ASSESSING THE FEASIBILITY OF COMBINING MONKFISH- AND HAKE-DIRECTED ANNUAL BIOMASS SURVEYS IN NAMIBIA

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ABSTRACT

Since 1990, Namibia has conducted annual hake biomass surveys in January and February for a period of six weeks, covering bottom trawl depths ranging from 80 to 700 metres at approximately 210 stations. Historically, monkfish have only been assessed as bycatch during hake surveys. The first annual monkfish biomass survey was conducted in November 2000, and the TAC was set in 2001. Biomass surveys for monkfish are now conducted annually in November for a period of three weeks, with 94 stations covering bottom depths ranging from 100 to 700m. The entire Namibian coastline was of interest during this study, spanning the various areas where monkfish and hake biomass surveys were conducted, to assess whether it was possible to combine hake and monkfish biomass surveys for estimating monkfish biomass while taking into account all factors, such as gear differences, survey design, biomass, size structure, spatial distribution, and survey time periods. A binomial GLM was performed to quantitatively estimate the size differences between the two surveys. If the Monkfish survey is merged with the Hake survey, the underrepresentation of smaller monkfish could become a major issue.

Keywords: Monkfish biomass survey, hake demersal survey, survey integration, catchability and size structure, fisheries management, Namibia.

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LIST OF ABBREVIATIONS

- GDP Gross Domestic Product
- CPUE Catch per Unit Effort
- TAC Total Allowable Catch
- GRT Gross Register Tonnage
- MFMR Ministry of Fisheries and Marine Resources
- NatMIRC National Marine Information and Research Centre
- NM Nautical Miles
- FAO Food and Agricultural Organisation of the United Nations
- ICSEAF International Commission of the Southeast Atlantic Fisheries
- GLM Generalized Linear Model
- CI Confidence Interval
- TL Total Length

1 INTRODUCTION

1.1 Namibian Fisheries

In Namibia, the fisheries sector, including processing, is the third largest industry in terms of gross domestic product (GDP) contribution, accounting for approximately 15% of total export value. In 2017, annual marine landings of approximately 550 000 tonnes were recorded, valued at an average of N$ 10 billion (approximately 625 million EUR). Approximately 16,000 people work directly in the fisheries sector, while others work indirectly in fisheries-related activities, such as supply and logistics. By providing a source of protein, the fisheries sector contributes significantly to domestic food security. The industry comprises onshore and offshore fishing and fish processing sectors, maritime sectors, and a developing aquaculture sector (Haimbala, 2021).

1.2 Monkfish fishery in Namibia

The demersal trawl fishery off the coast of southern Africa began before the turn of the nineteenth century (Boyer and Hampton, 2001); however, statistics on Namibian monkfish exploitation date only from 1974. Hake trawlers, monkfish vessels, and hake longliners comprise Namibia's demersal fleet. Hake and monkfish vessels can be classified as wetfish (fish landed fresh) or freezer vessels (Maartens and Booth, 2001). Hake trawlers and longliners land monkfish as bycatch.

Previously, monkfish were only considered bycatch in trawl fisheries targeting hake (*Merluccius spp.*); however, due to increased market demand and value, a fishery targeting monkfish was developed (Maartens and Booth, 2001). Fishing rights for monkfish were established in 1994, along with a bycatch quota in the hake fishery. Monkfish are also caught in experimental fisheries, but in small quantities.

Total allowable catches (TACs) have controlled annual catches in this fishery since the 2001 season (Iyambo, 2006). Because of the overlap of the habitats of Cape hakes and monkfish, approximately 5-7% of the monkfish TACs are allocated to the hake-directed fishery as unavoidable bycatch (Kathena, 2019).

The bulk of monkfish landed in Namibia is caught by bottom trawling. The two common denominators for these nets, however, are that all of them are fitted with "tickler chains" in front of the footrope to scare the fish off the bottom, and that in most cases, trawls have a fairly low vertical opening. The minimum legal mesh size for monkfish is 75 mm in the cod-end; however, the majority of the fleet uses a mesh size of either 110 mm or 120 mm (Maartens, 1999).

To standardise the CPUE and investigate other aspects of the fisheries, vessels in the fishery were divided into six categories depending on their Gross Register Tonnage (GRT) (Appendix VII). The gross register tonnage (GRT) of monkfish-targeted vessels has increased over the years, mostly owing to the introduction of larger vessels into the monkfish fishery (Erasmus, 2020). Monkfish vessels are mostly seen fishing at depths of 300–500 m, but they also fish along the entire Namibian coast (Iyambo, 2006).

In 2021, 16 monkfish vessels fished for a total of 1,644 fishing days, compared to 18 vessels for 1,861 fishing days in the previous year. During the 2020/21 fishing season, 7,799 tonnes of monkfish were landed from all fisheries, exceeding the overall TAC of 7,300 tonnes (Nangolo et al., 2022). Because the gear used to collect monk and hake is similar, six vessels used in the monk sub-sector are also used in the hake sub-sector.

1.3 Annual Biomass Surveys

Catch per unit effort (CPUE) has frequently been used in commercial fisheries to provide information on changes in fish abundance. In general, the relationship between commercial catch rate and stock abundance is assumed to be linear, with CPUE being directly proportional to abundance (Maartens and Booth, 2001). In recent years, there have been large changes in the structural specifications of the trawl gear used by the fleet targeting monkfish. This has resulted in an increase in the commercial CPUE (Kathena et al., 2018).

Research surveys are particularly useful because vessel characteristics are constant over time, and the region and time of the survey can be controlled. Therefore, they are less likely to be biased in providing estimates of trends than indices (CPUE) obtained from commercial fisheries. However, survey biomass estimates might be expected to show more variability than the CPUE indices because research surveys typically take place only once or twice a year, whereas commercial CPUE series are obtained from data averaged over a whole year (Iyambo, 2006).

Namibian hake biomass surveys have been conducted since 1990 on board the Norwegian research vessel Dr. Fridtjof Nansen. Monkfish survey data were collected during the hake biomass surveys as bycatch. These data have been considered not to represent reliable indices of abundance for monkfish for the following reasons: (i) these surveys were directed at catching hake, and the gear type used as well as the trawl speed differed considerably from that typical for the monkfish-directed fleet; and (ii) the catching efficiency for monkfish was therefore reduced using the research gear, and the calculated biomass estimates are considered to be underestimates of the stock size (Iyambo, 2006). Although these reasons do not exclude the use of these survey results relative indices of abundance, they were nevertheless later abandoned by the National Marine Information and Research Centre (NatMIRC) in favour of the use of results from monkfish dedicated surveys.

The hake biomass survey has followed the same design since 1990: a systematic transect design with a semi-random distribution of stations along transects (Figure 1b). Stations within the transects were selected such that each 100-m bottom depth had at least one station. In the extreme south, where the shelf is very wide, stations on the shelf were approximately 10 nautical miles (NM) apart. Transects ran perpendicular to the Namibian coastline and were approximately 20-25 NM apart, with transect lengths ranging from 20 to 80 NM (Paulus et al., 2016). All hauls shallower than 400 m were performed during the day, generally between 06:00 and 19:00, because hake (especially M. capensis) is known to lift off the bottom at night (Iilende et al., 2001), possibly in search of prey.

Swept-area biomass surveys for hake are conducted annually in January and February for a period of 6 weeks, where around 210 stations are trawled, covering the bottom depth between 80 and 700 m (Paulus et al., 2022). During these surveys, monkfish are assessed as bycatch.

1.4 Monk Biomass Surveys

The first dedicated monkfish biomass survey was conducted in November 2000. The objective was to test whether the length frequency and biomass estimates of monkfish differed from the biomass and length frequency of monkfish from a hake dedicated survey (Schneider and Johnsen, 2000).

The survey design was an optimised geostatistical stratified random design (Schneider and Johnsen, 2000). The strata, or cells, were created as follows: the distance between 17°01, 5 s and 30°00, 0’ S along the coast was divided into 40 equal intervals, while the east-west direction was divided into 19 nautical miles intervals. The survey area was defined by a polygon of the assumed monkfish distribution, which was then subdivided into smaller cells. In each cell inside this polygon, eleven positions were randomly selected. Position number one was trawled, if possible. If this was not possible due to an untrawlable bottom, the next position on the list was trawled, and this process continued until a station was identified and, if possible, trawled in the cell. The 2000 design was slightly modified as cells that were found untrawlable in 2000 (Schneider and Johnsen, 2000) due to rough bottoms were left out of this survey. Currently, the annual monkfish biomass surveys are based on 94 predetermined stations that have proven to be trawlable over the years, as illustrated in Figure 1(a).

1.5 Survey Gear Dynamics

Scientific surveys are a valuable source of data for estimating population abundance, and many stock assessments rely on time series of abundance indices obtained from these surveys. However, the temporal continuity of such time series may be hampered by changes in the survey vessel or fishing equipment (Pelletier, 1998).

Fish reactions to trawl components may alter herding and escape patterns, thereby reducing catch efficiency. Several studies have found that visual cues and trawl components (doors, bridles, and footgear) herd most fish in front of the trawl into the trawl path, where they are captured (Nguyen et al., 2023).

Seasonality, which is the availability of the target species at a certain time of year (factors such as migration, feeding, and spawning behaviour, as well as the environment, could all play a role here), trawl doors, bottom contact, geometry, herding capability, ground gear that determines escapement, and rigging, are all factors that could affect catch rates. In particular, for this study, the constraint rope used in hake survey gear and the tickler chain used in monkfish survey gear can considerably affect the catch rates of these trawls. The purpose of the constraining rope is to keep the doorspread fixed regardless of wire out. An increased doorspread increases the swept area while decreasing the opening and centre gear bottom contact.

A tickler chain is a chain attached to the ground gear and is designed to shake bottom-dwelling species, causing them to lift above the fishing line and enter the trawl. Smaller bobbins on the footrope of the net improved monkfish catchability.

A weighted footgear at the bottom of the trawl mouth keeps the trawl in contact with the seafloor and protects the netting from damage. The type of footgear used is determined by the type of bottom trawl, seabed, and target species. Rockhopper footgear has recently become popular in commercial trawl fisheries to allow for fishing on rougher bottoms, reducing net damage, and improving capture efficiency. Furthermore, rockhopper footgear has been shown to be more effective than traditional steel bobbin gear in catching fish close to the bottom. Interdisc spaces can be increased by using larger rubber spacers between the rockhopper discs, allowing small fish to escape under the footgear.

The effectiveness of fish behaviour (ability to escape) at the trawl mouth may differ according to fish size, resulting in differences in length-based escape under the footgear at particular locations (Nguyen et al., 2023).

The estimates of monkfish abundance from hake surveys were questionable because the gear used was designed to collect hake rather than monkfish. Monkfish act and distribute differently than hake, which could have major ramifications for the accuracy of the abundance estimates of the latter. Hake surveys are conducted using a 'rock-hopper' ground rope, which lifts the fishing line 25 cm above the seafloor. This may significantly reduce the catchability of epibenthic fish, such as monkfish, because the escapement under the fishing line may increase. Tickler chains are used by commercial monkfish trawlers to increase their monkfish catches. This suggests that monkfish were not caught efficiently using the ground gear of the hake survey. There was also concern about serious monkfish size selection in the hake survey trawl, which could lead to an underestimation of the number of small fish due to the higher escapement of small length classes of monkfish (Schneider and Johnsen, 2000).

During the monkfish annual biomass survey, which is conducted in November each year for approximately three weeks and covers the bottom depth between 100 and 800 m, a total of 94 stations are covered (Nangolo et al., 2022).

1.6 Objectives

The overall goal of this study is to determine whether it is possible to combine hake and monkfish biomass surveys while considering all factors, such as gear differences, survey design, survey time periods, biomass, size structure, and spatial distribution of monkfish.

The need for this assessment is driven by impending budget cuts, which may necessitate the consolidation of certain surveys in the near future.

1.6.1 Specific Objectives

The goals of this study are as follows:

- Assess differences in the biomass, length distributions, densities, and spatial distribution of monkfish from both monkfish and hake biomass surveys, using data from monkfish surveys from 2000 to 2022 and data from hake surveys from 1999 to 2022.

- Perform a generalized linear model (GLM) to compare length distribution of monkfish in the monk dedicated and the hake dedicated surveys to assess whether it is possible to combine monk and hake biomass surveys.

2 LITERATURE REVIEW

2.1 Fisheries Management

Namibia has a stringent regulatory system empowered by the Marine Resource Act (Act 27 of 2000) which outlines the procedures for applying for fishing rights and allocating fishing quotas. It sets out the procedures and criteria for licencing fishing vessels and controlling fishing activities. The act empowers the MFMR to take management measures which include setting TACs, specification of fishing gears, management measures to protect juvenile fish, minimum fish sizes to be landed, restriction of bycatch, and regulating fishing seasons and transboundary activities (Haimbala, 2021).

The main purpose of fishing rights is to limit entry into the fishing sector to protect fisheries and marine resources and ensure responsible utilisation, conservation, protection, and promotion of marine resources sustainably.

Namibia's Marine Resources Act of 2000 has been celebrated internationally as one of the most progressive and successful fisheries policies, earning Namibia the Food Security Policy Leadership Award in 2010 and the Silver Future Award in 2012 (Paterson et al., 2013).

The Benguela Current large marine ecosystem, in which Namibia's ocean falls, is one of the most productive large marine ecosystems in the world. Namibia's fishery resources have been of global importance for centuries now. Unlike other fishing nations, Namibia's fisheries did not originate from local small-scale subsistence fisheries. Instead, the country's marine resources have always been subject to foreign, industrial-style exploitation. Thus, when Namibia gained independence in 1990, the state restructured the fisheries sector to direct the flow of benefits toward Namibians (Paterson et al., 2013).

In line with neoliberal views of traditional fisheries economics, the Namibian government hoped that the economic rents and employment created by the fisheries sector would help address the country's pressing poverty issues, although other measures had been implemented to redress existing inequities more directly through the country's Namibianisation policy, which aims to increase the involvement of Namibians in the fishery. In addition, the Namibian Fish Consumption Trust has been established to provide Namibians with access to fish products at low prices to offset the potentially negative effects that an industry directed at global markets might otherwise have on local food security (Paterson et al., 2013).

Capture fisheries are governed by a rights-based system. The Ministry of Fisheries and Marine Resources (MFMR) conducts scientific research and provides scientific advice to determine the Total Allowable Catches (TACs) for each fishery to ensure resource sustainability. The TAC is allocated to fishing right holders by the MFMR through a quota-based system (MFMR, 2022).

2.2 Gear

Trawling is one of the most widely used fishing methods worldwide, catching a wide variety of marine organisms. It entails a wide range of gear sizes, from small towed gear to massive midwater trawls. Trawling techniques have evolved over time, with the most significant change being an increase in gear size, which has frequently resulted in better fishing efficiency for specific targets. Trawl gear has the inherent disadvantage of encountering and capturing organisms that should have been avoided for various reasons, such as undersized individuals of the target species, endangered species, low-value fish, and charismatic species such as sea turtles and marine mammals (Valdermarsen and Suuronen, 2001).

One major reason for non-target organism capture is that the trawl's retaining bag (the cod end) is made of a mesh that is too small to allow non-target organisms to escape. Consequently, trawl conservation regulations have focused on increasing the size selectivity of cod ends. Positive results have been obtained in single-species fisheries with relatively simple constructional changes, such as increasing the mesh size or modifying the shape of the cod end meshes. Size selection can also be improved by changing the overall cod-end design, twine type and thickness, and removing cod-end attachments, such as chafers and lifting bags. Sorting grids and special selectivity panels inserted into trawls have been successfully used for size sorting in certain fisheries, and recent developments in flexible sorting grids offer new opportunities for practical and effective size sorting. However, simple gear modifications do not improve size and species selectivity in mixed-species trawl fisheries. The basic strategy used in such situations is to exploit the differences in the behaviour patterns of target and non-target organisms during capture. The examples below show some successful developments in which trawl gear has been modified to reduce the capture of non-target organisms (Valdemarsen and Suuronen, 2001).

Otterboards or trawl doors help the trawl sink by creating lateral ground shear and hydrodynamic forces that spread the net horizontally. They are heavy structures to ensure sufficient strength; however, their static weight is partially offset by hydrodynamic forces when they are in operation (Valdemarsen and Suuronen, 2001).

Sweep and bridles connect the net to the trawl doors in a typical bottom trawl. These can be short or long, depending on the trawl size and whether they are intended to "herd" finfish into the trawl path. Sweeps and bridles can thus increase a trawl's effective fishing width many times over its actual wingspread. Sweeps and bridles can be made of wire rope, rope, or chain, or they can be threaded with rubber discs, bobbins spaced at different intervals, or other components, depending on the fishery, fishing grounds, and other factors. The lower bridle is usually in contact with or close to the bottom, but it is under such high linear tension that its downforce against a smooth bottom is modest and infrequent. However, it can exert powerful lateral forces against any vertically protruding structures or organisms that obstruct its forward motion, and these lateral forces can translate into downward forces if the bridle rides up over them rather than knocking them down or shearing them off (Valdemarsen and Suuronen, 2001).

The ground gear is the portion of the trawl that contacts the bottom. It plays an important functional role in the capture process by keeping the lower margin of the trawl in contact with or close to the seabed and protecting the rest of the net from damage caused by bottom contact. There are numerous types of ground gears used in bottom trawls. Many factors influence their design, including fishing strategy, bottom composition and topography, and target species. Ground gear can range from a simple length of chain, rope, or wire rope to heavy and complex structures of chains threaded with steel or rubber rollers (bobbin gear). Although a bare-chain footrope may appear light and harmless, it can undercut and shear off bottom structures or organisms. Alternatively, bobbins and rollers may appear dangerously large and heavy, but they actually spread the force of footrope contact, exposing a larger area to lower force per unit area, allowing the footrope to roll over boulders and other structures without dislodging them from the seabed. Large rollers may also allow many smaller bottom organisms to escape unharmed under the net, depending on their size and spacing along the footrope. Despite this, it is possible to conclude that large rollers, tyre gear, rock hoppers, and other specialized footropes were developed specifically to allow the net to be towed over rougher, possibly more complex substrata that may support many fragile organisms, serve as nursery areas, or have other critical functional significance. The use of such gear has increased the number of trawlable areas (Valdemarsen and Suuronen, 2001).

2.3 Monkfish (*Lophius vomerinus*) Biology

The distribution of *Lophius vomerinus* extends from northern Namibia (21˚S) in the southeast Atlantic to Durban, Natal (30˚S, 31˚E) on the east coast of South Africa and in the northern and western Indian Ocean (FAO, 2008). *Lophius vaillanti* is found in the eastern Atlantic from north of Walvis Bay (23˚S) to the Gulf of Guinea (Maartens and Booth 2005). The bathydemersal *Lophius vomerinus* is found on the continental shelf and upper slope at 150-800 m bottom depths, on soft-muddy to hard sand and gravel substrates (Bianchi et al., 1999). The early life stages (eggs and larvae) are pelagic (Bianchi et al., 1999).

Lophius vomerinus is commonly found in waters deeper than 100 m, with the majority of the stock found between 100 and 500m. Another *Lophiiformes* group species, *Lophius vaillanti*, is also found in northern Namibian waters deeper than 400m, but in less abundance (Bianchi et al., 1999).

Lophiiformes are one of the most common groups of fish sit-and-wait predators, and they lure their prey by moving the illicium. Monkfish are opportunistic predators, and their diet is determined by the size of their mouths and the available prey (Bianchi et al., 1999).

Two separate nursery areas are known to exist: one off Walvis Bay (23°–25°'S) at depths between 150 and 300 m and the other near the Orange River (28°35'S) at depths between 100 and 300 m (Nangolo et al., 2022).

According to gonadal development, *L. vomerinus* spawns all year, with a slight increase in spawning intensity during the winter (Maartens, 1999). *Lophius vomerinus* spawn veils, which are flat gelatinous egg masses that float near the water's surface. Monkfish spawning is thought to occur on or near the seafloor (Maartens, 1999).

The species may live for more than ten years, but only a few individuals of this age are found in trawl samples. During the biomass surveys, females outnumber males.

The ages of *L. vomerinus* are estimated using sectioned illicia based on increment counts of presumably annual successions of a dark opaque and translucent zone corresponding to a year (Kathena et al., 2018).

Larval *L. vomerinus*, 15-20 mm long, have been captured in pelagic fine-mesh nets, and it is therefore estimated that the eggs and larvae remain in the pelagic zone for 4-8 weeks (Leslie and Grant, 1990; Armstrong et al., 1992). During this time, surface currents can transport egg masses and larvae between 400-800 km. The gonad mass of a mature female in spawning condition forms up to 35-50% of the body mass (Walmsley et al., 2005), representing a considerable energetic contribution to reproduction. Female *Lophius* mature at a larger size than males, and spawning seasonality varies between species and geographic areas. The spawning season of *L. vomerinus* is during the austral spring (Maartens and Booth, 2005). The lengths-at-first maturity are 58.2 and 39.9 cm for females and males, respectively (Maartens and Booth, 2005). The common reproductive strategy of *Lophius*, releasing eggs in single veils, may facilitate their dispersion and that of the larvae over a great distance, which allows for protection against predators (Armstrong et al., 1992). Historically, the International Commission of the Southeast Atlantic Fisheries (ICSEAF), and in particular, Spanish researchers, identified two separate recruitment areas: the first off Walvis Bay (23ºS–25ºS) at depths between 150 and 300 m and the second near the Orange River (28ºS) at depths between 100 and 300 m (ICSEAF 1984). These observations were confirmed by independent data collected by the Norwegian RV Dr. Fridtjof Nansen during a trawl survey in 1990. A similar observation was recently confirmed by Erasmus (2018) using an *L. vomerinus* port sampling program. Erasmus (2018) confirmed the previous finding that peak spawning for *L. vomerinus* in northern Benguela occurs between July and September, similar to the findings of Maartens and Booth (2005).

Few fish have been reported to prey on *L. vomerinus* off the Namibian coast. *Chelidonichthys queketti*, on the other hand, would only feed on small monkfish, as they reach only 35 cm TL and weigh only 200 g (Iyambo, 2006).

3 METHODOLOGY

3.1 Study Area

The entire Namibian coastline is of interest in this study, spanning the various areas where monkfish and hake biomass surveys are conducted. This area encompasses the coastline between 17°01,5'S and 30°00,0'S.

A yearly monkfish survey is conducted in November. The hake biomass survey is also conducted annually in January and February. The station layouts from monk biomass surveys with 94 stations (Fig. 1a) and hake biomass surveys with 210 stations (Fig. 1b) are presented below. Both studies covered the entire Namibian coastline.

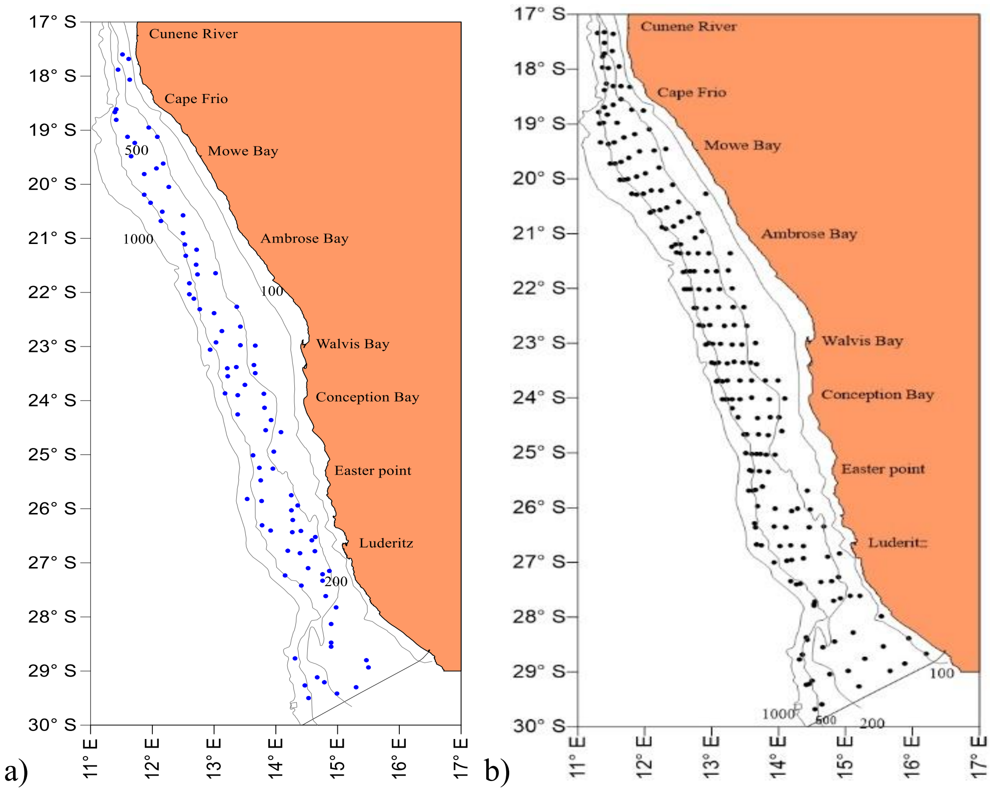

Figure 1: Station layout of the entire region covered during the a) standard monkfish biomass survey (Nangolo et al., 2022), b) standard hake swept-area biomass survey (Paulus et al., 2022) (with depth contours of 100, 200, 500, and 1000 m).

3.2 Data Collection (annual biomass surveys)

Monkfish biomass data were collected from monkfish annual biomass surveys from 2000 to 2022, as well as from hake surveys from 1999 to 2022, conducted by the Ministry of Fisheries and Marine Resources (MFMR). Note that there are a few missing surveys from the monkfish biomass surveys (2006, 2019, and 2020) and one missing survey from the hake biomass surveys

(2019). Table 1 summarises the data collected during the annual monkfish and hake biomass surveys.

Table 1: Data collected during annual monkfish and hake biomass surveys.

PARAMETERS	MONKFISH BIOMASS SURVEYS	HAKE BIOMASS SURVEYS
SURVEY TIMELINE	2000-2022 (no surveys in 2006, 2019 and 2020)	1999-2022 (no survey in 2019)
TRAWL INFORMATION	Duration: 30 minutes Door spread: 70 - 95 m Net opening: 1 - 1.4 m Trawl speed: Average 3 knots SCANMAR trawl sensors were used to monitor ground clearance, bottom contact and opening height of the trawl and the spread of the doors	Duration: 30 minutes Door spread: 45 - 50 m Net opening: 4.5 - 5.5 m Trawl speed: Average 3 knots SCANMAR trawl sensors were used to monitor ground clearance, bottom contact and opening height of the trawl and the spread of the doors
GEAR USED	Previous Trawl doors: 'Thyboron' trawl doors ($7.93m^2$), weighing 1936kg each Current Trawl doors: 'Steinshamn V' trawl doors of $7.1m^2$ weighing 1800kg each. No constraining rope. Trawl Net: 'Albatross' bottom trawl rigged with tickler chains along the footrope. The sweep lines consisted of 20 m bridals and 25 m long sweeps. Codend: The codend mesh size was 130 mm, with a 10 mm blinder	Previous Trawl doors: N/A Current Trawl doors: Steinshamn doors, with a total area of 6.7 m^2, weighing 1800 kg each. A 9 m constraining rope is attached between the warps, 150 m in front of the doors, to maintain a distance of 50 m between the doors. Distance between wings: 18-21 m (while towing) Trawl Net: 'Gisund Super' two-panel bottom trawl with head length 31 m, footrope 47 m Codend: outer lining of the cod-end mesh was 20 mm, inner-net was 10 mm
AGEING METHOD	Illicia	No Illicia collected
BIOLOGICAL SAMPLING	All Monkfish Biologicals collected (length, maturity, sex, illicia, gonad weight, individual weight, total weight)	Length and total weight collected
STOCK ASSESSMENT METHOD	Age Structured Production Model	Not Assessed with model, only bycatch estimates
ENVIRONMENTAL DATA	Temperature, Oxygen and Salinity	Temperature, Oxygen and Salinity

Data for both surveys were collected in a similar manner, with each trawl station recording the catch composition by weight and number of the entire catch or a sample, in addition to station and operation information. If the catch is small enough, all commercially important species are separated from the rest of the catch, and length and weight measurements are taken for these species.

Landings and logbook data from the monkfish and sole fisheries were collected to better understand the fishery dynamics, including what is landed annually and quarterly (Appendix IX), to estimate the annual CPUE (Appendix X), and the vessel category in relation to CPUE (Appendix VIII).

3.3 Length Frequency Analysis

Length distribution data from biomass surveys are important for understanding the characteristics of the target species and providing better management advice.

3.3.1 Methodology

To estimate the stock size from the surveys, the length frequencies of monkfish were assessed from both surveys using the R statistical software package.

The analysis results are expected to show the monkfish survey size distribution throughout the time series for both surveys. This can help determine which surveys have higher monkfish catches and which factors may contribute to the high catches.

Recruitments from both surveys were also analysed to determine which survey was more effective at identifying recruits. This information is critical for determining the number of fish that can be recruited into the fishery.

For a quantitative estimation of size differences between these two surveys, a binomial generalised linear model (GLM) with a confidence interval (CI) for each pair of surveys was performed (rate of fish/hour in each cm size class from each year). A CI covering the 0.5 line indicates whether there is a significant difference in size class between surveys.

3.4 Gear Specifications

Monkfish surveys were conducted using a commercial type of Albatross' monkfish bottom trawl. Tickler chains were strung along the footrope of the trawls. The sweep lines were composed of 20-meter bridals and 25-meter-long sweeps. The RV Mirabilis employs 7.1 m2 'Steinshamn V' trawl doors weighing 1800 kg each.

The mesh size of the cod-end is 130 mm, but to prevent small fish from passing through the meshes, a 10 mm blinder is installed inside the cod-end.

Hake surveys were conducted using a Gisund Super two-panel bottom trawl with a head length of 31 m, footrope of 47 m, and vertical net opening of 4.5–5.5 m. During towing, the distance between the wings was approximately 18-21 m. The outer lining of the cod-end mesh measured 20 mm, whereas the inner net measured 10 mm. The sweeps were 40 m long and connected the trawl to the Steinshamn doors, which had a total area of 6.7 meters squared and a mass of 1800 kg each.

SCANMAR trawl sensors were used to monitor the trawl's ground clearance, bottom contact, and opening height. This format was used for both surveys.

During the monkfish biomass survey onboard the RV Mirabilis, the Seabird SBE9plus CTD instrument and SBE32C rosette were used to measure temperature, salinity, and dissolved oxygen levels along fixed environment transects and inshore stations to collect water samples for calibration (Nangolo et al., 2022). The same methods were used in the hake survey.

4 RESULTS AND DISCUSSION

Monkfish are distributed along the entire Namibian coastline. Monkfish distribution in all dedicated monkfish biomass surveys from 2000 to 2022 showed lower densities in the northern and southern regions (Figure 2).

The highest densities were observed in 2000, which was the first year the monk survey was conducted and the year with the most survey stations in the entire time series. Since then, densities have varied over the years.

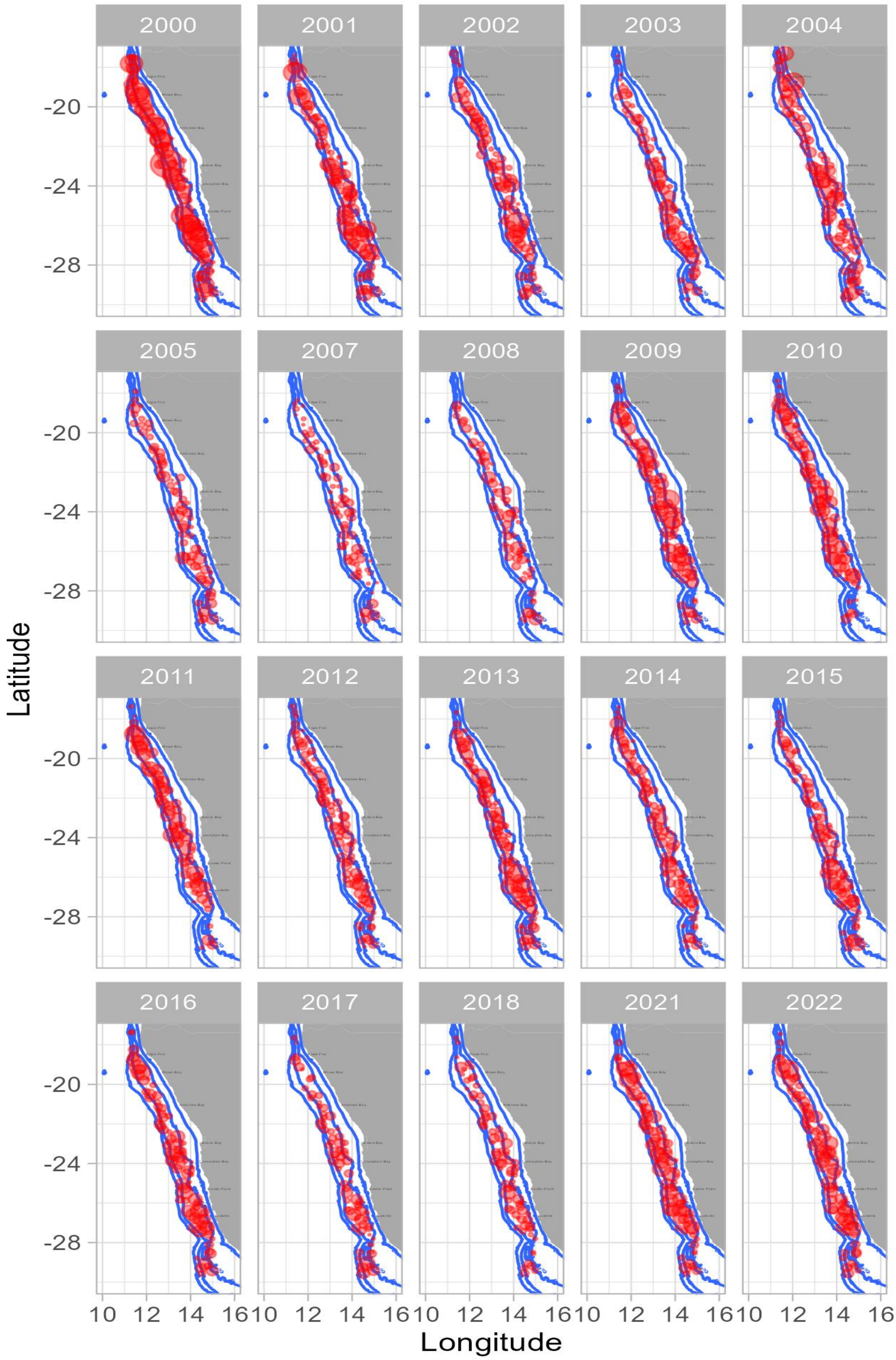

Figure 2: Spatial Distribution of Monkfish from Monk Biomass Surveys from 2000-2022.Surveys were not conducted in 2006, 2019 and 2020. Blue lines show the 100m, 200m, 500m and 1000m depth contours. Monkfish densities are shown as red circles, and the size of the circles is relative to the densities.

A similar pattern of monkfish distribution was observed in the annual hake biomass survey, that is, monkfish is distributed along the entire coastline, with higher concentrations in the central region. Densities showed high annual variation, with the highest density of the study period observed in 2015 (Figure 3). Despite having more stations, monkfish distributions from hake biomass surveys are generally lower than those from monk biomass surveys, which could be attributed to the selectivity of the tickler chains found in the monkfish, which aim to lift monkfish from the bottom.

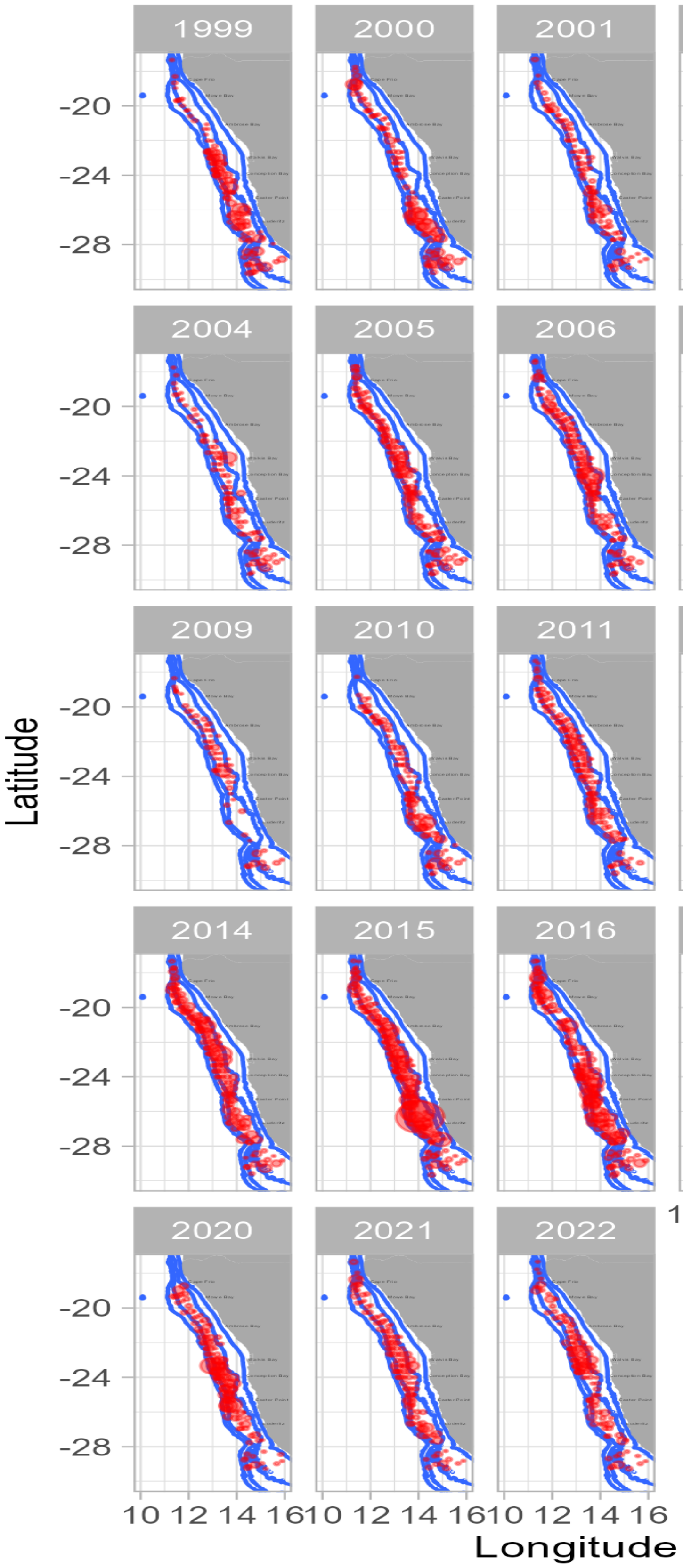

Figure 3: Spatial distribution of Monkfish from Hake Biomass Surveys from 1999 -2022. Survey was not conducted in 2019. Blue lines show the 100m, 200m. 500m and 1000m depth contours. Monkfish densities are shown as red circles, and the size of the circles is relative to the densities.

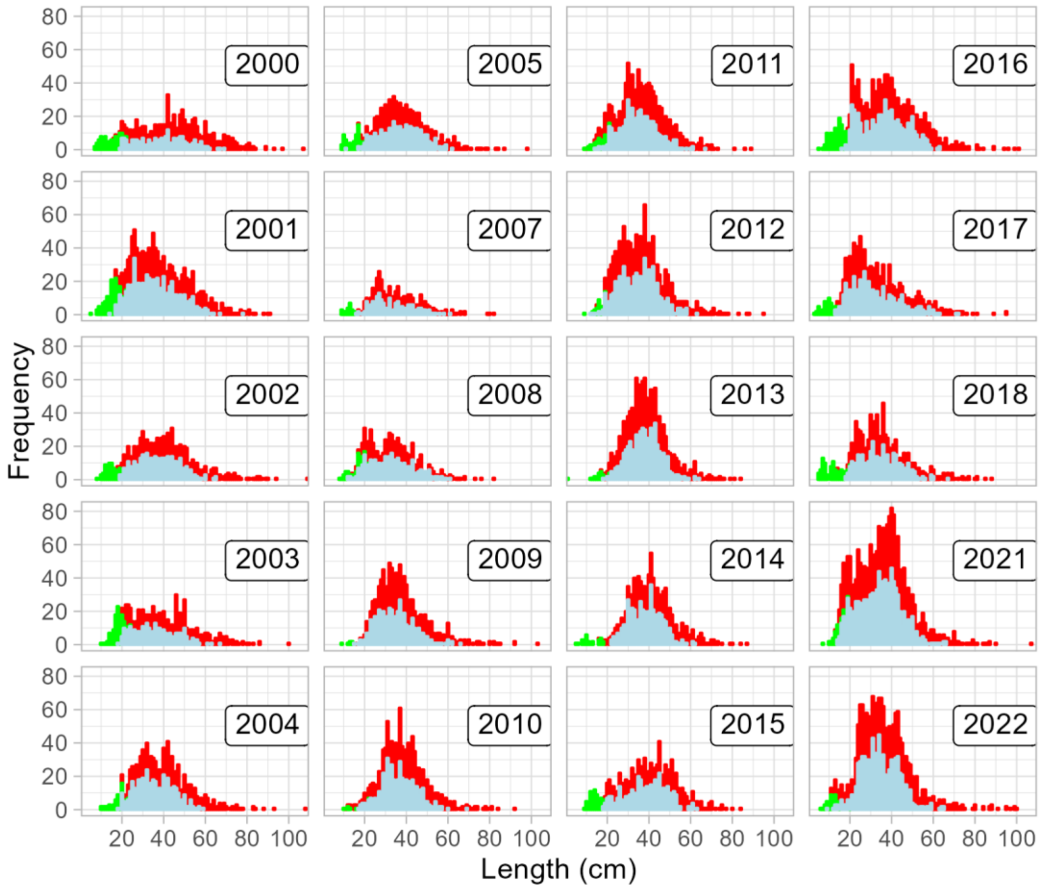

Figure 4: Length distribution of males (grey), females (red), and juveniles (green) which are fish less than 20 cm from Monk-directed surveys (2000-2022). No surveys were conducted in 2006, 2019, or 2020.

Size classes between 20-50 cm dominate the catch of monkfish in the monkfish survey, and length distributions varied between sexes. Females are larger than males, and males larger than 60 cm are rarely caught (Figure 4). In recent years, the length distribution of monkfish has shifted toward smaller monkfish compared to previous years.

Similar size classes dominated the catch of monkfish in the hake biomass surveys. In some years, pulses of juveniles were observed (Figure 5). The length frequencies were more concentrated on the shorter lengths, between 20 and 40 cm, throughout the time series.

Throughout the entire time series, it was observed that the length distribution from the monk dedicated surveys was more inclined towards smaller fish (juveniles) than that from the hake time series. Hake surveys are conducted using a 'rock-hopper' ground rope, which lifts the fishing line 25 cm above the seafloor. This may significantly reduce the catchability of epibenthic fish, such as monkfish, because the escapement under the fishing line may increase.

According to findings from the first survey conducted by Schneider and Johnsen (2000), there was a concern about monkfish size selection in the hake survey trawl, which could lead to an underestimation of the number of small fish due to higher escapement of small length classes of monkfish. We observe the underestimation of smaller fish, which are usually below 20 cm from the hake-directed survey, except for the years 2005, 2006, and 2018, where we observe some juveniles.

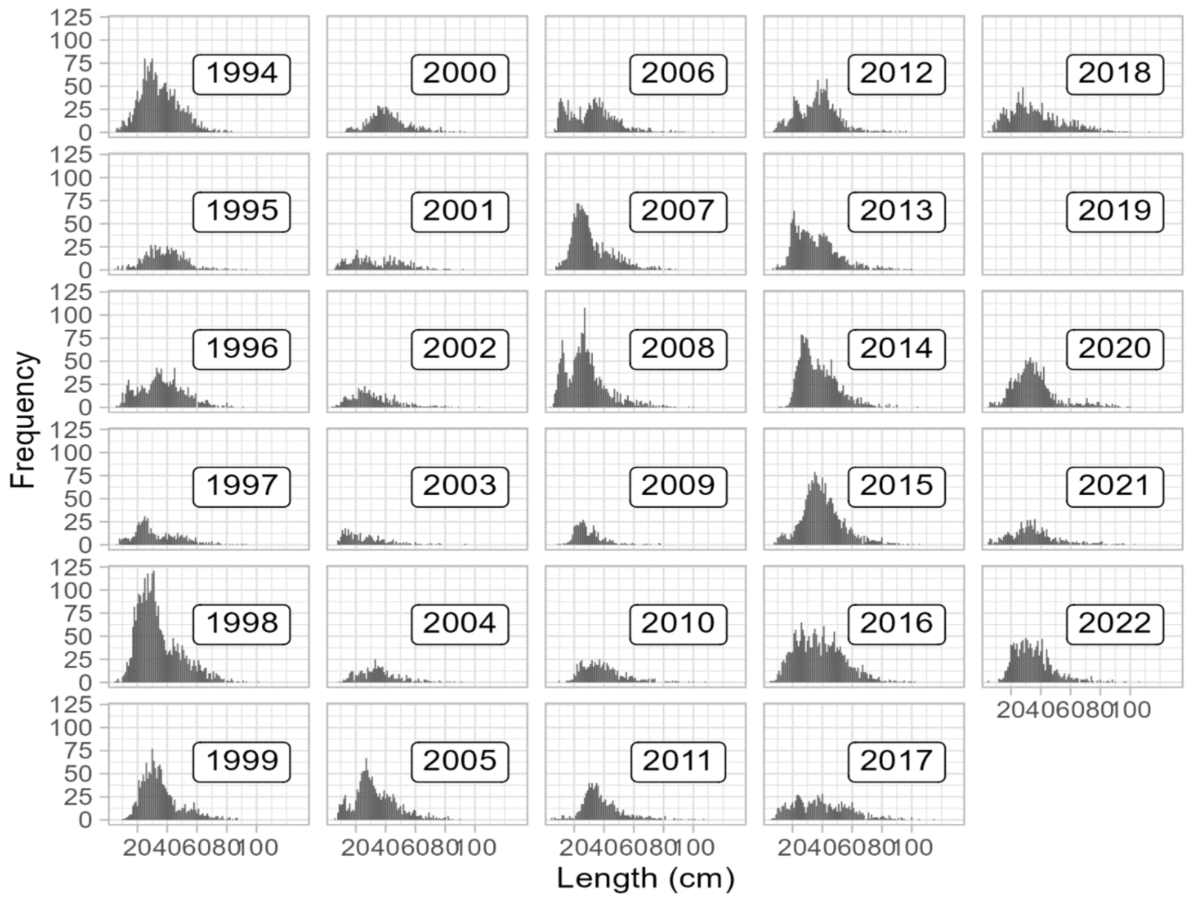

Figure 5: Length distribution of monkfish from hake directed surveys 1994-2022. No surveys were conducted in 2019.

The monkfish survey shows fluctuating biomass over the years, with higher biomass occurring in the earlier years, followed by a decrease. In recent years, biomass has increased again (Figure 6). Monkfish biomass from the Hake survey also fluctuated, but the biomass was lower at the beginning of the time series. The biomass has decreased since 2015, when it was at the highest level in the time series, and is now at a similar level as in 2000 (Figure 7).

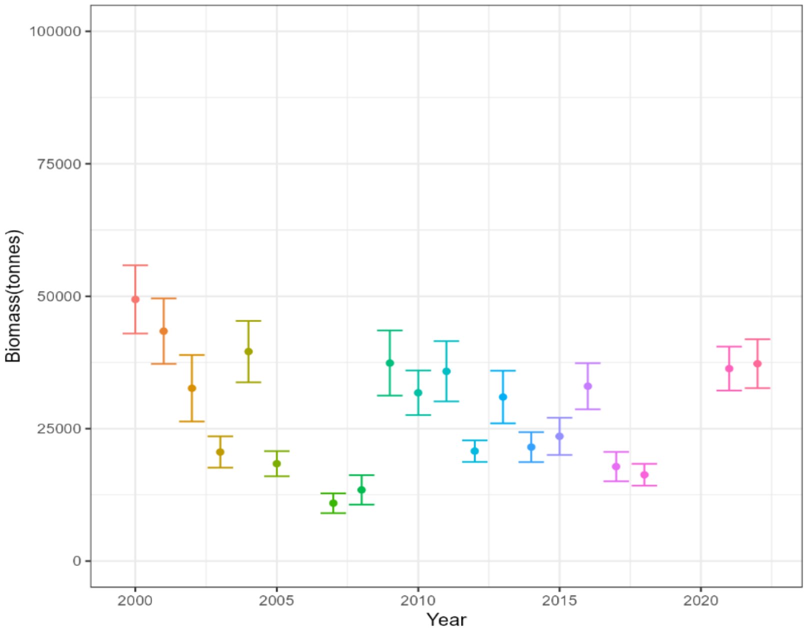

Figure 6: Monkfish biomass analysis from annual monkfish biomass surveys 2000-2022. Surveys were not conducted in 2006, 2019 and 2020.

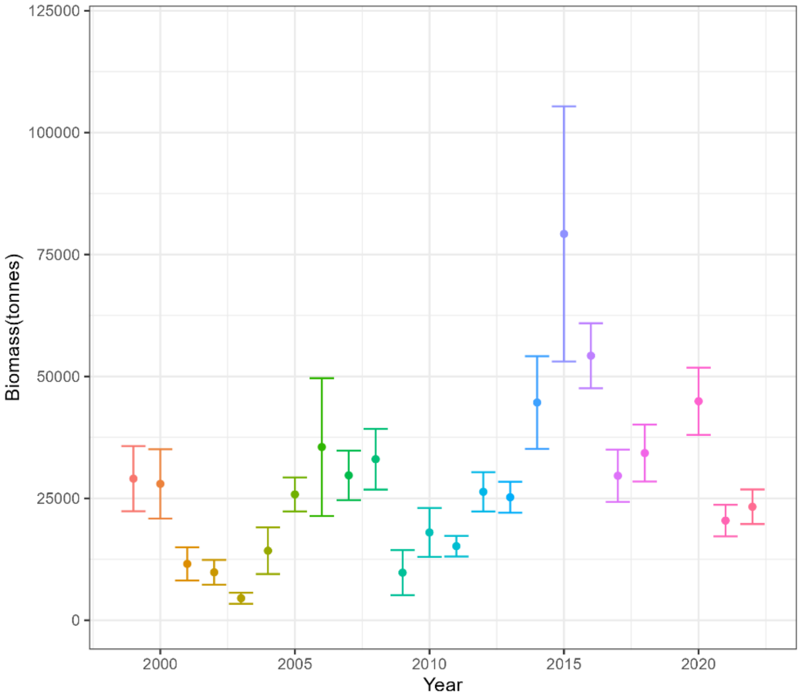

Figure 7: Monkfish biomass analysis from annual hake biomass surveys 1999-2022. Survey was not conducted in 2019.

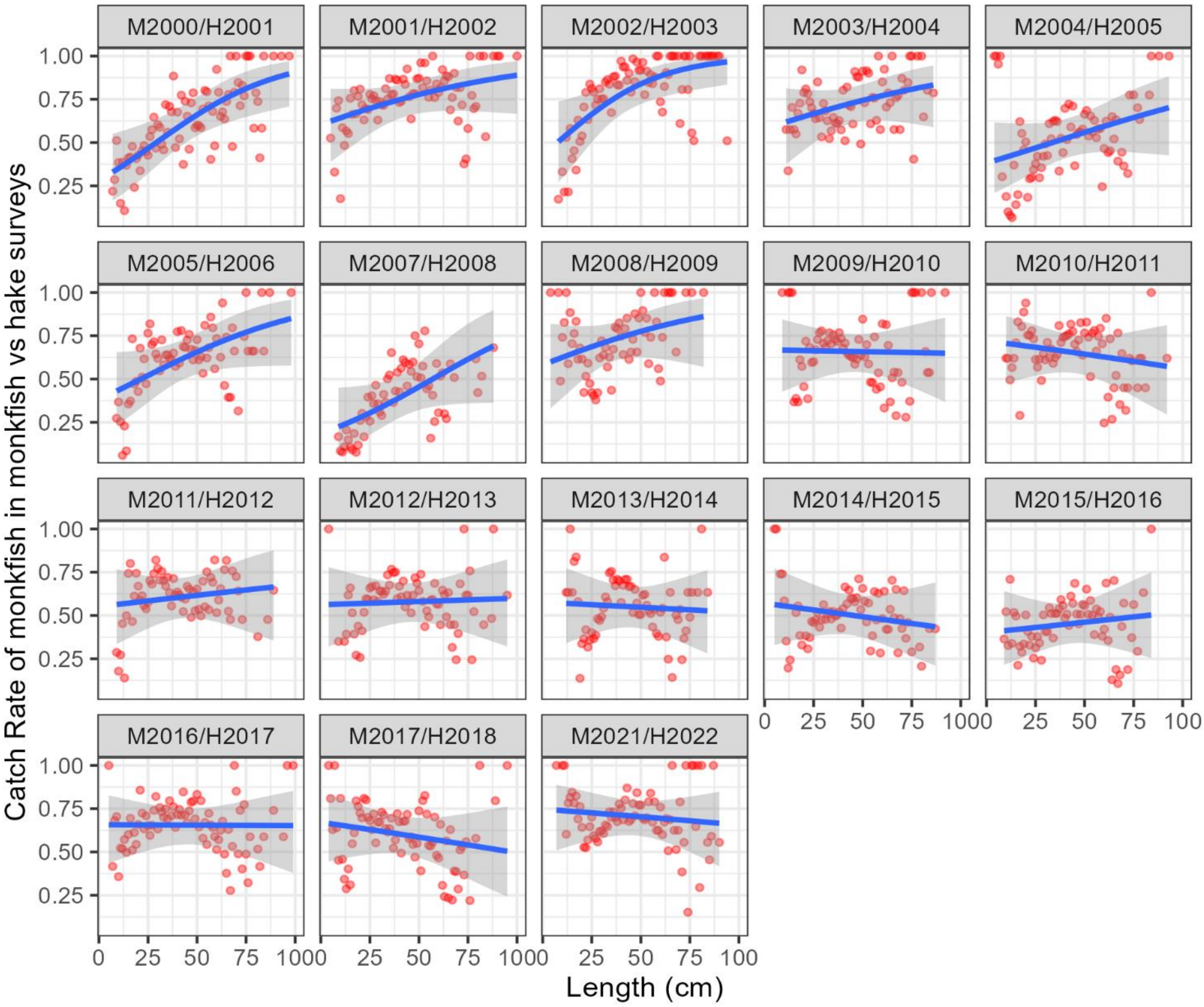

Figure 8: GLM with Confidence Intervals (CI) depicting rate of monkfish length from monk and hake surveys. Hake biomass survey is conducted in January and February each year. Thus, monkfish survey (conducted in November each year) was paired with a hake biomass survey in the following years. A value of 0.5 would indicate an even split between the two surveys for the specific length.

The rate of monkfish in monkfish surveys compared to the rate of monkfish in the hake survey is highly variable depending on the survey. For most years, the catch rate was higher in monkfish surveys than in hake surveys. However, some surveys show little difference in rates between these two surveys (i.e.M2004/H2005, and years 2011-2016, Figure 8). Combining all data showed that the catch rate differed in almost all size classes (Figure 9). These differences in catch rates indicate that the two trawls did not work in a similar manner. More in-depth analyses are needed for a better interpretation of these preliminary results.

The two trawls varied substantially in many aspects. A low headline height and tickler chains in front of the monkfish trawl make it effective for catching fish species such as monkfish. Hake tends to be more above the bottom than monkfish do. The hake trawl has a higher headline and lighter ground trawl than the monkfish trawl. This difference in catchability is dependant both on species and size.

However, it is clear that the two trawls do not work in a similar manner. More in-depth analyses are needed to fully understand this. However, this implies some incompatibility.

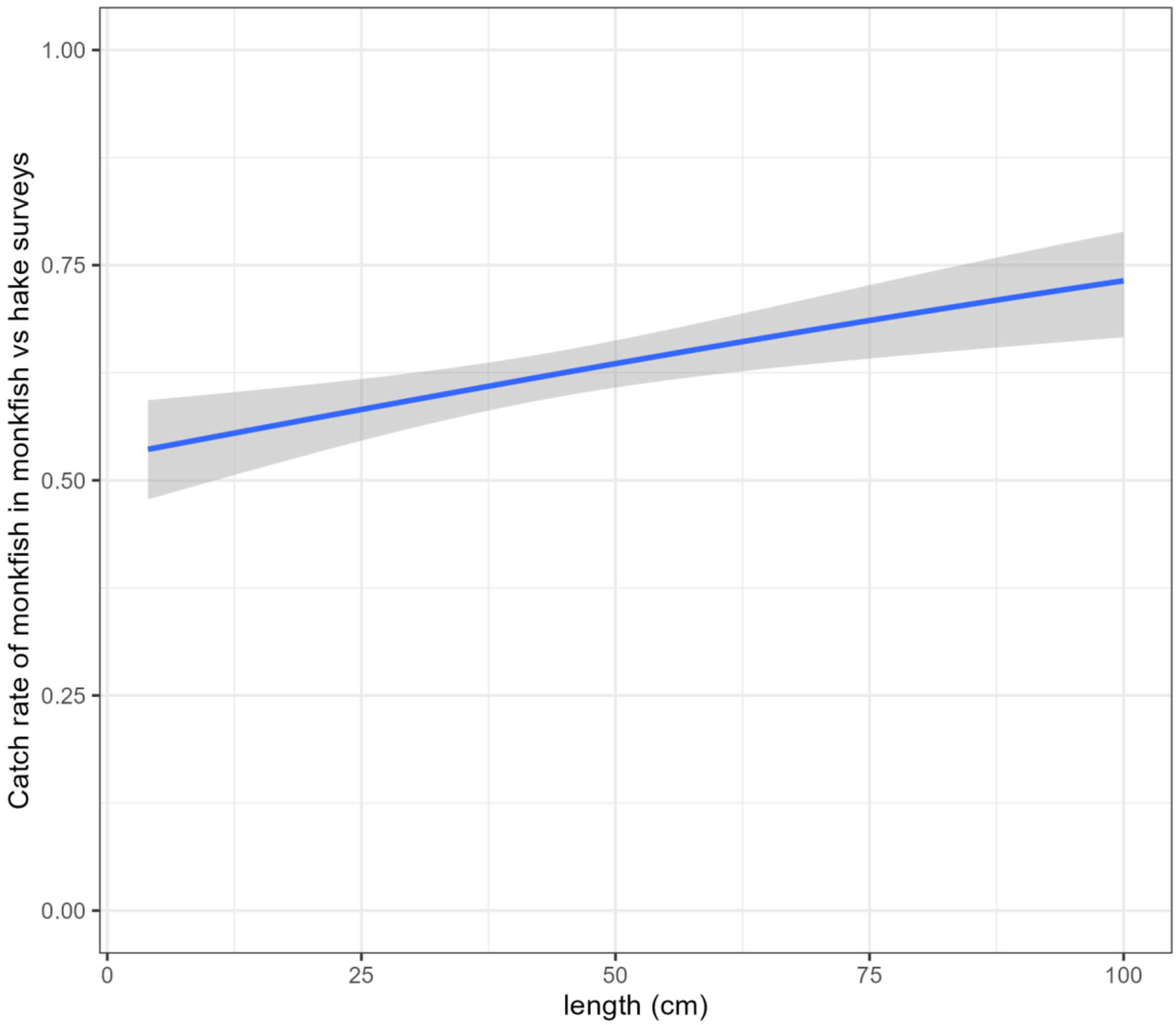

Figure 9: Rate of monkfish in monk and hake surveys combined. GLM with CI depicting combined rate of monkfish length for all years. A value of 0.5 would indicate an even split between the two surveys for the specific length.

5 CONCLUSION

If the Monkfish survey is combined with the Hake survey, the under-representation of smaller fish could be a serious concern. Knowing where smaller fish (juveniles) are found can help identify nursery areas that may require management interventions to ensure their survival. Stock assessment models are also used to predict recruits in the fishery, and current information on juveniles will aid in this determination.

The different survey designs and lengths of the surveys make it difficult to combine the hake and monkfish-directed surveys. The hake survey results biomass fluctuates, and in the most recent years, it has shown lower biomass compared to monk biomass surveys, despite covering more stations. This could be attributed to the monk gear being tailored to catch monk, unlike the hake gear.

The two trawls varied substantially in many aspects. A low headline height and tickler chains in front of the monkfish trawl makes it effective for catching fish species like monkfish. Hake tends to be more above the bottom than monkfish. The hake trawl has a high headline and lighter ground trawl than the monkfish trawl. This difference in catchability is dependant both on species and size.

Finally, one distinction between the two surveys is the type of survey equipment used. Tickler chains are used to lift monkfish from the ground and are not used in hake surveys because they are not required to herd hake into the net. Hake, on the other hand, has rockhoppers that can easily miss smaller monkfish, as well as a constraining rope that keeps the door spread constant.

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APPENDICES

APPENDIX I MONKFISH TRAWL GEAR

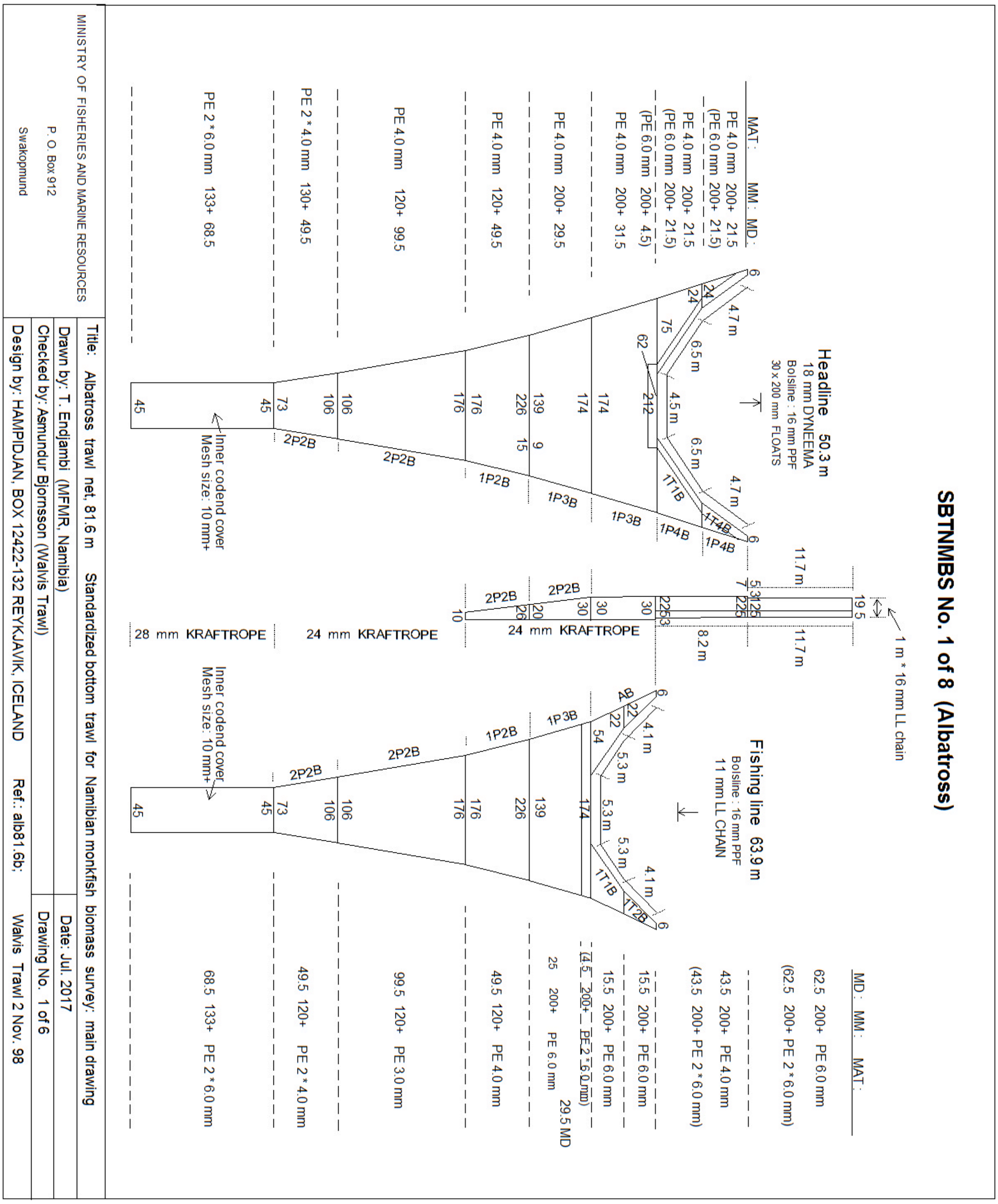
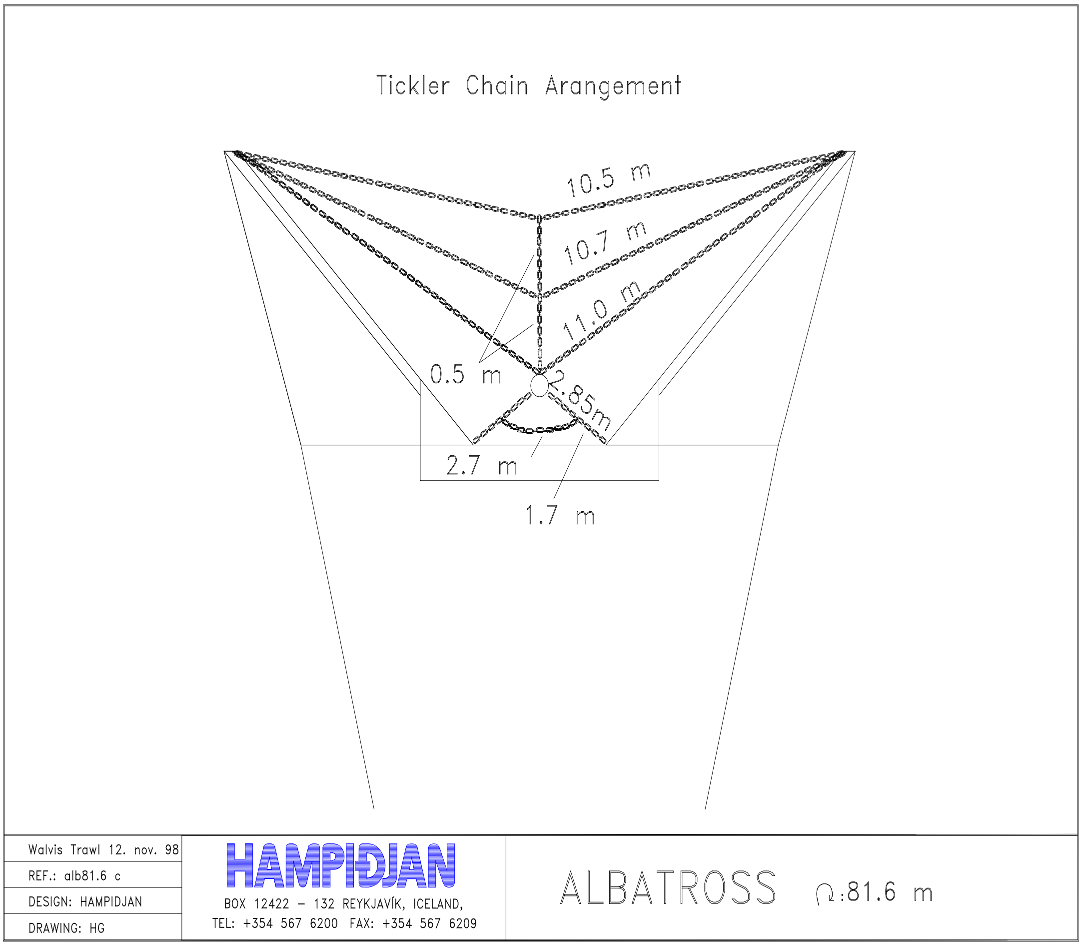


Figure 10: Standardised bottom trawl net for the Namibian Monkfish biomass survey (Endjambi, 2018)

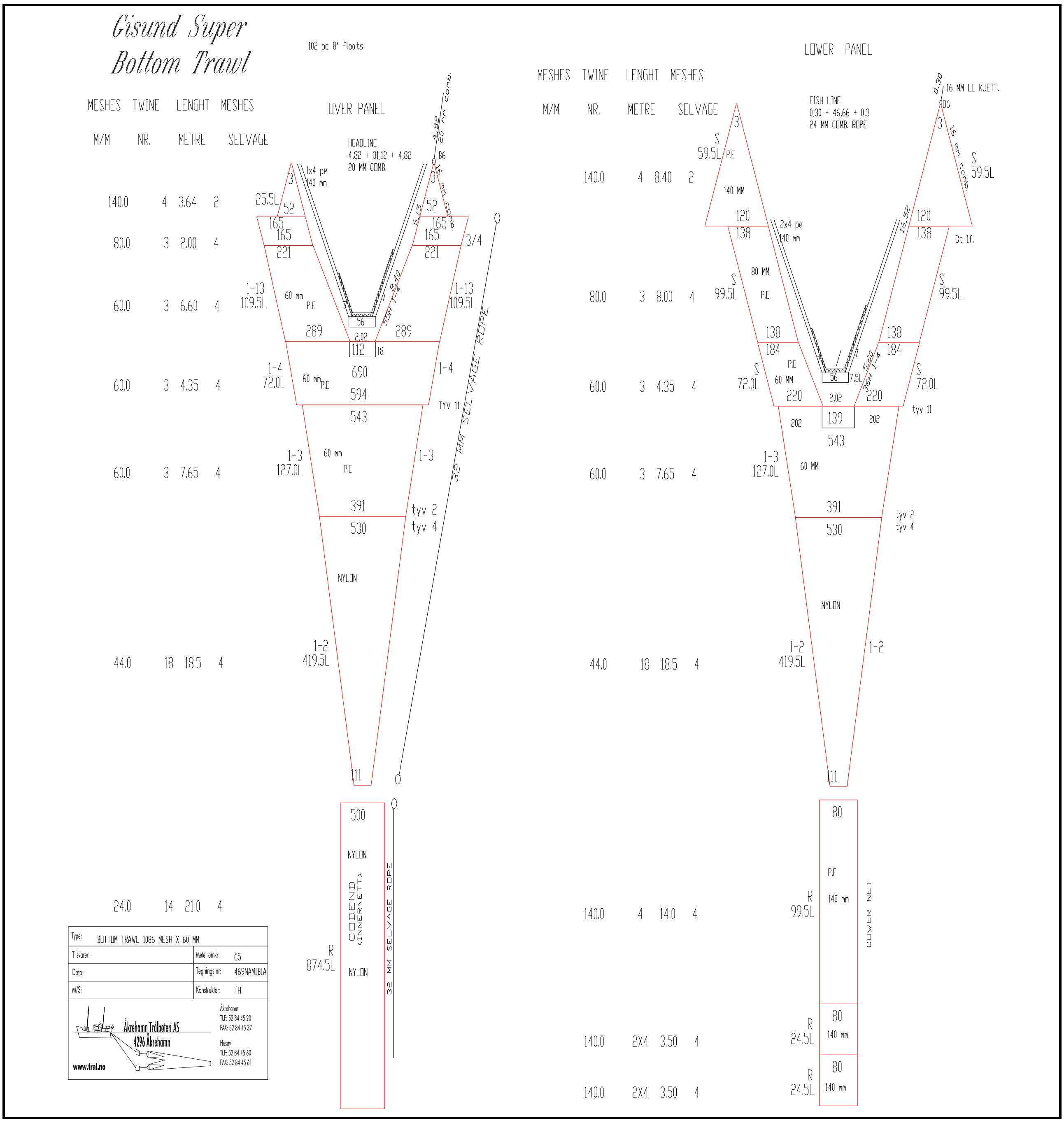
APPENDIX II MONKFISH TICKLER CHAINS



APPENDIX III HAKE GROUND GEAR, ‘ROCKHOPPERS’.

Diagram: ‘Rockhoppers’ similar to those on hake surveys.

APPENDIX IV HAKE TRAWL GEAR



APPENDIX V

Annual landings (tonnes) of Namibian monkfish for the period (1999-2023).

Year	Landings	Other Fishery Landings	**Total**
1999	10484.03	4318.126	**14802.16**
2000	10550.94	3807.3257	**14358.27**
2001	9,017.83	3372.1888	**12390.02**
2002	9,511.74	5662.5639	**15174.3**
2003	10,943.23	2191.6608	**13134.9**
2004	7379.081	1582.251872	**8961.333**
2005	8,167.81	2297.868717	**10465.68**
2006	8,430.52	1385.062756	**9815.585**
2007	7,834.73	1097.158624	**8931.886**
2008	8,046.37	1053.842964	**9100.216**
2009	6327.039	1083.04722	**7410.086**
2010	7898.529	1151.047168	**9049.576**
2011	6,280.03	962.504968	**7242.54**
2012	10,762.85	1204.226736	**11967.08**
2013	9470.693	1322.36238	**10793.06**
2014	10075.64	1185.89898	**11261.54**
2015	9388.777	1380.849284	**10769.63**
2016	8412.359	1111.347988	**9523.707**
2017	8000.956	879.248396	**8880.204**
2018	7,483.32	872.411448	**8355.734**
2019	7345.91	851.509232	**8197.419**
2020	7322.101	1024.687904	**8346.789**
2021	7209.174	1653.443052	**8862.617**
2022	6929.354	1214.7492	**8144.103**
2023	5211.09	104.708544	**5315.799**

Table 2: Annual Landings of Namibian Monkfish for 1999-2023

APPENDIX VI

Monk Biomass (tonnes) from Monk directed surveys with coefficient of variance (CV) and standard error (SE)

Year	Biomass (tonnes)	var3	se	cv
2000	49395.05492	41300366	6426.536	0.130105
2001	43399.50418	38266888	6186.024	0.142537
2002	32623.53349	39235761	6263.846	0.192004
2003	20585.53545	8746888	2957.514	0.14367
2004	39557.51666	33678094	5803.283	0.146705
2005	18386.95474	5652377	2377.473	0.129302
2007	10934.67447	3536392	1880.53	0.171979
2008	13429.73097	7723973	2779.204	0.206944
2009	37378.66548	37742455	6143.489	0.164358
2010	31768.78705	17866045	4226.824	0.13305
2011	35822.54384	32282742	5681.79	0.158609
2012	20764.34214	4107056	2026.587	0.097599
2013	30968.3775	24594549	4959.289	0.16014
2014	21520.56669	7992884	2827.169	0.131371
2015	23558.63906	12315701	3509.373	0.148963
2016	33012.04992	18980776	4356.693	0.131973
2017	17837.14195	7620871	2760.593	0.154767
2018	16293.93519	4272621	2067.032	0.126859
2021	36330.21634	17206888	4148.119	0.114178
2022	37257.68306	21192633	4603.546	0.12356

Table 3: Monkfish Biomass from Monk Directed Surveys 2000-2022

APPENDIX VII

Monk Biomass (tonnes) from Hake directed surveys with coefficient of variance (CV) and standard error (SE)

Year	**Biomass (tonnes)**	**var3**	**se**	**cv**
1999	29036.60679	44704850.27	6686.169	0.230267
2000	27971.13583	50400832.63	7099.354	0.25381
2001	11559.41284	11716568.73	3422.947	0.296118
2002	9835.787825	6473266.56	2544.261	0.258674
2003	4521.607769	1270201.948	1127.032	0.249255
2004	14261.74841	22796300.06	4774.547	0.33478
2005	25801.535	12122455.81	3481.732	0.134943
2006	35525.28716	199732463.9	14132.67	0.39782
2007	29710.66171	25726271.3	5072.107	0.170717
2008	33031.59849	38721453.21	6222.656	0.188385
2009	9761.250453	21266781.1	4611.592	0.472439
2010	18007.70248	25177289.73	5017.698	0.278642
2011	15193.94323	4458313.846	2111.472	0.138968
2012	26345.67947	16254632.25	4031.703	0.153031
2013	25222.21265	10120994.33	3181.351	0.126133
2014	44648.58591	90400407.57	9507.913	0.21295
2015	79226.23692	684287731.5	26158.89	0.33018
2016	54247.39562	44538606.25	6673.725	0.123024
2017	29633.42941	28732968.4	5360.314	0.180887
2018	34287.68757	34134140.8	5842.443	0.170395
2020	44914.8129	47343015.15	6880.626	0.153193
2021	20441.5142	10477967.59	3236.969	0.158353
2022	23271.54445	12625901.8	3553.294	0.152688

Table 4: Monkfish Biomass from Hake directed surveys 1999-2022

APPENDIX VIII

Monkfish and sole fishery vessel categories (CAT) and size intervals.

CAT	GRT (mt)
1	<100
2	>=100 and <199
3	>=200 and <299
4	>=300 and <399
5	>=400 and <499
6	>=500

Table 5: Vessel Categories from Monkfish and Sole fishery.

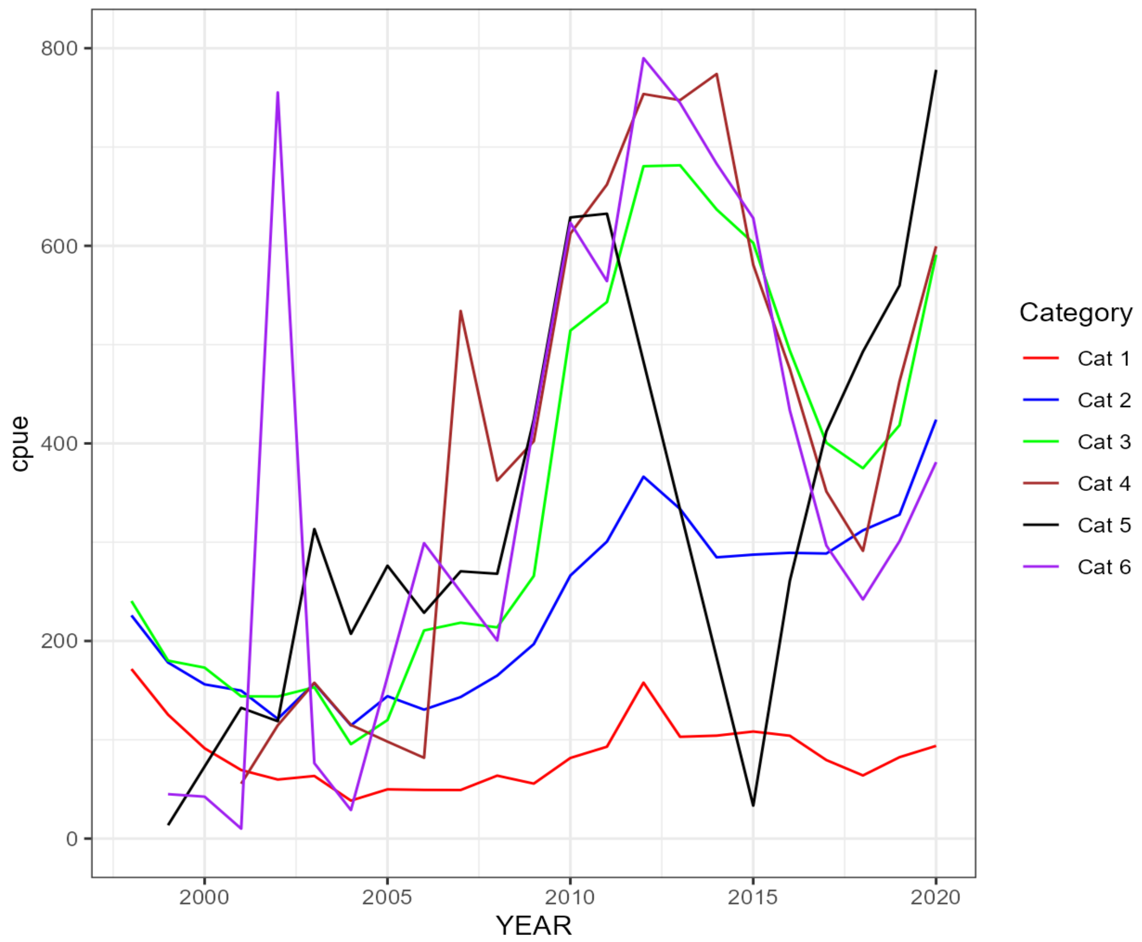


Figure 11: CPUE per Vessel Category from Monkfish fishery 1998 to 2020.

APPENDIX IX

Monk Landings from the Monk fishery from 1999 to 2022.

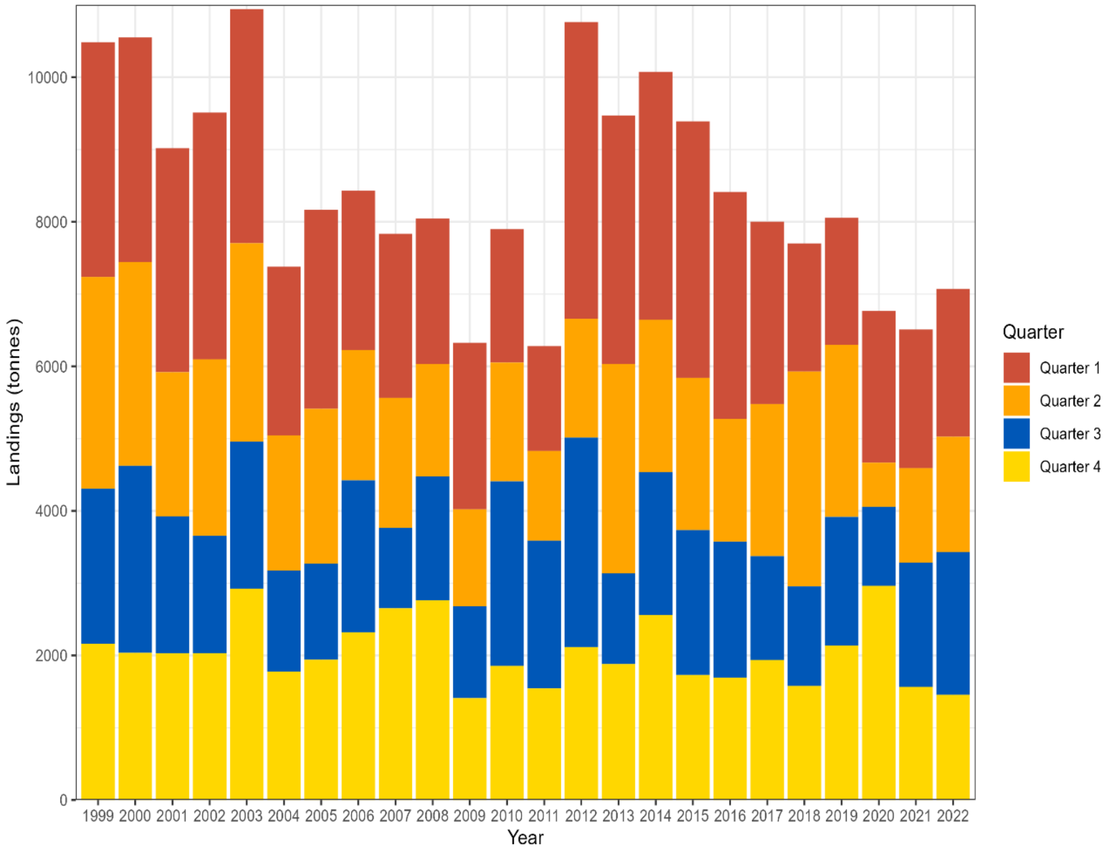


Figure 12: Monkfish Annual Landings from 1999 to 2022.

APPENDIX X

Monk Annual CPUE per year 1998 to 2020

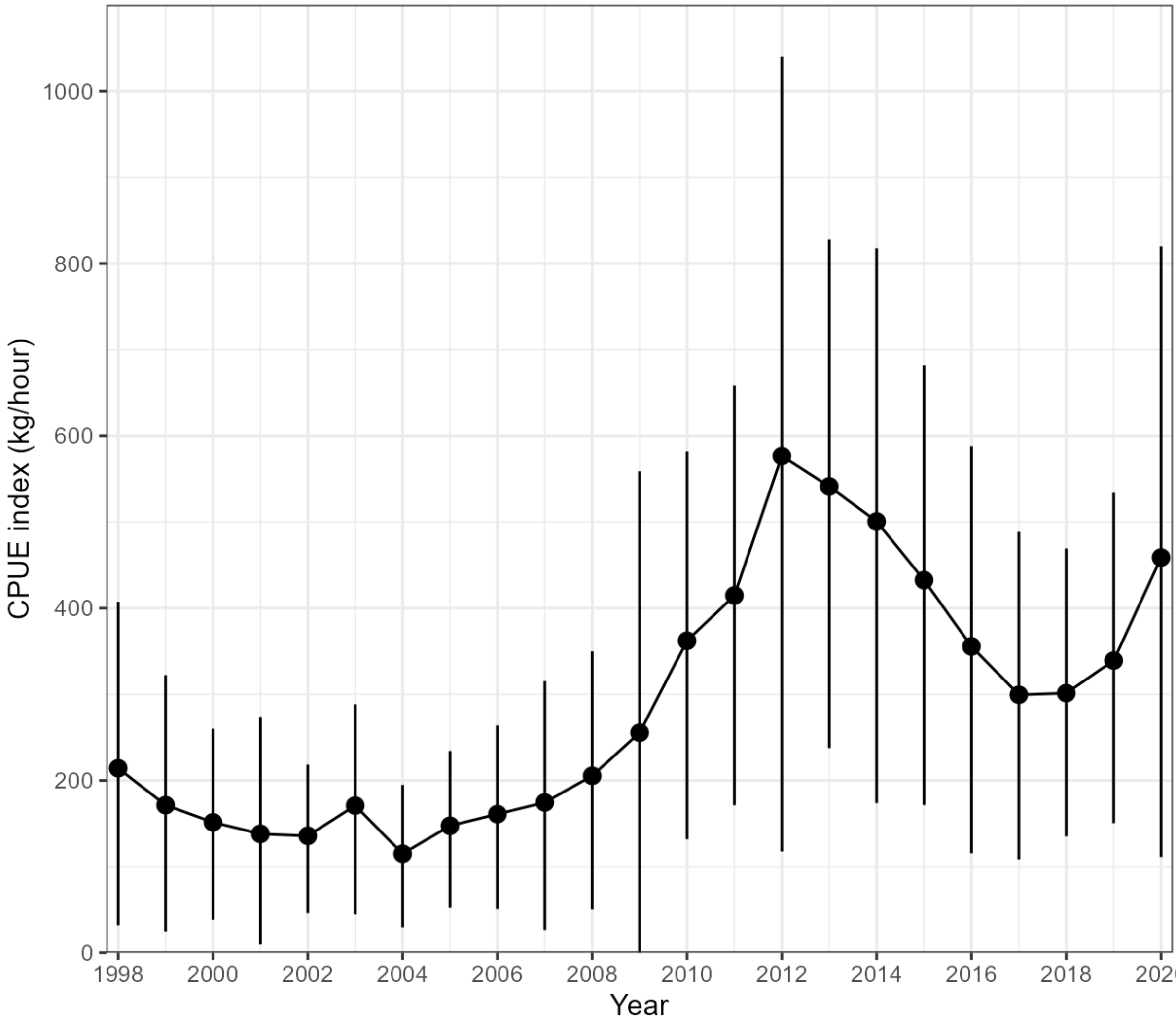


Figure 13: Monkfish Annual CPUE from 1998 to 2020.