in space and time; this is helpful in ecosystem approaches to management. The causes of variation in the study can be grouped into the following categories: those caused by fluctuations in population abundance and distribution due to migration of species and those introduced by changes in fishing strategy, such as gear-effects, time, location and depth of fishing activities.The findings in this study correspondingly showed that hake fishing has a huge potential to negatively influence the functioning of the Benguela ecosystem on the basis of the group and the number of species whose population it influences.

6.2 Recommendations

The availability of fish species (including bycatch) to a fishery is not only influenced by fishing but other factors also play a role i.e. availability of food (predator/prey relationship) for the species and as well as environmental factors. It is therefore recommended that future studies should investigate how these factors influence the catch rates of bycatch species in the hake bottom trawl fishery. More studies that seek to understand bycatch species should be done as they will eventually be important in developing ways/strategies to reduce or prevent bycatch. Additionally, studies that look at fleet dynamics and the biology of bycatch i.e spawning areas are recommended as they hold keys to protect key life stages of these species. The implementation of an ecosystem approach to hake fisheries management is recommended, as this study shows that the hake fishing may negatively affect the populations of other species and it can only be possibly mitigated if hake fisheries is managed at an ecosystem level rather than the current single-species approach.

6.3 Contribution to Knowledge

There is generally a lack of published work on bycatch in Namibia and this study has added value to bycatch studies in Namibia. The study has also contributed to the understanding of factors that influence bycatch catch rates. The findings from this study may be incorporated into management strategies for better conservation of marine resources by the Ministry of Fisheries and Marine Resources.

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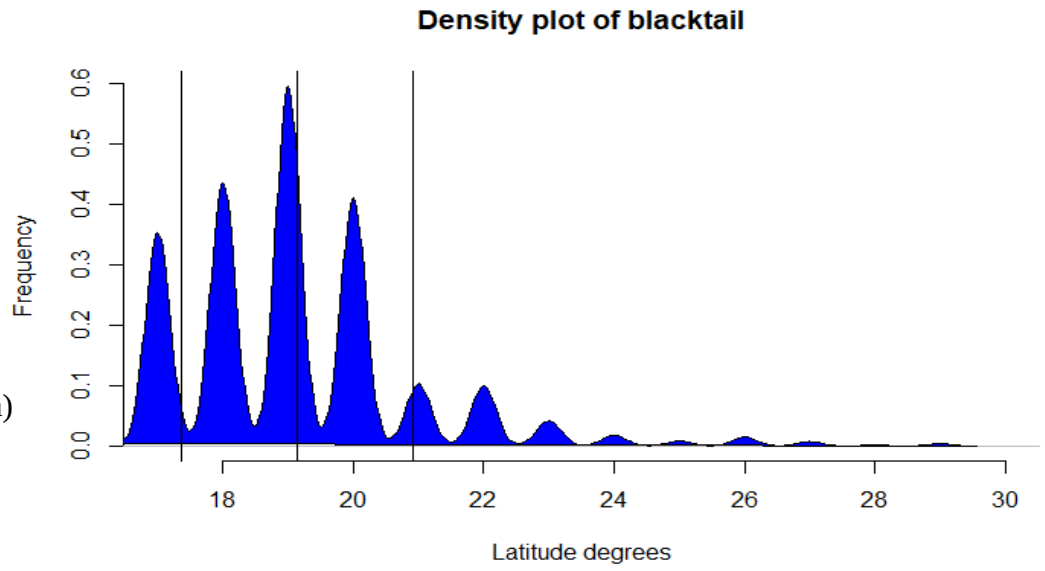
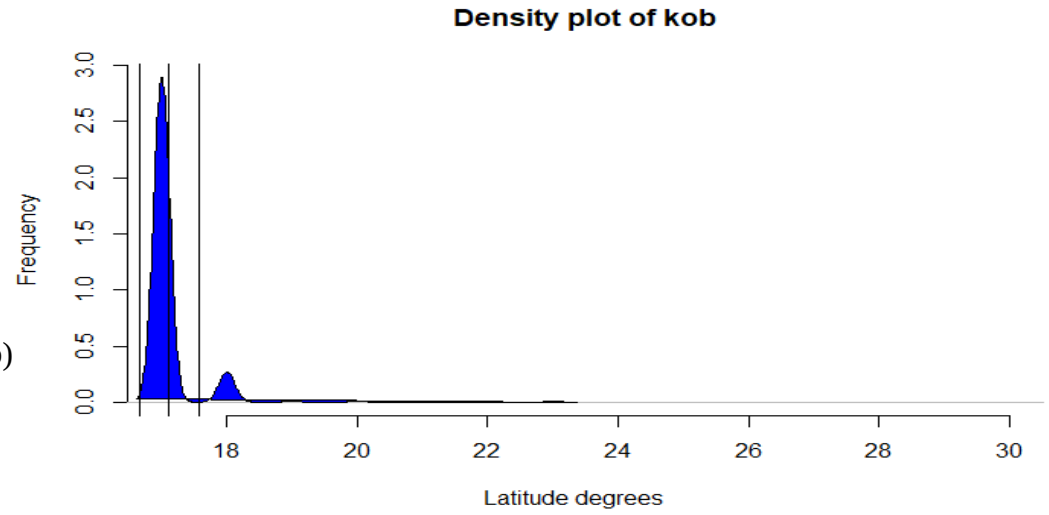
APPENDICES

APPENDIX I: Density plots showing contribution of hake bycatch (a-x) to latitude over the study period (1994-2014).

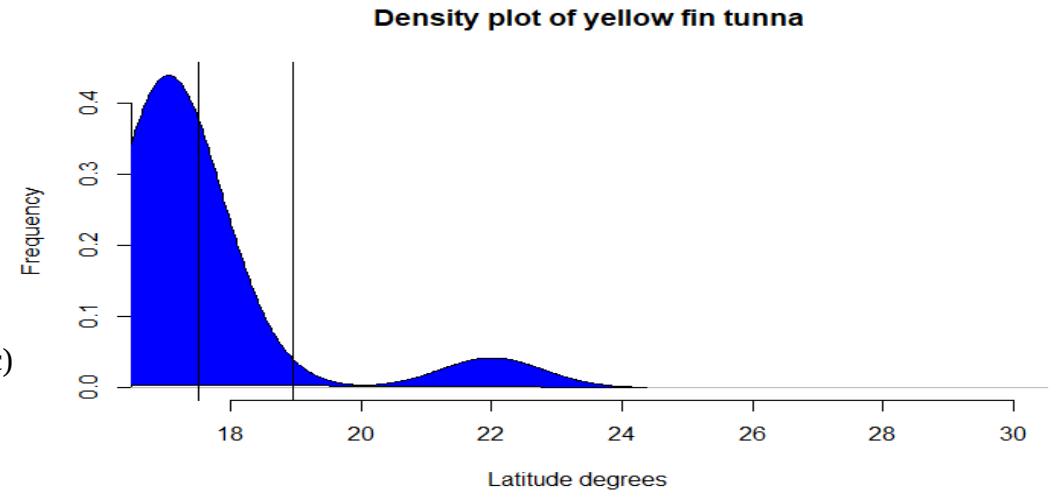
a)



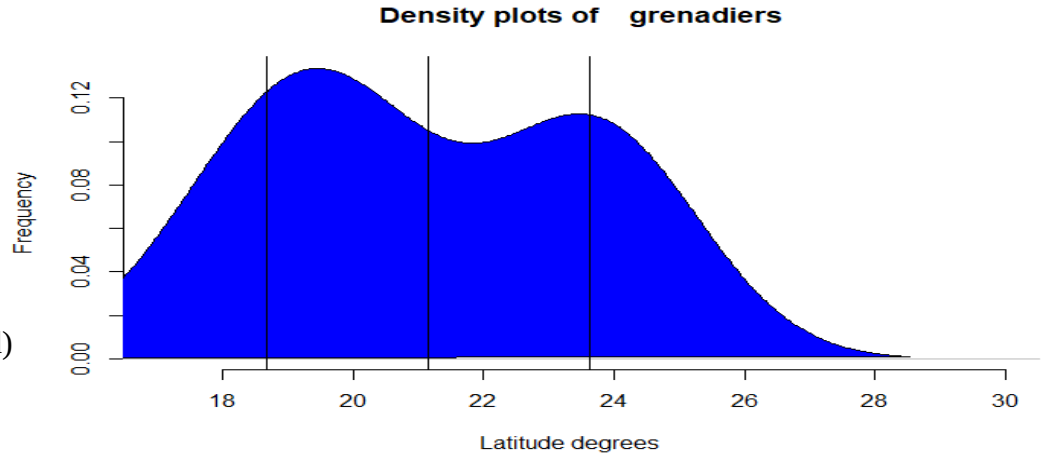
b)



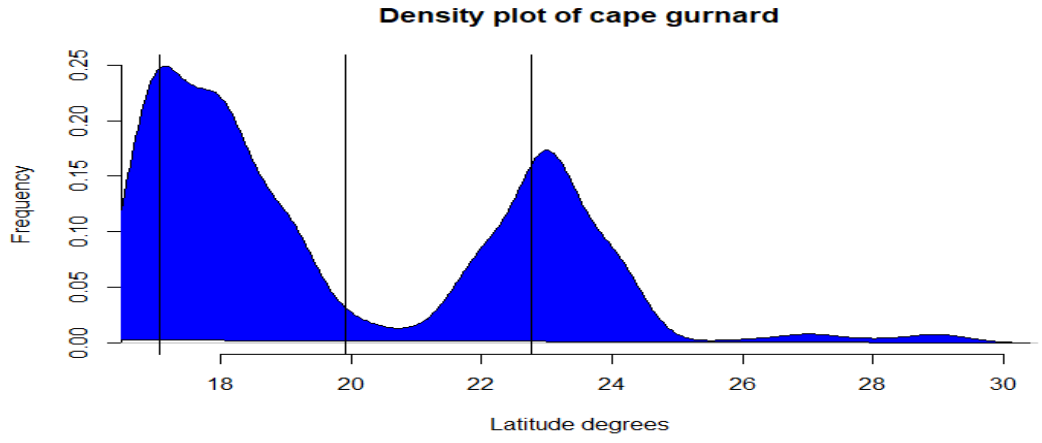
c)


Density plot of yellow fin tunna
Frequency
0.0
0.1
0.2
0.3
0.4
18
20
22
24
26
28
30
Latitude degrees

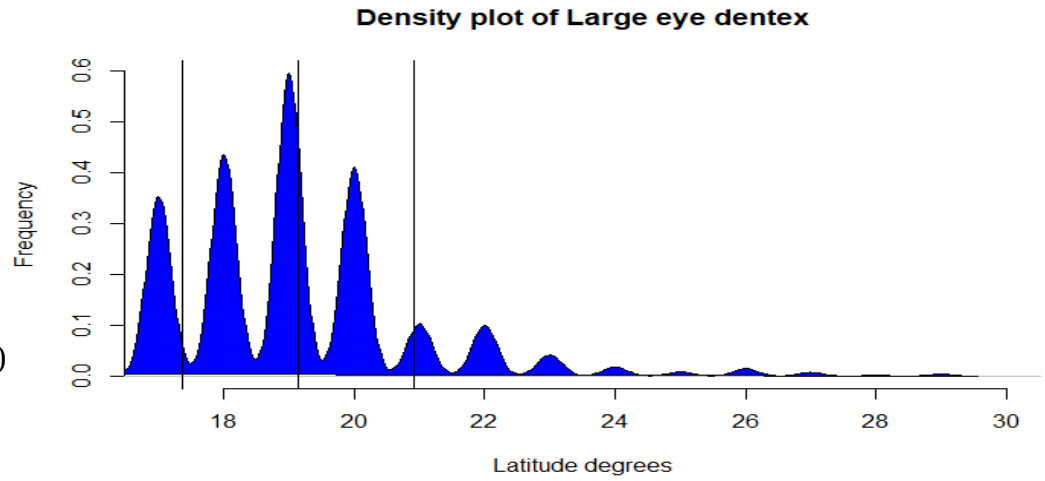
d)


Density plots of grenadiers
Frequency
0.00
0.04
0.08
0.12
18
20
22
24
26
28
30
Latitude degrees

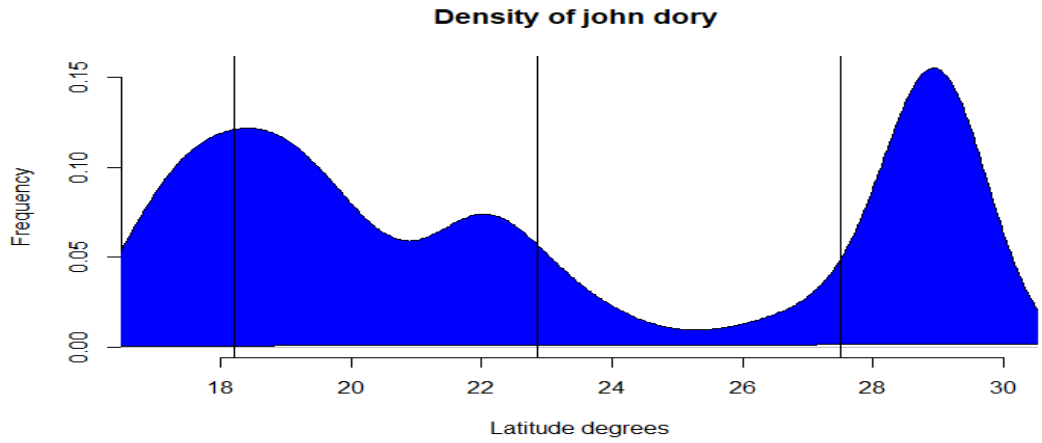
e)


Density plot of cape gurnard
Frequency
0.00
0.05
0.10
0.15
0.20
0.25
18
20
22
24
26
28
30
Latitude degrees

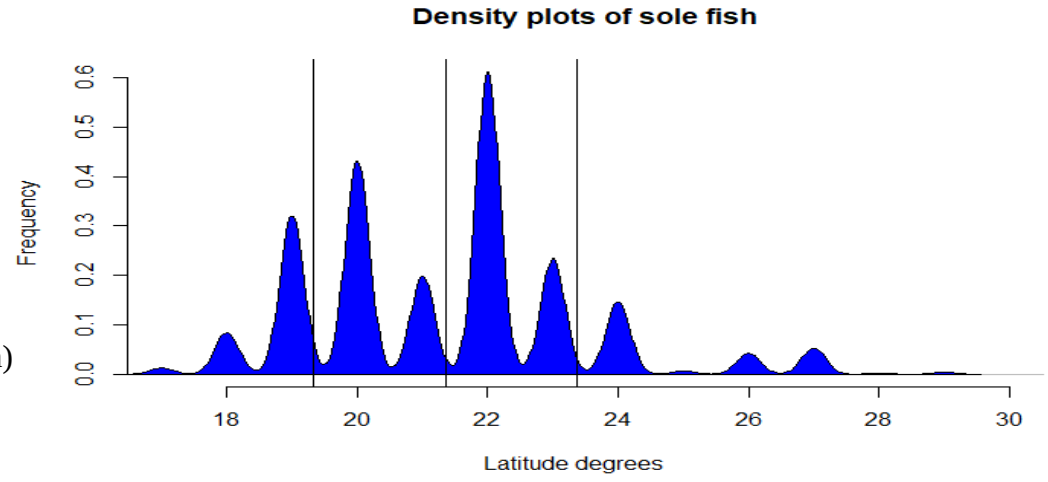
f)


Density plot of Large eye dentex
Frequency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18
20
22
24
26
28
30
Latitude degrees

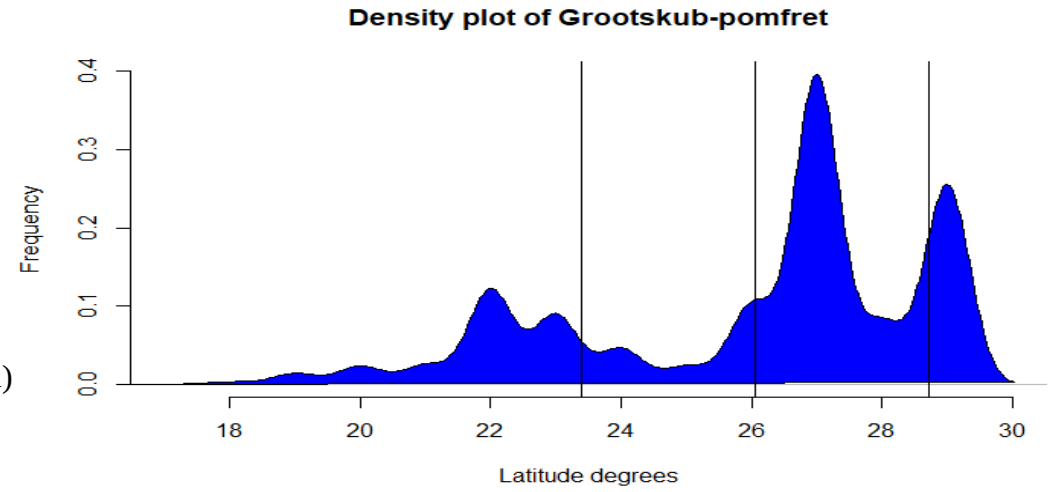
g)


Density of john dory
Frequency
0.00
0.05
0.10
0.15
18
20
22
24
26
28
30
Latitude degrees

h)


Density plots of sole fish
Frequency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18
20
22
24
26
28
30
Latitude degrees

i)


Density plot of Grootskub-pomfret
Frequency
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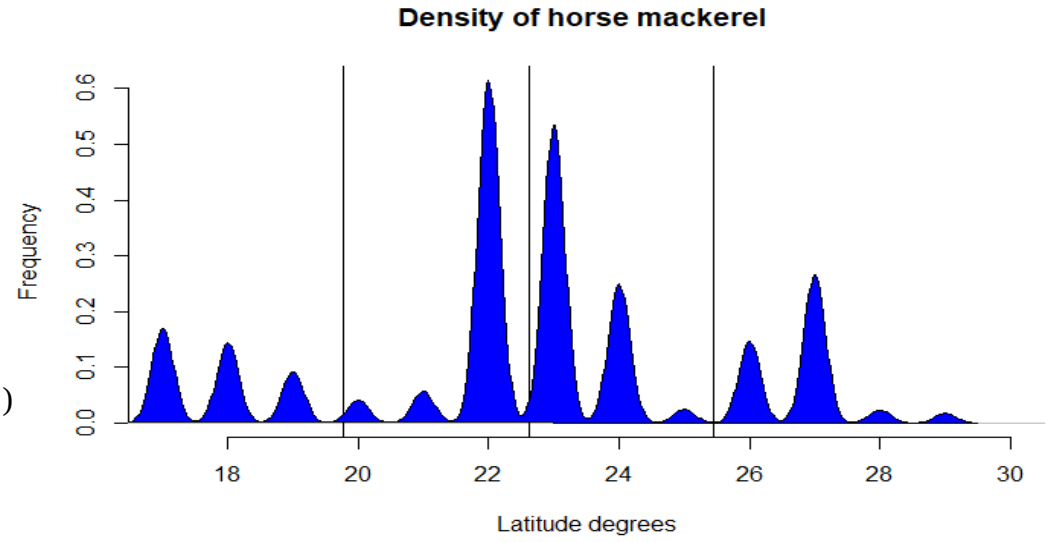
0.1
0.2
0.3
0.4
18
20
22
24
26
28
30
Latitude degrees

j)


Density of horse mackerel
Frequency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18
20
22
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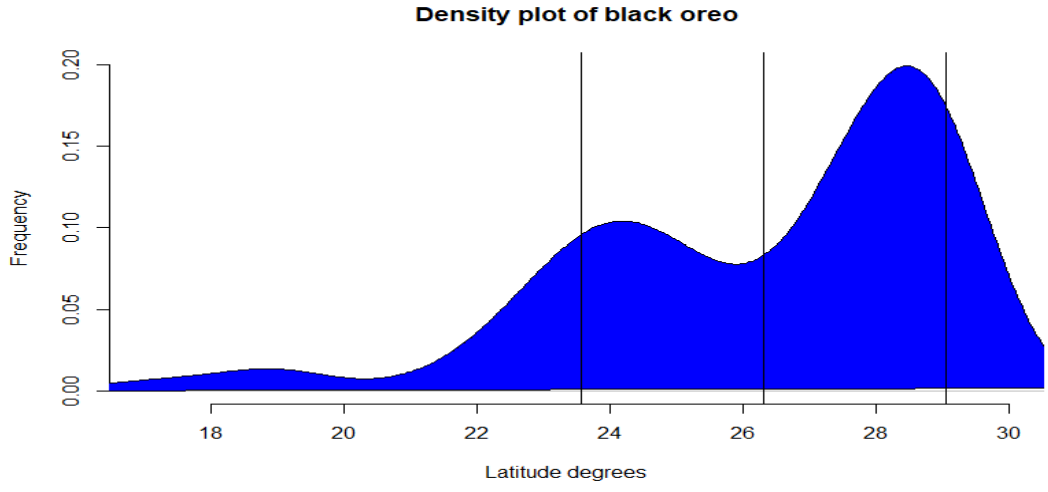
26
28
30
Latitude degrees

k)


Density plot of black oreo
Frequency
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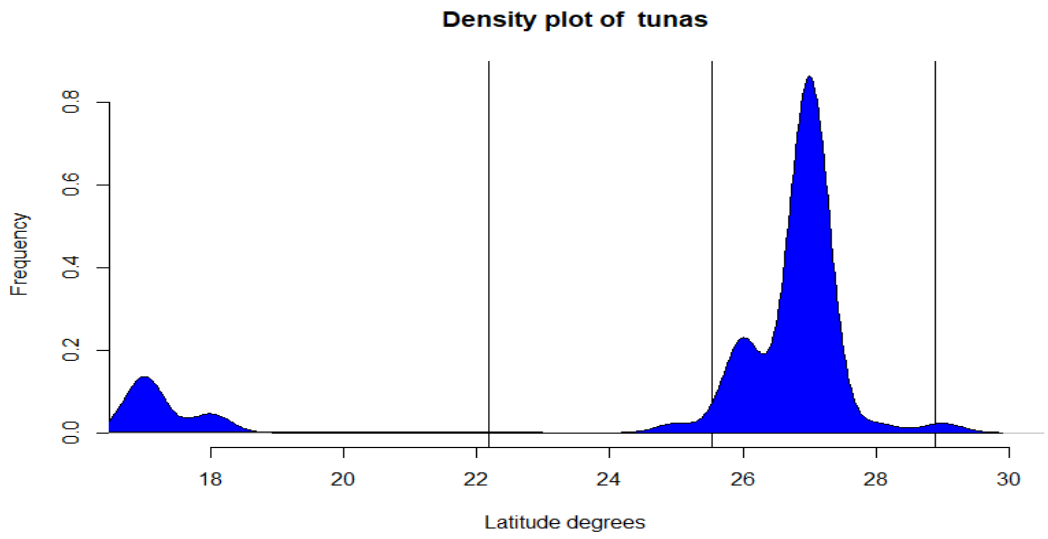
0.05
0.10
0.15
0.20
18
20
22
24
26
28
30
Latitude degrees

l)


Density plot of tunas
Frequency
0.0
0.2
0.4
0.6
0.8
18
20
22
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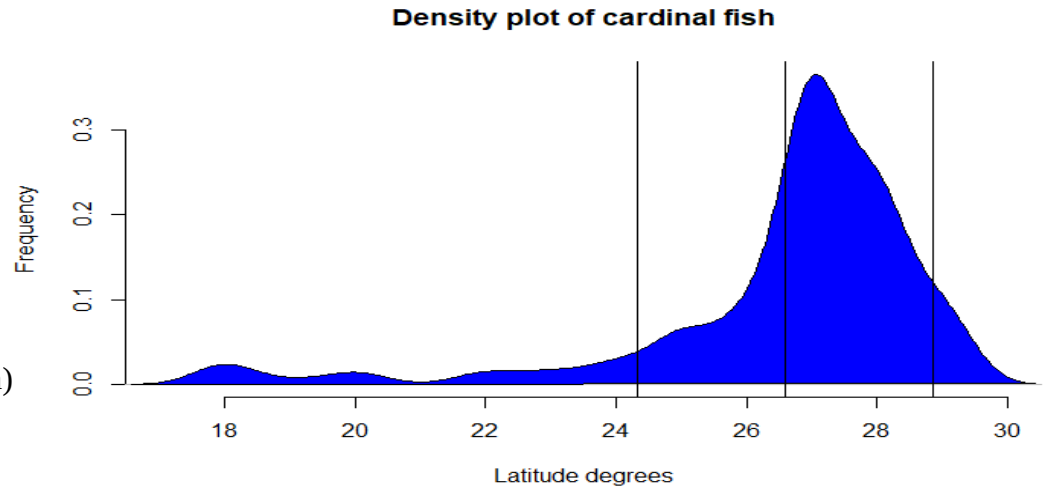
26
28
30
Latitude degrees

m)


Density plot of cardinal fish
Frequency
0.0
0.1
0.2
0.3
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20
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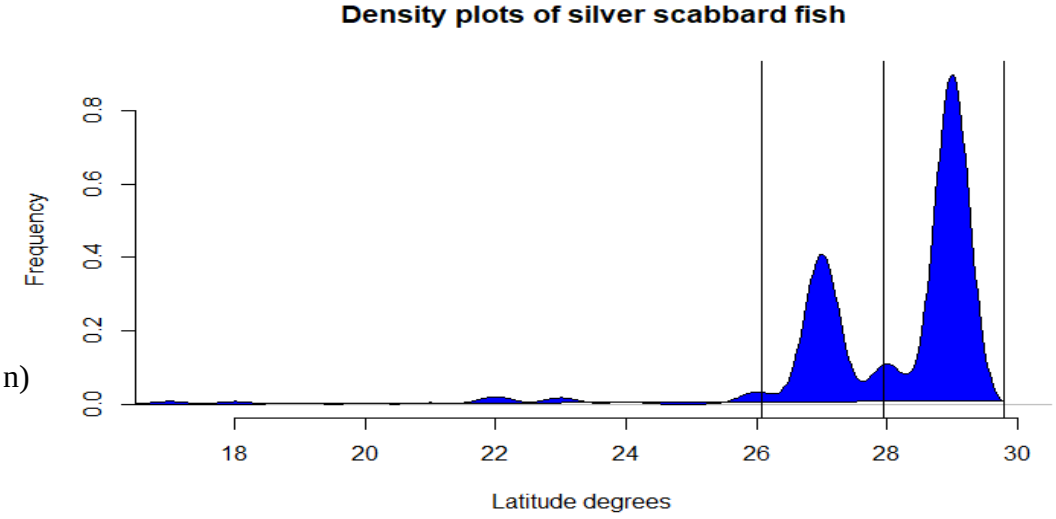
24
26
28
30
Latitude degrees

n)


Density plots of silver scabbard fish
Frequency
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0.2
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0.6
0.8
18
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22
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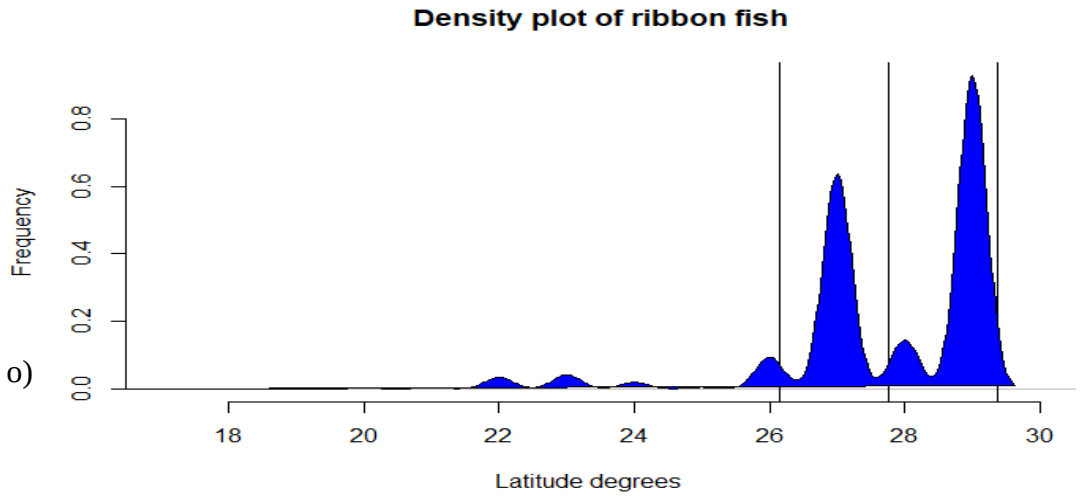
26
28
30
Latitude degrees

o)


Density plot of ribbon fish
Frequency
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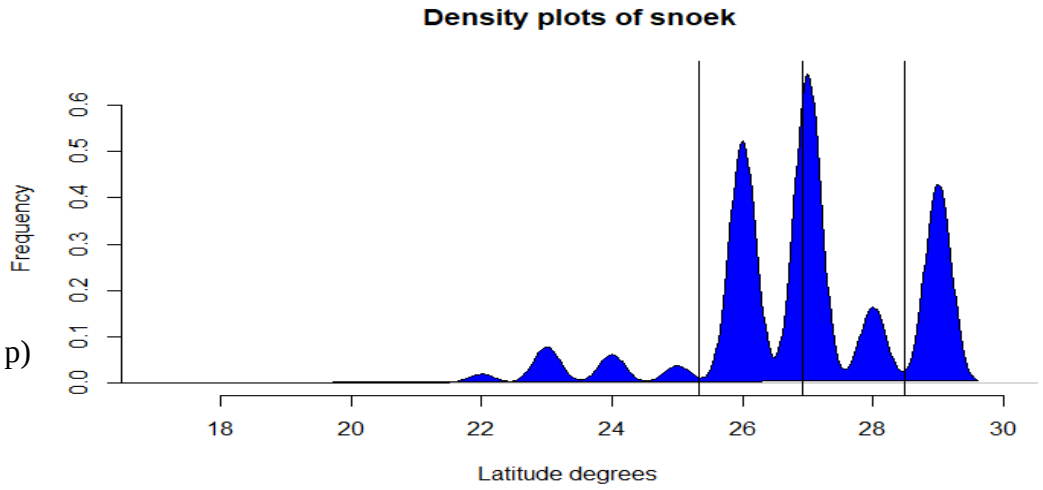
Latitude degrees

p)


Density plots of snoek
Frequency
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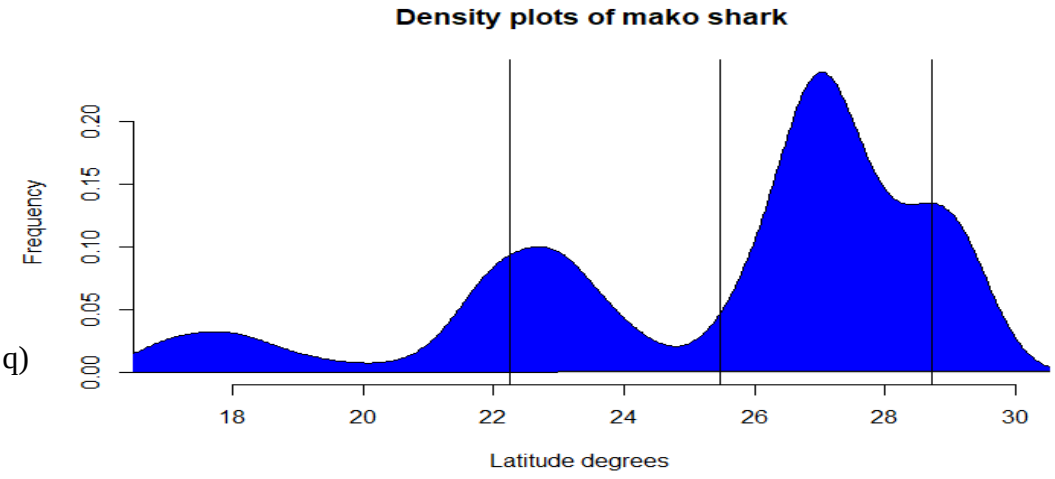
Latitude degrees

q)


Density plots of mako shark
Frequency
0.00
0.05
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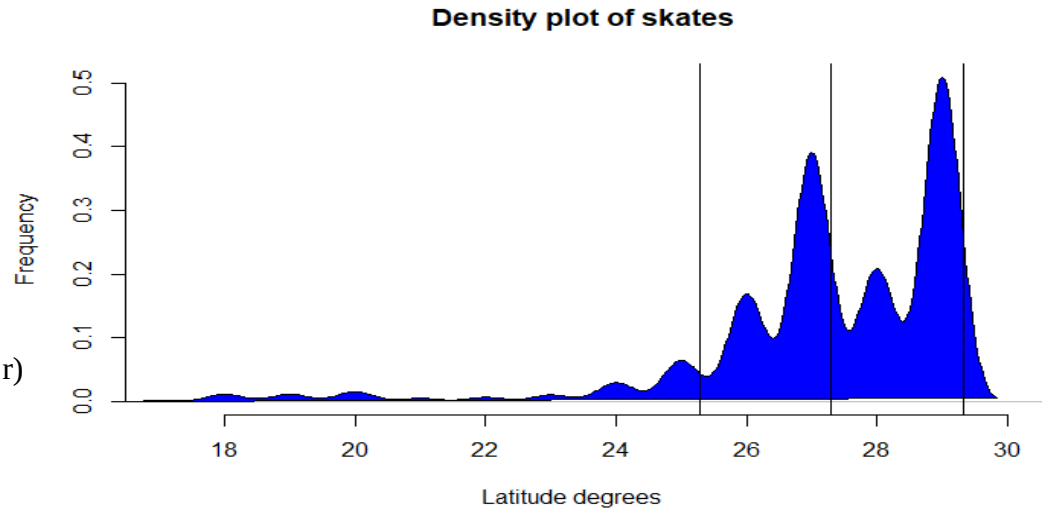
Latitude degrees

r)


Density plot of skates
Frequency
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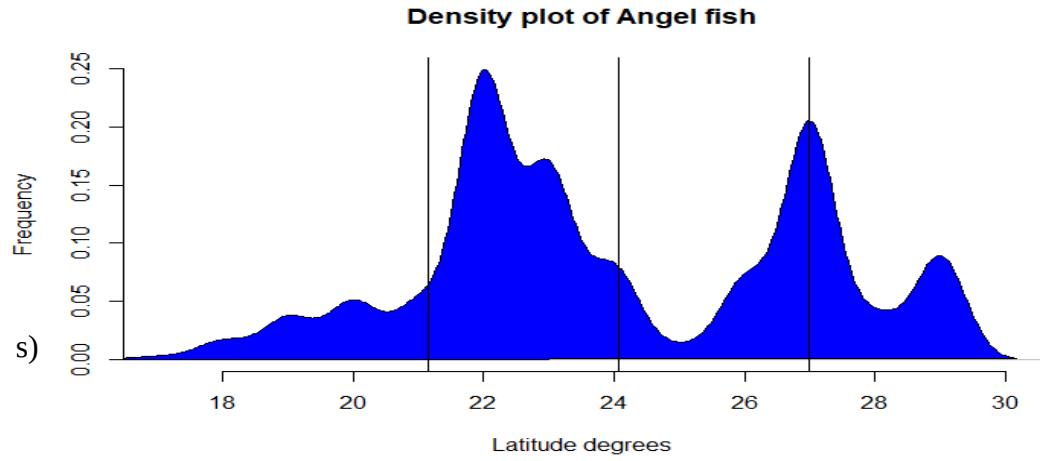
Latitude degrees

s)


Density plot of Angel fish
Frequency
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0.05
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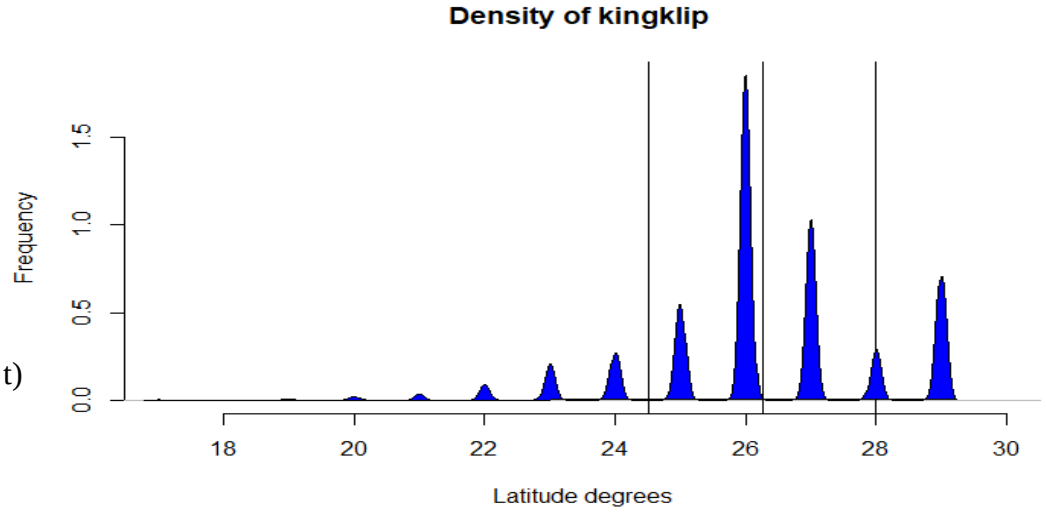
Latitude degrees

t)


Density of kingklip
Frequency
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1.5
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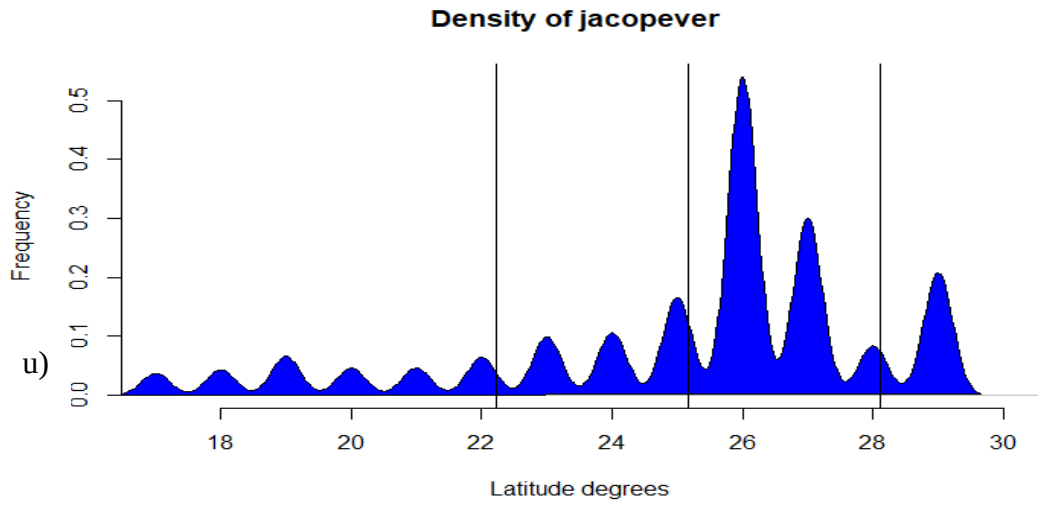
Latitude degrees

u)


Density of jacopever
Frequency
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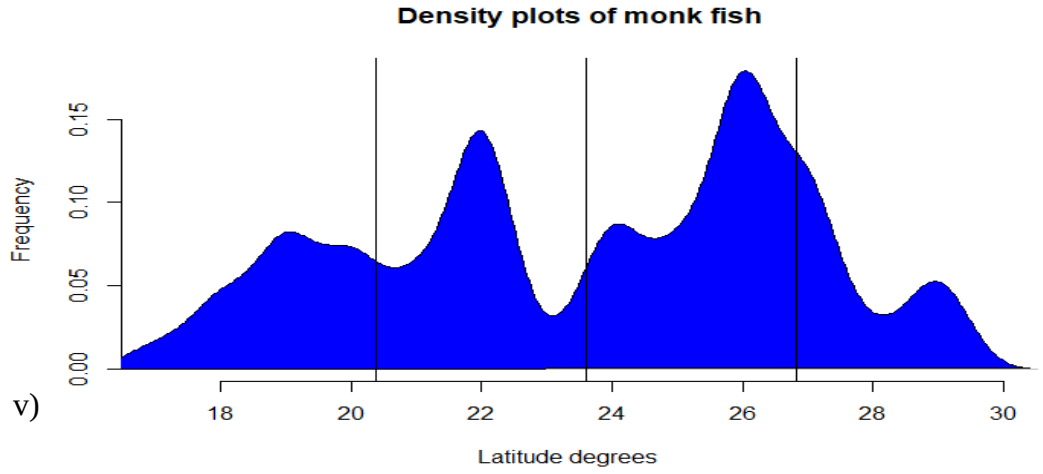
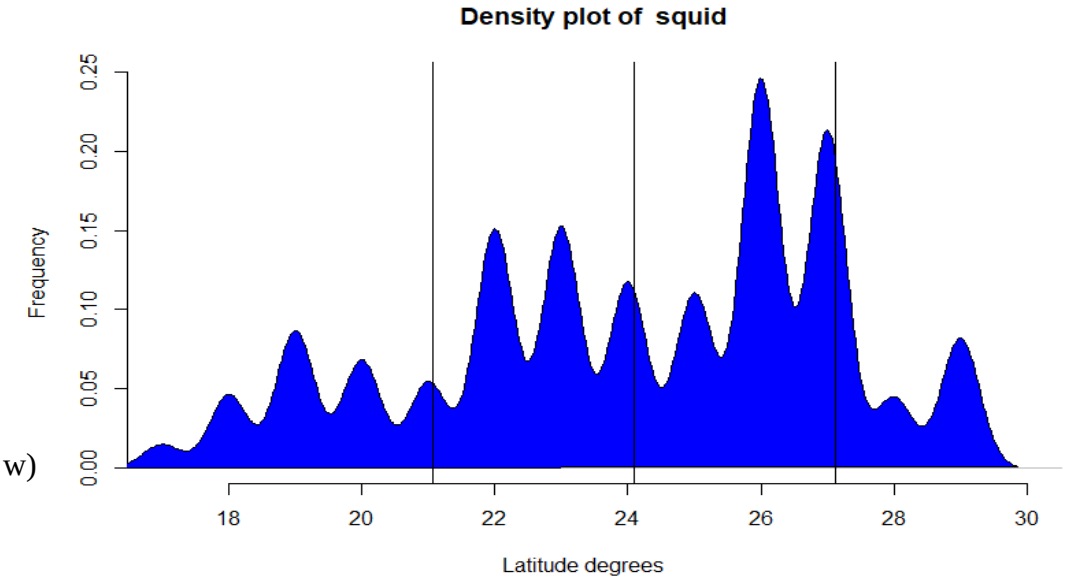
Latitude degrees

v)


Density plots of monk fish
Frequency
0.00
0.05
0.10
0.15
18
20
22
24
26
28
30
Latitude degrees

w)


Density plot of squid
Frequency
0.00
0.05
0.10
0.15
0.20
0.25
18
20
22
24
26
28
30
Latitude degrees

APPENDIX II: Results for Spatial distribution from analysis in Primer.

(a) MDS

Non-metric Multi-Dimensional Scaling

Resemblance worksheet

Name: Resem1

Data type: Similarity

Selection: All

Parameters

Kruskal stress formula: 1

Minimum stress: 0.01

Best 3-d configuration (Stress: 0.01)

Sample	1	2	3	%
29°	1.15	0.39	-0.38	13.6
28°	1.08	0.33	0.02	5.6
27°	1.03	0.31	0.23	6.6
26°	0.85	-0.31	0.30	4.6
25°	0.84	-0.68	0.11	2.4
24°	0.13	-0.08	0.16	8.6
23°	-0.12	0.25	0.10	4.7
22°	-0.32	0.26	-0.35	14.1
21°	-0.35	-0.22	-0.37	10.6
20°	-0.69	-0.48	-0.38	6.4
19°	-0.93	-0.41	0.06	5.9
18°	-1.12	0.05	0.42	3.2
17°	-1.54	0.58	0.10	13.7

Best 2-d configuration (Stress: 0.03)

Sample	1	2	%

29°	**1.08**	**-0.66**	**7.2**
28°	**1.12**	**-0.27**	**3.5**
27°	**1.11**	**-0.21**	**5.7**
26°	**0.89**	**0.26**	**4.2**
25°	**0.92**	**0.65**	**2.5**
24°	**0.16**	**0.11**	**9.8**
23°	**-0.11**	**-0.09**	**6.6**
22°	**-0.33**	**-0.23**	**16.3**
21°	**-0.38**	**0.34**	**10.9**
20°	**-0.73**	**0.61**	**8.3**
19°	**-1.00**	**0.27**	**10.1**
18°	**-1.18**	**-0.18**	**11.8**
17°	**-1.55**	**-0.60**	**3.1**

STRESS VALUES

Repeat	**3D**	**2D**
1	**0.01 ****	**0.03**
2	**0.01**	**0.03**
3	**0.01**	**0.04**
4	**0.03**	**0.05**
5	**0.02**	**0.04**
6	**0.02 ****	**0.04**
7	**0.01**	**0.04**
8	**0.01**	**0.03**
9	**0.01 ****	**0.09**
10	**0.01**	**0.03**
11	**0.01**	**0.03**
12	**0.02 ****	**0.04**
13	**0.01**	**0.03**
14	**0.02 ****	**0.03**
15	**0.01**	**0.04**

16	**0.01**	**0.04**
17	**0.02 ****	**0.04**
18	**0.01**	**0.03**
19	**0.01 ****	**0.05**
20	**0.01**	**0.03**
21	**0.03 ****	**0.03**
22	**0.03 ****	**0.05**
23	**0.01 ****	**0.03**
24	**0.02 ****	**0.04**
25	**0.01**	**0.03**

**** = Maximum number of iterations used**

3-d : Minimum stress: 0.01 occurred 16 times

2-d : Minimum stress: 0.03 occurred 12 times

(b) CLUSTER

Hierarchical Cluster analysis

Resemblance worksheet

Name: Resem1

Data type: Similarity

Selection: All

Samples

1	**29°**
2	**28°**
3	**27°**
4	**26°**
5	**25°**
6	**24°**

7 23°

8 22°

9 21°

10 20°

11 19°

12 18°

13 17°

Parameters

Cluster mode: Group average

(c) SIMPROF test

Data worksheet

Name: Data1

Data type: Biomass

Sample selection: All

Variable selection: All

SIMPROF Parameters

Permutations for mean profile: 1000

Simulation permutations: 999

Significance level: 5%

Resemblance:

Analyse between: Samples

Resemblance measure: S17 Bray Curtis similarity

Combining

2+3 -> 14 at 94.33; Pi: 0 Sig(%): 100

6+7 -> 15 at 94.11; Pi: 0 Sig(%): 100

4+5 -> 16 at 94.06; Pi: 0 Sig(%): 100

9+10 -> 17 at 92.54; Pi: 0 Sig(%): 100

1+14 -> 18 at 91.52; Pi: 1.06 Sig(%): 0.9

8+15 -> 19 at 90.77; Pi: 1.26 Sig(%): 0.2

11+12 -> 20 at 90.32; Pi: 0 Sig(%): 98.3

17+19 -> 21 at 87.35; Pi: 1.55 Sig(%): 0.1

13+20 -> 22 at 86.33; Pi: 2 Sig(%): 0.2

16+18 -> 23 at 86.07; Pi: 2.31 Sig(%): 0.1

21+22 -> 24 at 82.3; Pi: 2.31 Sig(%): 0.1

23+24 -> 25 at 75.89; Pi: 3.91 Sig(%): 0.1

(d) SIMPER

Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Spatial distributions
Data type: Biomass
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90.00%

Factor Groups

Sample	Regions
29°	a
28°	a
27°	a
26°	a
25°	a
24°	b
23°	b
22°	b
21°	b
20°	c
19°	c
18°	c
17°	c

Groups a & b

Average dissimilarity = 21.25

	Group a	Group c		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Raja species	7.81	3.47	2.12	3.81
9.97	9.97			
Austroglosus microlepsis	3.32	7.09	1.85	3.25
8.71	18.68			
Genypterus capensis	9.15	5.45	1.82	2.06
8.58	27.27			
Thyristes atun	6.71	3.19	1.72	2.31
8.11	35.38			
Tranchipterus trachypterus	5.61	3.03	1.32	1.63
6.21	41.59			
Dentex macrophthalmus	2.70	5.26	1.27	1.24
5.97	47.57			
Chelidonicthys capensis	1.98	4.51	1.22	3.42
5.76	53.33			
Lepidotus caudatus	3.95	1.96	1.08	1.49
5.10	58.42			
Tarnchurus capensis	5.62	7.50	0.99	1.52
4.64	63.07			
Helicolenus dactylopterus	9.20	7.23	0.98	1.56
4.63	67.70			
Brama brama	6.77	5.21	0.76	1.78
3.57	71.27			
Zeus faber	3.61	4.34	0.73	1.73
3.42	74.69			
Thunnus species	1.39	0.00	0.67	3.74
3.17	77.86			
Epigonus species	2.11	0.86	0.61	1.73
2.88	80.74			
Lophius vomerinus	9.38	9.66	0.61	2.58
2.87	83.61			
Todarodes sagittatus	9.64	8.64	0.59	1.72
2.76	86.37			
Isurus oxyrinchus	4.04	3.33	0.57	1.40
2.68	91.79			

Groups a & c
Average dissimilarity = 28.88

	Group a	Group b		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Dentex macrophthalmus	2.70	10.44	3.52	14.21
12.19	12.19			

Genypterus capensis	9.15	2.73	2.93	5.54
10.15	22.34			
Chelidonicthys capensis	1.98	7.70	2.60	6.76
9.00	31.34			
Thyristes atun	6.71	1.83	2.22	5.55
7.69	39.02			
Raja species	7.81	3.43	1.99	4.89
6.89	45.91			
Tranchipterus trachypterus	5.61	1.68	1.79	2.11
6.19	52.11			
Tarnchurus capensis	5.62	9.25	1.65	2.15
5.70	57.81			
Zeus faber	3.61	7.23	1.64	2.45
5.69	63.50			
Agyrosomus Inodorus	0.00	3.03	1.36	1.51
4.71	68.22			
Austroglosus microlepsis	3.32	6.25	1.36	1.67
4.69	72.91			
Brama brama	6.77	4.60	0.98	2.40
3.41	76.32			
Lepidotus caudatus	3.95	2.79	0.88	1.50
3.04	79.36			
Epigonus species	2.11	0.72	0.63	1.77
2.17	83.96			
Lophius vomerinus	9.38	10.11	0.61	1.34
2.13	86.09			
Thunnus albacores	0.00	1.11	0.50	1.29
1.73	87.81			
Helicolenus dactylopterus	9.20	8.57	0.49	1.25
1.70	89.51			

Groups c & b
Average dissimilarity = 17.70

	Group c	Group b		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Dentex macrophthalmus	5.26	10.44	2.49	2.56
14.06	14.06			
Chelidonicthys capensis	4.51	7.70	1.55	2.80
8.73	22.79			
Zeus faber	4.34	7.23	1.39	3.24
7.86	30.65			
Agyrosomus Inodorus	0.33	3.03	1.32	1.39
7.44	38.09			
Genypterus capensis	5.45	2.73	1.30	2.00
7.37	45.46			
Tarnchurus capensis	7.50	9.25	0.98	1.55
5.53	50.98			

Austroglosus microlepsis	7.09	6.25	0.80	1.41
4.54	55.52			
Thyristes atun	3.19	1.83	0.68	1.25
3.85	59.37			
Helicolenus dactylopterus	7.23	8.57	0.67	1.70
3.78	63.16			
Tranchipterus trachypterus	3.03	1.68	0.66	1.71
3.71	66.86			
Isurus oxyrinchus	3.33	4.06	0.57	1.44
3.22	70.08			
Thunnus species	0.00	1.18	0.56	1.32
3.18	73.26			
Taractichthys longipinnis	5.97	4.84	0.54	1.81
3.05	76.31			
Thunnus albacores	0.14	1.11	0.51	1.36
2.87	79.19			
Diplodus capensis	0.00	0.96	0.47	1.35
2.64	81.83			
Lepidotus caudatus	1.96	2.79	0.44	1.14
2.49	86.89			
Lophius vomerinus	9.66	10.11	0.41	3.09
2.30	89.19			
Raja species	3.47	3.43	0.34	1.41
1.92	91.10			

(e) ANOSIM

Analysis of Similarities

One-Way Analysis

Resemblance worksheet

Name: Resem1

Data type: Similarity

Selection: All

Factor Values

Factor: Regions

a

b

c

Factor Groups

Sample	Regions
29°	a
28°	a
27°	a
26°	a
25°	a
24°	b
23°	b
22°	b
21°	b
20°	b
19°	c
18°	c
17°	c

Global Test

Sample statistic (Global R): 0.885

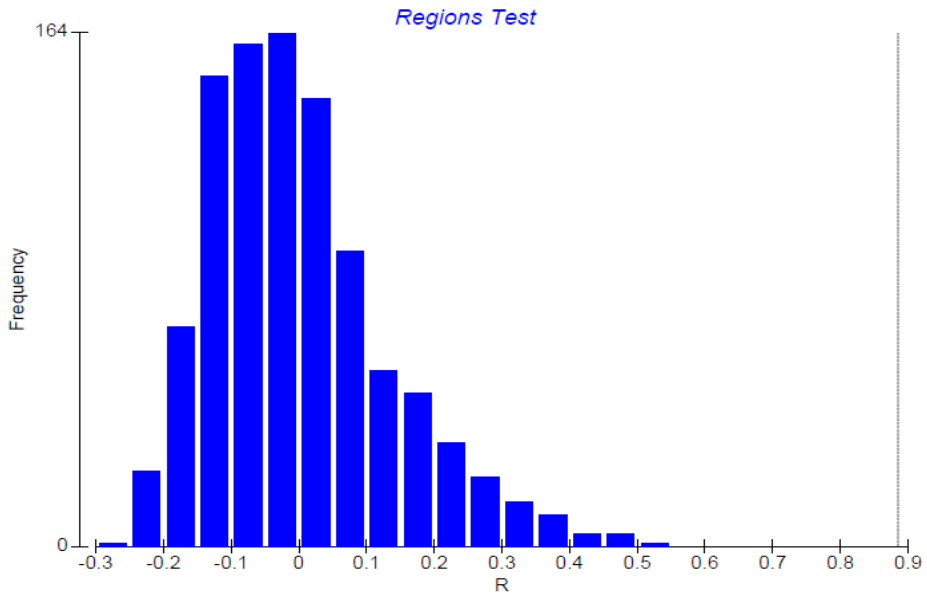
Significance level of sample statistic: 0.1%

Number of permutations: 999 (Random sample from 36036)

Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
a, b	0.908	0.8	126	126	1
a, c	1	1.8	56	56	1
b, c	0.754	1.8	56	56	1



APPENDIX III: Results Monthly variations from Analysis in Primer.

(a) MDS

Non-metric Multi-Dimensional Scaling

Resemblance worksheet
Name: Resem5
Data type: Similarity
Selection: All

Parameters
Kruskal stress formula: 1
Minimum stress: 0.01

Best 3-d configuration (Stress: 0.03)

Sample	1	2	3	%
9	-1.22	-0.40	0.08	6.8
11	-0.28	-0.51	0.52	9.6
6	-0.46	0.93	-0.16	21.7
2	1.00	0.02	-0.49	8.5
12	0.41	-1.29	0.10	8.3
8	-0.86	0.09	-0.39	13.9
1	0.29	-0.67	-0.33	15.8
3	0.92	0.49	0.42	5.6
4	0.43	0.54	0.56	4.3
7	-0.56	0.41	0.15	2.4
5	0.33	0.38	-0.46	3.1

Best 2-d configuration (Stress: 0.08)

Sample	1	2	%
9	-1.33	-0.31	3.4
11	-0.32	-0.67	28.0
6	-0.48	0.84	7.5
2	1.07	-0.14	12.6
12	0.36	-1.43	5.6
8	-0.89	0.32	9.6
1	0.28	-0.71	3.1
3	0.94	0.65	7.2
4	0.56	0.77	11.5
7	-0.53	0.40	2.8
5	0.33	0.27	8.7

STRESS VALUES

Repeat	3D	2D
1	0.03	0.08
2	0.04	0.22
3	0.03	0.08
4	0.03	0.08
5	0.03	0.08
6	0.03	0.08
7	0.03	0.08

8	0.03	0.08	
9	0.04	0.13	
10	0.03	0.08	
11	0.03	0.08	
12	0.03	0.08	
13	0.04	**	0.08
14	0.03	0.08	
15	0.2	0.08	
16	0.03	0.08	
17	0.03	0.08	
18	0.03	0.08	
19	0.03	**	0.08
20	0.03	0.08	
21	0.03	0.08	
22	0.03	0.08	
23	0.03	0.08	
24	0.03	0.08	
25	0.03	0.08	

** = Maximum number of iterations used

3-d : Minimum stress: 0.03 occurred 21 times
2-d : Minimum stress: 0.08 occurred 23 times

(b) CLUSTER

Hierarchical Cluster analysis

Resemblance worksheet
Name: Resem5
Data type: Similarity
Selection: All

Samples

1	9
2	11
3	6
4	2
5	12
6	8
7	1
8	3
9	4
10	7
11	5

Parameters
Cluster mode: Group average

(c) SIMPROF test

Data worksheet
Name: Data11
Data type: Biomass
Sample selection: All
Variable selection: All

SIMPROF Parameters
Permutations for mean profile: 1000
Simulation permutations: 999
Significance level: 5%
Resemblance:
Analyse between: Samples
Resemblance measure: S17 Bray Curtis similarity

Combining
8+9 -> 12 at 97.87
3+10 -> 13 at 97.86; Pi: 0 Sig(%): 100
1+6 -> 14 at 97.49; Pi: 0 Sig(%): 100
4+11 -> 15 at 97.19
5+7 -> 16 at 96.94
2+16 -> 17 at 96.42; Pi: 0.15 Sig(%): 55.4
12+15 -> 18 at 96.26; Pi: 0.22 Sig(%): 11.5
13+14 -> 19 at 96.18; Pi: 0.56 Sig(%): 0.1
17+18 -> 20 at 95.03; Pi: 0.35 Sig(%): 0.1
19+20 -> 21 at 94.87; Pi: 0.31 Sig(%): 0.1

(d) SIMPER
Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Monthly variations
Data type: Biomass
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 95.00%

Factor Groups

Sample	month
9	a
6	a
8	a
7	a
11	b

12	b
1	b
2	c
3	c
4	c
5	c

Groups a & b
Average dissimilarity = 5.14

	Group c	Group a		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Thyristes atun	6.95	4.99	0.82	7.90
15.98	15.98			
Thunnus species	1.22	0.00	0.51	1.51
9.87	25.85			
Tranchipterus trachypterus	5.04	5.99	0.40	1.89
7.82	33.67			
Chelidonicthys capensis	4.23	4.94	0.30	1.90
5.79	39.46			
Zeus faber	4.17	4.44	0.24	1.76
4.74	44.20			
Thunnus albacores	0.55	0.37	0.23	0.97
4.48	48.68			
Todarodes sagittatus	9.20	9.65	0.18	1.95
3.60	52.28			
Genypterus capensis	8.27	8.64	0.18	1.28
3.54	55.82			
Allocyttus verrucosus	1.38	1.71	0.17	1.81
3.37	59.19			
Taractichthys longipinnis	5.61	6.02	0.17	3.45
3.34	62.53			
Agyrosomus Inodorus	2.15	2.46	0.17	1.39
3.30	65.84			
Dentex macrophthalmus	5.78	6.18	0.17	1.28
3.29	69.13			
Epigonus species	1.69	2.08	0.16	2.96
3.20	72.33			
Helicolenus dactylopterus	8.67	9.03	0.16	1.34
3.11	75.44			
Brama brama	6.37	6.74	0.15	1.09
2.94	78.39			
Macrouridae *sps*	0.13	0.31	0.15	0.88
2.89	84.20			
Isurus oxyrinchus	3.92	4.26	0.14	1.57
2.78	86.98			

Raja species	6.58	6.89	0.13	2.36
2.52	89.50			
Lepidotus caudatus	4.00	4.19	0.12	1.56
2.29	94.17			
Tarnchurus capensis	7.46	7.61	0.11	1.31
2.21	96.37			

Groups a & c
Average dissimilarity = 5.13

	Group c	Group b		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Thyristes atun	6.95	5.52	0.60	5.24
11.67	11.67			
Zeus faber	4.17	5.46	0.54	2.06
10.52	22.19			
Dentex macrophthalmus	5.78	6.76	0.41	2.76
7.99	30.18			
Chelidonicthys capensis	4.23	5.16	0.39	3.58
7.58	37.76			
Diplodus capensis	0.00	0.81	0.34	1.62
6.57	44.33			
Austroglosus microlepsis	5.63	6.40	0.32	1.97
6.25	50.58			
Thunnus species	1.22	1.43	0.29	1.27
5.72	56.30			
Thunnus albacores	0.55	0.55	0.24	1.08
4.76	61.07			
Tranchipterus trachypterus	5.04	5.45	0.22	1.52
4.34	65.40			
Agyrosomus Inodorus	2.15	2.19	0.17	1.58
3.25	68.66			
Brama brama	6.37	6.23	0.16	2.51
3.08	71.74			
Tarnchurus capensis	7.46	7.22	0.15	1.45
2.90	74.63			
Lophius vomerinus	9.92	9.61	0.13	1.85
2.56	77.19			
Macrouridae *sps*	0.13	0.25	0.13	0.78
2.56	79.75			
Genypterus capensis	8.27	8.35	0.13	1.36
2.52	82.27			
Lepidotus caudatus	4.00	4.20	0.10	1.43
2.00	86.50			
Isurus oxyrinchus	3.92	4.15	0.10	1.46
1.89	88.39			
Allocyttus verrucosus	1.38	1.45	0.10	1.70
1.87	90.26			

Raja species	6.58	6.79	0.09	1.49
1.74	91.99			
Helicolenus dactylopterus	8.67	8.81	0.09	1.10
1.72	93.71			
Taractichthys longipinnis	5.61	5.49	0.08	1.67
1.66	95.37			

Groups b & c
Average dissimilarity = 4.97

	Group a	Group b		
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
	Contrib%	Cum.%		
Thunnus species	0.00	1.43	0.59	3.96
11.84	11.84			
Zeus faber	4.44	5.46	0.42	3.80
8.48	20.31			
Diplodus capensis	0.00	0.81	0.33	1.60
6.69	27.00			
Austroglosus microlepsis	5.73	6.40	0.28	1.78
5.58	32.58			
Dentex macrophthalmus	6.18	6.76	0.27	1.83
5.40	37.98			
Tranchipterus trachypterus	5.99	5.45	0.26	1.51
5.15	43.13			
Brama brama	6.74	6.23	0.25	1.77
5.08	48.21			
Thunnus albacores	0.37	0.55	0.24	1.03
4.77	52.98			
Thyristes atun	4.99	5.52	0.22	1.77
4.52	57.50			
Taractichthys longipinnis	6.02	5.49	0.22	2.60
4.36	61.87			
Agyrosomus Inodorus	2.46	2.19	0.21	1.45
4.14	66.00			
Allocyttus verrucosus	1.71	1.45	0.17	1.66
3.45	72.93			
Macrouridae *sps*	0.31	0.25	0.17	0.83
3.33	76.26			
Tarnchurus capensis	7.61	7.22	0.17	1.69
3.33	79.59			
Chelidonicthys capensis	4.94	5.16	0.14	1.23
2.82	82.40			
Lophius vomerinus	9.94	9.61	0.14	1.78
2.73	85.14			
Genypterus capensis	8.64	8.35	0.13	1.55
2.63	87.76			
Todarodes sagittatus	9.65	9.35	0.13	1.76
2.59	90.35			

Helicolenus dactylopterus	9.03	8.81	0.10	1.28
2.02	92.37			
Epigonus species	2.08	1.84	0.10	1.69
1.97	94.34			
Lepidotus caudatus	4.19	4.20	0.08	1.29
1.71	96.05			

(e) ANOSIM

Analysis of Similarities

One-Way Analysis

Resemblance worksheet

Name: Resem5

Data type: Similarity

Selection: All

Factor Values

Factor: month

1

2

3

Factor Groups

Sample month

9 1

6 1

8 1

7 1

11 2

12 2

1 2

2 3

3 3

4 3

5 3

Global Test

Sample statistic (Global R): 0.88

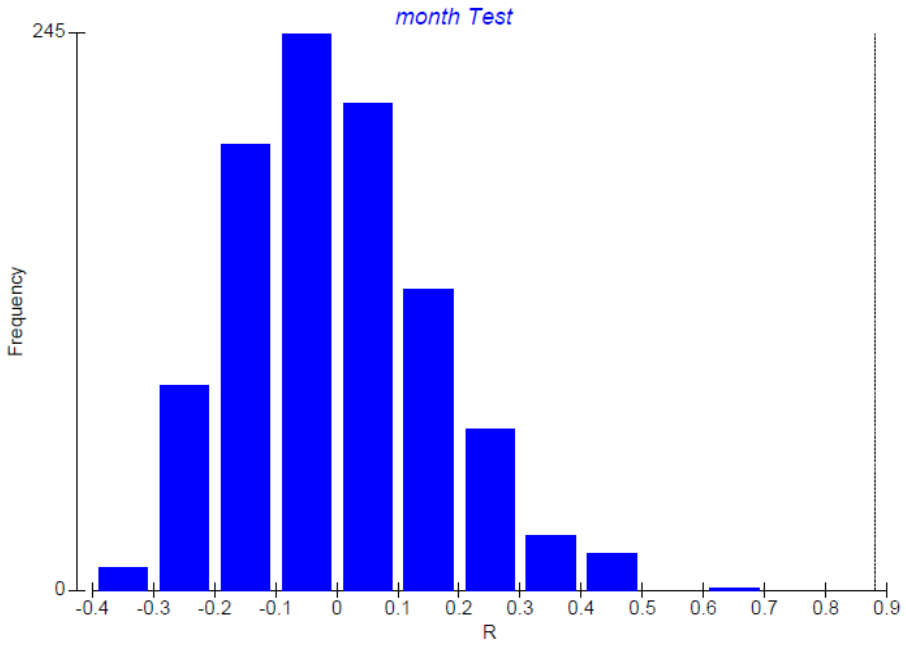
Significance level of sample statistic: 0.1%

Number of permutations: 999 (Random sample from 5775)

Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1, 2	0.833	2.9	35	35	1
1, 3	0.854	2.9	35	35	1
2, 3	0.963	2.9	35	35	1



APPENDIX IV : Table indicating lowest and highest average monthly CPUE of bycatch species.

Species name	Month with lowest average CPUE	Month with highest average CPUE
Lophius vomerinus	September	January
Raja species	May	December
Austroglossus microlepis	September	March
Todarodes sagittatus	August	February
Argyrosomus inodorus	September	April
Chelidonichthys capensis	July	April
Diplodus capensis	January, April and June	March
Helicolenus dachylopterus	May	December
Macrouridae *sps*	January, March, April, May June July, September and November	December
Taractichthys longipinnis	March	December
Dentex macrophthalmus	September	December
Isurus oxyrinchus	May	August
Thyrsites atun	January	June
Genypterus capensis	August	December
Allocyttus verrucosus	September	February
Brama brama	March	August
Zeus faber	May	April
Lepidopus caudatus	November	March
Thunnus albacores	January, February, August, September and December	March
Epigonus species	September	December
Thunnus species	January, September, November and December	February
Trachipterus trachypterus	July	December
Tranchurus capensis	July	September

APPENDIX V: Table indicating lowest and highest average annual CPUE of bycatch species.

Species name	Year with low catch rates year	Year with high cat rates
Lophius vomerinus	2007	1997
Raja species	2006	2014
Austroglossus microlepis	2008	2009
Todarodes sagittatus	2006	2002

Argyrosomus inodorus	No catches in ;1997,1998,1999,2011,2012,2013,2014	2003
Chelidonichthys capensis	2012	2002
Diplodus capensis	No catches for all the years in exception of 2004	2004
Helicolenus dachylopterus	1997	1999
Macrouridae *sps*	No catches for all the years in exception of 2002,2003 and 2005	2002
Taractichthys longipinnis	No catches in 1997,1998,1999,2001and 2003	2014
Dentex macrophthalmus	2002	2012
Isurus oxyrinchus	2010	1997
Thyrsites atun	2012	2014
Genypterus capensis	1997	2010
Allocyttus verrucosus	No catches in 1997,1998,1999,2012,2013 and 2014	2000
Brama brama	2008	2014
Zeus faber	2008	1998
Lepidopus caudatus	1997	1998
Thunnus albacores	No catches in all the years in exception of 2002,2003,2004 and 2005	2005
Tranchurus capensis	2000	2013
Epigonus sps	1997,1998 and 2014	2011
Thunnus sps	No catches in all the years in exception 2003,2004,2005,2006,2007,2008,2010 and 2011	2003
Trachipterus trachypterus	1997	2014

APPENDIX VI: Table indicating the significance of factors on CPUE of bycatch species (Estimated degree. of freedom, Degree of freedom, F value, P value)

Species Name	**Factors**	**Estimated degr. of freedom**	**Degr. of freedom**	F	P
Epigonus sps	Latitude	4.5585	5.4777	2.472	0.02254

	Month	2.6089	3.1718	3.992	0.00723
	Year	0.9999	0.9999	3.881	0.05050
Argryosomus inodorus	Latitude	2.363	2.849	6.691	0.00037
	Month	7.971	8.703	2.853	0.00384
	Year	1.452	1.756	5.559	0.00579
Thunus Sps	Latitude	3.183	3.926	4.030	0.00345
	Month	8.123	8.791	3.439	0.00107
	Year	1.000	1.000	6.237	0.01288
Tranchurus Capensis	Latitude	5.030	6.107	3.105	0.004610
	Month	5.129	6.258	1.530	0.178151
	Year	2.275	2.827	7.450	0.000162
Isurus oxyrinchus	Latitude	6.989	8.013	3.845	0.000156
	Month	2.131	2.676	2.426	0.078999
	Year	2.760	3.419	8.120	1.26e-05
Allocyttus verrucosus	Latitude	5.225	6.226	5.736	1.93e-05
	Month	8.233	8.808	9.711	9.50e-12
	Year	7.394	8.155	5.265	6.94e-06
Lepidotus caudatus	Latitude	6.350	7.365	4.512	3.76e-05
	Month	5.780	6.959	2.411	0.0195

	Year	2.273	2.847	3.651	0.0149
Taractichthys longipinnis	Latitude	8.815	8.989	64.543	< 2e-16
	Month	7.716	8.547	9.540	8.02e-14
	Year	8.036	8.623	74.071	< 2e-16
Brama brama	Latitude	8.032	8.693	33.696	<2e-16
	Month	8.688	8.971	12.774	<2e-16
	Year	7.433	8.387	148.572	<2e-16
Chelidonicthys capensis	Latitude	7.371	8.286	18.386	< 2e-16
	Month	7.516	8.456	19.431	< 2e-16
	Year	8.086	8.751	14.911	< 2e-16
Dentex macrophthalmus	Latitude	8.757	8.975	33.068	< 2e-16
	Month	4.197	5.187	6.131	8.54e-06
	Year	8.599	8.949	16.421	< 2e-16
Helicolenus dactylopterus	Latitude	8.921	8.998	407.02	<2e-16
	Month	7.503	8.454	17.68	<2e-16
	Year	8.773	8.979	35.20	<2e-16
Zeus faber	Latitude	8.871	8.994	47.795	< 2e-16
	Month	4.635	5.696	12.111	9.79e-13
	Year	5.317	6.442	16.720	< 2e-16

Genypterus capensis	Latitude	8.847	8.988	714.37	<2e-16
	Month	8.745	8.981	371.15	<2e-16
	Year	7.913	8.646	26.90	<2e-16
Lophius vomerinus	Latitude	8.717	8.975	43.62	<2e-16
	Month	4.038	4.985	46.67	<2e-16
	Year	8.969	9.000	597.51	<2e-16
Raja sps	Latitude	8.872	8.993	26.50	<2e-16
	Month	6.911	8.019	11.64	<2e-16
	Year	8.870	8.994	59.78	<2e-16
Thyristes atun	Latitude	4.213	5.175	20.297	< 2e-16
	Month	8.807	8.990	23.671	< 2e-16
	Year	8.901	8.996	45.288	< 2e-16
Austroglosus microlepsis	Latitude	8.927	8.998	84.22	< 2e-16
	Month	5.363	6.533	55.77	< 2e-16
	Year	8.752	8.981	15.22	< 2e-16
Todarodes sagittatus	Latitude	8.767	8.964	43.16	<2e-16
	Month	8.099	8.783	41.86	<2e-16
	Year	8.936	8.999	261.68	<2e-16

Tranchipterus tranchipterus	Latitude	6.959	7.885	16.101	< 2e-16
	Month	6.182	7.343	3.453	0.000764
	Year	5.427	6.529	2.666	0.010787

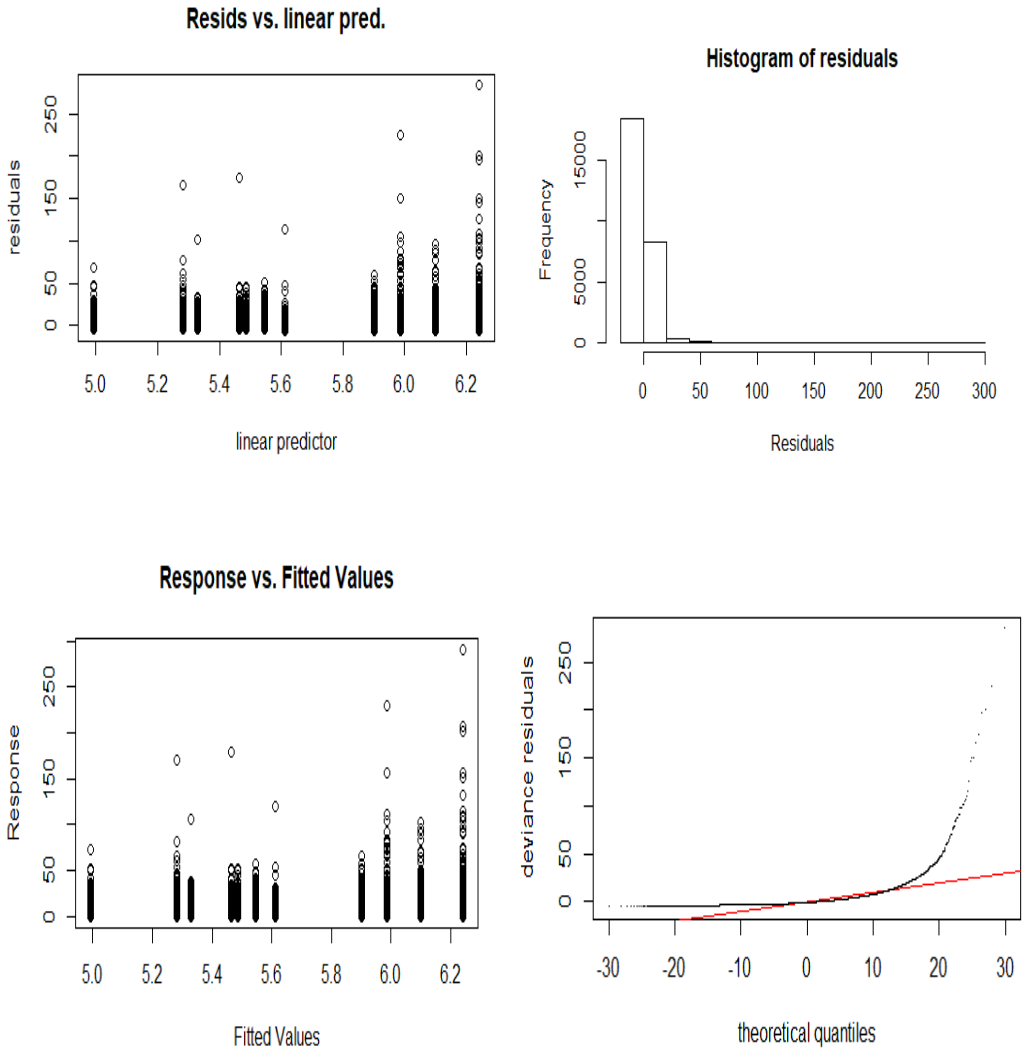
APPENDIX VII: Table indicating the significance of factors on CPUE of bycatch species as a whole (Estimated degree. of freedom, Degree of freedom, F value, P value).

Species Name	**Factors**	**Estimated degr. of freedom**	**Degr. of freedom**	F	P
All species	Latitude	4.585	5.601	6.796	7.93e-07
	Month	3.308	4.097	4.534	0.001111
	Year	2.250	2.817	8.237	4.89e-05

APPENDIX VIII: GAM diagnostics for figure 16 a-u.

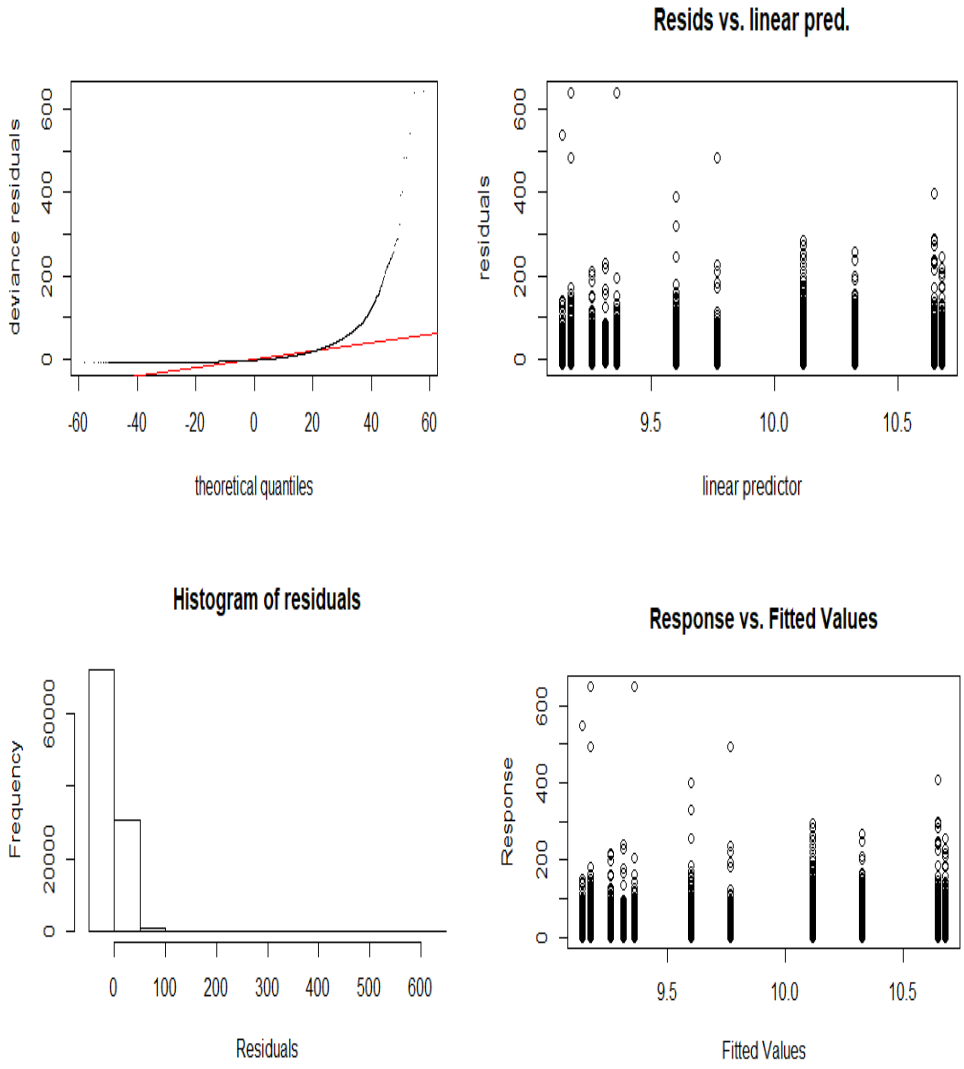
a) Raja species

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 3.437514e-07 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                       k'    edf     k-index p-value
s(Raja species$Month) 9.00 6.68       1    0.41
```



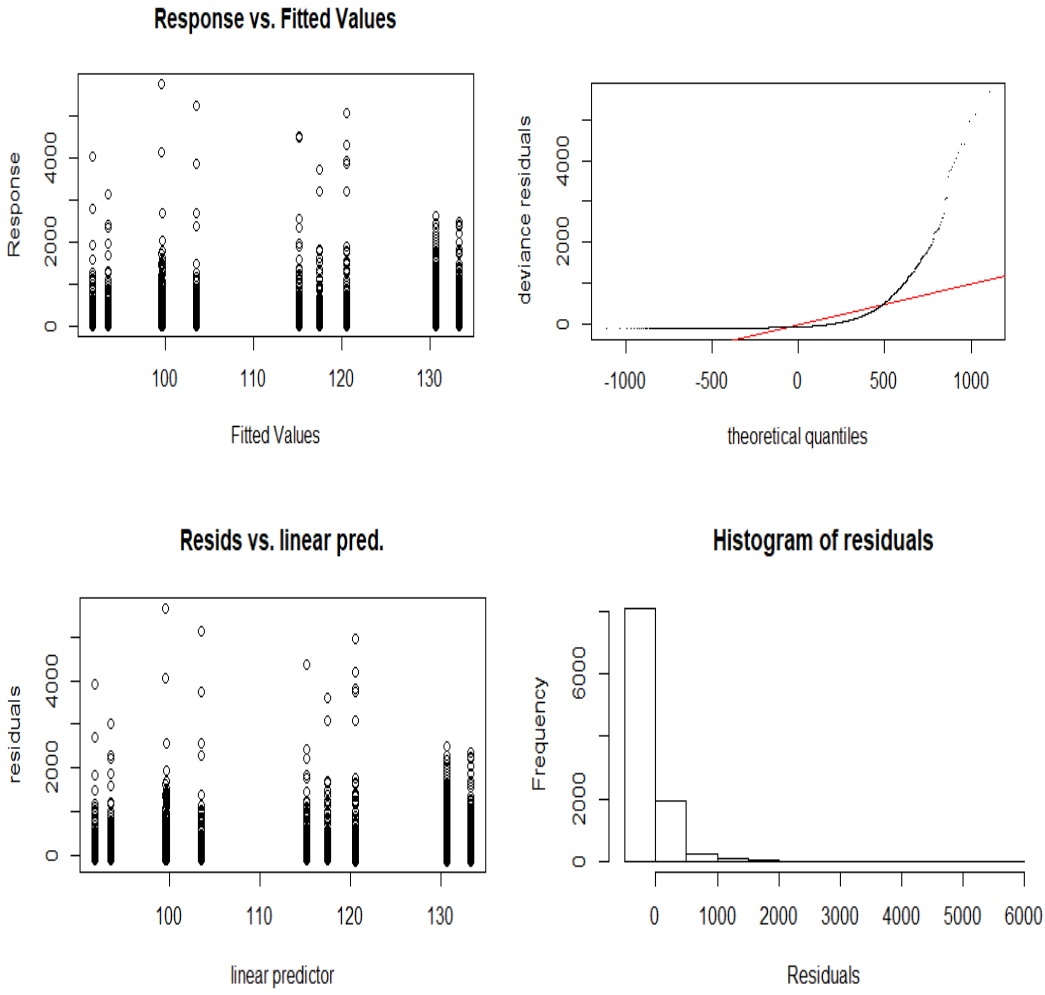
b) *Lophius vomerinus*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 3.67352e-11 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                       k'  edf     k-index p-value
s(L.vomerinus$Month) 9.00 5.63    1.01    0.76
```



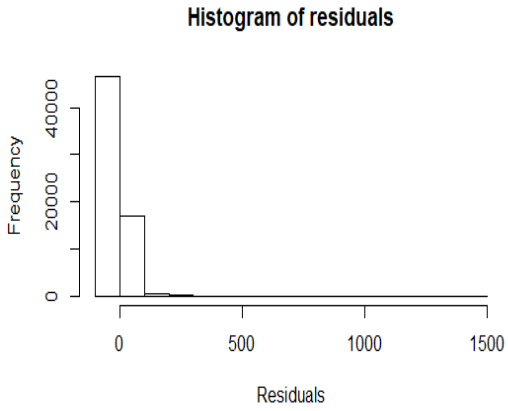
c) *Todarodes sagittatus*

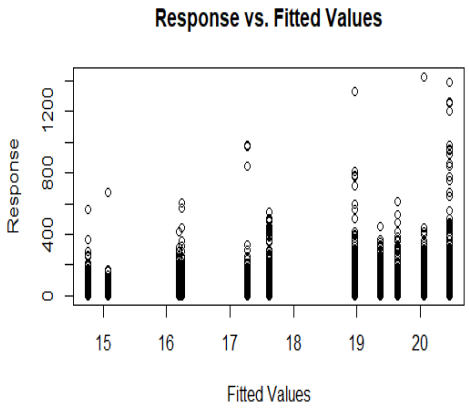
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.0002130917 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                          k' edf    k-index p-value
s(T. sagittatus$month) 9.0 8.2       1    0.41
```

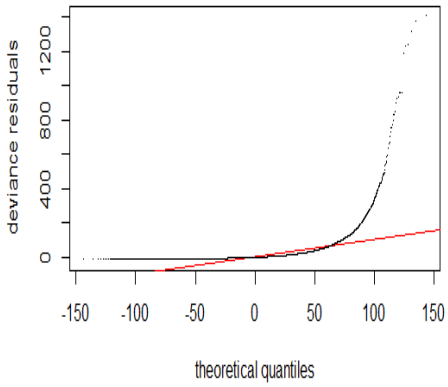


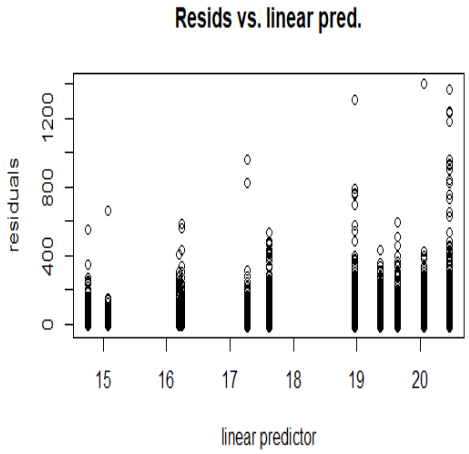
d) *Helicolenus dactylopterus*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 6 iterations.
The RMS GCV score gradient at convergence was 0.000202094 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                          k'  edf     k-index p-value
s(H.dactylopterus $month) 9.00 7.64    1.01    0.65
```





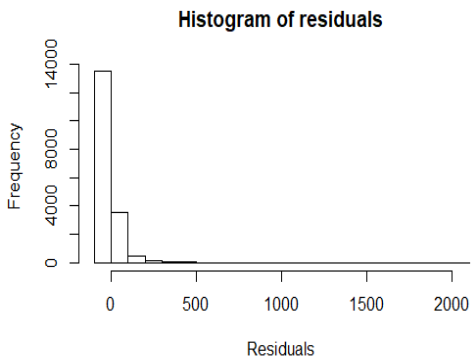


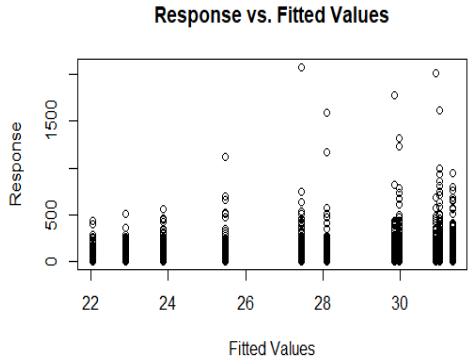


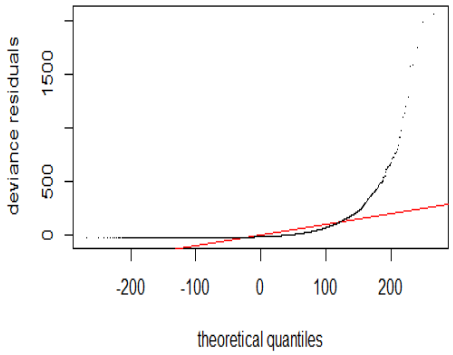
e) *Dentex macrophthalmus*

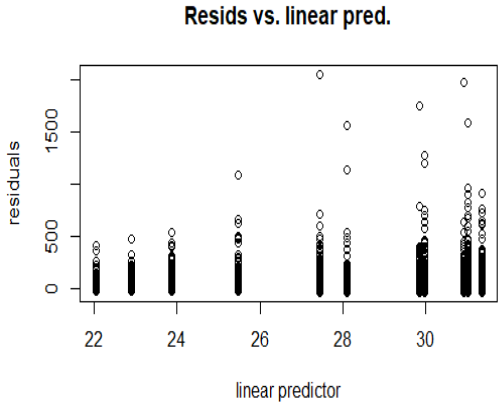
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.0004807186 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                              k'   edf     k-index p-value
s(D. macrophthalmus$month) 9.00 3.58    1.01    0.86
```

>



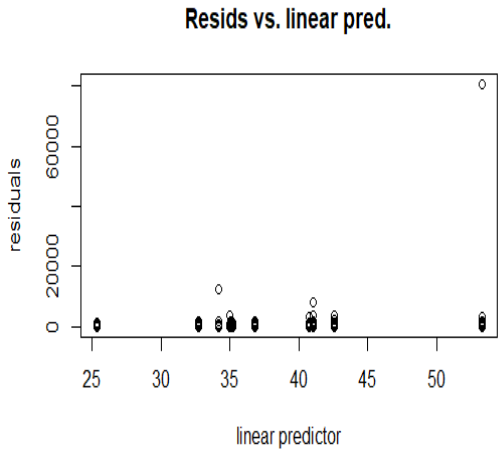


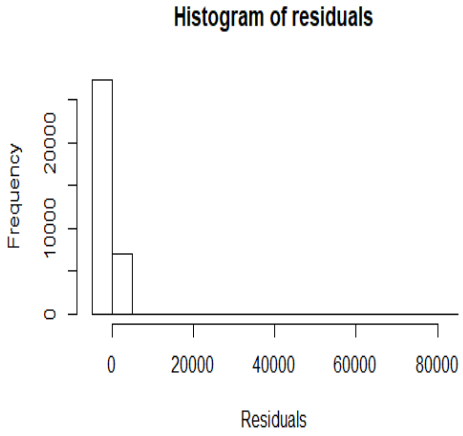


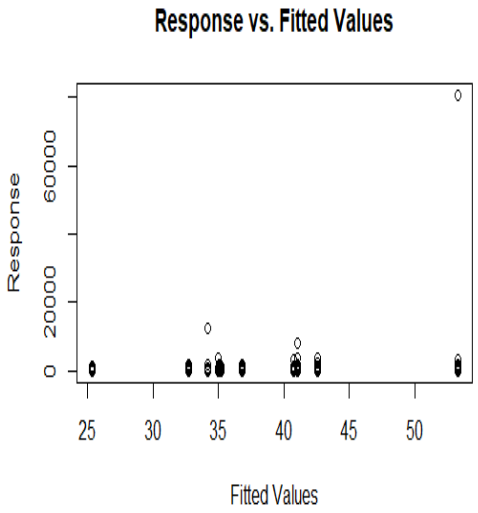


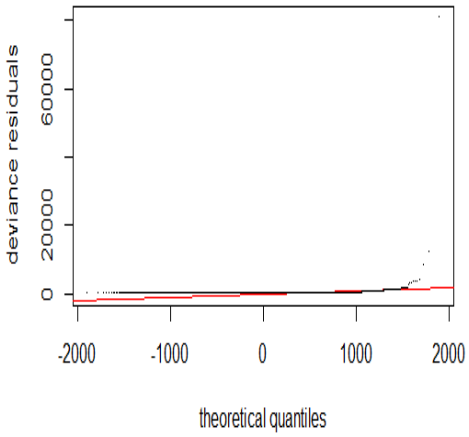
f) *Tarnchurus capensis*

```
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.1110736 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                        k'   edf       k-index p-value
s(T. capensis$month)  9.00  6.93        1       0.24
```



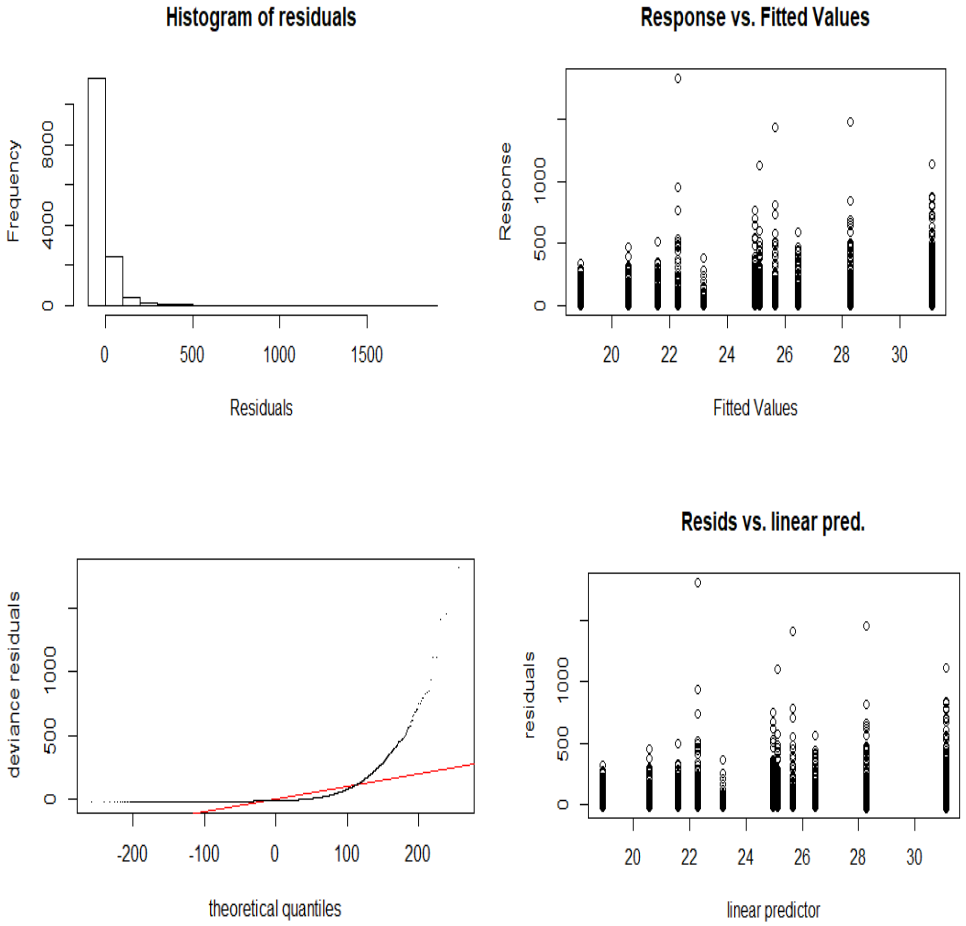






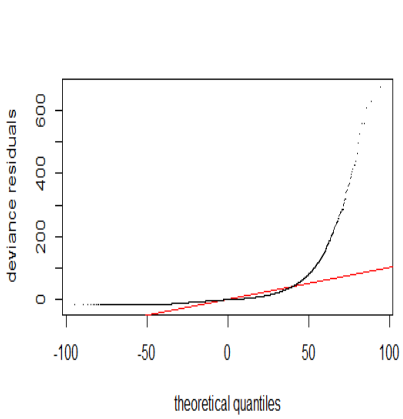
g) *Taractichthys longipinnis*

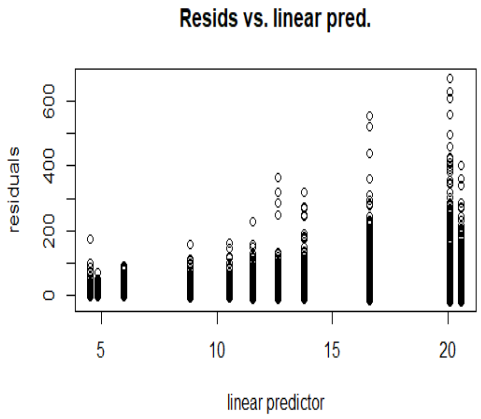
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.01285994 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                        k'   edf      k-index p-value
s(T.longipinnis$Month)  9.00 7.44        1     0.6
```

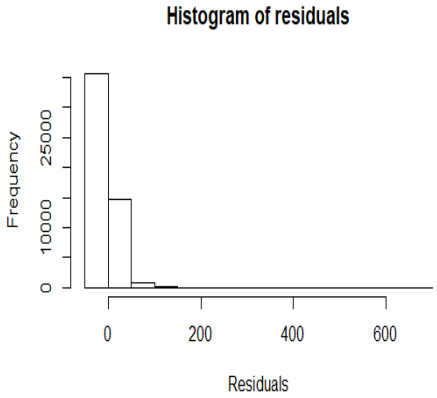


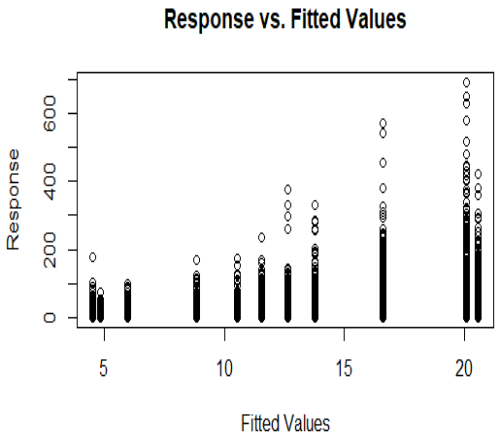
h) *Genypterus capensis*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 7 iterations.
The RMS GCV score gradient at convergence was 0.0004332055 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                       k'   edf      k-index p-value
s(G.capensis$month)  9.00  8.61    1.01    0.79
```



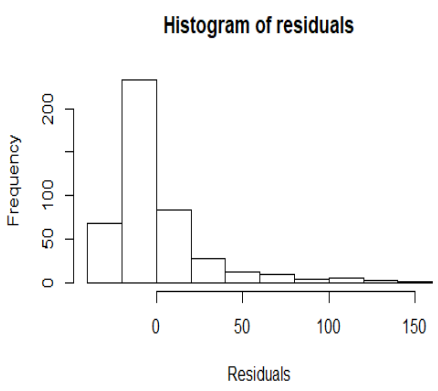


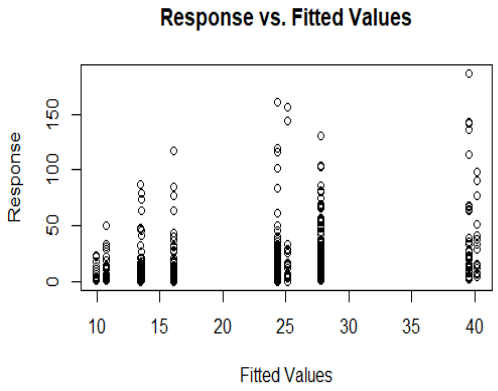


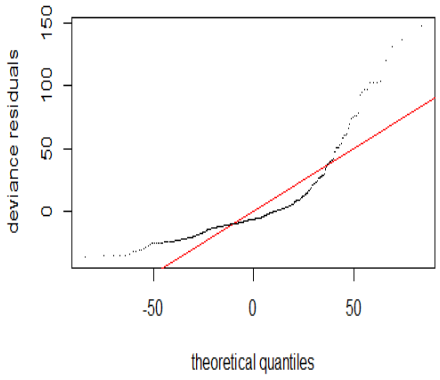


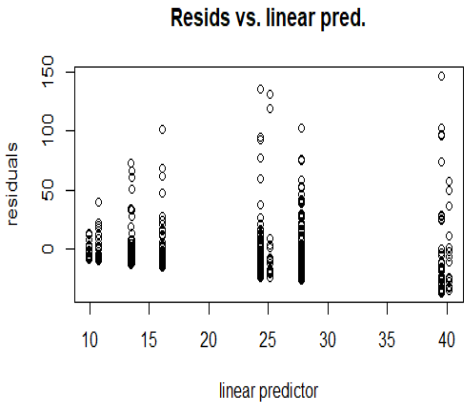
i) *Thunnus species*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.002842909 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Tunas$month) 9.00 7.98    0.85  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



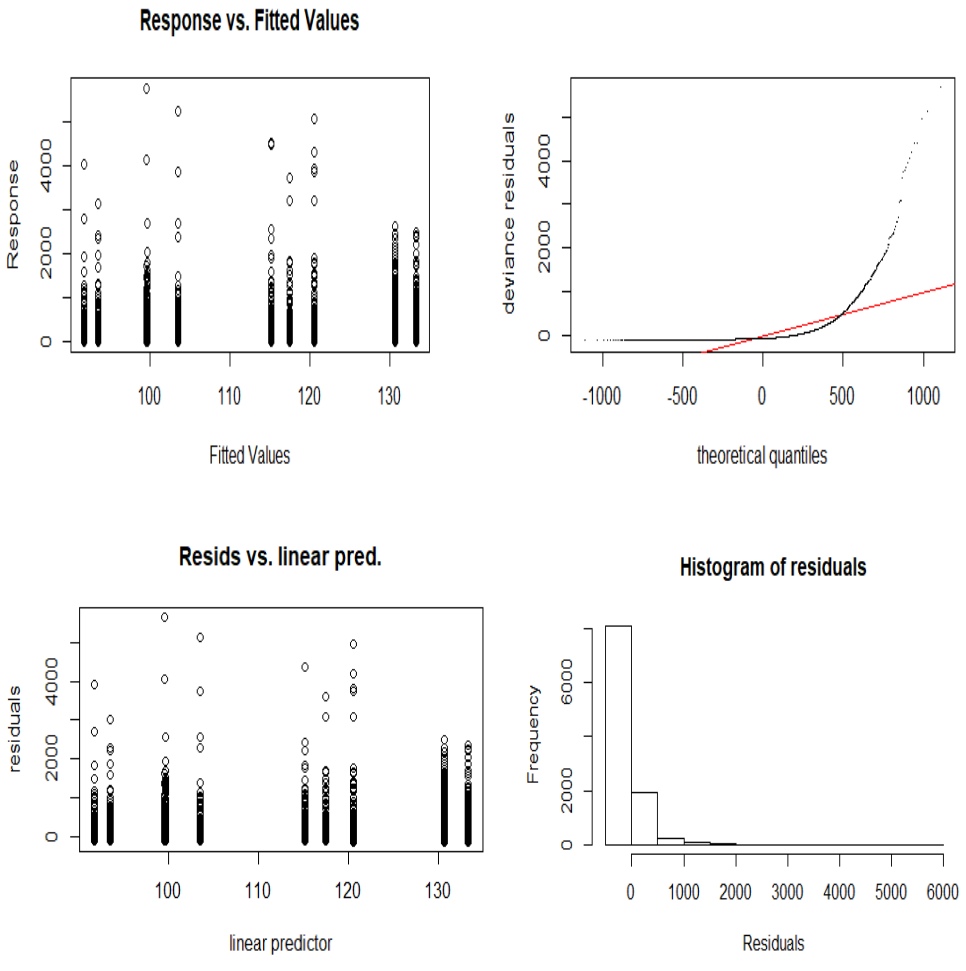






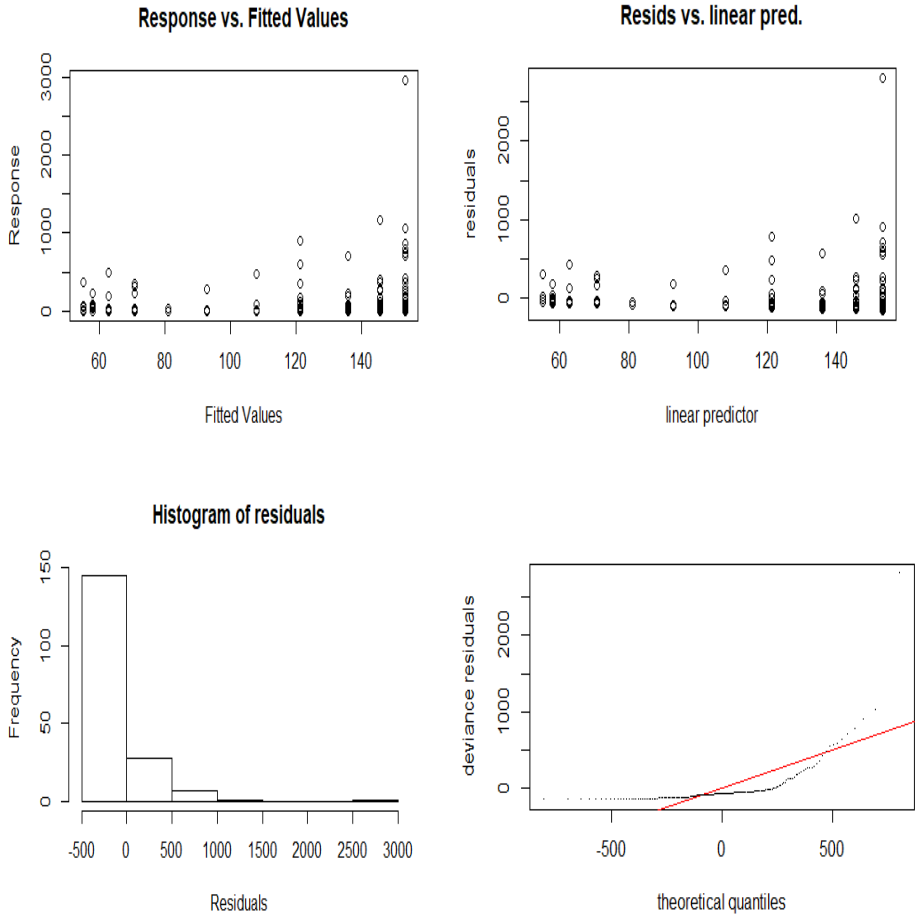
j) *Tranchipterus trachypterus*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 1.823951e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                          k'  edf      k-index p-value
s( T. trachypterus $MONTH) 9.00 5.38     1.01    0.77
```



k) *Epigonus species*

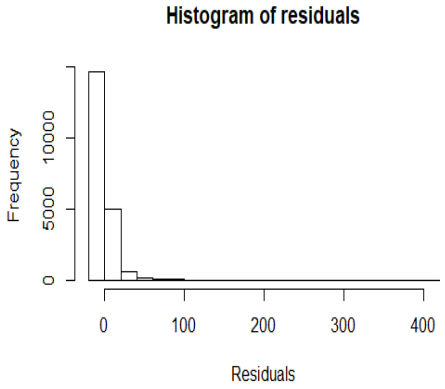
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.5200491 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                                k'   edf     k-index p-value
s(Epigonus species$Month) 9.00 1.52    1.01    0.37
```

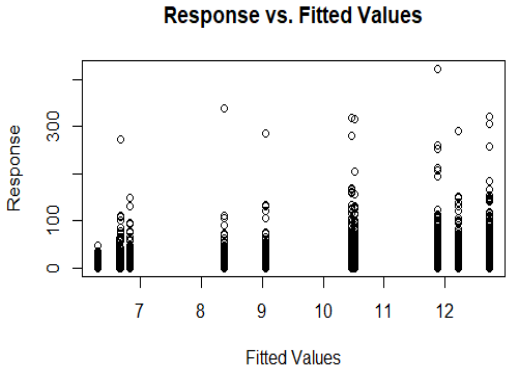


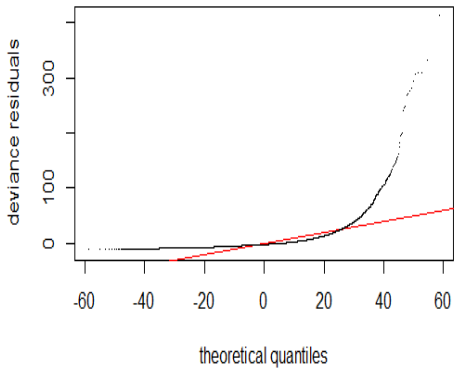
l) *Austroglosus microlepsis*

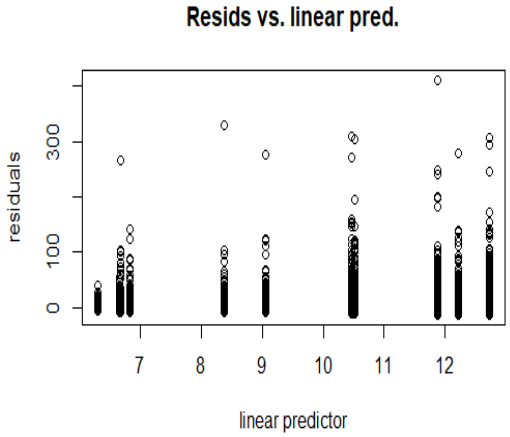
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 6 iterations.
```

```
The RMS GCV score gradient at convergence was 7.192901e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                                 k'  edf     k-index p-value
s(A. microlepsis  $Month)      9.00 8.02     1.01    0.78
```



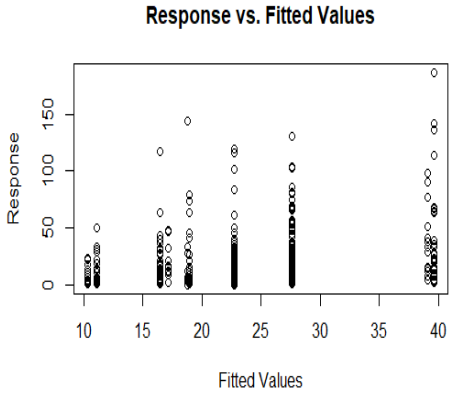


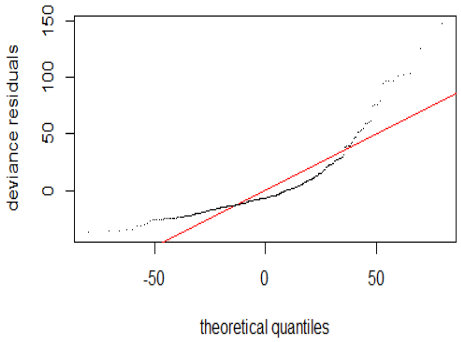


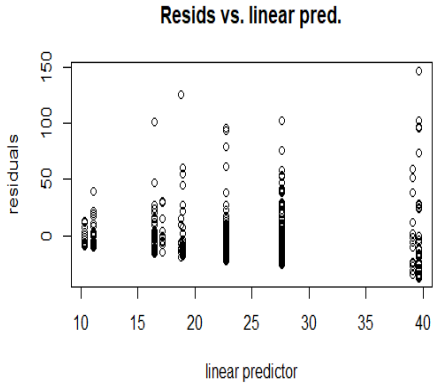


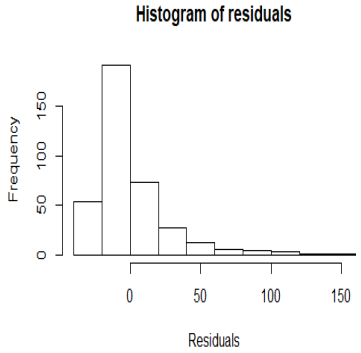
m) *Agyrosomus Inodorus*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.009730362 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species1$month) 9.00 7.35    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



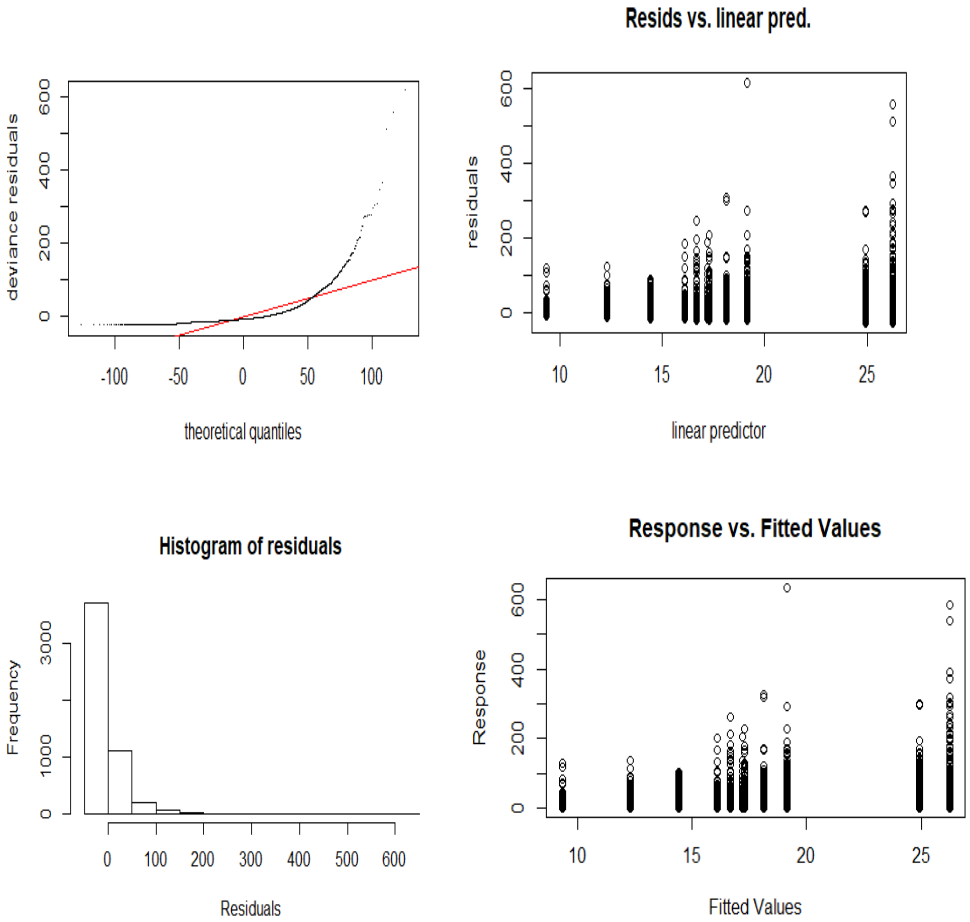






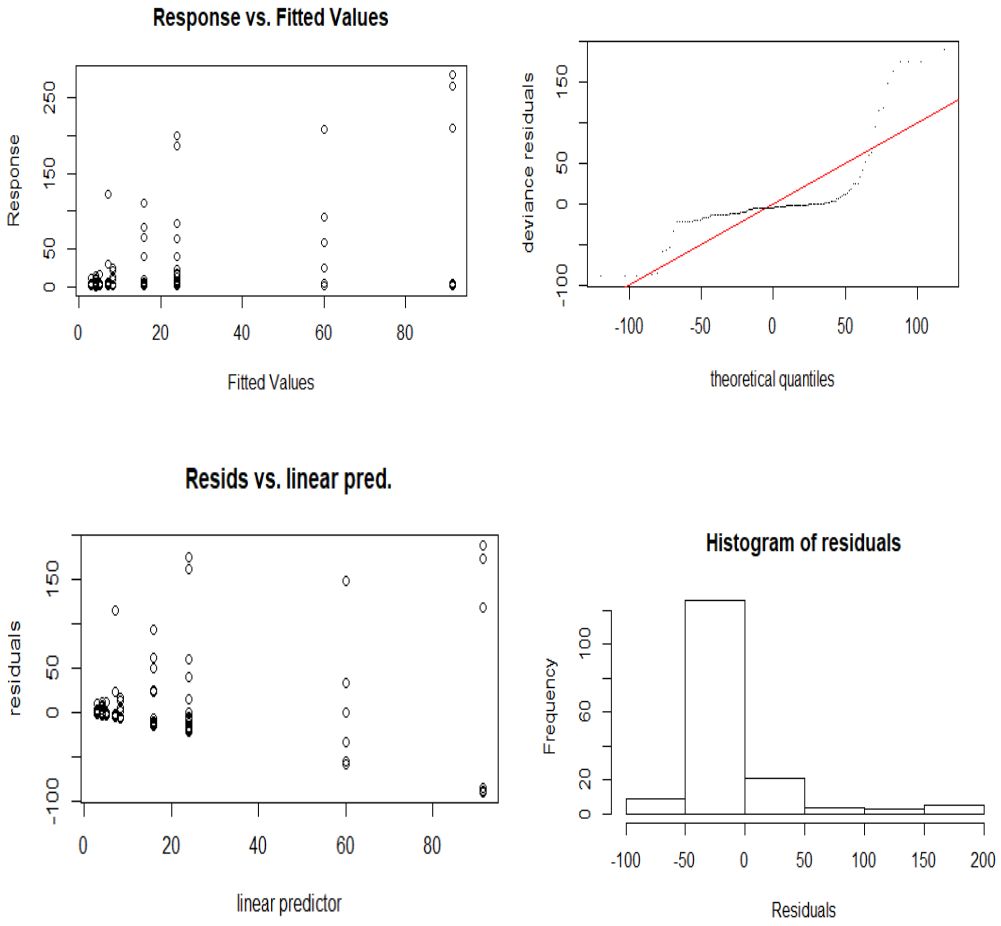
n) *Chelidonicthys capensis*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.0004392743 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf   k-index p-value
s(C.capensis$month) 9.0 6.6    1.03    0.99
```



o) *Allocyttus verrucosus*

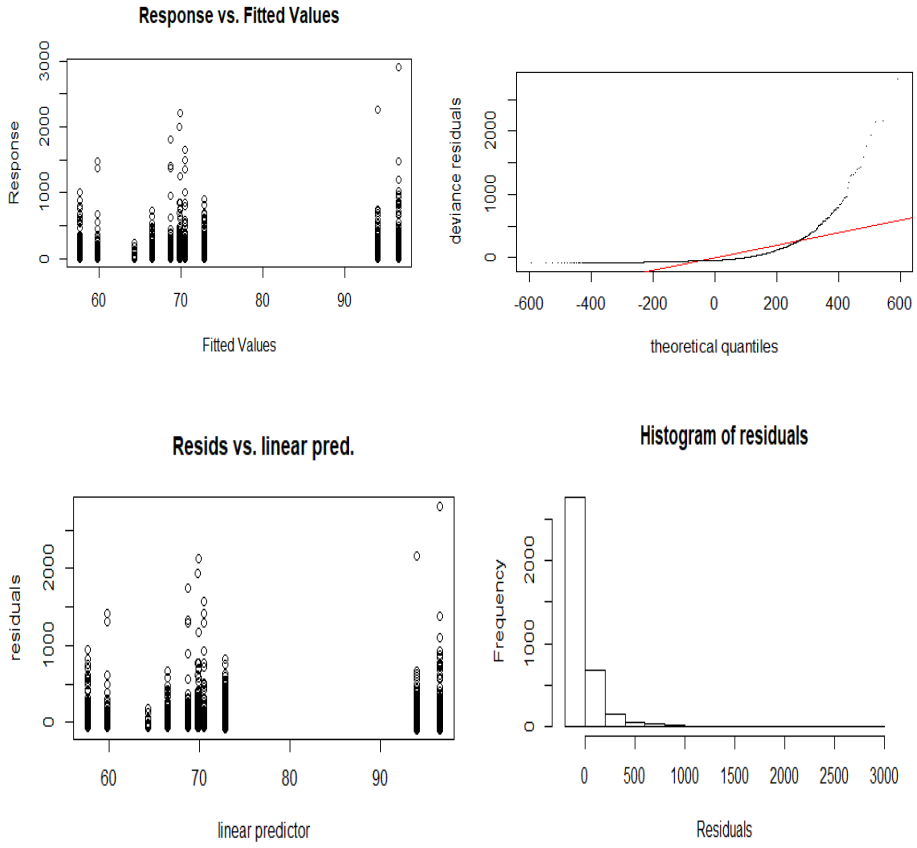
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.006356301 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species2$month) 9.00 7.65    0.72  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



p) *Lepidopus caudatus*

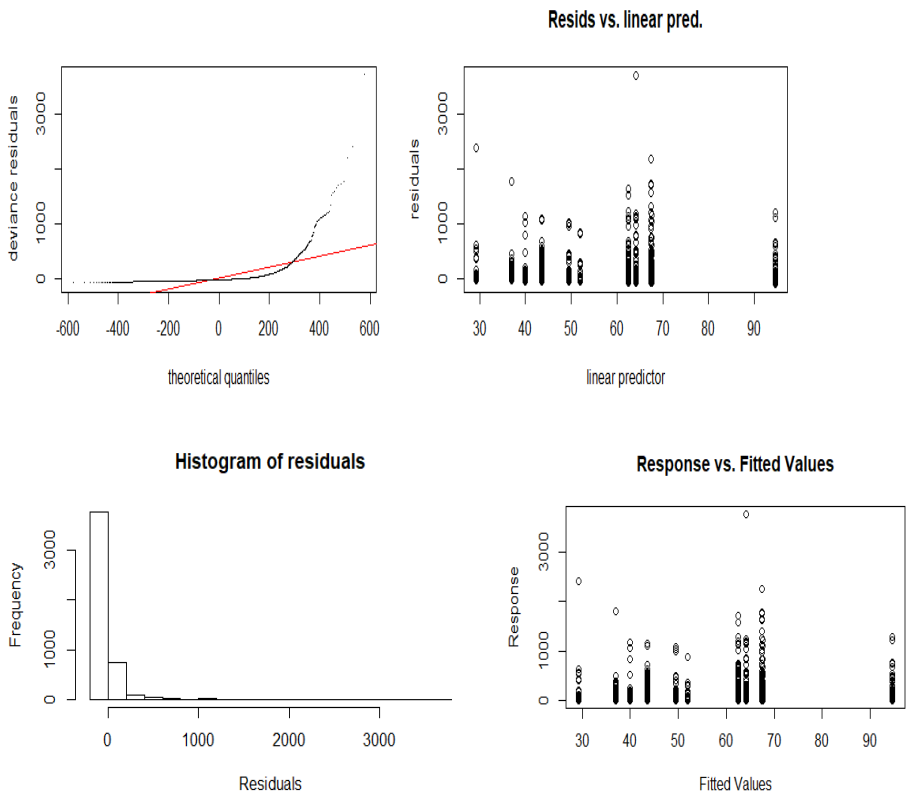
Species 14

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 1.358975e-08 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species14$month) 9.00 5.44    0.21  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



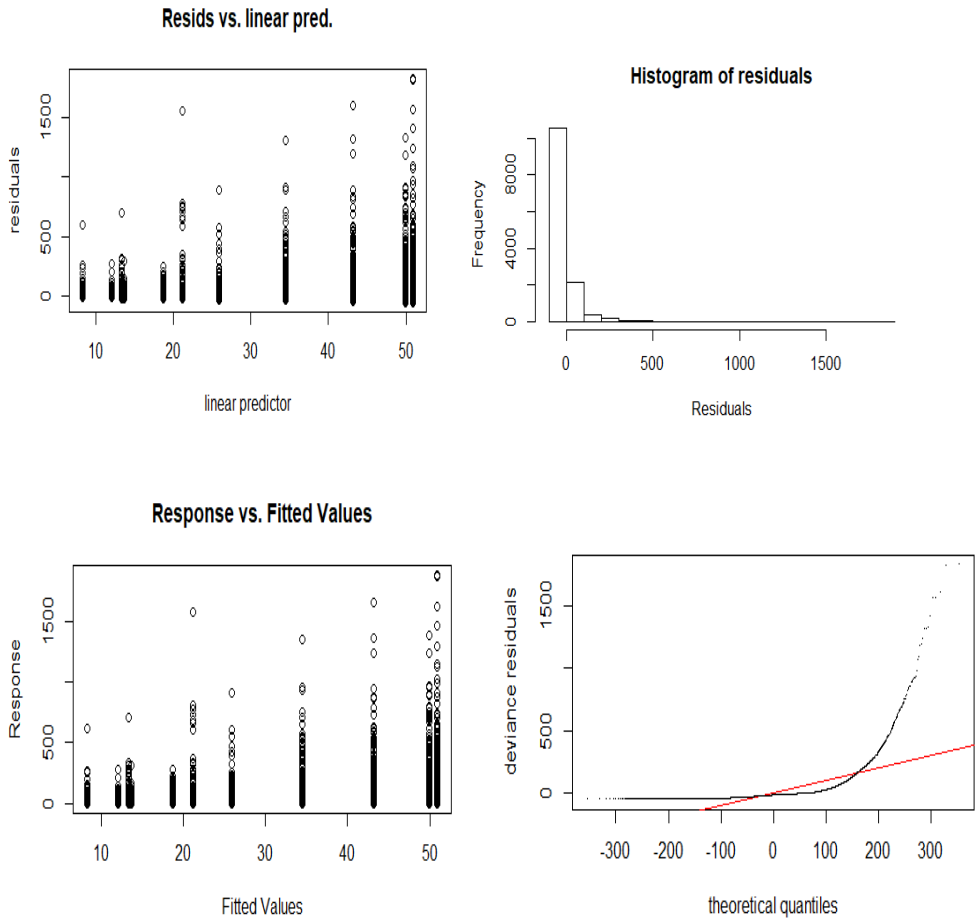
q) *Zeus faber*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 8 iterations.
The RMS GCV score gradient at convergence was 0.01711506 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species12$Month) 9.00 7.97    0.75  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



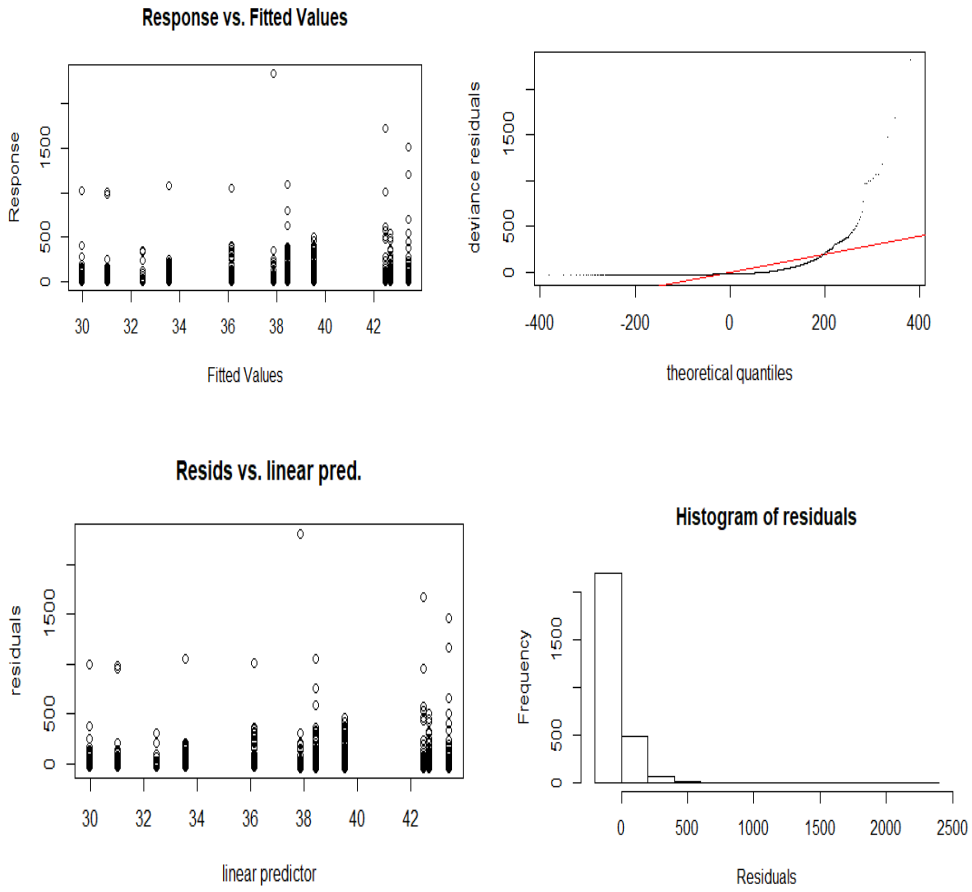
r) *Thyristes atun*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.03469199 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species20$Month) 9.00 8.05    0.98    0.07 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



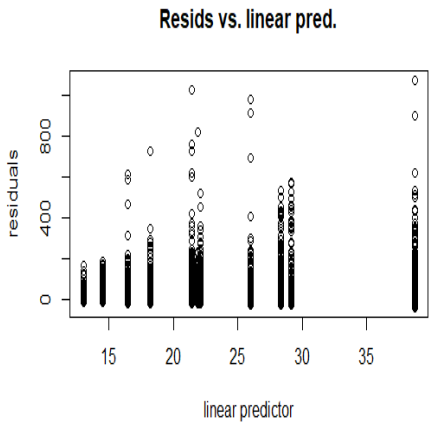
s) *Isurus oxyrinchus*

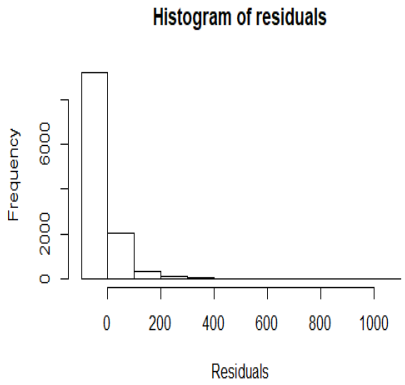
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.07649339 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species16$Month) 9.00 3.89     0.9  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

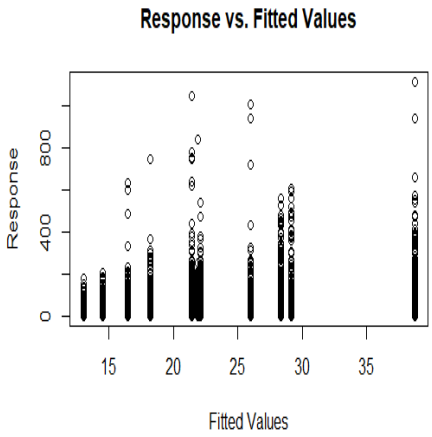


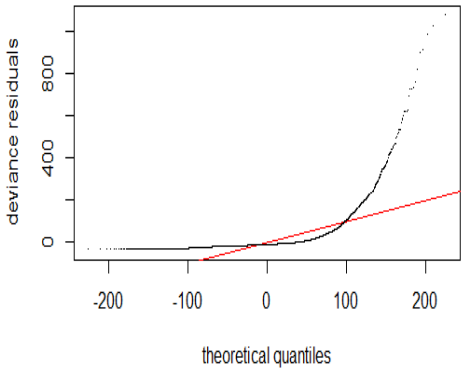
t) *Brama brama*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 6 iterations.
The RMS GCV score gradient at convergence was 0.002887801 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species4$Month) 9.00 8.09    0.99    0.24
```


Resids vs. linear pred.
residuals
0
400
800
15
20
25
30
35
linear predictor


Histogram of residuals
Frequency
0
2000
6000
0
200
400
600
800
1000
Residuals

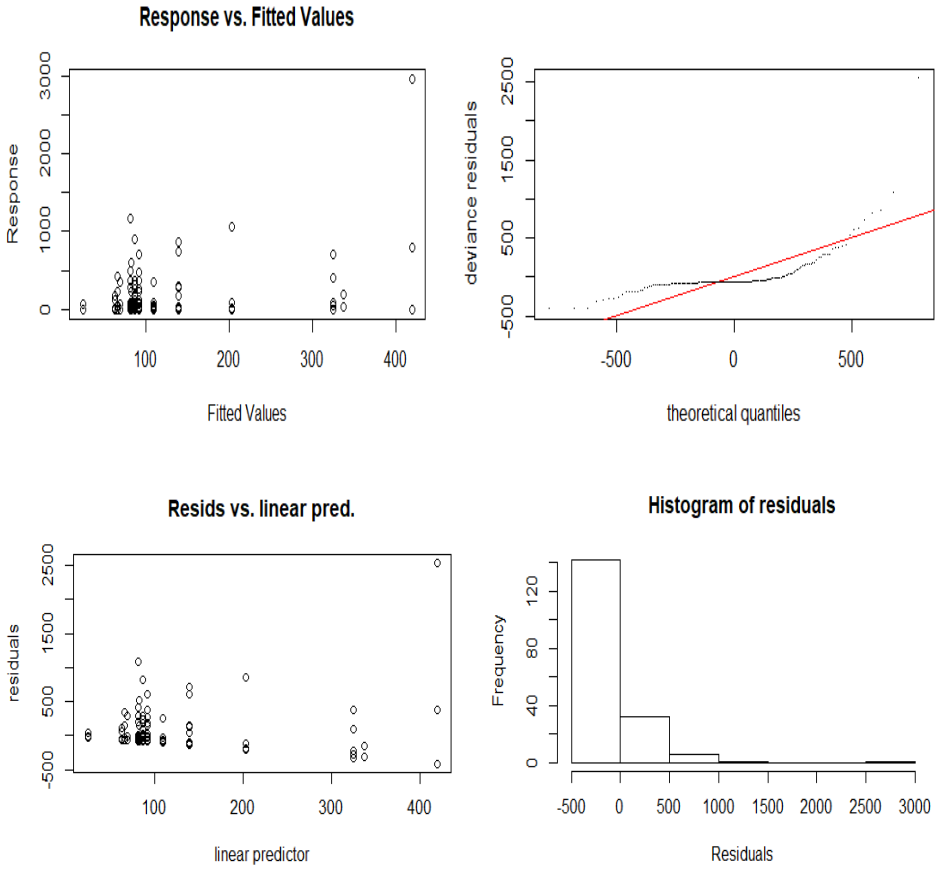

Response vs. Fitted Values
Response
0
400
800
15
20
25
30
35
Fitted Values


deviance residuals
0
400
800
-200
-100
0
100
200
theoretical quantiles

APPENDIX IX: GAM diagnostics for figure 18 a-u.

a) *Epigonus species*

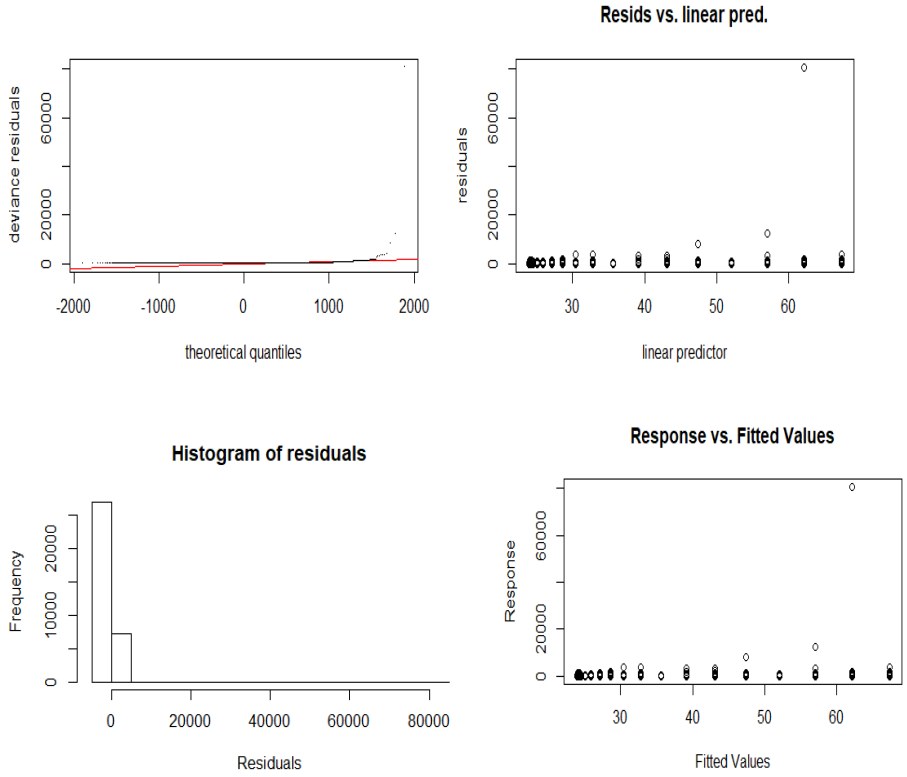
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 6 iterations.
The RMS GCV score gradient at convergence was 0.2421194 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species9$Year) 9.00 6.61    1.15       1

>
```



b) *Tarnchurus capensis*

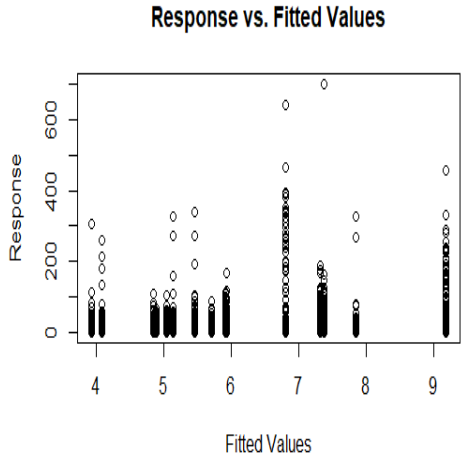
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
```

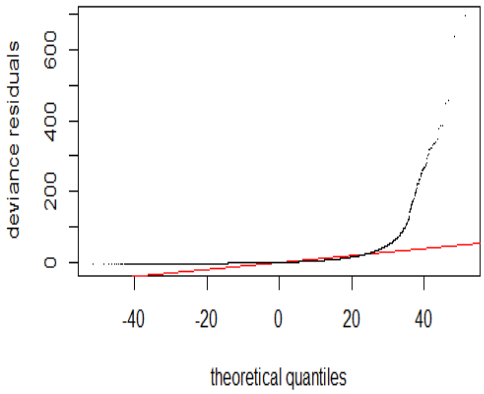
```
The RMS GCV score gradient at convergence was 0.009833967 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species10$year) 9.00 2.04       1    0.75

>
```

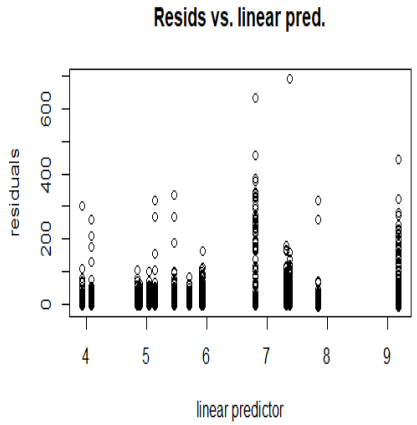


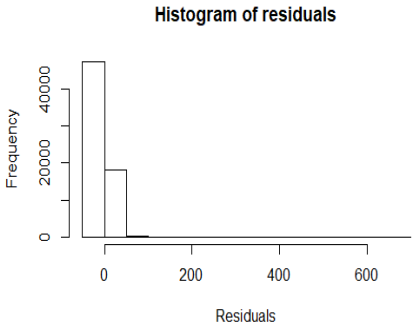
c) *Todarodes sagittatus*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 2.065564e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(species23$year) 9.00 8.88    1.01    0.98
```



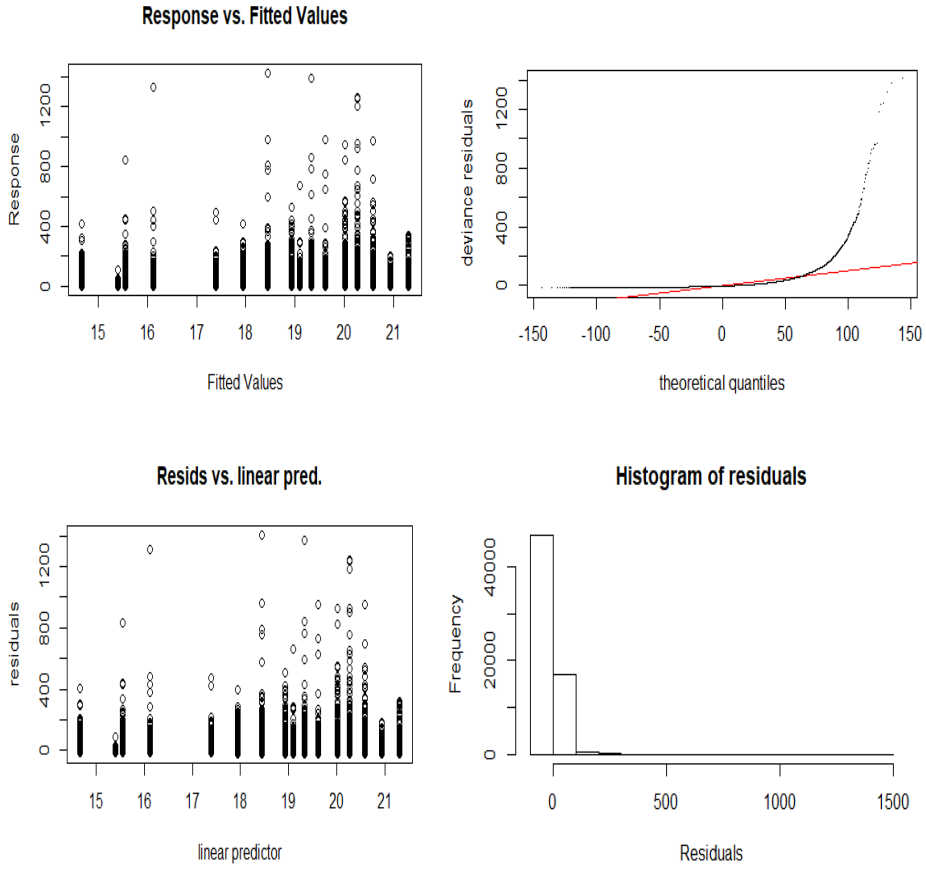






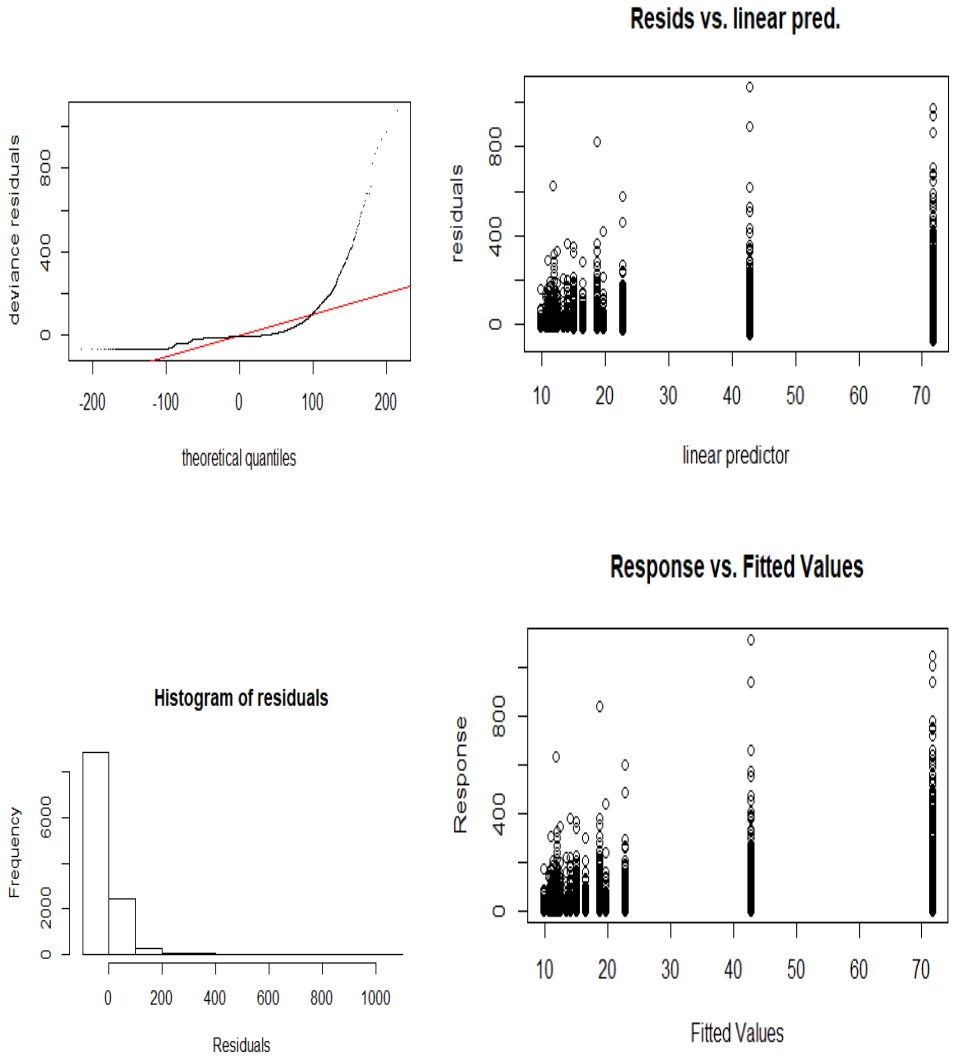
d) Helicolenus dactylopterus

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 7 iterations.
The RMS GCV score gradient at convergence was 0.0002299263 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species11$year) 9.00 8.82    1.01    0.78
```



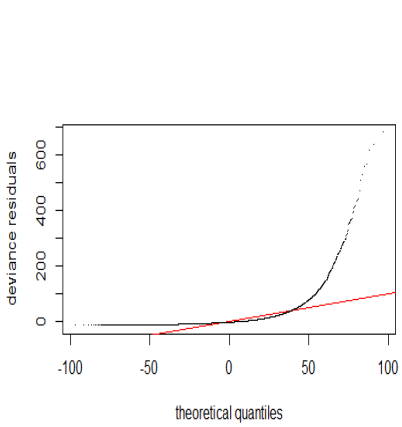
e) Brama brama

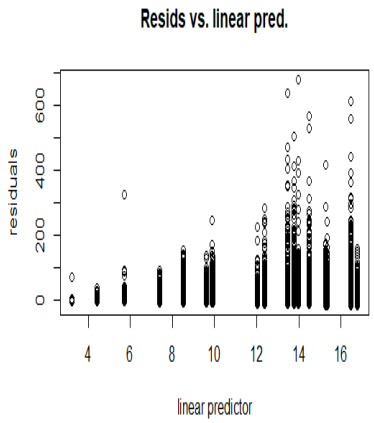
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.004296367 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species4$year) 9.00 7.97       1    0.45
```

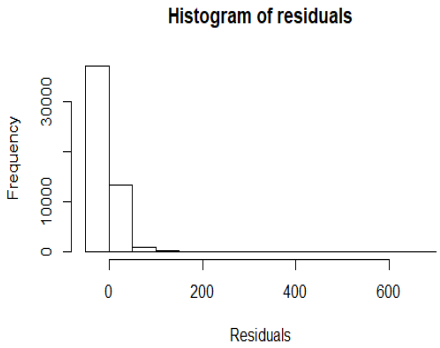


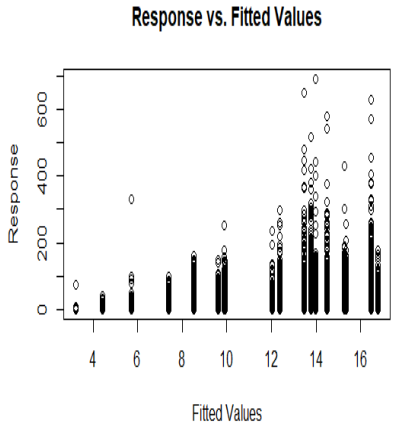
f) *Genypterus capensis*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 8 iterations.
The RMS GCV score gradient at convergence was 0.0002323525 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species13$year) 9.00 8.27    1.01     0.6
```



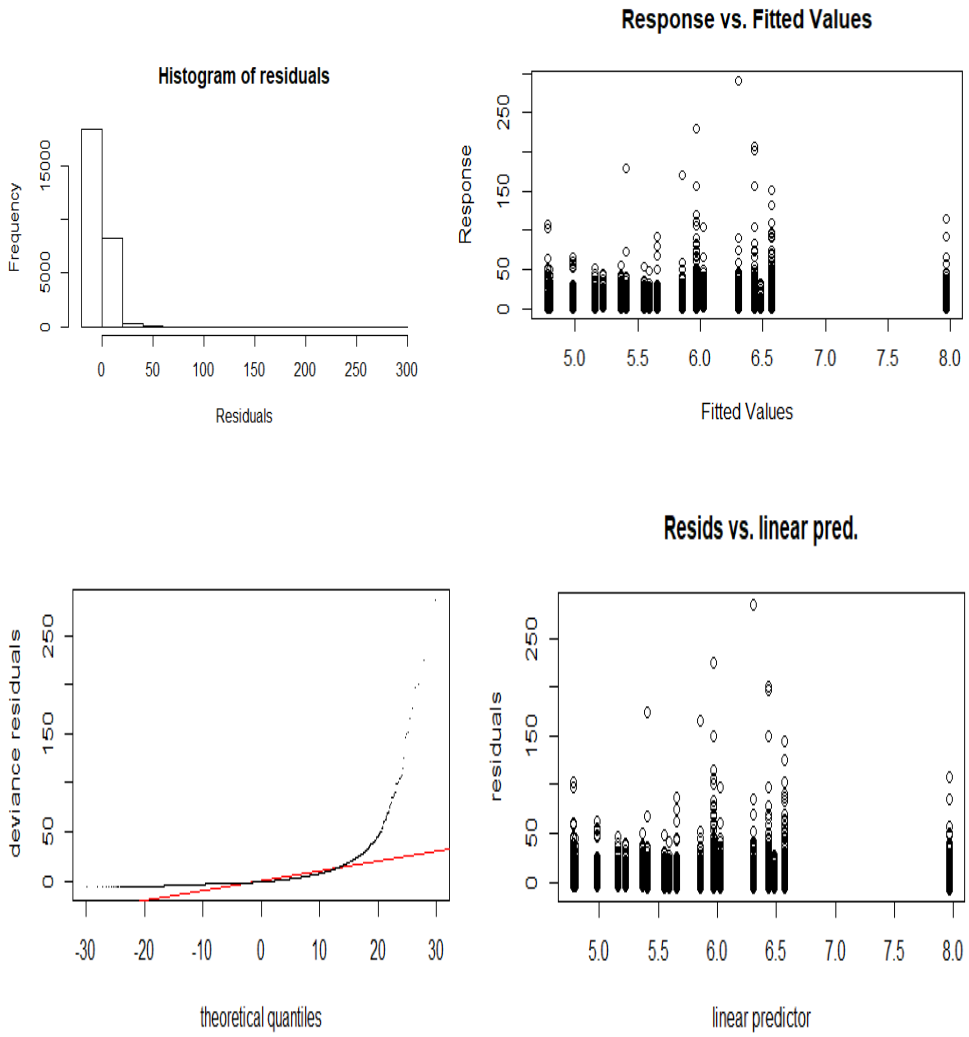






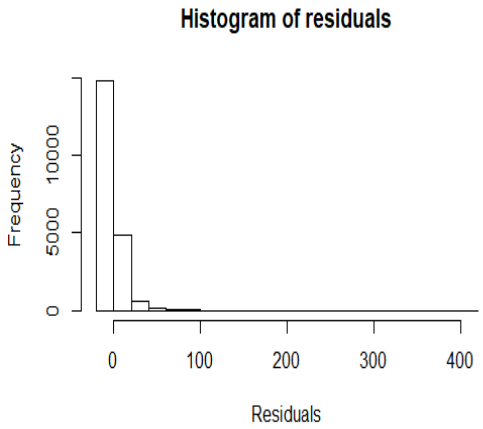
g) *Raja species*

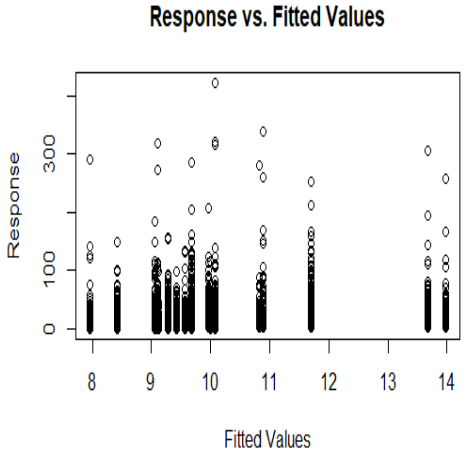
```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 9 iterations.
The RMS GCV score gradient at convergence was 1.218233e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species19$Year) 9.00 8.71    0.98   0.055 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

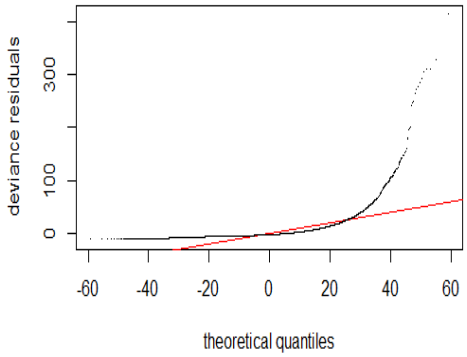


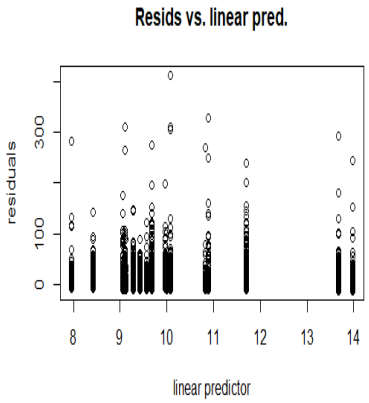
h) *Austroglosus microlepsis*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 7 iterations.
The RMS GCV score gradient at convergence was 0.0003131107 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species21$Year) 9.00 8.85    0.99    0.28
```


Histogram of residuals
Frequency
0
5000
10000
0
100
200
300
400
Residuals


Response vs. Fitted Values
Response
0
100
300
8
9
10
11
12
13
14
Fitted Values

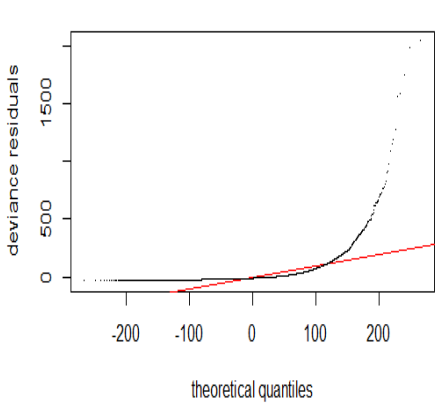

deviance residuals
0
100
300
-60
-40
-20
0
20
40
60
theoretical quantiles

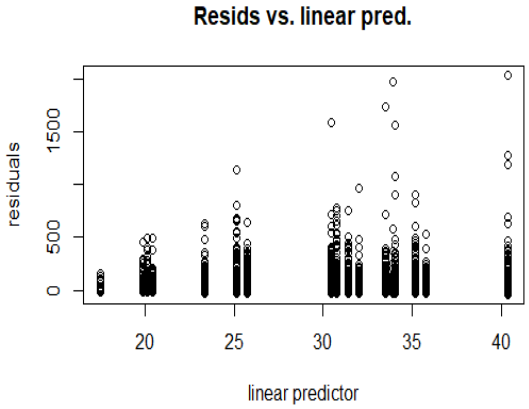

Resids vs. linear pred.
residuals
0
100
300
8
9
10
11
12
13
14
linear predictor

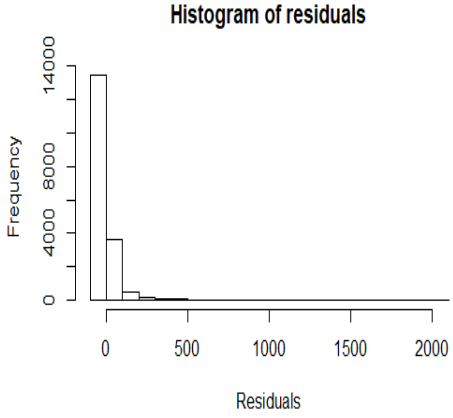
i) *Dentex macrophthalmus*

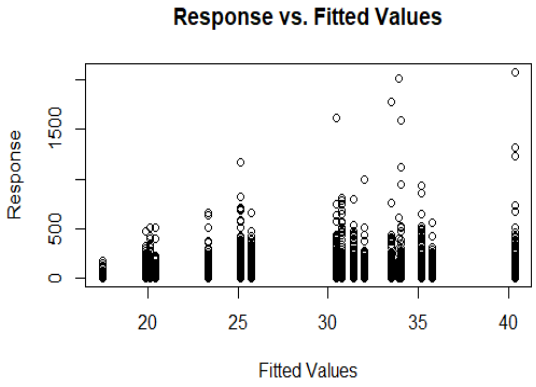
```
Smoothing parameter selection converged after 9 iterations.
The RMS GCV score gradient at convergence was 0.004960576 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species7$year) 9.00 8.65    0.99    0.22
```

```
>
```





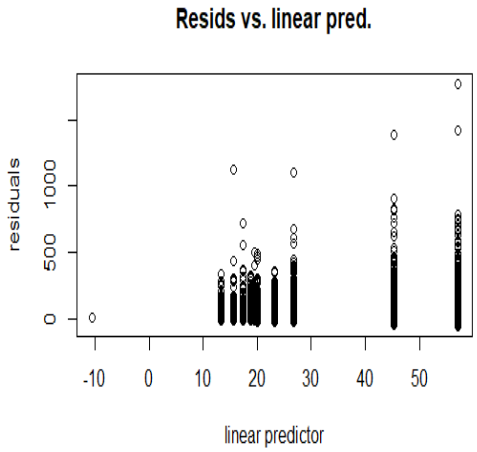


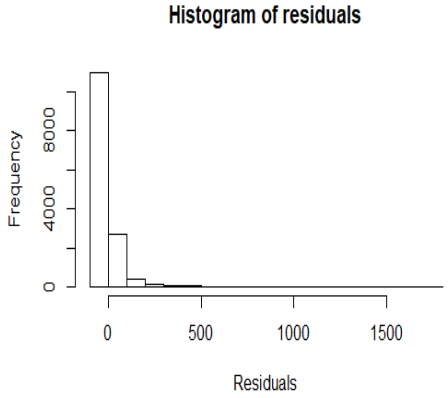


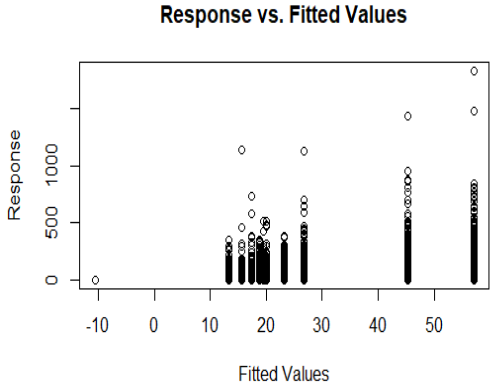
j) Taractichthys longipinnis

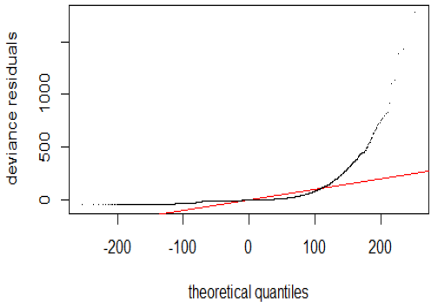
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 7 iterations.
The RMS GCV score gradient at convergence was 0.01123062 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
                      k'  edf k-index p-value
s(Species3$Year) 9.00 8.04    1.03       1
```



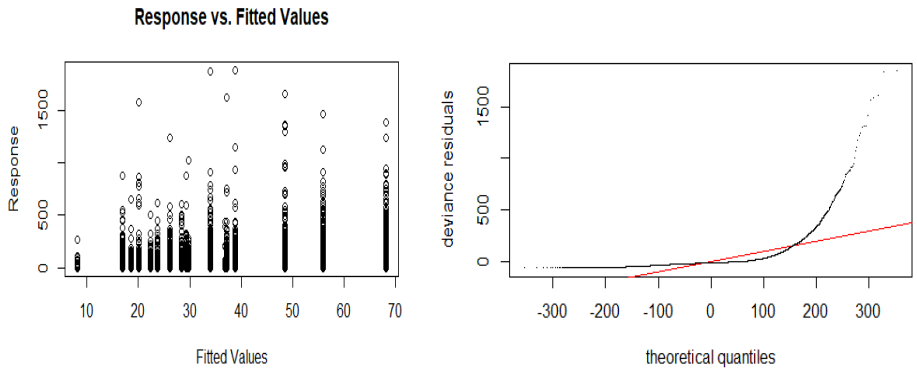


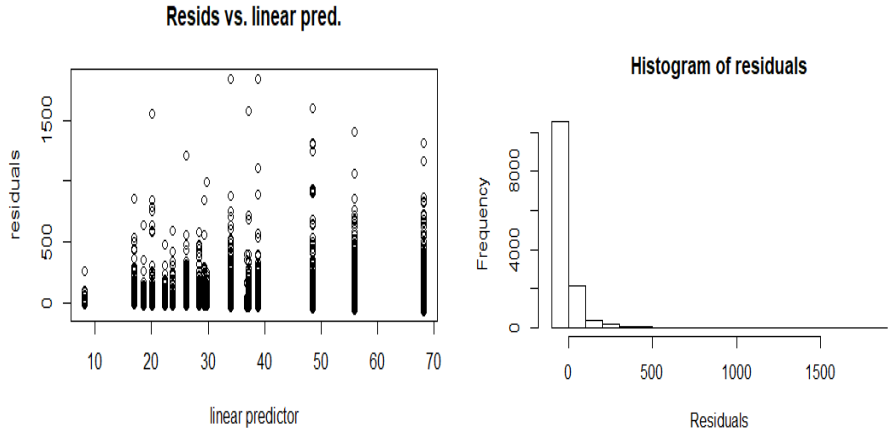




k) Thyristes atun

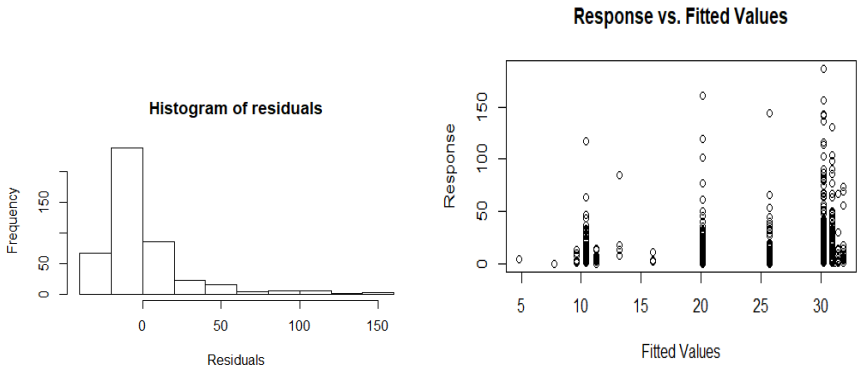
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 10 iterations.
The RMS GCV score gradient at convergence was 0.01700277 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'  edf k-index p-value
s(Species20$Year) 9.00 8.81    0.99    0.29
```

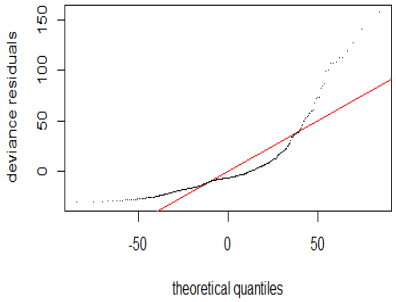


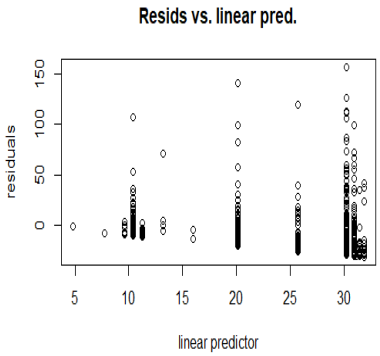


l) Thunnus species

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.0007968519 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species22$year) 9.00 3.71    0.78  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

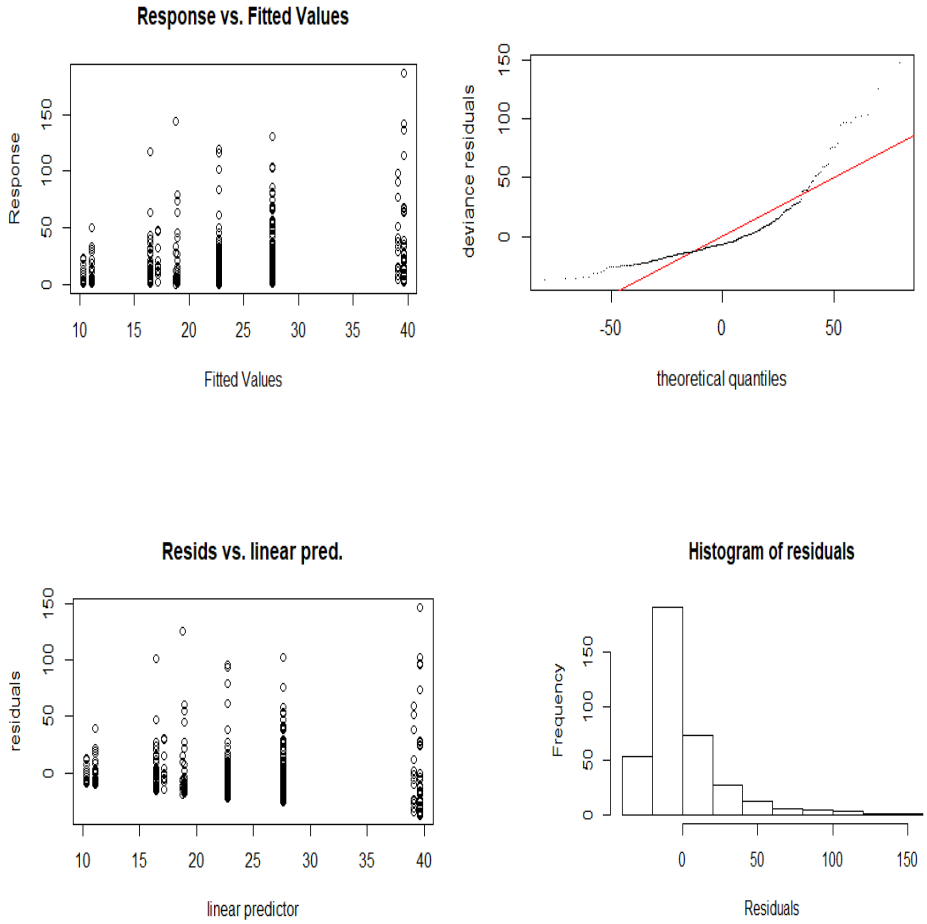






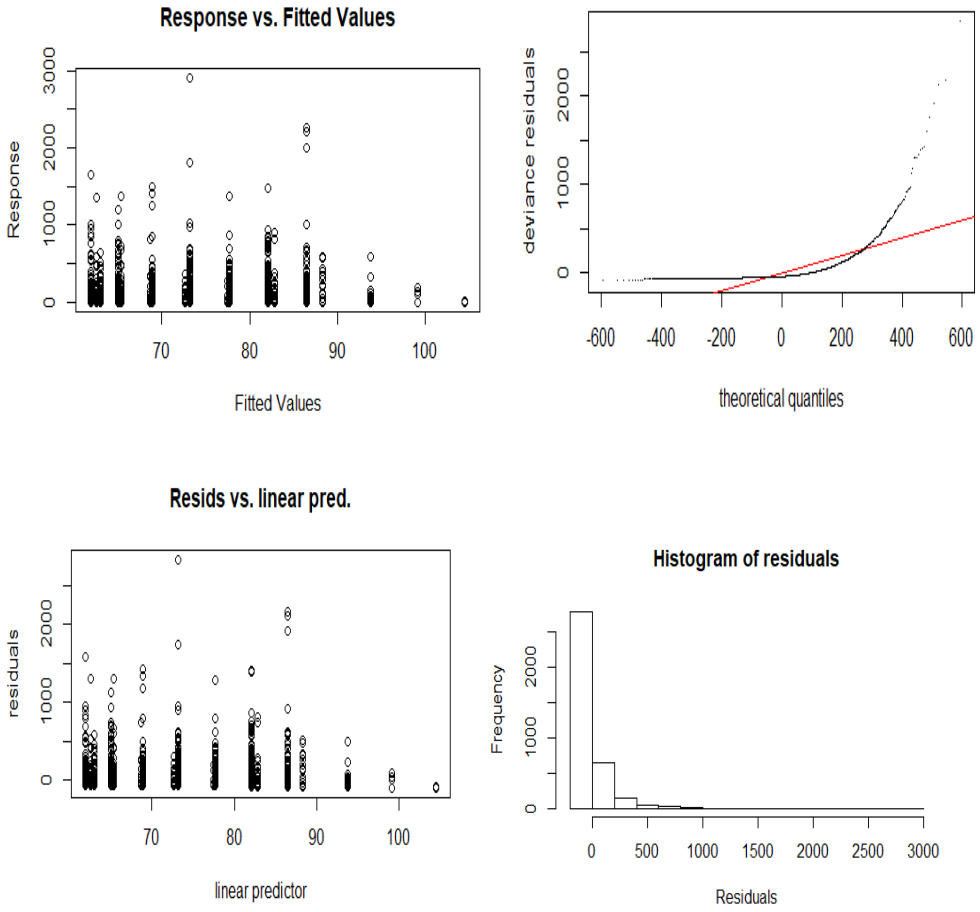
m) *Agyrosomus Inodorus*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 0.009730362 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species1$month) 9.00 7.35    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



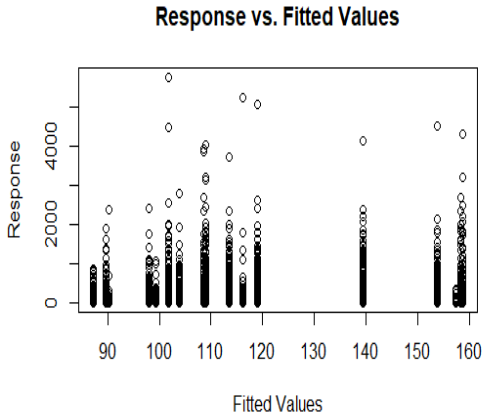
n) *Lepidotus caudatus*

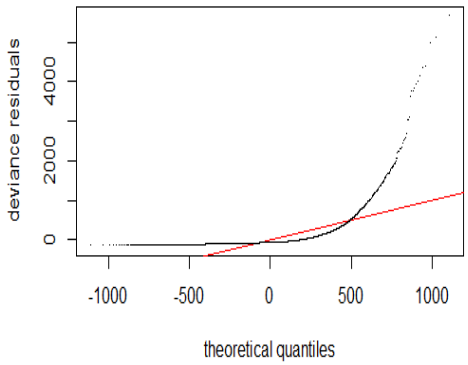
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 5 iterations.
The RMS GCV score gradient at convergence was 0.01268616 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species14$year) 9.00 2.43    0.19  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

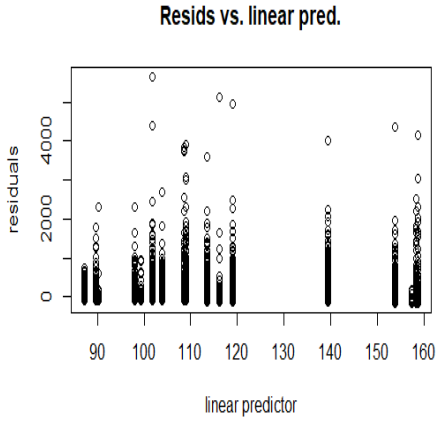


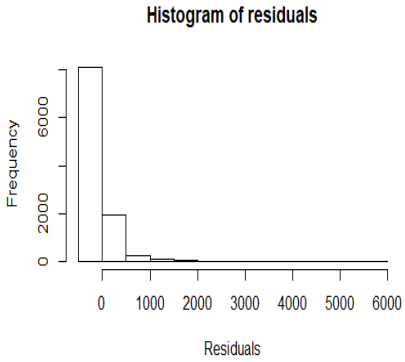
o) *Tranchipterus trachypterus*

```
 Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 8 iterations.
The RMS GCV score gradient at convergence was 0.007179304 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(species24$Year) 9.00 5.94    1.01     0.7
```



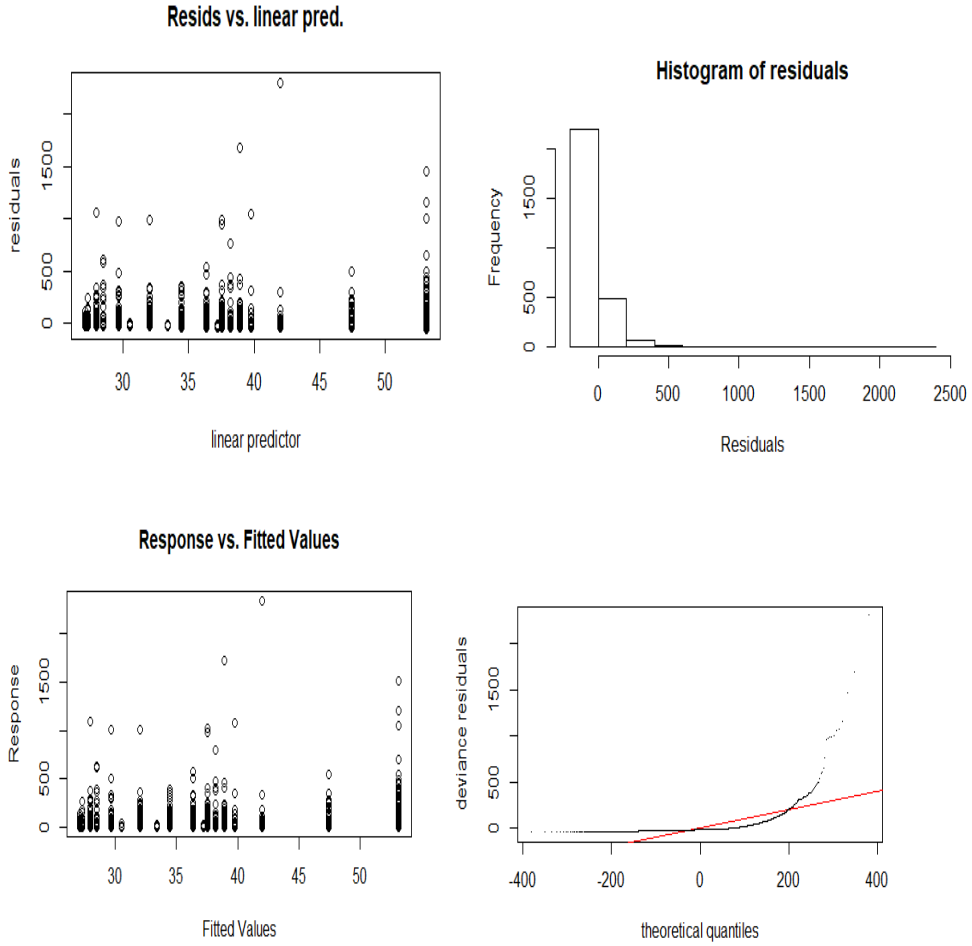






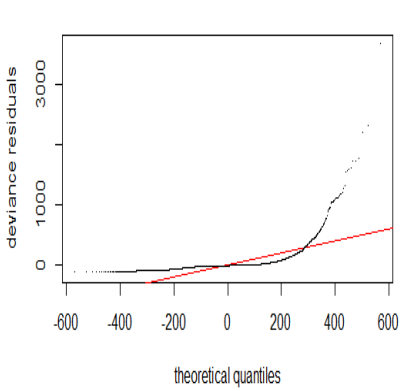
p) *Isurus oxyrinchus*

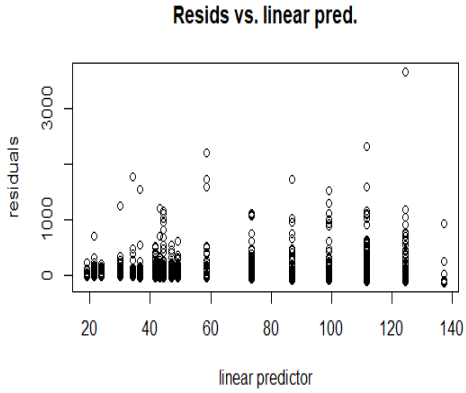
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 1.122577e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                     k'  edf k-index p-value
s(Species16$Year) 9.00 2.86     0.9  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

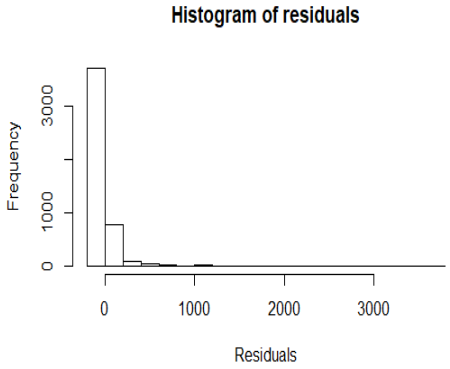


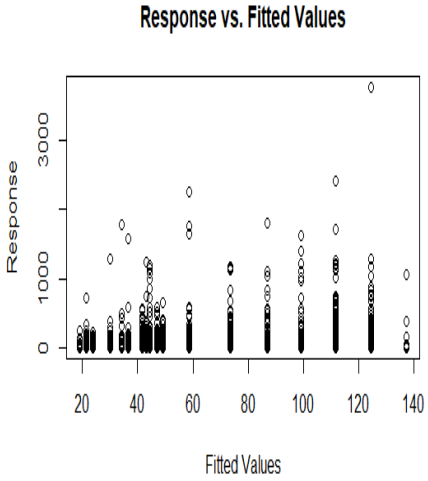
q) *Zeus faber*

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 6 iterations.
The RMS GCV score gradient at convergence was 0.008679259 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species12$year) 9.00 5.18    0.74  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



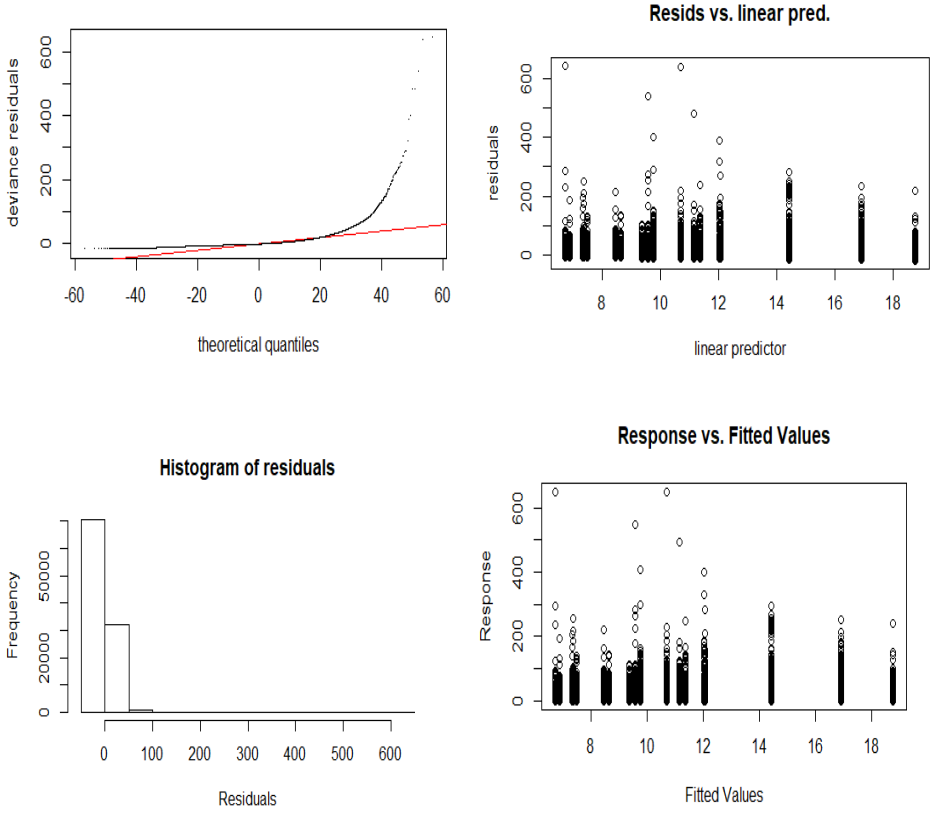






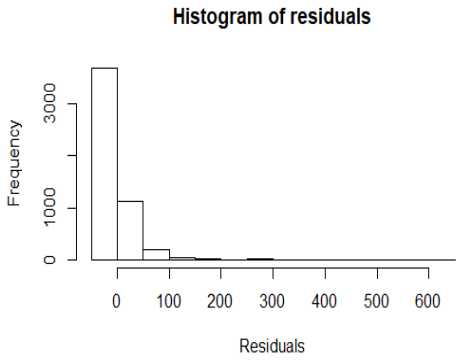
r) *Lophius vomerinus*

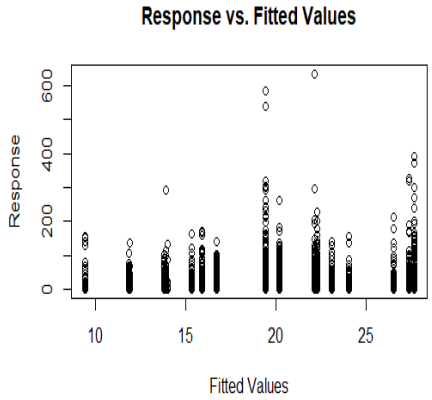
```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 10 iterations.
The RMS GCV score gradient at convergence was 6.647353e-05 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species17$year) 9.00 8.97    1.01    0.88
```

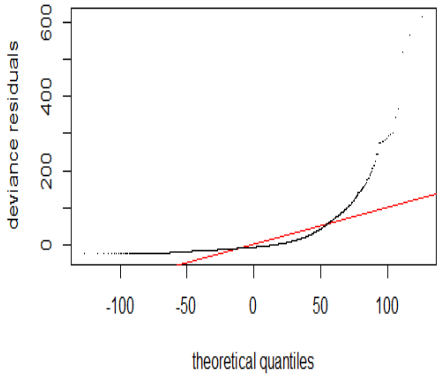


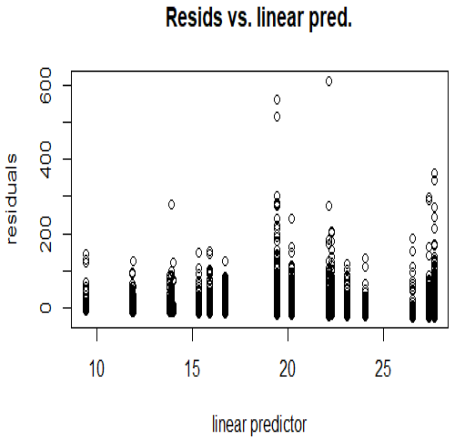
s) Chelidonichthys capensis

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 8 iterations.
The RMS GCV score gradient at convergence was 0.001678354 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                   k'  edf k-index p-value
s(Species5$year) 9.00 8.64    0.93  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

>
```



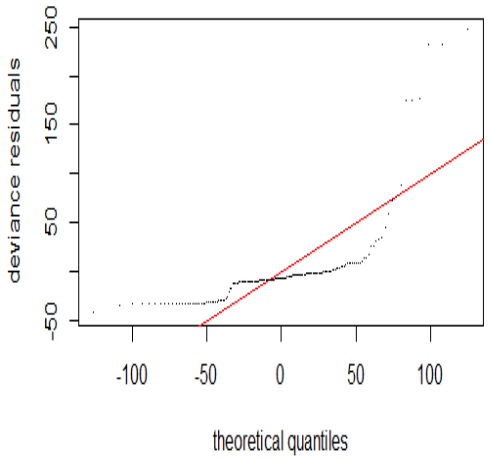


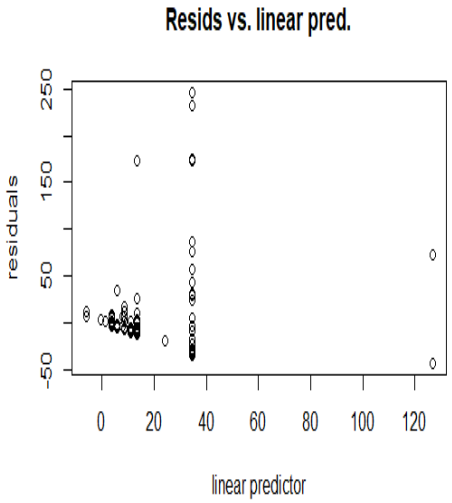


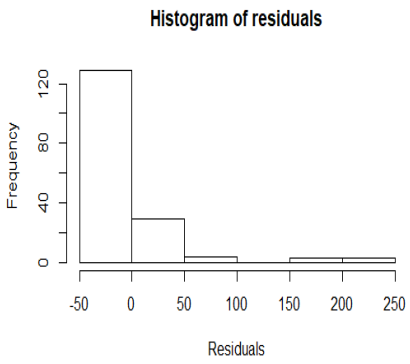


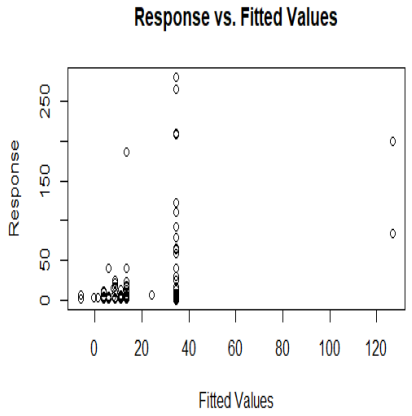
t) Allocyttus verrucosus

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 9 iterations.
The RMS GCV score gradient at convergence was 0.0003246574 .
The Hessian was positive definite.
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                    k'  edf k-index p-value
s(Species2$year) 9.00 6.97    0.68   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



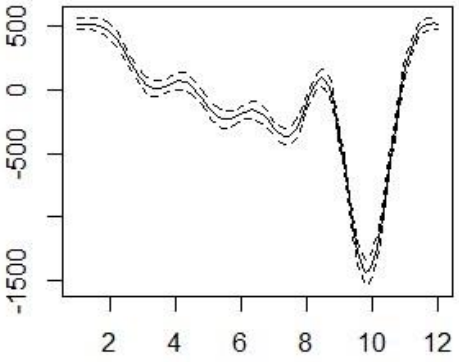




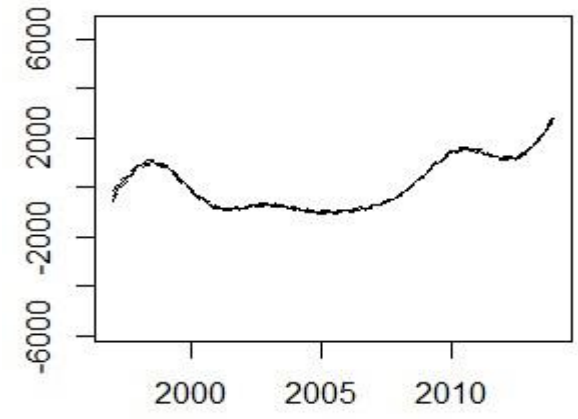


APPENDIX X: Results from GAM analysis on hake catch rates**.**

a) Monthly variations in hake catch rates



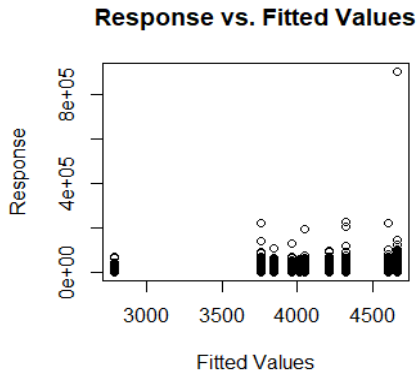
b) Inter-annual hake trends

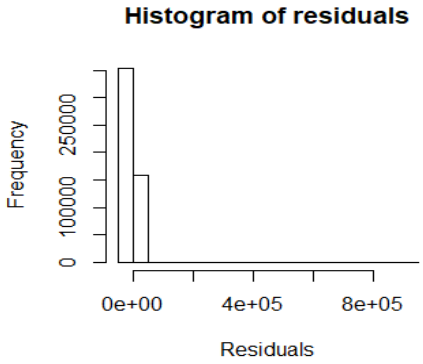


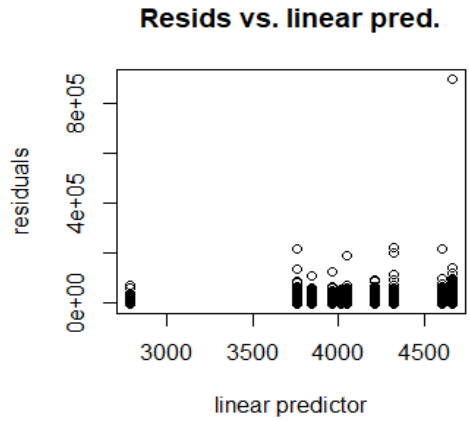
APPENDIX XI: GAM diagnostics for results on hake catch rates.

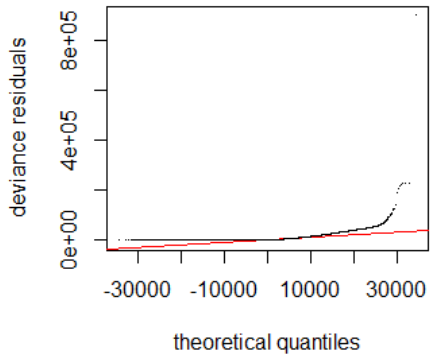
a) Monthly variations in hake catch rates

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 4 iterations.
The RMS GCV score gradient at convergence was 19.76845.
The Hessian was positive definite.
Model rank = 10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                       k'  edf k-index p-value
s(Hake- CPUE $month) 9.00 8.99    1.01    0.84
```



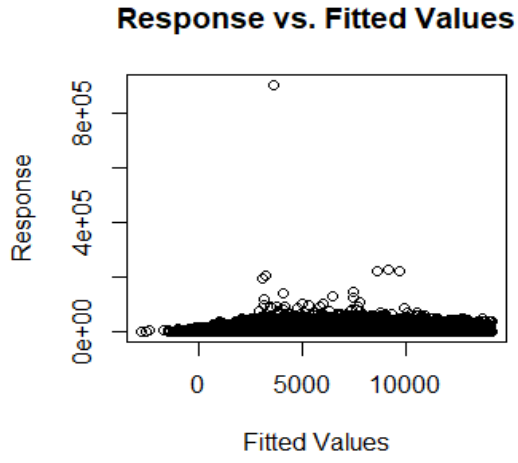


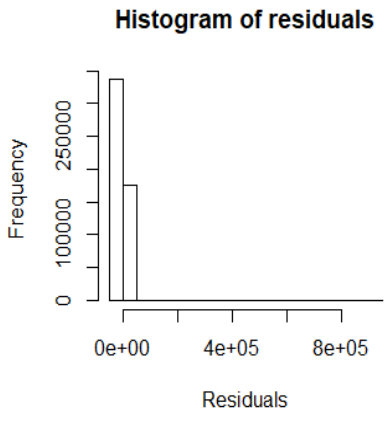


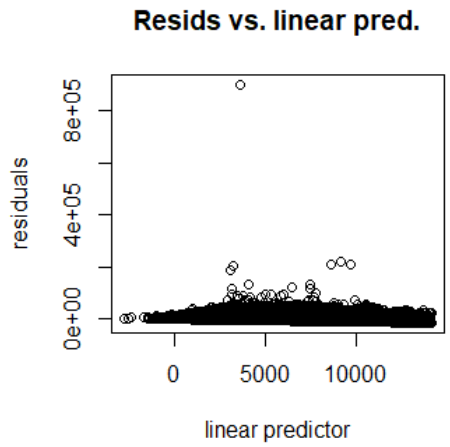


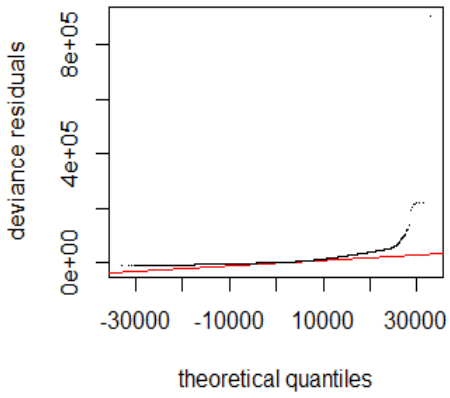
b) Inter- annual trends of hake catch rates

```
Method: GCV   Optimizer: magic
Smoothing parameter selection converged after 16 iterations.
The RMS GCV score gradient at convergence was 2.098794.
The Hessian was positive definite.
Model rank = 46 / 46

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                          k'  edf k-index p-value
s(Hake- CPUE$lat)       9.00 8.93    1.00   0.520
s(Hake- CPUE$month)     9.00 8.90    1.00   0.395
s(Hake- CPUE$year)      9.00 8.99    0.99   0.305
s(Hake- CPUE$Sea.Depth) 9.00 8.55    1.00   0.575
s(Hake- CPUE$GRT)       9.00 8.99    0.96   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

>
```









APPENDIX XII :Bycatch species from the hake bottom trawl fishery

Many bycatch species are distributed with the targeted species in assemblages as a result of their habitat requirement (Maurihungirire 2002). Because of this, the hake bottom trawl fishery catches many species of bycatch. Among them are the following species:

Blacktail (*Diplodus capensis*), is a coastal species usually on rocky grounds to a depth of 50 m. They occur along the entire coast of Namibia and is known to feed on seaweeds and benthic invertebrates (Bianchi et al. 1999). It grows to a size of about 40 cm. Blacktail is caught mainly with line gear by shore anglers and commercially from ski-boats but rarely caught in trawls.

Silver kob *Argyrosomus inodorus* occurs along the entire length of the Namibian coast but are most abundant from Meob Bay to Cape Frio (Kirchner & Voges, 1999). Namibian stocks are distinct from those occurring off South Africa (Van der Bank & Kirchner, 1997). Spawning adults move southwards from the northern end of their distributional range in early summer. Spawning occurs at Meob Bay and Sandwich Harbour (Holtzhausen *et al*. 2001). From here larvae drift northward to the nursery area between Sandwich Harbour and the Ugab River mouth. Two years after spawning juveniles reach the area north of the Ugab River. It is to this same area that adults return after spawning (Kirchner & Holtzhausen, 2001). In northern Namibia silver kob feed mainly on pelagic fish, shrimps and squid, whereas in the central and southern Namibia shrimps dominate the diet of these fish (Kirchner, 1999).

Yellowfin tuna *(Thunnus albacores)* is a cosmopolitan species. In the BCLME region the species forms part of an Atlantic population, which is found throughout the region (BCLME 2011) and hence found along the entire coast of Namibia. The main spawning ground of this population is off Brazil and the equatorial zone of the Gulf of Guinea, with spawning primarily occurring from January to April. Juveniles are generally found in coastal waters off Africa. Larger fish are found further offshore, along the edge of the continental shelf. The species occurs widely throughout the region (Bianchi et al. 1999). The yellow fin tuna is an opportunistic feeder, preys on almost any small pelagic organism such as fish, mantis shrimp, and squid.

Rattails are brown to black gadiform marine fish of the family Macrouridae. There are possibly 21 species from Namibia that mostly occur in the Northern parts. They are benthopelagic species that attain a maximum size of around 65 cm in length (Bianchi et al. 1999).

The Cape gurnard (*Chelidonichthys capensis*), is found throughout the length of the Namibian coast (Mafwila 2011), They are usually found on the continental shelf, from shallow depths to 390 m and feeds mainly on fishes and crabs (Bianchi et al. 1999). Caught mainly in bottom trawls and occasionally by shore anglers.

Large-eyed dentex also known as Reds (*Dentex macrophthalmus*), is occasionally caught with bottom trawls as a bycatch of the hake fishery, and as a bycatch of midwater trawlers. They inhabit rocky and sandy bottoms, from depths of 30 to 500 m. Inshore to offshore migrations of this species occurs seasonally in connection with spawning. Mainly off northern Namibia, where this species is very abundant (Bianchi et al. 1999).

John dory (*Zeus faber*), is a demersal species, found from coastal waters to a depth of 400 m. In the Eastern Central Atlantic, *Zeus faber* occurs from Norway and Faeroe Islands to South Africa. John dory feeds mainly on schooling bony fishes, occasionally on crustaceans and cephalopods (Bianchi et al. 1999).

West Coast sole, (*Austroglossus microlepis)*, is known as the only flatfish important commercially. They are found in waters 100−300 m deep along the entire Namibian coast and extends up to False Bay in South Africa (Mafwila 2011). Sole larvae are pelagic while adults live close to the sea bed. Adults prey on worms, crustaceans, molluscs, and fish (gobies and ladder dragonets) (Bianchi et al. 1999).

Grootskub-pomfret (*Taractichthys longipinnis*), is widely distributed in the epipelagic and mesopelagic zones of the Atlantic Ocean. In the eastern Atlantic it is known from Iceland and Norway south to Pointe Noire, the Gulf of Guinea and Namibia to False Bay, South Africa. The big scale pomfret is caught occasionally with trawls (Bianchi et al. 1999). It is a bycatch of the deep-water fishery that is found at a depth range of 0 - 500 m, but most common at 42 - 200 m depth. They feed mainly on shrimps and squids.

Horse mackerel (*Trachurus capensis)*, is of the abundant pelagic species found off the coast of Namibia. It is important not only as bycatch but support an important midwater fishery, firstly by volume, and secondly by value (Mafwila 2011). It is found mainly over the continental shelf, often over sand bottoms. It is observed at the surface as well as down to a depth of 400 m. Shoals rise to feed in surface waters at night while they are close to the bottom during daytime. It is an opportunist feeder, copepods are an important prey of juveniles, while adults feed on a wide range of invertebrates and fish (gobies and mesopelagic fish). Horse mackerel are widely distributed along the entire Namibian coast at 100−400 m water depth (Iitembu 2008, unpublished data).

Balck oreo (*Allocyttus verrucosus*) is a species with a circum–global distribution and thus it is found along the entire coast of Namibia. They are found over rough bottoms at depths between 338 and 1 300 m, but most common at depths greater than 800m. Juveniles are however pelagic and are found in midwater to surface. It is known to feeds on shrimp, cephalopods, and fish (Bianchi et al. 1999).

Thunnus species are highly migratory species, that are widely distributed throughout the Atlantic Ocean and Mediterranean Sea. Their dietary habits are varied and prey organisms include fish, mollusks and crustaceans (BCLME 2011).

Cardinal fish (*Epigonus species*) are sometimes caught in large quantities as bycatch by the deep-water fishery. They are demersal species found on soft bottoms at depths between 80 and 1 200 m. Four species reported from Namibia and another also possibly occurring there. They occur in depths between 75 and 1 200 m and attain a maximum size to about 60 cm total length (Bianchi et al. 1999).

Scabbard fish (*Lepidopus caudatus*) is normally caught by bottom-trawl net and long-lines. They are an important commercial fish species in the north eastern Atlantic and off Namibia and New Zealand (Barange et al. 1993; Nakamura and Parin 1993). They are a bycatch of the deep-water fishery and are usually caught on sandy bottoms. They are found in inshore waters of upwelling areas. They feed on krill, shrimps, clupeoids, mesopelagic fish, and chub mackerel (Bianchi et al. 1999).

Ribbon fish (*Trachipterus trachypterus*) occurs along the entire coast of Namibia (Heemstra and Kannemeyer 1986). They are offshore epipelagic species that swims with its head up. The are known to feed on squid and midwater fishes (Bianchi et al. 1999).

Snoek (*Thyrsites atun*) is a bycatch of midwater trawlers and occasionally caught in bottom trawls. They generally form schools which are found near the bottom or mid-water, and sometimes even at the surface at night (Nakamura and Parin 1993). They feed on pelagic crustaceans cephalopods and fish (Nakamura and Parin 1993) such as anchovy and sardine (Bianchi et al. 1999). *Thyrsites atun* has been recorded from 22° southward, at 100−350 m water depth (Iitembu 2008, unpublished data).

The Shortfin mako shark (*Isurus oxyrinchus),* is a coastal and oceanic species, with a circum–global distribution in all temperate and tropical seas (BCC 2011). It is distributed along the entire Namibian coast. This shark occurs from the surface down to at least 500 m, mostly in waters well offshore. It feeds on a wide variety of prey, including scombrids, carangids and cephalopods (BCC 2011). The Mako is a common by–catch in the tuna fisheries and is often caught as bycatch in other fisheries. It is one of the most vulnerable species to overfishing.

skates *(Raja species); The* munchkin skate (*Raja caudaspinosa*) is one of the raja species caught in Namibia. It grows at least 32 cm disc width. It is occasionally caught in bottom trawls. It inhabits depths of 310 to about 700 m and is mostly found in the south of Lüderitz.Feeds on mysids, lightfish, and polychaetes (Bianchi et al. 1999).

Angelfish (*Brama brama),* is a seasonal migrant, which comes close to shore (May and Maxwell 1986) and forms small schools. Their movement is known to be temperature related (Mafwila 2011). The *Brama brama* is also known to be an oceanic and epipelagic species, also found to depths of 1 000 m, moving to shallower waters for reproduction. They are preyed upon by oceanic predators such as tunas and billfishes, and in turn feeds on myctophids and other small bony fishes, euphasiids, and cephalopods (Bianchi et al. 1999). Angelfish are commonly found from 20° Southward in Namibian waters at 100−500 m water depth (Iitembu 2008, unpublished data).

The Shortfin mako shark is a coastal and oceanic species, with a circum–global distribution in all temperate and tropical seas (BCLME 2011). They are distributed along the entire Namibian coast. These sharks occur from the surface down to at least 500 m, mostly in waters well offshore. They feed on a wide variety of prey, including scombrids, carangids and cephalopods (BCLME 2011).

Kingklip (*Genypterus capensis*) is caught as bycatch in the Namibian hake fishery. They command a high price and are retained along with the hake (BCLME 2011). They were important commercially but were heavily overfished and catches now amount to a few thousand tons a year (Bianchi et al. 1999). They are known to be a bottom-dwelling fish inhabiting rocky areas of the continental shelf and upper slope from depths of 50 to 500 m but reported to be abundant between 250 and 350 m; juveniles occur in shallower waters than adults. They feed mainly on the bottom, on dragonets, mantis shrimps, hake, squid, and a variety of fish. They occur mainly in the southern parts of Namibia (Bianchi et al. 1999).

Jacopever (*Helicolenus dactylopterus*) is found in soft bottom areas of the continental shelf and upper slope (Bianchi et al. 1999). They feed on a wide variety of organisms, both benthic and pelagic organisms (crustaceans, fish, cephalopods and echinoderms) (Hureau and Litvinenko, 1986). From biomass surveys carried out by the Ministry of Fisheries and Marine Resources, this species has been found along the entire Namibian coast with the highest concentration in the Northern parts of Namibia, inhabiting water depths from 100−700 m (Iitembu, 2008, unpublished data).

The Monk fish (*Lophius vomerinus*), is known as a significant bycatch of the hake fishery.They are found on the deeper continental shelf and upper slope, from depths of about 200 to 500. According to Maartens et al.(1999) the highest densities occur at 300–400 m off the coast of Namibia, mainly in the central areas. The distribution of *L. vomerinus* ranges from northern Namibia to Durban (South Africa). According to Bianchi (1999), Monk feeds on various bottom- living fishes and occasionally on pilchard, round herring, hake and horse mackerel.

Flying squid (*Todarodes sagittatus*), is a demersal species found throughout Namibian waters at a depth range between 100−700 m (Iitembu, 2008, unpublished data). Their larvae are known to feed on plankton, adults feed on planktonic crustaceans, fish and other squids, since they are fast swimmers and active predators (Quetglas et al. 1999). They are also known to migrate to the surface at night.

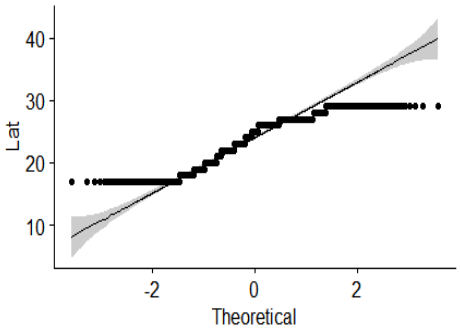
APPENDIX XIII: Table showing the annual CPUE of bycatch species (1997-2014)

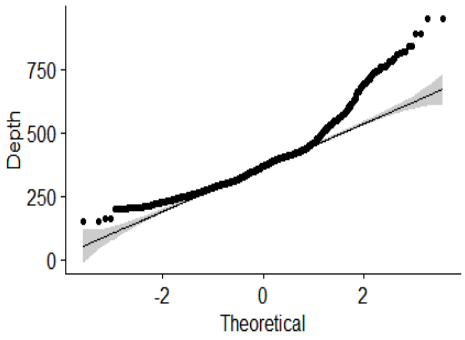
	Year																		Total
Species	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Argyrosomus inodorus	0	0	0	1.76131	0.179835	0.279372	3.369601	0.925795	1.362246	0.002239	0.017391	0.001661	0.310711	0.612092	0	0	0	0	8.822253
Diplodus capensis	0	0	0	0	0	0	0	0.227084	0	0	0	0	0	0	0	0	0	0	**0.227084**
Thunnus albacores	0	0	0	0	0	0.007143	0.375122	0.000335	0.23788	0	0	0	0	0	0	0	0	0	0.623494
Macrouridae sps	0	0	0	0	0	0.2113062	0.012632	0	0.042577	0	0	0	0	0	0	0	0	0	0.268270361
Chelidonichthys capensis	0.465066	2.487055	2.744883	8.293957	2.622313	7.492999	5.89397	2.523558	4.800047	2.601616	3.923137	4.357966	11.06142	2.428276	1.666752	4.801726	15.24363	8.3611	91.76948
Dentex macrophthalmus	1.59025	13.5602	33.65143	44.77053	23.88901	23.57682	26.95057	49.00303	48.84864	54.78051	26.45362	14.09947	27.60385	23.6819	13.11103	31.2733	20.18969	26.80664	503.8405
Zeus faber	1.833748	25.24451	45.32005	15.91321	17.56795	32.10741	14.30338	12.41745	6.429299	9.130286	4.157333	4.908459	5.687007	18.4553	12.434	13.44422	10.1315	9.03011	258.5152
Austroglossus microlepsis	1.074791	5.119861	11.10844	12.00126	14.60903	10.82278	17.8623	10.4866	16.17276	22.44551	14.5724	8.74365	21.07581	7.257106	7.158722	9.033125	9.080983	3.80239	202.4275
Taractichthys logipinnis	0	0	0	0	0	0.002102	0	21.9502	56.26368	45.72793	21.87087	20.1489	17.0061	18.58339	8.760096	16.86489	73.4805	60.88934	361.548

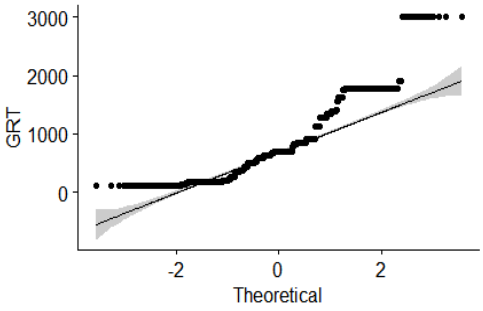
Trachurus capensis	17.15261	50.03969	60.77928	42.31807	34.39691	35.40019	44.71411	80.95459	82.0883	75.65452	28.96868	56.82988	105.7261	129.5189	47.54	95.74095	197.5011	115.9186	1301.242
Allocyttus verrucosus	0	0	0	0.283322	0.011263	0.411256	2.167321	0.063901	0.036625	0.086474	0.06615	0.002632	0.079741	0.002941	0.024354	0	0	0	3.23598
Thunus spp	0.001244	0	0	0	0	0	0.291106	0.011676	0.001286	0.014681	0.105298	0.074776	0	0.099761	0.066397	0	0	0.003974	0.670198
Epigonus spp	0	0	0.075717	0.324676	2.926449	2.656125	2.707993	0.454282	0.727877	1.132214	0.595754	2.42626	1.216644	1.358259	3.762617	0.224973	0.011529	0	20.60137
Lepidotus caudatus	0.024304	0.803721	2.008383	3.474742	4.821152	0.692151	2.270417	2.35096	7.622032	14.74934	21.13421	11.03038	32.58094	20.26102	31.94495	28.44337	54.73537	38.24838	277.1958
Trachipterus trachypterus	2.238141	52.0264	61.64036	79.37722	118.4322	165.4509	82.95177	114.4435	203.072	140.8168	118.3481	56.47414	42.94596	20.3626	6.507341	10.80737	15.43346	61.01624	1352.345
Thyrsites atun	2.19864	10.9247	16.85674	3.370902	16.3801	21.02051	17.3735	29.13211	46.92313	15.98799	17.38786	24.89745	68.345	55.19396	11.61809	3.845149	26.60947	73.17917	461.2445
Isurus oxyrinchus	2.255873	8.379888	5.281554	9.411398	9.277416	6.895987	8.707964	6.423671	7.458534	0.966098	1.22116	3.668603	0.357898	0.109818	0.054925	4.467542	5.133078	23.09424	103.1656
Raja species	0.092798	0.283237	0.444094	0.602168	.0	2.878749	0.693589	0.863131	1.253858	1.223639	0.470501	0.684593	0.584129	0.914509	0.439811	0.525679	0.874924	0.920972	15.05251
Brama brama	4.392271	14.24407	14.615	13.56074	31.29096	22.92483	31.38456	42.52535	9.3326	14.36473	4.525119	3.263243	5.754145	14.60322	9.695623	52.19683	84.51049	240.3047	613.4885
Genypterus capensis	0.227631	2.361962	3.150274	9.709348	14.59365	12.04001	64.60621	53.87559	59.16644	43.16389	248.7556	43.86724	59.79984	73.8952	33.16683	59.01484	46.15876	15.3665	842.9199
Helicolenus	1.577649	11.22268	20.60475	21.84576	31.76876	35.86763	105.8058	97.38023	81.61024	95.14888	84.7337	122.2994	105.5027	88.14409	62.15329	104.0909	82.96694	26.6209	1179.344

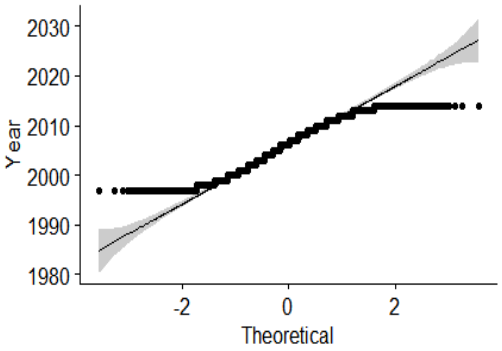
dactylopterus																		
Lophius vomerinus	23.47727	73.50093	83.56205	80.36365	96.02302	80.06924	69.97729	65.32694	68.50996	48.53093	34.75009	42.07245	42.94779	44.34278	38.17413	42.44909	39.60702	48.95119	1022.636
Todarodes sagittatus	3.61577	12.51054	18.88839	19.37857	45.35602	59.16599	66.0513	27.53305	17.87103	15.16818	18.82747	25.33892	17.94392	14.23536	6.553662	17.22751	9.667169	15.06372	**410.3966**

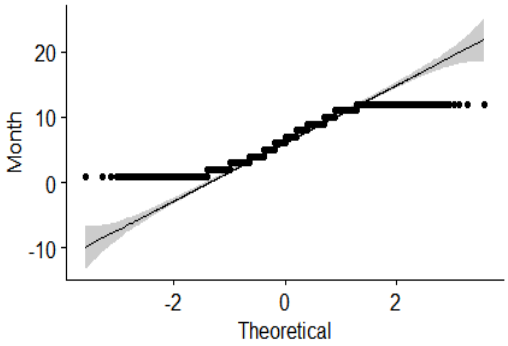
APPENDIX XIV: Normality using Q-Q plots (quantile-quantile plots)



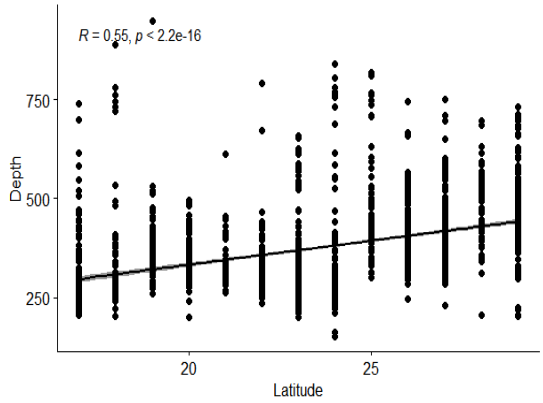


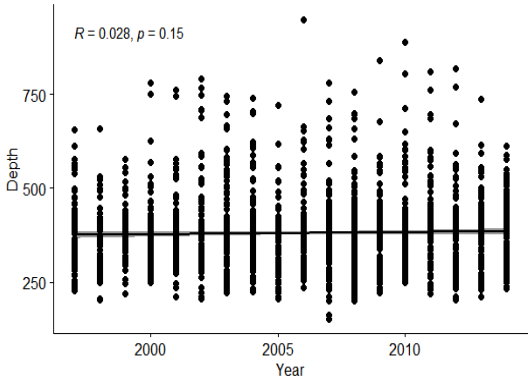


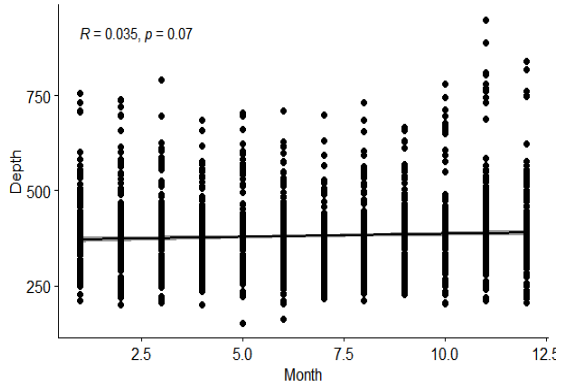


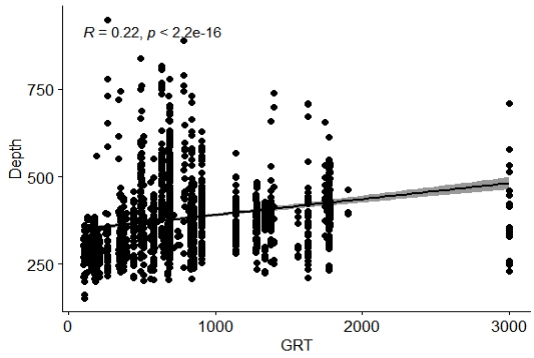


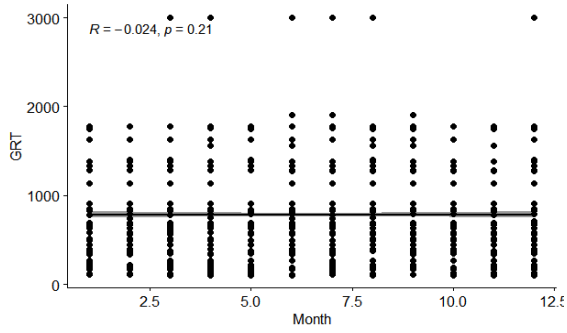
APPENDIX XV: Scatter plots from correlation test

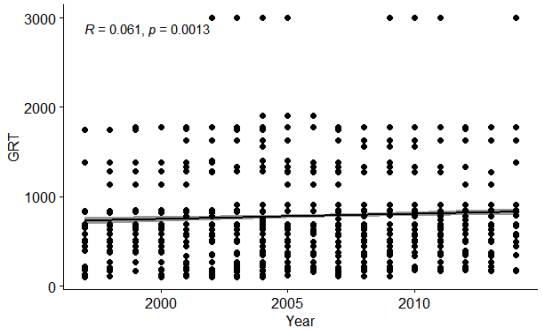


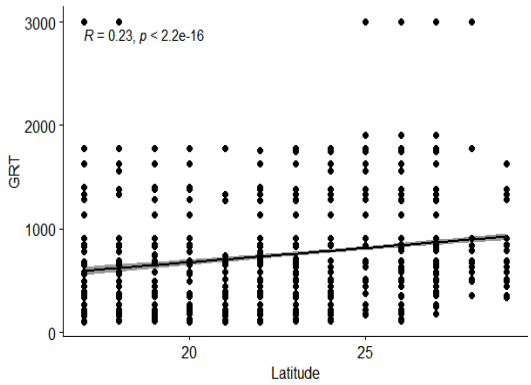








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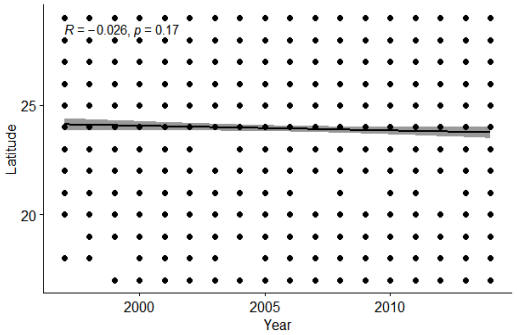
GRT
3000
2000
1000
0
20
25
Latitude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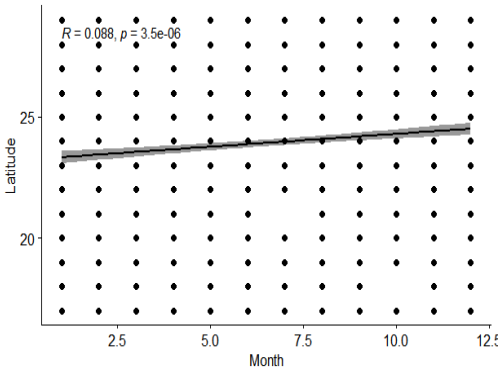
Latitude
25
20
2000
2005
2010
Year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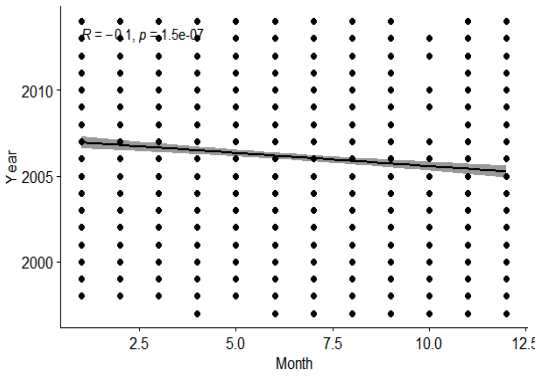
Latitude
25
20
2.5
5.0
7.5
10.0
Month


R = −0.1, p = 1.5e-07
Year
2010
2005
2000
2.5
5.0
7.5
10.0
Month

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UNAM
UNIVERSITY OF NAMIBIA

RESEARCH PERMISSION LETTER

25 October 2017

Student Name: Mr Greg Limbo Mbaimbai

Student number: 201203186

Programme: *MSc (Fisheries & Aquatic Sciences)*

Approved research title: Assessment of Bycatch from the Namibian Hake - Directed Bottom Trawl Fishery

TO WHOM IT MAY CONCERN

I hereby confirm that the above mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

25 Oct 17

Dr M Hedimbi
Director: Centre for Postgraduate Studies
Tel: +264 61 2063275
E-mail: directorpgs@unam.na

Date