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A REVIEW OF NAMIBIAN CAPE HORSE MACKEREL (*TRACHURUS CAPENSIS*) STOCK ASSESSMENT DATA AND COMPARISON OF THE EXISTING AGE-STRUCTURED PRODUCTION MODEL (ASPM) APPROACH WITH AN ALTERNATIVE APPROACH USING STOCK SYNTHESIS (SS)

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ABSTRACT

Evaluation of stock assessment input data was carried out to identify possible errors with the data to facilitate improvement of the horse mackerel stock assessment. Major issues were identified with the recording and processing trawl duration data and some causes of the errors were identified. The identified errors could not be corrected as they required reference to the raw data sheets. Comparison of the Age-structured production model (ASPM) and Stock Synthesis to provide exposure to the practice model-based fisheries stock assessment and this goal was realised in relative terms. The two models provided divergent outputs in terms of derived quantities but followed similar trends for the larger part of the data time series.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Horse mackerel constitute the most abundant commercial fish species in Namibia and the midwater trawl fishery targeting this species is the largest fishery by volume (Bauleth-D`Almeida *et al.*, 2001). Two species of horse mackerel, Cape horse mackerel, *Trachurus capensis* (Castelnau, 1861) and Cunene horse mackerel, *Trachurus trecae* (Cadenat, 1949) occur in the northern Benguela current region off Namibia where the latter has only an occasional occurrence in Namibian waters as it is mainly confined to Angolan territorial waters. Where the two species occurs together Namibian commercial catches, they are not separated, mainly due to the negligibly low abundance of the Cunene horse mackerel (Bauleth-D`Almeida, Krakstad *et al.*, 2001). The fishery for horse mackerel in Namibian waters came into existence in the 1960s when the species was mainly targeted by the midwater fleets of the USSR and other Eastern bloc countries (Paterson *et al.*, 2013). A purse-seine fishery targeting juvenile horse mackerel for fishmeal production was introduced in 1971 but was discontinued in 2014 as targeting of recruits was considered unsustainable for the stock. The bulk of the midwater fishing activity occurs north of 20ºS, while the bulk of the purse seine catches of juvenile horse mackerel usually came from the area between Cape Frio and Ambrose Bay (Bauleth-D`Almeida *et al.*, 2001). Some horse mackerel is also caught as bycatch in the demersal hake and monk fisheries. The species maintained a relatively high abundance over the years with large year to year fluctuations, as observed from abundance survey estimates. Commercial catch data indicates that the mean lengths of commercial catches and the size at maturity obtained from survey trawls has been decreasing over the years (MFMR unpublished data). However, the commercial CPUE of the midwater fishery has almost tripled in recent years and remained very high. Management of the resources were carried out by the International Commission of South East Atlantic Fisheries (ICSEAF) prior to Namibia’s independence in 1990 and thereafter the responsibility was transferred to the Namibian Ministry of Fisheries and Marine Resources (MFMR).

Fisheries stock assessment modelling is a data intensive undertaking and (Wilhelm *et al.*, 2008) the results of any stock assessment model are as accurate as their input data. However, the intensity of data needs differs from model to model as some simpler models can be performed with minimal data for the purposes for which they were designed (Methot Jr. & Wetzel, 2013). Irrespective of model complexity, a clear understanding of the assessment data is a prerequisite for conducting meaningful assessments. Data used in the assessment of the Namibian horse mackerel stock has been collected and processed under varying management regimes stored separately for each time period, thus constituting a separate dataset per time period (Table 1). Hence, comparability between datasets becomes an issue when the data must be used together in the models where some models are more sensitive to data comparability and completeness of data time series than others. Often models fail to fit data if different datasets exhibit divergent trends, especially where different sets of abundance indices are inconsistent (Fournier *et al.*, 1996). Conventionally catch-per-unit effort (CPUE) is a major input as an index of fish abundance into stock assessment models (Maunder & Punt, 2013). However, inconsistencies have been identified in the horse mackerel CPUE series especially a recent tripling in its magnitude. A clearer understanding of the causes of such changes in the CPUE series is needed in order to effectively model around such inconsistencies. The lack of reliable age data is another major setback for age-based methods that is also found with the Namibian horse mackerel assessment. Hence, the use of a length-based model or an adaptable age-based model that relies on a few age observations and can be adapted as more age data becomes available, could provide the best alternative.

Table 1: Fisheries dependent stock assessment data for the Namibian horse mackerel

Period	Management Authority	Source	Fishery	Notes on data
1961 - 1989	ICSEAF	Literature (mainly ICSEAF Bulletins)	Midwater trawl	Processed: total annual landings and CPUE for each fleet (i.e. Namibia, Bulgaria, Poland, Romania & USSR[1])
1971 - 1989	ICSEAF	Literature (mainly ICSEAF Bulletins)	Purse seine	Processed: available as total annual landings
1990 - 1996	MFMR	MS Access database	Midwater trawl	Semi-processed: Daily catch and trawled hours pooled per vessel before storage
1990 - 2013	MFMR	MS Access database	Purse seine	Raw: Catch per set and biological data
1997 - 2003	MFMR	MS Access database	Midwater trawl	Semi-processed: duration per trawl calculated before storage
2004 - 2015	MFMR	MS Access	Midwater trawl	Raw: catch, trawl start and end times.

[1]Union of Socialistic Soviet Republics

The current age-structured production model (ASPM) was implemented since 2002, and currently forms the basis of management of the horse mackerel stock through annual TAC's (Kirchner *et al.*, 2010). The model is fleet-disaggregated between the midwater and purse seine fishery, each with its own selectivity, and includes fluctuations about the stock-recruitment relationship. Acoustic survey biomass estimates and CPUE of the midwater fisheries are both used as indices of abundance in the fitting process. However, this model often fails to fit horse mackerel data well owing to inconsistencies in the data series (Kirchner *et al.*, 2010), or probably fitting the wrong models to the wrong data. CPUE as used in ASPM assessment is capped by removing 15% of the highest and lowest CPUE values from the assessment, as well down-weighting in some models during the fitting process (Kirchner *et al.*, 2010). However, the down-weighting approach has been less effective as the Akaike Information Criteria (AIC) used to select the best-fit model has often resulted in the selection of the model with no CPUE down-weighting as the best-fit model, and thus resulting in the management of the Namibian horse mackerel stock on the basis of questionable data. Also, no CPUE series exist for the purse seine fishery as purse seining does not allow for determination of CPUE, and hence the index does not capture the abundance of the juvenile fish targeted by this fishery. Although, a series of survey biomass and abundance exist for years before 1999, the data are not used as they are not comparable with the most recent survey series. This coupled with the lack of reliable age data as a result of (Wilhelm *et al.*, 2008) little regard for horse mackerel aging, makes (Bauleth-D`Almeida *et al.*, 2001) the results of the age-structured production model (ASPM) unreliable and therefore (Kirchner *et al.*, 2010) sustainable total allowable catches (TAC's) estimated within these questionable models follow the precautionary approach. An observation was also made that the biomass estimates from this model, for the period 1961 – 1982, were much higher than was estimated for the same period in the ICSEAF assessments despite that the current model incorporates the same historical ICSEAF data together with the current catch, age, and size distribution data (Kirchner *et al.*, 2010). Nevertheless, this model and the models used at that time are not the same as the ICSEAF model were virtual population analyses (VPA's), which the current model is not.

A possible alternative to the current ASPM is Stock synthesis (SS), as it is also a statistical age structured modelling framework and has been in existence for approximately 30 years and has been evolving ever since (Methot Jr. & Wetzel, 2013). The model was made available for free under the NOAA Stock Assessment Toolkit and in its most recent form the SS code has been translated into Auto Differentiation Model Builder (ADMB) to take advantage of the power of auto differentiation that allows for speedier computations of model convergence and variance estimation through the Markov Chain Monte Carlo (MCMC) method. The model flexibility allows the use of SS as both an age structured and a length-based stock assessment model, as it was designed to accommodate both age and length structures. Unlike, ASPM where some model parameters assume constant values, all the model parameters in SS can be allowed to change over time (Methot Jr. & Wetzel, 2013). The convention in the modelling of age is that all fish born in the same calendar year will have same integer age on January 1 and this should already be defined as such at age reading. Where age data is uncertain SS has the capability to estimate weight-at-age from weight-at-length and size specific selectivity, and this is critical for the Namibian Cape horse mackerel age data situation. Fishing mortality is estimated independent of catchability and rather directly as fishing intensity to match the observed catch.

As a result of high staff turnover, the National Marine Information and Research Centre (NatMIRC) lost years of experience in stock assessment and although the staff that remained can run the existing model and obtain results, they are unable to make much sense of it. Due to lack of standard procedures for preparation of stock assessment data, compilation of the data has been relatively inconsistent, particularly with regard to the use of catch data in calculating CPUE, where skipper estimates of catch were sometimes considered less reliable than the daily production and *vice versa*. Hence, a critical review of the data used to assess this stock as well as a look at alternative approaches for stock assessment may aid in providing understanding of the issues surrounding Cape horse mackerel stock assessment in Namibia. Therefore, the main purpose of this study was to acquire competences in carrying out model-based stock assessment of the Namibian Cape horse mackerel stock and compare an alternative stock assessment approach using Stock Synthesis with the current ASPM approach. The goal of this study was to review and evaluate raw data in terms of erroneousness and their reliability for use in stock assessment models and to then compile the models and conduct the assessment.

2 LITERATURE REVIEW

Fisheries data come from a variety of sources and is collected at varying spatial and temporal scales (Fournier *et al.*, 1996). Such data should be consistent within the data set and with other data sets used together in a given study, and hence it is essential that data consistency be examined prior to usage. Management of fish stocks is mostly based on information obtained from analyses of catch-at-age data in age structured models whereby studying hard parts such as otoliths provide the estimates of the ages. In the absence of such age reading it would be convenient to derive age composition estimates from catch-at-length data, given the fact that the data are much less costly to obtain compared to ageing methods based on hard parts, coupled with the inaccurate nature of age determination in many species (Fournier *et al.*, 1996).

The basic concept in most stock assessment models is that an exploited stock of fish will increase or decrease from an earlier population size according to a stock-recruitment relationship, where such change is also influenced by mortality imposed both naturally and as a result of fishing pressure (Haddon, 2011). Statistical stock assessments start with the population dynamics model outlining the population size and its structure, including how process error is modelled, then the data and associated observation model, including the likelihood function or sampling process and ends with the estimation algorithm (Maunder & Punt, 2013). Additional information is then included in the likelihood function as products of likelihood or sum of log likelihoods, sometimes requiring changing the population dynamics model for the model to be able to predict quantities based on the added information.

Stock assessment models are complex mathematical notations devised to simplify even more complex real-world processes (Lee *et al.*, 2014; Haddon, 2011). The models sometimes exhibit purely mathematical behaviours that the modelled biological populations do not or are unable to exhibit, and therefore it is prudent that such behaviours of the models be identified and understood (Haddon, 2011). Methods used in stock assessment can be broadly categorised as yield-per-recruit-, surplus production- and age-or length structured methods (Punt *et al.*, 2014). Yield-per-recruit methods cannot yield absolute estimates of biomass because they ignore stock-recruitment relationship. Statistical assessment methods, such as the age-structured population dynamics models rely on multiple sources of input data some of which are generated using the other model approaches. Age structured assessments are further categorised on the basis of whether catch-at-age data are known with negligible error, or whether no catch-at-age data is available for some years with allowance for error in the assessment (Punt *et al.*, 2014). Since fishing mortality and biomass are negatively correlated, reliable estimates of stock abundance are not possible with only catch-at-age data, and hence some effort data and assumptions on stock-recruitment relationship are needed (Maunder & Punt, 2013). To ensure that model assumptions are not violated it is required that fit diagnostics be performed to identify systematic patterns in the residuals of model fits to data (Maunder & Punt, 2013; Lee, Punt *et al.*, 2014). However, lack of pattern in the residuals becomes less reliable with model misspecification as the parameters maybe estimated to fit the misspecification, or in data rich situations, the pattern could be a result of multiple sources of information for the same model component (Maunder & Punt, 2013). When relating model variables and parameters to reality, assumptions made about that relationships including the implications of such assumptions on the dynamics of the modelled population need to be listed explicitly (Haddon, 2011). Therefore, even though it is known that the assumptions are unlikely or unrealistic, they still need to be expressed factually to ensure model simplicity.

Modelling-based stock assessments of horse mackerel in the Namibian region, started with virtual population analyses (VPA) carried out annually by ICSEAF from 1970 to 1989 in the ICSEAF Divisions 1.3 – 1.5 (Kirchner *et al.*, 2010). At that time production models based on catch-per-unit-effort (CPUE) were considered to be inapplicable in the stock situation of the Namibian Cape horse mackerel (Wysokiński, 1981). Later, the use of VPA for the estimation of TAC's was also abandoned, because the total allowable catch (TAC) was overestimated, because of arbitrary VPA solutions caused by subjective tuning of terminal fishing mortalities (Butterworth *et al.*, 1990). Subsequently, between 1990 and 2001, stock assessment models were not used, and acoustic survey estimates formed the basis of stock assessment as they were considered to be absolute indices of stock abundance (Kirchner *et al.*, 2010). In the current ASPM model for the assessment of the Namibian horse mackerel, historic catch and catch-at-age data for the period 1965 to 1990 were obtained from the literature, as well as the effort data that was used to calculate the CPUE by dividing the fleet disaggregated annual catch by the annual duration (Kirchner *et al.*, 2010). Catch and effort data for the period since 1991were obtained from catch databases at the Ministry of Fisheries and Marine Resources (MFMR). The model is fitted to the survey index of abundance and CPUE data by minimising the log-likelihood function while relating survey and commercial catch-at-age to estimate their selectivity (Kirchner *et al.*, 2010). The lowest value of the Akaike Information Criteria (AIC) is used to select the best model specification while the Markov Chain Monte Carlo (MCMC) is used to estimate the 90% confidence intervals of the ratio of current biomass to biomass at MSY (Maximum Sustainable Yield).

Stock synthesis (SS) was previously coded in FORTRAN (Formula Translating System) were the best set of model parameters were iteratively obtained from gradient information derived as numerical derivatives (Methot Jr. & Wetzel, 2013). The FORTRAN-based SS was devised to improve the assessment of west coast groundfish stocks of sablefish (*Anoplopoma fimbria*) and whiting (*Merluccius productus*). In the case of sablefish, the driving force behind the development of SS was to find a modelling framework that would enable utilisation of a new and growing time series of fishery and survey size-composition data while reliable age data was absent, whereas for whiting it was the need for an alternative modelling framework that could account for spatial transboundary variability in stock abundance. In its most recent form, SS was coded in ADMB (Auto Differentiation Model Builder) as a way of utilising the features of the FORTRAN sable and whiting assessments within a fully generalized framework (Methot Jr. & Wetzel, 2013). The major features of SS include stock-structure, spawner–recruitment, life history and biology, selectivity, fishing mortality, observation sub-model, variance estimation, fishery management targets and forecasting, and output processing.

3 METHODOLOGY

3.1 Data collection and collation procedures

Fisheries dependent data collected during the early years of the existence of the fisheries covered the period 1961 to 1998 and are found in the literature (Table 1). A comprehensive account on the origin and compilation of these data is available in Kirchner et al. (2010). The data for the period 1990 to 1996, 1997 to 2003 and 2004 to the present are stored in separate MS Access databases owing to differences in the characteristics of the data between those time periods (Table 1). The data were usually extracted separately from these databases and processed and combined in MS Excel spreadsheets. At collection the fisheries dependent data constituted catches in tonnes as recorded by the skippers on commercial fishing vessels on daily log sheets, and which for the midwater vessels included data on some measures of fishing effort as the hours and minutes spend trawling in the earlier years and in the more recent years they are recorded as the start and end times of the trawls (hours and minutes). Length composition data from the midwater fishery were collected by fisheries observers on board the vessels, whereas for the purse seine fishery the data were obtained from port samples and processed at NatMIRC's laboratories. These data were all stored in separate databases and housed on different computers.

Abundance data of the Namibian horse mackerel were obtained from acoustic scattering coefficient (Sa) and biomass calculation spreadsheets compiled during the annual horse mackerel acoustic survey surveys conducted on the *R.V. Welwitchia* from 1999 to 2014, and the *R.V. Mirabilis* for the 2015 data set. The survey strategy involved a stratified sampling approach in which the survey area was divided into two broad regions, viz. inshore and offshore, separated by the 200m depth contour on account of known latitudinal variation in horse mackerel abundance (Bauleth-D`Almeida *et al.*, 2001). Each of the two regions was subdivided into three discrete strata, representing areas of low, medium and high densities as previously observed in the southern, central and northern regions of the Benguela system. A SIMRAD acoustic system was deployed along east-west parallel transects and was accompanied by trawling with scientific midwater and bottom trawls targeting fish aggregations as observed on the acoustic system. Abundance estimates from earlier surveys are available but are considered less reliable and not comparable with the recent time series as the surveys strategies and purposes varied during that period. The trawl samples provide the length frequency data which were raised to the acoustic backscatter to estimate abundance, and also allowed for collection of other biological data. Length-weight relationships used for estimation of weight-at-length in stock assessments were also calculated from the survey biological data that are stored in an Access database. Details on survey strategy and the standard trawl sampling procedures are described by Bauleth-D`Almeida *et al*. (2001). Although, horse mackerel survey abundance indices exist for the period since 1990, the data from the surveys made before 1999 are not currently used for stock assessment because the surveys before 1994 were dedicated to the small pelagic species sardine (*Sardinops sagax*), round herring (*Etrumeus whiteheadi*) and Cape anchovy (*Encraulis encrascicolus*), with horse mackerel only estimated as a by-product. Horse mackerel dedicated surveys were started in 1994 and the surveys carried out between 1994 and 1998 employed a different methodology to those carried out since 1999, with a consequence that these surveys are not comparable. The longest survey time series cover the period since 1999, also representing the surveys with the most consistent survey methodology.

3.2 Data review

An R script was developed and coded to read data and compile the model input data and visuals for examining the data directly from the raw data sources. Patterns observed in the catch data led to further examination of the data which involved investigating patterns in trawl durations with respect to different trawl catch sizes. Trawl durations were examined for possible erroneous records, based on consistency of trawling times among adjacent trawls. The data was queried by trawl duration in the R script noting the inconsistent trawling times, starting with the highest trawl durations, and reducing the search with 1 hour every time until there were no more or too few inconstant trawling times. To gain an understanding of the observed patterns in the data, the Namibian midwater fishing industry was also consulted to give an account of possible changes in fishing operations that could have led to the observed patterns in the data so as to establish if the observed pattern was a consequence of changes in fishing operations, changes in stock status or a consequence of data recording or capture errors.

3.3 ASPM Model setup

The existing ASPM was run in its current form using the existing data and model structure as described by Kirchner *et al.* (2010). The ASPM catch data consisted of a catch and CPUE time series for the different fleets that targeted horse mackerel (Kirchner *et al.* (2010), Bauleth-`Dalmeida *et al.*, 2001, Wilhelm, 2010), resulting in a six-fleet model setup. From the surveys is obtained the survey biomass estimates and coefficient of variation (CV). Due to comparability problems, only the latest survey series (since 1999) were used in the ASPM. Length composition data did not feature in the ASPM as the catch-at-length of the catches and the surveys are converted to catch-at-age as proportions by age before they are added to the model data file. Model runs were carried in ADMB from the MS DOS Prompt. Detailed ASPM parameter setup and assumptions are concisely described by Kirchner *et al.* (2010).

3.4 SS Model compilation

The structure of SS model framework is concisely described in the literature (Methot Jr. & Wetzel, 2013). Standard SS files were obtained from examples provided with the SS software and were adapted for horse mackerel assessment. During compilation SS runs were performed with each addition of horse mackerel data to the data file and parameter settings adjustment in the control file while ensuring that the model gradient remained within reach of the default model convergence criteria of 0.0001. The model was constructed using the same data compiled for the existing ASPM model, restructured to make them compatible with the SS data structures. Unlike in ASPM in which the catch data were arranged by row for each fishery, in SS catch data were rearranged by column with the catch of each fishery in its own column. Also, while the different midwater fleets (Table 1) were disaggregated in ASPM, in SS catches of the different midwater fleets were aggregated resulting in 2 fisheries (midwater and purse seine) and 1 survey model setup. The earlier horse mackerel dedicated surveys conducted on board the RV Dr. Fridtjof Nansen between 1994 and 1998 were included in SS together with the usual (for ASPM) RV Welwitchia survey series, and the data structure was then made compatible with SS as with the catch data above. Composition data were added into SS as numbers of fish per 1cm length class raised to the total annual catch for the commercial data and as abundance estimates per 1cm length class for the survey data, which in ASPM were included as proportions by age for each fishery and survey. CPUE was excluded from SS. Appropriate changes were also made to the Starter.ss and Forecast.ss files. All files were edited with WordPad. Model runs were also carried out in ADMB from the MS DOS Prompt. Initial parameter settings for SS are shown in Table 2.

4 RESULTS

4.1 Data review

An unusually low total catch of only 100,000 tonnes was recorded in the database for the 1990 fishing season, which represented the lowest total annual catch of this time series (Figure 1). Annual total catches were variable with the highest of about 400,000 tonnes recorded in 1993. Relatively constant annual total catches hovering around 250,000 tonnes were recorded between 1998 and 2006 after which the total annual catch dropped to about 150,000 tonnes in 2007. A gradual increase was established in the catches since 2008 but remained lower than the high catches of the early 1990’s.

Figure 2 shows the total trawl duration recorded in each year since 1990 to 2013. As observed with the total annual catches, the trawl duration for 1990 were very low compared to that recorded in the immediate subsequent years, although not the lowest as much lower trawl durations were recorded later in 2009 to 2011. Total annual trawl duration started very low just below 15,000 hours in 1990 and then more tripled to just below 50,000 in 1991. High and variable trawl durations of between 30,000 and 50,700 were recorded in subsequent years up to 2006. Thereafter, a declining trend was established that continued into the present and included the lowest annual trawl duration ever of about 10,000 hours recorded in 2010. However, a gradual increase was observed in total trawl duration in 2011 and 2012, followed by another decline in 2013.

Table 2 [1]Abridged parameter settings and assumptions for Stock Synthesis

PARAMETER	LOW	HI	INITIAL	PRIOR	[2]PHASE
Natural mortality (M)	0.1	0.55	0.45	0.3	-3
Minimum length (at Min age)	-3	10	3	2	3
Maximum length (at Max age)	30	60	43	43	-6
Von Bertallanfy K	0.06	0.3	0.18	0.18	5
CV growth young	0.05	0.3	0.2	0.2	-6
CV growth old	0.05	0.5	0.2	0.2	-6
Weight-length coefficient	-1	0.1	$5.28x\ 10^{-6}$	$5.28x\ 10^{-6}$	-3
Weight-length exponent	2	4	3.074	-1	-3
Length at 50% maturity	10	25	12.85	12.85	-3
Slope of maturity ogive	-1	1	-0.2	-0.2	-3
Fecundity intercept	-3	3	1	0.8	-3
Fecundity slope	-3	3	1	0.8	-3
Ln (R0)	16	17.5	16.6	16.6	2
Beverton-Holt Steepness par.	0.3	0.7	0.6	0.6	-6
SigmaR	0.2	0.8	0.5	0.5	-3
Initial F Fishery1	0	1	0	0.01	-1
Initial F Fishery2	0	1	0	0.01	-1
Catchability Fishery1	0	2.5	1	0.1	-4
Catchability Fishery2	0	2.5	1	0.1	-4
Catchability Survey	-4	2	0	-10	2
Size selectivity Fishery1_P1	11	20	17.28	17.28	2
Size selectivity Fishery1_P2	0.1	10	5	5	4
Size selectivity Fishery2_P1	0.18	1	0.3	-10	3
Size selectivity Fishery2_P2	0.01	0.99	0.5	0.5	4
Size selectivity Fishery2_P3	0.001	0.5	0.02	0.01	4
Size selectivity Survey_P1	0.02	1	0.8	-10	3
Size selectivity Survey_P2	0.01	0.99	0.5	0.5	4
Size selectivity Survey_P3	0.001	0.5	0.02	0.01	4
Age selectivity Fishery1_P1	0	3	2	2	3
Age selectivity Fishery1_P2	0	5	4	4	3
Age selectivity Fishery2_P1	0.02	1	0.8	-10	3
Age selectivity Fishery2_P2	0.01	0.99	0.5	0.5	4
Age selectivity Fishery2_P3	0.001	0.5	0.02	0.03	4
Age selectivity Survey_P1	0.02	1	0.8	-10	3
Age selectivity Survey_P2	0.01	0.99	0.5	0.5	4
Age selectivity Survey_P3	0.01	0.5	0.02	0.03	3

[1]Parameters included in the control file but not used in the model are excluded
[2]Negative phase indicate that the parameter initial value was fixed, and the number is the model phase

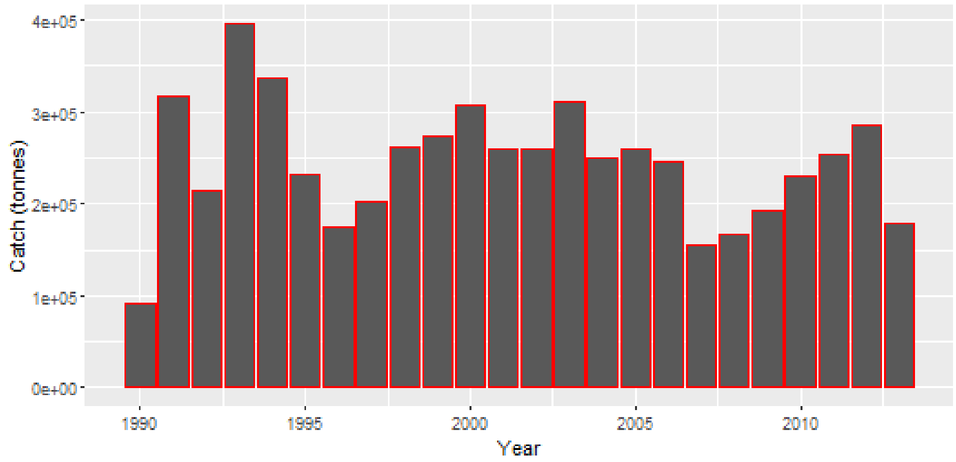


Figure 1: Total annual catch since 1990

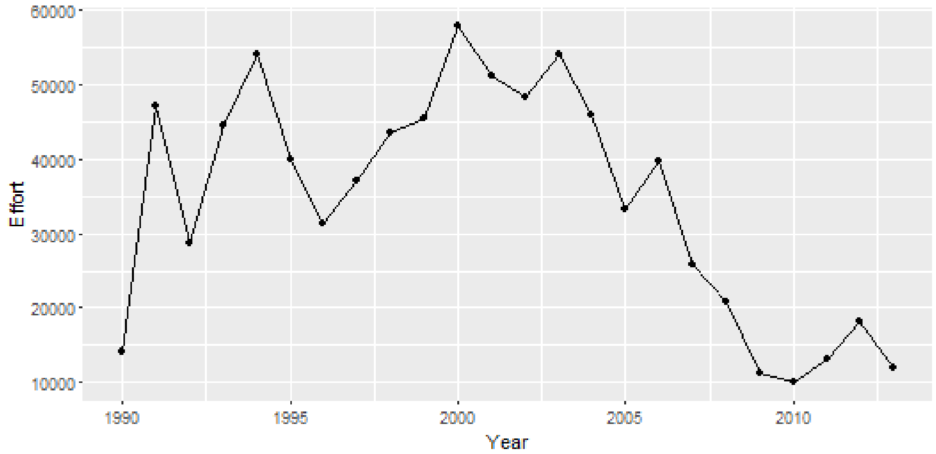


Figure 2: Daily total trawl duration since 1990

CPUE as tonnes per hour was obtained from dividing the annual catches by the annual trawl duration (Figure 3). A relatively constant but low CPUE of less than 10 tonnes/hour was maintained during the period 1990 up to 2008 with a peak of about 13 tonnes/hour in 1993. A drastic increase was recorded in CPUE in 2009 and remained high ever since with wider year to year variability. However, it should also be noted that minor variability did occur in the CPUE before 2009, but this was masked by the magnitude of increase and variability after 2009. The trend in CPUE reflected the observations made with the trawl catches (Figure 1) and trawl duration (Figure 2), where high trawl duration was accompanied by high trawl catches and *vice versa*. On the contrary, CPUE recorded since 2009 came from large trawl catches made with the lowest trawl durations.

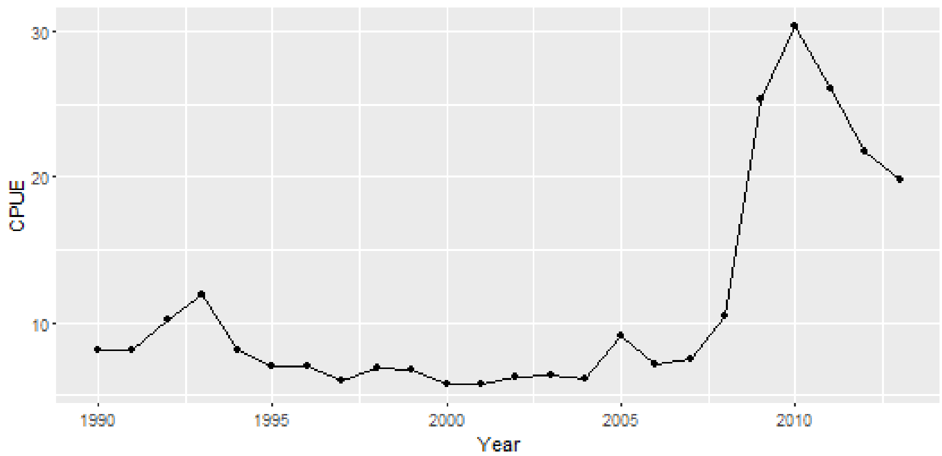


Figure 3: Daily average CPUE since 1990

Examination of individual trawl catches with a violin plot (Figure 4) revealed that a larger number of trawls made between 1997 to 2008 consisted of catches below approximately 20 tonnes, whereas trawls conducted since 2009 were predominantly made up of catches above 20 tonnes as shown by the width of the violin bars and density of jitters (red dots). The narrow bases of the violin bars since 2009 showed the low presence of small trawls in recent years. Similarly, the tops of the bars were also narrower for the same years compared to the preceding years. The largest trawl catches of over 40 tonnes per trawl were most prevalent between 2003 and 2008 as those years had the widest range trawl catch sizes.

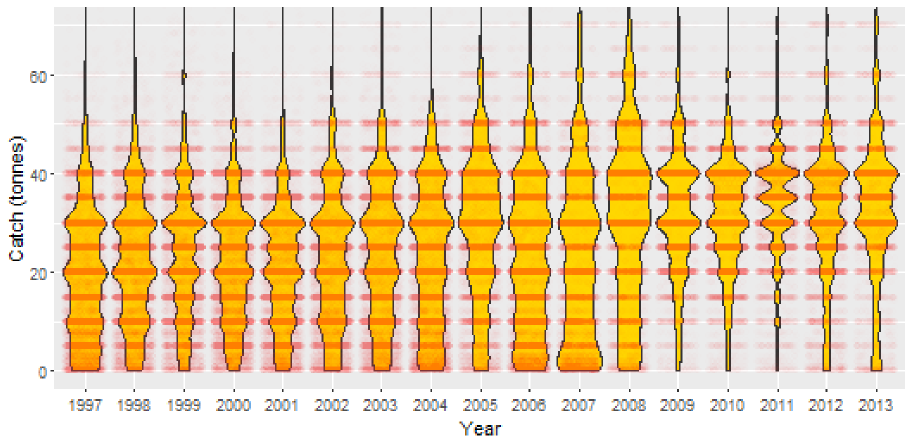


Figure 4: Trawl catch distribution for the period 1997 to 2013

As with trawl catches the annual trawl durations were also examined on a trawl by trawl basis using violin plots (Figure 5). Patterns were also shown where trawl durations during the years after 2009 were more vertically compressed with the bulk of trawl operations lasting less than 5 hours. On the contrary trawl durations recorded before 2009 were more widely distributed with durations in excess of about 10 hours for a larger number of trawls. This implied that before 2009 the fleets were trawling for longer than they did after 2009, and viewed in conjunction with Figure 2 the longer trawl durations were generally associated with a high prevalence of trawls with smaller catches, and *vice versa*.

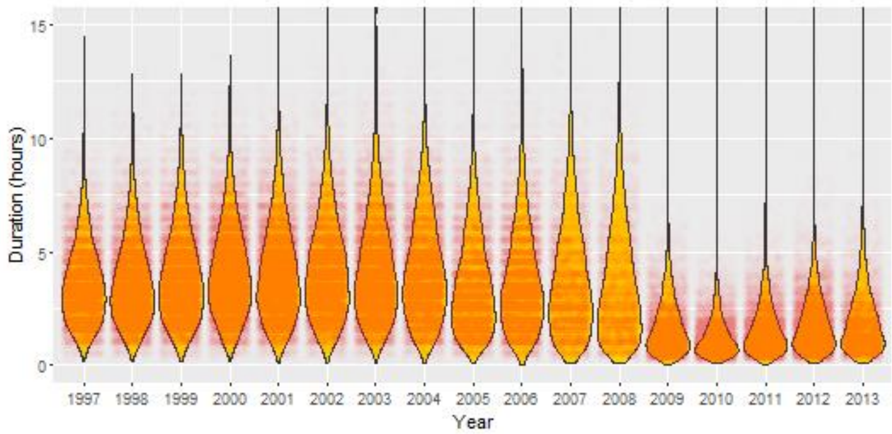


Figure 5: Trawl duration distribution for the period 1997 to 2013

A general observation was that durations of the earlier trawls of the day recorded some of the highest durations compared to the trawls made later in the day (Figure 6). This pattern was mainly conspicuous in the trawl durations recorded between 1997 and 2003, where only Trawls 1 and 2 had trawl duration ranging up to 23hours after which the maximum trawl duration declined sharply towards the last trawl of the day (Figure 6a). In the data recorded after 2003 the range of trawl durations included 23 hours up to Trawl 5 (Figure 6b).

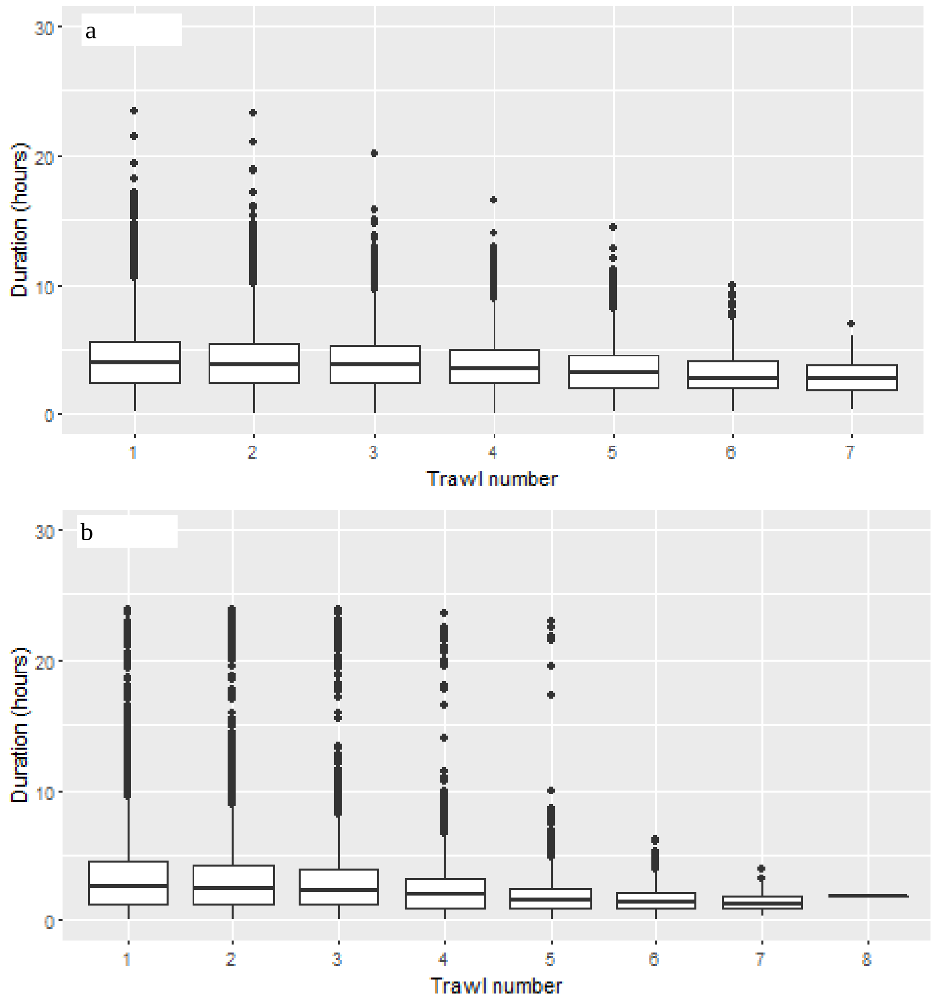


Figure 6: Distribution of trawl durations per trawl number during a) 1997 to 2003 and b) 2004 to 2013

The patterns in trawl duration observed above necessitated this further examination of the raw data during which some inconsistencies were identified in the processed trawl durations (1997 – 2003 dataset) and the raw trawling time data (2004 – 2013 dataset). The analysis considered all trawl records with durations above 10 hours and a total of 1,660 such records were examined (Table 3). A total of approximately 272 of those records were found to contain inconsistent trawling times of which all trawling times where durations exceeded 23 hours, as well the majority (about 55%) of records with durations above 14 hours included inconsistent trawling times. Trawl durations below 14 hours included >88% correct records.

Table 3: Trawl times and/or durations examined for erroneous records

Trawl duration (hours)	Records examined	Correct records	Inconsistent records
> 23	28	0	28
22 – 23	37	3	34
21 – 22	37	2	35
20 – 21	24	1	23
19 – 20	15	1	14
18 – 19	16	3	13
17 – 18	18	5	13
16 – 17	25	11	14
15 – 16	36	15	21
14 – 15	43	19	24
13 - 14	77	68	9
12 – 13	175	167	8
11 - 12	395	378	17
10 – 11	734	715	19
TOTAL	**1,660**	**1,388**	**272**

The distribution of CPUE was mainly concentrated below 20 tons per hour during the period before 2009. On the contrary after 2009 the distribution of CPUE values had a wider range that included both high and lower values. There was fewer of the very small CPUE values during 2009 to 2011 as shown by the narrow bases of the violin bars in Figure 7, particularly during 2009 to 2011. Some widening of the bases of the bars was visible during 2012 and 2013 as the CPUE started declining again.

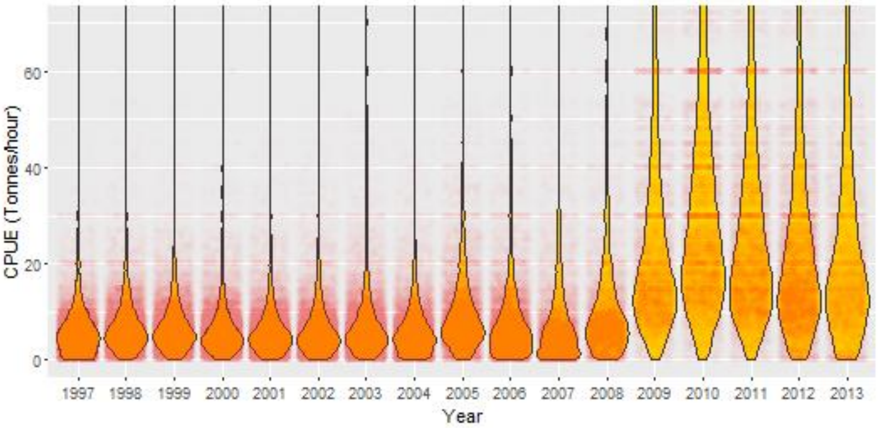


Figure 7: Trawl catch per hour (CPUE) distribution for the period 1997 to 2013

Trends in survey biomass estimates have been variable year to year with wider error bars for the 1991 to 1998 dataset and narrower error bars for the 1999 to 2015 dataset (Figure 8). The survey biomass index has characteristics of a cyclic event where it remains above a million tonnes for a number of years, before dropping below a million tonnes but above 500,000 tonnes where it remains for about 2 years before shooting up or increasing gradually again to above one million tonnes. Horse mackerel biomass was the highest (just below 2,000,000 tonnes) in 1998 and 1999 and the lowest (just above 500,000 tonnes) in 2006 and 2007. Despite the issues concerning comparability between the two-survey series the general biomass trend was relatively consistent (Figure 8).

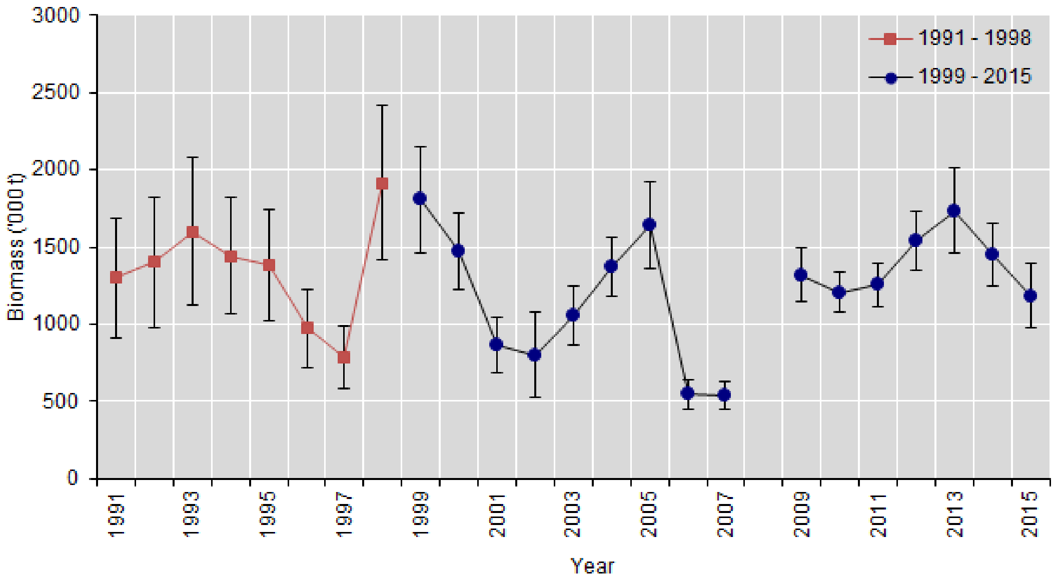


Figure 8: Survey biomass estimates since 1991, error bars represent the estimate +/- CV

Size frequency distributions obtained from the survey samples from 1999 to 2015 are shown in Figure 9. Mainly bimodal distributions consisting of respective prominent size groups of small fish and big fish were observed most of the years, except in 2003 when the size distribution was overwhelmingly composed of bigger fish (>17 cm TL). The following year in 2004 the numbers of the smaller fish (<17 cm TL) was overwhelming larger than that of the bigger fish. During 2006 to 2009 the bigger fish made up the predominant size group, although a size group made up the very small of <10 cm TL could be distinguished. The group of fish <10 cm TL also persisted longer on the surveys between 2010 and 2015 (Figure 9).

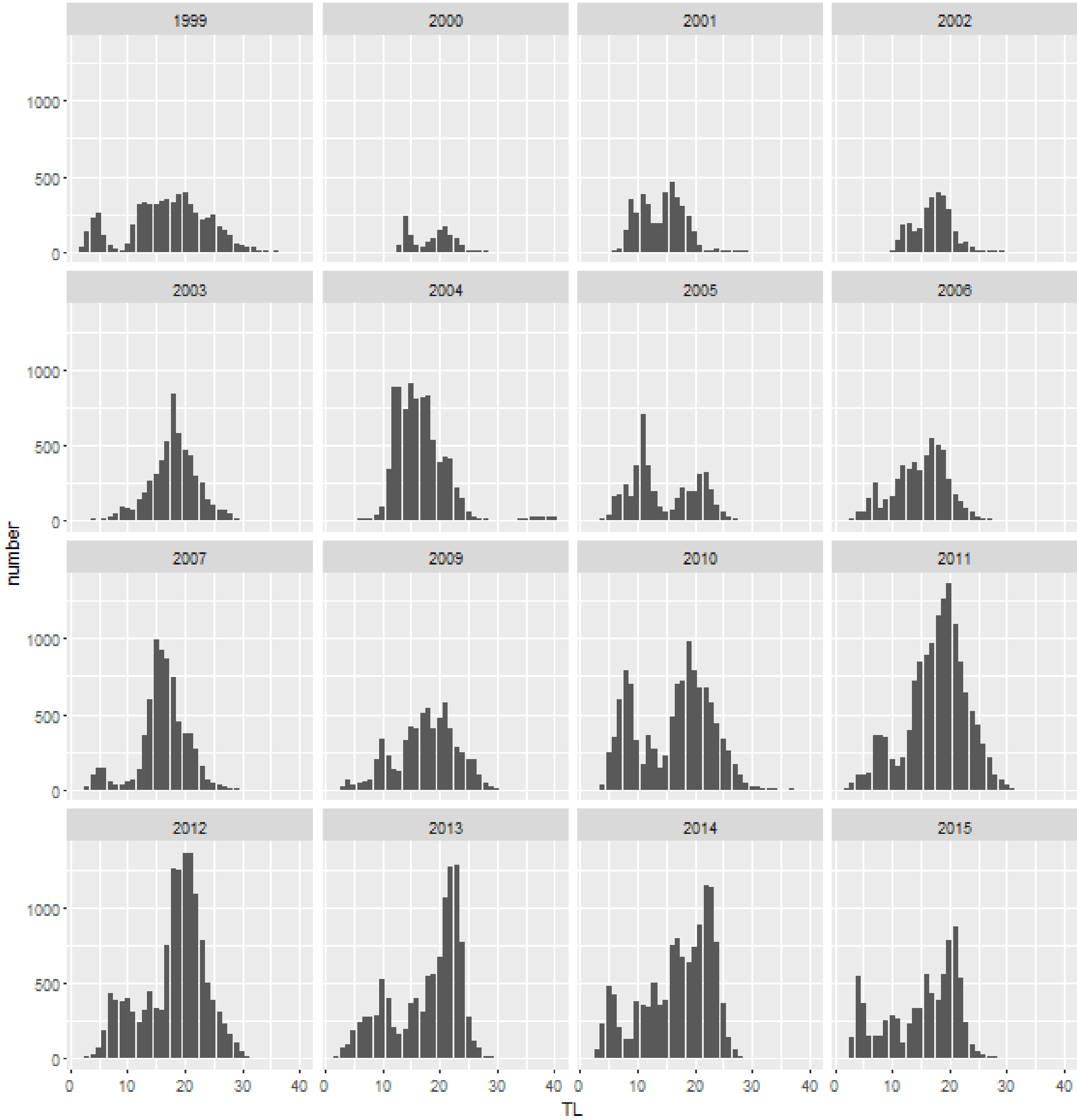
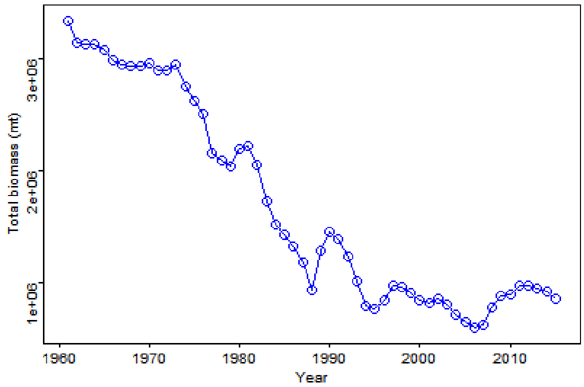


Figure 9: Size frequencies of survey samples 1999 - 2015

4.2 Comparison of ASPM with SS outputs

ASPM estimated total stock biomass from a very high (assumed) virgin biomass of more than 3,000,000 metric tonnes (Mt) in 1960 (Figure 10, left panel). With the start of exploitation in 1961 the biomass started a gentle decline to a biomass of about 3,000,000mt in 1972, and this was followed by a further but steeper decline of approximately 1,000,000mt from 1973 towards a predicted biomass of about 2,000,000mt in 1978. During the next 3 years (1979 to 1981) total biomass hovered around the 2,000,000mt level, after which a further steep decline was predicted up to 1988 when the total biomass was predicted at about 935,000mt. A somewhat steep increase was predicted between 1988 and 1990 reaching a peak of about 1,459,630mt in 1990. After 1990 the ASPM predicted a decline in the biomass that continued until 1995 when a biomass of about 766,000mt was predicted. From then on, the ASPM predicted total biomass stabilised and remained below 1,000,000mt in the last 2 decades.

SS started with a predicted virgin biomass of about 3,000,000 metric tonnes in 1959, and then predicted a much lower initial biomass of about 2,000,000mt in 1960 and 1961 (Figure 10, right panel). Then the biomass increased up to a biomass of about 2,500,000mt in 1973. SS predicted declining biomass between 1974 and 1987 where a lower biomass of about 960,000mt was reached. As was the case with ASPM, SS also predicted a peak in biomass but in 1991 and the prediction was lower at 1,200,000mt. Thereafter SS predicted total biomass fluctuated but with a declining trend from about 90,000mt in 1994 to about 250,000mt in 2006. For the remainder of the years SS predicted a steep increase in biomass and the highest predicted biomass of about 3,600,000mt was shown for 2015 that was even higher than the predicted virgin biomass. In general SS derived higher biomass indices than ASPM (Table 4), although there was a similarity in the biomass trend for the period between 1970 and 2010 (Figure 10).



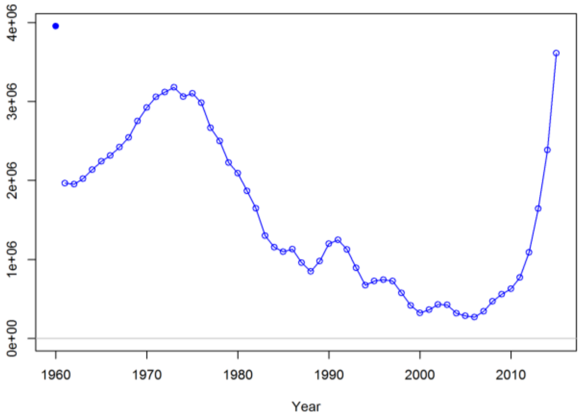


Figure 10: ASPM (left) and SS (right) predicted population biomass of horse mackerel

Table 4: Derived biomass indices of stock status in 2015

Index	ASPM	SS
Spawning stock K (Ksp)	2,812,990	3,574,810
Spawner biomass	672,608	2,547,260
Total biomass	858,033	3,614,110
MSY (K/2)	1,406,495	1,787,405

ASPM fit was evaluated against survey biomass and the fleet-disaggregated CPUE observations, and the model failed to fit the data well for almost all the observed data points from these data series (Figure 11). The 1980 data point in the Bulgarian CPUE series was grossly overestimated, while the 1981 was relatively less overestimated. The fit to the 1982 and 1983 data points were better than for all the other points in this series. The 1984 data point was underestimated but less so than the 1985 and 1986 data points. The Namibian Midwater fishery CPUE data points between 1990 and 2004 were all overestimated, while those after 2005 were under-estimated and more so for the data points later than and including 2009. The CPUE series of the Polish fleet between 1973 and 1977, and that of 1984 were overestimated, while those of 1978 to 1983 were underestimated. In the CPUE series from the Romanian fleet the data points of 1978, 1980 and 1981 were over-estimated whereas those of 1979 and 1982 to 1985 were underestimated, but less so for the 1982 and 1985 data points. The survey biomass data points of 1999 and 2000 were under-estimated, followed by those 2001 to 2003 which were overestimated but less so for the 2003 data point. The 2004 and 2005 data points were underestimated while the next two in 2006 and 2007 were overestimated. A better fit was shown between the ASPM predicted and the observed survey series from 2009 to 2012, with 2010 and 2011 data points marginally overestimated and the 2009 and 2012 data points marginally underestimated. The 2013 to 2015 data points were also underestimated. ASPM prediction of the USSR CPUE series was better, as in this fleet the observed points were closer to the prediction than the fits obtained with the other fleets (Figure 11, left lower panel). In the USSR data series the 1973 and 1975 to 1977 data points were overestimated while the 1978 and 1979 data points were marginally underestimated, as was the 1985 data point. The 1980 to 1984 data points were marginally overestimated. The 1974 and the 1986 data points were grossly underestimated.

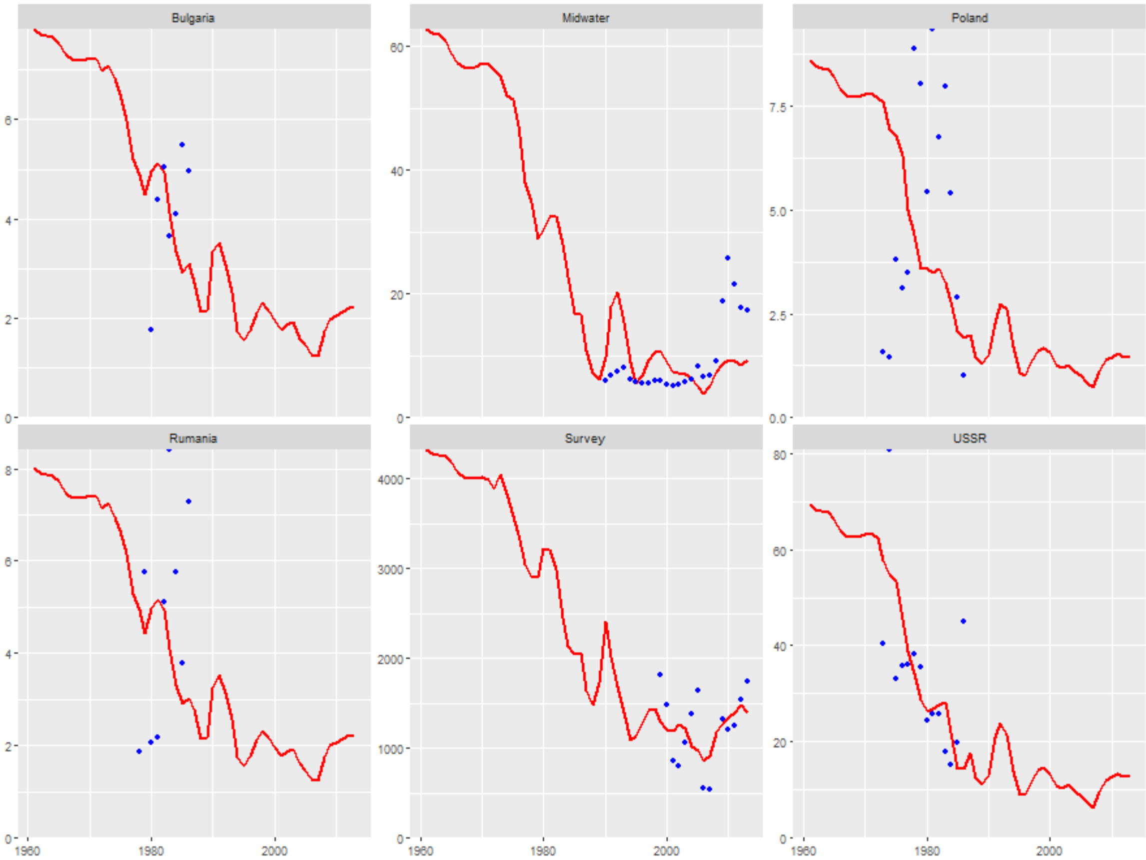


Figure 11: Fit of ASPM to the fleets' CPUE

SS predicted midwater mean lengths were smaller than observed between 1991 and 2000, except in 1994 when the predicted mean length was about 26cm and the observed mean length was about 25cm (Figure 12). The exact same mean lengths of about 22cm and 24cm were predicted and observed in 1996 and 2000, respectively. Thereafter higher mean lengths were predicted than observed until 2008, followed by lower predicted than observed mean lengths in 2009 and 2010. For the remainder of the time series the model predicted midwater mean lengths were generally similar to those observed. Nevertheless, all midwater predicted mean lengths were within the error bars of the observed midwater mean lengths. In the case of the purse seine fishery almost all model predicted mean length were higher than observed mean lengths, although not much so compared to those of the midwater fisheries (Figure 12). Too wide error bars were observed with the 2008 and 2013 observed mean lengths of which some had negative values. The 1999, 2004 and 2011 purse seine predicted mean lengths were outside the range of the observed mean lengths as the line did not cut across the observed error bars in those years.

The model fit on survey observed mean lengths was poorer compared to that of the fisheries, but the model did follow the trend in survey mean lengths, except in 2003 when the model predicted a decline in mean lengths while an increase was observed (Figure 12). The 2003 and 2009 model estimates were outside the range of observed purse seine mean lengths as the model did not cut across the observed error bars. The model predicted survey biomass was just below 1,000,000mt in 1994 and 1995 while the observed survey index for those years was higher (just below 1,500,000mt). While the observed index for 1996 and 1997 was a decline SS predicted an increase in those years, reaching predicted biomass of over 2,000,000mt and the prediction was also out of range of the observed values as the line did not cross the errors bars of the observations. The declining trend in the observed index was also predicted for the 1998 and 2000 data points but the predictions were much lower, ranging from about 1,300,000 to 300,000mt, while the observed index ranged from 1,900,000 to about 1,470,000mt. An increase was predicted in the biomass index for 2001 and 2002 while the observed index was declining in those years. However, despite the discrepancy in the trend the same biomass value was estimated as was observed for 2002. The next two years, 2003 and 2004, also saw the model estimating a decline while the observation was an increase. Similarly, the observed index declined in 2007 and 2006 whereas an increase was predicted that continued to the end of the time series. SS estimated biomass of about 1,280,000mt was similar to the observed value of 1,320,000 in 2009. Unrealistically high values of between 4,157,000 and 9,860,000mt were predicted between 2013 and 2015 (Figure 13).

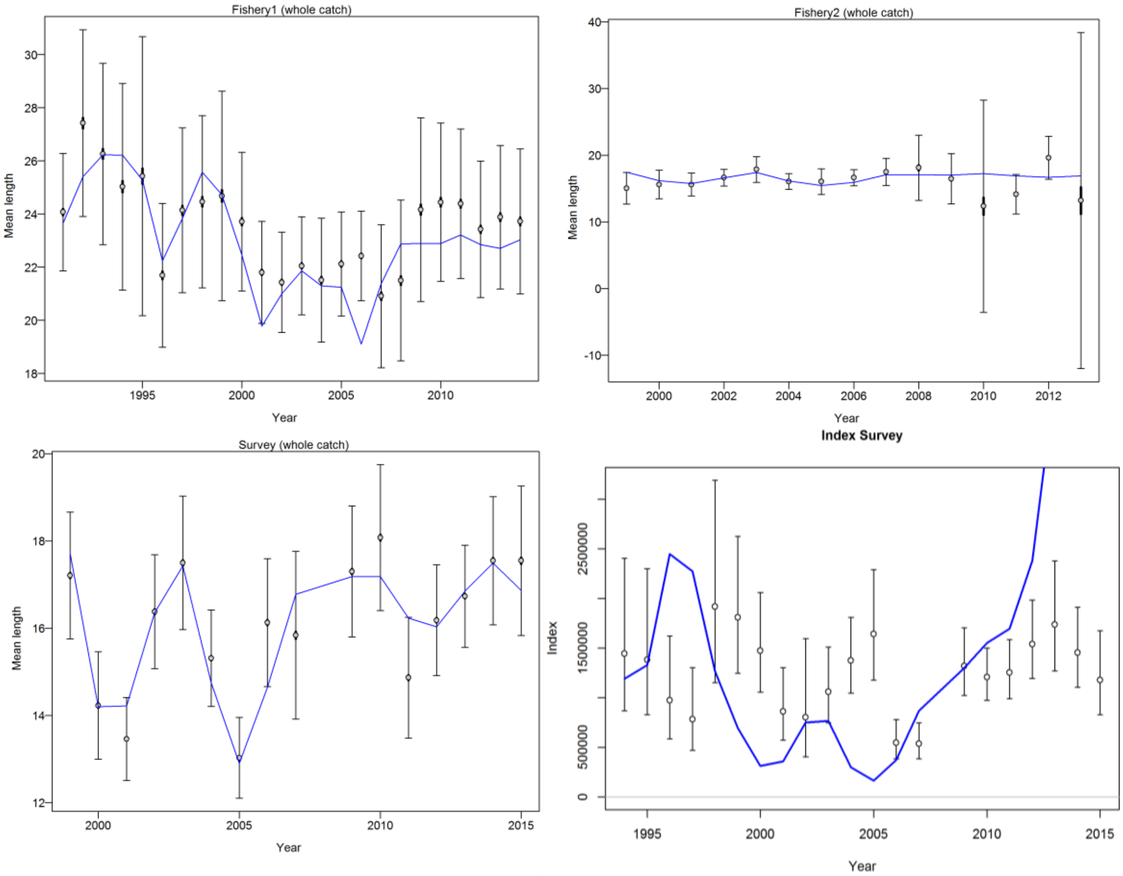


Figure 12: SS predicted (line) vs. observed (points with error bars) midwater (Fishery 1), purse seine (Fishery 2) and survey mean length

In ASPM as in SS a logistic selectivity pattern was specified and estimated for the midwater fisheries (Figure 13). Dome-shaped selectivity was allocated to the purse seine fishery in both models, whereas in ASPM survey selectivity followed a Cubic-spline pattern as opposed to a dome-shaped selectivity pattern in SS. ASPM only estimated age-based selectivity while SS estimated both length-based as well as age-based selectivity from the length-based selectivity for the fisheries. Survey age-based selectivity was not estimated in SS. The size-based selectivity for the aggregated midwater fishery in SS showed a point of inflection around 20 cm TL and fish of size >25 cm was fully selected (Figure 13, top right panel). The survey size selectivity peaked at a size just above 20 cm while for the purse seine fishery it peaked below a size of 20 cm. In ASPM the age-based selectivity for the purse seine fishery showed a single peak at age 1 (Figure 13, left panel), whereas a flattop between ages 3 and 4 was shown for the selectivity of that fishery, suggesting that those ages were equally selected in SS. While ASPM estimated a steeper gradient for the selectivity of the midwater with points of inflection around age 1 (Bulgaria and Romania), age 2 (Namibian midwater), age 3 (USSR), and between age 3 and 4 (Poland), the point of inflection for the age-based selectivity of the aggregated midwater fishery in SS was situated around age 4 (Figure 13, bottom right panel).

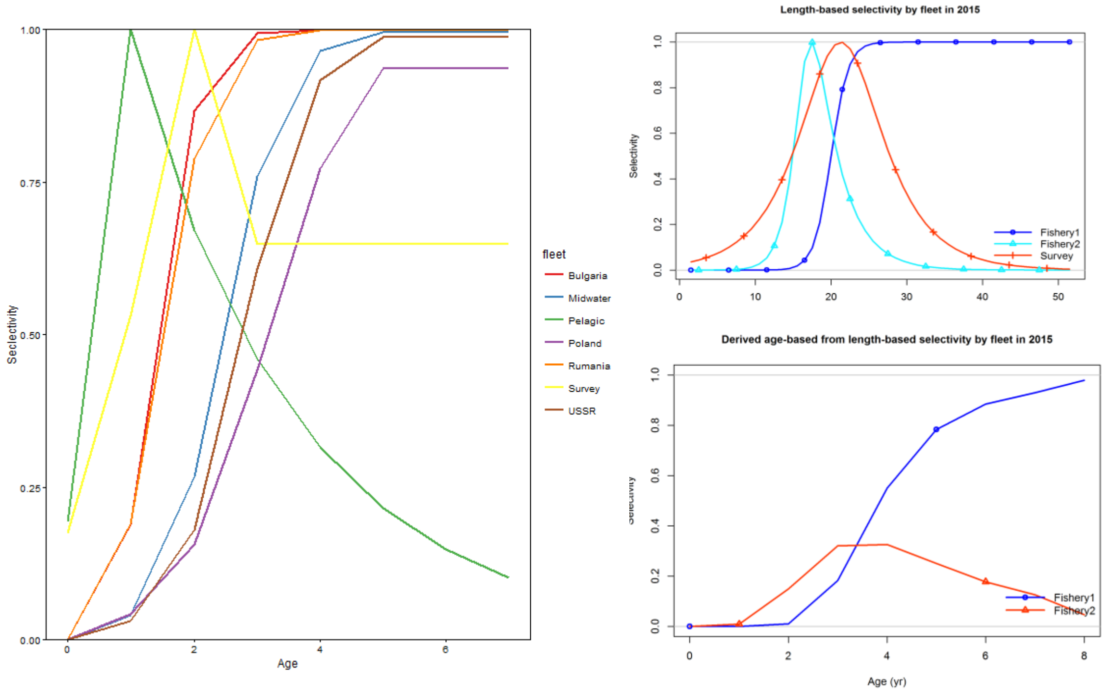


Figure 13: ASPM (left) and SS (right) estimated selectivity patterns

Year of first recruitment deviation was set at 1982 and hence SS estimated constant recruitment up to that year (estimated remarkable recruitment in 2015 (Figure 14). The highest recruitment estimate of about 700 trillion fish was estimated for 2015. Recruitment was above the expected Beverton-Holt recruitment curve since 2004. Previously relatively higher recruitment was estimated for 1983, 1987 and 1993, while lower recruitment was but with wider deviations was estimated in most of the years before 1998. The period since 1999 could be was predicted as a period of relatively high recruitment, except that lower predictions were made for 2001 and 2003.

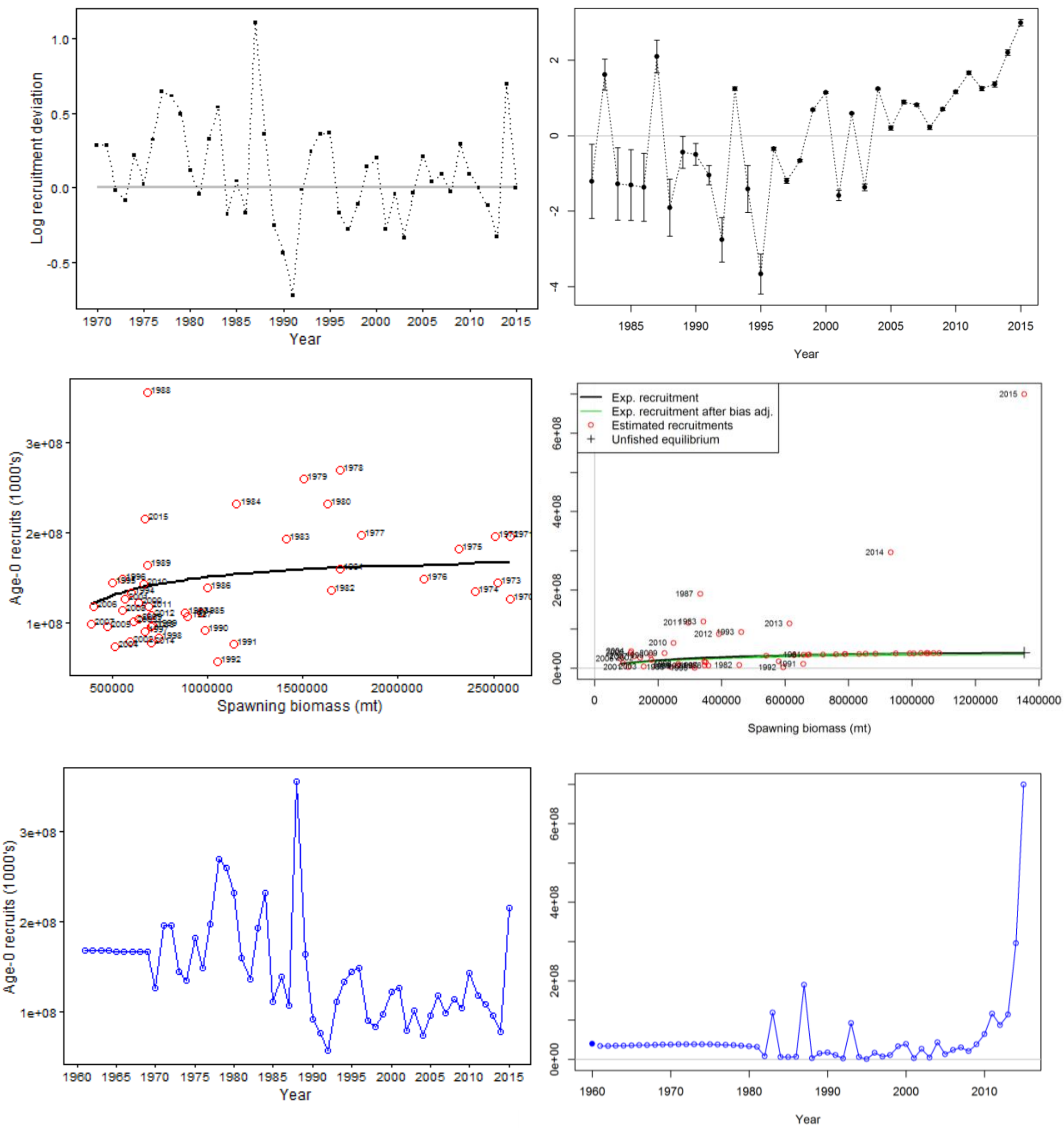


Figure 14: ASPM (left) and SS (right) estimated recruitment, Beverton-Holt spawning biomass recruitment relationship and recruitment deviations

5 DISCUSSION

5.1 Data review

Total annual catches usually reflected the annual TACs as catches rarely exceeded the TAC. The low trawl catches and low trawl durations recorded in 1990 could be a consequence of misreporting or incomplete capture of the log sheet catch data which was at the time of Namibia's independence, and thus a time when new data management systems were being put in place. The highest catches as well as trawl durations as per the database records were obtained during the early 1990s but the catches were reduced, accompanied by reduced trawl durations, when it was realised that the TACs were set too high. This also coincided with the implementation of a policy for rebuilding stocks that was adopted by the new Ministry of Fisheries and Marine Resources after independence. Relatively constant TAC's in subsequent years kept the catches relatively constant at least until 2007 when the fishing industry requested for a further reduction of the TAC as the stock status at the time showed indications that they were not going to be able to fill their quotas. However, trawl durations were not as constant at the time and this time also had the highest trawl durations of the time series, particularly between 200 and 2004, probably as the fishermen were increasing effort in the face of dwindling resources. A gradual increase in the TAC since 2008 resulted in a gradual increase in catches that maintained an increasing trend into the present.

In addition to logsheet records made during catch operations, the usual practice is also that all catches are landed in the presence of Fisheries Inspectors who record, verify and report these as the official landings statistics. However, it is known that discrepancies do exist between the logsheet data and the official landings statistics and hence mechanisms have been put in place to address these discrepancies and improve the quality of the catch data recorded in the scientists databases. Such mechanisms also include verifying the tallied data against the logsheet records of hauled and processed catches, and substantial progress has been made in this regard as the most recent logsheet catch data do not deviate much from the tallied official data. Hence, conclusions derived from some of this historic data sets should be made cautiously. Also, as a consequence of the discrepancy the total catch data used in stock assessments are derived from the official statistics rather than the logsheet catches. However, logsheet catch records are used for the calculation of CPUE because the duration of trawling operations which can only be recorded during the trawling operations are used as the measure of fishing effort.

Tripling of horse mackerel CPUE since 2009 has been a cause of concern for stock assessment, because when CPUE is used as an index of stock abundance, as in stock assessment models, the trend suggested that stock status should follow a similar trend. However, the CPUE trend was not reflected in other measures of abundance such as resource surveys, at least not in the same magnitude. Hence, it was necessary in this analysis to delve to the bottom of the causes of this trend in CPUE by examining the catch and trawl duration data points on which the calculation of CPUE was based. Evaluation of patterns in the catch and duration data was limited to the data for 1997 to 2013 as the data before this were pre-processed and summarised by day and hence would allow for a trawl by trawl evaluation. Similarly, a different database was recently introduced, since 2014, and hence data for the period after 2013 was not available for this evaluation as that new database is still under construction and the data was hence not accessible at the time of this evaluation. Furthermore, the 2013 catch and duration data point for both catch and catches and hence CPUE does not reflect the actual annual trawl duration for this fishery as the data was captured halfway before migration into a different database for which access is still being established. The pattern where trawl catches were widely distributed by including both very low catches and relatively high catches in the earlier periods of available data as opposed the observation of almost exclusively higher catches in recent years was so systematic to be a consequence of the natural temporal distribution of the fish. Coupled with the observed patterns in trawl durations an understanding was needed as to what made it so easy to catch horse mackerel in recent years which was absent in the earlier years. The wide range of trawl sizes recorded, before 2009, particularly the period between 2003 and 2008 suggested a wider use of different bag sizes, probably because of no bag size restrictions in the fishery. Similarly, the narrow range of trawl catch sizes in recent years suggested that the majority of the vessels were making similar catch size and hauled the gear when that size was reached in the gear, unlike in earlier years were the vessels appear to have hauled their indiscriminately. Such situations would arise if in recent years the gear were fitted with sensors that informed the fishers of the levels of catch in their gear while the gears were still in the water and including the use of a universal standard bag size for all vessels. Although, the use of ‘improved’ sensors were confirmed by the fishermen, the use of a standard gear size was not.

With the above speculations in mind it was delved deeper into the trawl durations to identify patterns that may not have been a consequences of fishing operations but probably of data recording and processing, as it was known that data from different periods in the development of the fishery were processed differently. Instances were found were one of the trawl times, i.e. start or end time, were wrongly recorded or captured resulting in some of these exorbitant trawl durations. All trawls with durations above 23 hours were found to have been wrongly captured. The observed pattern of a decreasing range of trawl duration with increasing trawl number implied that lesser and lesser effort was needed in catching horse mackerel as the day grew older. Furthermore, the differences observed between the 1997 to 2003 dataset and the 2004 to 2013 data (Fig. 5) would imply that something must have changed with the fishery or with the stock between these two time periods. However, the fact that trawl durations were calculated before the data was capture in the 1997 to 2003 dataset while the data for 2004 to 2013 were captured raw may have resulted in the data containing more errors, as it is often observed with the most recent data that at times fishermen record erroneous trawling times, particularly when trawls are set one day and hauled the next day. Erroneous trawling time are corrected at data capture by ensuring consistency in the recorded trawling times, an approach also used in this study to evaluate the validity of the trawl durations. However, the fact that trawl durations in the 1997 to 2003 dataset were pre-calculated made it difficult to ascertain consistency between trawls and hence patterns in the values were rather used as a diagnostic feature.

Although, it is not known with certainty what caused the large number of trawls with very small catches, (i.e. <=20,000 kg) made at very large trawl durations before 2009, or the observation that almost all trawls made after 2009 caught >20,000kg of fish and at very low trawl durations. A probable cause could be the illegal modifications in the fishing gear referred to as ‘zippers’ which were detected in the fishing gear of the majority of operators in 2008 and resulted in arrests and charging of those operators. The ‘zippers’ were panels in the gear that was designed to snap when the gear gets to full to handle and which in the process dumped some of the catch while the gear was still in the water. The detection of the zippers may have led to improvement in the monitoring and surveillance of fishing operations of this fishery, which could have benefited the stock, hence improving stock abundance or left the operators with less options than to land all the catch resulting in the recent patterns in trawl catches. One other reasonable explanation for the wide distribution of catch sizes before 2009 that the operators were unable to provide, was the possibility that trawls were left floating for extended periods to allow for more fish to be dumped though the ‘zippers’ which may have led to the high durations at the time. However, the operators’ account on the observed catch pattern was that due to limited processing capacity on these trawlers, trawl durations, particularly during the period before 2009 were extended to allow for the factories to complete processing earlier catches (Rocher, personal communication). Modification were made to the factories on the vessels to increase their processing capacities as well as product quality after 2009 which were completed during the 2012 fishing season and hence trawl durations were shortened. The view of the operators for the recent observation of mainly large trawl catches was that stock status has improved after a reduction in the size of the fleet following the zipper incident of late 2008. From the above it became clear that trawl durations recorded at the time before the modification were not the actual trawling hours as they were influenced by the processing capacities of the vessels, and hence for those trawl durations to be representative of trawling activities, the time spend waiting with the net in the water for processing of a previous catch should be removed from the recorded trawl durations. Similarly, since the zippers were devices for reducing excessive catches the quantities released through the zippers should be added back to the catch amount unless it can be shown that the fish so released did survive, and the amount of effort spend on reducing the catch through the zippers should also be removed from the calculation of catch effort. Furthermore, the patterns in the catch catch and trawl duration patterns was observed for the entire time series as far back as 1990 as could be deduced from the trend in the CPUE, hence implying the implications goes as far back. The above brings into disrepute the use of CPUE as index of abundance in this fishery. However, the identified errors in the data could not be corrected in this study as in most instances required verification with the actual raw data records in the log sheets.

Data from surveys conducted before 1999 are not used in the usual horse mackerel stock assessment due to possible incomparability of the survey series, since the 1991 to 1998 surveys most of the surveys at that time mainly targeted sardine and were hence not specifically designed for horse mackerel or those designed for horse mackerel employed a different survey strategy to that of the current surveys. The survey strategy in the latter surveys involved exclusively parallel transect grids while the former surveys were surveyed using zig-zag survey grids or sometimes a mixture of both zig-zag and parallel grids. However, both survey series were included in this evaluation due to the observed similarity in the biomass trend from the two-survey series. The variability observed in the survey biomass index was not reflected in the CPUE index, particularly during the period before 2009. The index showed a cyclic pattern where a high biomass is maintained for a number of years before plummeting to very low values that are maintained for about two years before rising again. This pattern maybe a consequence of exploitation where increases biomass lead to increases in exploitation which then cause a reduction in the biomass followed later by a reduction in exploitation levels.

5.2 Comparison of ASPM and SS

For consistency and the purpose of this study the usual stock assessment data were used in this exercise in spite of the data issues identified during the data evaluation exercise. It is anticipated that future stock assessments would take consideration of these data issues. Starting at the very high virgin biomass and carrying capacity (K) assumed at the start of the fishery, the ASPM model responded by reducing the resource so as to account for the relatively lower (far lower than K) observed yield levels in subsequent years. The same high virgin biomass was also an integral assumption of SS but instead of gradual reduction of the stock from a high initial biomass, a lower initial biomass was predicted in SS that then followed the trend of increasing catches in the earlier as these were the only available data for the model. With the introduction of the purse seine catch series in 1971, both model responded by reducing the biomass, which was a further reduction in the case of ASPM and a change from an increasing trend in the case of SS. Both models showed an almost identical performance during the period after 1989, probably coinciding with increased data richness (Methot Jr. & Wetzel, 2013). ASPM, the biomass model, captured biomass trends better than SS which estimated biomass from the information obtained from composition data. Hence, while ASPM estimated a reduction in biomass in response to declining survey biomass estimates and declining CPUE, SS estimated in increase in biomass in response to exceptional recruitment estimates deduced from the high prevalence of juvenile fish observed in the composition data, particularly during 2014 and 2015 surveys. However, this predicted increase was unrealistic as it appeared to have gone beyond the carrying capacity, or that the observed recruitment appears to have shifted the stock's carry capacity. Hence, there was insufficient information in the data to contain the model. Probably, ASPM was probably contained in the last few years by the inclusion of the declining CPUE series, in spite that the series contributed a weight of only 10%. Lack of purse seine catch-at-age data in the last two modelled years as well as lack of midwater catch-at-age in the last year, which were presented to the model with zero values, could have also contributed to ASPM showing a different prediction of total biomass to that shown by SS in the last years of the model. While ASPM requires the same number of observations for all input, e.g. that the start and end year of catch data be the same as that in the age composition data, SS was less sensitive to missing data as it could execute well with unequal numbers of observations. The ability of SS in estimating ages from the length composition data was also demonstrated. While missing data is not accounted for in SS, in ASPM missing data takes the value of zero which if treated as a value should result in a different behaviour in the model as opposed to where they were completely excluded completely. The ASPM may probably be improved by recoding it to be able to accept missing values. Thus, the fact that the two models were used to fit different kinds of composition data, where ASPM was fitted to age and SS to length composition data may also have contributed to the different prediction capacities between the models.

Lack of proper fit to the data was a feature of both models which was probably a consequence of model misspecification resulting from the modeller's unfamiliarity with the models. Hence, it is expected that with practice and effort the outputs and hence the comparisons between the two models will be improved. The assumption of a high virgin biomass in both models may also be unrealistic, hence the behaviour shown in SS where it was unable to account for the large difference between the virgin biomass and the initial biomass. Since, it is argued that (Boyer *et al.,* 2000) horse mackerel has benefit from the regime change that came with the collapse of the northern Benguela sardine it would be expected that this purported benefit should have been shown in the status of the horse mackerel stock, whereby the species carrying capacity would have been lower before and higher after the sardine collapse.

6 CONCLUSION

Due to the issues identified surrounding the recording and/or processing of log sheet trawl data the use of CPUE as an index of abundance in this fishery should be halted until all issues surrounding this index are ironed out. The high trawl durations recorded as a result of the alleged low processing capacity of the factory vessels need to be effectively accounted for and corrected. Similarly, a possible high fishing mortality as a result of past use of 'zippers' should be investigated, quantified and the findings included in the assessment process. It is also imperative that the quality of data in the respective databases available for this be improved and made comparable with the official statistics, and even compiled within a single database such that stock assessment data is not assembled from diverse sources. Management of the resources may benefit from some form of maximum bag size restriction that is tailored to the vessels' hauling and processing capacities to avoid a reintroduction of fish dumping devices such as the infamous 'zippers'.

Identification of alternative stock assessment approaches has potential future applications in the assessment of other similar stocks, such as the crustaceans for which the absence of reliable ageing data also hampers the application of age-based stock assessment models. Assessments of data poor stocks with limited and/or questionable data may benefit from conducting parallel assessments using different approaches as a way of quantifying and reporting of uncertainties in the assessments due uncertainties in the quality and quantity of the data. SS appeared to be a suitable alternative to the current ASPM as SS can be executed with limited data and especially its robustness in the absence of catch-at-age data. Although comparability between the two was not effectively performed as was hampered by lack of competence in modelling, the observation that the two models showed almost identical behaviour for some part of the modelled period was rather encouraging.

In general, the main goal of this study was realised since competencies were acquired in compiling data analysis scripts using R as well as competencies in compiling files and executing stock assessment models. However, a great deal of work is still needed to fully understand and successfully execute models, such as making stock forecasts and the derivation and interpretation of management quantities. An understanding of the different model outputs, such as the multitude of visuals generated by r4ss need to be attained to make better use of the modelling exercise and provide valuable information for the management of the stock through better interpretation of the model outputs.

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APPENDICES

Size composition data used in tuning SS

```
#Yr Seas Flt/Svy Gender Part Nsamp datavector (female-male)
#Midwater
 1991 1 1 0 0 3005 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 5 16 24 120 312
639 574 335 213 138 139 147 121 83 57 25 22 14 11 5 2 0 0 0 0 0 0 0
0 0 0 0 0 0
 1992 1 1 0 0 1860 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 4 7 9 14 46 122
136 183 249 305 249 150 100 69 52 35 33 27 21 19 13 8 5 2 1 0 0 0 0
0 0 0 0
 1993 1 1 0 0 2786 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 10 13 44
146 485 572 479 350 234 154 105 73 35 25 18 13 9 6 3 4 2 2 1 0 0 0 0
0 0 0 0
 1994 1 1 0 0 2520 0 0 0 0 0 0 0 0 0 0 0 0 1 4 12 20 34 60 82 96 98
105 173 307 429 371 258 148 91 58 44 33 30 20 13 11 8 6 4 3 1 0 0 0
0 0 0 0 0 0
 1995 1 1 0 0 2205 0 0 0 0 0 0 0 0 0 0 0 0 6 12 38 62 140 223 215
192 182 139 157 192 182 139 157 192 176 121 73 33 33 27 34 23 24 21
19 17 19 10 6 4 3 3 4 0 0
 1996 1 1 0 0 2558 0 0 0 0 0 0 0 0 0 0 0 0 17 27 79 150 242 251
278 313 296 234 164 113 107 91 72 35 25 18 15 10 7 6 4 1 1 1 0 0 0 0
0 0 0 0 0 0 0
 1997 1 1 0 0 1821 0 0 0 0 0 0 0 0 0 0 0 0 1 2 5 15 34 64 117 147
185 201 228 226 196 148 106 63 36 17 8 6 5 4 2 2 1 1 0 0 0 0 0 0 0
0 0 0
 1998 1 1 0 0 2365 0 0 0 0 0 0 0 0 0 0 1 2 4 8 14 26 55 89 138 175
188 221 262 279 244 203 148 114 81 46 22 14 8 5 3 4 3 2 1 1 0 0 0 0
0 0 0 0 0
 1999 1 1 0 0 2175 0 0 0 0 0 0 0 0 0 1 4 5 3 4 10 24 41 56 81 130
169 175 210 212 198 168 158 120 110 90 60 36 30 19 13 11 10 6 8 8 2
2 1 0 0 0 0 0 0 0
 2000 1 1 0 0 2610 0 0 0 0 0 0 0 0 0 1 5 16 22 33 49 78 121 147 172
211 216 211 216 211 227 231 207 153 126 99 83 62 45 31 22 14 10 6 5
3 2 1 1 0 0 0 0 0 0 0
 2001 1 1 0 0 2460 0 0 0 0 0 0 0 0 0 0 1 3 6 18 53 95 162 225 254
263 251 198 171 149 142 113 102 74 56 37 27 19 15 9 6 4 3 1 2 1 0 0
0 0 0 0 0 0 0 0
 2002 1 1 0 0 2685 0 0 0 0 0 0 0 0 0 1 0 1 5 16 50 96 151 196 281
326 376 286 259 190 143 92 61 43 34 28 19 11 7 4 3 2 2 1 1 0 0 0 0 0
0 0 0 0 0 0
 2003 1 1 0 0 3151 0 0 0 0 0 0 0 0 0 0 0 0 0 2 5 20 66 186 333 416
468 422 380 295 198 125 81 48 35 24 17 11 8 5 2 2 1 1 0 0 0 0 0 0 0
0 0 0 0 0
 2004 1 1 0 0 3013 0 0 0 0 0 0 0 0 0 0 0 1 2 9 24 56 131 226 354 405
422 357 303 241 180 119 76 43 27 14 8 5 4 2 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0
 2005 1 1 0 0 2483 0 0 0 0 0 0 0 0 0 9 5 4 5 8 14 22 62 149 266 305
362 310 268 198 147 83 65 49 39 32 28 18 11 6 4 2 4 2 2 2 2 1 0 0 0
0 0 0 0 0
 2006 1 1 0 0 2359 0 0 0 0 0 0 0 0 0 0 0 2 5 19 25 60 94 150 199 254
264 228 222 212 174 123 96 65 50 31 19 20 13 7 5 4 6 5 2 2 3 1 1 0 0
0 0 0 0 0
```

```
 2007 1 1 0 0 1239 0 0 0 0 0 0 0 0 0 0 0 1 1 6 17 39 86 130 163 171
166 128 99 76 55 34 23 14 10 7 5 3 2 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0
0
 2008 1 1 0 0 1629 0 0 0 0 0 0 0 0 0 1 1 3 6 18 36 60 93 118 138 155
187 204 189 146 100 58 37 23 16 11 8 4 3 3 2 2 2 1 1 1 1 1 0 0 0 0 0
0 0 0
 2009 1 1 0 0 1529 0 0 0 0 0 0 0 0 0 0 0 0 0 1 4 9 18 41 68 110
151 192 237 239 181 128 69 37 18 11 6 3 2 1 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0
 2010 1 1 0 0 1938 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 7 14 30 57 117
190 262 322 315 235 174 98 55 25 14 7 5 2 2 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0
 2011 1 1 0 0 2379 0 0 0 0 0 0 0 0 0 0 0 0 0 1 4 9 20 49 90 144
230 342 397 357 260 199 110 68 38 26 14 9 5 2 2 1 0 1 0 0 0 0 0 0 0
0 0 0 0
 2012 1 1 0 0 2929 0 0 0 0 0 0 0 0 0 0 0 0 1 2 10 34 75 133 206
308 404 428 374 308 214 162 95 65 42 28 16 11 7 3 2 1 1 0 0 0 0 0 0
0 0 0 0 0 0
 2013 1 1 0 0 2467 0 0 0 0 0 0 0 0 0 0 0 0 1 2 8 20 35 65 122 235
319 371 371 298 215 153 85 57 38 25 16 10 8 4 4 3 1 1 0 0 0 0 0 0 0
0 0 0 0
 2014 1 1 0 0 2445 0 0 0 0 0 0 0 0 0 0 0 0 1 2 6 22 48 84 119 197
283 385 416 312 230 152 73 50 24 16 9 7 4 2 2 1 1 1 0 0 0 0 0 0 0 0
0 0 0

#Purse_seine
 1999 1 2 0 0 954 0 0 0 0 0 0 0 0 1 10 39 79 100 135 152 202 136 58
27 14 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2000 1 2 0 0 1129 0 0 0 0 0 0 0 0 0 0 4 13 57 174 246 323 248 49 10
2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2001 1 2 0 0 1114 0 0 0 0 0 0 0 0 2 6 26 36 103 184 208 158 169 140
50 12 5 7 4 3 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2002 1 2 0 0 2172 0 0 0 0 0 0 0 0 0 0 0 0 51 112 369 538 467 390
161 61 7 7 4 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2003 1 2 0 0 1270 0 0 0 0 0 0 0 0 2 6 7 15 24 26 82 162 182 258 239
162 55 20 12 5 6 4 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2004 1 2 0 0 2138 0 0 0 0 0 0 0 0 0 1 14 13 27 321 495 491 374 228
113 41 17 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2005 1 2 0 0 1618 0 0 0 0 0 0 0 0 0 1 4 61 155 303 236 255 208 215
164 82 19 7 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2006 1 2 0 0 1865 0 0 0 0 0 0 0 0 0 0 2 15 32 133 264 423 461 300
141 60 34 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2007 1 2 0 0 1023 0 0 0 0 0 0 0 0 0 0 0 0 8 49 97 186 192 168 166
110 19 27 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2008 1 2 0 0 213 0 0 0 0 0 0 0 0 0 0 0 0 0 33 34 21 26 34 31 21 8
2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2009 1 2 0 0 321 0 0 0 0 0 0 0 0 0 1 1 0 7 29 55 70 67 50 31 7 2 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2010 1 2 0 0 20 0 0 0 0 0 0 0 0 0 4 1 3 8 4 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2011 1 2 0 0 601 0 0 0 0 0 0 0 6 13 10 9 16 134 187 111 65 29 11 6
2 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2012 1 2 0 0 475 0 0 0 0 0 0 0 0 0 0 0 2 5 6 8 15 34 50 66 55 59 44
47 34 21 12 8 2 6 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2013 1 2 0 0 7 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
#Survey
 1999 1 3 0 0 31300 0 9 50 127 92 26 57 81 294 1070 2829 2665 1879
1889 1346 1468 1498 2497 3003 2812 2284 1390 637 679 524 523 556 394
182 130 106 96 30 17 16 12 12 15 6 0 0 0 0 0 0 0 0 0 0 0
 2000 1 3 0 0 38726 0 0 0 0 0 118 2002 3366 3076 2290 2343 2674 4502
4709 2449 855 428 507 752 1850 2381 1526 741 510 383 279 275 212 156
149 66 41 41 16 13 3 6 1 2 0 0 0 0 0 0 0 0 0 0 0
 2001 1 3 0 0 30768 0 6 56 67 87 155 527 2703 2184 2409 2020 1424
1767 3208 3848 3547 2991 2234 999 294 71 24 67 18 29 22 7 0 0 4 2 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2002 1 3 0 0 19106 0 0 0 0 0 0 0 0 0 153 595 1199 1144 1008 2153
3531 2894 2641 1949 894 418 221 180 47 23 18 6 15 11 0 1 0 4 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0
 2003 1 3 0 0 18245 0 0 1 1 1 0 12 157 132 268 482 1172 444 372 1705
2248 2102 2130 1847 1337 1286 1046 666 447 175 127 51 30 2 0 0 0 4 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2004 1 3 0 0 35830 0 0 0 0 5 20 10 73 108 330 2821 4198 3391 4339
5187 4552 3552 2212 1146 813 1552 707 350 217 85 54 19 26 5 11 4 0 1
3 5 5 6 8 5 5 3 1 0 0 0 0 0 0 0 0
 2005 1 3 0 0 50798 0 0 83 136 570 1553 1598 1391 1923 6996 9518
6239 3969 3911 1258 843 1661 1654 750 1047 1866 1689 1134 484 240
158 61 21 10 15 5 15 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2006 1 3 0 0 13164 0 0 26 57 62 142 55 108 131 264 548 575 493 504
1132 2399 2330 1790 1085 605 338 169 116 81 36 52 64 0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2007 1 3 0 0 11878 0 0 11 43 114 117 32 3 2 43 178 724 1384 1635
1892 1487 985 838 721 412 439 336 182 116 69 42 28 12 14 1 4 3 6 1 0
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2009 1 3 0 0 21229 0 0 73 90 52 80 48 111 895 1259 529 274 448 1200
1177 1392 2352 2075 2034 2261 1867 886 570 476 494 359 138 64 18 4 1
0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2010 1 3 0 0 20097 0 0 1 26 79 224 371 438 268 101 259 95 35 99 925
1784 2629 3418 3004 2109 1265 819 603 494 383 294 185 76 31 26 18 9
11 3 0 11 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0
 2011 1 3 0 0 33225 0 279 868 1231 529 848 1798 1636 922 995 649 549
1768 2116 1924 1711 2119 2518 2465 2092 1972 1371 1041 767 463 297
139 89 46 18 1 1 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2012 1 3 0 0 32584 0 19 64 116 224 550 1115 1984 1853 937 765 671
1046 1060 686 1691 3799 3546 3116 2952 2451 1570 955 593 351 278 105
61 24 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2013 1 3 0 0 33555 0 0 86 191 501 632 625 715 1008 1053 1099 1189
1663 1297 3536 2715 1170 1251 1494 2583 3591 3472 2176 848 315 219
79 32 13 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2014 1 3 0 0 25748 0 114 371 389 632 470 387 187 174 187 232 1453
2409 1442 867 1007 892 1019 1191 1727 2317 2368 2075 1824 1209 460
213 75 43 12 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 2015 1 3 0 0 25748 0 114 371 389 632 470 387 187 174 187 232 1453
2409 1442 867 1007 892 1019 1191 1727 2317 2368 2075 1824 1209 460 213
75 43 12 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```