SECTION C - SPECIALIST STUDIES

C3.4 Fish Reproduction Dynamics and Stock Distribution

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

REPRODUCTION DYNAMICS AND STOCK DISTRIBUTION STUDY WITH RESPECT TO A PROPOSED DEVELOPMENT OF PHOSPHATE DEPOSITS IN THE SANDPIPER PHOSPHATE LICENCE AREA OFF THE COAST OF CENTRAL NAMIBIA

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Dr Hilkka O.N. Ndjaula

June 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

With respect to the stock structure and gonad maturation of the main commercial species the data available showed that there were no special characteristics of their reproductive dynamics in the proposed dredging area (MLA). Further, the study showed that there was no deviation expected that would make the area unique with respect to these reproductive biological characteristics. The study also considered cohorts for all the species analysed and showed that a mix of small and large fish for most of the Namibian EEZ was typical and that for the MLA there were no indications of any deviation from this norm and that the MLA was not a unique spawning area that supported significantly different levels of recruitment of the main commercial species to the fisheries in the proximity of the MLA. Monthly trends also did not indicate any gonad development beyond “maturing stage” of the commercial species found in the MLA. This supported the suggestion that fish move in and out of such grounds over time. Annual maturity trends have also not shown repeated dynamics, implying that spawning grounds for these species are not localized. Multiple cohorts observed per year and by area suggest that high and low recruitment events occur. This again indicated the lack of a “homing behaviour” for adults and that recruitment and spawning grounds are not clearly defined.

contents

figures

tables

1 BACKGROUND

This report presents the results of an investigative study, aimed at describing the reproduction dynamics of commercially important fish species in Namibian waters, mainly within the area proposed for phosphate dredging. This report seeks to establish an understanding and to set the baseline of the current reproduction dynamics of the main commercial fish species in the area concerned. Namibian Marine Phosphate (NMP) (PTY) Ltd has been granted a mining licence (ML 170) for the area situated offshore from the Namibian coast (Figure 1). There are three general target areas, Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3), with dredging initially proposed for SP-1.

In accordance with the Terms of Reference (Annexure 2) this investigation seeks to provide a professional opinion on the likely area of impact of the proposed dredging and likelihood that the reproduction and reproductive potential of six commercial species potentially would be impacted relative to the known distribution of these species and their reproductive biology. The six commercial fish species include, hake (*Merluccius capensis* and *M. paradoxus*), monk (*Lophius vomerinus* and *L. vaillanti*), horse mackerel (*Trachurus capensis*) and sardine (*Sardinops sagax).*

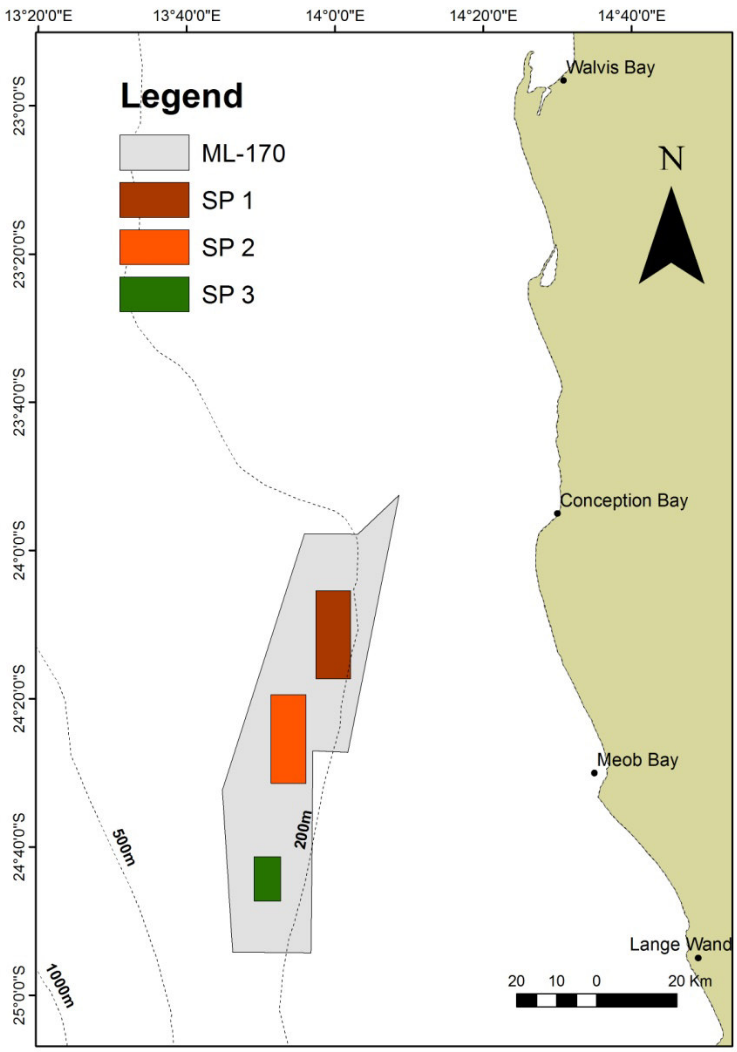


Figure 1. The location of the Sandpiper Phosphate mining licence area (ML 170) and the three target areas off the coast of central Namibia

2 GENERAL INTRODUCTION

A fundamental requirement of the precautionary approach to fisheries management is to identify the stock complexity (Hilborn *et al*., 2001), and where multiple species are differentially exploited, such understanding is necessary for a meaningful resource management system. A multiplicity of fish species forms part of the complex ecosystem in the Namibian marine environment, including the area proposed for phosphate dredging. The spatial and temporal dynamics of population cohort analysis is expected to provide an understanding of reproduction dynamics of the commercial fish species in Namibian waters, information which could highlight the homing, the movement, and the possible changes in various components of these populations and their life history traits. Similarly, knowledge of the population cohort structure and composition are also useful in identifying the location of adult fish aggregations (likely spawning stock), aggregation of juveniles or small fish (likely recruitment stock). Such analysis of population cohort structures and composition is therefore a good proxy for spawning and or recruitment grounds, as it could suggest separate grounds for the younger or adult cohorts of the population. Such knowledge will also suggest separate reproduction grounds, be it bathymetrically separated or isolated by various oceanographic conditions, which are well known to vary along the Namibian coast (Shannon & O'Toole 1998, Shannon *et al*., 2006). Such analysis therefore will be useful in evaluating the intensity and extent of the potential impact of phosphate dredging on fish species population dynamics and the related fisheries.

In order to establish the nature and vulnerability of fish to phosphate dredging such as environmental changes in the area, knowledge of spawning aggregations and reproduction ground preference for the species in question is required. With respect to mapping spawning and reproduction grounds, it is desirable to identify signs of spawning, which include identification of eggs at the earliest developmental stage or the availability of fish in their late gonad maturation as a sign of active spawning in a particular area. Other proxies such as the Gonado Somatic Index[1] (GSI), as well as the presence of the adult population (regarded as the spawning stock) have typically been used as indicators of spawning signs at a particular area or season.

The presence of larvae and juvenile fish in an area or during a particular time can also be used as an indication of reproduction. Similarly, knowledge of the distribution patterns and abundance of eggs and larvae within and around the area of concern is important in evaluating and discussing the impacts of any varied or altered environment. However, for most of the main commercial fish species found in Namibian waters, there have been few dedicated ichthyoplankton or egg surveys intended to identify spawning areas (except for sardine and anchovy). In the absence of egg and larvae surveys, the closest we can investigate is the gonad maturation dynamics of the species in question, in the form of maturity stages of the fish reproductive organs and relative gonad weight through GSI analysis. While GSI is generally used in spawning proxies, its use in indeterminate spawners (egg production is continuous during a spawning season) has been questioned (Kainge *et al*., 2007 and references therein, Ndjaula *et al*., 2013) and might not be a reliable proxy for spawning time and location. Although GSI does indicate the time and area when the gonads are largest, a reduction in gonad size due to the released egg batches during a particular spawning event could lead to a misinterpretation of spawning by indeterminate spawners. Similarly, although visual maturity staging

[1] The GonadoSomatic Index (GSI) is the ratio of fish gonad weight to total body weight and is particularly useful in identifying spawning time and location. It is represented by the formula: GSI = [Gonad Weight / Total Tissue Weight] x 100.

(referred also as macroscopic staging) also has its drawbacks with regard to maturity classifications, it can be more reliable than GSI in indeterminate spawners because fish that have no visible eggs are classified either immature or spent, to indicate that such is the case before spawning or after spawning respectively. The maturity stage which indicates visible eggs does therefore become an important proxy of the spawning signature and spawning residency, even when batches are released, which would otherwise translate into low GSI. The use of visual maturity staging was therefore regarded as less biased, and thus was selected for the analysis of potential spawning prevalence in this study.

This study has combined analyses of fish size and maturity stages as a way of identifying recruits (juvenile fish) as well as spawners (adults or active gonad stage) and looked at these in a spatial, temporal and depth gradient. Such analyses will give a three dimensional picture of fish distribution in size and gonad maturation composition.

2.1 HISTORICAL SPAWNING BEHAVIOUR OF COMMERCIAL SPECIES IN NAMIBIAN WATERS

The spawning areas, ichthyoplankton drift areas and reproduction grounds from the historical and contemporary literature has been reviewed as part of this project's initial Environmental Impact Assessment (Japp in Midgley 2012). They summarized their study with the following:

- A low abundance of hake eggs occur near the MLA off Hollam's Bird Island. Larvae are found in high abundance from Conception Bay to Palgrave Point. A significant number of juvenile *M. capensis* is likely to occur within the MLA;
- According to the historical literature juvenile monkfish are likely to be distributed within the MLA;
- Aggregations of spawning horse mackerel and juveniles are most prevalent outside the MLA;
- Sardine spawn off Walvis Bay and only the northern extent of the MLA coincides with the assumed southern part of the spawning area;
- Historically spawning and larval distributions of anchovy took place north of Walvis Bay (outside the MLA);
- Snoek migrate southwards to spawn offshore and in deep waters near St Helena Bay and off the Cape Peninsula in South Africa. The MLA is within the assumed migration corridor of this species;
- Silver kob spawn inshore of the MLA in Meob Bay and larvae drift northwards to the nursery grounds between Sandwich Harbour and the Ugab River mouth;
- Goby larvae are in high abundance in the MLA. They also inhabit the bottom sediments and are likely to be locally disturbed by the proposed dredging activity; and
- West coast rock lobster are found inshore and south of the MLA.

This study did not attempt to replicate the above reported review, but used the actual data to investigate the reproduction and population structure dynamics of the commercially important species, with respect to the MLA.

3 APPROACH TO THE STUDY (METHODOLOGY)

This reproduction dynamics assessment utilises the existing data from the Namibian Ministry of Fisheries and Marine Resources (MFMR) and information from a literature review of international peer-reviewed scientific literature, information from MFMR internal reports, information available on the internet, as well as studies conducted in the proposed mining area. Information obtained through personal communication during the consultation is also included where appropriate.

The data were collected from 1999 to 2012 during the assessment surveys by the Namibian National Marine Information and Research Centre (NatMIRC), and at times, during port sampling (Table 1). When and where available, data were gathered for the entire coast, and for as far back in time as 1999 (horse mackerel). For some species, data were provided for the past six years and only for the areas within the close proximity of ML 170. Data were made available for the following species: *Merluccius capensis*, *Merluccius paradoxus*, *Lophius vomerinus*, *Lophius vaillanti*, *Trachurus capensis* and *Sardinops sagax*. Various stations from surveys were grouped together by degree of latitude, longitude and depth to investigate the stock as a whole.

Table 1. Data sets provided by NatMIRC and used in this investigation

Dataset	Dates	Species	GSI	Maturity staging	Area
Hake survey data	2007 – 2012	*Merluccius capensis, M. paradoxus*	Yes	Yes	Entire Namibian coast (17°S to 29°S)
Monk survey data	2007 – 2012	*Lophius vomerinus, L. vaillanti*	No	Yes	Between 22- 26°S
Horse mackerel survey data	1999 – 2012	*Trachurus capensis,*	Yes	Yes	Between 16- 24°S
Small pelagic survey data	2007 – 2012	*Sardinops sagax*	Yes	Yes	Between 16- 24°S
Port Sampling	2006 – 2013	*M. capensis, M. paradoxus*	Yes	Yes	Entire Namibian coast (17°S to 29°S)

Ideally, a study of reproduction should consider the potential spawning stock, egg and larvae availability as well as the presence of young-of-the-year cohorts in the population. However, knowledge of all such components is not undertaken in the current fisheries monitoring and management approach conducted by MFMR. The information available for the main commercial species in this regard is the biological analysis of the gonad maturity stages and the gonad weight, together with fish size. Data obtained from MFMR however were sufficient and were used for this analysis of reproduction dynamics. Three approaches were taken.

1) Data were used to analyse stock structures for both spatial and temporal dynamics. Stock structure was also analysed for depth profiles.

2) Data were analysed for both spatial and temporal maturity development, and where necessary analyses for depth profiles were also undertaken.

3) Where data were available, GSI was evaluated for both spatial and temporal dynamics. However, due to the nature and interpretation of GSI in serial spawners (which is the egg

production strategy used in hake and horse mackerel), the GSI results were not presented in this report, as it would be a repetition of information gained from more reliable gonad maturity staging.

Care was taken to not use the data from the biological samples for the population structure analysis to avoid duplication, because such samples are mostly, if not always taken from the length frequency samples. Care was also taken in the case of hake and monkfish where two species are analysed, so that the data are correctly presented.

Maturity proportions were calculated as the number of fish according to assigned maturity stages considering its frequency in each latitude, month and depth (represented as a percentage of that group). Staging scales used for hake are presented in Table 1, which is more or less the same for all classification keys used in other species, which are often spread over 7 stages in pelagic species.

Table 2. Macroscopic maturity stage classifications of the hake species, which are used in the field (Botha, 1986).

Stage	Female	Male
1 Inactive	Gonads small, slender, transparent, no visible signs of eggs	Gonads very small, slender, transparent and ribbon like, unlobed
2 Active	Gonads larger and filling with small, pink-orange, opaque and visible eggs	Larger and distended, white opaque, typically lobed
3 Ripe	Gonads very large in relation to fish size, distended and filled with clearly visible opaque eggs-some eggs already translucent; colour of ovaries bright orange to deep pink	Gonads very large in relation to fish size, white opaque, distended with sperm, with pronounced lobes
4 Ripe and running	Translucent eggs can be extruded through the cloaca with slight abdominal pressure	Gonads very large and distended, with sperm flowing spontaneously
5 Spent	Gonads visually completely empty, but large, flabby, prominently veined and often bloodshot	Gonads very large, lobed, flabby but not distended

4 RESULTS

4.1 STOCK STRUCTURE (SIZE DISTRIBUTION/ RECRUITS VERSUS ADULTS)

Fish size distribution for commercial species that occur in MLA 170 (hake and monkfish) showed population cohort structures which indicate no special dynamics exclusive to the proposed phosphate mining area (Figure 2, area at 23° and 24° degrees south) in space and time. The area covered was sufficient for the analysis, either spanning the entire coast or two degrees of latitude from the mining site. This was generally true for all species studied, with the exception of the pelagic species (horse mackerel and sardine), whose dynamics were random. In all species, the proportions of the younger stock were generally not recorded in MFMR surveys. Further results of this study are summarized below per species.

4.1.1 Hake

Hake, a serial spawner may potentially be impacted by the proposed phosphate dredging activities (Figure 2). Analyses of the population structure of the two species separately indicated dynamics that showed similar structure over the years with a broader size frequency for *M. capensis* than for *M. paradoxus* (Figure 3). *M. paradoxus* size structure indicated multiple cohorts every year since 2007, but this was not clearly indicated for *M. capensis*, despite a broader size distribution (Figure 3). *M. paradoxus* is differentially distributed along the coast, with larger fish found in the north and smaller fish found in the south, as opposed to *M. capensis*, which is distributed along the coast in one broad cohort, peaking at 30 cm fish size (Figure 4). The presence of juveniles is observed for *M. paradoxus* in the far southern part of Namibia, while there is not a pronounced area of juvenile *M. capensis* (Figure 4).

Depth stratification analysis confirmed that *M.capensis* is distributed in shallower water than *M. paradoxus* (Figure 5), with bigger fish found in deeper waters for both species. Similarly, there is a visible movement of larger *M. paradoxus* into deeper water, as opposed to a consistent homogeneous depth distribution of *M. capensis* (Figures 2 and 5). These differences in spatial dynamics for the two hake species are also evident in the length data extracted from monkfish surveys (Annexure 1).

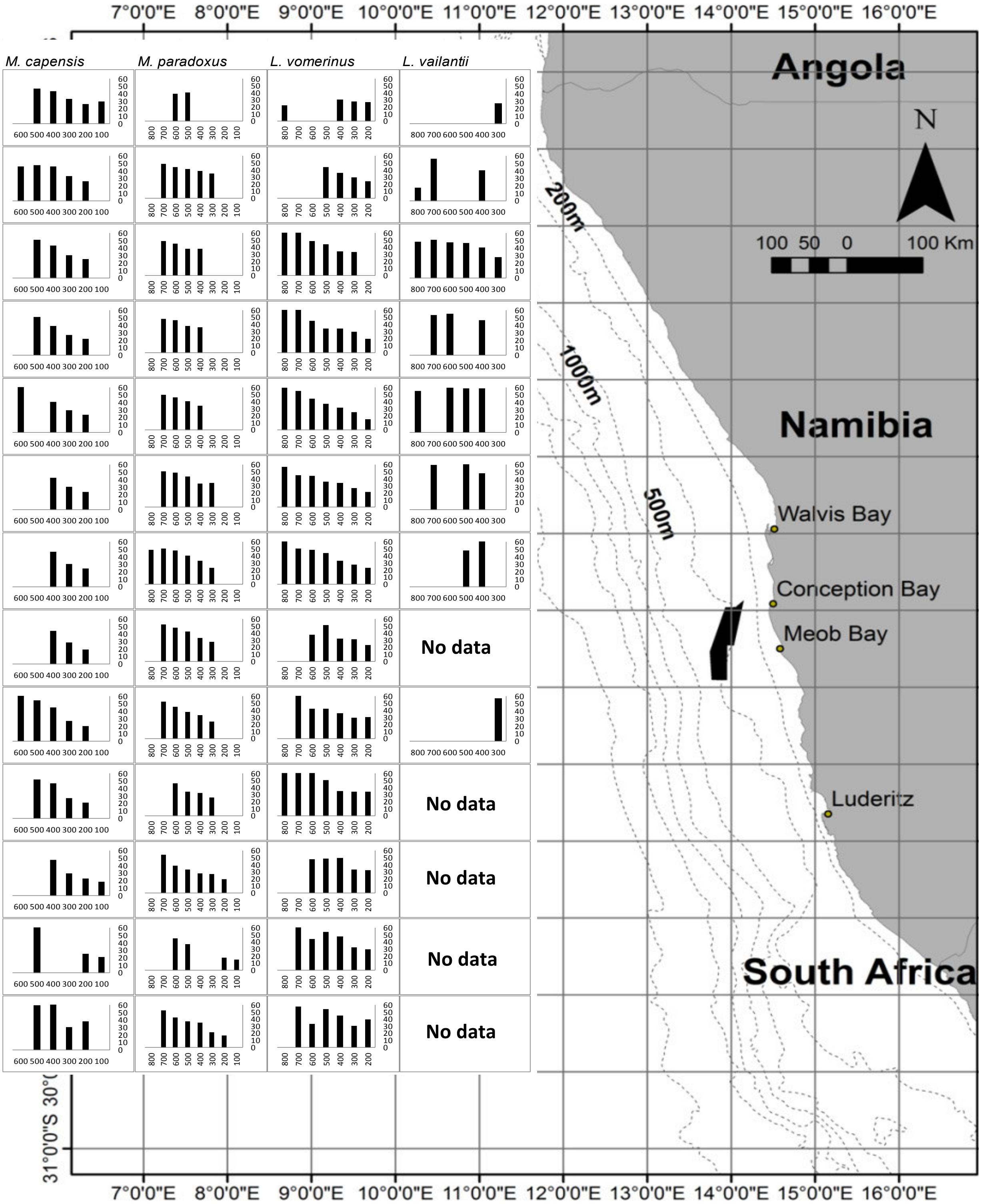


Figure 2. The distribution of mean size per depth and latitude of hake and monkfish.
Graphs show depth (x-axis in 100 m intervals) against mean length (y-axis in 10 cm units).
Scale is not precise and used only schematically.

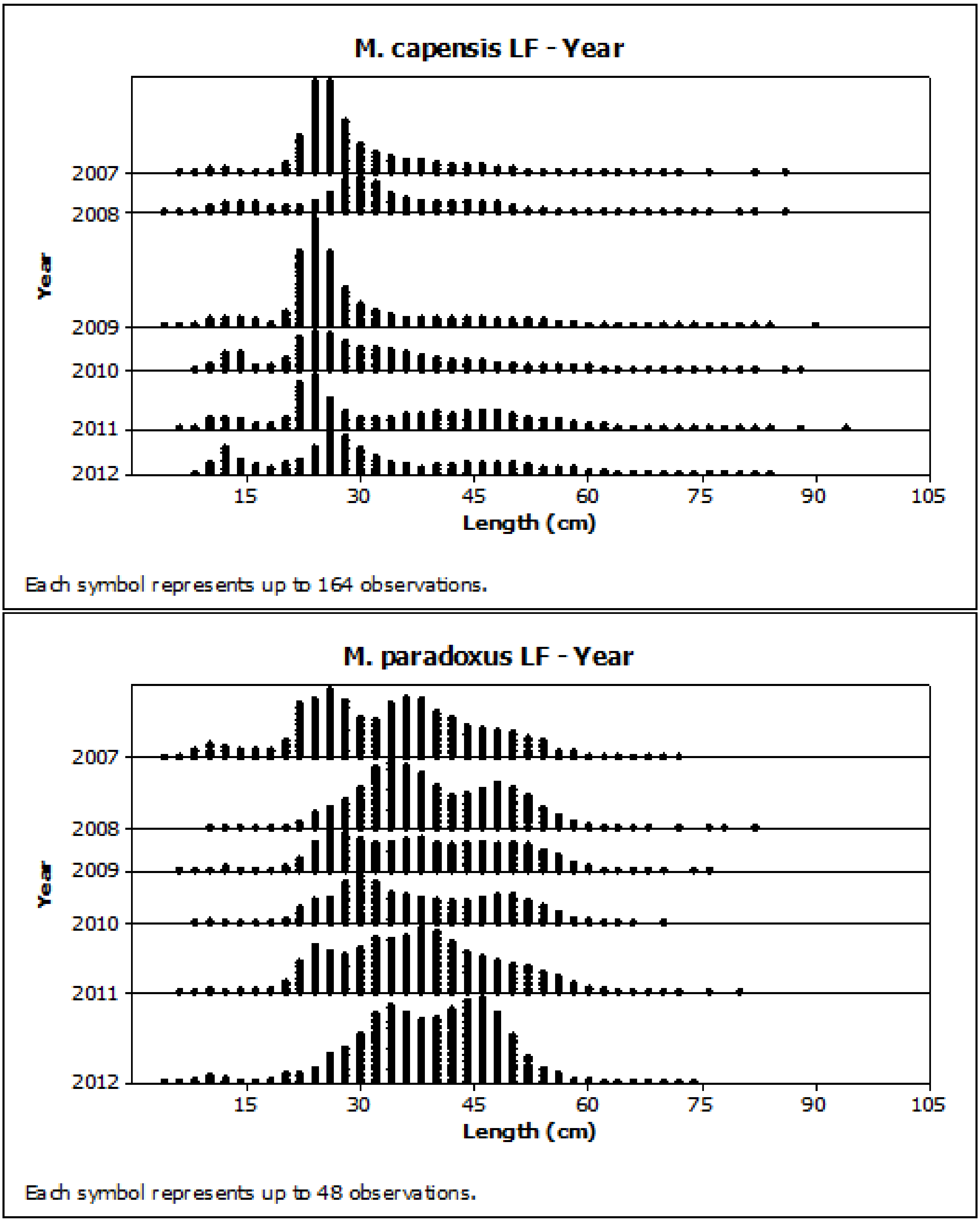


Figure 3. Hake population structure as observed over the years along the entire Namibian coast.

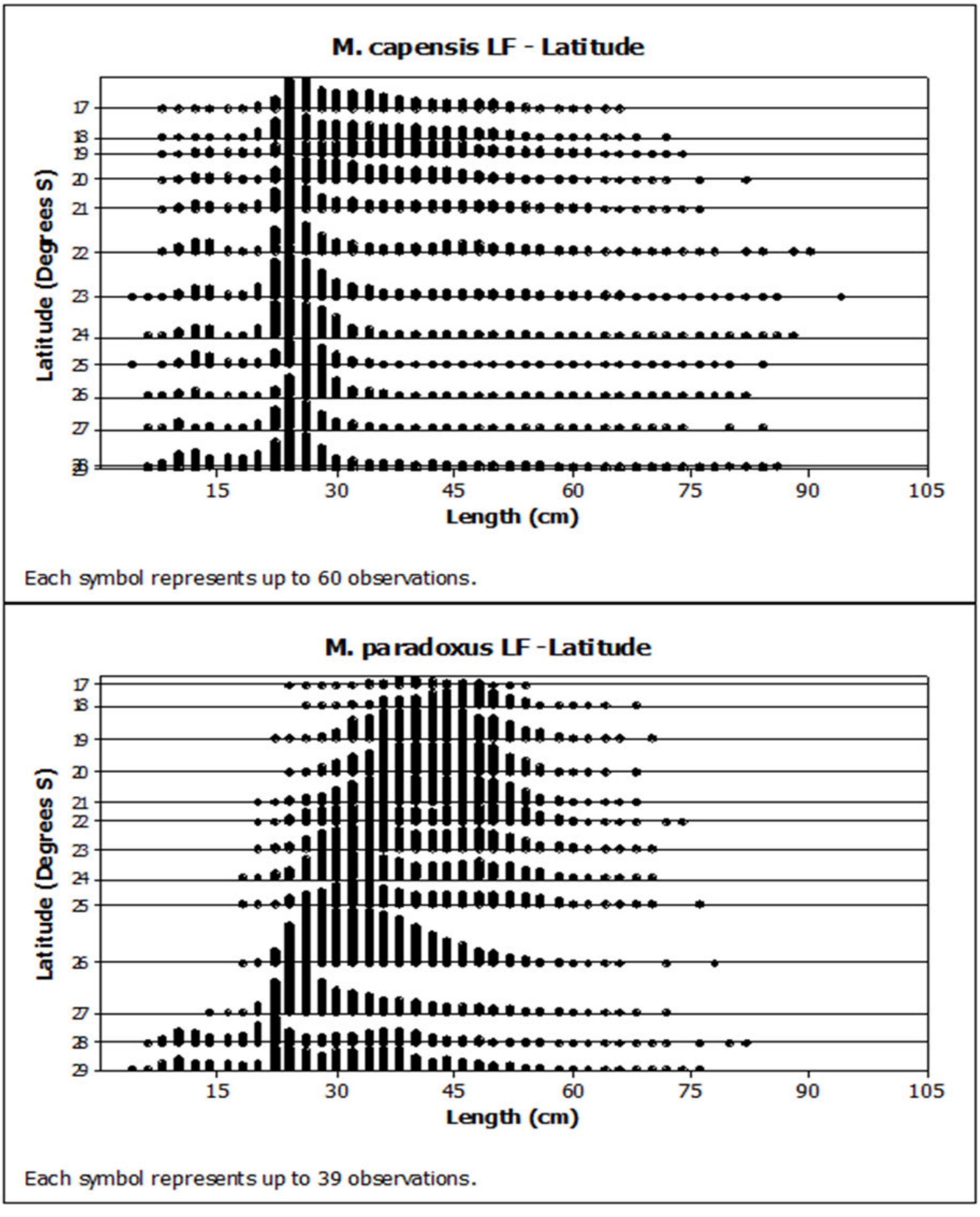


Figure 4. Hake population structure at all latitudes in Namibia from 2007 to 2012.

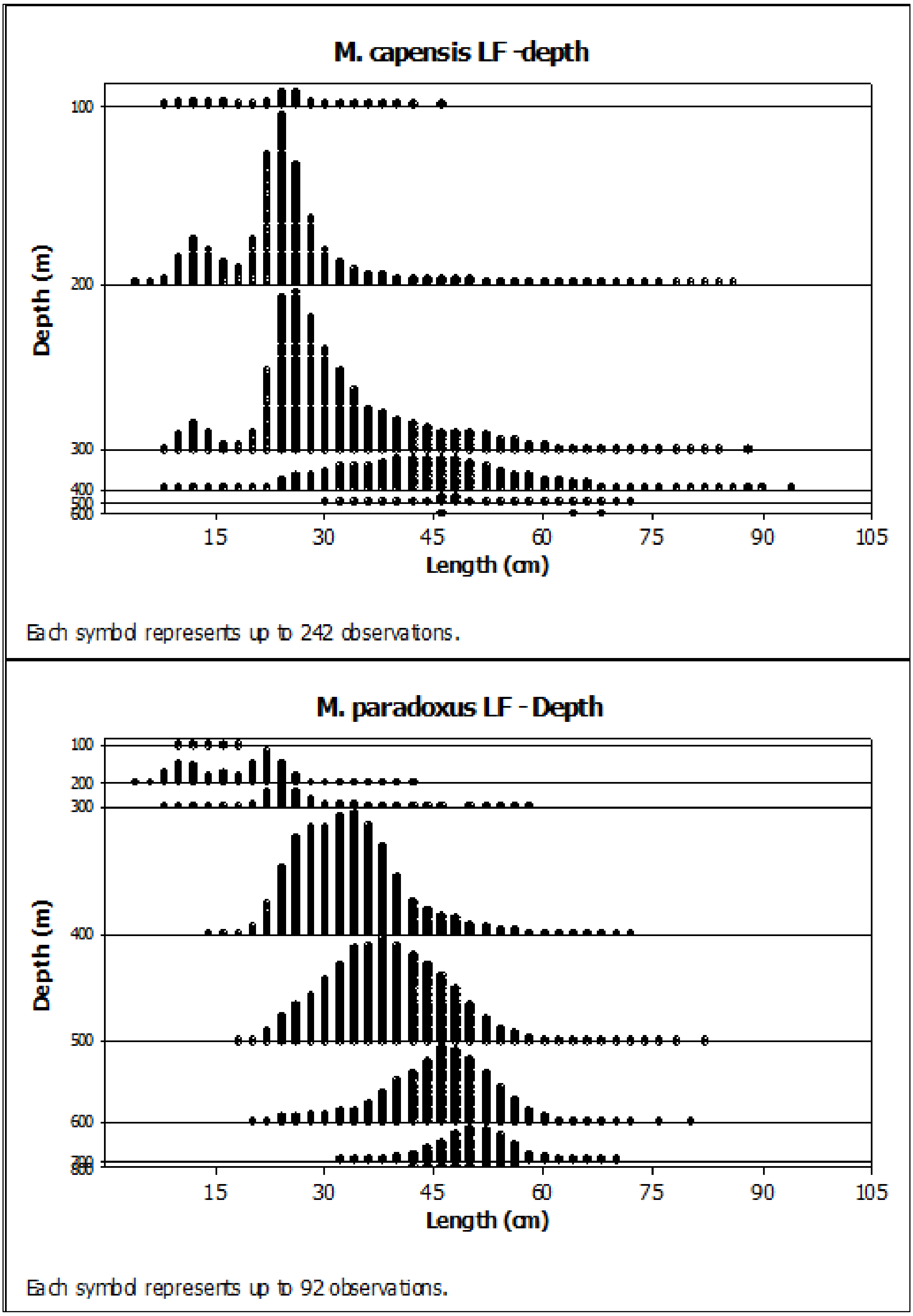


Figure 5. Hake population structure at various depths along the entire Namibian coast during 2007 to 2012.

4.1.2 Monkfish

Due to the predominantly southern distribution of monkfish in Namibian waters, there is a concern that the proposed phosphate dredging activities could potentially impact the reproductive potential. The two species *Lophius vomerinus* and *L. vaillanti* showed population dynamics with no unique features particular to the proposed mining lease area (ML 170) in relation to the rest of the stock distribution and dynamics (Figure 2). Since 2001, *L. vomerinus* has been dominated by similarly broader cohorts that peaked at fish smaller than 40 cm, although fish as large as over 100 cm have been observed (Figure 6). The picture was however different for *L. vaillanti*, which showed no strong cohort dynamics, possibly due to small sample size. The absence of smaller than 20 cm *L. vaillanti* since 2001 was observed, although the sample size was too small to draw any conclusion.

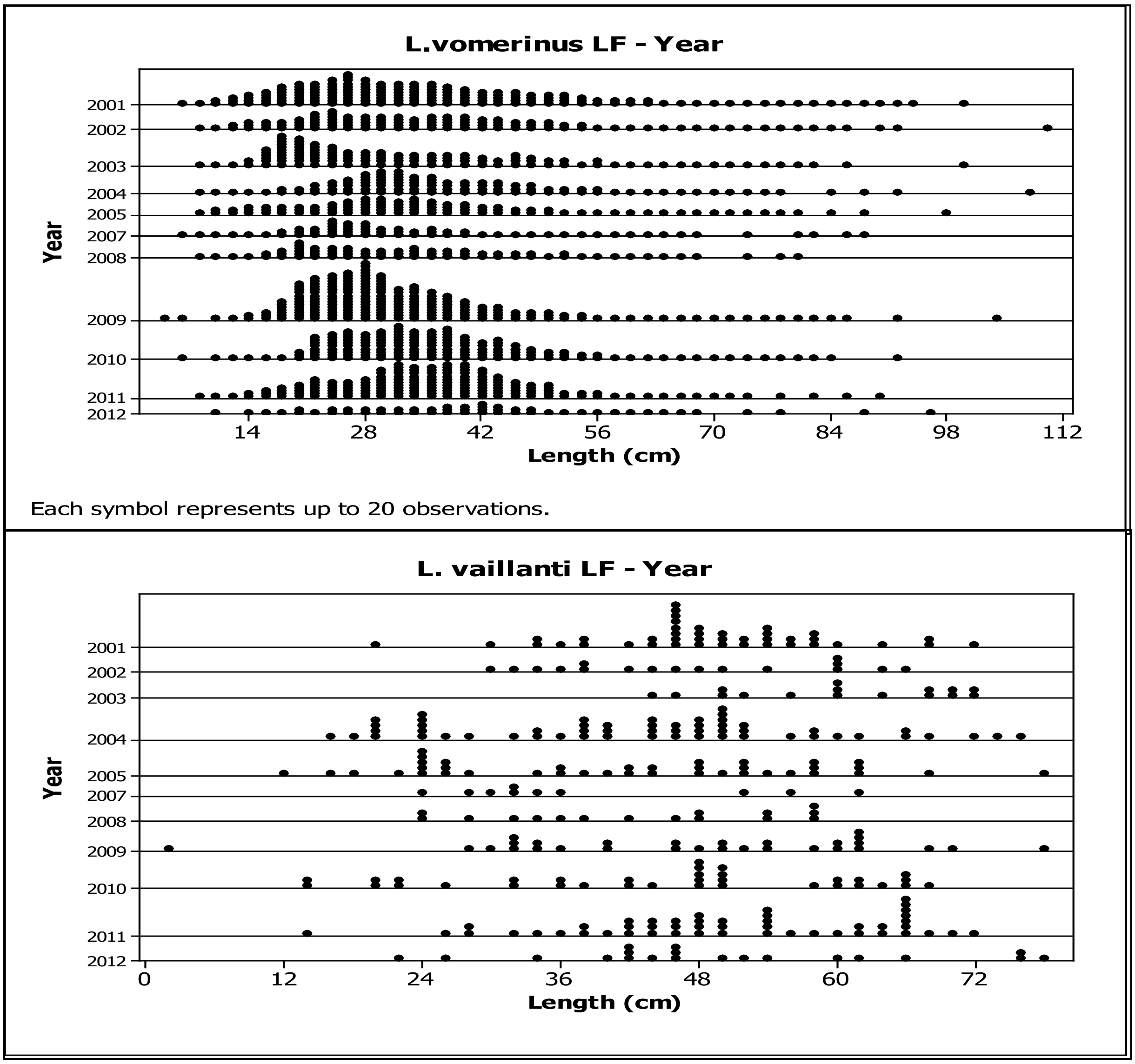


Figure 6. Monkfish population structure as observed over the years along the entire Namibian coast.

With regard to spatial dynamics, single broad cohorts for both species were homogeneous along the entire coastline, with a tendency of larger *L. vaillanti* dominant south of 22°S (Figure 7). Cohorts were again observed to be broad across longitudinal profiles (Figure 8), indicating a mix of big and small fish.

In respect of depth stratification, there is a visible trend of *L. vomerinus* fish to increase in size with depth but not for *L. vaillanti* (Figure 9 and 2). An overlay of these three spatio-temporal layers in the cohort structure does not suggest any localized reproduction ground for these two species as both juveniles and adults co-exist.

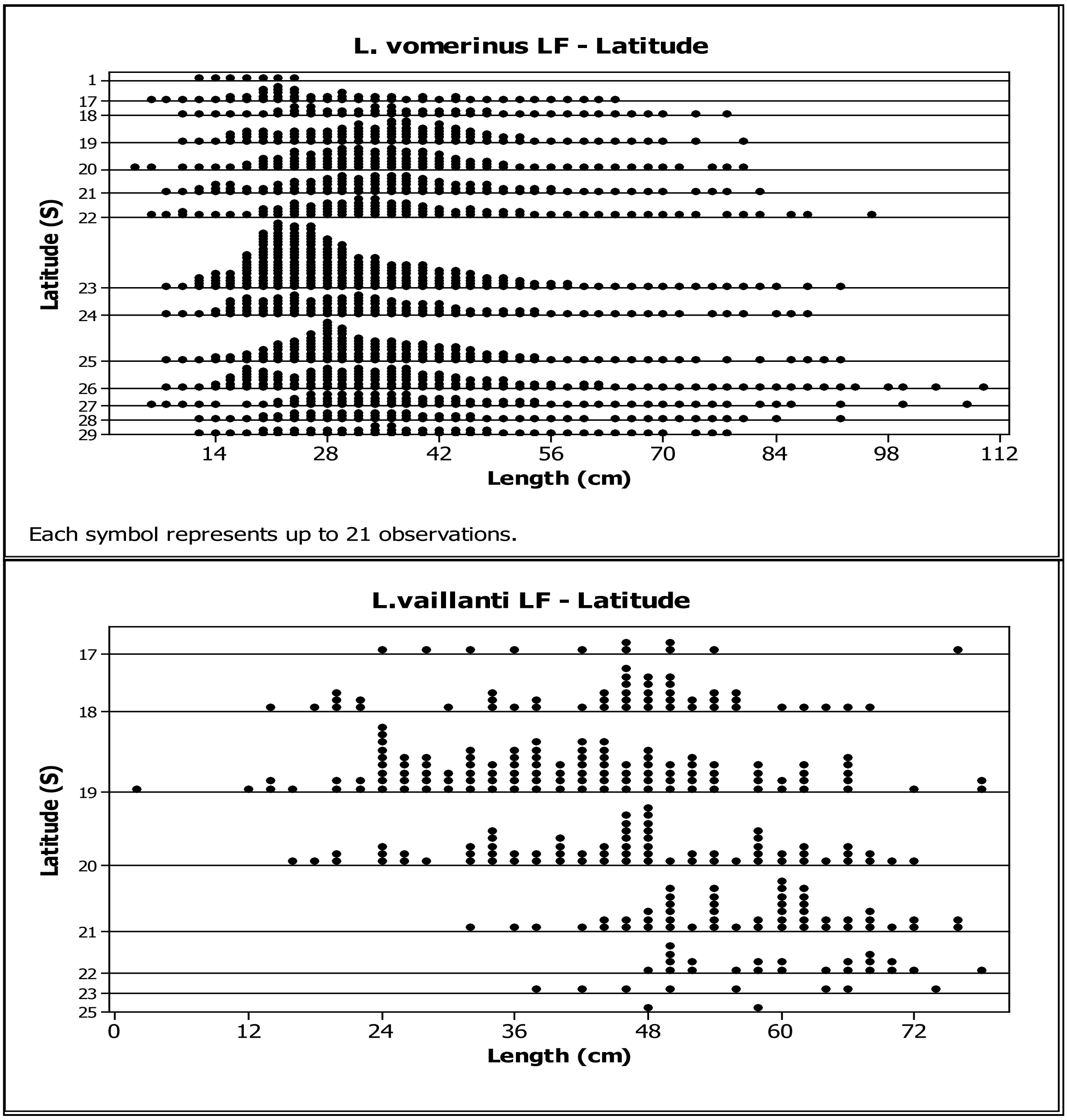


Figure 7. Monkfish population structure at all latitudes along Namibia's coast from 2001 to 2012.

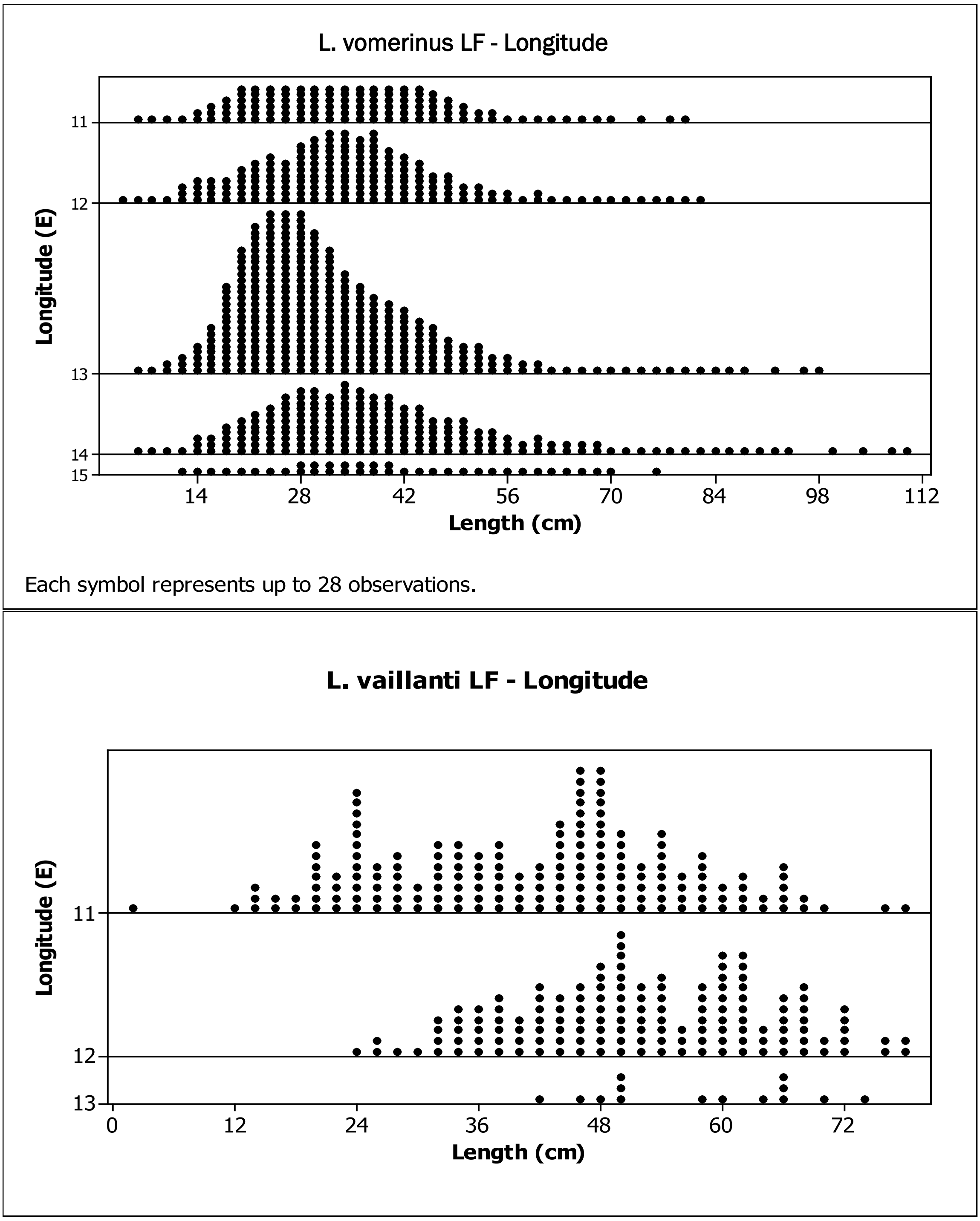


Figure 8. Monk population structures at various longitude along the entire Namibian coast during 2001 to 2012.

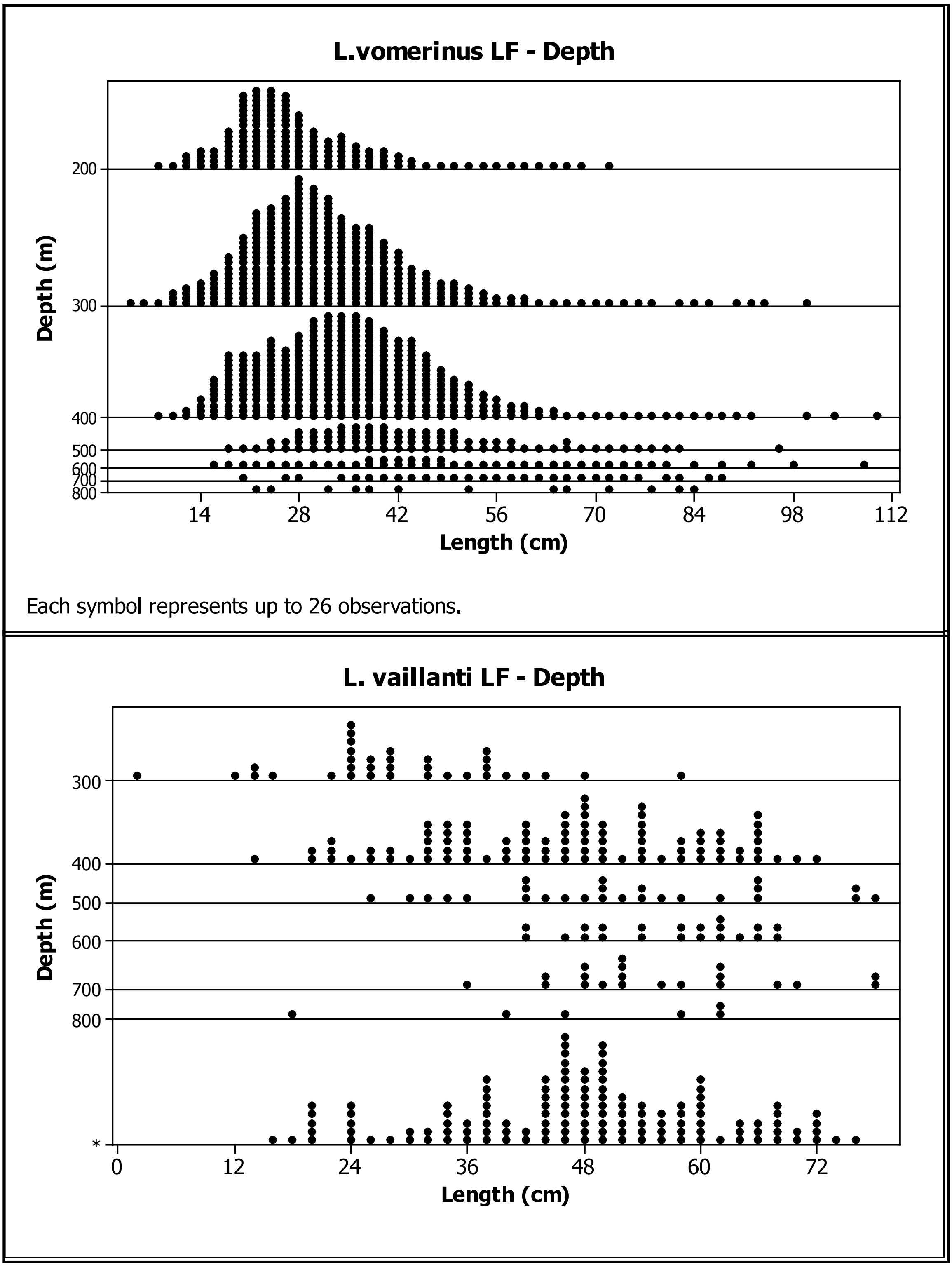


Figure 9. Monk population structures at various depths along the entire Namibian coast during 2001 to 2012.

4.1.3 Horse mackerel

Horse mackerel (*Trachurus capensis*) is a serial spawner with a population size structure that varies over time. This is observed in samples from both horse mackerel dedicated surveys and from sardine dedicated surveys (Figure 10). Historically (as far back as 1999), distinct cohorts were mainly observed for fish below 27 cm, although horse mackerel exceeding 60 cm were observed. Only fish smaller than 30 cm were observed among the sardine targeted samples. Multiple cohorts are observed in one particular year, (Figure 10), as well as at various areas (Figure 11) suggesting a heterogeneous horse mackerel population in time and space in Namibian waters. No horse mackerel data were available for the area south of 24°S since there is a low abundance of horse mackerel in this area and surveys do not extend into this area.

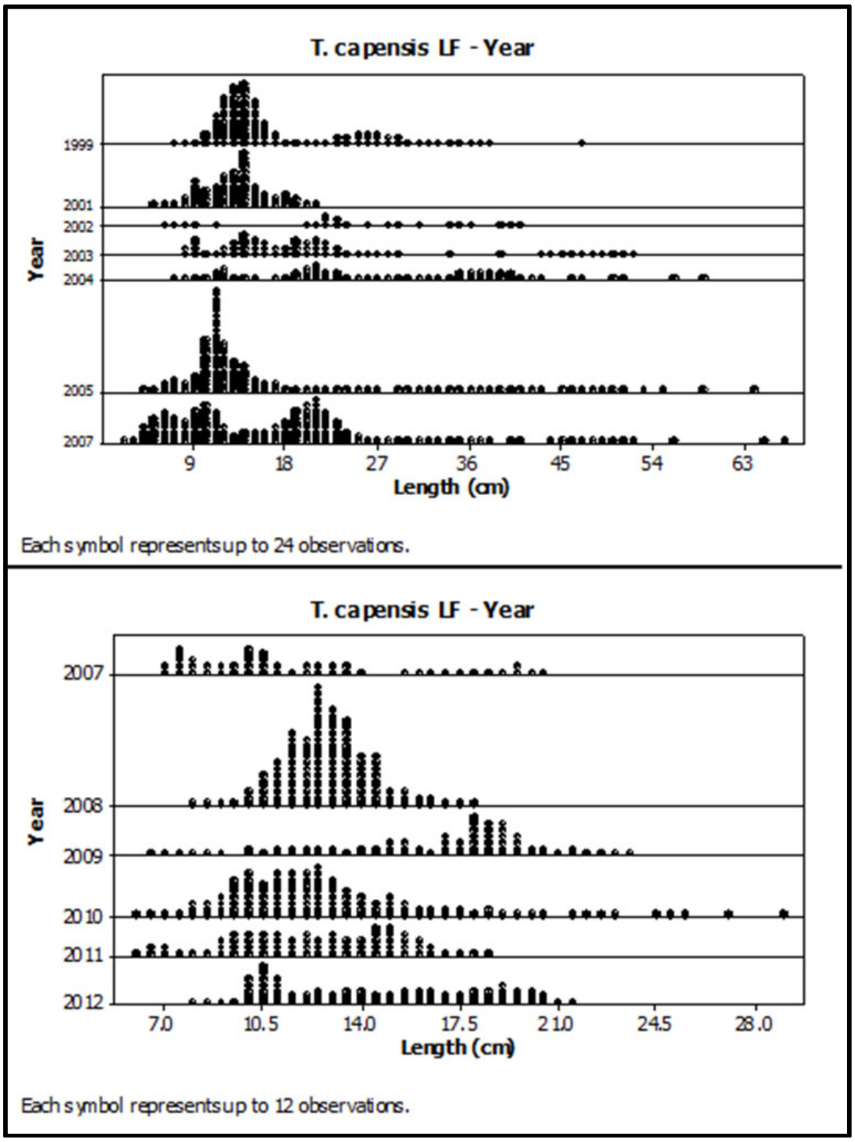


Figure 10. Horse mackerel fish size structure over the year.
The data for the top figure are from the horse mackerel surveys and the data for the bottom figure are from the sardine surveys

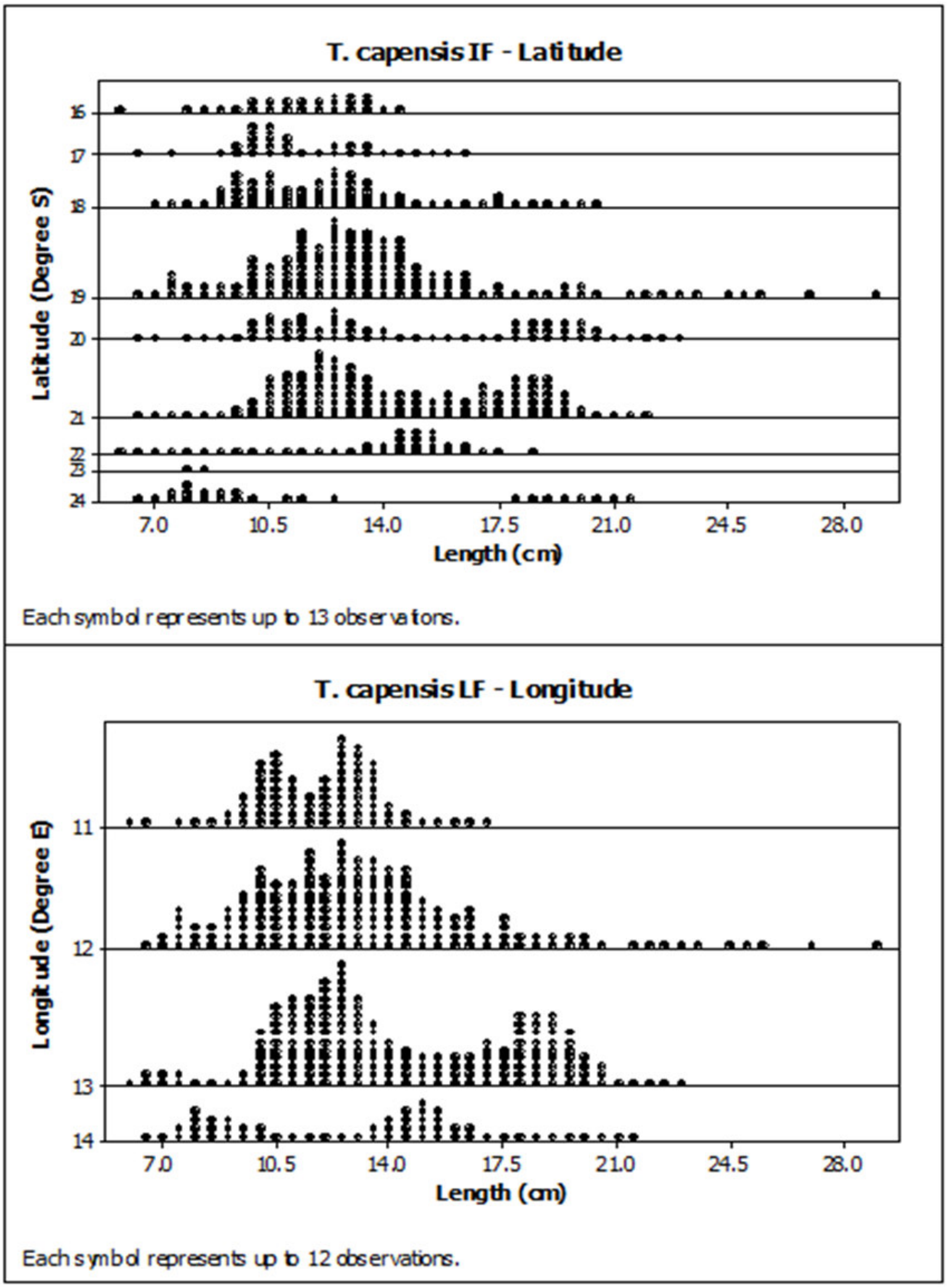


Figure 11. Horse mackerel size structure along latitudes and longitude.

4.1.4 Sardine

Cohort analysis for sardine (*Sardinops sagax*) indicated more defined and well separated cohorts as opposed to the other species. These cohorts were also more heterogeneously distributed both spatially and temporally (Figure 12). A strong recruitment cohort is observed for the year 2010, which corresponds to the cohort observed at 17°S and 11°E. There is a general shift of bigger fish to the south, although patches of small fish are also observed at southern areas. Longitudinal distribution of sardine cohorts (Figure 13) also suggests multiple cohorts at all longitudes. In all these respects, the population structure through cohort analysis indicated a more co-existing stock, as observed through broader cohorts with multiple peaks suggestive of recruitment waves, with cohorts moving in and out of particular areas.

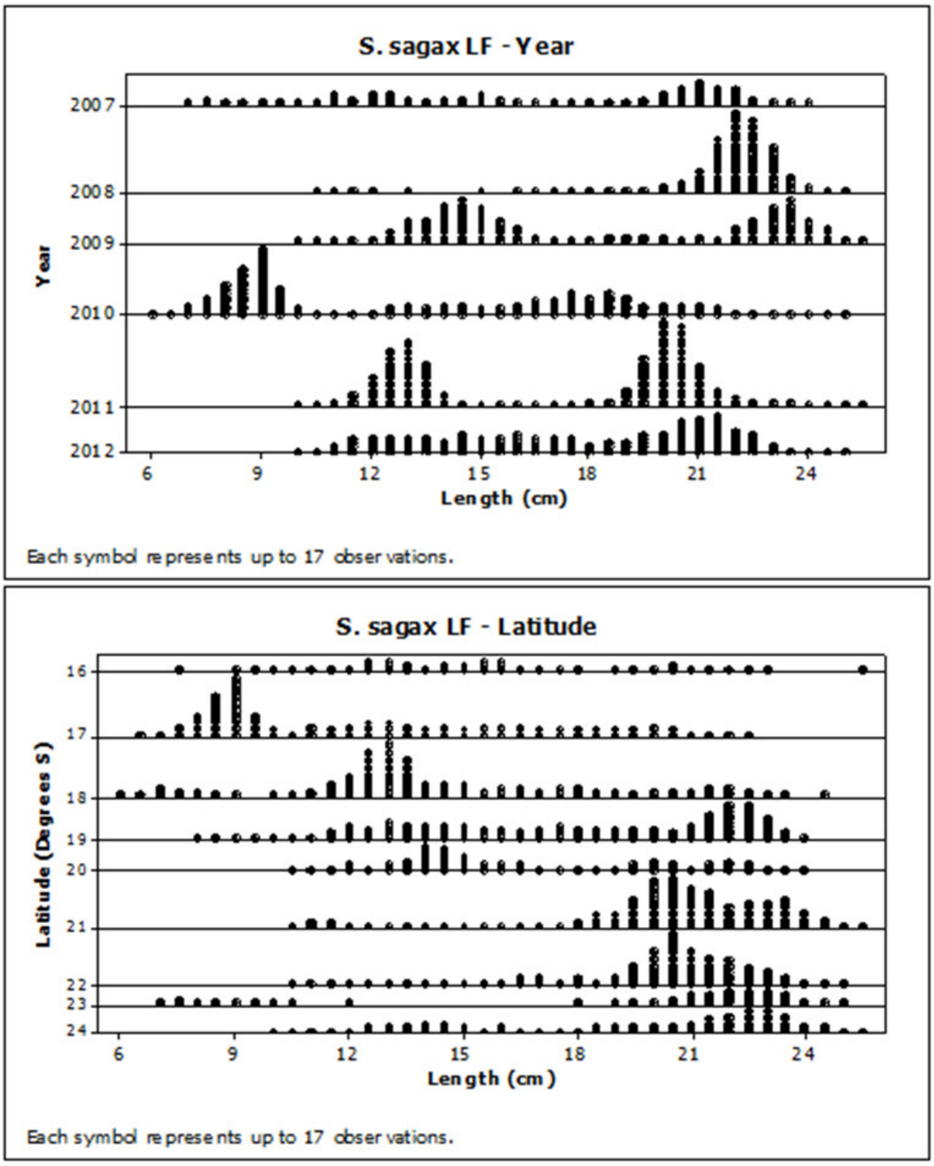


Figure 12. Sardine population structure along the coast of Namibia during the period 2007 to 2012 and along the latitudes 16 - 24^{0}S.

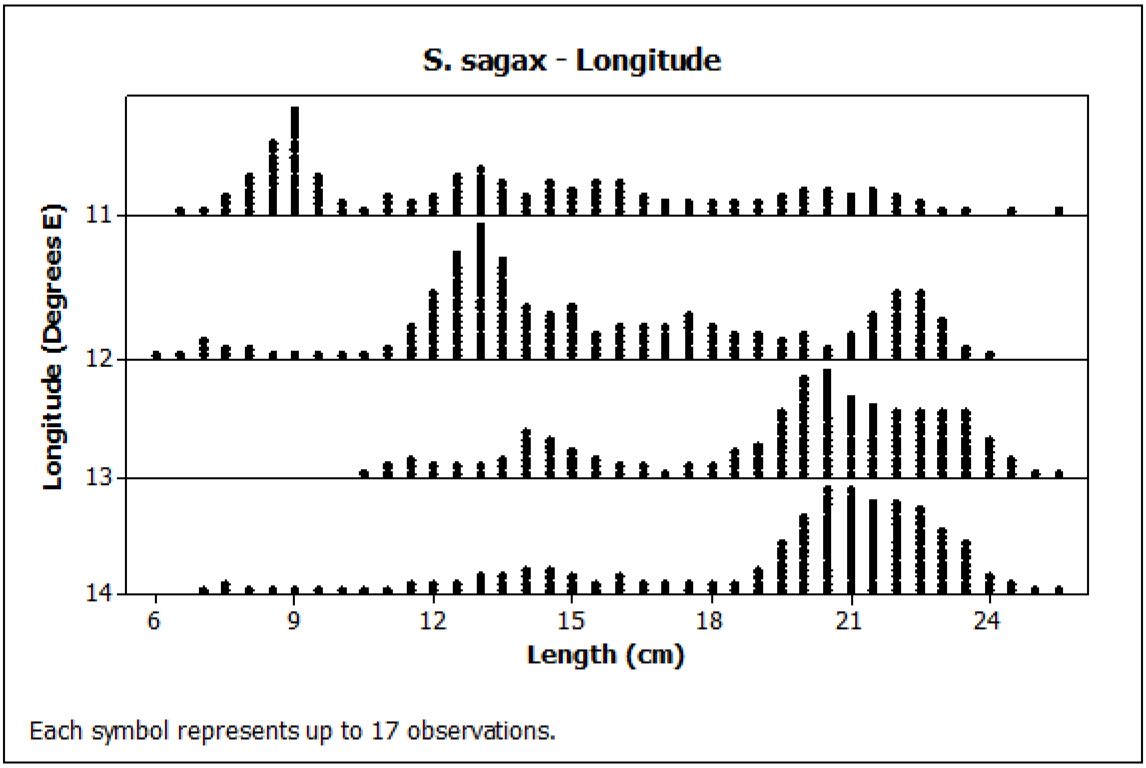


Figure 13. Sardine population structure along the coastline of Namibia during the period 2007 to 2012 and along the latitudes 16 to 24°S.

4.2 MATURITY

To assess the relevance of the proposed area as a spawning ground, maturity stages for hake, horse mackerel and sardine were mapped spatially and temporally. Fisheries observer data for hake species were also included, but no maturity information was available for monkfish species. The results showed that the maturity dynamics over the years and along the coast did not indicate unique features specific to the area proposed for dredging activities and in relation to the surrounding or the rest of the sampled coast. Using gonad maturity stage 4 and 5 as a proxy the results also demonstrated large areas over which spawning occurred (Figure 14).

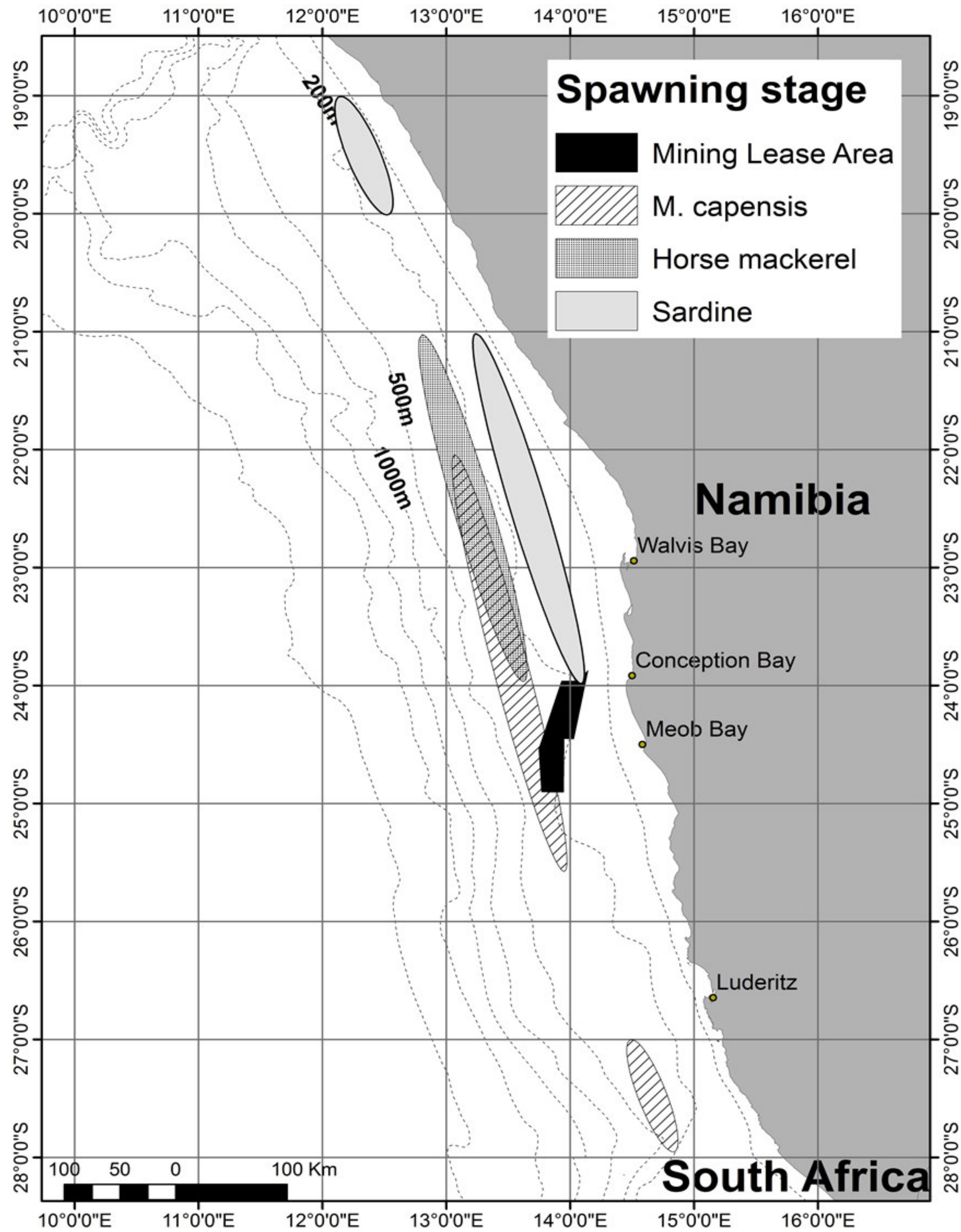


Figure 14. The areas in which spawning (stage 4 hake and 5-horse mackerel and sardine) was recorded for hake (*M. capensis)*, horse mackerel and sardine.

4.2.1 Hake

Maturity dynamics for hake indicated that more advanced stages (stage 3, 4 and 5) peak in the months June, July and August for *M. capensis* (Figure 15). *M. paradoxus* has been dominated by fish in the early maturity stages (stages 1 and 2), with as little as 10% at maturity stage 3 in March and April (Figure 15). On a spatial gradient, more stage 3 fish were observed at latitude 25°S for *M. capensis,* at depths greater than 300 m.

4.2.2 Horse mackerel

Only three months of data are available to profile maturity stages for horse mackerel, indicating a very large proportion of juveniles (maturity stage 0) in April at 24° S (Figure 16).

4.2.3 Sardine maturity

Sardine maturity profiles were also not available for a full year, but one can observe signs of spawning in March, June and October, when maturity stages 4, 5 and 6 are observed (Figure 17 -top). The presence of those three stages is generally spread along the entire coastline; with high prevalence of stage 3 and 4 at latitudes 21°S to 24°S (Figure 17- bottom).

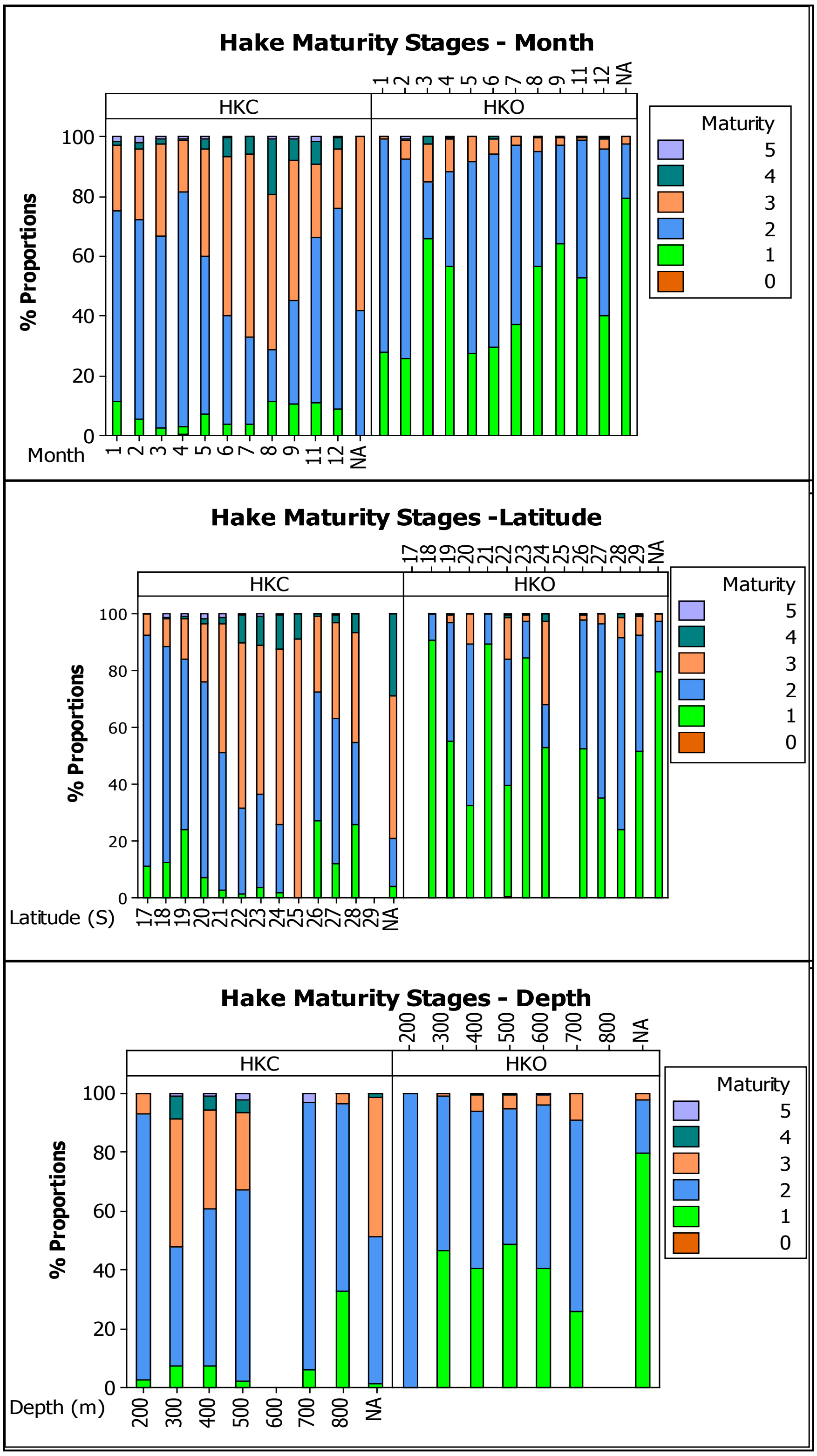


Figure 15. Maturity stage profiles for two hake species (HKC = *M. capensis* HKO = *M. paradoxus*) in Namibia. The top graph is mapped against months (January =1 to December =12), the middle graph is maturity mapped against latitudes (degrees South) and the bottom graph is maturity mapped against depths (m).

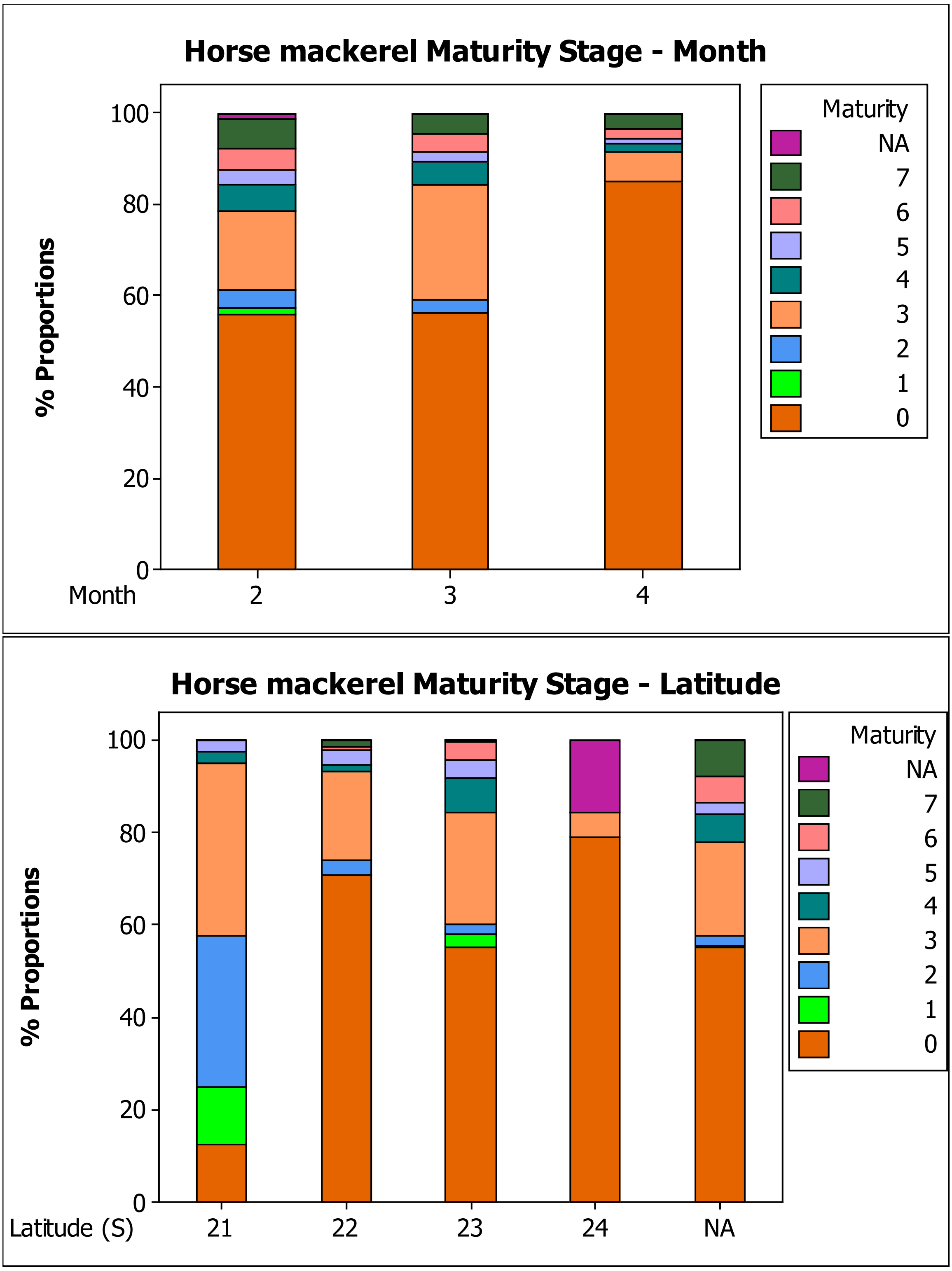


Figure 16. Maturity stage profiles for horse mackerel in Namibia.
The top graph is mapped against months (January =1 to December =12), the bottom graph is maturity mapped against latitudes (degrees South). NA refers to fish that did not have maturity assigned (top graph) or have no latitude assigned (bottom graph).

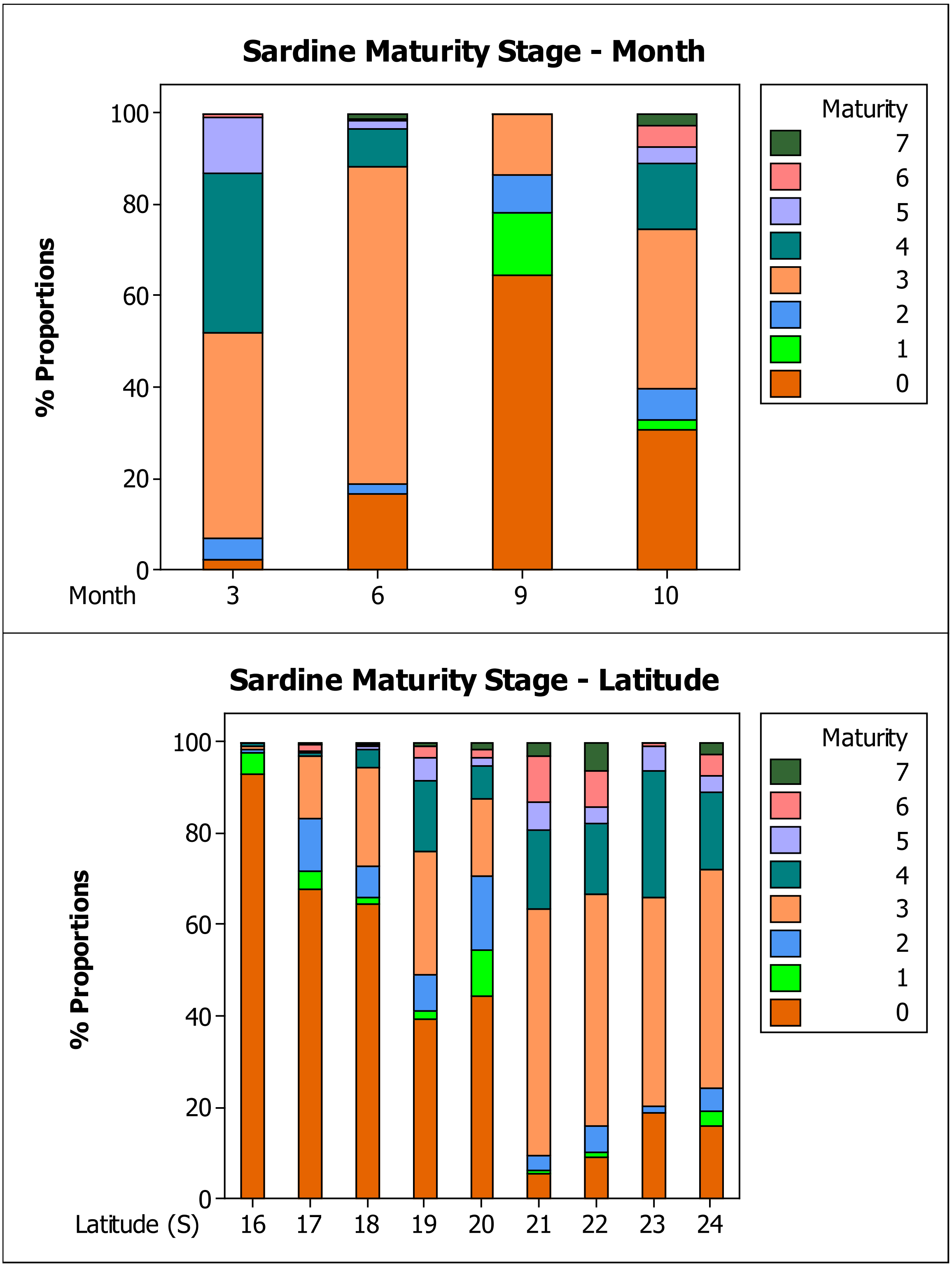


Figure 17. Maturity stage profiles for sardine in Namibia.
The top graph is mapped against months (January =1 to December =12), the bottom graph is maturity mapped against latitudes (degrees South).

5 DISCUSSION

The results of an investigative study, aimed at presenting the reproduction dynamics of commercially important species along the entire Namibian coast, mainly within the area proposed for phosphate mining are presented here. This report seeks to establish an understanding and to set the baseline of the current reproduction dynamics with respect to the Sandpiper phosphate mining licence area (ML 170).

Observed multiple cohorts both in spatial and temporal analysis suggest that factors other than habitat preference are responsible for the distribution of Namibian marine species. The presence of both adults and juveniles (simultaneously or at separated times) imply that grounds that are good for adults at one particular time could be occupied by adults or both adults and juveniles at another time. Such dynamics are indicative of varied environmental and oceanographic conditions thus fish do migrate extensively in response to conditions relevant for their life stage. Discrimination of factors that determine reproductive areas remains poorly understood (based on the historical and current information) and many more observations and analysis beyond the scope of this study would be needed. It can however be stated that these results suggest that when a particular area is not favourable for reproduction or other biological requirements, fish will move out of an area and into other more suitable areas. Keeping in mind the importance of environmental effects on reproduction, it is important to remember that Namibian waters fall within the strong Benguela upwelling system, where differential behaviour of the upwelling goes from one extreme (calm/weakest) to another (strongest). Major stock fluctuations have undoubtedly been influenced by the large-scale environmental perturbations, such as the Benguela Niño that occur periodically in the system (Shannon & O'Toole 1998, Shannon *et al*. 2006). Reproduction success and failure in such conditions is therefore better viewed through spawning stock biomass than a perceived stable environment. These cohort structures will therefore provide a good baseline in assessing how these stocks will respond to the potential impacts of phosphate dredging.

Several studies have reported that reproduction in sardine stocks is highly dependent on density-independent and density-dependent factors (Daskalov *et al*., 2003). We have observed in this study that variation in the stock structure for the Namibian sardine population suggests that conditions elsewhere (be they environmental or anthropogenic) in the ocean can impact its reproductive potential, because the data do not suggest any specific area (at small scale) where sardine are consistently found. The proposed dredging is therefore likely to have less of an effect upon the spawning dynamics of a highly migratory species such as the sardine.

The observed maturity profile dynamics are a somewhat rough but nevertheless a recognised method of analysing reproductive potential of any stock. The observed maturity profiles suggest the months from June to August as the months when *M. capensis* are in their most advanced maturity stage at depths deeper than 300 m. This advanced stage is still far from the spawning stage, and as observed in Kainge *et al*., 2007, no hake spawning activities have been observed in Namibia, except maturation and larger fish aggregations in the southern part of Namibia. Besides these *M. capensis* observations, other species (*M. paradoxus*, horse mackerel and sardine) for which maturity analyses were done in this study, no conclusion can be drawn from them as their data were not sufficiently adequate and these data covered a few months and the surveys did not extend into the area of interest. The presented results can however be used for drawing broader conclusions.

An aspect that was initially a concern is the use of data collected for a different purpose being used for this investigation. It was believed and assumed that these data are the true representation of the species population dynamics and the best available database, which is used for the current management decisions to which their fisheries status quo is mapped. The purpose of this study is to identify possible impacts of the proposed dredging activities on reproduction of the main commercial species (hake, monk, horse mackerel and sardine), and this database and approach is one way to make the best use of the available data. This information provides the status quo of these species with respect to spatio-temporal stock distribution, and it provides a baseline against which any further and future analyses could be evaluated.

Acknowledging that a better understanding of recent reproduction dynamics is needed, results of this study have generally agreed with the historical information. This could indicate that the system is perhaps robust enough to have sustained the dynamic environmental variability in the Benguela region. The extent to which the impact from phosphate dredging is assessed should therefore be seen in context with the acceptance that the Benguela Current is well known for its environmental variability; complex species interactions; ecosystem changes which can still not be separated in terms of natural and/or anthropogenic causes; non-linear impacts of environmental variability as well as resource exploitation impacts.

Results from this study indicated a homogenous system. The extent and severity to which any impact from phosphate dredging activities could be extrapolated is therefore difficult to quantify and perhaps of little relevance at this point, because the study area showed no unique features with respect to the entire Namibian coast(from latitude 17°S to latitude 29°S).

However, the results from this investigation could be used, together with data collected during a verification / monitoring survey, to show how (if any) mining activities could affect the current observed dynamics. It is therefore necessary to recognize that a state of the stock monitoring survey be built into the environmental management plan. Results of such studies will play an important part as a baseline for future monitoring and evaluation plan, and could be used as indicators of impacts phosphate mining might have on the reproductive biology and reproduction of commercial fish species found in the dredged area.

6 CONCLUSION

6.1 SIZE DISTRIBUTION

No significant spawning areas were observed, specifically not in the areas surrounding the proposed mining site. While the data show there are certain dynamics relating to stock structure (mainly offshore-onshore and vertical with depth for all species analysed, as well as latitudinal for *M. paradoxus*), growth seems to be generally poorly defined since stock structure, as shown by the cohort indicators, is generally broad. The area proposed for dredging has no special biological reproductive characteristics for the main commercial species found in the area to be dredged compared with the rest of the Namibian waters. For example, there are no specific indicators suggesting the dredged area is exclusively home to adult fish (spawner biomass), and has no pronounced recruitment of small and young fish.

For horse mackerel, hake and monk, data were available from 1999 to date, covering the entire coast (17°S to 29°S), whereas for sardine there were only data from 2007 ranging from 22°S to 25°S. In the case of hake, the data available suggest no significant reproductive characteristics particular to the area to be dredged.

This analysis has also shown that for all species analysed their distributions were heterogeneous. Variation in population structure was also not indicative of defined reproduction grounds and in particular the area around 23 to 25°S showed patterns just as complex and undefined as previously observed in historical studies. The results of this study did not show any special features of the proposed dredging area, with respect to the rest of the Namibian coast in both space and time. Cohort analyses for all the species analysed were a mix of small and large fish for most of the areas, and therefore lacking signs of well defined spawning areas and/or recruitment of small fish.

6.2 GONAD MATURATION

Whilst hake with more advanced gonad maturity were present around the latitudinal area of interest, they were found mostly in greater depths than those of the proposed dredging activities. Monthly dynamics have also not indicated any progress (beyond a maturing stage) in gonad maturity at that particular area, suggesting that fish do move in and out of such grounds over time. Annual maturity dynamics have also not shown repeated dynamics, implying that spawning grounds for these species is not localized. However, more data are needed to fully assess any risk to the resource. These multiple cohorts as observed per year and by area, are suggestive of high and low reproduction events. This has again indicated lack of homing for adults and undefined reproduction and spawning grounds.

It is recommended that various 'state of the stock' monitoring surveys could be built into the environmental management plan. The presence of phosphate as a resource in this area and given the importance of information needed on the dynamics of the commercial fish stocks in the MLA, it is worth noting that moving forward, the area should be included in the routine surveys undertaken by MFMR. Results of such studies will play an important part as a control measure, as well as a baseline for future monitoring and evaluation plans. Similarly, results from such monitoring programmes could indicate the extent of the impact of phosphate mining. The currently planned verification survey is highly recommended as it will add resolution to this study, by focusing in the proposed area at high sampling resolution. *Note*: this verification survey was undertaken in June 2014 and is reported in Section C, Chapter 3.1.

7 REFERENCES

Botha, 1986 Reproduction, sex ratio and rate of natural mortality of Cape hakes *Merluccius capensis* cast. and *M. paradoxus* Franca in the Cape of Good Hope Area. *South African Journal of Marine Science*. **4**: 23 - 35

Hilborn R, Maguire JJ, Parma AM and Rosenberg AA (2001) The precautionary approach and risk management: can they increase the probability of successes in fisheries management? *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 99 – 107.

Japp DW and Smith M (2011) Review of the spawning activity, icthyplankton drift routes and the recruitment of Namibian marine fauna with reference to the proposed marine phosphate mining area, Internal Report, Capricorn Fisheries. Pp. 21.

Kainge P, Kjesbu A, Thorsen A and Salvanes AG (2007). *Merluccius capensis* spawn in Namibian waters, but do *M. paradoxus*? *African Journal of Marine Science* **29**: 379 -392.

Ndjaula HON, Krakstad J-O, and Kjesbu OS (2013) Reproductive biology of horse mackerel *Trachurus capensis* and *Trachurus trecae* in Namibia and Angola, *African Journal of Marine Science*,**35**(2) : 141-150.

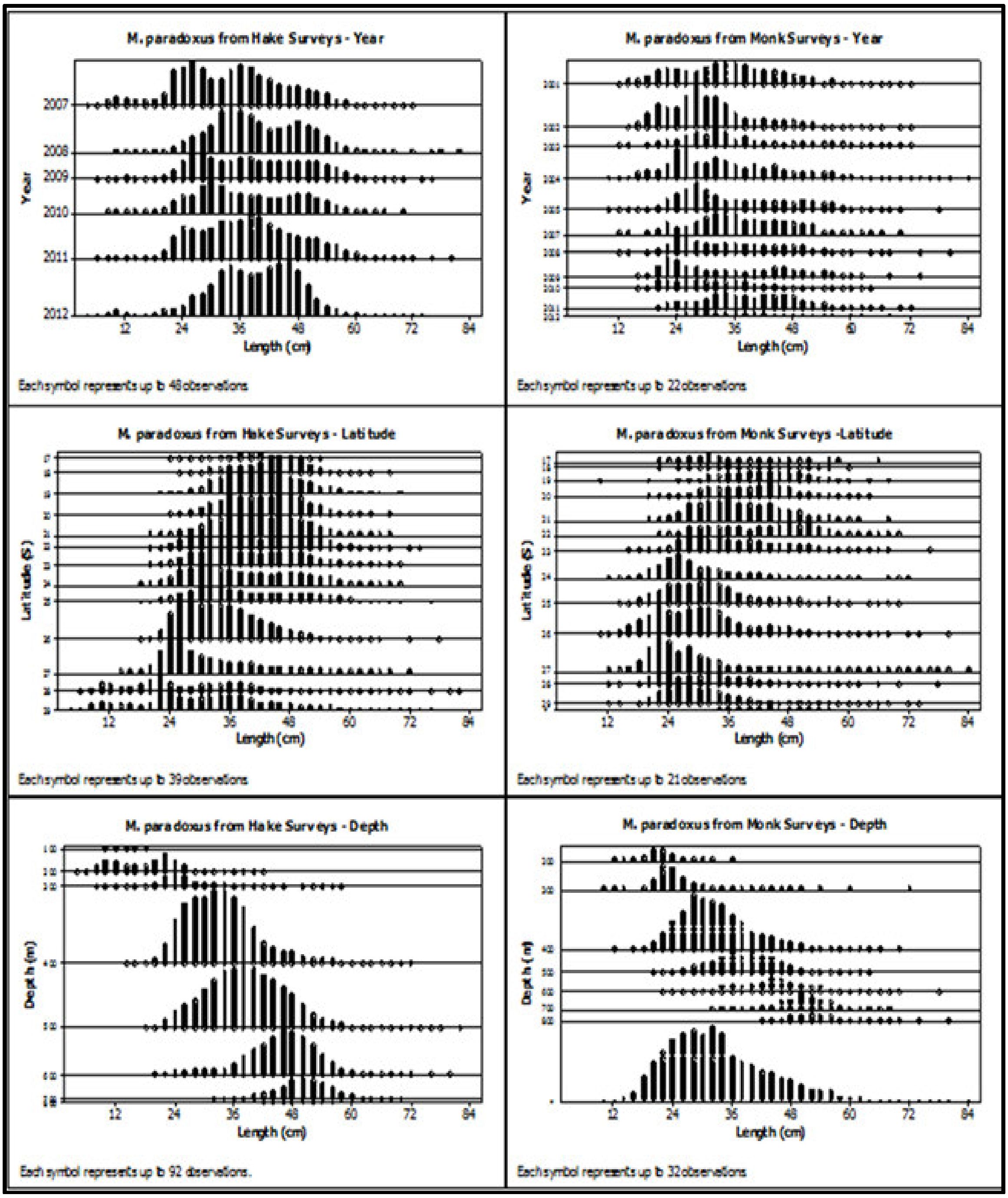
Osborne RF, Mello YC, Hofmeyr MD and Japp DW (1999) Serial spawning and batch fecundity of *Merluccius capensis* and *M. paradoxus*. *South African Journal of Marine Science* **21**: 211-216.

Shannon LV and O'Toole MJ (1998) An Overview of the Benguela Ecosystem. Collected papers, First Regional Workshop, Benguela Current Large Marine Ecosystem (BCLME) Programme, UNDP. 22-24 July 1998, Cape Town, South Africa.

Shannon, V., Hempel, G., Melanotte-Rizzoli, P., Moloney, C. and Woods, J. eds. (2006) *Benguela: Predicting a Large Marine Ecosystem*. Elsevier Science.

ANNEXURE 1: HAKE SIZE DISTRIBUTION

M. paradoxus size distribution from data collected on monk survey (right column), presented together with *M. paradoxus* size distribution from hake surveys for comparison purposes.



ANNEXURE 2: TERMS OF REFERENCE

Dredging of Phosphates offshore Namibia (Sandpiper Project)

Overview of the recruitment of the principal commercial fish species found in Namibian waters. Provide an opinion on the extent of the known recruitment and the possible impacts on this recruitment in a spatial and temporal context relative to the proposed mining for Phosphates in the Sandpiper Mining Lease area.

1. Undertake a review of the available literature and information available on the recruitment of the main commercial fish species in Namibian waters. By recruitment it is meant to include a) egg and larval distributions, b) spawning frequency and areas, c) juvenile abundance and migrations (north south, inshore offshore, shallow deep etc), d) Substrate preferences if any d) recruitment to the main fishery sectors in particular monk and hake.
   The species should as far as possible include (but not exclusively):

   a) Hakes (2 species)
   b) Monk (2 species)
   c) Horse mackerel
   d) Pilchard
   e) Other small pelagic species (anchovy, red eye herring, lantern and light fishes)
   f) Rock lobster
   g) Pelagic gobies

2. Review the available literature and or available information on seabirds and seals and related colonies in the proximity of the Sandpiper MLA and provide an opinion on the possible impact the dredging may have on their behaviour;

3. Report on the historical and on-going research undertaken on the recruitment/ spawning of the above species and the extent to which it may cover the area impacted by the Sandpiper mining area.

4. Provide an opinion on the scaling effect – that is the likely area of impact of the proposed dredging and likelihood that recruitment and reproductive potential of the main commercial species may be impacted relative to the known distribution of these species and their reproductive biology.

5. With respect to this reproductive knowledge comment on the uncertainty that may prevail due to environmental effects – e.g. sea surface warming, current regimes.

6. Provide a report of no more than 20 pages – this should include a comprehensive reference list. Appendices containing relevant information should also be included.