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 Total Allowable Catches (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 have been high relative to other components, particularly when most of the biomass is located on the south coast. This has necessitated the implementation of a form of spatial management to promote 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 South African sardine 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. While some sardine eggs and larvae resulting from spawning on the South Coast are hypothesised to be transported up the West Coast together with West Coast spawning products (Miller et al. 2006), eddies and currents also retain eggs and larvae inshore of the South Coast (Lett et al. 2006). Whilst a substantial number of sardine recruits have 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 and 9).

Biology and ecology

Sardine generally exhibit schooling behaviour, and are relatively short-lived, fast-growing fish (seldom reaching more than 5 years 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 on the Agulhas Bank. 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.

A prolonged period of low sardine recruitment since 2004, 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 and 65 000t in 2018 (in the 1990s, 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, but a more recent socio-economic study indicated that the industry has developed strategies to cope with fluctuations and reductions in sardine TAC by e.g., increased diversification and importation of frozen cutlets for local canning; Hutchings et al. 2015). Following the declaration of Exceptional Circumstances for sardine in December 2018 after recording a sardine survey biomass estimate which was below the range simulated during the development of OMP-18, the 2019 directed sardine TAC was only 12 250t, with <1000t landed by the end of October 2019.

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, peaking in 2005, the first year in which more sardine were caught east of Cape Agulhas than west of Cape Agulhas (Figure 5). The harvest proportion levels on the western component of the sardine resource have been higher than that on the southern component in most years, sometimes substantially so (Figure 6).

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 (apart from the recruit survey of 2018) 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 TACs 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 7a). 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 7b). 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 recent lows of 258 000 t in 2016 and a thirty-year low of only 91 000t in 2018 (Figure 8).

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 four recent years (2011, 2015, 2017 and 2018) 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 9).

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 a Management Procedure (MP) approach, which is an adaptive management system that is able to respond, 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 were conditioned on low probabilities that the abundances of these resources drop below agreed threshold levels below which successful future recruitment might be compromised. Given the exceptionally low sardine biomass observed in November 2018, the primary and overriding objective for sardine has become to assist the speedy recovery of sardine to a higher biomass level, while still having consideration for the socio-economic implications associated with any recommendation.

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 associated 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, was used to recommend TACs and TABs for the small pelagic fishery from 2015 to 2018. 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 tuned using an operating model which reflected a single homogeneously distributed sardine stock.

OMP-18, which was adopted in December 2018, has, however been developed using an operating model of the sardine resource consisting of two mixing components with differential exploitation levels. The model of two sardine components, assumed to be distributed west and east of Cape Agulhas, 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 (de Moor *et al*. 2017). Simulations using this two-component Operating Model of population dynamics for the sardine resource assume that the proportion of future catches west of Cape Agulhas will mimic that which has been observed in the past with the proportion of directed sardine catch taken west of Cape Agulhas decreasing when the ratio (TAC : west coast biomass) increases (Figure 10).

Further spatial management considerations of OMP-18 include provisions for a 'preventative' red flag and 'penalty' red flag (linked to a 'benefit' green flag). The preventative red flag triggers spatial management (≤40% of the sardine TAC may be taken west of Cape Agulhas) of the directed sardine TAC if the sardine biomass surveyed west of Cape Agulhas is below 100 000t. Penalty red and green flags aim to account for circumstances when catch patterns do not mimic past behaviour and take the form of future TAC decreases/increases for situations in which a the proportion of the catch taken west of Cape Agulhas was appreciably higher/lower than that expected (Figure 10). Formal spatial management was implemented for the first time in 2019, with each sardine Right Holder's West Coast allocation being capped at 43% of the TAC. A schematic representation of OMP-18 is given in Figure 11.

In addition to the directed sardine and anchovy TACs, several bycatch limits and Precautionary Upper Catch Limits (PUCLs) are also stipulated. Juvenile sardine and juvenile horse mackerel are both taken as by-catch during anchovy-directed fishing operations and associated TABs 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 juvenile and adult sardine with round herring and anchovy with sardine (for sardine only Right Holders). In addition, a fixed 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. The benefit of such closure has been demonstrated for some breeding islands but not for others. 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 the sardine TAC there would be little benefit for penguins.

Data

The full set of data available as inputs into the sardine (and anchovy) assessments are described in detail elsewhere (de Moor *et al*. 2019) 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. 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 in November are available from 1984 to 2018, 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, 2019) are also available. 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 from 2010 to 2016 and 2018, are available. 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 but is not currently used in the assessment.

Stock assessments

The assessment of the South African sardine resource which informed the Operating Model used during the development of OMP-18 was conditioned on data available up to November 2015. Following the declaration of Exceptional Circumstances for sardine in 2018, an "initial" assessment of the sardine resource using data from 1984-2018 was conducted to assist in making 2019 sardine catch limit recommendations (MARAM/IWS/2019/Sardine/P1). An updated assessment conditioned on data from 1984-2018 is currently underway (MARAM/IWS/2019/Sardine/P2). The assessments are reported elsewhere (e.g., de Moor *et al*. 2017, de Moor 2019) and hence described only briefly here.

The two-mixing component 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 growth curve 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 estimated independently during conditioning. Any stock-recruitment curves are estimated after conditioning, with recruitment to each component assumed to be dependent on the "effective" spawner biomass of that component only (where the "effective" spawner biomass allows for alternative assumptions of the proportion of south componnet spawning biomass to west component spawning biomass as a proxy for south coast spawning contributing to west coast recruitment (Miller *et al*. 2006)).

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 year (de Moor 2019).

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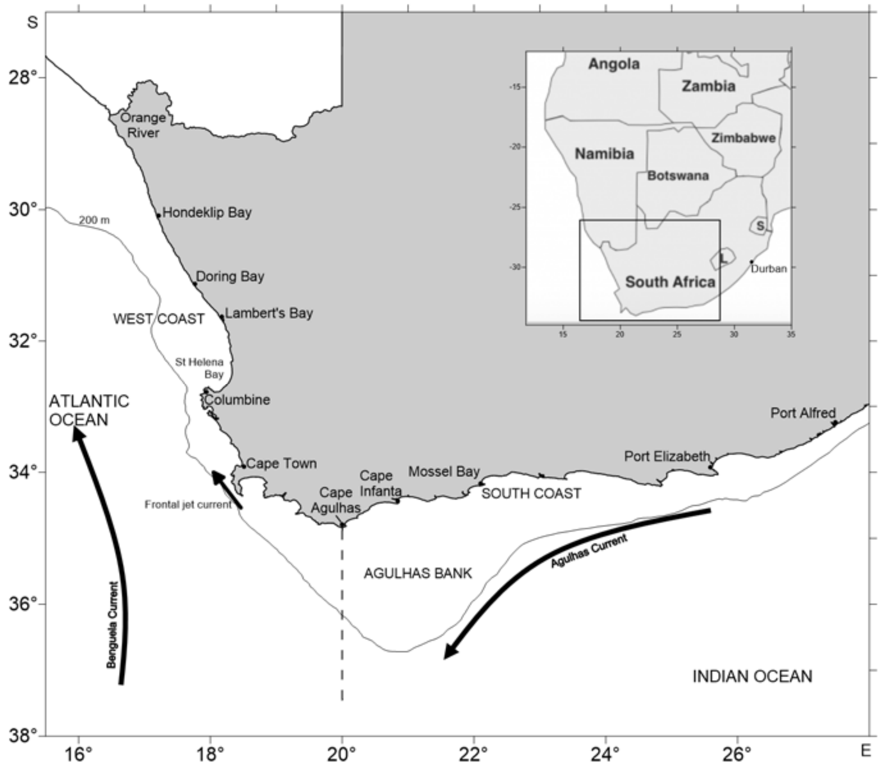

Figure 1: Map of South Africa showing the location of places mentioned in the text, the continental shelf (the 200-m isobath is shown) and the Agulhas and Benguela Currents. The west coast system is defined as extending from Cape Agulhas west and north, and the South coast system as the area east of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

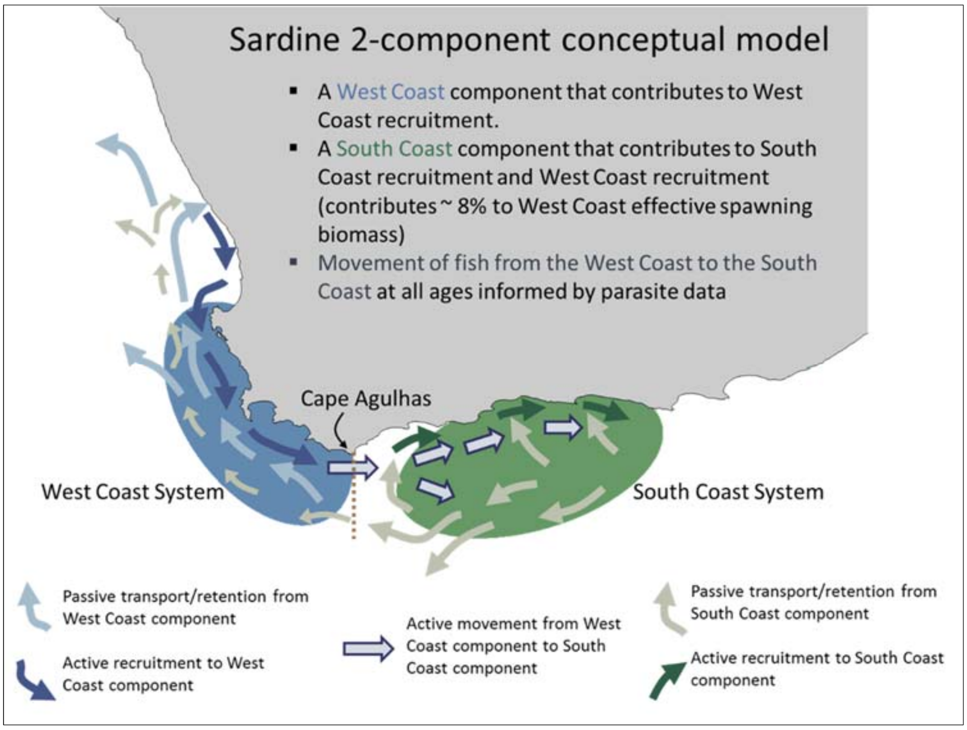

Figure 2: A conceptual model showing spawning grounds (ellipses) and passive (for early life history stages) and active (for recruit and older fish) movement of sardine from and between the hypothesized western and southern components.

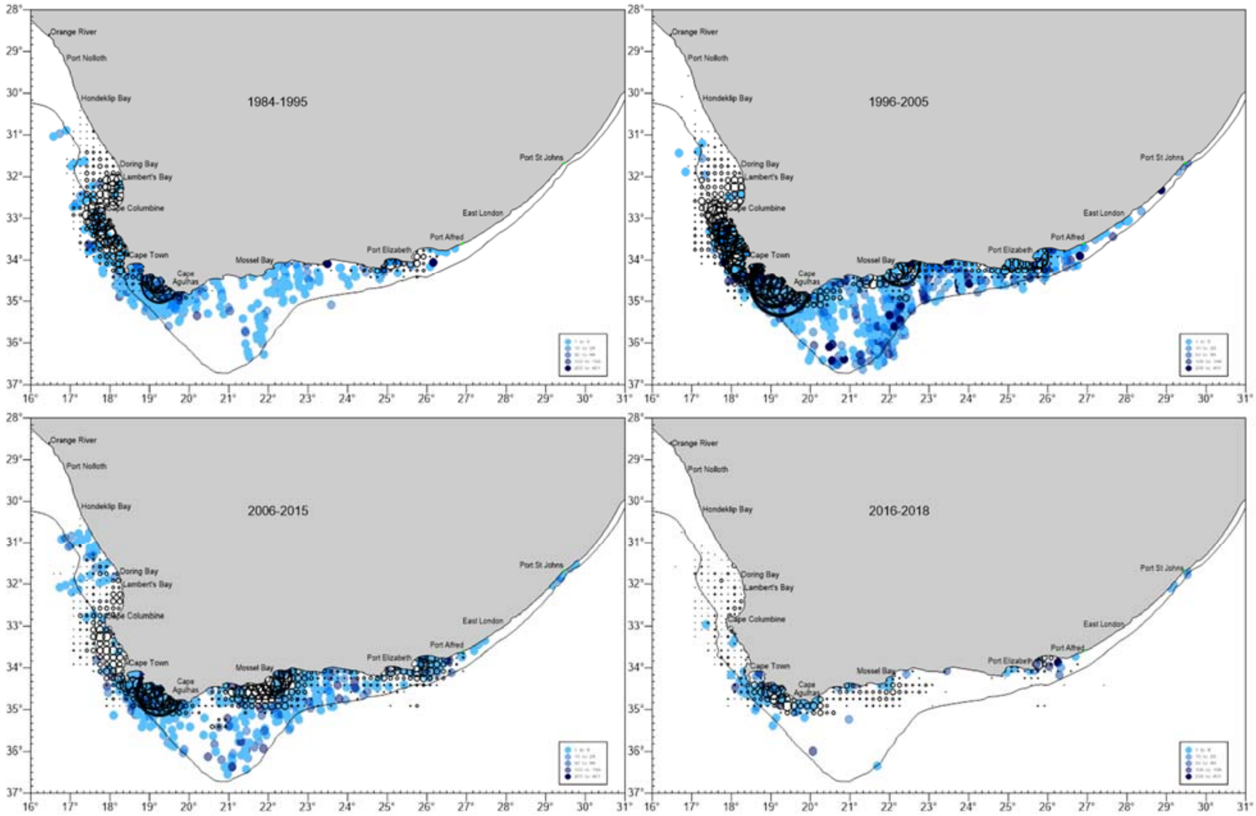

Figure 3. Composite maps of sardine catches (open circles, proportional size) and sardine density from hydro-acoustic surveys (dots) for three 10 year periods and the most recent 3 years.

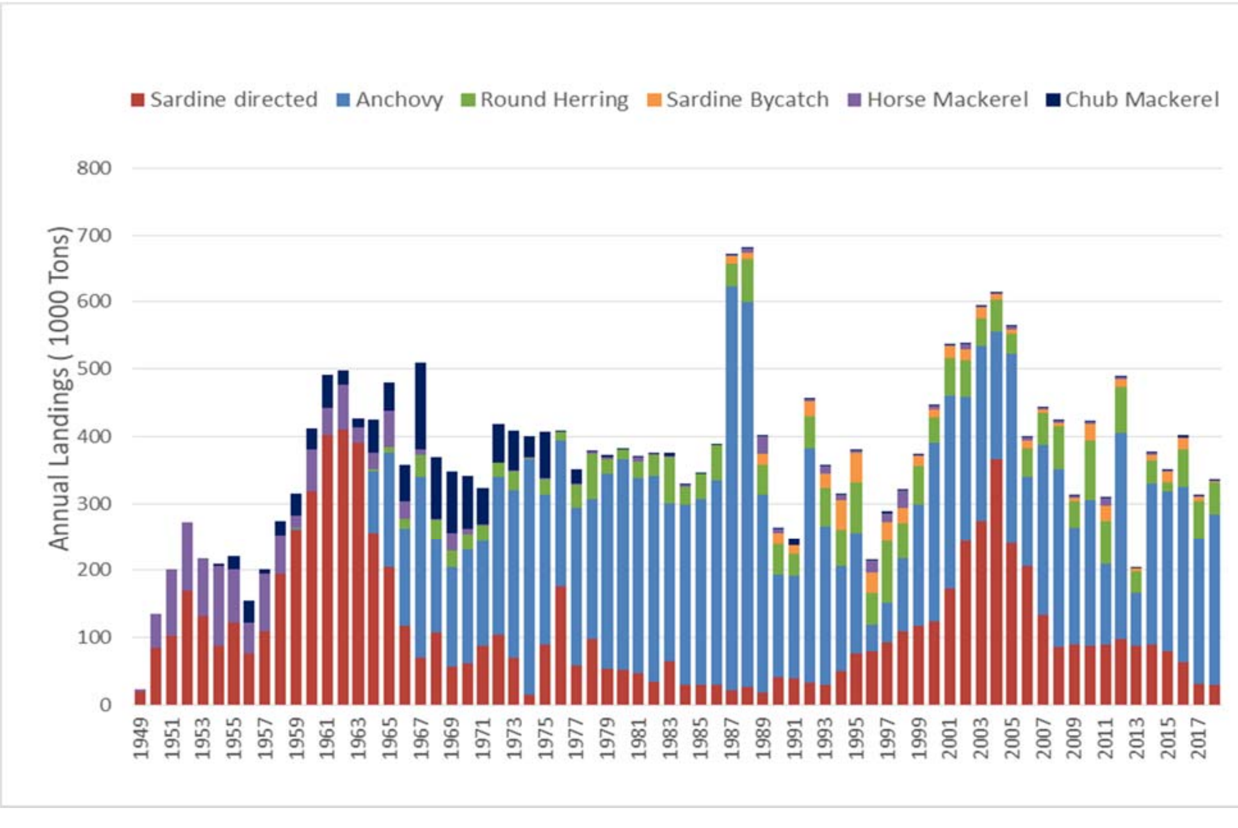

Figure 4: Annual landings of sardine and other small pelagic fish by the South African purse-seine fishery since 1949.

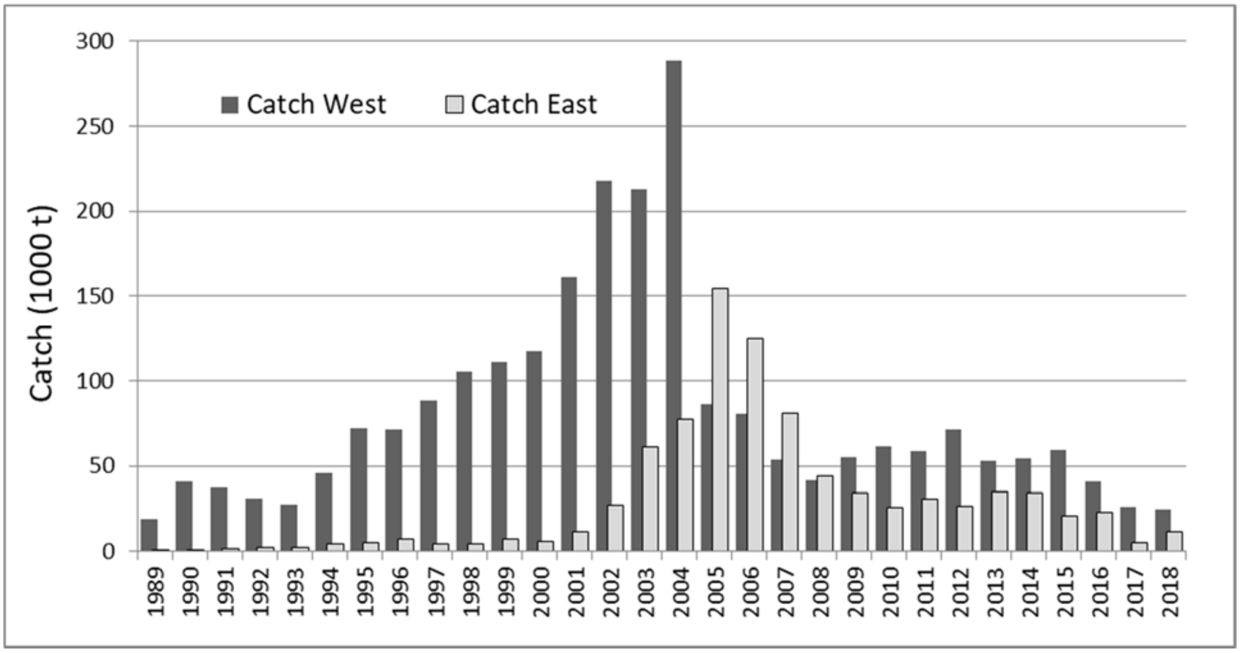

Figure 5. Annual spatially-disaggregated landings of directed sardine by the South African purse-seine fishery.

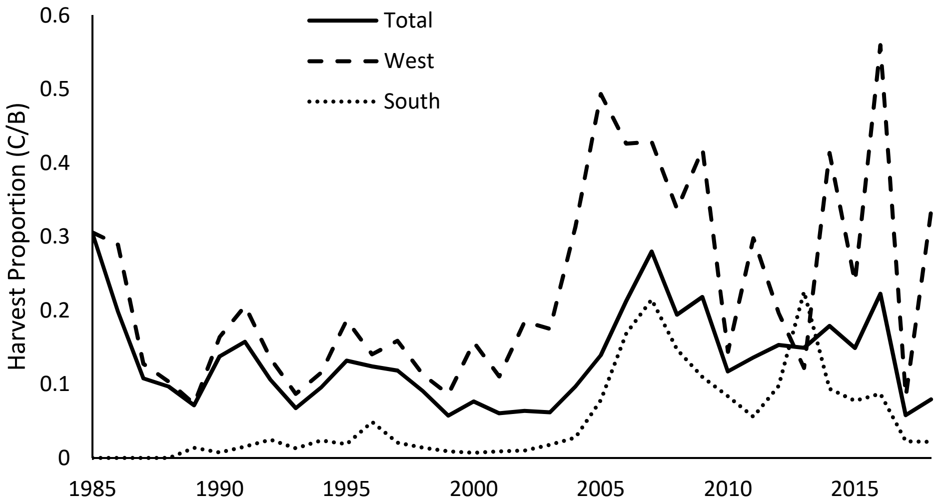

Figure 6. Harvest proportion (catch in current year/model predicted biomass in previous year) for the area to the west of Cape Agulhas, East of Cape Agulhas and for the entire coast.

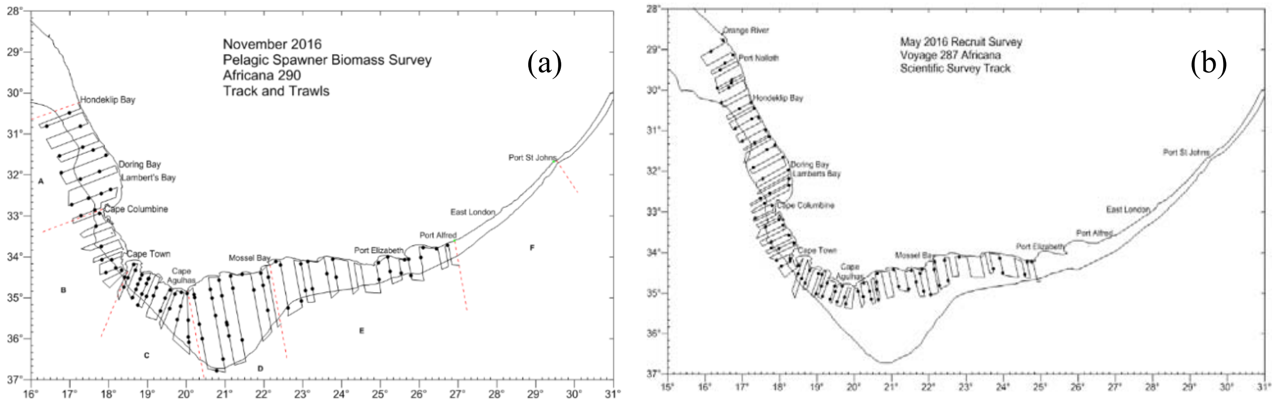

Figure 7: Typical random-stratified hydro-acoustic survey design for summer biomass surveys (a) and winter recruitment surveys (b).

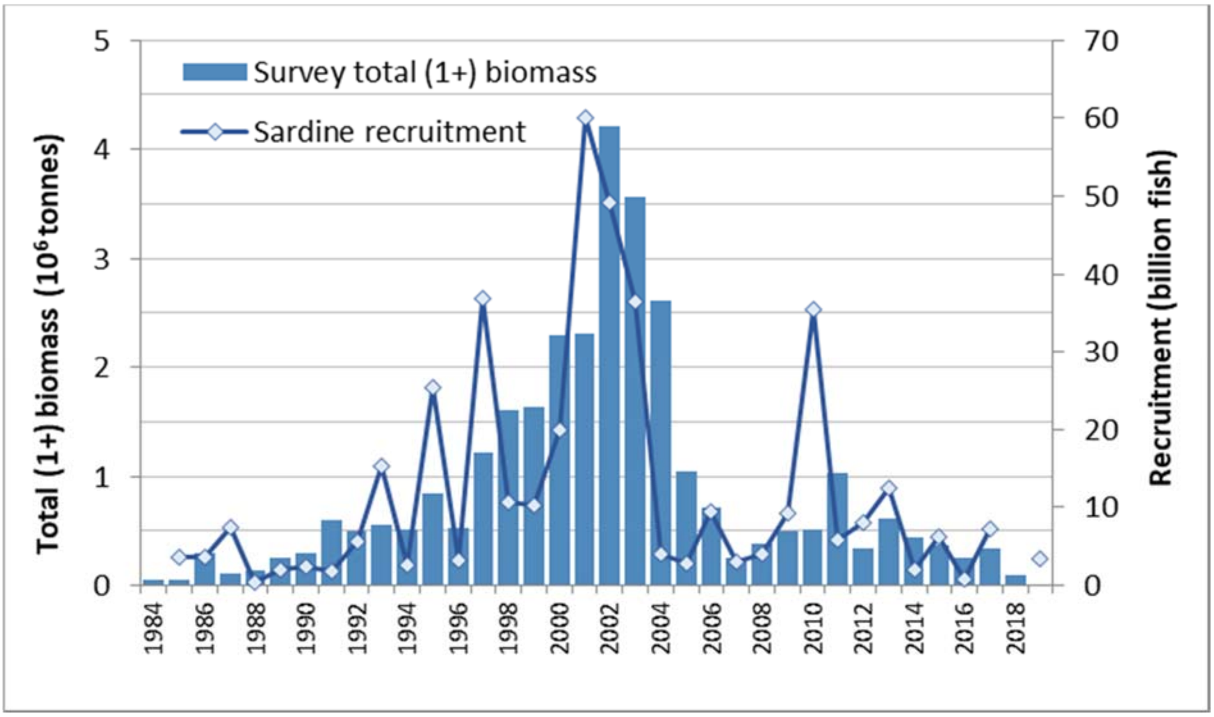

Figure 8: Time-series of acoustic survey estimates of total sardine biomass in October/November (bars) and recruitment in May/June (lines) since the start of the acoustic survey program.

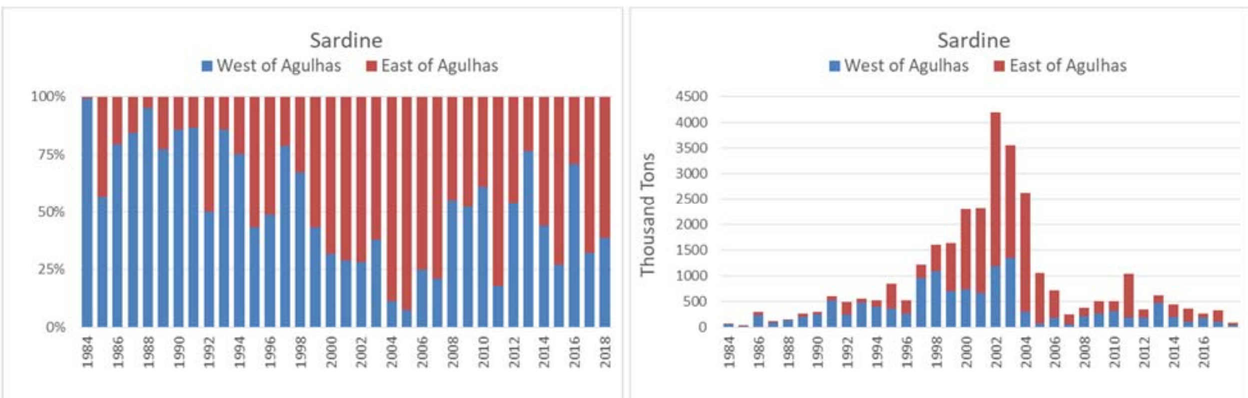

Figure 9: The proportion (left) and biomass (right) of sardine found to the west and east of Cape Agulhas during November acoustic surveys.

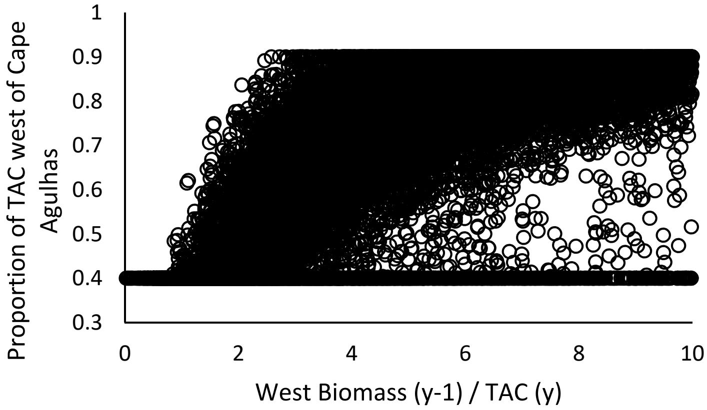

Figure 10: The future generated proportion of directed sardine TAC taken west of Cape Agulhas in year y plotted against the ratio of the west coast biomass in November (y-1) : TAC(y) for the 1000 simulations of OMP-18 on the baseline Operating Model.

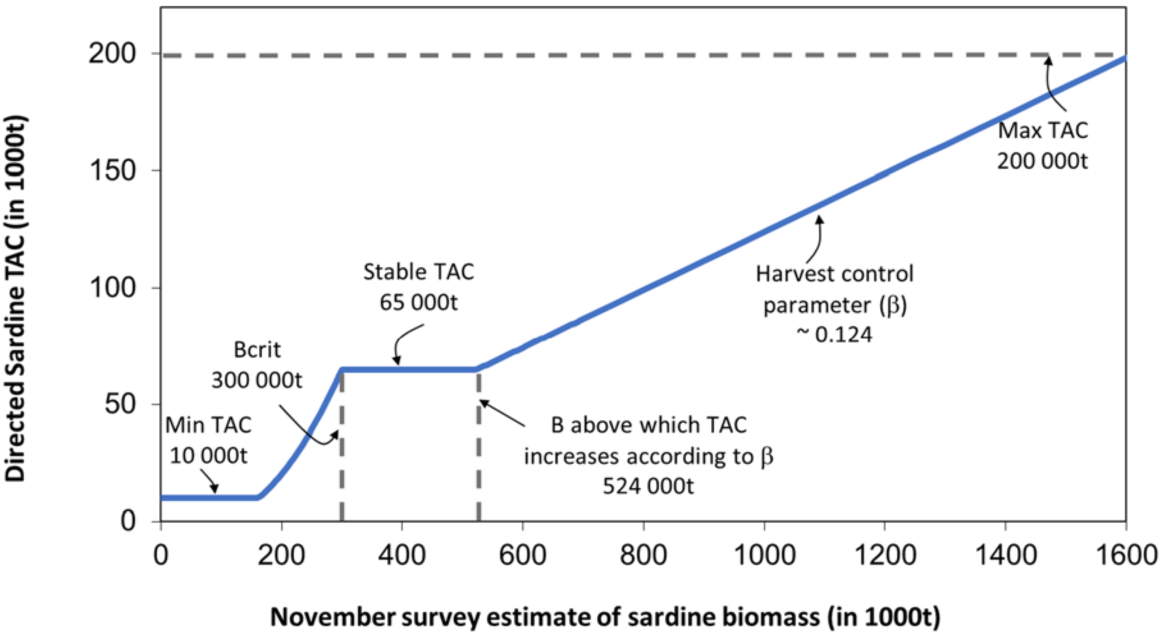

Figure 11: A schematic of OMP-18 sardine HCR. Changes from OMP-14 include a higher catch control parameter (up from 0.087 to 0.124) lower maximum TAC (down from 500 000t to 200 000t), a decreased stable TAC (65 000t down from 90 000t) and the introduction of an absolute minimum TAC at 10 000t.