Report of the Benguela Current Commission ECOFISH WP1-WP2 Hake Stock Structure Workshop

DAFF Research Aquarium at Sea Point

26 – 28 March 2014

EXECUTIVE SUMMARY

The ECOFISH project (a collaborative Benguela Current Commission – European Union project) aims to develop regional stock assessments of marine fish resources that may be shared between countries in the Benguela Region (i.e. of a transboundary nature). The first of the resources being considered by ECOFISH is hake, specifically the two species that may be shared between Namibia and South Africa (shallow-water hake *Merluccius capensis* and deep-water hake *M. paradoxus*). There remains uncertainty concerning the stock structure of these two species. In the absence of definitive information concerning the possible transboundary distribution of stocks of these two species, a workshop was convened from 26 – 28 March 2014 by the Benguela Current Commission with the objective of initiating co-ordinated discussions towards developing hypotheses regarding the stock structure of these two species of hake. The available information that was reviewed during the course of the workshop included some results of genetics analyses, data collected during research surveys (primarily spatial patterns in abundance and size structure) that had been analysed using GeoPop techniques, spatial patterns in spawning, age and growth. Based on these data, a number of alternative hypotheses concerning the stock structure of the two species were developed. In terms of *M. capensis*, three alternative hypotheses were recommended, while two hypotheses of *M. paradoxus* stock structure were proposed. The workshop also recommended several fields of future/continued research on this topic, providing a basis for a second phase of the ECOFISH programme.

RATIONALE

Progress on the ECOFISH project, and specifically on Work Package I (stock assessment) and Work Package II (input to stock assessment models) was reviewed during the annual DAFF/NRF/MARAM International Stock Assessment Review Workshop convened at the University of Cape Town in December 2013. The International Panel, having reviewed available documentation and information made the following general recommendation:

> *"The Panel recommends that the biologists and modellers (South African, Namibian and Danish) collaborate to: (a) identify alternative hypotheses regarding stock structure, (b) test those hypotheses using existing data (i.e. the tests to be undertaken as part of the genetics study should be based on the identified hypotheses to the extent possible), and (c) population models should be implemented for the hypotheses that cannot be rejected given the tests conducted, to ensure that the models used for management reflect the range of plausible stock structure hypotheses."*

In line with this recommendation, the Benguela Current Commission convened a workshop in March 2014 during which key ECOFISH participants met address the first of these recommendations.

OBJECTIVE

Initial discussion of integrated information from various biological sources to inform the construction of alternative plausible hake stock structure hypotheses (i.e. number of stocks, possible overlap and movements during the year) for both *M. capensis* and *M. paradoxus* off Namibia and South Africa.

It was intended that the outcomes of the discussions during this workshop would inform subsequent meetings aimed at furthering the objectives of the ECOFISH programme, specifically:

i. ECOFISH modelling workshop - Copenhagen 26-28 May 2014
ii. Second ECOFISH biology meeting – revisit (and finalise to the extent possible) hypotheses given results available from further genetics work (November 2014)
iii. Annual DAFF/NRF International Stock Assessment Review meeting (Cape Town, 1-5 December 2014) – translating stock structure hypotheses into detailed alternative model specifications as the basis for trans-boundary assessments.

PARTICIPATION

Benguela Current Commission
Hashali Hamukuaya
Margit Wilhelm (Rapporteur)
Monica Thomas (Rapporteur)

MFMR
Paulus Kainge
John Kathena
Sarah Paulus
Johannes Iitembu

DAFF
Deon Durholtz (Chair)
Rob Leslie
Jean Glazer
Tracey Fairweather
Larvika Singh
Rob Cooper
Carl van der Lingen

University of Cape Town
Doug Butterworth

University of Stellenbosch
Conrad Matthee
Marek Lipinski
Romina Henriques

DTU-Aqua
Niels G Andersen
Jan Beyer

FAO/EAF-Nansen
Tore Stromme

Others
Melanie Smith (CapFish)
Mike Bergh (OLRAC-SPS)
Roy Ross (SADSTIA)
Rob Landman (I&J)

INTRODUCTION

An opening presentation on extending hake assessments to include both SA and Namibia was given by Prof. Doug Butterworth. As a starting point, the current approach and data used in the South African hake assessments was described. Additional issues that would arise in joint assessments were then highlighted, specifically stock structure, explicit modelling of movement and the use of non-standard assessment data such as genetics. As an illustration of the complexities inherent in incorporating spatial components (distribution, movements and overlaps of multiple stocks), the assessments of multiple stocks of Minke whales in the Northwest Pacific was described (a study that has been ongoing for several decades). The key points to be taken from this were:

- There had been considerable disagreement on the structure of the Minke whale stocks, with a relatively large number of different stock structure hypotheses that had been argued to be compatible with the available data.
- As a result, fitting the assessment models describing the hypotheses to the data has been very complex and time/labour intensive
- Genetics data had been very useful to inform on relative proportions of different stocks present in areas where these stocks overlapped.

The emphasis of this ECOFISH meeting should therefore be to keep the hypotheses of hake structure as plausible, simple and few in number as possible. It was suggested that genetics information coupled with GeoPop analyses of size distribution and spawning patterns were likely to be the most useful sources of information towards clarifying stock structure questions.

It was proposed that following this workshop, a further 3 meetings should be held during 2014:

- May 2014 (Copenhagen) - refine the methods to implement scenarios in assessment models
- November 2014 (Cape Town) - refine the stock structure hypotheses with updated genetics results
- December (Cape Town, DAFF/NRF/MARAM International Stock Assessment Workshop) - finalise hypotheses and get advice from the International Panel on the most appropriate method of fitting the assessment models.

In closing the introductory session, it was noted that the question is not whether there is interchange between putative Namibian and South African stocks of hake, but whether there is sufficient interchange to warrant joint management by the two countries.

INFORMATION REVIEW

A number of sessions were devoted to presentations and discussion of currently available information, as well as alternative data sources that could be informative in future.

a) Using parasites as biological tags for examining population structure of *M. capensis* and *M. paradoxus* in the Benguela (Carl van der Lingen)

Parasites are useful as biological tags if all fish are infected by parasites and the infection occurs within an *endemic area* (i.e. an area where conditions are suitable for transmission). If an infected fish is found outside of the endemic area, one can assume that the fish has been in the endemic area at some stage in its life cycle. In order for parasites to be useful for stock structure analyses, they should:

- Be long-lived
- Have a minimum effect on the host
- Be "site-specific"
- Be endoparasites (ectoparasites may fall off during capture)
- Have a well understood life cycle
- Temporal variability in infection patterns should be understood and accounted for

A large body of literature describing stock structure studies using parasites for other fish species is available. A number of examples were described. Two parasites (*Dacnitis* and *Triaenophorus*) infecting sockeye salmon in the North Pacific were used to separate the salmon population into Eastern and Western stocks. The HOMSIR study on horse mackerel in the north Atlantic found parasites to be strong indicators in determining stock structure. Parasites were successfully used to clarify the structure of central and southern Chilean hake stocks.

In terms of local hake, three studies on parasites have been done:

- Botha (1986) – describes major endoparasites and some conspicuous ectoparasites of SA hake, and suggests that the field should be explored further in the context of stock structure studies
- Reimer 1993 (abstract only) – study on Namibian hake indicates a border between a northern and southern Benguela stocks at 25º30'S for both hake species.
- Reed *et al.* (in press) – synthesises previous work.

It was suggested that parasitology, perhaps used in conjunction with otolith morphometrics, should be considered for future work within ECOFISH. Parasite research has recently been initiated for SA hake, and perhaps should be extended to Namibian hake.

Key points arising from discussion:

– Considering the results of Reimer 1993 (only abstract available – efforts should be directed at obtaining the full paper), this research seems promising, and should be repeated. The 25º30'S boundary between northern and southern Benguela stocks suggested in the paper conforms to current perceptions of *M. capensis* stock structure derived from size structure information (size structure shows a contained stock north of Lüderitz - see later presentations)

– I**t was agreed that sampling for this research (both parasites and otolith morphometrics) should be initiated throughout the Benguela region as soon as possible.**
– Tore Stromme mentioned that in ICSEAF times and the early 1990s hardly any *M. paradoxus* were found in Namibia.

b) Population genetics of hake (Romina Henriques)

Research on the genetics of hake stocks in the Benguela has aimed at investigating:

- Population structure of deep and shallow-water hake across Southern Africa
- Connectivity patterns between populations
- Temporal and/or geographical structuring
- Effective population sizes and demographic history
- Hybridization events

Markers that have/are being employed:

- Mitochondrial DNA (mtDNA) – provides a "longer view", informs on historical processes, population structure and evolutionary history
- Nuclear microsatellites - recent population structure, migration rates, demographic history and effective population sizes. Fine scale structuring
- NGS: evidence for local adaptation and natural selection, fine scale structuring

Data collected to date suggest a 99% chance of population structure between *M. capensis* and *M. paradoxus*, but further conclusions require completion of the analyses of the samples collected during 2013 and 2014 (it is anticipated that these results will be available in November 2014).

The issue of hybridization requires further consideration in view of the results recently published by Miralles *et al.* (Journal of Sea Research, 2014). Analysis of samples collected over the 2002-2003 period indicates appreciable levels of hybridization (36% in *M. capensis* and 20% in *M. paradoxus*) between the two hake species in the Northern Benguela (although much lower levels in the Southern Benguela). The hybrids are viable and can reproduce with each other and with the parental species.

Key points arising from discussion:

- The results of Miralles *et al.* (2014) are surprisingly high (20 – 36%, compared to levels less than 8% in a recent study of kob), with the high levels of hybridization only detected in the Northern Benguela from a relatively small sample size (n=88).
- It is possible that inaccurate baseline allele frequencies, coupled with incorrect vial sample labelling may have contributed to the results.
- 250 individuals have been analysed for stock structure so far (available samples were collected in 2005, 2012 and 2013, all in summer so no seasonal information). The stock structure seen in the 2005 data did not compare with that from the 2013 samples. Sampling ideally should encompass the entire coastline at one time.
- Samples have recently been collected in summer 2014 along the entire coastline. The SA west coast and south coast samples have been provided to Conrad Matthee. Paul Kainge is to send Conrad the samples collected in Namibian waters. These samples will be analysed and results provided by the November meeting.

- **It was recommended that some hypotheses from the genetic results need to be developed before the planned November 2014 meeting to enable sufficient time for these to be incorporated into the assessment modelling to be presented at the December 2014 International Stock Assessment Review workshop.**
- Delays in the genetics project from the planned schedule are due to the lack of sample collection in 2011.

c) Spawning patterns of shallow-water hake (*Merluccius capensis*) and deep-water hake (*Merluccius paradoxus*) in the Benguela Current Large Marine Ecosystem shown by the gonadosomatic index (Jansen *et al*., presented by Niels Andersen)

A method of identifying spawning fish using Gonadosomatic indices (GSI) was applied to data from 54 000 samples of gonad and body mass collected in the region. Spawning *M. capensis* were observed throughout the study area on the continental shelf and shelf break, mainly at locations with bottom depths shallower than 200 m. Spawning *M. paradoxus* were found further down the continental shelf and slope mainly at depths between 200 and 650 m (Fig. 1). The data indicate that there may be some spawning of *M. paradoxus* in Namibian waters (Fig. 1 – refer to Table 1 for the co-ordinates of key locations along the Southern African coastline).

In the northern Benguela (central Namibia), strong seasonality was observed, with the main spawning season of *M. capensis* in winter from July to September, peaking in August (Fig. 2). Larger fish appeared to initiate spawning first. The results furthermore suggested a regional contrast between winter spawners in the north (Namibia) and summer spawners in the south-east (Fig. 3). This pattern coincided with strong upwelling and phytoplankton production, a proxy for larval food. Hake condition was shown to follow the spawning cycle, with a decrease in relative body weight following the development of the gonads. The temporal spawning pattern of *M. paradoxus* differed from *M. capensis* in that *M. paradoxus* appeared to spawn throughout the year on the South African south coast with increased intensity in two periods, namely autumn and spring (Fig. 2). The current October-closure of the fishery in Namibia does not match the peak spawning in August/September.

Key points arising from discussion:
- Depth-frequency plots should be re-plotted as proportions - the frequency of spawning females is an effect of the number of fish sampled at each depth.
- Sampling happened throughout the year in Namibia, but not in South Africa, so no conclusions concerning seasonality can be made for SA hake.
- It was suggested that using the “ripe-and-running” gonad stage as an indicator of spawning may be more useful than using GSI in some instances.
- Maturity stage data from the South African observer programme exists and should be used.
- Did *M. paradoxus* spawn in Namibia before this study and were not captured, or were they not spawning there? Assorov and Berenbeim 1983 ICSEAF data suggest that *M. paradoxus* spawned in Namibia in the 1980s.

d) Inter-calibration of survey trawl gear using paired hauls (Jan Beyer)

A statistical method for the inter-calibration of survey gear (i.e. determining the relative selectivity of two different gear types) was described. The method is based on Poisson distributed catch counts in each length class, conditional on log-Gaussian variables that prescribe the expected counts. These log-Gaussian variables yield over-dispersion relative to Poisson statistics as well as the correlation between catch counts, and model the size spectrum of the underlying population, size-structured clustering of fish at small temporal and spatial scales, as well as the relative selectivity of the two gear types in each length class.

The method was applied to catches of hake (*M. paradoxus* and *M. capensis*) in paired trawl hauls taken with RVs *Africana*, with "old" and "new" gear, and *Dr. Fridtjof Nansen*, with Gisund gear. The results are very preliminary due to several issues in the data base that remain to be dealt with, and should be seen largely as a proof of concept. The results demonstrate that it is feasible to estimate the relative selectivity in each size class, but it has to be recognized that the confidence limits are wide. The Gisund gear generally catches smaller fish than does the *Africana* gear.

Key points arising from discussion:

- It was suggested that depth differences should be taken into account (the results presented were integrated over all 236 parallel trawls, which had been conducted at different depths), as well as the area swept
- Smoothing criteria were used in this model – it was suggested that perhaps AIC model criteria should be considered
- The "old" vs. "new" *Africana* gear comparison demonstrate larger uncertainty that has been assumed in the past.
- It was suggested that GeoPop does not need to be brought into a stock assessment environment (e.g. to estimate recruitment parameters), but should rather be used as an independent evaluation of the key features of the stocks that can then be used to put external constraints on the stock assessment models.

e) Analysis of spatio-temporal stock structure for Namibian hakes (Paul Kainge)

Preliminary results for a study aimed at investigating alternative methods for the fish stock assessment of Namibian hakes (*Merluccius capensis* and *M. paradoxus*) were presented. The two species are currently assessed as one stock in Namibian waters, assuming that both stocks are homogeneously distributed along the Namibian coast. However, two distinct stocks may be more accurately modelled separately taking additional spatio-temporal effects into account.

The study involves the use of spatially and temporally explicit commercial trawl catch and effort data (CPUE) for assessment purposes, through the analysis of CPUE data in order to identify alternative stock boundaries. Preliminary results based on unstandardised trawl CPUEs from 2010-2012 indicate consistently high CPUEs off Lüderitz and northwards (17–20°S) during the entire year, as well as in the central areas during August–November. The exception is 2011 when high CPUEs where observed along the entire coast.

If appropriate, comparative runs with the SAM model will be done. It is expected that this study will provide new information on the transboundary stock structure of the two hake species.

Key points arising from discussion:

- An ICSEAF paper (Chaplowski?) describing seasonal movement of peak CPUE along the Namibian coast was mentioned (Rob Leslie to attempt to find the paper)
- Gordoa *et al.* 2006 showed that catchability in the hake fishery is negatively correlated with by-catch of hake in the horse mackerel fishery, indicating a seasonal spawning migration northwards and inshore. The lowest observed catchability of hake (in both targeted trawl catch and by-catch) in October was argued to coincide with the spawning peak.
- It was suggested that:
  - Rather than using unstandardised CPUE, it would be more appropriate to use GLM-standardised CPUE where wetfish and freezer trawlers are separated, and vessel size effects are taken into account.
  - It was recommended that the analysis should separate the two species.
  - Observer data (size structure and split species) should be used in parallel with the CPUE data

f) Distribution and migration of shallow-water hake (*Merluccius capensis*) and deep-water hake (*Merluccius paradoxus*) in the Benguela Current Large Marine Ecosystem examined with a geostatistical population model – a preview (Jansen *et al*., presented by Jan Beyer)

Existing data from demersal trawl survey were used to map and plot the distribution and migration of *M. capensis* and *M. paradoxus* for the entire Benguela-Agulhas large marine ecosystem. Analyses were done with a new Latent Cohort GeoPop model – a geostatistical model (aggregated log Gaussian cox process model with correlations). This version tracks the cohorts in time and space. The spatial population structures and dynamics is a dimension of hake population ecology that is not currently accounted for in stock assessment and management of these resources.

The study has yet to be finalised due to ridge problems. Preliminary results:

M. capensis. The initial distribution of the 0.5-year-old recruits revealed five areas with high densities (Figs 4 - 6):

1. Walvis Bay (17-27ºS, centred on 23 ºS)
2. Orange River (27-31ºS, centred on 29ºS)
3. Olifants River / Elands Bay (31-33 ºS centred on 32ºS)
4. The Agulhas Bank
5. The Port Elizabeth area on the south coast.

From the most northern Walvis Bay centre fish moved northwards and offshore and return again by age 5, while from the Agulhas centre they remain or move eastwards and returns again (Figs 5 and 6). This suggests natal homing, but with unknown precision. Spatial population structures (sub-populations or stocks) may thus be persistent from generation to generation, or only be maintained during certain phases of the hake life history. The stability over time, as well as the level of mixing between these migration patterns and subpopulations requires further analysis.

M. paradoxus. The 0.5-year-old recruits were concentrated in an elongate retention area from on the South African West coast from Cape point to 50 km north of the Orange River mouth. Highest densities were found around the Orange River mouth area (Figs 7 - 9).

From this initial pattern *M. paradoxus* initiate their migration in their second year. The resident hakes stay or they move 300–400 km northwards or southwards or northwards to return at age 3-4 years. The migratory hakes migrate up to 1200 km northwards or southwards/eastwards to return at ages 6+ years. This indicates a trans-boundary nursery hotspot, as well as transboundary migration of several cohorts. They also suggest that the southern migratory part of the population migrate out of the area covered by the surveys. Incomplete coverage of the stock appears to be a problem for stock assessment; an extension of the survey should therefore be considered.

The alongshore migrations are combined with migrations towards deeper waters for both species.

Key points arising from discussion:

- Growth rates are currently estimated – they should be input. Alternatively, input some alternatives of growth rates to test differences and robustness in the model.
- Catchability differences between the different gears need to be considered in more detail.
- Trawls should be standardised before input.
- Very few eggs spawned east of Agulhas make it westwards – how does that go with the results? Most fish are found west of Agulhas (Plot distribution and migration). Why would most of the population go East of Agulhas if the eggs don't return? To be noted but good counter arguments were made.
- The results suggest that for *M. paradoxus*, there are either two stocks with the same nursery area or one stock that splits into two components that move northwards into Namibia and southwards into SA
- *M. paradoxus* may spawn in Namibia. If they don't spawn in Namibia, they either move south into SA waters to spawn or they are fished out in Namibia before they spawn. This would be a loss to the population.
- Given the narrow shelf in northern Namibia, it is possible that an appreciable proportion of the fish are located in deeper water that is not sampled by the surveys.
- Place names should be indicated on all distribution/migration figures.

g) *M. paradoxus* catchability (Tore Stromme and Marek Lipinski)

Data collected during transboundary surveys by the *Dr Fridtjof Nansen* and *Blue Sea* over the period ??? were presented.
A key finding was that small fish occur only in SA waters, spreading northwards into Namibian waters with increasing size. Fish of lengths greater than 60 cm are absent from Namibian waters, the larger fish again only occurring south of the border.
Fish < 10 cm are pelagic, and so are not well represented in bottom trawl data

Conclusions arising from the results:

- *M. paradoxus* (at the population level) only spawns between Cape Agulhas and St Helena Bay.
- The main *M. paradoxus* nursery ground is in the Hondeklip Bay – Orange Banks area.
- Movement between the nursery grounds and spawning area is largely passive.
- From the nursery grounds, *M. paradoxus* actively migrates northwards into Namibia and southwards up to the SA south coast.
- *M. paradoxusi* does not spawn in Namibia or in the eastern parts of the SA south coast.

h) Area-specific growth rates of Namibian and South African *M. capensis* and *M. paradoxus* (Margit Wilhelm)

Margit Wilhelm presented a summary of the species-specific area-specific and cohort-specific growth rates calculated for both *M. paradoxus* and *M. capensis*. Modal progression analysis was done on length frequency distribution (LFD) samples from Namibian seal scats, Namibian surveys and monthly commercial observer samples, all split into North (<24ºS) and South (>24 ºS) and South African surveys (split into West and South coasts) for *M. capensis* and only Namibian (no area split) and South African (W and S coast) survey samples for *M. paradoxus*. The results showed significant cohort-specific differences but no significant area-specific differences in growth rates of each species. *M. capensis* grow twice as fast as previously estimated from otoliths. *M. paradoxus* grow slower than *M. capensis*, but faster than previously estimated from otoliths. LFDs from the South coast show a potential missing age group and therefore indicate faster growth than from SA West coast and Namibian samples. The potential catchability differences or migration (out of the area or deeper) of *M. paradoxus* between 30–40 and 50 cm length classes on the South coast need to be discussed. The area split and monthly observed samples need to be added for Namibian *M. paradoxus*.

A conceptual model of spawning centres and migration of *M. capensis* in Namibia drawn up from densities at depth, area and size from Namibian surveys 1990–2007 (Wilhelm *et al.* in press) was presented. Two nursery areas were identified; one in central Namibia (Walvis Bay) and one in southern Namibia (south of Lüderitz). The migration of the northern aggregation indicates a closed stock unit with fish between 29 and 45 cm found in the far north (17–19 ºS) with larger fish returning inshore and southwards (Fig. 10). The theory is that they migrate northwards to feed/fatten/gain energy for spawning and then migrate southwards again for spawning. The southern aggregation often moves across the border into South African waters. Spawning peaks of both stocks are in winter (July–August).

A method to convert existing age data from the “old” (slow growth rate hypothesis) to “new” (fast growth rate hypothesis) data for *M. capensis* was also described. The fast growth rate hypothesis will change weight at age exponentially, maturity at age, selectivity at age (from mainly catching age 5 in commercial catches to mainly catching age 3 *M. capensis*). The observed winter hatching should be taken into consideration in the assessment.

To further analyse the differences in age and growth between South Africa and Namibia for potential stock differences, the following is required from South Africa for both species: monthly commercial LFDs, monthly otolith collection, monthly spawning information (staging)

Key points arising from discussion:

- The conceptual model illustrated in Fig. 10 compares well with the GeoPop results illustrated in Figs. 4 – 6 (other than the differences in age at length estimates arising from differences in the growth rates assumed in the two approaches).
- The results are a basis for three *M. capensis* stocks in the region, with two in Namibia (one of which straddles the transboundary area) and one in South Africa.

IDENTIFICATION OF APPROPRIATE DATA SOURCES AND DEVELOPMENT OF PRELIMINARY HYPOTHESES OF STOCK STRUCTURE

a) Data / information sources to be considered at this meeting:

The workshop agreed that the available data / information sources that should be used to develop preliminary hypotheses of stock structure / movement models at this meeting were:

M. capensis

- Spatial distribution of spawning females – GSI (Jansen *et al.* 1) [Figure 1]
- Temporal spawning patterns – GSI (Jansen *et al.* 1) [Figure 2]
- Spatio-temporal spawning patterns – GSI (Jansen *et al.* 1) [Figure 3]
- Average alongshore distribution by age – Geopop (Jansen *et al.* 2) [Figure 4]
- Cohort-separated alongshore distribution by age – Geopop (Jansen *et al.* 2) [Figure 5]
- Alongshore and depth distributions with centre of gravity (Jansen *et al.* 2) [Figure 6]
- Nursery and migration patterns Namibia (Wilhelm *et al.* in press) [Figure 10]

M. paradoxus

- Spatial distribution of spawning females – GSI (Jansen *et al.* 1) [Figure 1]
- Temporal spawning patterns – GSI (Jansen *et al.* 1) [Figure 2]
- Average alongshore distribution by age – Geopop (Jansen *et al.* 3) [Figure 7]
- Cohort-separated alongshore distribution by age – Geopop (Jansen *et al.* 3) [Figure 8]
- Alongshore and depth distributions with centre of gravity (Jansen *et al.* 3) [Figure 9]
- Stromme and Lipinski stock structure hypothesis from transboundary surveys (see text above)

b) Data / information that should be considered in future:

1. Hake spawning patterns:

The workshop agreed that consideration of hake spawning patterns should be deferred pending the completion of Melanie Smith's analyses of hake spawning and life history.

2. Genetics information:

Information that would ideally be required:

(i) Number of stocks
(ii) If more than 1 stock, what is the degree of interchange between them?
(iii) Migration rates?

While genetics data should be able to provide a clear answer on (i), definitive answers on (ii) and (iii) are unlikely, but the data may at least be able to provide an indication.
If large genetic differences between N and S exist, the interchange between stocks would be more readily detected than would otherwise be the case. The more likely scenario is that if more than one stock is detected, they would be closely related with

only minor genetic differences. The importance of quantifying the level of exchange between stocks relates to management in terms of fishing strategies (i.e. differential fishing mortalities on stocks, with some degree of replacement between the stocks). It would be important to establish how the exchange rate between the stocks compares to the natural growth rate of the resource.

3. Other useful information sources that may require further/new research

- Parasitology (has been initiated in SA, perhaps extend into Namibia through the second phase of ECOFISH that is being considered).
- Otolith shape analysis
- Scientific observer data in SA. (Deon Durholtz to contact SADSTIA regarding access to the data)
- Paul Kainge to provide the information on length, frequency and observer coverage.
- Re-look at the feasibility of a tagging study
- Validate hake age estimates derived from otolith analyses
- Ichthyoplankton surveys in Namibia
- New growth data: age/length key assessment model (Rebecca to provide results by May)
- GeoPop does not match the Afticana and Nansen egg-larval survey especially in Namibia
- Include WPII components

c) Preliminary stock structure hypotheses:

The workshop agreed that the following stock structure hypotheses (illustrated in Figure 11) are generally compatible with the available information. It would be appropriate to develop stock assessment models according to the various alternative scenarios listed below, pending refinement of the hypotheses in the light of future data/analyses.

1. M. capensis

A. One stock: Distributed through the entire Benguela-Agulhas region (scenario 1A)
B. Two stocks: Winter spawners in the Northern Benguela extending southwards to 27°S, and summer spawners in the southern Benguela and Agulhas distributed southwards and eastwards from 25°S. The stocks consequently overlap in the area 25–27ºS (scenario 1B)
C. Two stocks: Winter spawners in the Northern Benguela extending southwards to 33°S, and summer spawners in the southern Benguela and Agulhas extending from 31°S southwards and eastwards. The stocks overlap in the area 31–33ºS (scenario 1C)
D. Three stocks: A northern Benguela stock extending southwards to 27ºS; a central (SA-Namibian) stock distributed between 25ºS and 33ºS, and a southern stock extending southwards and eastwards from 31°S. The northern and central stocks overlap in the area 25-27°S, while the central and southern stocks overlap in the area 31-33°S (scenario 1D)

2. *M. paradoxus*

A. One stock: Distributed through the entire Benguela-Agulhas region (scenario 2A).
B. Two stocks: A northern stock extending southwards to 33ºS and a southern stock extending southwards and eastwards from 31°S. The two stocks overlap in the area 31-33°S (scenario 2B).

In developing these hypotheses, it was noted that the "separation" area between 25 and 27°S could be an artefact arising from lack of sampling during surveys in the untrawlable grounds between 25 and 26 ºS (Conception Bay – Lüderitz). Recruits and adults may in fact be distributed continuously through this area. It was suggested that commercial longline data be interrogated to clarify this.

TABLES AND FIGURES

Table 1: Co-ordinates of key locations along the Southern African coast

	Latitude	Longitude
Walvis Bay	22°57.00' S	014°28.80' E
Luderitz	26°38.40' S	015°09.00' E
Oranjemund	28°33.00' S	016°25.20' E
Port Nolloth	29°15.00' S	016°52.20' E
Cape Columbine	32°49.50' S	017°50.76' E
Cape Town	33°55.20' S	018°26.40' E
Cape Agulhas	34°49.20' S	020°00.60' E
Mossel Bay	34°09.60' S	022°09.00' E
Port Elizabeth	33°54.00' S	025°36.00' E
Port Alfred	33°35.88' S	026°54.10' E

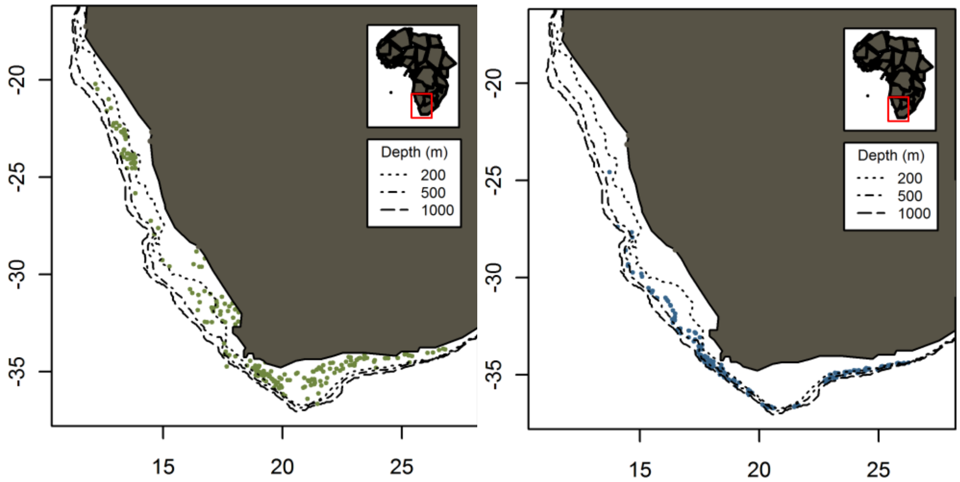

Figure 1: Maps illustrating locations of spawning female *M. capensis* (right panel, green dots, GSI > 10%) and *M. paradoxus* (left panel, blue dots, GSI > 9%).

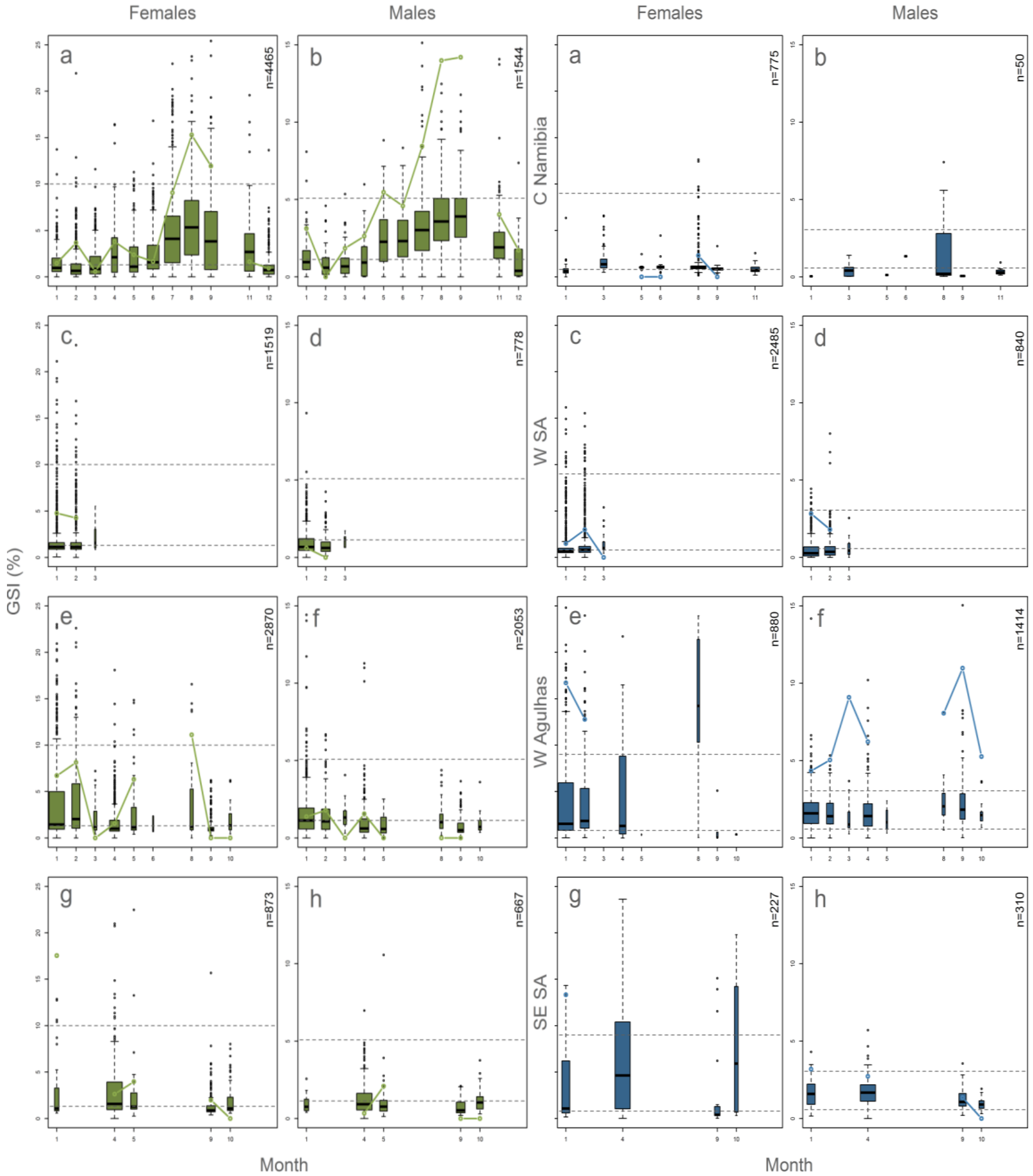

Figure 2. Timing of spawning of shallow-water hake *M. capensis* (green in the left panels) and deep-water hake *M. paradoxus* (blue in the right panels) in central Namibia for females (a) and males (b) and the central South African West coast (c, d) and western Agulhas bank (e, f) and eastern part of the South African south coast (g, h). The solid green and blue lines indicate the proportion of spawning hake among the sampled maturing/mature (ex. spent) hake. Box-whisker-plots of gonadosomatic index (GSI) by month, area (rows) and sex (columns). The lower horizontal dashed line indicates the transition between immature/spent and maturing/mature hake. The upper horizontal dashed line indicates the threshold value above which only spawning hake are found. Widths of boxes are proportional to the square-roots of the number of observations. Total number of observations (n) by sex and area are printed in top right corner of each plot.

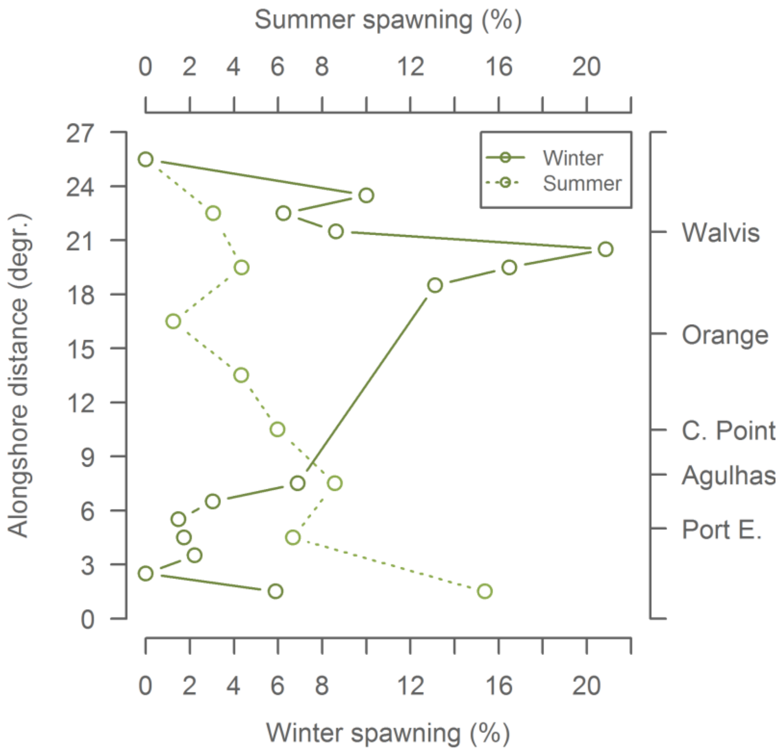

Figure 3. Summer and winter spawning of shallow-water hake (*M. capensis*) along the coast line from the eastern part of the South African south coast (0°) to northern Namibia. Spawning intensity indicated for each season as the proportion of spawning hake among the sampled maturing/mature (ex. spent) female hake per 3° of the coast line.

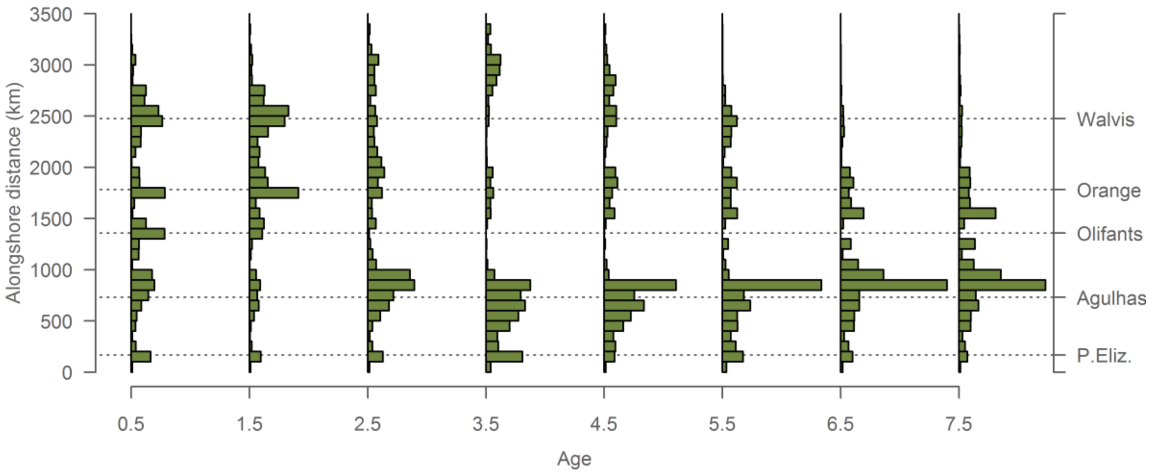

Figure 4. Jansen et al. (2). Alongshore distribution (number of fish) by age of *M. capensis* from Geopop analysis: Average of all cohorts. The spatial distribution has been projected onto a curvilinear axis following the coastline from Port Elizabeth in the South-East to the Namibia-Angola border (Kunene River) in the North.

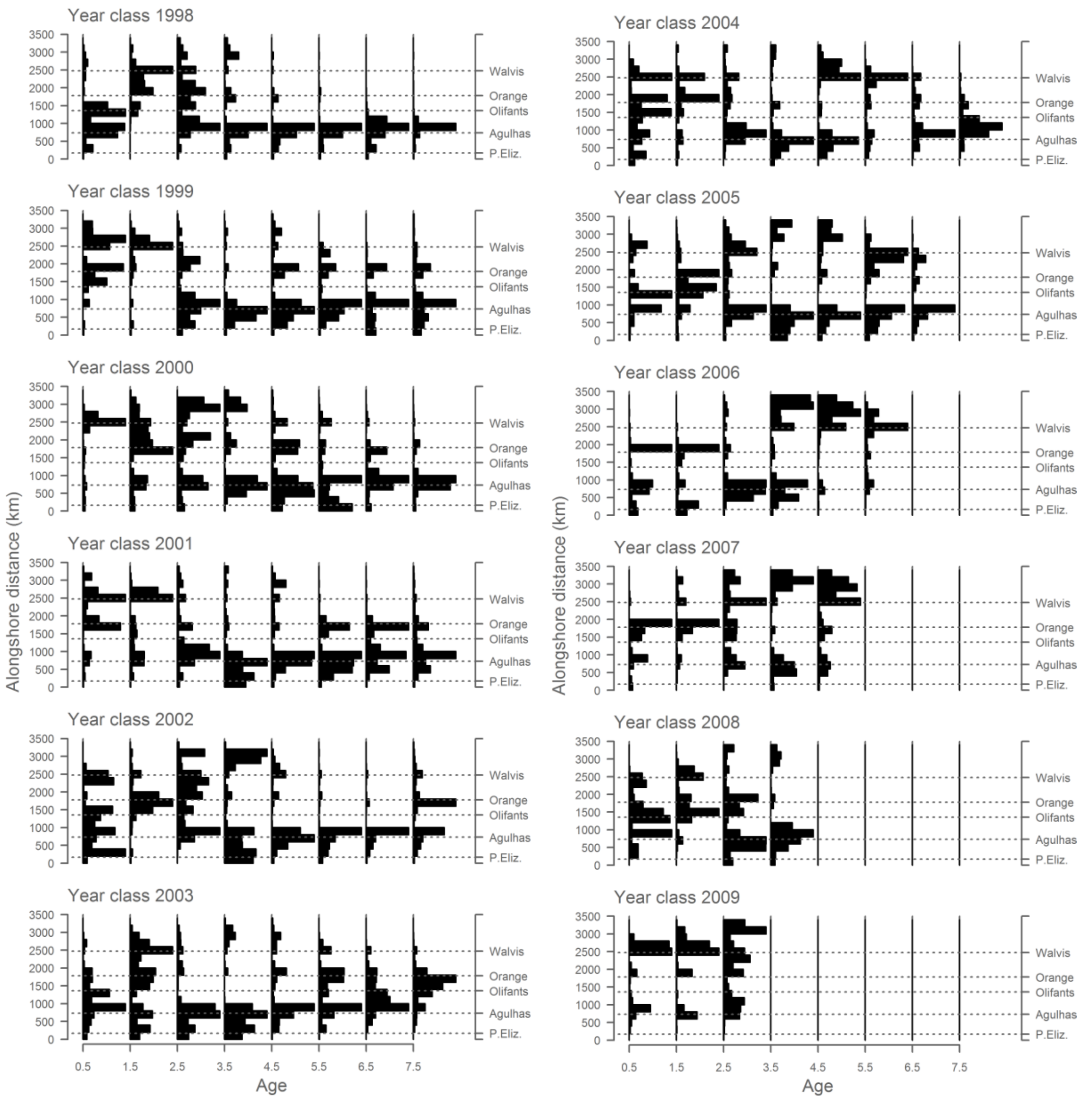

Figure 5. Jansen et al. (2). Alongshore distribution (number of fish) by age for cohorts 1998-2009 of *M. capensis*. The spatial distribution has been projected onto a curvilinear axis following the coastline from Port Elizabeth in the South-East to the Namibia-Angola border (Kunene River) in the North.

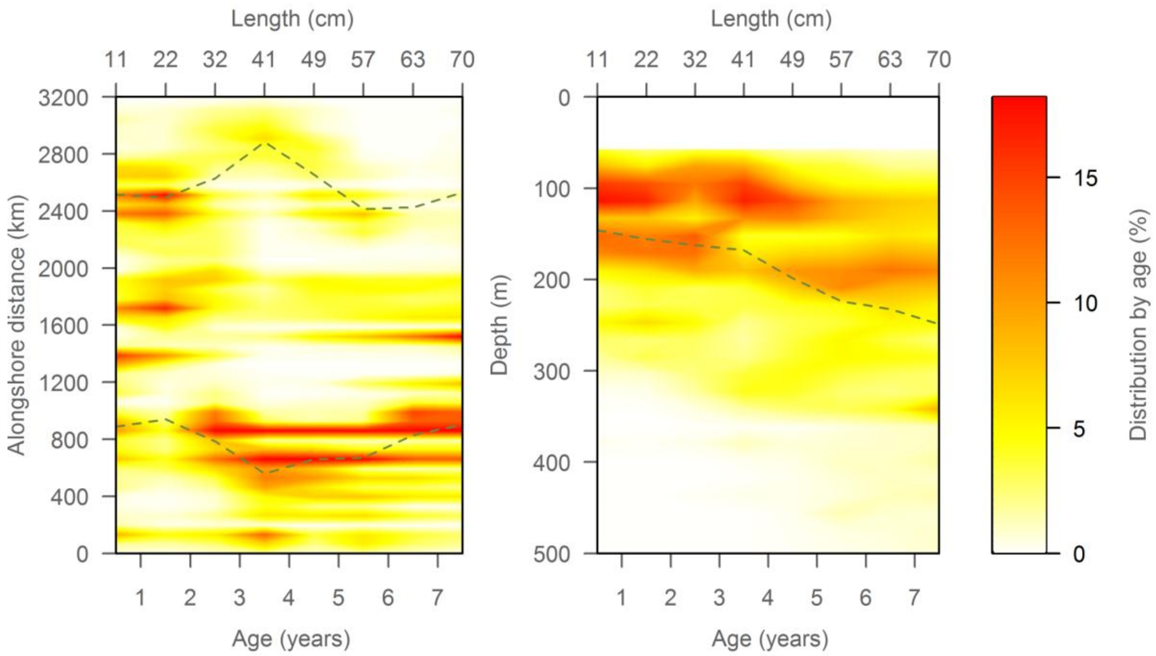

Figure 6. Jansen et al. (2) Left panel: Alongshore distribution of *M. capensis* by age and mean length. The centre of gravity is indicated by grey dashed lines for hakes north of 2150 km and south of 1550 km. The spatial distribution has been projected onto a curvilinear axis following the coastline from Port Elizabeth in South-east to the Kunene River in the North. Right panel. Depth distribution of *M. capensis* by age and mean length. Grey dashed lines indicate the mean depth.

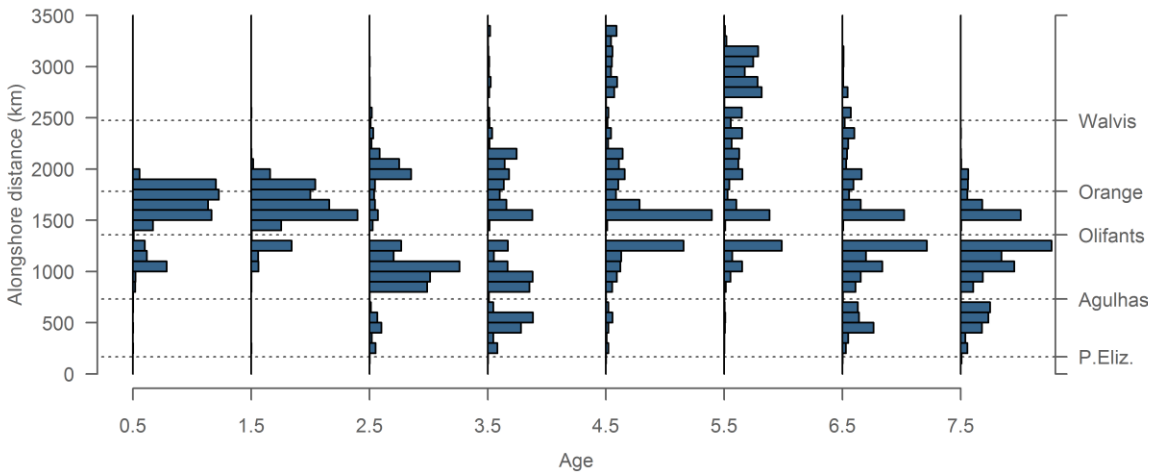

Figure 7. Jansen et al. (3). Alongshore distribution by age of M. paradoxus. Average of all year classes. The spatial distribution has been projected onto a curvilinear axis following the coastline from Port Elizabeth in the south-east to the Namibia-Angola border (Kunene River) in the North

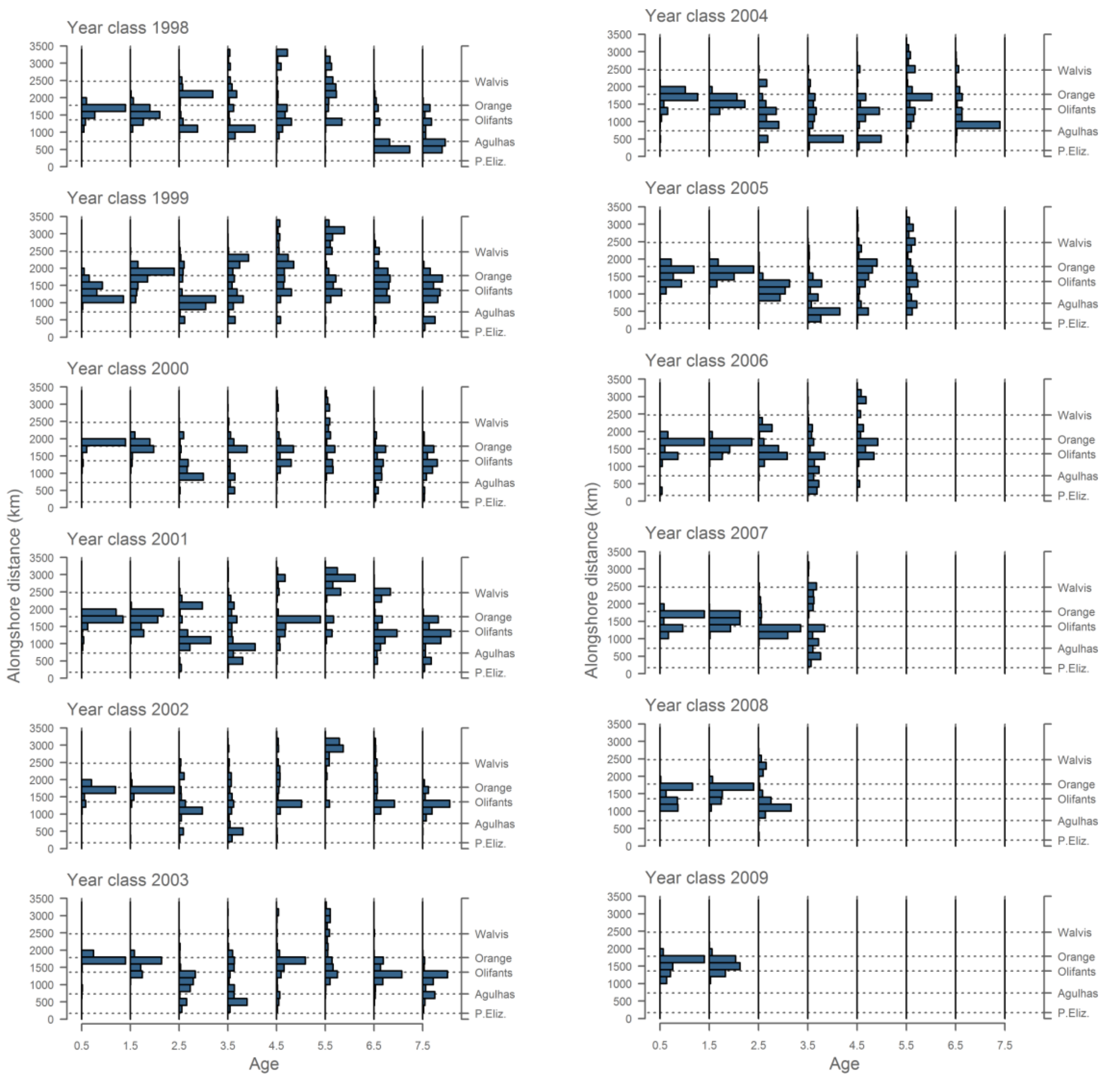

Figure 8. Jansen et al. (3). Alongshore distribution in number of fish by age for cohorts 1998-2009 of *M. paradoxus*.

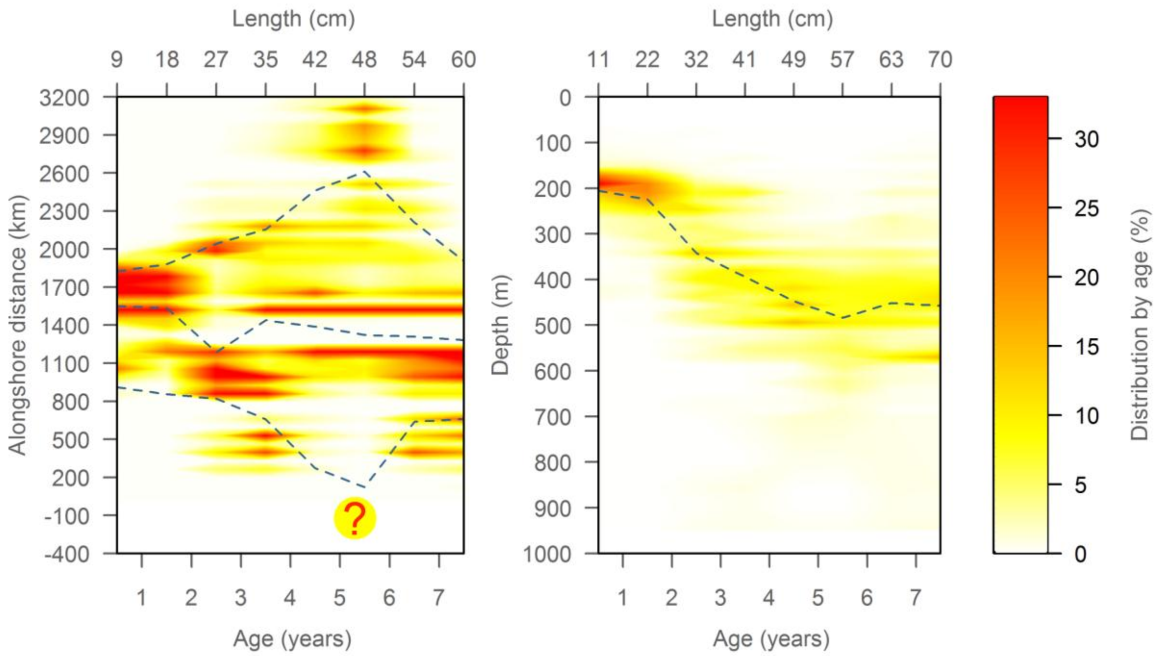

Figure 9. Jansen et al. (3). A Left column. Alongshore distribution of *M. paradoxus* by age and mean length. The Centre of Gravity is indicated by grey dashed lines for hakes north of 2150 km and south of 1550 km. B. Right column. Depth distribution of M. paradoxus by age and mean length. Grey dashed line indicates the mean depth.

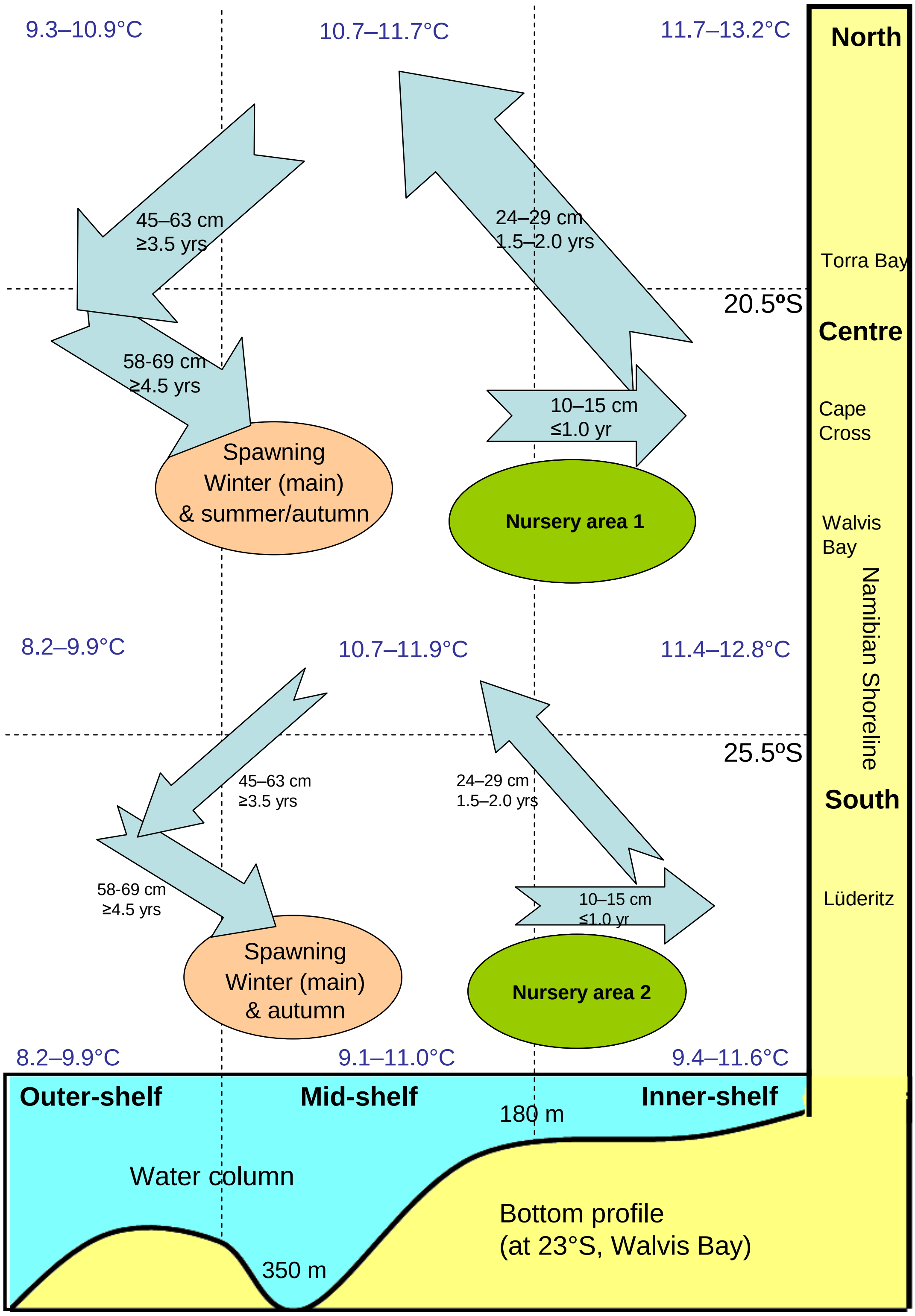

Figure 10. Wilhelm *et al.* (in press). Proposed migration patterns of *Merluccius capensis* in relation to latitude and bottom depth off the coast of Namibia. Ellipses indicate spawning and nursery areas and arrows show inshore–offshore and alongshore migration. Temperatures given in ranges of means of the coldest and warmest months at specific depths and areas, based on CTD samples (A. van der Plas, MFMR, Namibia).

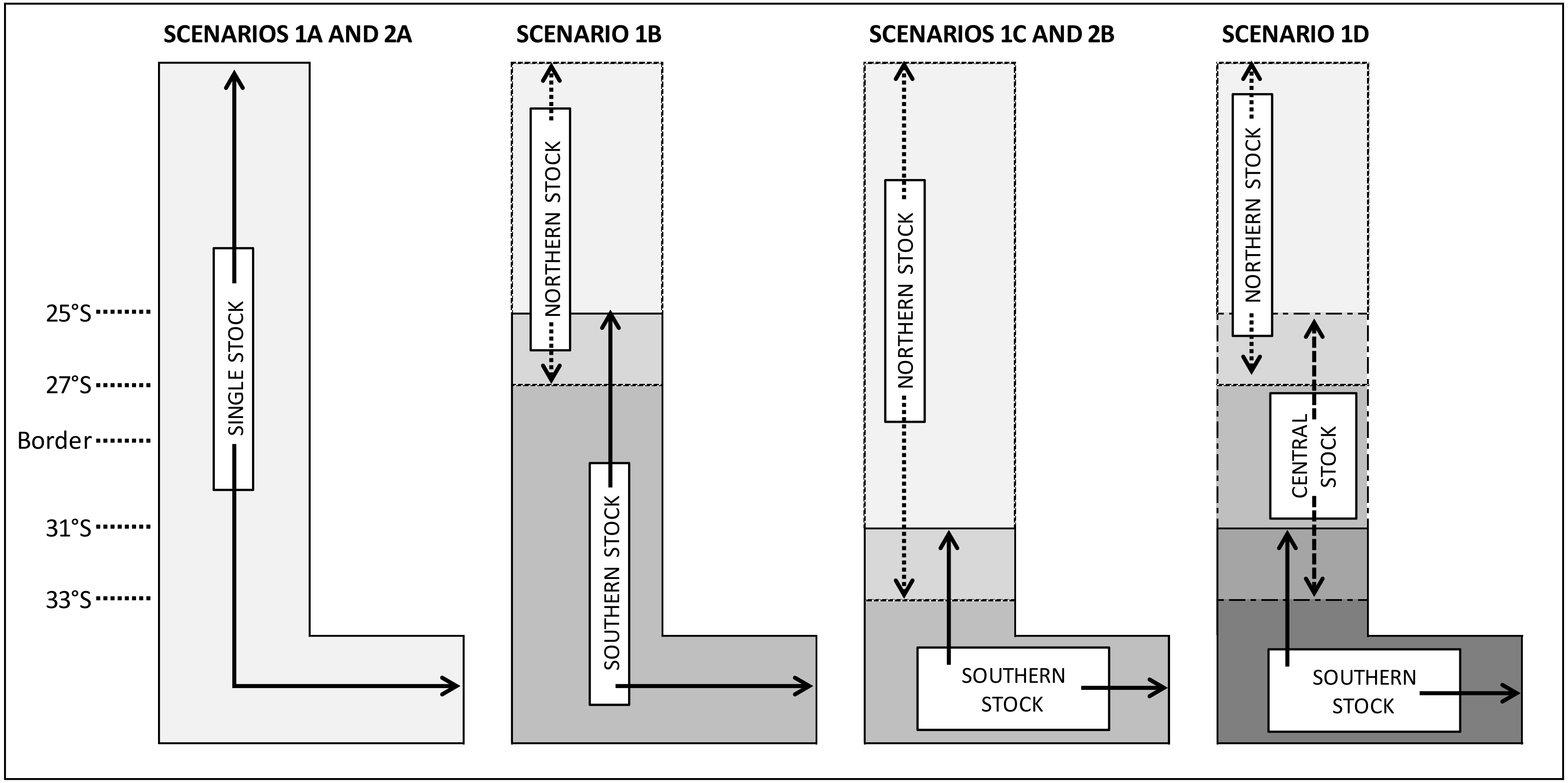

Figure 11: Schematic illustration of the preliminary hake stock structure hypotheses developed during the workshop. *Merluccius capensis*: Scenarios 1A – 1D. *M. paradoxus*: Scenarios 2A and 2B.