A summary of the South African sardine (and anchovy) fishery

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Summary

The sardine fishery is an important component of the South African purse-seine fishery, the largest commercial fishery in South Africa (by landed mass). This fishery, initially established on the West Coast, but with some subsequent infrastructure development on the South Coast, is currently under pressure because of recent low biomass levels, reduced TACs and frequent changes in the spatial distribution of the resource. The current low biomass followed from prolonged poor recruitment, whereas the distributional changes are plausibly linked to processes related to spatial structuring of the population, which is now hypothesized to comprise multiple components (western, southern and eastern), with interchange amongst them. Given the predominantly west-coast-based location of sardine processing infrastructure, exploitation levels on the western component is high relative to other components, particularly when most of the biomass is located on the south coast. This has sparked debate about whether there is need for spatially differentiated management to ensure both a healthy ecosystem and a more soundly managed resource. This document summarises the history of the fishery, the current status of the resource and data used in its assessment and management.

Distribution and Stock structure

South African Sardine *Sardinops sagax* are found in continental shelf waters between Hondeklip Bay (~30°S) on the West Coast and Durban on the East Coast (Figure 1). Sardine found northwards along the Namibian coast as far as Southern Angola (~15 °S) are considered a separate stock, separated from the South African stock by a semi-permanent intense upwelling cell off Luderitz (27°S).

Current understanding is that the South African sardine stock comprises a single “stock” (in the sense of a reproductively isolated biological unit), but there is spatial structure within this stock, which has been hypothesized to comprise multiple components, with a western (distributed off the West Coast; i.e. to the west of Cape Agulhas), southern (distributed off the South Coast from Cape Agulhas to Port Alfred) and eastern (distributed off the South Coast in spring/summer and the East Coast in autumn/winter when they undertake the annual sardine run) components (or sub-stocks) suggested. The South African purse-seine fishery mainly targets sardine off the West and South Coasts and thus only the putative western and southern components are currently considered in a commercial management sense. There is movement of sardine of all ages between the two coasts, assumed almost exclusively west to south and some eggs spawned off the South Coast may be transported to the West Coast nursery area and thus contribute to recruitment to the western component (Figure 2).

The bulk of the adult sardine biomass has been confined to the lower west coast and Agulhas Bank area as far east as Port Alfred during most of the period for which we have survey observations. Sardine eggs and larvae are transported west and north towards a west coast nursery ground by a jet current associated with a strong thermal front between cold upwelled water and warmer oceanic water flowing northward along the shelf-edge of the west Cape coast. A return migration of juveniles southwards along the west coast occurs predominantly during late summer/early autumn, with recruitment to the adult population on the Agulhas Bank occurring during autumn and winter. This return migration of sardine recruits coincides with a similarly-timed, southward migration of anchovy recruits and gives rise to important interactions between the sardine recruits and the directed fishery for anchovy recruits. Whilst a substantial number of sardine recruits have also been observed at times on the south coast, west coast recruitment remains dominant.

Shifts between predominantly West Coast-based and South Coast-based spawning have occurred frequently in the past. A gradual expansion in the distribution of sardine towards the east coincided with a period of rapid growth in the size of the sardine population from the mid-1990s to the early 2000s. In recent years the distribution of sardine has changed on an almost annual basis from being predominantly located on the South Coast in one year to being found mainly on the West Coast in the next year. This has had severe cost and logistical implications for the fishery and management of the stock as there is frequently a mismatch between the location of sardine availability and fish processing facilities as well as between fish abundance and fishing effort which is linked to some extent to the location of processing facilities (Figure 3).

Biology and ecology

Sardine generally exhibit schooling behaviour, and are relatively short-lived, fast-growing fish (seldom reaching more than 5yrs of age). The accuracy of ageing from otoliths is extremely variable because sardines frequently deposit two to three rings in each growth zone, and the pattern of ring deposition varies among years. Sardine have a protracted spawning season, with more than one spawning event and larger females having a higher reproductive potential (number of spawnings). GSI values (indicators of spawning) are highest in sardine from the West Coast during spring and summer (August to February), whereas those for fish off the South Coast are highest in winter and spring (June to November). The relative quantitative importance of winter spawning by sardine off the South Coast is unclear.

Sardine play an important role in regulating ecosystem functioning. Shifts in sardine distribution and fluctuations in sardine abundance have been hypothesised to have had substantial ramifications for top predators, in particular the distribution and relative abundance of seabird species for which sardine are an important dietary component such as Cape gannets *Morus capensis* and African penguins *Spheniscus demersus*.

Purse-seine fishery

Sardine and anchovy *Engraulis encrasicolus* generally account for more than 80 % of the total pelagic purse-seine catch, the remainder being made up largely by redeye round herring *Etrumeus whiteheadi* and juvenile horse mackerel *Trachurus Capensis*. Adult sardine are

generally targeted for canning and bait. Approximately 85% of the sardine catch is canned, whilst the remainder is frozen and packed in boxes for local and international bait markets. Juvenile sardine are also caught as by-catch in the anchovy recruitment (reduction) fishery on the West Coast.

The first pelagic fishing operations began in South Africa in 1935, but commercial operations started in the St Helena Bay area only in 1943 in response to the increased demand for canned products during the Second World War, with purse-seiners operating between Lambert's Bay and Cape Hangklip. Initially targeting sardine and horse mackerel, the purse-seine industry prospered from the late 1950's with sardine dominating the escalating catches until 1964 (Figure 4).

Following rapid declines in the landings of sardine during the mid-1960s, the industry changed its fishing strategy and used smaller-meshed nets to target juvenile anchovy as the recruits moved from the West Coast nursery grounds to the spawning grounds off the South Coast. Anchovy dominated the catches for the next two and a half decades (peaking at around 600 000 t in the late 1980s) while catches of sardine gradually increased throughout the 1990s under a conservative management strategy. Sardine catches increased substantially in the early 2000s (reaching 374 000 t during the early-2000s) as a consequence of exceptionally good sardine recruitment and subsequent rapid growth in the size of the population, particularly on the South Coast. These large catches of sardine coincided with increased catches of anchovy and resulted in annual total pelagic fish landings in excess of 500 000 tonnes between 2001 and 2005.

Several successive years of low sardine recruitment since 2004, however, resulted in a rapid decline in the size of the sardine stock with sardine TACs and catches dropping to levels in the order of 90 000 t between 2008 and 2014 and to only 45 560 in 2017 (90 000 t had been muted as the level below which the sardine industry would need to undergo substantial restructuring in order to remain viable). The current low sardine TACs are insufficient for profitable operation of the major canning facilities and the bulk of canned sardine products currently produced in South Africa contain sardine that are sourced from Morocco and elsewhere. This has enabled the industry to retain market share and to keep their workers employed, though current unfavourable exchange rates are affecting profitability and threatening the long-term viability of the canning industry, particularly if directed sardine TACs remain at low levels.

During the early years of the fishery, most of the fishing effort was concentrated on the West Coast where sardine were abundant for most of the year, resulting in intensive development of infrastructure related to fish processing centred around the harbour at St. Helena Bay. During the 1960s and 1970s there was an expansion of the fishing ground for sardine southwards and eastwards as far as Cape Agulhas. Since the mid-1990s, following the eastward expansion of the sardine distribution, fishing effort increased further east, particularly in the Mossel Bay area, with the establishment of a new cannery in Mossel Bay in 2007. A small portion of the sardine TAC is also regularly taken in the vicinity of Port Elizabeth on the South Coast.

Currently the cannery in Mossel Bay and the various smaller sardine processing establishments on the South and East Coasts have access to about 15% of the annual TAC (based on RH affiliation and vessel home-port locations). The amount of sardine caught east of Cape Agulhas increased gradually from 2001 onwards, although this remained small in comparison to landings made to the west of Cape Agulhas, resulting in relatively higher harvest proportion levels on the western component of the sardine resource in most years (Figure 5).

Catches of sardine on the South Coast have exceeded those taken on the West Coast in only four years (2005-2008) with the majority of those sardine caught on the South Coast being transported back to factories on the West Coast, either by large refrigerated-sea-water vessels or by truck. Presently, the majority of sardine processing infrastructure is still based on the West Coast and most of the lease agreements and systems established for the offloading of sardine in Mossel Bay for road transport, by West Coast-based Rights Holders, during years when the sardine TACs and availability of sardine on the South Coast were high, have been discontinued.

Biomass surveys

The biomass and distribution of sardine and anchovy, and also of other schooling pelagic and meso-pelagic fish species such as round herring, juvenile horse mackerel and lantern- and light fish (*Lampanyctodes hectoris* and *Maurolicus walvisensis*, respectively) are assessed biannually using hydro-acoustic surveys based on a random stratified sampling design These surveys, which have been conducted without interruption since 1984, comprise a summer biomass survey and a winter recruit survey. Biomass estimates obtained from these surveys are key inputs into the anchovy and sardine assessments and form the basis for recommendations of annual total allowable catches of anchovy and sardine.

The surveys cover the entire area of the South African continental shelf between Hondeklip Bay on the west coast and Port Alfred on the east coast during the summer biomass surveys (Figure 6a). Sampling effort during the recruit surveys is concentrated mainly on the inshore areas of the shelf, but the survey is extended westward and northward to the Namibian Border (Orange River Mouth; Figure 6b). Although recruit surveys initially covered only the main distribution of anchovy recruits, which was considered to extend as far as Cape Infanta on the South Coast, the most recent surveys have been extended further eastward to estimate the strength of sardine recruitment on the South Coast as well.

The biomass of sardine increased gradually from under 50 000 tons in 1984 to around 2.5 million tons in 2000, and whilst consecutive years of very good recruitment pushed the total biomass up to record levels above 4 million tons in 2002, a period of prolonged poor (or below average) recruitment since 2004 has led to a decline in the adult biomass to below 500 thousand tons in most years since 2007, and to a recent low of just 258 000 t in 2016 (Figure 7).

The contribution of the biomass west of Cape Agulhas to the total sardine biomass was larger than that of the biomass east of Cape Agulhas up until 1998. In 1999, a large increase in the biomass east of Cape Agulhas relative to that west of Cape Agulhas caused a “shift” in the relative distribution of sardine to the Central and Eastern Agulhas Bank. Further increases in the biomass of sardine east of Cape Agulhas after 1999 were mainly as a result of the influx of a large number of 1-year old sardine in 2001 and 2002 emanating from very successful west coast recruitment. Apart from two recent years (2011 and 2015) the biomass of sardine has since 2008 been more evenly distributed between the west and south coasts with close to or more than 50% of the biomass being located in the area to the west of Cape Agulhas (Figure 8).

Assessment and Management

Management of the small pelagic fishery in South Africa has changed over time. A combined small pelagic TAC was implemented from 1971 and is recorded as having been the most effective and important means of limiting exploitation. However, although total yield stabilised, this 'stability' masked a highly unstable species composition with catches changing from predominantly large sardine to anchovy of only two age classes. Species specific TACs were introduced from 1983 to encourage diversification, protect the depleted sardine resource and prevent over-exploitation of anchovy. Other small pelagic species were designated 'non-quota' in 1983 again to encourage diversification. Since 1991 the sardine and anchovy directed fisheries have been regulated using an MP approach, which is an adaptive management system that is able to respond rapidly, without increasing risk, to major changes in resource abundance. The first joint anchovy-sardine OMP was implemented in 1994, with subsequent revisions. The OMP formulae are selected with the objectives of maximising average directed sardine and anchovy catches in the medium term, subject to constraints on the extent to which TACs can vary from year to year in order to enhance industrial stability. These formulae are also conditioned on low probabilities that the abundances of these resources drop below agreed threshold levels below which successful future recruitment might be compromised.

A joint anchovy-sardine OMP is needed because sardine and anchovy school together as juveniles, resulting in an unavoidable by-catch of juvenile sardine with the mainly juvenile anchovy catch during the first half of the year. This results in a trade-off between catches of anchovy (and hence juvenile sardine) and future catches of adult sardine, and the OMP aims to ensure some "optimal" utilization of both resources. TACs for both species and a Total Allowable Bycatch (TAB) for sardine bycatch are set at the beginning of the fishing season, based on results from the previous November biomass survey. However, because the anchovy fishery is largely a recruit fishery, the TAC of anchovy and the juvenile sardine bycatch allowance is revised in mid-year following completion of the recruitment survey in May/June.

OMP-14, which was finalised in December 2014, has been used to recommend TACs and TABs for the small pelagic fishery since 2015. A new feature of OMP-14 was the inclusion of a "buffer rule" for the directed sardine TAC that is applied in cases where the sardine biomass estimated during the previous November survey was between 300 000t (below which Exceptional Circumstances would be declared and the TAC decreased rapidly) and 600 000t. This results in a conservative initial directed sardine TAC being recommended at the beginning of the year, below the minimum 90 000t that would apply at higher biomass levels. The initial directed sardine TAC is increased mid-season, depending on the survey estimate of sardine recruitment (Figure 9).

Although development of OMP-14 also included substantial analyses related to the implications of the sardine resource consisting of two components with different spatial distributions rather than a single stock, OMP-14 was still based on an operating model which reflects a single homogeneously distributed sardine stock. At the time of its acceptance, there was however agreement that until such time as a new OMP developed and tested assuming a defensible two sardine component operating model is ready to be implemented, some guidelines for spatial management of the directed sardine catches be developed and implemented. This took the form of a "Gentlemen's agreement" whereby the industry was requested to adhere to restrictions (based on average survey estimates of biomass proportions west and east of Cape Agulhas over the most recent two years) on the maximum amount of the TAC to be caught in the area to the west of Cape Agulhas. The agreed method for calculating the maximum percentage of the directed sardine TAC to be caught west of Cape Agulhas was revised during 2016 so that the recommended maximum catch in this area had a low relative

probability of negatively impacting short-term future recruitment. Industry associations have, however, found it difficult to "manage" this informal agreement in most years.

The implications of the sardine resource consisting of two components with differential exploitation levels, rather than a single "fully mixed" stock, is currently being investigated in the development of a new OMP (OMP-18), which may include the introduction of formal spatial management measures to safeguard the sardine resource, possibly in the form of separate sardine-directed TACs for the areas to the west and east of Cape Agulhas. The sardine assessments conducted assume the population consists of two components, west and east of Cape Agulhas, and estimates the extent of west to south movement of fish of ages 1 and above each year.. This assessment indicates that in terms of recruits-per-spawner, the western component is much more productive than the southern component by about an order of magnitude.

In addition to the directed sardine and anchovy TACs, several bycatch limits and Precautionary Upper Catch Limits are also stipulated. Juvenile sardine and juvenile horse mackerel are both taken as by-catch during anchovy-directed fishing operations and associated Total Allowable Bycatch limits are set. Small-sized sardine landed with the directed sardine catch is also catered for in a small bycatch pool as is the bycatch of adult sardine with round herring. In addition, a fixed Precautionary Upper Catch Limit (PUCL) of 100 000 tons applies for round herring and 50 000 tons for mesopelagic fish species.

Ecosystem considerations in this fishery currently include the experimental closure of areas to fishing around some important seabird (e.g. African penguin and Cape gannet) breeding colonies (islands) in an attempt to assess the impact of localized fishing effort on the breeding success of these birds. A model of penguin dynamics has also been developed for use in conjunction with the small pelagic fish OMP so that the impact on penguins of predicted future pelagic fish trajectories under alternative harvest strategies can be evaluated. These studies have so far indicated that even with large reductions in pelagic catches under an alternative management procedure, there would be little benefit for penguins. Further evaluation of these results under a sardine two-spawning component operating model will be attempted during the development of OMP-18.

Data

The full set of data available as inputs into the sardine (and anchovy) assessments are described in detail elsewhere (MARAM/IWS/DEC16/Sardine/BG4) and hence summarised only briefly here:

1. Commercial Catch Data

   Monthly catch length frequencies are constructed for the sardine landings. From 1987 onwards, these are available by area (east and west of Cape Agulhas).

   Between 1987 and 2011, sardine landings were categorized as either directed (>50% sardine mass in landing) or bycatch by the scale monitor. The bycatch was recorded as being either caught with anchovy or round herring, with the allocation determined by the species which had the highest mass in the landing. From 2012 onwards, the sardine landings have again been categorized as either directed >14cm (>50% sardine mass in

landing) or bycatch by the scale monitor. The bycatch is now recorded as either 'small' (≤14cm) sardine with directed >14cm, or 'small' (≤14cm) bycatch with anchovy or round herring. As fish of a similar size tend to shoal together, the assumption is made for this assessment, that the 'small' sardine bycatch is primarily bycatch from directed anchovy fishing and the time series is comparable with the 1987-2011 time series of sardine bycatch with anchovy. Anchovy is seldom landed with adult sardine and/or round herring. The >14cm sardine bycatch is assumed to be primarily bycatch with round herring and the time series is assumed comparable with the 1987-2011 time series of bycatch with round herring.

The sardine bycatch with anchovy (or 'small, <14cm sardine bycatch) is used separately in the assessment to the directed sardine catch and sardine bycatch with round herring. Quarterly data used in the assessments are taken over the months November y-1 to January y, February to April y, May to July y, and August to October y.

2. Survey biomass estimates and weighted length frequencies

   Time series of total biomass estimates and associated CVs from the acoustic surveys (1984 – 2016) in November each year, corresponding to the standard survey area between Hondeklip Bay and Port Alfred. Length frequencies (scaled to the total biomass) are also available.

   Time series of recruit biomass and associated CVs from the May/June recruit surveys (1985-2017). The average recruit weight is calculated by applying a length-weight regression to the survey weighted length frequency. In the assessments, the recruit numbers are used together with the CVs on recruit biomass.

3. Ageing

   Inconsistencies between age-length keys derived for sardine by various otolith age-readers preclude the use of age data in the assessments.

4. Parasite infection rates

   Time series of infection prevalence of the "tetracotyle" type digenean endoparasite by length as sampled from November surveys between 2010 and 2015. This is the proportion of sardine-by-length that are infected with the parasite. The prevalence for west component sardine is estimated using data from fish collected to the west of Cape Agulhas (20°E), whereas that for south component fish is based on samples collected between 22°E (roughly Mossel Bay) and 30°E (roughly Port St Johns). This is to exclude age-1 individuals in the hypothesized mixing zone (20°-22°E) that may be west component fish. An alternative time series of south coast prevalence based on samples collected between Cape Agulhas and 30°E is used for a model sensitivity test. Alternative information on the intensity of parasite infection, i.e. numbers of parasite per infected fish, is also available.

Stock assessments

The most recent assessments of the South African sardine resource use data available up to November 2015. These are reported elsewhere (e.g., MARAM/IWS/2017/Sardine/BG3) and hence described only briefly here

Two primary hypotheses regarding the sardine spatial structure have been agreed for investigation. The first considers sardine distributed off the west and south coasts of South Africa to form a single homogeneous “stock” (or “population”). The second considers the sardine to consist of a western “component” and southern “component” with some mixing between the two. While there is growing evidence supporting the existence of sub-population structure amongst sardine distributed off the west and south coasts of South Africa, the single stock hypothesis continues to be modelled as it allows for easy comparison to past assessments and, in particular, to past risk statistics and previous Operational Management Procedures. It also reflects a limiting case of the mixing model as the extent of mixing becomes very large.

The same generalised operating model for the South African sardine resource is used for both the single and two mixing-components hypotheses. The single stock hypothesis uses abundance indices and proportion-at-length data for the whole west-south coast combined and excludes the parasite data used to inform mixing between the components in the two mixing-components hypothesis.

The model is age-structured with a plus group of age 5. A distribution of length-at-age is used to model the length-structure of the population at fixed times during the year, and the length-at-age 0 distribution differs by year to allow for variations in the time of peak recruitment (thus being able to accommodate early/late recruitment). Recruitment to each component is dependent on the spawner biomass of that component only (though the equations are generalised to allow for alternative assumptions of south coast spawning contributing to west coast recruitment).

Spawner biomass is calculated assuming a maturity-at-length ogive which changes over time, and using weight-at-length. The trawl survey selectivity-at-length is assumed to be logistic (hence allowing for some escapement of small fish). The estimated component-specific commercial selectivity-at-length curve is described by a logistic distribution at greater lengths. Time-varying commercial selectivity is assumed, with selectivity varying by quarter and between four pre-specified periods (1984-1986, 1987-1997, 1998-2001, 2002-2015).

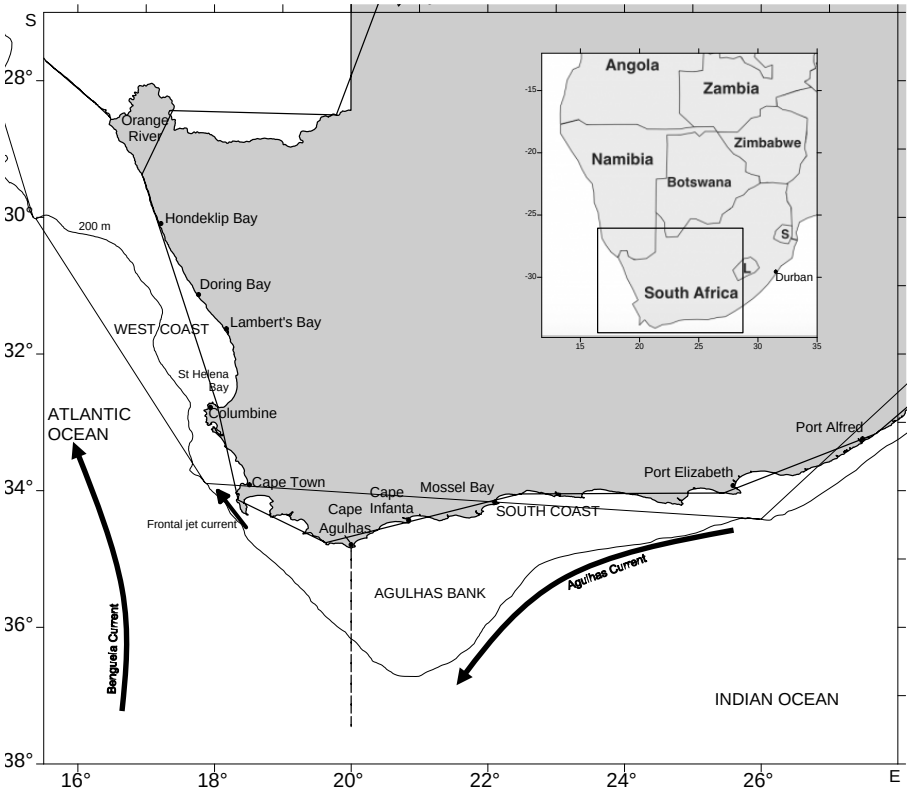

Figure 1: Map of South Africa showing the location of places mentioned in the text, the continental shelf (the 200-m isobath is shown) and the Agulhas and Benguela Currents. The west coast system is defined as extending from Cape Agulhas west and north, and the South coast system as the area east of Cape Agulhas.

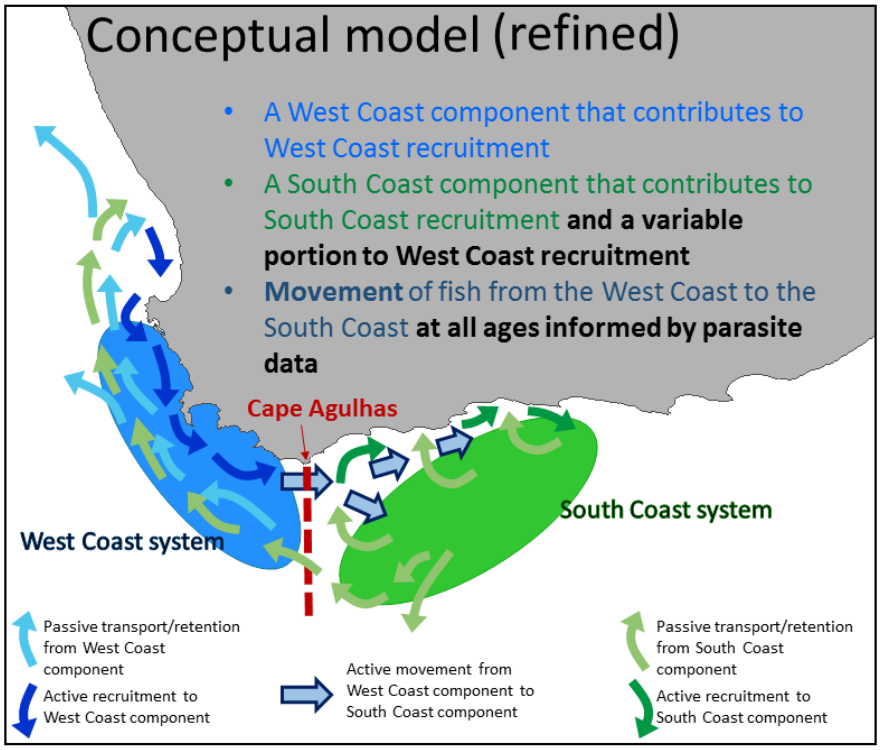

Figure 2: A conceptual model showing spawning grounds (ellipses) and passive (for early life history stages) and active (for recruit and older fish) movement of sardine from and between the hypothesized western and southern components.

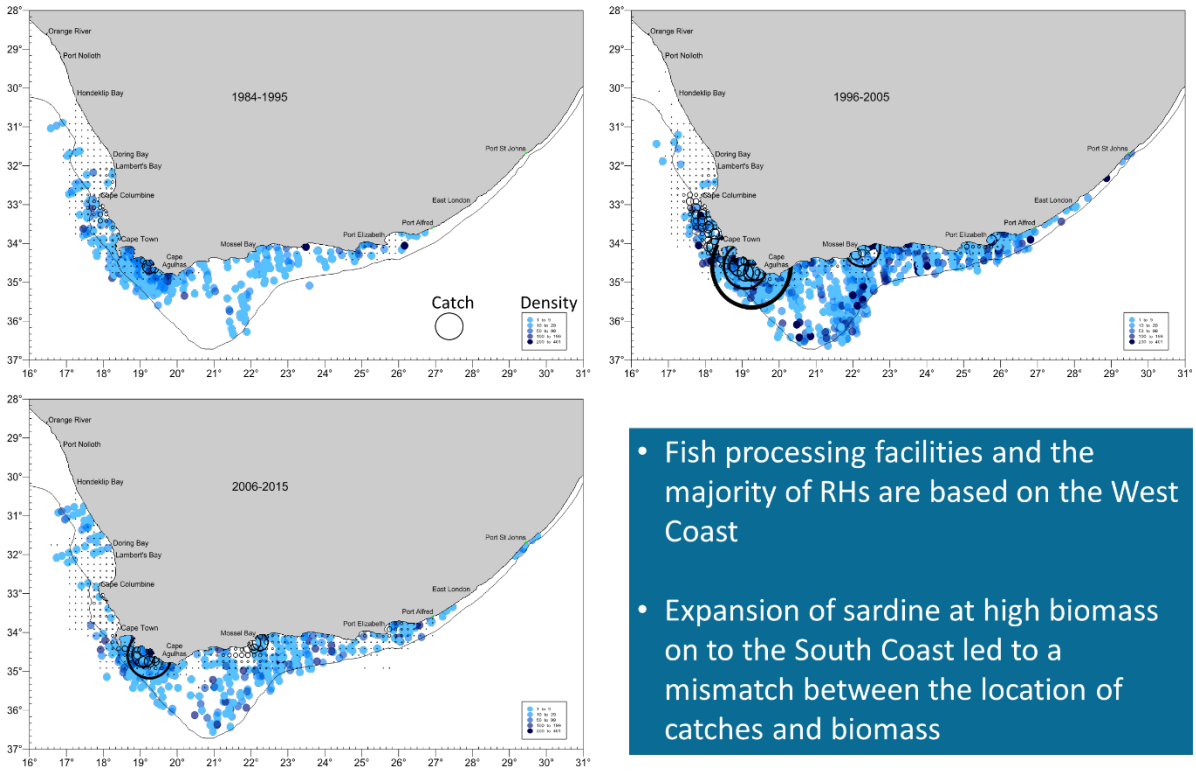

Figure 3. Composite maps of sardine catches (open circles, proportional size) and sardine density from hydro-acoustic surveys (dots) for three 10 year periods.

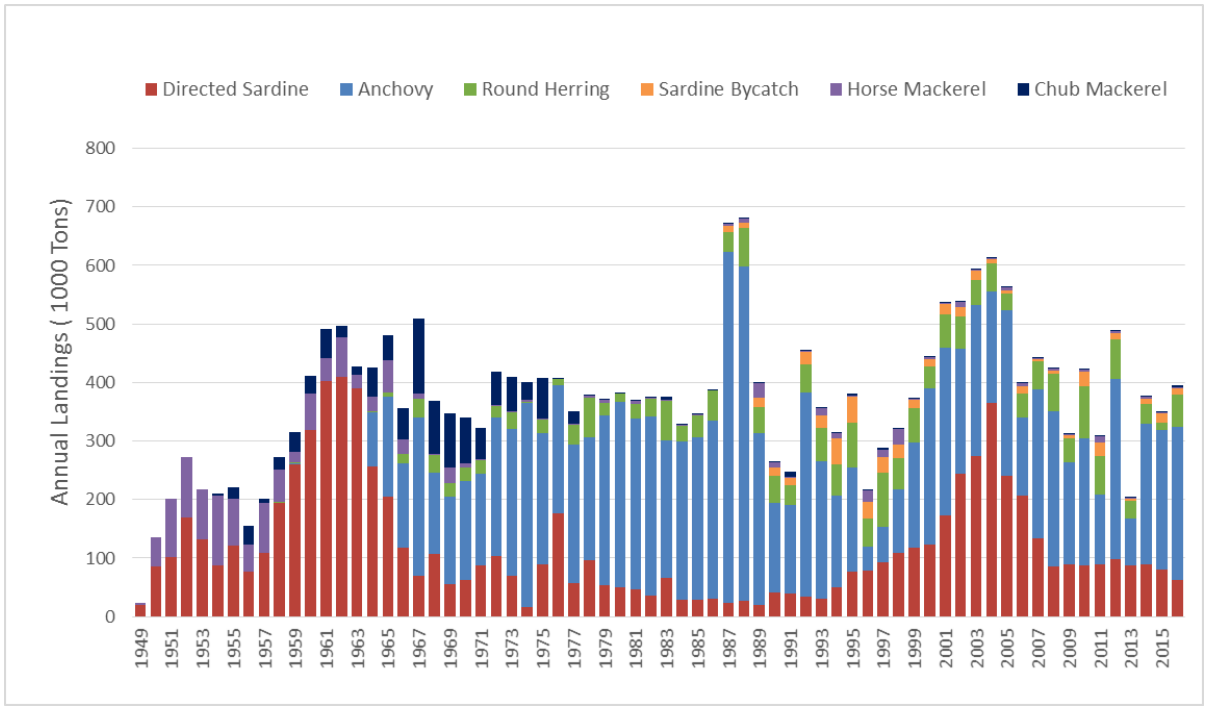

Figure 4: Annual landings of sardine and other small pelagic fish by the South African purse-seine fishery since 1949.

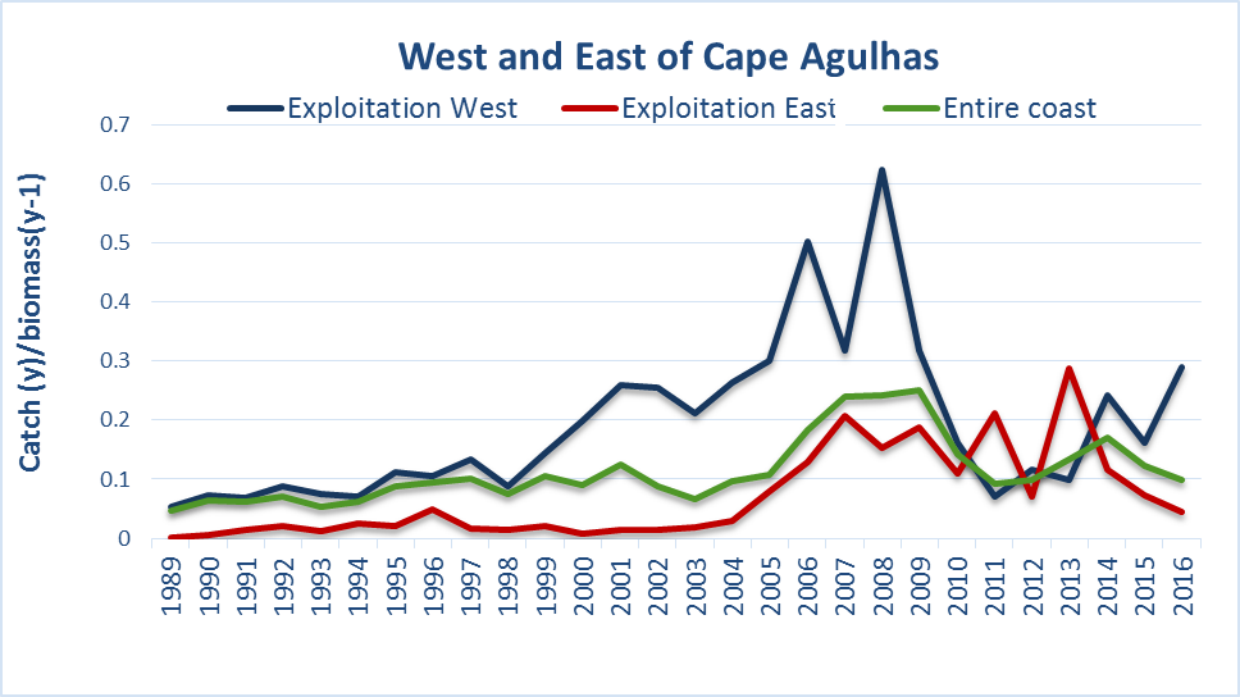

Figure 5. Harvest proportion (catch in current year/model predicted biomass in previous year) for the area to the west of Cape Agulhas, East of Cape Agulhas and for the entire coast.

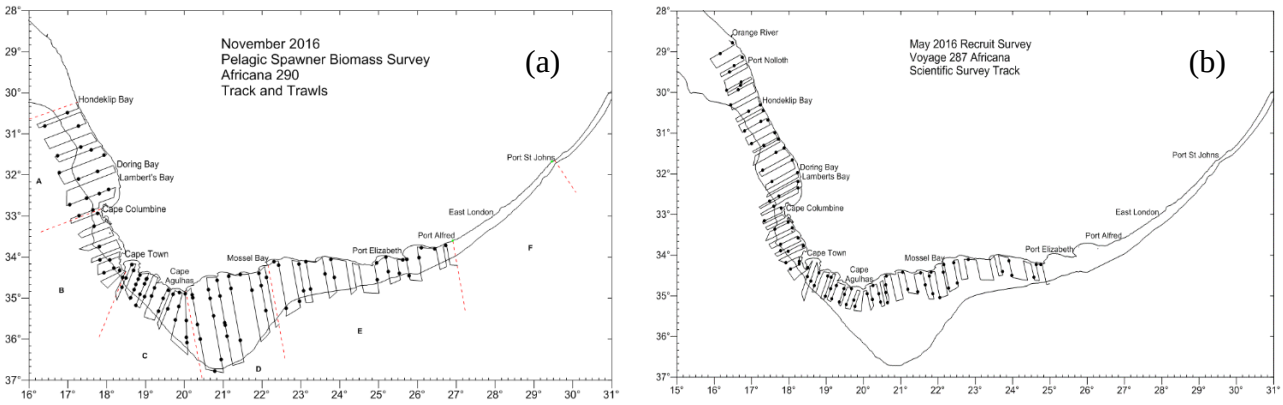

Figure 6: Typical random-stratified hydro-acoustic survey design for summer biomass surveys (a) and winter recruitment surveys (b).

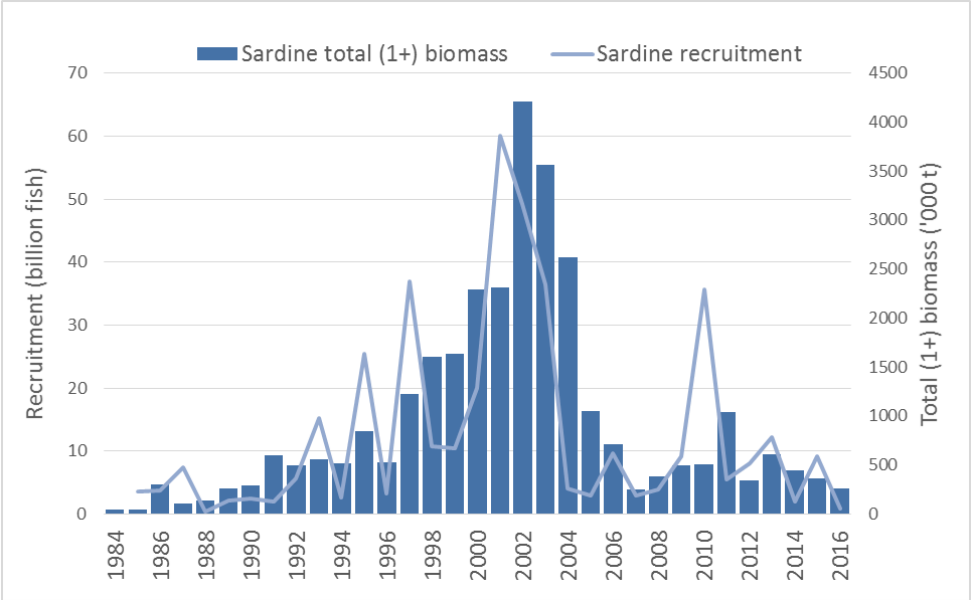

Figure 7: Time-series of acoustic survey estimates of total sardine biomass in October/November (bars) and recruitment in May/June (lines) since the start of the acoustic survey program.

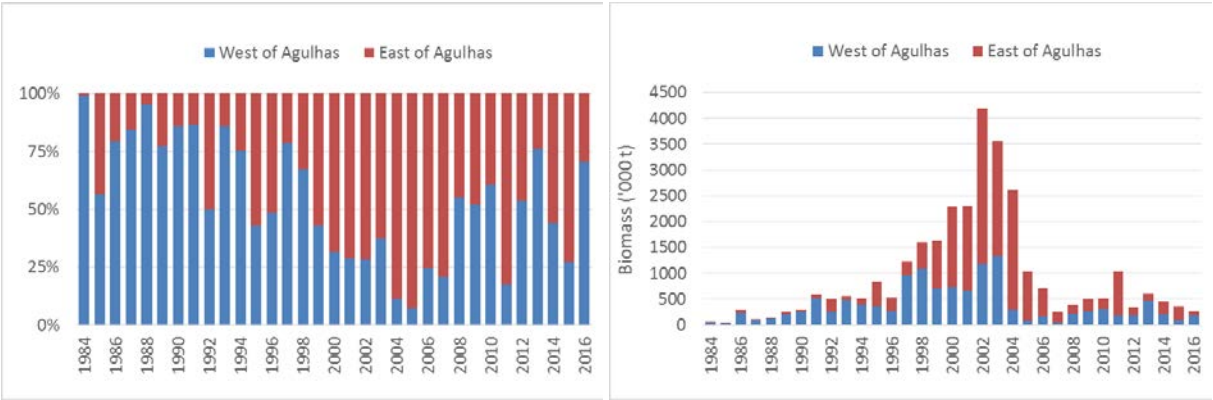

Figure 8: The proportion (left) and biomass (right) of sardine found to the west and east of Cape Agulhas during November acoustic surveys.

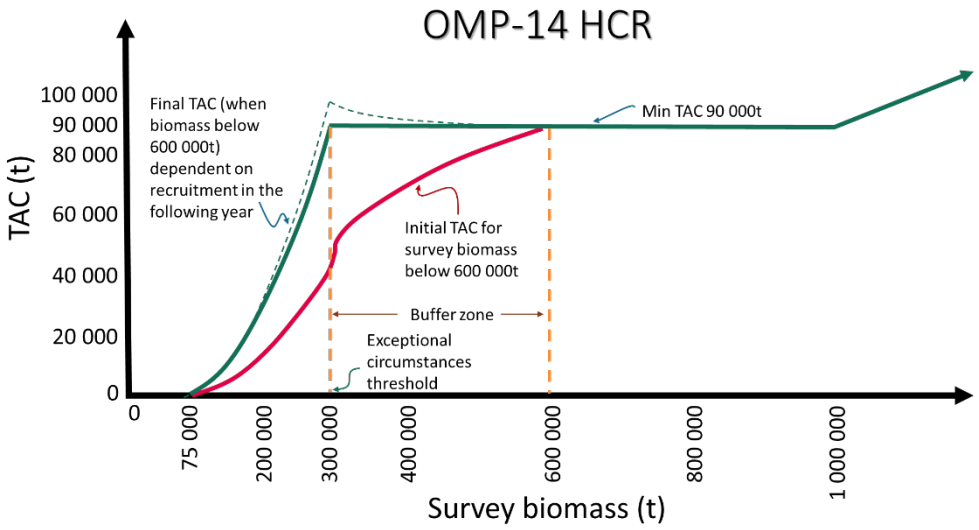

Figure 9: A schematic of the OMP-14 HCR for calculating initial (when survey biomass is less than 600 000t) and final TACs. Note that the final TAC (dotted green line) could be higher than the original calculated TAC (solid green line) if above average recruitment is measured during the subsequent recruit survey.