STATUS OF THE SOUTH AFRICAN MARINE FISHERY RESOURCES

2020

environment, forestry & fisheries

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Acronyms and abbreviations

ASPM	Age-structured production model
CAL	Catch-at-length
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CL	Carapace length
CoG	Centre of gravity
CPUE	Catch per unit effort
DEFF	Department of Environment, Forestry & Fisheries
EC	Exceptional circumstances
EEZ	Exclusive economic zone
EFZ	Exclusive fishing zone
FIAS	Fishery-independent abalone survey
FIMS	Fishery-independent monitoring survey
F_{MSY}	Fishing mortality that would produce MSY level
GERMON	Genetic structure and migration of albacore tuna project
GIS	Geographic information system
GLM	General linear model
GLMM	General linear mixed model
GSI	Gonadosomatic index
ICCAT	International Convention for the Conservation of Atlantic Tunas
ICSEAF	International Commission for the South East Atlantic Fisheries
IFREMER DIO	French Research Institute for Exploration of the Sea, Indian Ocean Delegation
IOTC	Indian Ocean Tuna Commission
IUCN	International Union for Conservation of Nature
IUU	Illegal, unreported and unregulated fishing
KZN	KwaZulu-Natal
LMP	Linefish management protocol
MLRA	Marine Living Resources Act
MLS	Minimum legal size
MPA	Marine protected area
MSY	Maximum sustainable yield
NMLS	National marine linefish system
NPOA	National plan of action
NRCS	National Regulator for Compulsory Standards
OMP	Operational management procedure
ORI	Oceanographic Research Institute
PEI-EEZ	Prince Edward Island exclusive economic zone
PMCL	Precautionary management catch limit
PSAT	Pop-up satellite archival tag
PUCL	Precautionary upper catch limit
RFMO	Regional fisheries management organization
SB	Shell breadth
SPOT	Smart position-only tag
SSB	Spawning stock biomass
SSB_{MSY}	Spawning stock biomass at MSY level
SWIO	Southwest Indian Ocean
SWIOFP	Southwest Indian Ocean Fisheries Programme
TAB	Total allowable bycatch
TAC	Total allowable catch
TAE	Total allowable effort
TRAFFIC	The Wildlife Trade Monitoring Network
TURF	Territorial user Rights in fisheries
USA	United States of America
WWF	World Wide Fund for Nature




Overview

This report presents the most up-to-date information and analyses of the status of marine fishery resources in South Africa at the time of compilation. The number of fish stocks covered has increased steadily from 43 in 2012 to 61 in the current report (Figure I). Among the species included for the first time are a number of linefish species (black musselcracker, dageraad, Roman and white stumpnose), five species of skate (which replace the generic 'skate' in the 2016 report), octopus and East Coast round herring and two species of shark (oceanic whitetip and great hammerhead). Species included in the 2016 report but excluded from this one include some other linefish species (elf and white steenbras) and requiem sharks.

The latest assessments indicate that 61% of stocks are considered not to be of concern (blue and green categories)[1] , while 39% of stocks are of concern (orange and red categories). These figures indicate an improvement over the past eight years, with 46% of stocks considered not to be of concern in 2012, 49% in 2014 and 52% in 2016 (Table I).

Table I: Number and percentage of stocks considered of concern or not

	2012	2014	2016	2020
Stocks not of concern	20 (46%)	22 (49%)	27 (52%)	37 (61%)
Stocks of concern	23 (54%)	23 (51%)	25 (48%)	24 (39%)
Number of stocks assessed per year	**43**	**45**	**52**	**61**

There are some changes to the perception[2] of certain fish stocks since the previous report in 2016. The number of stocks for which the status and fishing pressure (Figure II) are unknown increased from two to seven. The number of stocks considered under-utilised has increased from five in 2016 to nine in 2020.

The number of stocks that are considered to be in an optimal state has increased from 15 in 2012 to 21 in 2020. The small net increase in 2020, compared to the 20 recorded in the 2016 report, is the result of five stocks moving into this category (two from unknown status, one from under-utilised and two from 'of concern') and three moving out of it (two to under-utilised status and one to 'of concern').

The number of stocks that are considered to be of concern has decreased from 10 in 2014 and 2016 to nine in 2020. The number of stocks considered to be over-exploited has remained at 15. This is the net result of the inclusion of new resources in this assessment since 2016 (dageraad, oceanic whitetip shark and great hammerhead shark), the exclusion of two resources included in the 2016 report (elf and white steenbras), the decline in status of one resource (shortfin mako sharks) and the improvement of status for Atlantic yellowfin tuna and silver kob.

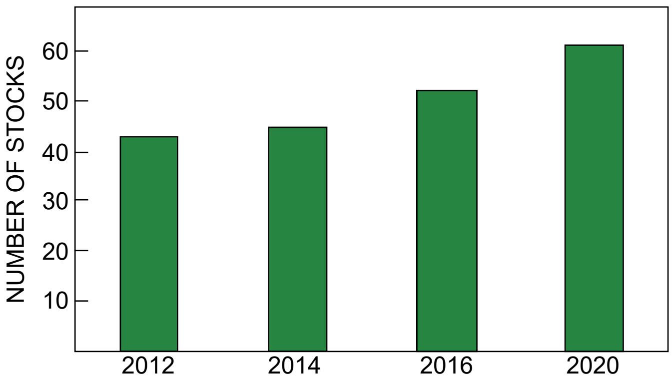


Figure I: The number of fish stocks assessed between 2012 and 2020

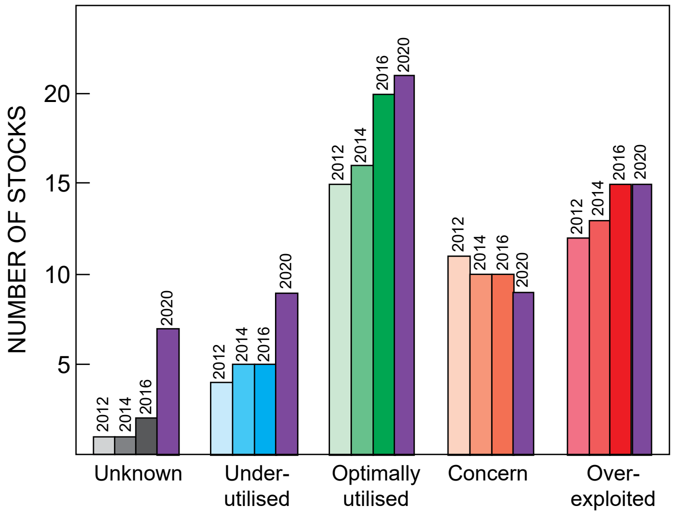


Figure II: Number of fish stocks according to status from 2012–2020

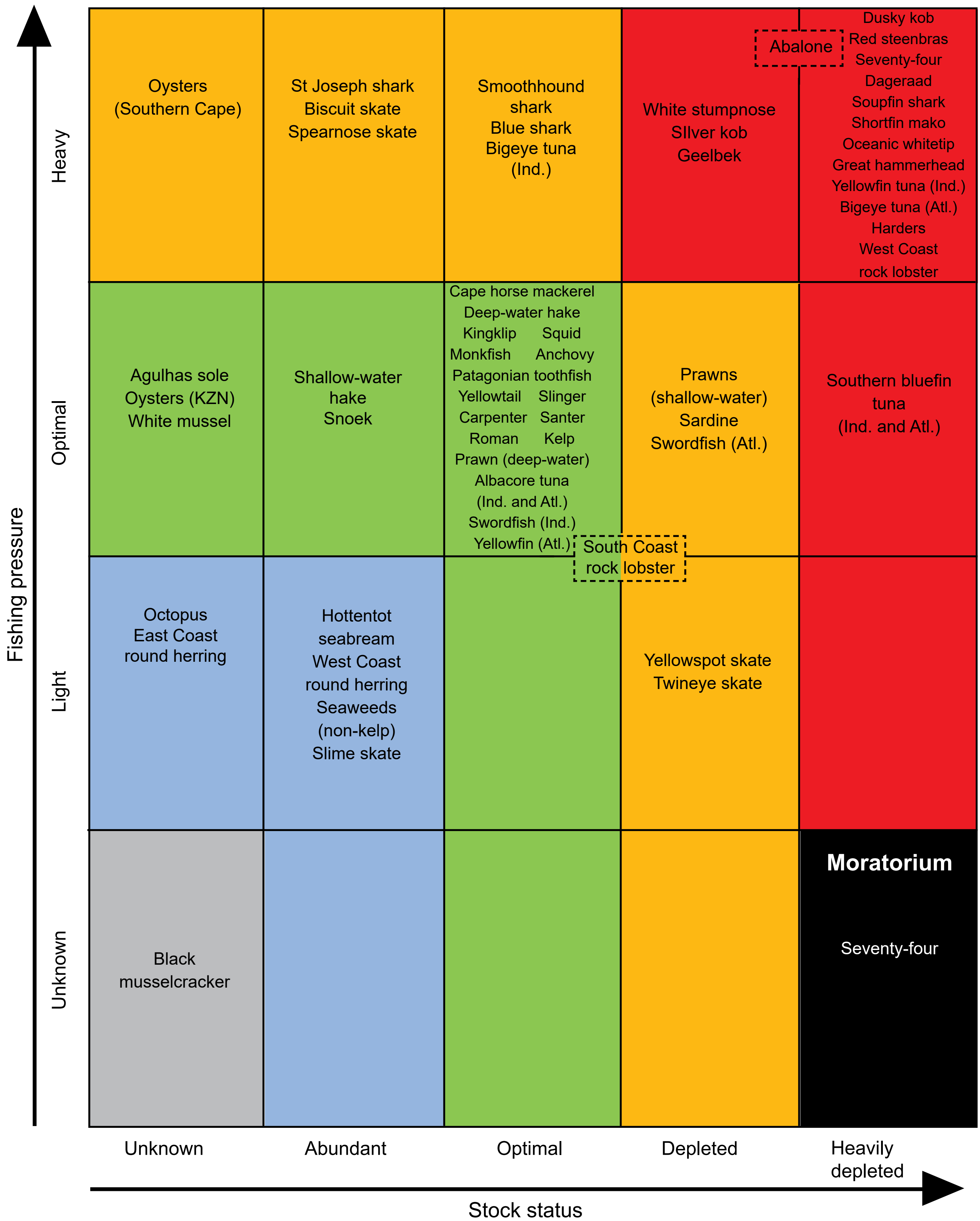
The following is a brief summary for each resource:

- **Abalone:** The status of the abalone resource continues to decline in response to extremely high levels of illegal harvesting and over-allocation of Total Allowable Catches (TACs).
- **Agulhas sole:** Uncertainty still remains regarding the true status of the Agulhas sole stocks. However, recent assessments took account of the increase in CPUE that was observed during 2017, and the results suggested a slightly more optimistic perception of resource status than had been the case in the 2016 report.
- **Cape hakes:** Recent updated assessments indicate that the deep-water hake resource was appreciably above the biomass level at which maximum sustainable yield (MSY) is obtained (B_{MSY}) from 2010 onwards. While this improvement in the perception of the resource could be partially attributed to the rebuilding strategy inherent in recent operational management procedures (OMPs), the

[1]For this summary appraisal, where a particular resource falls across two categories of stock status or pressure, precaution was applied and the resource has thus been assigned to the 'worst case scenario'.
[2]Perceptions of stock status may change with improvements in the information available for that stock. Thus either deteriorations or improvements in the perception of status may not necessarily be indicative of actual changes in the stock status.

improvements to the assessment methodology and input data have had a major influence. Shallow-water hake remains well above the estimated MSY level.

- **Cape horse mackerel:** The most recent assessments for Cape horse mackerel indicate that the estimates of current spawning biomass are well above those that yield MSY.
- **KIngklip:** Recent research suggests that there are genetically separate stocks on the West and South coasts, but with some degree of gene flow between the two components. Recent assessment results suggest that the South Coast component of the resource is decreasing in abundance at about 0.8% per annum, whereas the West Coast component is increasing at about 2.4% per annum. The precautionary upper catch limit (PUCL) for this resource has remained stable in recent years.
- **Linefish:** Stocks of hottentot seabream, snoek, carpenter, santer, slinger, Roman and yellowtail are considered to be in good condition and are not over-fished. Silver kob, geelbeck and white stumpnose are considered depleted and continue to be over-fished. Collapsed resources, such as seventy-four, red steenbras, dageraad and dusky kob, require stronger intervention in order to rebuild stocks.
- **Monkfish:** Recent assessment indicates that while the resource has shown marginal increases on the West Coast, the increase is not as apparent as in previous years. The South Coast component of the resource appears to remain stable.
- **Netfish:** Harders, the main target of the beach-seine and gillnet fisheries, remain in a depleted state as a result of overfishing, illegal harvesting and adverse environmental conditions which disrupt breeding cycles.
- **Oysters:** The oyster resource along the KwaZulu-Natal coast is considered to be optimally exploited, although uncertainty remains around the actual stock status. Similar uncertainty also remains regarding the status of oysters in the Southern Cape. Their level of exploitation, considered to be heavy, together with illegal harvesting from subtidal "mother beds", remain causes for concern.
- **Patagonian toothfish:** Recent assessment of the Patagonian toothfish resources indicate that uncertainties still remain around the true status of the resource, largely due to the difficulties of accounting for the removal of fish from longlines by predatory marine mammals in the catch-per-unit-effort (CPUE) index.
- **Prawns:** Deep-water prawns are considered to be optimally exploited. The status of shallow-water prawns, however, is considered to be depleted, largely due to the closure of the mouth of the St Lucia Estuary blocking the recruitment of shallow-water prawns to the Thukela Bank
- **Seaweeds:** Kelp resources are considered optimally exploited and stable in most areas, although some areas offer the opportunity for greater harvesting. Other seaweed resources generally also offer opportunities for increased harvesting.
- **Sharks:** Recent assessments indicate that slime skate, spearnose skate, biscuit skate and St Joseph are abundant, blue and smoothhound sharks are at optimal status, whereas yellowspot and twineye skates are depleted. Oceanic whitetip, great hammerhead, soupfin and shortfin mako sharks are considered heavily depleted.
- **Small invertebrates and new fisheries:** The status of white mussel remains unknown. Potential new fisheries currently under investigation include octopus and redeye round herring in KwaZulu-Natal.
- **Small pelagic fishes:** Small pelagic fishes are characterised by high levels of natural variability. Recent assessments indicate that sardine stocks are depleted, anchovy are considered at optimal status and West Coast round herring are considered abundant.
- **South Coast rock lobster:** The South Coast rock lobster resource is considered to be in an optimal to depleted state. In order to ensure rebuilding of the stock, fishing pressure on this resource is being maintained at light to optimal levels.
- **Squid:** The most recent assessment indicates a more positive outlook of resource status than did the 2016 assessment. The squid resource is currently estimated to be at around 41% of its pre-fished level. Fishing effort has been adjusted to be appropriate to this new perception of the resource.
- **Tunas and swordfish:** Stock assessments and country allocations for tunas and swordfish are the responsibility of the relevant regional fisheries management organisations (RFMOs). The statuses of swordfish (Atlantic Ocean), southern bluefin tuna (Indian and Atlantic oceans), yellowfin tuna (Indian Ocean) and Atlantic bigeye tuna are of concern.
- **West Coast rock lobster:** The West Coast rock lobster resource remains heavily depleted, with stocks currently being at only 1.8% of pre-fished levels. There is continued concern regarding the levels of illegal harvesting of the resource.



Fishing pressure
Heavy
Optimal
Light
Unknown
Oysters (Southern Cape)
St Joseph shark
Biscuit skate
Spearnose skate
Smoothhound shark
Blue shark
Bigeye tuna (Ind.)
White stumpnose
SIlver kob
Geelbek
Abalone
Dusky kob
Red steenbras
Seventy-four
Dageraad
Soupfin shark
Shortfin mako
Oceanic whitetip
Great hammerhead
Yellowfin tuna (Ind.)
Bigeye tuna (Atl.)
Harders
West Coast rock lobster
Agulhas sole
Oysters (KZN)
White mussel
Shallow-water hake
Snoek
Cape horse mackerel
Deep-water hake
Kingklip
Squid
Monkfish
Anchovy
Patagonian toothfish
Yellowtail
Slinger
Carpenter
Santer
Roman
Kelp
Prawn (deep-water)
Albacore tuna (Ind. and Atl.)
Swordfish (Ind.)
Yellowfin (Atl.)
South Coast rock lobster
Prawns (shallow-water)
Sardine
Swordfish (Atl.)
Southern bluefin tuna (Ind. and Atl.)
Octopus
East Coast round herring
Hottentot seabream
West Coast round herring
Seaweeds (non-kelp)
Slime skate
Yellowspot skate
Twineye skate
Black musselcracker
Moratorium
Seventy-four
Unknown
Abundant
Optimal
Depleted
Heavily depleted
Stock status

About the report

The purpose of this report is to make available information related to the current status of South Africa's major exploited marine fishery resources, and largely reflects the work of the Fisheries Research and Development Chief Directorate up to and including 2019.

A quick-view assessment appears at the beginning of each section, is colour-coded for ease of reference, and provides an indication of stock status and fishing pressure. The first line indicates the present status of the resource, which is the result of different pressures, such as fishing and environmental fluctuations, and past management practices. The second measure indicates the present level of fishing pressure exerted on that resource. The aim of sustainable management is to have resources that are in an optimal state and that are fished at optimal levels. However, historical overfishing may have reduced some stocks to depleted or heavily depleted levels, and rebuilding these stocks could be attempted by reducing fishing pressure. Such rebuilding can take several years or even decades as the rate of recovery is dependent both on the biology of the species concerned and on natural recruitment fluctuations. Additionally, short-lived species (e.g. anchovy and squid) typically show high levels of recruitment variability that can result in substantial inter-annual fluctuations in population size; these could lead to the status of that resource changing from being depleted in one year to being optimal in the next. Five categories are defined for stock status, ranging from 'Abundant' though to 'Heavily depleted', and including an 'Unknown' category for which there are insufficient or conflicting data to enable an accurate estimate to be made. Four categories of fishing pressure are defined, from 'Light' though 'Optimal' to 'Heavy', and again including an 'Unknown' category for data-poor resources. The definitions used to assign a resource to a status or category and fishing to a pressure category are given in the following tables:

Stock status

Category	Abundant	Optimal	Depleted	Heavily depleted	Unknown
Definition	$B > B_{MSY}$	$B \approx B_{MSY}$	$B < B_{MSY}$	$B << B_{MSY}$	B = ?

where B is the present biomass level (or population size) and B_{MSY} is that biomass level at which maximum sustainable yield (MSY) is obtained.

Fishing pressure

Category	Light	Optimal	Heavy	Unknown
Definition	$F < F_{MSY}$	$F \approx F_{MSY}$	$F > F_{MSY}$	F = ?

where F is the present fishing pressure and F_{MSY} is that fishing pressure level at which MSY is obtained.

For some, but not all, multiple-species fisheries, both the status and pressure measures are given per species. In some cases the stock status and/or fishing pressure may vary around South Africa's coastline, which is indicated using multiple categories. Furthermore, available information may not unambiguously indicate the appropriate category for a resource, and this is also indicated by using multiple categories

Abalone

Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	**Unknown**	**Light**	**Optimal**	**Heavy**	

Introduction

Abalone *Haliotis midae*, locally called 'perlemoen', is a large marine snail that is a highly prized seafood delicacy in the Far East. Abalone are slow-growing, reaching sexual maturity at around seven years of age, and take approximately 8-9 years to reach the minimum legal size of 11.4 cm SB. They reach a maximum size of 18 cm SB, and are believed to live to an age of greater than 30 years. They occur in shallow waters less than 20 m depth, but the highest densities occur in waters less than 5 m depth.

Abalone are widely distributed around the South African coastline, from St Helena Bay on the West Coast to just north of Port St Johns on the East Coast. Historically, the resource was most abundant in the region between Cape Columbine and Quoin Point and supported a commercial fishery for about 65 years. Along the East Coast, the resource was considered to be discontinuous and sparsely distributed and as a result no commercial fishery for abalone was implemented there. However, experimental and subsistence permits were allocated along the East Coast at various times in the past. The recreational sector also caught abalone for many years, but due to illegal fishing and the decline in the resource, this component of the fishery was suspended in 2003/2004.

Once a lucrative commercial fishery, earning up to approximately R100 million annually at the turn of the Century, rampant illegal harvesting and continued declines in the abundance of the resource resulted in a total closure of the fishery in

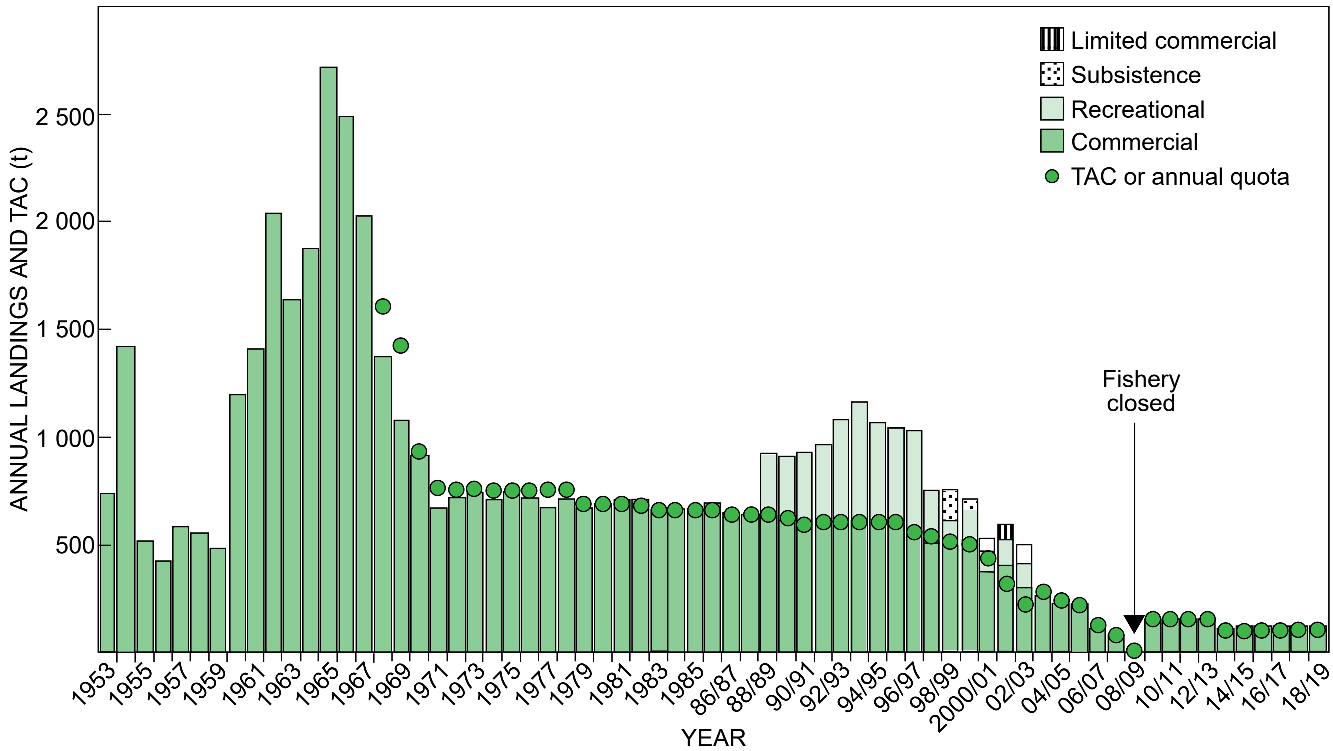


Figure 1: TAC and recorded (legal) annual landings for the abalone fishery from 1953 to 2018/19. Landings for the recreational sector are only available since 1988/1989. Note that the substantial illegal catches are not shown

Figure 2: Abalone fishing Zones A to G, including sub-zones, and distribution of abalone, *H. midae* (inset). The experimental fisheries (2010/11–2013/14) on the western and eastern sides of False Bay and in the Eastern Cape are also shown. These areas within False Bay, included in the commercial fishery recommendations for 2017/18, are referred to as Sub-zone E3 and Sub-zone D3

February 2008. The resource has also been heavily impacted by an ecosystem shift that was brought about by the migration of West Coast rock lobster into two of the main, most productive, abalone fishing areas. The commercial fishery subsequently reopened in July 2010.

History and management

The commercial (diver) fishery for abalone started in the late 1940s. During the early phase, the fishery was dominated by five large abalone processing plants. Initially, catches were unregulated, and reached a peak of close to 3 000 t in 1965 (Figure 1). By 1970 catches had declined rapidly, although the fishery remained stable with a total annual catch of around 600–700 t until the mid-1990s, after which there were continuous declines in commercial catches.

The early 1990s saw the booming of the recreational fishery, and a significant increase in illegal fishing activities. Continued high levels of illegal fishing and declines in the resource led to closure of the recreational fishery in 2003/2004. Transformation of the fishery in post-apartheid years sought to increase participation in the fishery, particularly by people who had been previously marginalised. Subsistence Rights were introduced in 1998/1999, and were replaced by two-year medium-term Rights. In 2003/2004, 10-year long-term Rights were allocated, broadening participation in the fishery to some 300 Right Holders. At this time, the previous management zones were replaced with Territorial Use Rights in Fisheries (TURFs), aimed at developing a sense of ownership of the resource by the new Right Holders and, in so doing, introducing co-management of the resource and improving compliance with regards to illegal fishing activities.

Illegal fishing, however, remained high despite the introduction of TURFs and increased compliance effort, including strengthening of the compliance fleet, introduction of stricter penalties for offenders, and controls on international trade.

Although illegal fishing of abalone occurs in all areas, its concentration has shifted from one area to another over the years in response to resource abundance and law enforcement presence. Illegal fishing is not selective with regard to the size of abalone taken, and around two-thirds of confiscated abalone are below the minimum legal size of 11.4 cm SB.

Table 1: The availability of data for TAC assessments since 2017. Y indicates data were available, N indicates data were not available. FIAS = fishery-independent ablone survey'

Data inputs		Zones A-D	Zones E-G	Aggregated
FIAS	Abundance	N	N	
	Size composition	N	N	
Commercial	CPUE	Nominal only	Nominal only	
	Size composition	N	N	
Poaching	Compliance	N	N	
	TRAFFIC			Y

Therefore, most of the illegally caught abalone are taken before having had the opportunity to reproduce.

The continued high levels of illegal fishing and declines in the resource led to the introduction of diving prohibitions in selected areas and the closure of the commercial fishery in February 2008. The fishery was subsequently reopened in July 2010, conditional on a 15% per annum reduction in poaching. The required reduction in illegal harvesting has, however, not been achieved.

The management objectives for the sustainable utilisation and recovery of the abalone resource have been to prevent the abalone spawning biomass in each zone from dropping below 20% of its estimated pre-fished biomass (a "limit reference point"), and to see it recover to 40% of that level (a "target reference point") within 15 years of the re-opening of the commercial fishery in 2009/10, i.e. by the 2024/25 season. The 20% and 40% values are in line with international norms, and the 40% target reference point approximates the level at which the greatest catches can be sustained. In order to achieve this, illegal harvesting (poaching) must be substantially reduced.

Research and monitoring

The data inputs usually used in the assessment of the abalone resource are derived from the commercial fishery (CPUE and size composition), from fishery independent abalone surveys (FIAS; abundance and size composition), and from poaching information (numbers and size composition of poached abalone confiscated by Compliance officers). International trade data on imports of *Haliotus midae* by key importing countries provided by WWF's wildlife trade monitoring network, TRAFFIC, also inform on the trends in illegal harvesting of this species.

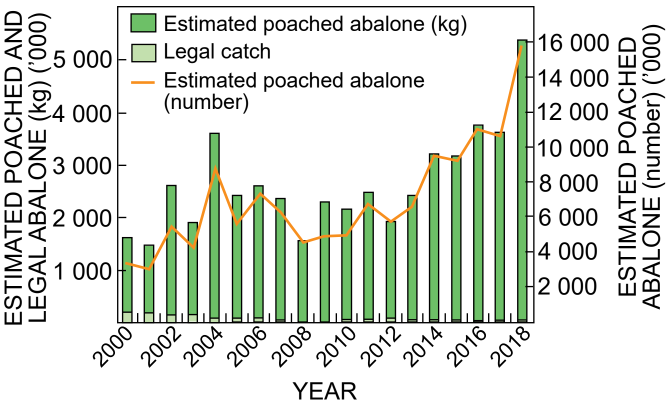


Figure 3: Estimated weight and number of poached abalone based on international trade data for the calendar years 2000–2018 (adapted from Burgener. 2019). An estimation of the international trade in illegally harvested *Haliotis midae*, 2000-2018. FISHERIES/2019/AUG/SWG-AB/05), and recorded legal abalone catch (weight) for the calendar years 2000–2018

A summary of the data available since 2017 is presented in Table 1. Due to capacity and administrative issues no FIAS were completed and FIAS abundance and size composition information was therefore not available for the TAC assessments. In addition, while nominal commercial CPUE for Zones A to D and E to G were recorded, the CPUE standardisations could not be performed, nor was the corresponding size composition information able to be determined. Prior to 2017, trends in illegal catch were assessed using DEFF Compliance data on confiscations and inspections ('policing') effort and international trade data of imports of *Haliotis midae* into key importing countries provided by TRAFFIC. While the aggregated poaching information (TRAFFIC) is available from 2017, the Compliance data on confiscations and policing effort are not.

Resource assessment

In 2016 the main historic fishing areas, namely Zones A, B, C and D (Figure 2), were assessed by means of a spatially explicit ASPM, which was fitted to commercial CPUE and FIAS data as abundance indices, as well as to catch-at-age information inferred from catch-at-length data. The model also estimated the reduction in recruitment of juvenile abalone in Zones C and D due to ecosystem changes and illegal catches.

An updated model-based assessment was not undertaken in 2017 due to administrative issues.

In 2017, data on trends in illegal catch (poaching), FIAS and commercial CPUE that had become available since the 2016 assessment were inspected to determine if any change to the TAC recommendation made in 2016 was required. No justification in moving away from the projections made in the full 2016 assessment was indicated by the data and these were therefore used in the 2017 recommendation.

TAC recommendations for Zones E, F and G (Figure 2) have not been subject to similar model analyses in the past because of data limitations, and advice for these zones has been based on inspection of trends in commercial CPUE, density from FIAS (for Zone F) and size composition.

As in 2017, an update of the 2016 model-based assessment was not undertaken in 2018 due to administrative issues. As in 2017, the 2018 recommendations for Zones A to D were based on the examination of available indices to ascertain whether there had been any meaningful changes since the full assessment completed in 2016. Absence of compelling evidence to the contrary justified the continued use of these projections in 2018. In addition, in the absence of any new information, the decision rules used for Zones E to G in 2016 and 2017 were applied in 2018.

Current status

Trends in illegal catch (poaching)

The analysis of international trade data indicates a significant increase in levels of illegal catch (Figure 3) in 2018 (47% increase from 2017 levels). These estimates are the highest over the 19-year review period. This trend broadly corroborates the inferences from the DEFF Compliance data in recent years of continued high levels of illegal abalone catch.

Commercial catch per unit effort (CPUE)

Zones A and B (Figure 4)

An inspection of the nominal CPUE data shows no marked changes in the CPUE from Zone A over the past three seasons. The apparent slight increase in the nominal CPUE in Zone B over the past three seasons must however be weighed against the consideration that these are nominal and not standardised CPUE data, and concerns that have been raised about the accuracy of CPUE data-reporting in Zones A and B in recent years. One of these is the concern that abalone commercial fishing vessels have been observed around the Dyer Island closed area, so that the recent CPUE values for Zones A and B may have been artificially inflated by catches off Dyer Island.

Zones C-D

Spawning biomass projections in 2016 showed continuing declines in resource abundance in Zones C and D at recent estimated levels of illegal take. The resource in these Zones has been severely reduced by the lobster-urchin effect on recruitment (see below), in addition to the effects of illegal fishing. Populations in these two Zones were also estimated to be below the 20% limit reference point set out in the management objectives. No new data have become available to suggest a change in the previously estimated status of the resource in these Zones.

Zones E to G (Figure 5)

There were no marked changes in the nominal CPUE data for Zones F and G. A sharp decline in CPUE was, however, noted in Zone E.

Ecosystem interactions

Since the early 1990s, ecological changes have severely disrupted normal abalone recruitment patterns in two of the major fishing zones, i.e. Zones C and D. These involved the large-scale incursion of West Coast rock lobsters into Zones C and D. The lobsters have now altered the ecosystem by consuming large numbers of sea urchins as well as most other invertebrate species, including juvenile abalone. Sea urchins perform the important function of providing protection for juvenile abalone. A recent study found that, in Zone D, there have been substantial increases in rock lobsters, seaweeds and sessile species and a substantial decline in grazers (of which abalone are a component). The current ecosystem state in Zone C is

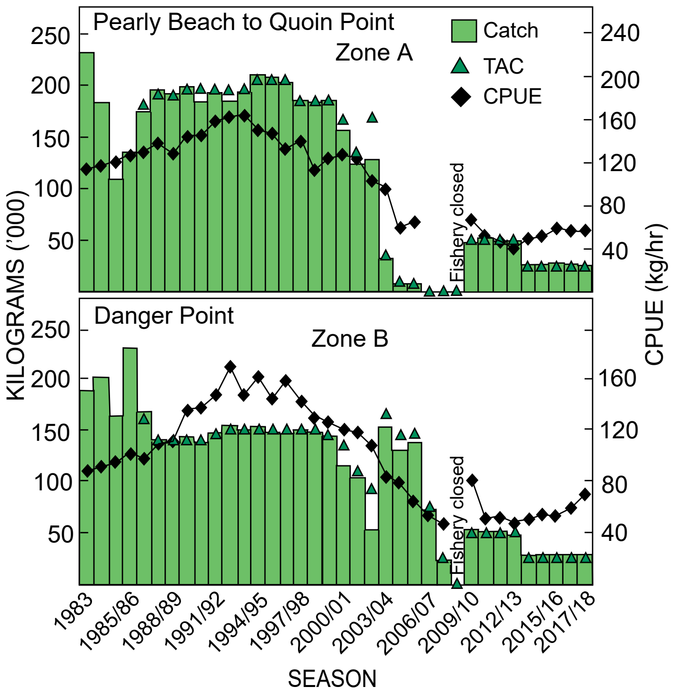


Figure 4: Catch and nominal (unstandardised) CPUE, with annual TAC indicated for Zones A and B for the period 1983 to 2017/18. Note that the fishery was closed during the 2008/09 season

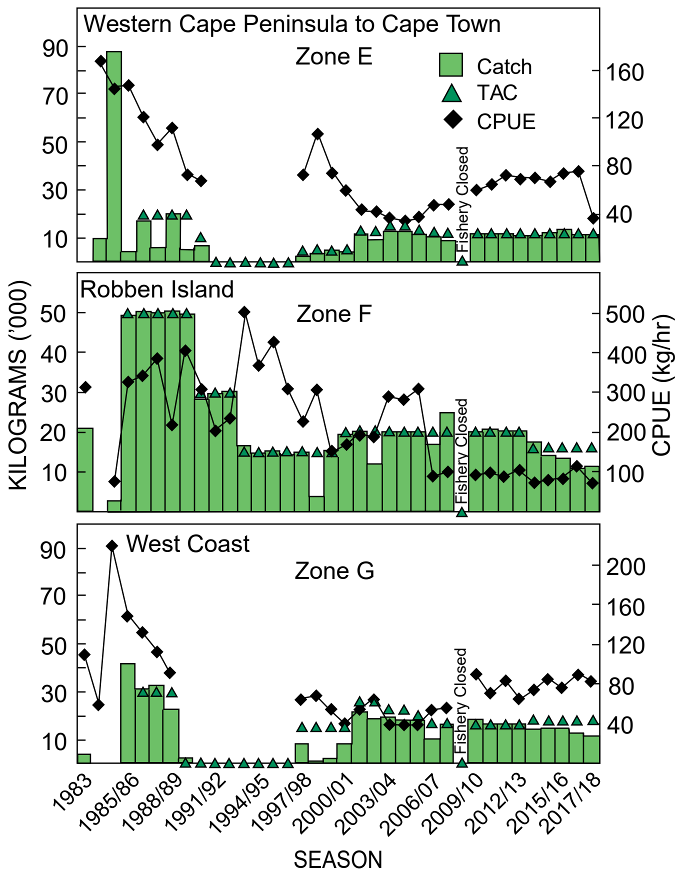


Figure 5: Catch and CPUE data, with annual TAC indicated for Zones E, F and G for the period 1983 to 2017/18. Note that the fishery was closed for the 2008/09 season

similar to Zone D.

The ecosystem state in Zones A and B is currently different to Zones C and D, with very few lobsters present, a lower biomass of seaweeds and sessile species, more encrusting corallines, and urchins and grazers still present in relatively high abundance.

The combined effect of poaching and ecological changes has resulted in severe declines in the abalone resource in Zones C and D. The Betty's Bay Marine Protected Area (MPA), situated within Zone D, was also affected, which meant the loss of the main conservation area for abalone. As a result, Dyer Island has been closed to commercial fishing since the 2003/2004 season to function as a refuge area for abalone. FIAS surveys undertaken at Betty's Bay MPA in 2012 indicated that the mean density of abalone dropped to 1% of the level recorded in the 1990s. This confirms that Betty's Bay no longer functions as a closed area (reserve) for abalone, indicating that Dyer Island should continue as a closed area.

Further reading

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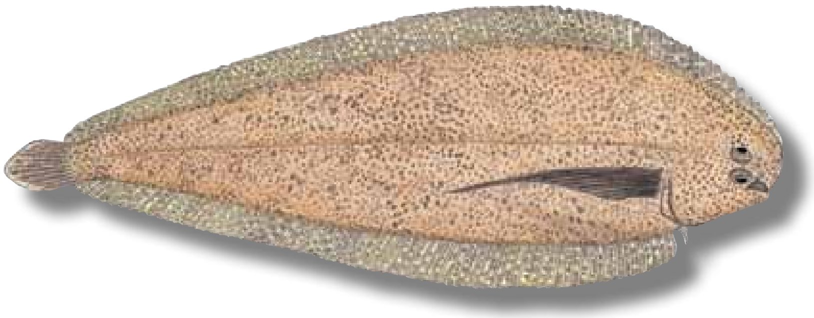
Useful statistics

Total Allowable Catches (TACS) and catches for the abalone fishery.

Season	TAC (t)	Total commercial catch (t)	Total recreational catch (t)
1993/94	615	613	549
1994/95	615	616	446
1995/96	615	614	423
1996/97	550	537	429
1997/98	523	523	221
1998/99	515	482	127
1999/00	500	490	174
2000/01	433	368	95
2001/02	314	403	110
2002/03	226	296	102
2003/04	282	258	0
2004/05	237	204	0
2005/06	223	212	0
2006/07	125	110	0
2007/08	75	74	0
2008/09	0	0	0
2009/10	150	150	0
2010/11	150	152	0
2011/12	150	145	0
2012/13	150	*	0
2013/14	96	95	0
2014/15	96	95	0
2015/16	96	98	0
2016/17	96	89	0
2017/18	96	87	0
2018/19	96	53	0

Agulhas sole



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

Agulhas or East Coast sole *Austroglossus pectoralis* belong to a group of fish referred to as flatfish because they have adapted to lying on their side on the seabed by evolving a laterally compressed body shape with both eyes migrating to the upper side of the head during larval development. Well-developed fins encircle the body. They are bottom-dwelling, preferring sand or silt substrates, and feed on small crustaceans, molluscs, worms and brittle stars. They occur mainly in the area between Cape Agulhas and Port Alfred (Figure 6) between depths of 10 and 120 m, although they have occasionally been caught in deeper water during research surveys. The average size landed by commercial vessels is between 32.0 cm and 33.6 cm.

The Agulhas sole resource is a small but commercially important component of the mixed-species inshore trawl fishery on the South Coast. The inshore trawl fleet comprised 15 ac-

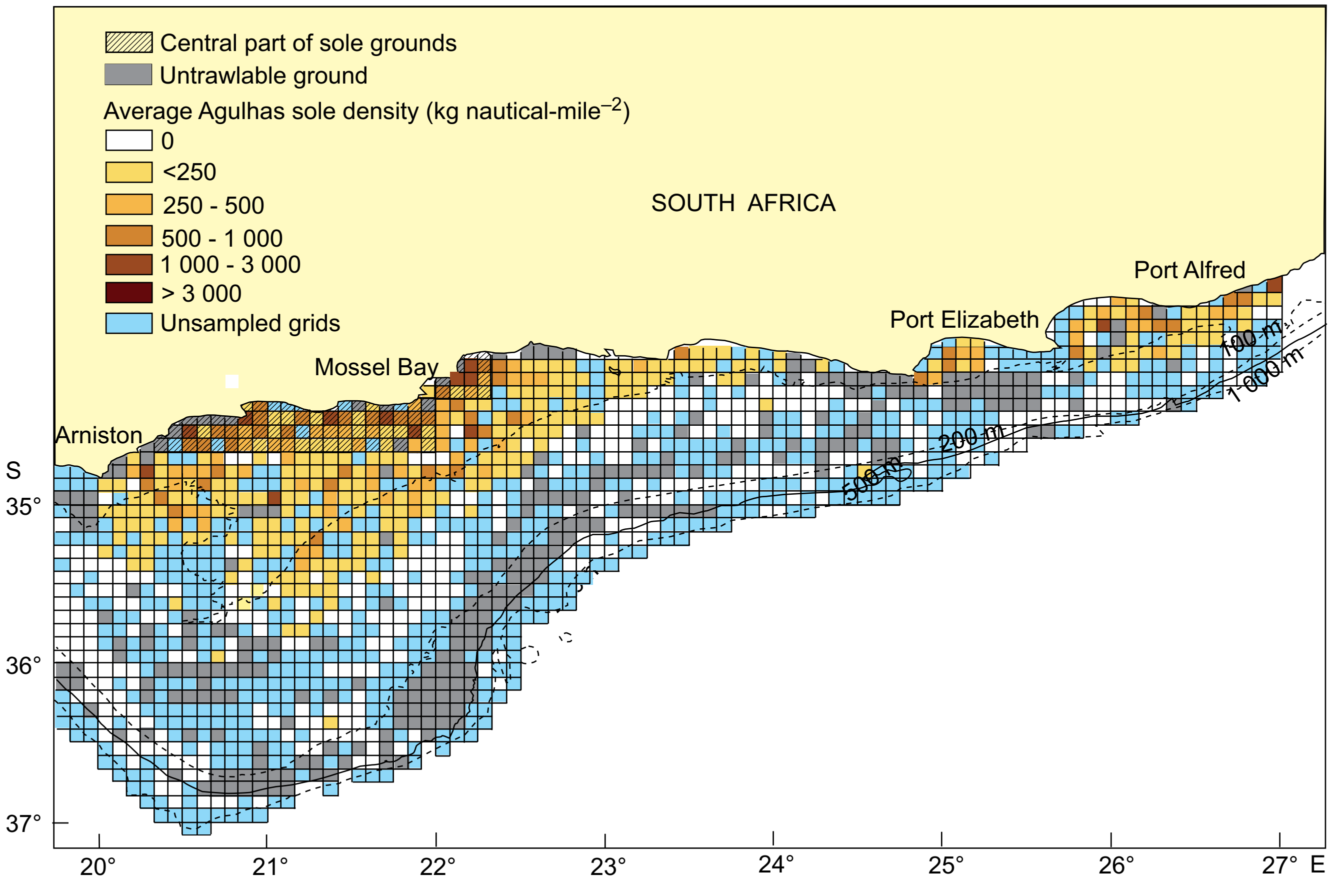


Figure 6: Distribution of Agulhas sole *Austroglossus pectoralis* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical-mile^{-2}) are averages over all survey stations within each survey grid block. The area considered to be the central part of the sole grounds is indicated

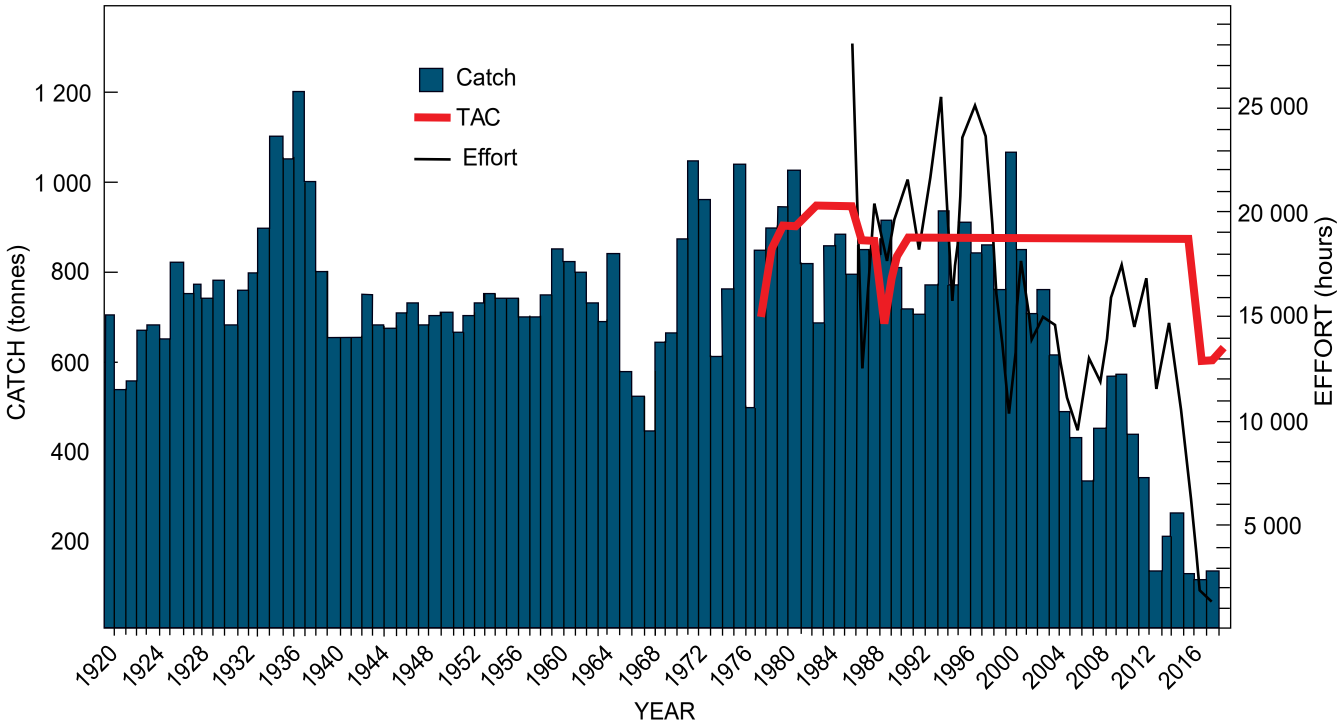


Figure 7: Annual catches (landings), TACs (both in tonnes) and an estimate of annual total sole-directed fishing effort on the Agulhas sole grounds (hours) in the Agulhas sole fishery 1920–2019. The large over-catch in 2000 was due to catches that were permitted to be carried over from 1999 when the fleet was tied up for five months

tive vessels in 2018, of which four primarily target the sole resource but also rely on hake bycatch, while the remainder of the fleet targets primarily hake. The 2019 annual total allowable catch (TAC) of 627 t is estimated to be worth approximately R25 million.

History and management

The Agulhas sole resource has been exploited since the 1890s, and was one of the first fish stocks to be managed in South Africa. Exploitation of Agulhas sole was the economic base for the early fishery on the Cape south coast and was the driving force for the development of the coastal fishing fleet. In the early years, fishing was directed largely at Agulhas sole, but the fishery gradually shifted to targeting a number of additional species, including hake and various linefish species, by the late 1970s. The first formal attempt at managing the Agulhas sole fishery was made in 1935, with the introduction of a 75 mm minimum mesh size for bottom trawl nets. The inshore trawl fishery was formally defined as a management unit, i.e. the hake and sole inshore trawl sector, separate from the hake deep-sea trawl sector, in 1978. An annual TAC of 700 t was first introduced in 1978, and individual quotas were introduced in 1982. The TAC remained fairly stable thereafter, varying between 700 t and 950 t between 1982 and 1992, and was subsequently maintained at 872 t until 2016 (Figure 7). Management of the fishery has, since 1978, restricted its operations to the South Coast between the 20° E line of longitude and the line drawn due east from the mouth of the Great Kei River, and since the start of 2015, to the area defined as the "hake trawl ring fence" (see the section on Cape hakes).

Landings of Agulhas sole have declined substantially subsequent to 2000, with a slight increase in 2008–2010, but still well below the TAC (Figure 7). At that time, the decline was attributed mainly to a reduction in the overall effort deployed by the fishery (Figure 7), rather than a decline in the abundance of the resource. The effort reduction was primarily the result of an appreciable decrease in the number of active inshore vessels in the fishery over time (50 in 1979, decreasing to 32 in 2000, and 14 in 2015). The reasons for this are complex, but can be largely attributable to companies not replacing old/damaged vessels due to the limited availability (and substantial costs) of suitable replacement vessels, compounded by uncertainty regarding future long-term Rights allocations. Market/economic forces have also resulted in changes in fishing strategies, with many Right Holders moving either all or part of their hake quotas to the hake deep-sea trawl sector (with a consequent reduction in sole catch), or directing limited resources (vessels and sea days, and hence effort) to filling hake quotas rather than attempting to fill sole quotas.

In spite of this marked reduction in fishing effort, an appreciable decline in the commercial catch per unit effort (CPUE) (the index that has been used to monitor Agulhas sole abundance) became apparent subsequent to 2009, with CPUE reaching unusually low levels over the period 2012 to 2016 (Figure 8). While this decline could reflect a decrease in resource abundance, the possibility that it could rather reflect a decline in catchability (i.e. in the availability of sole to the fishery) could not be discounted. Confronted with this uncertainty regarding resource dynamics, a series of assessments using a dynamic Schaefer production model approach that incorporated these two hypotheses were developed in 2014 and used to project forwards in time under various management strategies. Following evaluation of the results of these analyses, a spatial effort limitation strategy was adopted in 2015 as the primary regulatory measure, while maintaining the TAC at 872 t. This "trade-

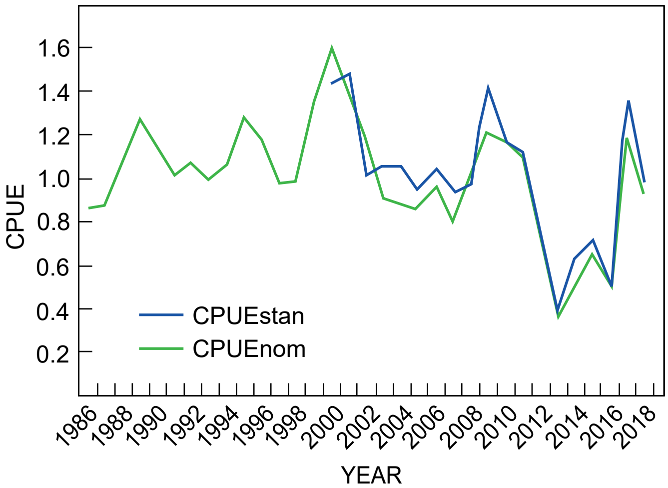


Figure 8: Commercial catch per unit effort (CPUE) indices of abundance for Agulhas sole. A GLM standardised index ("CPUEstan") that uses drag-level catch and effort data over the period 2000-2018 is illustrated, and compared to a coarser nominal index ("CPUEnom") that is calculated from cumulative annual catch and effort data for the period 1986–2018. Both indices are normalised to their respective means

off" approach was intended to limit fishing mortality (thereby providing scope for resource recovery in the event that the reduced abundance hypothesis was correct), but also to allow scope for an increase in catches if the decline reflected the catchability hypothesis and catch rates returned to "normal" in the short- to medium-term. Considering that about 95% of the total annual catch of Agulhas sole is typically taken from the central part of the sole grounds (see Figure 6), the effort restriction was applied to sole-directed fishing operations within this area only.

An update of the assessment was conducted in 2017 using additional catch and CPUE data for 2015 and 2016 that had become available. Based on the results of the analyses, the effort limitation strategy was maintained for 2018, and coupled with a reduction in the TAC to 600 t. The assessment conducted in 2018 took account of the increase in CPUE that was observed during 2017, and the results suggested a slightly more optimistic perception of resource status than had been the case in the 2017 assessment. The effort limit imposed on the fishery was consequently increased by 10%, with an associated slight increase in the TAC to 627 tonnes.

Research and monitoring

Fishery-independent estimates of Agulhas sole abundance (Figure 9) are derived from demersal research surveys conducted on the South Coast using the swept-area method (see section on Cape hakes). These surveys are designed to estimate the abundance of hakes, although other demersal species (including Agulhas sole) are included in the data collection. The area encompassed by these surveys generally extends to the 500 m isobath (and to the 1 000 m isobath since 2011), with only a few sampling locations falling within the area of Agulhas sole distribution. Consequently, the sole population is not comprehensively sampled and the resulting sole abundance indices should therefore be interpreted with caution. While four intensive Agulhas sole-directed surveys have been conducted (2006–2008) to improve temporal and spatial coverage of the population, budgetary constraints have precluded continuing these surveys, limiting the usefulness of the data that were collected.

Fishery-dependent data (landings, size-composition of the catch, drag-level catch and effort data) are routinely collected.

Current status

The 2019 assessment of the Agulhas sole resource was conducted in circumstances where the standardised commercial CPUE index of abundance had increased from the low levels

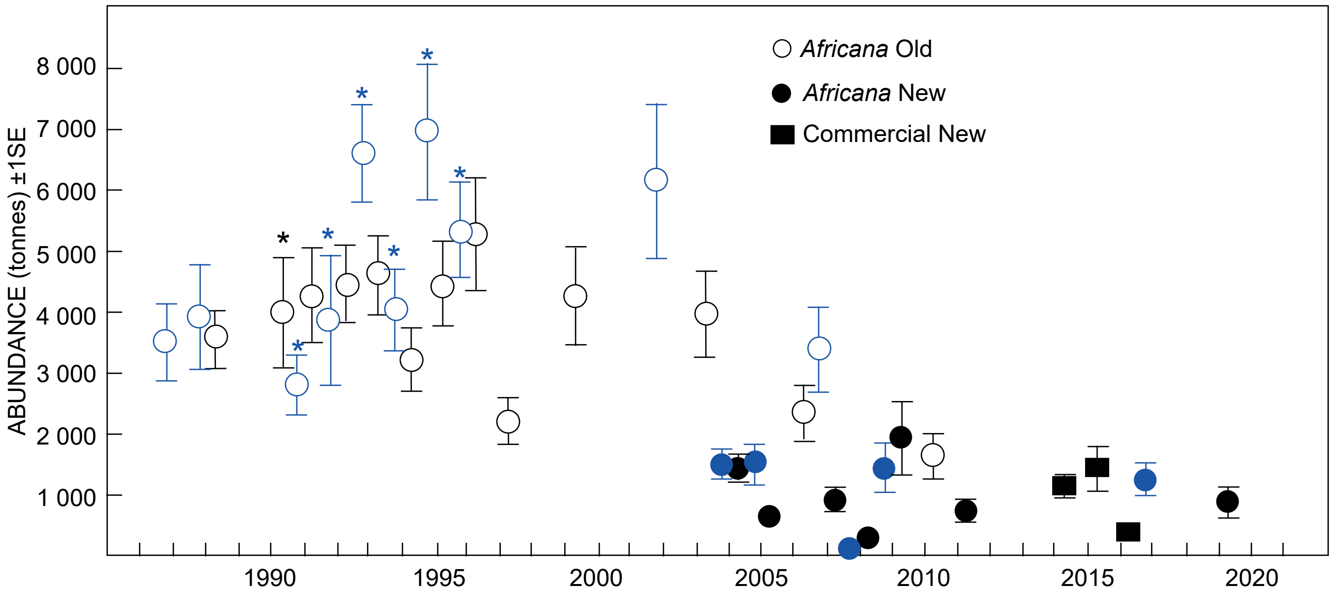


Figure 9: Agulhas sole abundance estimates (tonnes) derived from fishery-independent swept area demersal surveys. Estimates are illustrated for the various vessel-gear combinations. Autumn South Coast surveys are indicated with black symbols, while spring South Coast surveys are indicated with blue symbols. Surveys that only extended to the 200 m isobath have been included in the figure (indicated with an asterisk) because Agulhas sole are largely distributed at depths that are shallower than 200 m. Note that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability. *Africana* = research vessel FRS *Africana*, Commercial = commercial fishing vessel

observed for the period 2012–2016 to levels that were more comparable to those observed prior to 2010. The 2019 assessment differed from those conducted in recent years in several respects:

- Fishery-independent demersal survey estimates of abundance encompassing the period 1986 to 2019 were included in the model fitting.
- A relatively crude nominal CPUE index encompassing the period 1986 to 2018 was used, rather than the standardised CPUE index (which could be computed for the period 2000 to 2018 only because the drag-level data prior to 2000 that are required for this purpose are unavailable). In view of the close similarity in trends between the two indices over the common period (Figure 8), it was felt that the benefits of an index of abundance extending further back in time justified the use of the nominal CPUE index.
- In view of the extent of increase in the CPUE that has been observed subsequent to the 2012–2016 "low" period, it was considered that the decrease-in-abundance hypothesis is no longer defensible (as it is very unlikely that abundance could have almost doubled in such a short period). The 2019 assessment consequently only considered a reduction in catchability to account for the 2012–2016 low CPUE.
- An observation of some concern, however, was that in spite of the marked decline in effort (and hence catches) that has been apparent in the fishery since the turn of the Century (Figure 7) the resource does not appear to have responded with a corresponding increase in abundance. The 2019 assessment therefore allowed for the possibility of a period of reduced resource productivity from 2000 onwards.

The assessment approach involved fitting a series of dynamic Schaefer production models to the data, with the models assuming various combinations of period-specific (pre- and post-2000) intrinsic population growth rates. Initial model runs where the *r* parameter (the measure of intrinsic population growth rate) was kept unchanged or decreased only slightly post-2000 yielded markedly poorer fits to the data because these scenarios would imply a recent increase in abundance that is not apparent in the data. These initial model runs were consequently not considered further. Subsequent analyses considered various combinations of two period-specific productivity "regimes", but the results indicated that the data were relatively uninformative as to which combination best fit the data. In view of this feature, and further considering that only two years of higher CPUE had been observed, a precautionary approach was adopted in regulating the fishery in 2020. The TAC was reduced to 502 t, and the effort limitation was retained, albeit somewhat relaxed.

Ecosystem interactions

Measures aimed at reducing the ecosystem impacts of the hake-directed demersal trawl fisheries are contained in Sections B and C of the current permit conditions (see section on Cape hakes), and these measures are also applied to the Agulhas sole-directed component of the hake inshore trawl fishery.

Further reading

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Heemstra E. 2004. *Coastal fishes of southern Africa*. Grahamstown: National Inquiry Service Centre (NISC) & South African Institute for Aquatic Biodiversity (SAIAB).

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Useful statistics

Total catch (tonnes) of Agulhas sole per calendar year and the annual TACs (tonnes) for the period 1920 – 2019.

Year	Catch	TAC
1920	700	
1921	540	
1922	560	
1923	670	
1924	680	
1925	650	
1926	820	
1927	750	
1928	770	
1929	740	
1930	780	
1931	680	
1932	760	
1933	800	
1934	900	
1935	1 100	
1936	1 050	
1937	1 200	
1938	1 000	
1939	800	
1940	650	
1941	650	
1942	650	
1943	750	
1944	680	
1945	675	
1946	710	
1947	730	
1948	680	
1949	700	
1950	710	
1951	670	
1952	700	
1953	730	
1954	750	
1955	740	
1956	740	
1957	700	
1958	700	
1959	750	
1960	850	
1961	820	
1962	800	
1963	732	
1964	690	
1965	841	
1966	575	
1967	520	
1968	445	
1969	642	

Useful statistics *cont.*

Year	Catch	TAC
1970	663	
1971	877	
1972	1 044	
1973	961	
1974	611	
1975	763	
1976	1 040	
1977	500	
1978	850	700
1979	899	850
1980	943	900
1981	1 026	900
1982	817	930
1983	682	950
1984	857	950
1985	880	950
1986	796	950
1987	855	868
1988	839	868
1989	913	686
1990	808	834
1991	716	872
1992	704	872
1993	772	872
1994	938	872

Year	Catch	TAC
1995	769	872
1996	909	872
1997	840	872
1998	859	872
1999	757	872
2000	1 060	872
2001	850	872
2002	702	872
2003	754	872
2004	612	872
2005	485	872
2006	428	872
2007	331	872
2008	448	872
2009	568	872
2010	570	872
2011	442	872
2012	338	872
2013	127	872
2014	208	872
2015	258	872
2016	125	872
2017	113	600
2018	132	600
2019		627

Cape hakes

Stock status	Unknown	Abundant Shallow-water hake	Optimal Deep-water hake	Depleted	Heavily depleted
Fishing pressure	**Unknown**	**Light**	**Optimal** Shallow-water hake Deep-water hake	**Heavy**	

Introduction

The South African hake resource comprises two species: shallow-water Cape hake *Merluccius capensis* and deep-water Cape hake *M. paradoxus*. The Cape hakes are distributed on the continental shelf and upper slope around the coast of southern Africa. *Merluccius paradoxus* are distributed from northern Namibia to southern Mozambique, whereas *M. capensis* are distributed from southern Angola to northern KwaZulu-Natal. As the names suggest, the distributions of the two hake species differ with depth, although there is a substantial overlap in their depth ranges. *Merluccius capensis* are distributed over a depth range of 30 to 500 m with most of the population occurring between 100 and 300 m (Figure 10a). In contrast, *M. paradoxus* are distributed over a depth range of 110 m to deeper than 1 000 m with most of the population occurring in depths of between 200 and 800 m (Figure 10b). The sizes of both species increase with depth and large *M. capensis* consequently co-exist with and feed extensively on smaller *M. paradoxus*. It is difficult to distinguish between the two hake species, so they are generally processed and marketed as a single commodity.

Cape hakes are targeted by four fishery sectors: hake deep-sea trawl, hake inshore trawl, hake longline and hake handline. The deep-sea trawl sector lands the most hake of the four sectors (Figure 11). Approximately 80% of the total annual hake catch in the last decade has been *M. paradoxus*. Hakes are also caught as incidental bycatch in the horse-mackerel-directed midwater trawl and demersal shark longline fisheries, and to a lesser extent in the linefish sector. The inshore trawl and hake handline sectors operate only on the South Coast, whereas the deep-sea trawl and longline fleets operate on both the West and South coasts. On the West Coast, the continental shelf is fairly narrow so most trawling is in deep water on the shelf edge and upper slope, and as much as 90% of the hake caught are *M. paradoxus*. In contrast, most trawling on the South Coast is on the wide continental shelf, the Agulhas Bank, and as much as 70% of hake catches on this coast are *M. capensis*. The hake fishery is the most valuable of South Africa's marine fisheries, providing the basis for some 30 000 jobs and an annual landed value in excess of R5.2 billion.

History and management

The demersal fishery off southern Africa started with the arrival of the purpose-built research vessel, *Pieter Faure*, in 1897 and the first commercial trawler, *Undine*, in 1899 off the Cape. In the early years of the fishery, Agulhas and West Coast sole (*Austroglossus pectoralis* and *A. microlepis*, respectively) were the primary target species, with hake being caught as an incidental bycatch. Directed fishing of Cape hakes began towards the end of the First World War, with catches averaging about 1 000 t per annum until 1931. The fishery then began escalating during and after World War II, with catches increasing steadily to around 170 000 t by the early 1960s. The incursion of foreign fleets in 1962 led to a dramatic increase in fishing effort, and catches in South African waters eventually peaked in 1972 at over 295 000 t (Figure 11). By this time, effort had extended farther offshore and also into Namibian waters, with over 1.1 million t being caught in the South-East Atlantic in 1972.

In 1972, following concerns over the combination of increasing catches and decreasing catch rates, the International Commission for the South East Atlantic Fisheries (ICSEAF) was established in an attempt to control what had become an international fishery. Various management measures such as a minimum mesh size, international inspections and quota allocations to member countries were implemented through ICSEAF. However, catch rates continued to decline, and in November 1977 the declaration of a 200 nautical mile exclusive fishing zone (EFZ) by South Africa marked the onset of direct management of the South African hake resource by the South African government. With the exception of a few vessels operating under bilateral agreements and subject to South African regulations, foreign vessels were excluded from South African waters.

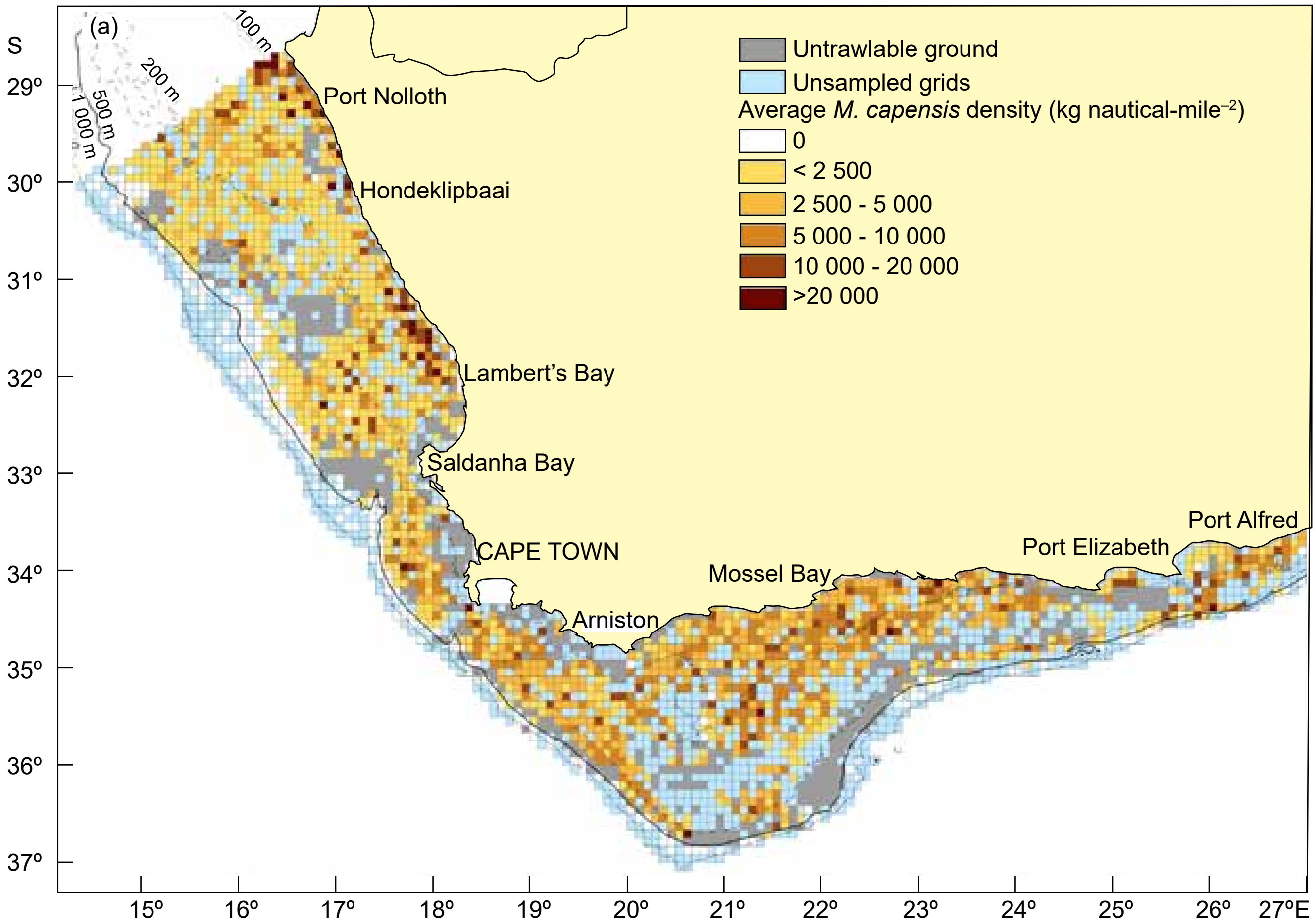

Figure 10 (a): Distribution of shallow-water hake *Merluccius capensis* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical-mile^{-2}) are averages over all survey stations within each survey grid block

Subsequent to the declaration of the EFZ, South Africa implemented a relatively conservative management strategy in order to rebuild the hake stocks to B_{MSY}, the biomass level that would provide the maximum sustainable yield (MSY). Total allowable catch (TAC) restrictions were imposed on the fishery, aimed at keeping catches below levels deemed necessary for stock rebuilding. The TACs were recommended on the basis of assessments of the resource using first steady-state models, then dynamic production models, and finally age-structured production models. An operational management procedure (OMP) approach was adopted in 1990 to provide a comprehensive basis for management of the hake resources. The hake OMP is essentially a set of rules that specifies exactly how the TAC is calculated using stock-specific monitoring data (both commercial and fishery-independent indices of abundance). Implicit in the OMP approach is a four-year schedule of OMP revisions to account for possible revised datasets and understanding of resource and fishery dynamics. Assessments are routinely updated every year to check that resource indicators remain within the bounds considered likely at the time that the OMP was adopted.

As a result of the substantial overlap in distribution and the difficulty of distinguishing between the two hake species, species-specific catch and effort data are not available from the commercial fishery, and the two species were initially assessed and managed as a single resource. However, the development of the longline fishery during the 1990s led to shifts in the relative exploitation rates of the two species, rendering species-combined assessments of the resource inappropriate. Algorithms to apportion the commercial hake catch between the two species were developed using research survey data, enabling the development of species-disaggregated assessment models. The first such algorithm was developed during 2005 and was used in the development of the revised OMP implemented in 2006. Subsequent revisions of the species-splitting algorithms using updated datasets have coincided with the routine OMP revision conducted every 4 years. The most recent (2018) revision of the hake species-splitting algorithm used scientific observer records of catch composition as well as research survey data.

The management strategies implemented since the EFZ was declared showed positive results initially, with both catch rates and research survey abundance estimates (and hence TACs and annual catches) increasing gradually through the 1980s and 1990s (Figure 11). In the early 2000s, however, the hake fishery again experienced a decline in catch rates. Results of the species-disaggregated assessments developed in 2005 revealed that the decline was primarily attributable to a reduction in the *M. paradoxus* resource to well below B_{MSY}. Although the *M. capensis* resource had also declined, the

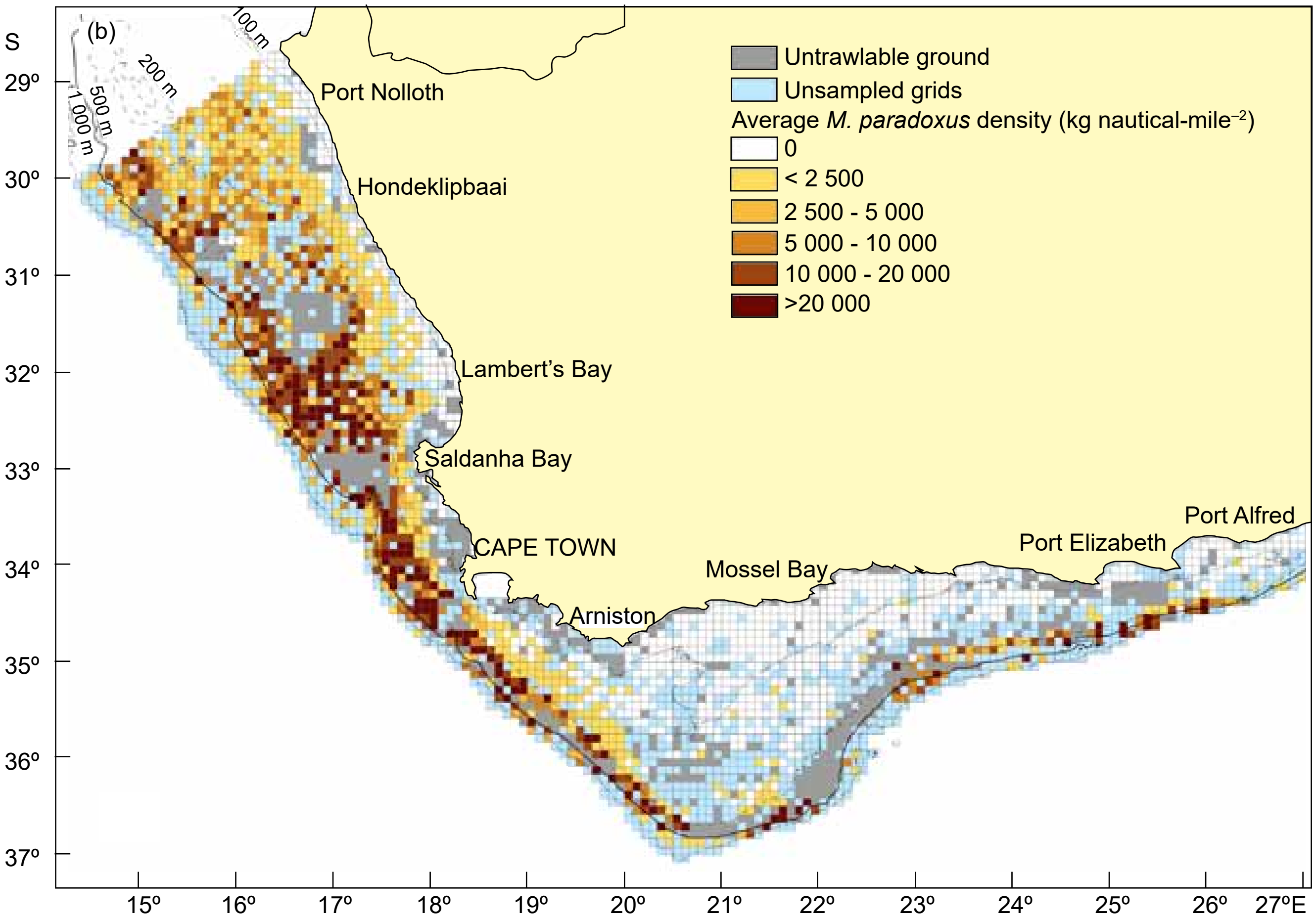

Figure 10 (b): Distribution of deep-water hake *Merluccius paradoxus* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical-mile^{-2}) are averages over all survey stations within each survey grid block

estimated biomass was still above B_{MSY}. The decline was likely a response to several years of below-average recruitment for both species in the late 1990s and early 2000s. The reasons for the poor recruitment are not known.

The OMP developed in 2006 was based on a species-disaggregated assessment available for the first time, and amidst industry concerns about financial viability given the downturns in catch rates. This OMP provided TAC recommendations for the period 2007–2010 that aimed to allow recovery of the *M. paradoxus* resource to 20% of its pre-exploitation level over a 20-year period, while restricting year-to-year fluctuations in the TAC to a maximum of 10% in order to provide stability for the industry. Implementation of this OMP led to substantial reductions in the TAC from 2007 until 2009 (Figure 11), but TACs subsequently increased as the resource responded positively to the recovery plan, with survey indices of abundance, and to some extent commercial catch rates, turning around to show increasing trends (Figures 12 and 13). In accordance with the agreed OMP revision schedule, revised OMPs were developed in 2010 (OMP-2010) and 2014 (OMP-2014) to provide TAC recommendations for the years 2011–2014 and 2015–2018 respectively. OMP-2010 was aimed at continuing the *M. paradoxus* rebuilding strategy inherent in OMP-2006, with the objective of returning the *M. paradoxus* resource to B_{MSY} by 2023. OMP-2014 was developed in circumstances where, although the *M. paradoxus* resource was estimated to have improved to above B_{MSY} during 2012-2013 (indicating that the rebuilding strategy inherent in OMP-2010 had been successful), the stock had experienced below-average recruitment over 2009–2013, likely to result in a short-term reduction in spawning biomass. OMP-2014 was consequently aimed at reversing this downward trend and returning *M. paradoxus* to B_{MSY} by 2023. The most recent revision of the hake OMP was conducted during 2018 (see "Current status").

An important consideration in the development of the recent hake OMPs has been the certification of the South African hake trawl fishery (both the deep-sea and inshore trawl sectors) by the Marine Stewardship Council (MSC). The fishery first obtained this prestigious eco-label in 2006, and was successfully re-certified in 2010 and again in 2015. MSCcertification has provided substantial socio-economic benefits to the fishery through enabling access to international markets that are increasingly demanding that seafood products are MSC-certified. Recent economic studies conducted by the Bureau of Economic Research and independent consultants have indicated that withdrawal of MSC certification of the South African hake trawl fishery would decrease the net present value of the fishery by about 35% over a five-year period, and result in a potential loss of up to 13 600 jobs. In fulfilling their mandate of ensuring responsible and sustainable fishing practices through granting the use of the MSC eco-label to a fishery, the MSC have stringent standards in terms of assessments and subse-

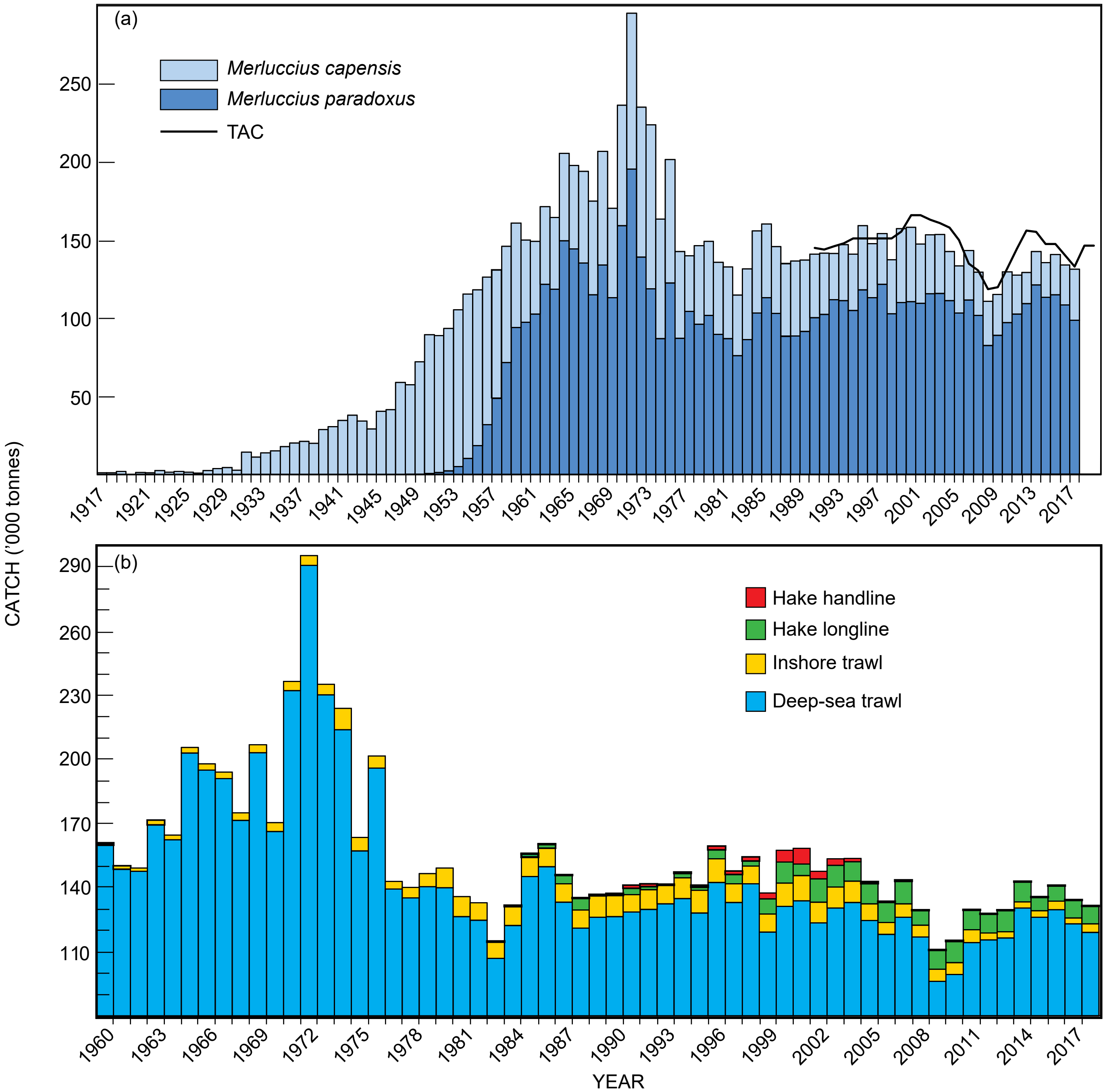

Figure 11: (a) Total catches ('000 tonnes) of Cape hakes split by species over the period 1917–2018 and the TAC set each year since the implementation of the OMP approach in 1991. Prior to 1978, where the data required to split the catch by species are not available, the split is calculated using an algorithm that assumes 1958 as the centre year for the shift from a primarily *M. capensis* to a primarily *M. paradoxus* deep-sea trawl catch. (b) Catches of Cape hakes per fishing sector for the period 1960–2018. Prior to 1960, all catches are attributed to the deep-sea trawl sector. Note that the vertical axis commences at 80 000 tonnes to better clarify the contributions by each sector

quent management of exploited fish resources. The development of the recent iterations of hake OMPs had to conform to these standards to ensure that certification of the hake trawl fishery will not be jeopardised. In particular, the importance of returning the *M. paradoxus* resource to its median B_{MSY} level by 2023 and maintain it fluctuating around that level had to be taken into account during the development of OMP-2010 and OMP-2014.

Uncertainty remains as to the extent to which the *M. paradoxus* resource is shared between South Africa and Namibia, and the influence of catches by the two national fleets on the resource as a whole. At present, the two fisheries are managed independently, although the recently established Benguela Current Commission (BCC) aims to work towards joint management of this resource if it is established that there is sufficient sharing of the resource between the two countries to warrant this. Efforts are being directed at developing a joint SA–Namibia assessment of the *M. paradoxus* resource, but limited information on the possible movement of various life-stages between the two fisheries remains an obstacle to effective modelling of resource dynamics.

Research and monitoring

Fishery-independent hake abundance indices (Figure 12) are determined from research surveys conducted on the West Coast (WC) in summer and the South Coast (SC) in autumn each year since 1985. Additional winter WC and spring SC surveys have been conducted in some years, but budgetary and operational constraints have prevented these surveys from being routinely conducted. Prior to 2011, surveys typically encompassed the area between the coastline and 500 m isobath. Since 2011, the surveys have been extended to the 1 000 m isobath. For each survey, 120 trawl stations are selected using a pseudo-random stratified survey design. The survey area is subdivided by latitude (WC) or longitude (SC) and depth into a number of strata, and the number of stations selected within each stratum is proportional to the area of the stratum. Areas of rough ground that cannot be sampled using demersal trawls are excluded from the station-selection process, and it is assumed that fish densities in these areas are the same as those in adjacent areas that can be sampled. Trawling is conducted only during the day to minimise bias arising from the daily vertical migration of hake, which are known to move off the sea floor and into the water column at night to feed. All organisms in the catch, including benthic invertebrate macrofauna, are identified to species level where possible, in some cases also separated by gender, and the catch weight of each species is then recorded. The size composition of the catch of each species is measured and more-detailed biological analyses are conducted on sub-samples of commercially important species. Biological data and samples routinely collected include individual fish length and weight measurements, macroscopic estimation of maturity stage, gonad and liver weight measurements and samples, evaluation of stomach contents and extraction of otoliths for age determination. Data and samples collected during the surveys are also being used in research projects aimed at elucidating questions regarding the trophodynamics, stock structure and migration patterns of hake, kingklip and monkfish, as well as the potential impacts of climate change and variability on demersal fish populations. The analyses of hake stomach contents have provided useful data towards estimating natural mortality of hake using intra- and interspecific predation models.

Abundance indices are calculated from the survey data using the swept-area method, which, in part, relies on fishing

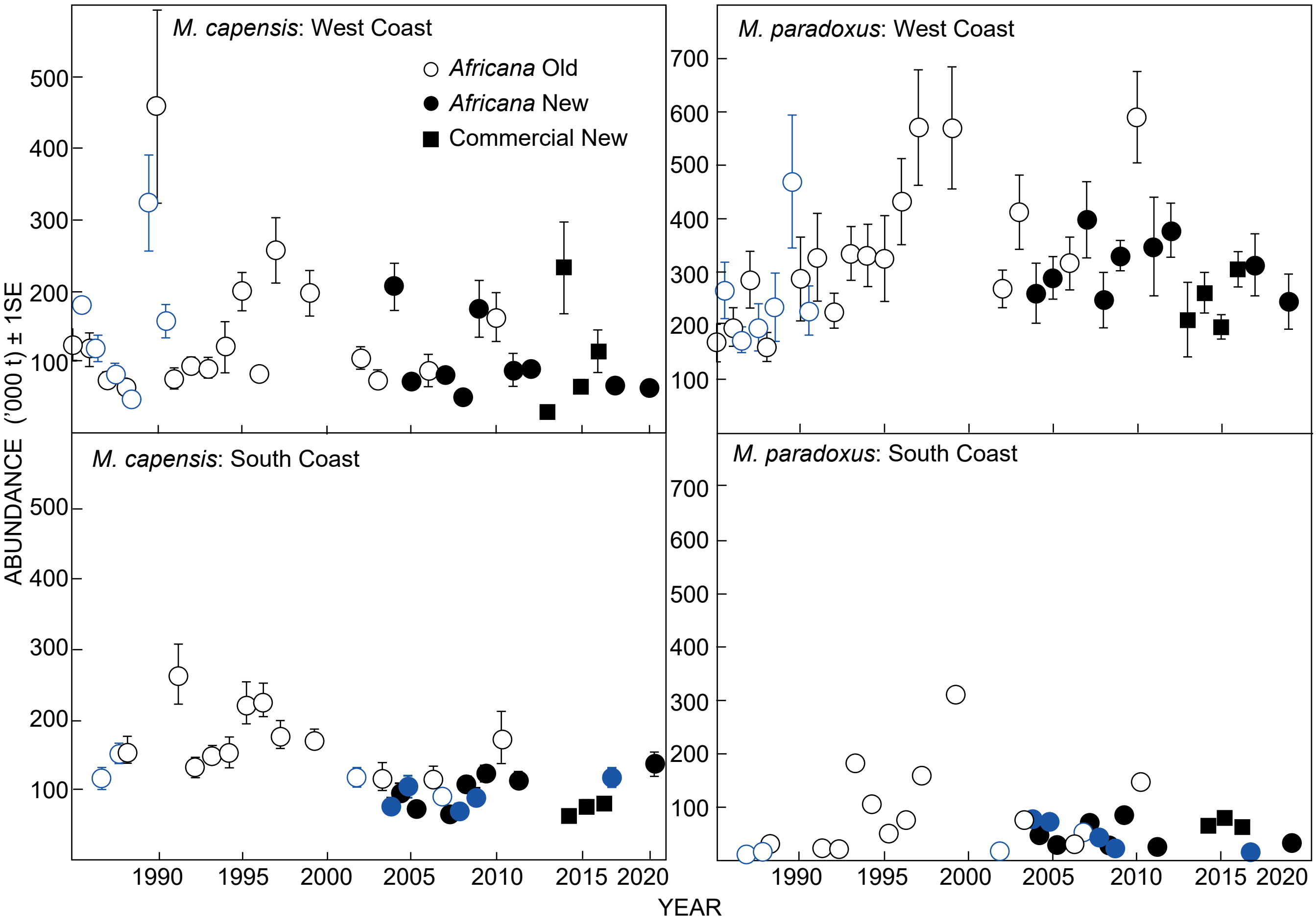

Figure 12: Hake abundance estimates ('000 t ± 1 SE) derived from fishery-independent swept area demersal surveys. Estimates are illustrated by species and coast for the various vessel-gear combinations. Summer (West Coast) and autumn (South Coast) surveys are indicated with black symbols, while winter (West Coast) and spring (South Coast) surveys are indicated with blue symbols. Note that only results from surveys that encompassed the area between the coast and the 500-m isobath are shown and that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability. *Africana* = research vessel FRS *Africana*, Commercial = commercial fishing vessel

methods and gear remaining unchanged between surveys. In 2003, it was considered necessary to change the trawl gear configuration on the FRS *Africana* because net-monitoring sensors showed that the gear was being over-spread (i.e. the wings of the net were being pulled too far apart, which reduced the vertical opening and frequently lifted the foot rope off the sea bed). In selecting a new gear configuration, particular emphasis was placed on minimising the possible effect of herding on the abundance indices. This change is currently taken into account in the assessment model by the application of conversion factors estimated from experiments. Another recent (2011) change to the survey design is the extension of the survey area into deeper water (1 000 m) to encompass the full extent of the *M. paradoxus* resource. However, abundance estimates for input to assessments and the hake OMP are still calculated for the historical survey area (<500 m) for consistency purposes. Once abundance time-series of sufficient duration are available for the extended survey area it will be possible to incorporate these data into the assessments and OMP. Operational problems with the departmental research vessel (FRS *Africana*) prevented this vessel conducting demersal surveys between March 2012 and September 2016. In the absence of the FRS *Africana*, the research surveys were conducted on board commercial vessels (the MV *Andromeda* and the MV *Compass Challenger*), although no autumn SC surveys were conducted in 2012 and 2013. Technical problems with the FRS *Africana* also prevented the completion of the autumn 2017 (SC), summer 2018 (WC) and autumn 2018 (SC) surveys.

Species-specific catch-per-unit-effort (CPUE) time-series derived from commercial catch and effort data are standardised using general linear modelling (GLM) techniques to account for differences in factors such as depth, area, and vessel power. These time-series (Figure 13) are then used in the assessment to provide additional estimates of resource abundance and trends.

Assessments of the hake resources in recent years have typically followed a two-year cycle. An in-depth assessment that fits a suite of age-structured production models (ASPMs) to updated data sets is conducted every two years, timed to coincide with the four-year schedule of OMP revision. The suite of operating models that is considered, referred to as the reference set (RS), is designed to encompass major sources of uncertainty, and includes the reference case (RC) model that is considered to provide the most plausible measures of stock status and dynamics. A routine update of the RC model is conducted every year to ensure that the resources have not deviated from what was predicted during the course of OMP testing.

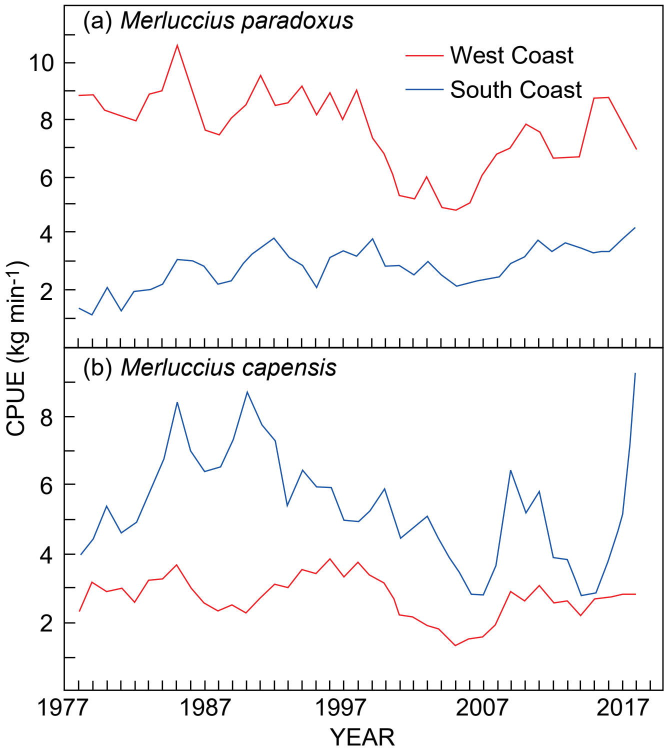

Figure 13: Coast and species-specific standardised indices of abundance (CPUE) for the deep-sea trawl sector. The CPUE indices are calculated using a GLM after application of the revised species-splitting algorithm to updated catch and effort data

Current status

Considerable effort has been directed at improving the data inputs and assessment structure prior to the routine review of the hake OMP that was conducted during 2018, including:

- The coding used to run the models was independently checked and verified, with some minor corrections being implemented.
- Intensive research on hake cannibalism and inter-specific predation yielded improved estimates of natural mortality-at-age. This enabled a reduction in the number of models that need to be considered within the reference set.
- The method of incorporating catch-at-length data into the assessment was revised.
- The species-splitting algorithm used to separate species-aggregated commercial catches was revised using both fishery-independent survey data and information recorded by scientific observers on commercial vessels, yielding updated species-specific catch (Figure 11) and CPUE (Figure 13) data for input to the assessments.

Key sources of uncertainty that needed to be encompassed by the 2018 RS were consequently reduced to:

- The central year of the shift from primarily *M. capensis* to *M. paradoxus* exploitation (1952, 1958 and 1963)
- The nature of the stock-recruit relationship for which three options were considered (Ricker, Beverton-Holt with steepness fixed at 0.9 and Beverton-Holt with steepness fixed at 0.7)

This matrix of uncertainties required an RS of nine operating models to be used in developing OMP-2018.

Implementation of these changes in the comprehensive assessments that were conducted during 2018 (which encompassed datasets extending to the end of 2016) yielded somewhat different perceptions to those of preceding years concerning current resource status, particularly in the case of *M. paradoxus*. Previous perceptions of the status of the hake resources (illustrated by the results of the 2017 RC assessment shown in Figure 14) suggested that while the *M. capensis* resource had been well above B_{MSY} since the early 1980s, the *M. paradoxus* resource had declined to below B_{MSY} for most of

Table 2: Parameter estimates for the reference set (RS) of operating models used in developing OMP-2018, which are also compared to those for the 2017 reference case model (2017 RC). The 2018 RS models encompassed three options for the central year of the shift from primarily *M. capensis* to *M. paradoxus* exploitation (1952, 1958 and 1963) and three options for the stock-recruit (S-R) function. The Beverton-Holt (B-H) stock-recruit options encompassed steepness parameters (*h*) set at either 0.7 or 0.9. Model RS02 (shaded) is viewed as the 2018 reference case model that provides the most plausible measures of stock status and dynamics

			M. paradoxus							*M. capensis*						
Model	Central year	S-R function	K^{sp}	B^{sp}_{MSY}	B^{sp}_{2017}	B^{tot}_{2017}	B^{sp}_{2017}/K^{sp}	$B^{sp}_{2017}/B^{sp}_{MSY}$	MSY	K^{sp}	B^{sp}_{MSY}	B^{sp}_{2017}	B^{tot}_{2017}	B^{sp}_{2017}/K^{sp}	$B^{sp}_{2017}/B^{sp}_{MSY}$	MSY
2017RC	1958	Ricker	515	115	127	245	0.25	1.11	137	196	63	141	334	0.72	2.23	81
RS01	1952		306	49	74	172	0.24	1.52	143	379	88	268	587	0.71	3.04	110
RS02	1958	Ricker	294	51	78	181	0.27	1.55	144	272	81	186	415	0.68	2.30	84
RS03	1963		245	58	89	201	0.36	1.53	146	437	134	323	701	0.74	2.41	106
RS04a	1952		443	42	65	164	0.15	1.54	142	410	80	31	90	0.08	0.39	54
RS05a	1958	B-H (*h* = 0.9)	435	42	68	172	0.16	1.65	141	483	97	24	75	0.05	0.25	63
RS06a	1963		457	44	86	206	0.19	1.96	144	584	121	18	60	0.03	0.15	83
RS04b	1952		751	170	233	474	0.31	1.37	122	514	146	82	195	0.16	0.56	48
RS05b	1958	B-H (*h* = 0.7)	739	167	222	456	0.3	1.33	121	579	166	66	164	0.11	0.40	55
RS06b	1963		820	186	321	658	0.39	1.73	134	718	206	55	140	0.08	0.27	70

K^{sp} Pre-exploitation biomass ('000t)
B^{sp}_{MSY} Spawning biomass yielding MSY ('000t)
B^{sp}_{2017} Spawning biomass in 2017 ('000t)
B^{tot}_{2017} Total biomass in 2017 ('000t)
B^{sp}_{2017}/K^{sp} Spawning biomass in 2017 relative to pre-exploitation biomass
$B^{sp}_{2017}/B^{sp}_{MSY}$ Spawning biomass in 2017 relative to biomass yielding MSY
MSY Maximum Sustainable Yield ('000t)

the 2000s, recovering to only slightly above MSY from 2011 onwards. The updated 2018 and 2019 RC models (Figure 14) indicated that while the status of *M. capensis* was slightly more positive than estimated previously, the *M. paradoxus* resource was appreciably above B_{MSY} from 2010 onwards. While this improvement could be partially attributed to the rebuilding strategy inherent in OMP-2010 and OMP-2014, the improvements to the assessment methodology and input data listed above have had a major influence.

The results of the full RS of 2018 models generally conform to this perception of the current status of the hake resources (Table 2), with estimates of *M. paradoxus* spawning biomass in 2017 (B^{sp}_{2017}) resulting from the various operating models ranging from 53% to 107% above B_{MSY}. Results for *M. capensis* across the RS models are considerably more variable, with three of the models (RS04a, RS04b and RS06b) estimating *M. capensis* spawning biomass in 2017 at below B_{MSY}. The remaining RS models estimate current (2017) *M. capensis* spawning biomass relative to B_{MSY} within the range 2.30 to 4.31. Given these results, a slightly more aggressive management strategy aimed at increasing the exploitation of the resource was considered during the 2018 review of the hake OMP.

The performances of various management strategies were evaluated through projections of stock status and TACs 25 years into the future as predicted by the various RS models within a simulation framework, and under the constraints imposed by the various management strategies considered. Management strategies that were considered comprised various combinations of an upper TAC bound, levels of the species-specific tuning parameter that determines the extent to which the TAC changes in response to changes in future abundance indices and whether or not the 2019 and 2020 TACs were fixed at a level 10% above the 2018 TAC. A suite of robustness tests were also conducted to ensure that the performance of the management strategies being considered would be robust to various major sources of future uncertainty (such as the frequency with which future surveys might be conducted, natural mortality-at-age vectors and carrying capacity).

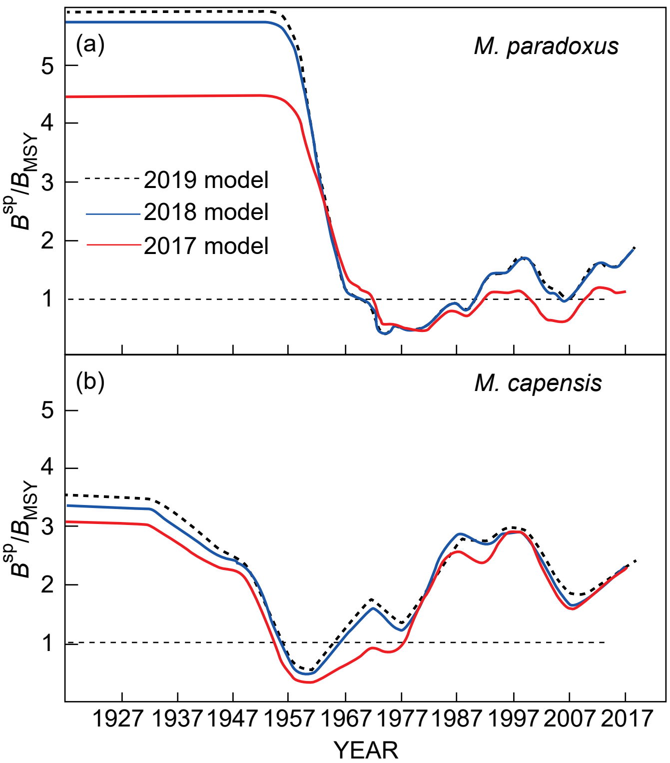

Figure 14: Trajectories of female spawning biomass (B^{sp}) relative to maximum sustainable yield biomass (B_{MSY}) estimated by the 2017, 2018 and 2019 reference case operating models.

The management procedure that was adopted as OMP-2018 following these analyses has the following general specifications:

a) The TAC for 2019 and 2020 is set at 146 431 tonnes per annum.
b) For 2021 and 2022, the TAC for each year is calculated as the sum of the intended species-disaggregated TACs.
c) The intended TAC for each species is calculated as a function of the difference between a measure of the immediate past level in the abundance indices (survey and CPUE) and a pre-specified target level.
d) A 160 000 tonne upper "hard cap" (i.e. the TAC over the period 2019–2022 may not exceed 160 000 tonnes per annum).
e) The TAC may not be increased by more than 10%, or decreased by more than 5% from one year to the next.
f) A "safeguard" meta-rule that over-rides the percentage TAC decrease constraint in the event of large declines in resource abundance. This allows the TAC to be decreased by more than 5% from one year to the next, depending on the level of the *M. paradoxus* resource relative to pre-specified thresholds.
g) An additional pre-specified *M. capensis* threshold below which action would be needed to reduce the catch of this species without reducing the catch of *M. paradoxus* unnecessarily.
h) "Exceptional Circumstances" provisions that regulate the procedures to be followed in the event that future monitoring data fall outside of the range simulated in the development of the OMP.

Ecosystem interactions

South Africa has committed to implementing an "ecosystem approach to fisheries management" (EAF). This approach extends fisheries management beyond the traditional single-species approach to the entire marine ecosystem. In 2006, the permit conditions for all sectors in the hake fishery contained a specific "ecosystem impacts of fishing" section for the first time, and reflected the first concrete step towards the implementation of an EAF in South Africa. These clauses in the permit conditions (and subsequent additions and improvements) are aimed at:

- Minimising seabird mortalities through the deployment of "tori" (bird-scaring) lines, management of offal discharge and regulating the nature of the grease on the trawl warps (substantial numbers of seabird mortalities have been attributed to the "sticky warps" phenomenon).
- Reducing damage to the seabed through restrictions on trawl gear and restriction of fishing operations by the demersal trawl fleet (both deep-sea and inshore) to the "trawl ring fence" area.
- Reducing bycatch through per-trip catch limits for kingklip, monkfish and kob as well as annual bycatch limits for kingklip and monkfish.
- Reducing bycatch through the "move-on" rule for kob, kingklip and snoek (if bycatch of these species is above a specified threshold, then the vessel may not redeploy fishing gear in that locality, but must move at least five miles away).
- Prevention of overharvesting of kingklip through a time-area closure on the Southeast Coast near Port Elizabeth where the species aggregates to spawn, rendering it susceptible to excessive catches.

Explicit in the permit conditions are also restrictions on fishing in specified fishery management areas (FMAs) and proclaimed marine protected areas (MPAs).

A procedure to limit fishing capacity in the hake trawl sectors (through matching the fishing capacity that is available to a Right Holder to their hake allocation) has been developed jointly with Industry and has been implemented (and reviewed each year) since 2008. This management tool has been effective in limiting the capacity in the trawl fishery, in terms of the number of active vessels as well as the number of days spent fishing, to what is required to catch the TAC.

Considerable effort is being directed at developing a management strategy for the inshore trawl sector that aims at minimising bycatch of potentially vulnerable chondrichthyan and linefish species. A co-management plan for this purpose has been developed through consultation between the South East Coast Inshore Fishing Association (SECIFA), the World Wide Fund For Nature (WWF) and academics at the University of Cape Town (UCT) and is currently being tested using a suite of experimental catch thresholds for 10 species. In parallel with this initiative, research efforts are being directed at formally assessing the status of a number of key hake trawl bycatch species (additional to kingklip, horse mackerel and monkfish, which are already assessed and managed). Key species have been identified, and work is progressing on collating available data and identifying and conducting the most appropriate assessment approaches.

In order to promote the continued certification of the South African hake trawl fishery by the MSC, the hake trawl industry implemented the "trawl ring fence" initiative in 2008 as a precautionary measure to address the issue of impacts of demersal trawling on marine benthic habitats. This voluntary initiative was a commitment by the industry to prevent the expansion of trawling into new areas until such time as an improved understanding of the impacts of bottom trawling on the sea floor has been reached. This measure was formalised in 2015 through incorporation into the permit conditions for the two trawl sectors, and will ensure that impacts on benthic habitats will not extend beyond currently fished areas. Research into the impacts of trawling on benthic habitats is being conducted through the "benthic trawl experiment", a collaborative initiative between DEFF, the South African Environmental Observation Network (SAEON), the South African National Biodiversity Institute (SANBI), UCT and the South African Deep Sea Trawling Industry Association (SADSTIA). The experiment involves a closure of specified locations in the Childs Bank area off the West Coast to trawling, while immediately adjacent sites remain open to fishing. A series of five annual surveys of the "trawled" and "untrawled" sites were conducted over the period 2014 to 2018. The surveys encompass monitoring of sediments and benthic infauna through use of cores and grab samples, as well as benthic epifauna using an underwater camera system. Analyses of the data collected during this research are in progress.

An ecological risk assessment (ERA) was conducted for the South African hake fishery in 2008 and progress was reviewed in 2011. The results of the 2011 review indicated a general improvement in the implementation of EAF considerations in the management of this fishery since the 2008 risk assessment.

Further reading

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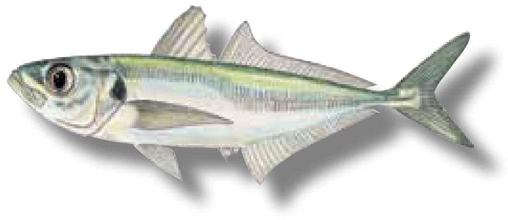
Useful statistics

Annual total allowable catch (TAC) limits and catches (tonnes) of the two species of hake by the hake-directed fisheries on the West (WC) and South (SC) coasts.

Year	TAC	*M. paradoxus*					*M. capensis*								TOTAL (both species)
		Deep-sea		Longline		TOTAL	Deep-sea		Inshore		Longline		Handline	TOTAL	
		WC	SC	WC	SC		WC	SC	SC	WC	WC	SC	SC		
1917		0					1.000							1.000	1.000
1918		0					1.100							1.100	1.100
1919		0					1.900							1.900	1.900
1920															
1921		0					1.300							1.300	1.300
1922		0					1.000							1.000	1.000
1923		0					2.500							2.500	2.500
1924		0					1.500							1.500	1.500
1925		0					1.900							1.900	1.900
1926		0					1.400							1.400	1.400
1927		0					0.800							0.800	0.800
1928		0					2.600							2.600	2.600
1929		0					3.800							3.800	3.800
1930		0					4.400							4.400	4.400
1931		0					2.800							2.800	2.800
1932		0					14.300							14.300	14.300
1933		0					11.100							11.100	11.100
1934		0					13.800							13.800	13.800
1935		0					15.000							15.000	15.000
1936		0					17.700							17.700	17.700
1937		0					20.200							20.200	20.200
1938		0					21.100							21.100	21.100
1939		0					20.000							20.000	20.000
1940		0					28.600							28.600	28.600
1941		0					30.600							30.600	30.600
1942		0.001				0.001	34.499							34.499	34.500
1943		0.001				0.001	37.899							37.899	37.900
1944		0.002				0.002	34.098							34.098	34.100
1945		0.004				0.004	29.196							29.196	29.200
1946		0.010				0.010	40.390							40.390	40.400
1947		0.020				0.020	41.380							41.380	41.400
1948		0.056				0.056	57.744							57.744	57.800
1949		0.106				0.106	57.294							57.294	57.400
1950		0.257				0.257	71.743							71.743	72.000
1951		0.620				0.620	88.880							88.880	89.500
1952		1.188				1.188	87.612							87.612	88.800
1953		2.395				2.395	91 105							91 105	93.500
1954		5.092				5.092	100.308							100.308	105.400
1955		10.229				10.229	105.171							105.171	115.400
1956		18.335				18.335	99.865							99.865	118.200
1957		31.885				31.885	94.515							94.515	126.400
1958		48.593				48.593	82.107							82.107	130.700
1959		71.733				71.733	74.267							74.267	146.000
1960		94.095				94.095	68.805		1.000					68.805	160.900
1961		97.390				97.390	51.310		1.308					52.618	150.008
1962		102.622				102.622	44.978		1.615					46.593	149.215
1963		121.695				121.695	47.805		1.923					49.728	171.423
1964		118.512				118.512	43.788		2.231					46.019	164.531
1965		149.541				149.541	53.459		2.538					55.997	205.538

Year	TAC	*M. paradoxus*					*M. capensis*							TOTAL (both species)
		Deep-sea		Longline		TOTAL	Deep-sea		Inshore	Longline		Handline	TOTAL	
		WC	SC	WC	SC		WC	SC	SC	WC	SC	SC		
1966		144.301				144.301	50.699		2.846				53.545	197.846
1967		131.066	4.260			135.326	45.634	9.926	3.154				58.714	194.040
1968		106.642	8.391			115.034	36.958	19.517	3.462				59.936	174.970
1969		122.685	11.412			134.097	42.415	26.518	3.769				72.703	206.799
1970		105.925	7.140			113.064	36.575	16.583	4.077				57.236	170.300
1971		150.177	9.065			159.242	51.823	21.050	4.385				77.258	236.500
1972		181.368	14.057			195.425	62.565	32.639	4.692				99.896	295.321
1973		117.318	21.782			139.100	40.464	50.574	5.000				96.088	235.138
1974		91.458	27.351			118.809	31.542	63.502	10.056				105.100	223.909
1975		66.637	20.310			86.947	22.980	47.153	6.372				76.505	163.452
1976		106.996	15.634			122.630	36.898	36.296	5.740				78.934	201.564
1977		76.089	11.131			87.219	26.239	25.841	3.500				55.581	142.800
1978		101.042	3.220			104.263	26.470	4.365	4.931				35.766	140.029
1979		94.331	1.924			96.255	39.192	4.995	6.093				50.280	146.535
1980		99.654	2.206			101.861	33.873	4.254	9.121				47.248	149.109
1981		88.883	910			89.793	32.048	4.575	9.400				46.023	135.816
1982		83.618	3.353			86.971	29.732	8.005	8.089				45.825	132.796
1983		71.238	4.723	0.126		76.088	23.195	7.792	7.672	0.104			38.763	114.851
1984		82.358	3.796	0.200	0.005	86.359	28.897	7.139	9.035	0.166	0.011		45.248	131.607
1985		94.428	8.059	0.638	0.091	103.216	30.642	11.957	9.203	0.529	0.201	0.065	52.597	155.813
1986		103.756	8.580	0.753	0.094	113.183	30.049	7.385	8.724	0.625	0.208	0.084	47.075	160.258
1987		93.517	7.459	1.952	0.110	103.038	24.008	8.225	8.607	1.619	0.243	0.096	42.798	145.836
1988		79.913	5.876	2.833	0.103	88.725	26.669	8.640	8.417	2.350	0.228	0.071	46.375	135.100
1989		82.230	6.182	0.158	0.010	88.581	25.029	12.730	10.038	0.132	0.022	0.137	48.087	136.668
1990		81.996	9.341	0.211		91.548	21.640	13.451	10.012	0.175		0.348	45.626	137.174
1991	145.000	87.093	12.448		0.932	100.474	19.357	9.626	8.206		2.068	1.270	40.526	141.000
1992	144.000	84.768	17.297		0.466	102.531	18.519	9.165	9.252		1.034	1.099	39.069	141.600
1993	146.000	102.125	9.880			112.005	15.940	4.380	8.870			0.278	29.468	141.473
1994	148.000	103.541	6.726	0.882	0.194	111.342	20.327	4.326	9.569	0.732	0.432	0.449	35.835	147.177
1995	151.000	100.268	4.004	0.523	0.202	104.997	20.629	3.146	10.630	0.434	0.448	0.756	36.043	141.040
1996	151.000	107.381	8.966	1.308	0.568	118.223	21.794	4.323	11.062	1.086	1.260	1.515	41.040	159.263
1997	151.000	100.654	10.509	1.410	0.582	113.155	16.500	5.327	8.834	1.170	1.290	1.404	34.525	147.680
1998	151.000	111.154	9.742	0.505	0.457	121.858	16.499	4.411	8.283	0.419	1.014	1.738	32.364	154.222
1999	151.000	88.581	11.420	1.532	1.288	102.822	15.179	3.926	8.595	1.272	2.856	2.749	34.577	137.399
2000	155.500	96.587	7.700	2.706	3.105	110.098	21.114	5.830	10.906	2.000	1.977	5.500	47.327	157.426
2001	166.000	101.247	7.850	1.417	0.084	110.598	16.349	8.306	11.836	2.394	1.527	7.300	47.713	158.311
2002	166.000	91.207	12.443	4.469	1.585	109.704	13.724	6.141	9.581	2.391	2.546	3.500	37.883	147.587
2003	163.000	93.711	17.397	3.305	1.252	115.665	11.665	7.636	9.883	2.526	3.078	3.000	37.788	153.453
2004	161.000	85.722	26.065	2.855	1.196	115.838	12.510	8.704	10.004	2.297	2.731	1.600	37.846	153.684
2005	158.000	85.869	21.778	3.091	0.472	111.210	9.398	7.468	7.881	2.773	3.270	0.700	31.490	142.700
2006	150.000	81.513	18.050	3.241	0.485	103.289	11.984	6.578	5.524	2.520	3.227	0.400	30.233	133.522
2007	135.000	92.724	13.488	2.512	3.021	111.745	16.145	3.757	6.350	2.522	2.522	0.400	31.696	143.441
2008	130.532	85.538	13.191	2.255	0.809	101.792	13.838	4.316	5.496	1.937	1.893	0.231	27.711	129.503
2009	118.578	68.202	10.895	2.410	1.069	82.576	12.296	4.806	5.639	2.828	2.520	0.265	28.354	110.930
2010	119.831	69.709	15.457	2.394	1.527	89.087	10.186	4.055	5.472	3.086	3.024	0.275	26.098	115.185
2011	131.780	76.576	17.904	2.522	0.140	97.142	15.673	4.086	6.013	3.521	3.047	0.186	35.525	129.667
2012	144.671	81.411	16.542	4.358	0.306	102.616	12.928	4.584	3.223	2.570	1.737	0.008	25.050	127.666
2013	156.075	74.341	28.859	6.056	0.060	109.316	8.761	4.475	2.920	2.606	1.308	0.000	20.071	129.387
2014	155.280	73.252	41.156	6.879	0.008	121.295	9.671	6.286	2.965	2.123	0.315	0.001	21.361	142.656
2015	147.500	77.521	31.745	4.001	0.018	113.286	12.727	4.085	3.077	2.325	0.053	0.001	22.217	135.503
2016	147.500	93.173	18.968	2.806	0.001	114.948	14.744	2.810	3.973	4.360	0.002	0.001	25.889	140.837
2017	140.125	72.326	30.961	5.288	0.025	108.600	15.273	4.466	2.812	2.807	0.126	0.004	25.488	134.088
2018	133.119	64.252	29.218	5.156	0.089	98.715	12.689	12.863	3.983	2.615	0.481	0.024	32.655	131.370
2019	146.431													

Cape horse mackerel



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

Cape horse mackerel (*Trachurus capensis*) are semi-pelagic shoaling fish that occur on the continental shelf off southern Africa from southern Angola to the Wild Coast. Off South Africa, adult horse mackerel are currently more abundant off the South Coast than the West Coast (Figure 15). They are replaced by the very similar Cunene horse mackerel (*T. trecae*) and African horse mackerel (*T. delagoa*) to the north and east, respectively. Horse mackerel as a group are characterised by a distinct dark spot on the gill cover and a row of enlarged scutes (spiny scales) along the S-shaped lateral line. It is difficult, however, to distinguish between the three species that occur off southern Africa. Cape horse mackerel generally reach

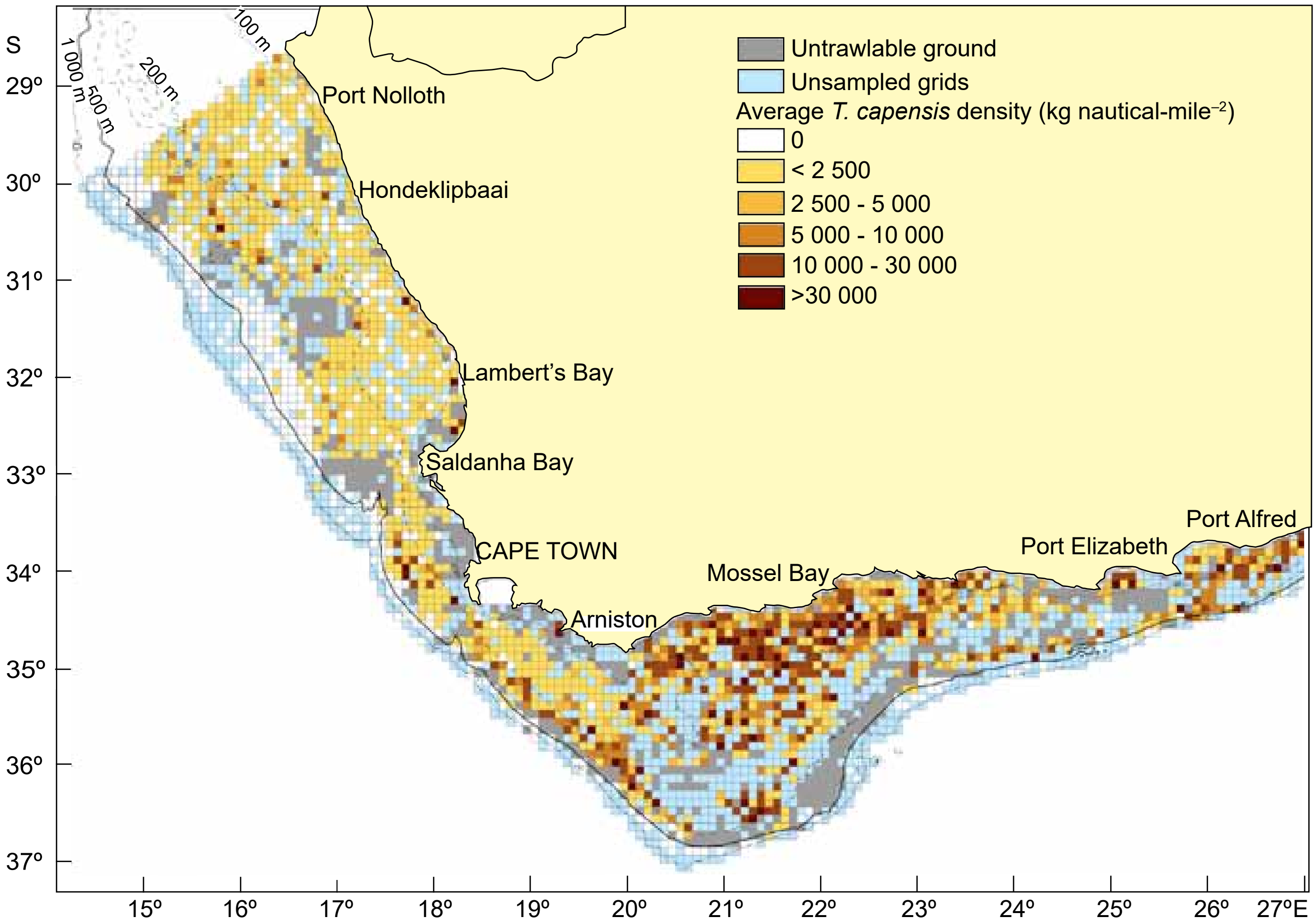


Figure 15: Distribution of Cape horse mackerel *Trachurus capensis* in South African waters, as derived from fishery-independent demersal research surveys. Data are shown as the average density (kg nautical-mile^{-2}) per grid block over surveys conducted from 1986 to 2017

40–50 cm in length and become sexually mature at about three years of age when they are roughly 20 cm long. They feed primarily on small crustaceans such as copepods and euphausiids, which they ingest using their protrusible mouths and filter with their modified gill rakers.

Historically, large surface schools of adult Cape horse mackerel occurred on the West Coast and supported a purse-seine fishery that made substantial catches, particularly during the early 1950s (Figure 16). These large schools have since disappeared from the South African West Coast but still occur off Namibia, where horse mackerel catches dominate marine fishery landings. Purse-seine catches of Cape horse mackerel on the West Coast of South Africa currently comprise mainly juvenile fish that shoal together with, and are caught as incidental bycatch during directed fishing for, small pelagic species such as sardine and anchovy.

Adult Cape horse mackerel are currently caught as incidental bycatch by the hake-directed demersal trawl fleet and as a targeted catch by the midwater trawl fleet, mainly on the South Coast. At present, the midwater trawl fleet comprises a single, large midwater trawler (the FV *Desert Diamond*, which lands about 70% of horse mackerel trawl catches) and a number of smaller hake trawlers carrying both hake and horse mackerel Rights (the so-called "dual Rights vessels") that allow them to opportunistically target horse mackerel with midwater gear additional to their normal hake fishing operations using demersal trawl gear. Horse mackerel yield a low-value product and are a source of cheap protein.

History and management

Purse-seine catches of adult Cape horse mackerel on the West Coast peaked at 118 000 t in the early 1950s (Figure 16) and declined to negligible levels by the late 1960s. In the 1990s, purse-seine catches of Cape horse mackerel (now comprising largely juvenile fish taken as bycatch in anchovy-directed fishing) again showed an increasing trend, reaching 26 000 t in 1998. This increase raised concerns as to the likely effects of large catches of juvenile Cape horse mackerel on the trawl fishery for adults. Analyses exploring this potential impact indicated a pronounced yield-per-recruit effect, leading to the introduction of an annual 5 000 t precautionary upper catch limit (PUCL) for horse mackerel in the purse-seine fishery in 2000. Subsequent to this measure being implemented, the average annual horse mackerel catch by the purse-seine fleet has been 3 400 t. The 5 000 t annual PUCL was changed to a "PUCL3" system in 2013 to enable flexibility in horse mackerel bycatch management within the small pelagic purse-seine sector. This system, which effectively uses a three-year "running average" catch limit approach, was developed to enable continued fishing for anchovy by the purse-seine fleet during periods of unusually high juvenile horse mackerel abundance (as was the case during 2011).

In the 1950s and 1960s, trawl (midwater and demersal) catches of horse mackerel on the South Coast were incidental to directed hake and sole fishing and amounted to less than 1 000 t per annum. Japanese vessels using midwater trawl gear then began targeting the resource in the mid-1960s and catches rapidly escalated, peaking at over 116 000 t in 1977. Following the declaration of the South African exclusive fishing zone (EFZ) in 1977, foreign participation in the fishery was controlled and catches stabilised at between 27 000 t and 58 000 t per annum. When foreign fleets were finally phased out in 1992, annual catches (now by South African vessels only) declined to about 10 000 t in 1995. Whereas demersal trawl catches have subsequently remained low, the re-establishment of a midwater trawl fishery for Cape horse mackerel in 1997 resulted in an increase in the annual catch (Figure 16),

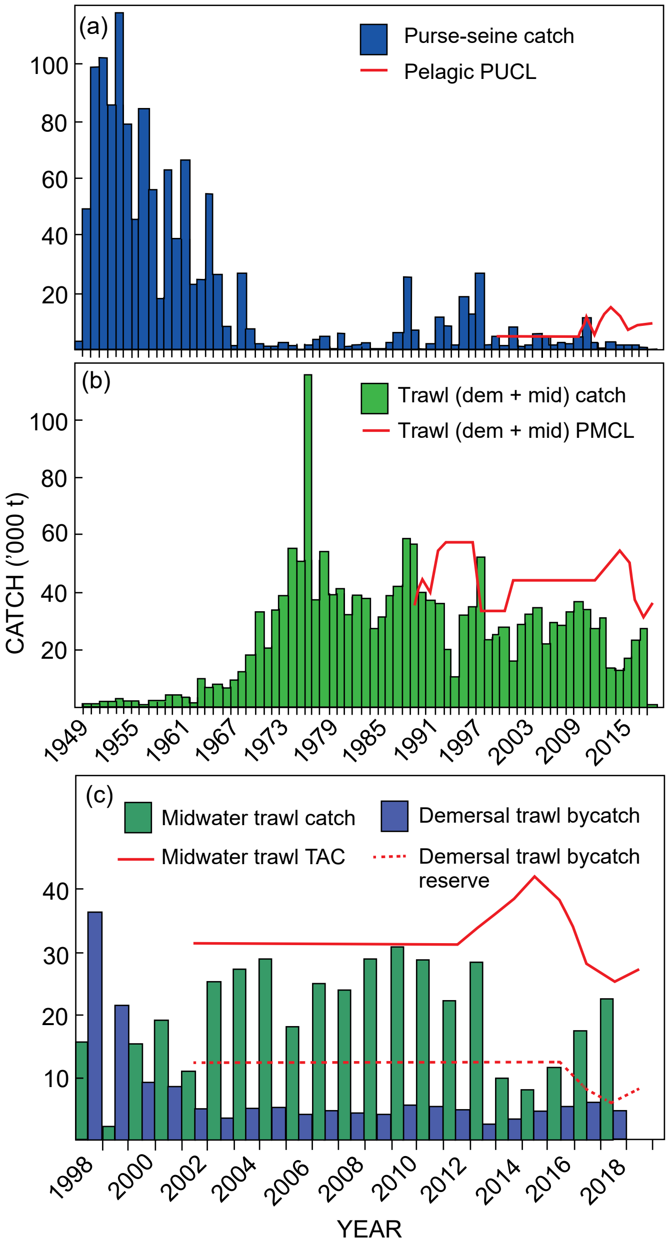


Figure 16: Catches and catch limits of Cape horse mackerel *Trachurus capensis*. (a) Pelagic purse-seine catches 1949–2018 and the precautionary upper catch limit (PUCL) first imposed on the fishery in 2000. (b) Trawl (demersal and midwater combined) catches 1949–2018 and the precautionary maximum catch limit PMCL) first imposed in 1990. Catches cannot be reliably separated by sector (demersal versus midwater) or fleet (local versus foreign) prior to 1998. (c) Trawl catches 1998–2018 (all by SA vessels) split into the demersal and midwater trawl components. The midwater trawl TAC (solid line) and demersal trawl bycatch reserve (dashed line) are also shown

which has fluctuated between 8 000 t and 31 000 t since the 2000 fishing season.

Annual total allowable catch (TAC) restrictions for the trawl fishery (both demersal and midwater components) were set for 1990 (35 000 t) and 1991 (45 000 t) using assessments of the resource based on catch per unit effort (CPUE) data derived from the Japanese fleet, combined with survey biomass and egg abundance indices. With the phasing out of the foreign fleets in 1992, the Japanese CPUE time-series was terminated and this modelling approach was no longer appropriate. A precautionary maximum catch limit (PMCL) of 40 000 t was set for 1992. Thereafter, a yield-per-recruit modelling approach was adopted on which to base PMCLs until 1999, when an age-structured production model (ASPM) of the resource was developed. Biomass projections using the model indicated that a PMCL of 34 000 t for the trawl fishery combined with the 5 000 t PUCL for the purse-seine fishery would be appropriate, and these catch restrictions were imposed for the 2000 fishing season. The trawl PMCL was increased to 44 000 t for 2002, and was maintained at that level until 2012. Between 2002 and 2012, the trawl PMCL was separated into a 12 500 t reserve to account for incidental bycatch of horse mackerel in the hake demersal trawl fishery, and a 31 500 t allocation for the directed midwater trawl sector.

In 2012, an operational management procedure (OMP; see the section on Cape hakes) was implemented for the directed midwater trawl fishery to improve utilisation of the resource (to allow increased catches during periods of high horse mackerel abundance) without undue increase in the risk of unintended reduction of resource abundance. The horse mackerel OMP incorporated a harvest control rule that adjusted the annual TAC each year (either upwards or downwards) depending on the level of current resource abundance indices relative to averages over a fixed past period. Note that this approach applied only to the directed midwater trawl fishery; the 12 500 t demersal trawl bycatch reserve, which had been in place since 2002, was maintained. Implementation of the midwater harvest control rule resulted in 10% per annum increases in the midwater TAC over the period 2013–2015.

The 2015 assessment of the horse mackerel resource was conducted in circumstances where the only reliable index of horse mackerel abundance (the commercial CPUE for the FV *Desert Diamond*) was at a level in 2014 that was appreciably lower than the bounds projected by the horse mackerel OMP, having declined from a relatively high level the previous year (Figure 17). In these Exceptional Circumstances, it was recognised that the horse mackerel OMP was no longer an appropriate means of providing scientific advice for the management of the resource. Initial analyses demonstrated that the available data were insufficient to inform on whether the low CPUE reflected a decline in catchability or an increase in natural mortality. Further analyses encompassing a suite of possible management responses that included both TAC reductions and effort limitations were conducted. Following consideration of these analyses, it was agreed that the most appropriate precautionary approach for managing the horse mackerel resource would be to set the midwater component of the 2016 TAC at the level indicated by the OMP (38 658 tonnes) and to additionally implement an effort limitation scheme that would restrict the midwater trawl effort in 2016 to a level comparable to the annual average realised over the 2010 to 2013 period.

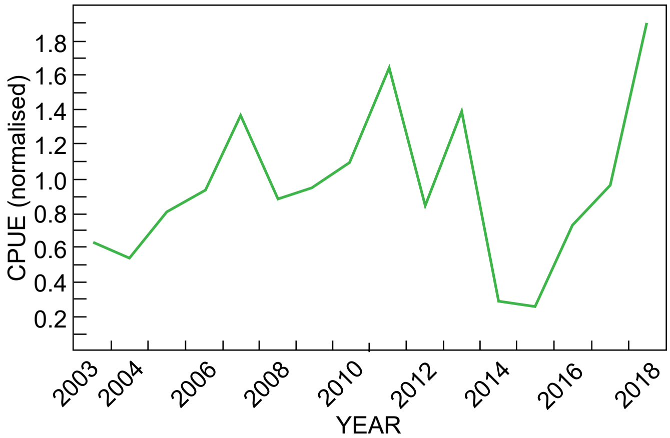


Figure 17: Annual standardised CPUE estimates for the midwater trawler FV *Desert Diamond* over the period 2003–2018. Note that the series of estimates have been normalised to the mean, and that due to the absence of scientific observers on the vessel in 2015 (and consequently lack of drag-level data required for the CPUE standardisation), the value for 2015 is an estimate derived from a comparison of standardised and crude nominal (catch per trip) CPUE estimates

These measures would avoid the necessity for a substantial reduction in the TAC, and would allow for the possibility of large midwater catches in the event that the 2014 CPUE reflected a downward fluctuation in catchability, rather than an increased natural mortality event.

The low-CPUE circumstances persisted until 2017, and assessments conducted in 2016 and 2017 consequently followed the same approach as described above, resulting in recommendations for maintaining the effort limitation scheme as well as for sequential reductions in both the midwater TAC and demersal trawl bycatch reserve for the 2017 and 2018 fishing seasons.

Although the CPUE in 2017 had increased from the low levels observed in the previous year, the assessment conducted in 2018 followed the same approach as previously, and yielded results that were slightly more optimistic. Further analyses indicated that the slightly reduced rate of resource recovery under a relaxed effort-restriction strategy in the event that the increased-mortality hypothesis is correct was an acceptable trade-off for the somewhat larger future catch that is likely under this management strategy. The midwater trawl effort limit for the 2019 fishing season was consequently increased by about 18% with a corresponding increase in the midwater trawl horse mackerel TAC to 27 670 tonnes (the catch expected in 2019 under the reduced-catchability hypothesis).

Research and monitoring

The assessment and management of the horse mackerel resource is currently limited by uncertainties regarding resource abundance. Fishery-independent indices of abundance that are used in the assessment are derived from the demersal hake-directed surveys conducted on the South Coast (Figure 18). However, because horse mackerel can occur at any depth within the water column, an unknown proportion of the biomass is distributed above the headline of the demersal trawl gear used for the surveys and is therefore not sampled. It is also likely that the proportion of the biomass that is available

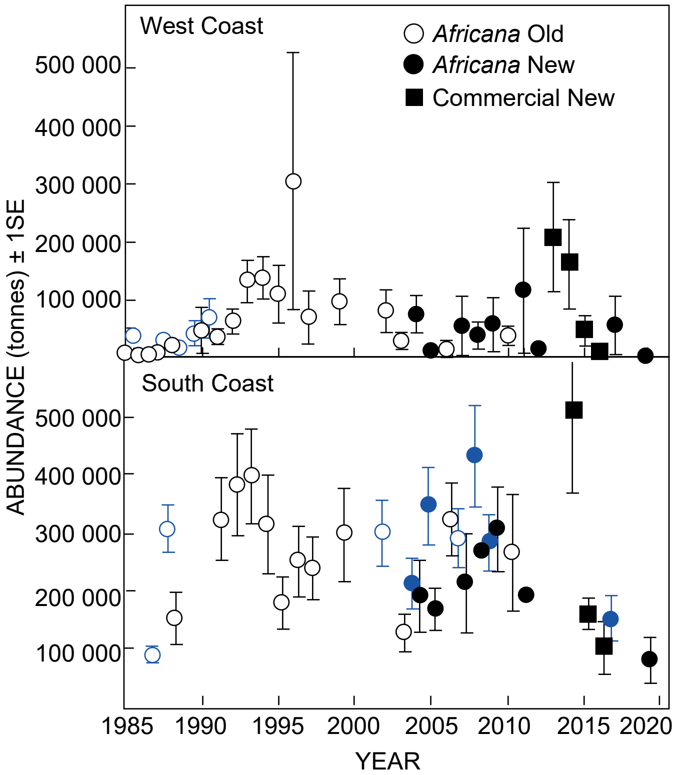


Figure 18: Cape horse mackerel *Trachurus capensis* abundance estimates (tonnes) derived from fishery-independent swept area demersal surveys. Estimates are illustrated by coast for the various vessel-gear combinations. Summer (West Coast) and autumn (South Coast) surveys are indicated with black symbols, while winter (West Coast) and spring (South Coast) surveys are indicated with blue symbols. Note that surveys that only extended to the 200-m isobath have been excluded from the figures, and that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability. *Africana* = research vessel FRS *Africana*, Commercial = commercial fishing vessel'

to demersal trawl gear varies between surveys. Trends in the time-series of survey abundance indices could consequently be influenced by changes in availability as well as by changes in abundance.

Unfortunately, acoustic methods are also unable to provide unbiased biomass estimates as it is not possible to detect horse mackerel acoustically when they are close to the seabed. A dedicated horse mackerel survey employing both demersal trawl and hydro-acoustic techniques in combination was conducted in 2016 in an attempt to quantify the level of error inherent in the estimates of horse mackerel abundance derived from the hake-directed surveys. Analysis of the hydro-acoustic data collected during the survey indicated that a negligible proportion of horse mackerel biomass was distributed above the headline of the demersal trawl gear during sampling, suggesting that the demersal surveys do, in fact, provide a useful index of horse mackerel abundance.

A second source of information concerning resource abundance has recently been developed from commercial midwater trawl catch and effort data. CPUE data are standardised using generalised linear modelling techniques to account for factors such as depth, location, time of day, lunar phase and wind speed.

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Current status

The 2019 assessment of the horse mackerel resource was conducted in circumstances in which the commercial CPUE index of abundance had increased to a level in 2018 that was the highest on record. This observation suggested that the large-mortality-event hypothesis employed in recent assessments was less likely (it is unlikely that recovery from a large increased mortality event would have occurred in such a short period of time). The results of an assessment that assumed a period of large natural mortality showed a much poorer fit to the data than did the assessments that assumed a period of reduced catchability (Table 3), and the large-mortality-event hypothesis was consequently not considered in further analyses. A suite of assessments that included gear-specific selectivity functions and explored different natural mortality (M) at age variants was then conducted. Increasing M yields lower estimates of the absolute magnitudes of spawning biomasses (Table 4), as well

Table 3: Results for the four different operating model variants exploring the catchability and mortality hypotheses. The negative log likelihood (-lnL) is a measure of how well the models fit the data, with a smaller value reflecting a better fit. For definitions of symbols see Table 2

		Catchability unchanged	Catchability low 2014–2016	Catchability low 2014–2015	Increased mortality 2014
-lnL	Negative log likelihood	-228.376	-263.161	-262.56	-126.362
K^{sp}	Pre-exploitation spawning biomass ('000 t)	709	760	758	709
B^{sp}_{2018}	Spawning biomass ('000 t) in 2018	420	465	456	251
B^{sp}_{MSY}	Spawning biomass ('000 t) yielding MSY	174	186	185	184
MSY	Maximum sustainable yield ('000 t)	53	55	55	96
B^{sp}_{2018}/K^{sp}	Depletion in 2018	0.592	0.612	0.601	0.354

Table 4: Results for the new base case model (2019 BC) compared to the previous base case (2018 BC) as well as two model variants exploring different natural mortality (*M*) scenarios. VAR1 applies a high *M* to the older (10+ years) age groups whilst age groups 9 and younger are subjected to an *M* of 0.3. VAR2 subjects all ages to an *M* of 0.5. The base-case models both assume *M* = 0.3 for all ages. The negative log likelihood (-lnL) is a measure of how well the models fit the data, with a smaller value reflecting a better fit. For definitions of symbols see Table 2

		2018 BC $M_a = 0.3$	2019 BC $M_a = 0.3$	VAR1 $M_{0\text{-}9} = 0.3$ $M_{10+} = 2.0$	VAR2 $M_a = 0.5$
-lnL	Negative log likelihood	-260.35	-257.571	-257.421	-257.153
K^{sp}	Pre-exploitation spawning biomass ('000 t)	789	799	580	441
B^{sp}_{2018}	Spawning biomass ('000 t) in 2018	512	525	385	340
B^{sp}_{MSY}	Spawning biomass ('000 t) yielding MSY	193	196	155	107
MSY	Maximum sustainable yield ('000 t)	58	58	59	65
B^{sp}_{2018}/K^{sp}	Depletion in 2018	0.649	0.658	0.633	0.771

as estimates of biomass yielding maximum sustainable yield (MSY) and MSY itself. In all cases, however, the estimates of current (2018) spawning biomass are well above those for the biomass that yields MSY. Results generated by the 2019 base-case operating model suggests that the Cape horse mackerel resource is currently at about 66% of pre-exploitation biomass, and more than double the level that produces MSY.

Projections of future resource status using this suite of assessment models under various management options (that took account of incidental pelagic and demersal bycatch) indicated that all future levels of midwater catch would lead to a reduction in spawning biomass and CPUE in median terms. For midwater catches up to 30 000 tonnes per annum, however, this was not a concern in terms of stock status, which remained well above MSY level (although CPUE would be expected to drop by about 15%). Projections were somewhat more pessimistic if the lower 5 percentiles of the depletion distributions were considered rather than the medians. In view of these results, there was no compelling reason to alter the management measures imposed for the previous fishing season, and all catch and effort limits that were set for 2019 were maintained for the 2020 fishing season.

Ecosystem interactions

The midwater trawl fleet currently comprises a few relatively small demersal hake trawlers that are permitted to carry midwater gear in addition to the standard demersal trawl gear (the so-called "dual Rights vessels"), and a single large, dedicated midwater trawler. The vessels using dual hake and horse mackerel permits must also comply with restrictions applied to the demersal hake trawl fishery aimed at minimising other ecosystem impacts such as damage to benthic habitats and bycatch of non-target species (see the section on Cape hakes).

All vessels catching horse mackerel (those conducting horse-mackerel-directed midwater trawling as well as demersal hake trawlers catching horse mackerel as incidental bycatch) are required by permit condition to deploy bird-scaring ("tori") lines and refrain from discharging offal while trawling in order to minimise seabird mortalities.

The dedicated midwater trawler uses a large midwater net that catches a number of non-target species, including marine mammals, sunfish and various large pelagic shark species. These incidental catches have raised a number of conservation concerns. Recent research has been directed at evaluating the extent of these catches, as well as their potential impacts on the populations concerned. Preliminary results suggest that, on average, annual catches of the bycatch species are relatively low, suggesting no immediate cause for concern. There have been cases, however, of isolated short-term events of large catches of certain species. Further research is being directed at evaluating whether or not such cases reflect more serious impacts than the long-term averages would suggest.

Research has also been directed at developing an effective bycatch mitigation device to mitigate catches of the larger bycatch species. Collaborative efforts with the fishing industry have tested various configurations of such a device, but have as yet been unsuccessful.

Further reading

Barange M, Pillar SC, Hampton I. 1998. Distribution patterns, stock size and life-history strategies of Cape horse mackerel *Trachurus trachurus capensis*, based on bottom trawl and acoustic surveys. *South African Journal of Marine Science* 19: 433–447

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Kerstan M, Leslie RW. 1994. Horse mackerel on Agulhas bank - summary of current knowledge. *South African Journal of Marine Science,* 90: 173–178.

McLaverty KJ. 2012. A re-evaluation of the life history strategy of Cape horse mackerel, *Trachurus capensis* in the southern Benguela. MSc thesis, University of Cape Town, South Africa. Available at https://open.uct.ac.za/handle/11.

Useful statistics

Catches and catch limits of Cape horse mackerel *Trachurus capensis* in South African waters. Note that trawl catches cannot be reliably separated be sector (demersal versus midwater) or fleet (local versus foreign) prior to 1998. Dem = demersal; Mid = midwater; Pel = pelagic; Dem Res = demersal trawl bycatch reserve

	Catch (t)	
Year	Purse-seine	Trawl (Dem+Mid)
1949	3.360	
1950	49.900	0.445
1951	98.900	1.105
1952	102.600	1.226
1953	85.200	1.456
1954	118.100	2.550
1955	78.800	1.926
1956	45.800	1.334
1957	84.600	0.959
1958	56.400	2.073
1959	17.700	2.075
1960	62.900	3.712
1961	38.900	3.627
1962	66.700	3.079
1963	23.300	1.401
1964	24.400	9.522
1965	55.000	7.017
1966	26.300	7.596
1967	8.800	6.189
1968	1.400	9.116
1969	26.800	12.252
1970	7.900	17.872
1971	2.200	33.329
1972	1.300	20.560
1973	1.600	33.900
1974	2.500	38.391
1975	1.600	55.459
1976	0.400	50.981
1977	1.900	116.400
1978	3.600	37.288
1979	4.300	53.583
1980	0.400	39.139
1981	6.100	41.217
1982	1.100	32.176
1983	2.100	38.332
1984	2.800	37.969

	Catch (t)				Catch limits (t)			
Year	Purse-seine	Dem	Mid	Trawl (Dem+Mid)	Pel PUCL	Mid TAC	Dem Res	Trawl PMCL
1985	0.700			27.278				
1986	0.500			31.378				
1987	2.834			38.571				
1988	6.403			41.482				
1989	25.872			58.206				
1990	7.645			56.721				35.000
1991	0.582			39.759				45.000
1992	2.057			37.208				40.000
1993	11.651			35.998				55.000
1994	8.207			20.030				58.000
1995	1.986			10.790				58.000
1996	18.920			31.846				58.000
1997	12.654			31.671				58.000
1998	26.680	36.279	15.770	52.049				34.000
1999	2.057	21.580	2.161	23.741				34.000
2000	4.503	9.229	15.408	24.637	5.000			34.000
2001	0.915	8.814	19.198	28.011	5.000			34.000
2002	8.148	4.863	11.098	15.961	5.000	31.500	12.500	44.000
2003	1.012	3.562	25.306	28.869	5.000	31.500	12.500	44.000
2004	2.048	4.933	27.153	32.086	5.000	31.500	12.500	44.000
2005	5.627	5.280	28.998	34.278	5.000	31.500	12.500	44.000
2006	4.824	4.133	18.057	22.190	5.000	31.500	12.500	44.000
2007	1.903	4.812	25.028	29.840	5.000	31.500	12.500	44.000
2008	2.280	4.449	23.772	28.221	5.000	31.500	12.500	44.000
2009	2.087	4.129	29.019	33.147	5.000	31.500	12.500	44.000
2010	4.353	5.596	30.791	36.387	5.000	31.500	12.500	44.000
2011	10.990	5.228	29.048	34.277	12.000	31.500	12.500	44.000
2012	2.199	4.941	22.579	27.520	5.000	31.500	12.500	44.000
2013	0.596	2.695	28.417	31.112	12.469	34.650	12.500	47.150
2014	2.760	3.087	10.053	13.140	15.194	38.115	12.500	50.165
2015	2.040	4.747	7.976	12.723	12.233	41.927	12.500	54.427
2016	1.588	5.230	11.613	16.843	7.268	38.658	12.500	51.158
2017	1.466	5.703	17.545	23.234	8.372	28.200	8.004	36.204
2018	0.967	4.626	22.775	27.400	8.947	25.500	5.977	31.477
2019					9.567	27.670	8.455	36.125

Kingklip

Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

Kingklip *Genypterus capensis* (Figure 19) belongs to the cusk-eel family (Ophidiidae) and is a demersal fish that is endemic to southern Africa. Its distribution ranges from Walvis Bay in Namibia to KwaZulu-Natal in South Africa (although there are indications that their distribution extends even further eastwards). Kingklip are found at depths between 50 m and 800 m (Figure 20), generally in rocky areas on the continental shelf and shelf edge. Juveniles feed on benthic fish, crustaceans and squid, whereas the diet of the adults consists almost entirely of demersal fish. Kingklip move further offshore (and deeper) as they get older, with juveniles largely restricted to depths shallower than 200 m. They are relatively slow-growing and long-lived (about 25 years), and grow to lengths of up to 1.6 m. Although female kingklip grow faster than males, male fish generally reach maturity at a younger age than do females. Males also appear to mature later on the West Coast than on the South Coast. Length at 50% maturity for male fish on the West Coast is approximately 65.5 cm (~5 years) and on the South Coast about 62 cm (~4 years). The length at 50% maturity for females is 81 cm (~6.5 years) and 72.5 cm (~5.6 years) on the West and South coasts, respectively. Spawning takes place on both the West and South coasts, generally from autumn to spring, with peak spawning between June and September. Kingklip form large aggregations to spawn and the largest known such aggregation is on the Southeast Coast near Port Elizabeth. Although the kingklip resource is relatively small in comparison to other exploited South African fish populations, it is an important bycatch species due to its high market value and is of appreciable economic importance to several South African fisheries. Kingklip is currently mostly caught as incidental bycatch by the hake trawl and hake longline sectors.

Figure 19: Kingklip *Genypterus capensis*. Photograph courtesy of SAEON

Recent research suggests that there are genetically separate stocks on the West and South coasts, but with some degree of gene flow between the two components. The degree of demographic separation remains unknown, and the current management approach consequently assumes a single stock distributed around the coast of South Africa, separate from the stock in Namibian waters.

History and management

Annual catches of kingklip (all taken as incidental bycatch by the hake trawl fleet prior to 1983) fluctuated between 400 t and 700 t in the 1930s and 1940s (Figure 21), and then increased steadily to a peak of 5 800 t in 1973, with most of the catch being taken on the West Coast. Catches then fluctuated between about 3 000 and 5 000 t until the start of the kingklip-directed longline fishery in 1983. The substantially increased catches made by the longline sector over the period 1983–1989 (peaking at over 8 000 t in 1986) clearly impacted the resource and catches in both longline and trawl sectors decreased until the directed longline fishery was closed in 1990. An almost immediate increase in catches by the hake trawl sectors followed, reaching a peak of 4 759 t in 2002. This peak coincided with increased levels of kingklip bycatch in the hake-directed longline fishery that had been established in 1994. Bycatch of kingklip in both the hake trawl and longline fisheries then showed a decline, prompting the introduction of an annual precautionary upper catch limit (PUCL) in 2005 (Figure 21) that has subsequently been retained as the primary regulatory measure for the resource. This PUCL is a "global" catch limit that applies to the hake-directed sectors (trawl and longline) in which kingklip is caught as bycatch. Efforts to ensure that the PUCL is not exceeded have followed a co-management approach, with the Department interacting closely with the relevant fishing associations.

The results of the first assessment of the kingklip resource conducted in 1992 indicated that the resource was severely depleted. A subsequent assessment undertaken in 2002 used a deterministic age-structured production model (ASPM) and indicated limited recovery (10%) of the resource since the previous assessment. Projections indicated that catches of 3 000 t per annum would keep the stock relatively stable, and this was the basis for the 3 000 t PUCL introduced in 2005. The PUCL was increased to 3 500 t for 2006, and was subsequently maintained at this level until 2014 (Figure 21). An updated assessment was conducted in 2008 using catch and survey abundance data that had since become available. The assessment indicated that estimates of resource status were very sensitive to assumptions with respect to stock structure. If the kingklip on the South African coast is regarded as a single stock, then the resource was estimated to be fully exploited. However, if West and South Coast stocks are assumed to be separate, then the West Coast stock was estimated to be healthy whereas the South Coast stock was estimated to be over-exploited. The 2008 updated assessment suggested further analyses were required before an alteration to the PUCL could be considered. Additionally, a seasonal (September–November) closed area on the shelf edge near Port Elizabeth was implemented in 2008 as a management tool to assist the recovery of the stock by protecting a spawning aggregation.

The kingklip PUCL was increased to 5 264 t for the 2014 season based on the results of a simple replacement yield (RY) assessment of the resource conducted during 2013, and this level was maintained for the 2015 and 2016 fishing seasons. An updated RY assessment was conducted in 2016, during which difficulties in properly estimating survey catchability resulted in some uncertainty regarding reliable estimates of replacement yield. Confronted with this uncertainty, a relatively conservative approach was adopted and the PUCL was reduced to 4 450 tonnes for the 2017 fishing season. An ASPM assessment was conducted in early 2017, but problems were encountered in obtaining satisfactory fits to the available data, again leading to unreliable results. No further adjustments to the PUCL were implemented for the 2018 and 2019 fishing seasons.

Research and monitoring

Abundance estimates for kingklip (Figure 22) are derived from demersal research surveys conducted using the swept-area

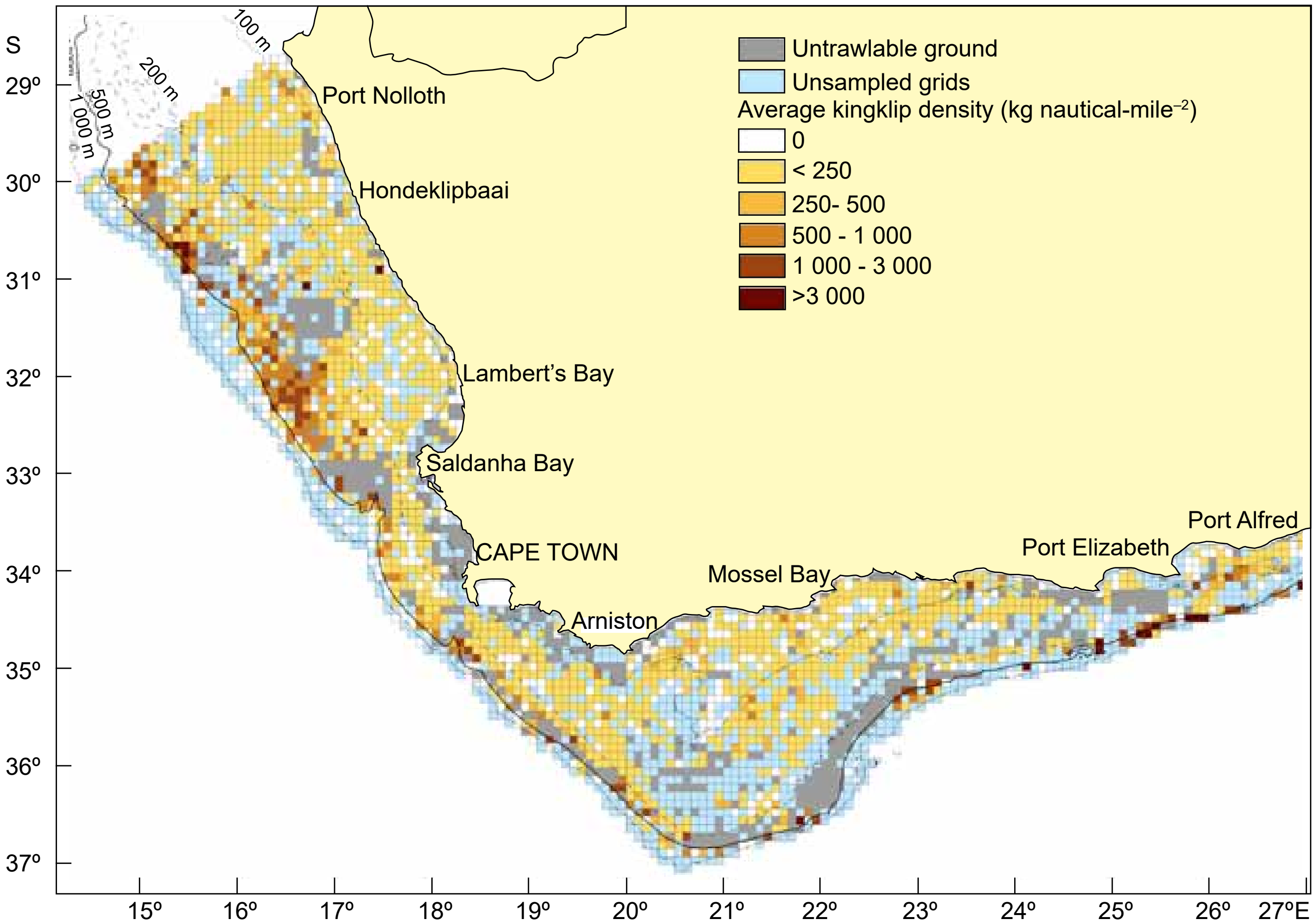


Figure 20: Distribution of kingklip *Genypterus capensis* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical-mile^{-2}) are averages over all survey stations within each survey grid block

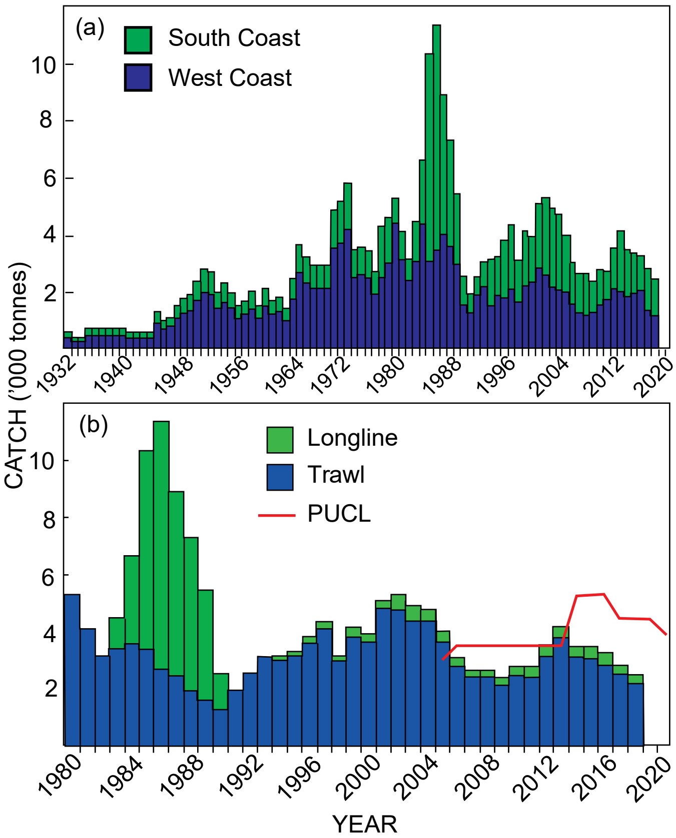


Figure 21: (a) Annual catches (tonnes) of kingklip *Genypterus capensis* on the West and South Coast for the period 1932–2018. (b) Annual catches per fishing sector for the period 1980–2018 (catches prior to 1983 were all made by the trawl fishery), and the precautionary upper catch limit (PUCL) that was introduced in 2005

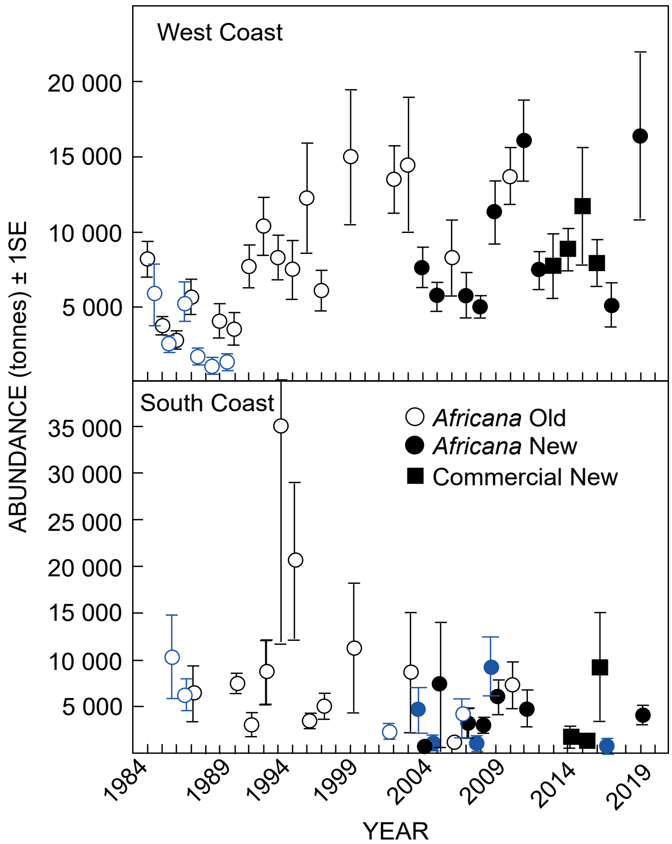


Figure 22: Kingklip abundance estimates (tonnes ± 1 SE) derived from fishery-independent swept area demersal surveys. Estimates are illustrated by coast for the various vessel-gear combinations. Summer (West Coast) and autumn (South Coast) surveys are indicated with black symbols, while winter (West Coast) and spring (South Coast) surveys are indicated with blue symbols. Note that surveys that only extended to the 200 m isobath have been excluded from the figures. Also note that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability. *Africana* = research vessel FRS *Africana*, Commercial = commercial fishing vessel

method. These surveys are designed to estimate the abundance of hakes, although other demersal species (including kingklip) are included in the data collection. Additional to the abundance estimates, the surveys provide length-frequency data and biological information on sex, maturity, age, body condition and diet. A detailed description of the surveys is provided in the section on Cape hakes.

There is some uncertainty concerning the stock structure of kingklip, a feature that has compromised the reliability of attempts to assess the status of the resource. Early studies using morphometrics and otolith shape suggested two, and possibly even three, stocks of kingklip; one on the West Coast, one on the South Coast and possibly a third stock on the central Agulhas Bank. Differences in growth and size/age-at-maturity estimates obtained from West and South Coast fish could be considered to provide some support for at least the two-stock hypothesis, but it must be recognised that such differences can be realistically obtained from a single breeding stock where the offspring move to different areas with different environmental conditions. A genetic study conducted in 2005 using analyses of allozyme markers indicated a single genetic stock. A recent study employing advanced genetic techniques (analyses of both microsatellites and mitochondrial DNA) indicated separate West and South coasts stocks of kingklip, but the data did indicate appreciable gene flow between the two components. Further work on this is being conducted using a single nucleotide polymorph (SNP) approach. A multiple-method study that includes parasite biotags, otolith shape and microchemistry, as well as meristic and morphometric characteristics, to examine kingklip population structure is also underway.

Current status

The 2019 update of the kingklip RY assessment used catch data (coast-specific trawl and longline) extending to the end of 2018 and fishery-independent survey abundance estimates extending to the 2019 summer West Coast and autumn South Coast surveys. The assessment results suggested that the South Coast component of the resource is decreasing in abundance at about 0.8% per annum while the West Coast component is increasing at about 2.4% per annum (Table 5, Figure 23). Estimates of RY generated by the assessment (modes of the posterior distributions) were 1 320 tonnes for the South Coast component of the resource and 3 104 tonnes for the West Coast component (Table 5). In view of the uninformative nature of the assessment in terms of resource status, a precautionary approach in setting the PUCL was adopted. The sum of the 25th percentiles of the posterior distributions of the

Table 5: Parameter estimates of kingklip coast-specific replacement yield (tonnes) and average percentage change in abundance per annum arising from the Bayesian analyses framework. The 95% probability intervals about each estimate are provided in parentheses

		South Coast	West Coast
Replacement yield	Mode	1 320 (826; 1 814)	3 104 (2 429; 3 799)
	25th percentile	919	2 986
Average % change in abundance per annum	Median	-0.766 (-2.923; 1.685)	2.405 (1.922; 2.820)

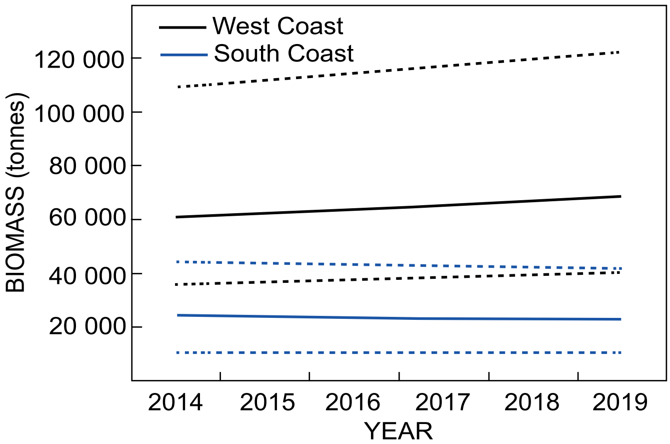


Figure 23: Bayesian posterior medians of abundance (solid lines) over the last five years for the West and South Coast components of the kingklip resource off South Africa. 95% probability-interval envelopes are shown as dashed lines

South and West Coast RY estimates (919 and 2 986 tonnes respectively, see Table 5), corresponding to a total of 3 905 tonnes, was set as the PUCL for the 2020 fishing season.

Ecosystem interactions

South Africa has committed to implementing an ecosystem approach to fisheries management (EAF). This approach extends fisheries management beyond the traditional single-species approach to the entire marine ecosystem. In 2006, the permit conditions for all sectors in the hake fishery contained a specific "ecosystem impacts of fishing" section for the first time. Given that kingklip are taken as bycatch in the hake fishery sectors, these conditions (see the section on Cape hakes) would also apply to kingklip.

Further reading

Henriques R, Nielsen ES, Durholtz D, Japp, D, von der Heyden, S. 2017. Genetic population sub-structuring of kingklip (*Genypterus capensis* - Ophidiidiae), a commercially exploited demersal fish off South Africa. *Fisheries Research* 1877: 86–95.

Japp DW. 1990. A new study on age and growth of kingklip *Genypterus capensis* off the south and west coasts of South Africa, with comments on its use for stock identification. *South African Journal of Marine Science* 9: 223-237.

Olivar MP, Sabatés A. 1989. Early life history and spawning of *Genypterus capensis* (Smith, 1849) in the southern Benguela system. *South African Journal of Marine Science* 8: 173-181.

Payne AIL. 1986. Observations on some conspicuous parasites of the southern African kingklip *Genypterus capensis*. *South African Journal of Marine Science* 4: 163-168.

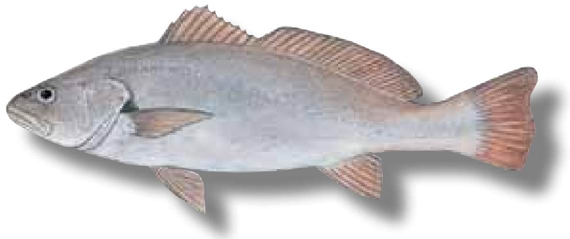
Useful statistics

Annual catches (tonnes) of kingklip *Genypterus capensis* by coast and fishing sector and the precautionary upper catch limit (PUCL) that was introduced in 2005. WC = West Coast; SC = South Coast

	Catch (t) - trawl		
Year	WC	SC	Total
1932	436	164	600
1933	290	110	400
1934	290	110	400
1935	508	192	700
1936	508	192	700
1937	508	192	700
1938	508	192	700
1939	508	192	700
1940	508	192	700
1941	436	164	600
1942	436	164	600
1943	436	164	600
1944	436	164	600
1945	944	356	1 300
1946	726	274	1 000
1947	798	302	1 100
1948	1 089	411	1 500
1949	1 307	493	1 800
1950	1 379	521	1 900
1951	1 742	658	2 400
1952	2 032	768	2 800
1953	1 960	740	2 700
1954	1 452	548	2 000
1955	1 669	631	2 300
1956	1 452	548	2 000
1957	1 089	411	1 500
1958	1 234	466	1 700
1959	1 452	548	2 000
1960	1 089	411	1 500
1961	1 524	576	2 100
1962	1 234	466	1 700
1963	1 307	493	1 800
1964	1 016	384	1 400
1965	1 815	685	2 500
1966	2 686	1 014	3 700
1967	2 323	877	3 200
1968	2 105	795	2 900
1969	2 105	795	2 900
1970	2 105	795	2 900
1971	3 557	1 343	4 900
1972	3 774	1 426	5 200
1973	4 210	1 590	5 800
1974	2 532	956	3 488
1975	2 600	982	3 582

	Catch (t) - trawl			Catch (t) - longline			
Year	WC	SC	Total	WC	SC	Total	PUCL
1976	2 519	952	3 471				
1977	1 953	737	2 690				
1978	2 551	1759	4 310				
1979	3 080	1532	4 612				
1980	4 415	878	5 293				
1981	3 149	963	4 112				
1982	2 410	721	3 131				
1983	2 246	1 169	3 415	842	200	1 042	
1984	2 558	1 034	3 592	1 881	1 159	3 040	
1985	1 750	1 650	3 400	1 314	5 656	6 970	
1986	2 287	399	2 686	1 231	7 453	8 684	
1987	2 083	392	2 475	1 948	4 504	6 452	
1988	1 519	408	1 927	2 091	3 311	5 402	
1989	1 407	223	1 630	1 607	2 209	3 816	
1990	1 002	266	1 268	557	708	1 265	
1991	1 271	680	1 951	0	0	0	
1992	1 884	676	2 560	0	0	0	
1993	2 207	884	3 091	0	0	0	
1994	1 445	1 560	3 005	92	48	140	
1995	1 863	1 275	3 138	65	48	113	
1996	1 596	1 981	3 577	170	60	230	
1997	1 972	2 128	4 100	155	120	275	
1998	1 632	1 366	2 998	53	87	140	
1999	2 104	1 737	3 841	141	171	312	
2000	2 166	1 465	3 631	199	103	302	
2001	2 651	2 210	4 861	183	57	240	
2002	2 280	2 479	4 759	312	202	514	
2003	1 870	2 558	4 428	317	160	477	
2004	1 823	2 539	4 362	266	141	407	
2005	1 790	1 851	3 641	255	121	376	3 000
2006	1 476	1 322	2 798	110	127	237	3 500
2007	1 213	1 223	2 436	105	85	191	3 500
2008	1 122	1 307	2 429	83	118	202	3 500
2009	1 153	958	2 111	138	140	278	3 500
2010	1 405	1 057	2 462	199	149	348	3 500
2011	1 540	891	2 431	212	126	338	3 500
2012	1 866	1 272	3 138	270	112	383	3 500
2013	1 801	1 995	3 796	281	84	365	3 500
2014	1 525	1 584	3 109	327	25	352	5 264
2015	1 610	1 441	3 051	335	28	363	5 264
2016	1 613	1 217	2 829	414	21	434	5 264
2017	1 085	1 412	2 497	297	2	299	4 450
2018	969	1 231	2 200	237	10	246	4 450
2019							4 450

Linefish



Stock status	Unknown Black musselcracker	Abundant Hottentot seabream Snoek	Optimal Yellowtail Santer Slinger Carpenter Roman	Depleted Silver kob Geelbek White stumpnose	Heavily depleted Seventy-four Dageraad Red steenbras Dusky kob
Fishing pressure	**Unknown** Black musselcracker	**Light** Hottentot seabream	**Optimal** Snoek Yellowtail Santer Slinger Carpenter Roman	**Heavy** Silver kob Geelbek White stumpnose	

Introduction

Linefishing in South Africa is defined as the capture of fish with hook and line, but excludes the use of longlines. Together, the three sectors of the linefishery (commercial, recreational and small-scale) target between 95 and 200 of South Africa's 2 200 marine fish species. Species targeted in the linefishery display diverse life-history strategies, including many traits that cause these populations to be particularly vulnerable to overfishing e.g. long lifespans (>20 years), estuarine-dependence, sex change and aggregating behaviour. Furthermore, many of the species are endemic to South Africa. Target species of the linefishery include temperate, reef-associated seabreams (e.g. roman, hottentot seabream, santer and slinger), coastal migrants (e.g. geelbek and dusky kob) and nomads (e.g. snoek and yellowtail). More than 90% of the current linefish catch is derived from the aforementioned eight species.

Linefish species are typically predatory in nature and include several apex predators such as sharks, groupers, tunas and large seabreams. Most of the linefish caught are not targeted exclusively by this fishery, but form important components of the catch or the bycatch of other fisheries. Effective management of linefish resources that are shared among different fishery sectors can be complex.

The commercial linefishing sector is exclusively boat-based. The total number of registered vessels operating in this sector was estimated at 700 in the late 1990s, which accounted for 37% of all boats operating in marine fisheries in South Africa. From 2006 a maximum allocation of 455 boats has been maintained; however, the number of boats allocated per zone has varied. Linefishing is a low-earning, labour-intensive industry and therefore important from a human livelihood point of view. Employing an estimated 27% of all fishers, it has the lowest average employment income of all South African fisheries. Although the commercial linefishery has the largest fleet, it contributes only 6% of the total estimated value of all South African marine fisheries.

After the introduction of the towable skiboat in the late 1940s, the recreational boat-based sector expanded rapidly, with an estimated minimum number of 4 000 vessels. Landings from this open-access recreational fishery are not reported throughout the region, and for some areas and species the total catch from this sector could be equivalent to that reported by the commercial sector. The recreational linefishery has by far the largest number of participants (>450 000) of all fishery sectors in South Africa and consequently has great economic value. This is especially important to coastal regions dependent on the tourist trade, but also to industries associated with the small craft, outboard motor, fishing tackle and bait trades.

Recently, the small-scale sector was legally created to recognise those fishers who depend on marine living resources for direct food security – usually very poor coastal communities or those using simple traditional methods. There are an estimated 30 000 small-scale fishers active along the South African coastline and 85% of them harvest linefish.

History and management

The origins of linefishing in South Africa can be traced back to the fishing activities of indigenous Khoi people and European seafarers in the 1500s. Despite an abundance of fish, the fishery was slow to develop in the 1700s due to various restrictions implemented by the Dutch administration. These fishing restrictions were removed when the British captured the Cape Colony in 1795, and during the 1800s boat-based linefishing developed into a thriving industry.

Fishing effort in the Cape at the turn of the 19th Century was already considerable (between 0.12 and 0.37 boats per kilometre of coastline). This increased dramatically during the 20th Century and peaked in the 1980s and 1990s (>3 boats per kilometre of coastline). The sharp increase in fishing effort, together with an increase in operational range brought about by the introduction of motorised skiboats on trailers, the rapid development in fishing technology (echosounders, nylon line, etc.), and the additional offtake by other fishing fleets such as trawl and purse-seine, led to overfishing of most of the linefish resources around the coast during the last quarter of the 20th Century.

Despite its long history, the first comprehensive management framework for the linefishery was only introduced in 1985 when this fishery was formally recognised. However, successive research surveys indicated continuing declines of linefish resources. In December 2000, the Minister of Environmental Affairs and Tourism, taking cognisance of the critical status of many linefish stocks, declared linefish resources to be in an Emergency, as provided for in the Marine Living Resources Act (MLRA, Act 18 of 1998). Effort was reduced in the commercial sector and fixed at 450 vessels and the hake and tuna components were developed into separate sectors. To rebuild collapsed stocks and to achieve a sustainable level of catch, a linefish management protocol (LMP) was developed in 1999 in order to base regulations in the linefishery on quantifiable reference points. This remains the basis of linefish management.

Several regulations were put in place to manage fishing pressure on linefish resources. To accommodate the large number of users, launch sites and species targeted, and to allow flexibility of the operational range, the commercial linefishery is currently managed through a total allowable effort (TAE) allocation, based on boat and crew numbers. The recreational fishery is managed by a number of output restrictions, such as size and bag limits, closed areas and seasons (Table 6). The small-scale fishery will also be managed through a combination of size and bag limits, closed areas and seasons. However, this sector differs in that community-based management is the core principle on which the small-scale sector is based, and local communities are encouraged and empowered to promote sustainability. The level of commercial effort was reduced to the levels stipulated in the declaration of the emergency when linefish Rights were allocated in 2003 (for the medium-term) and in 2005 for the long-term fishing Rights. The TAE was set to reduce the total catch by at least 70%, a reduction that was deemed necessary to rebuild the linefish stocks. There has also been a reduction in recreational fishing pressure through the implementation of more realistic species-specific daily bag and size limits since 2005.

Although this appears to be a substantial reduction in the commercial linefish effort, it must be noted that trends in the catch information derived from the historic commercial landings for the period 1985–1998 indicated that a relatively small number (20%) of the vessels in the fishery accounted for the majority (80%) of the reported catches, and these highly efficient vessels remained in the fishery. On the other hand, the number of Right Holders who activate their annual permits has steadily decreased in recent years (Table 7), indicating that the TAE might be exceeding the number of economicallyviable fishing units.

The first small-scale co-operative was launched in Port Nolloth in September 2018. More than 300 communities in the four coastal provinces have been identified as small-scale fishing communities. These community co-operatives will be given 15-year small-scale fishing Rights and each will be able to access a "basket" of species based upon their needs and location along the coast. The traditional, commercial linefish Rights expire in 2020 and the small-scale fishing sector will be given priority in the subsequent linefish Rights-allocation process. Furthermore, the number of recreational angling permits may have to be limited in order to accommodate the newly established small-scale fisheries sector so as not to compromise resource sustainability.

Many species allocated to the small-scale "baskets" are primary targets of the commercial and recreational linefish sectors, and these shared resources must be carefully monitored given the increased fishing pressure expected. A revision of the LMP is also underway to ensure the future sustainability of linefish stocks.

Research and monitoring

Monitoring of the boat-based linefishery in the Cape was introduced by Dr JDF Gilchrist in 1897, in the form of a shore-based observer programme that aimed to record statistics on catch and effort at all the fishing centres. Comprehensive per-species catch-and-effort data from the boat-based commercial fishery have been collected since 1985 and stored in the National Marine Linefish System (NMLS). A national observer programme was implemented from 2008 until 2010, in which scientific observers recorded catch-and-effort data and collected size frequencies per species from the boat-based fishery at access points around the country. A comparison between this information and the data handed in by the fishery confirmed the accuracy of the NMLS catch data, which is based on man-

datory catch reports by the fishery. Validating catch data is an important component of fisheries monitoring and the implementation of a new national observer programme is now required.

With the increased focus on formalising the small-scale fishery around the country, a national, shore-based monitoring programme was implemented from June 2012 to May 2013. Data from this programme were used to investigate whether fishing effort and catch were sustainable. Thus far, the data have been used to assess the stocks of seven of the most important target species along the Eastern Cape coast. Spawner-biomass-per-recruit analyses revealed that two of these species (bronze bream and stone bream) are sustainably fished, but that the population status of dusky kob is estimated to be at only 1.3% of pristine spawner biomass. These assessments need to be considered during the implementation of the small-scale fishery and in the selection of co-operatives' species baskets, as recovery of these stocks is essential for growing the potential revenue of fishers in this important sector.

In addition to fisheries-dependent data, which can only provide indirect measures of resource status, novel methods to investigate fish abundance and species composition are being employed. A comprehensive comparison of monitoring methods, including standardised angling, underwater visual census by divers and remote underwater video, suggests that the latter provides the most unbiased census method. After successful application of this method in selected areas, an even more sophisticated version, the stereo baited remote underwater video (sBRUV) technique has been used in a nationwide investigation of fishing hotspots and marine protected areas to determine fish abundance, species composition and size frequencies of reef-associated linefishes.

The biology of fishes caught in the linefishery has been remarkably well-studied considering the large variety of target species in comparison with other fisheries, as evident from the published linefish species profiles that contain information on life history, ecology and population status of 139 linefish species.

Marine protected areas (MPAs) not only provide reference areas for research on the effects of fishing and climate change but can enhance and sustain surrounding fisheries. A recent study has shown that, in some instances, this can be achieved without the commonly predicted negative effects on the fishery, in particular for depleted temperate-reef-fish stocks with complex life histories. This study showed that catch rates of fishers that targeted reef fish near the boundary of a newly-established marine reserve increased slowly at first and then more rapidly due to the export of larger fish and, five years later, spill-over of eggs and larvae.

Assessing the status of linefish stocks has been a priority in recent years. Drawing on the enormous body of data contained in the NMLS, the largest spatially referenced marine dataset in the world, a novel method to standardise catch-per-unit-effort (CPUE) data that accounts for targeting in the multi-species linefish sector has been developed. Following on, a comprehensive Bayesian state-space surplus production model framework (JABBA: Just Another Bayesian Biomass Assessment) was developed and its extension (JABBA-Select) was applied to the seven most important species, namely slinger *Chrysoblephus puniceus*, carpenter *Argyrozona argyrozona*, hottentot seabream *Pachymetopon blochii*, snoek *Thyrsites atun*, yellowtail *Seriola lalandi*, santer *Cheimerius nufar* and silver kob *Argyrosomus inodorus* (Table 8).

The type of stock assessment applied is determined by the nature and quality of data available. In situations where traditional stock assessment methods are not applicable, alternative methods must be developed. For rare linefish species, such as red steenbras and dageraad that are caught infrequently and are subject to stringent bag and size limits, a novel approach based on encounter probabilities in the catch has been applied. Application of this robust method confirms the continuous decline of these once-abundant species to critically low levels (Figure 24). These two species are now of serious conservation concern and have been included on the IUCN Red List of Threatened Species list as Endangered. Furthermore, a unique spatio-temporally disaggregated model has been successfully applied to geelbek *Atractoscion aequidens* as this species undertakes a complex, size-dependent migration. Sector-specific assessments, such as that of white stumpnose *Rhabdosargus globiceps* which quantifies the relative contribution of the commercial and recreational fishing sectors to the species' decline in Saldanha Bay, seek to address equality issues that arise in a multi-sector fishery.

Current status

The results of stock assessments conducted in 2017 indicate that the drastic reduction of fishing effort from 2003 onwards resulted in the partial recovery of some species, such as the slinger, santer, hottentot seabream and carpenter (Figure 25). However, other important stocks such as silver kob are still being overfished, given the cumulative impact of the linefishery and inshore-trawl fishery on this species. The yellowtail assessment suggests that the stock is optimally exploited, while snoek remains underexploited. The annual catch of the nomadic yellowtail and snoek is dependent on their availability to nearshore linefishers and is, therefore, highly variable. Moreover, the inconsistent quality of yellowtail and snoek landed by the linefishery detracts from the optimal use of these important stocks. There is also considerable inter-fishery conflict around these species which are also caught by other fisheries (i.e. tuna pole-line, trawl and hake handline fishery in the case of snoek, and tuna pole-line and beach seine-net fisheries in the case of yellowtail).

The recovery of overexploited species hinges on the increased protection of juveniles and spawning stock inside MPAs and offshore refugia. In September 2018 the South African Cabinet approved the declaration of 20 new MPAs within the South African economic exclusive zone (EEZ) - a bold and positive step towards promoting sustainability of our marine resources. However, for some severely depleted linefish species such as seventy-four, red steenbras and dageraad, even the rigorous enforcement of all existing regulations may not be sufficient to induce a recovery, and more drastic measures might be required. Notably, numerous species that are important to shore- and estuarine-based subsistence fishing, such as dusky kob, are considered collapsed. Rebuilding these stocks will be crucial for small-scale fishing communities that rely on these resources.

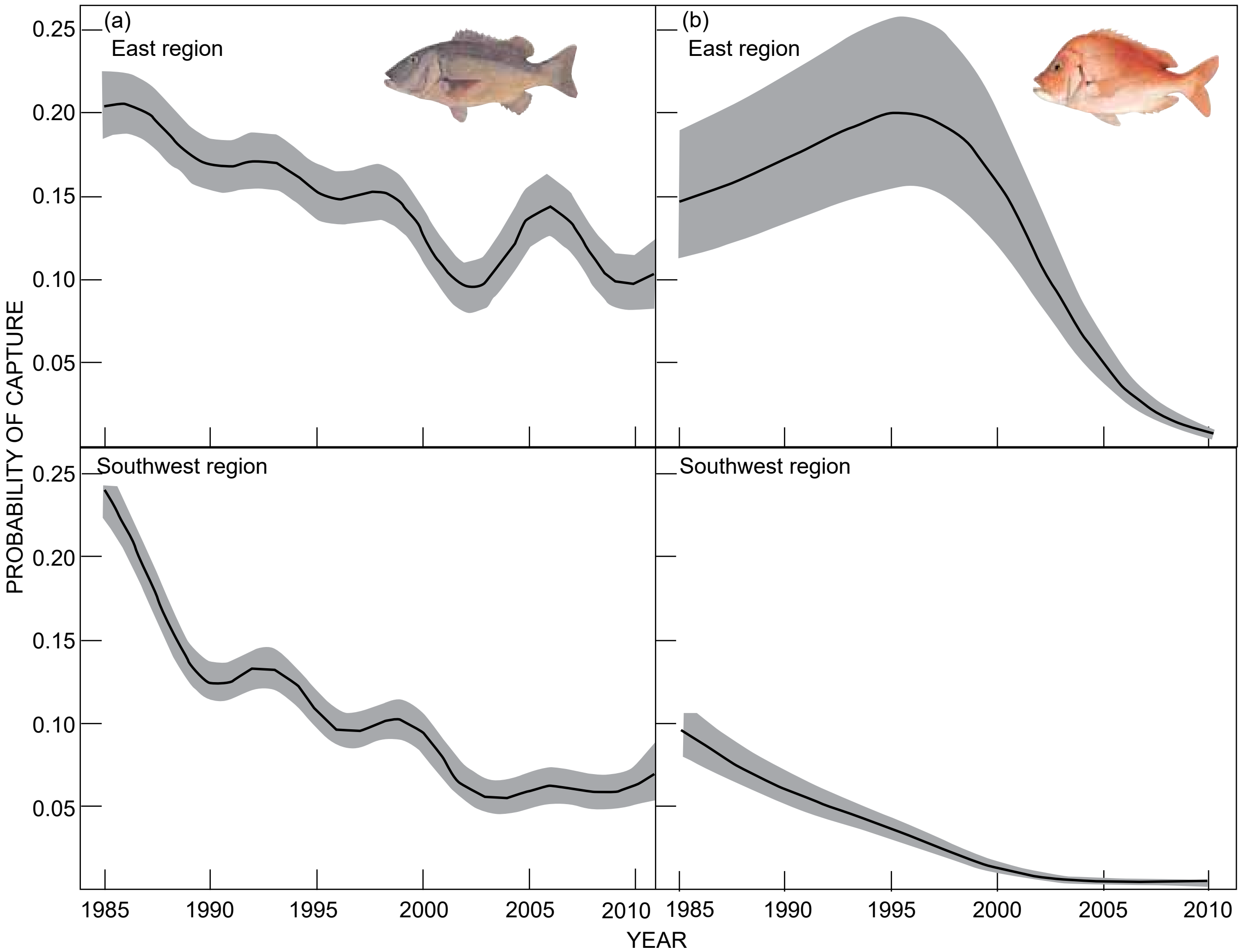


Figure 24: Time-series of standardised capture probability for (a) red steenbras *Petrus rupestris* and (b) dageraad *Chrysoblephus cristiceps* in commercial linefish catches for the period 1985–2011 along the South African East (top panel) and Southwest coasts (bottom panel)

Ecosystem interactions

The linefishery has the potential to be one of the most ecologically and economically viable fisheries in South Africa, due to the following factors: (i) the fishing method can be highly selective and bycatch of undersized fish and unwanted species can be avoided; (ii) the labour-intensive, low-technology, low-investment method maximises employment opportunities; (iii) the product is potentially of high quality and many species command a high price on local and international markets; and (iv) linefishing inflicts comparatively minimal impact on the broader ecosystem.

However, numerous studies suggest that trophic cascades in a coastal food web are dependent on the functional composition of both predator and herbivore communities, as well as on resource availability. The linefishery predominantly targets large, predatory species that occupy the upper trophic levels of the marine system. The systematic removal of these apex predators can therefore have a detrimental effect on the coastal functional ecology. Furthermore, the removal of large, fecund individuals may also weaken the genetic resilience of a species.

Of all South African marine fisheries, the linefishery suffers the most from external impacts. Linefish resources are at risk of overcapacity as they are directly or indirectly exploited by numerous sectors. These include the traditional commercial, recreational and small-scale linefishery, as well as the inshore and offshore trawl fisheries, the tuna pole-line fishery, the inshore netfishery and the demersal shark longline fishery. The increased expectation of commercial access to linefish resources combined with the localised anticipation of community ownership of adjacent resources may impact linefish stocks to the detriment of all.

The bycatch of linefish species by the trawl fishery (inshore and offshore) is of considerable concern. Undersized linefish, caught as trawl bycatch, can be legally sold and consequently linefishers are frequently unable to obtain economically viable prices for their catches, given market saturation from trawl bycatch and mariculture product. Furthermore, trawl gear also damages habitat that may be critical to linefish life histories.

Many linefish species are piscivores that are heavily reliant on abundant small pelagic fish (sardine, anchovy, round herring, etc.) as a source of nutrients. The small pelagic fishery is the largest of all South African fisheries, by weight landed, and the sardine stock is currently considered to be depleted. Recent research has demonstrated the importance of sardine as a prey species for geelbek and has emphasised the need for conservative management of small pelagic fisheries, given the

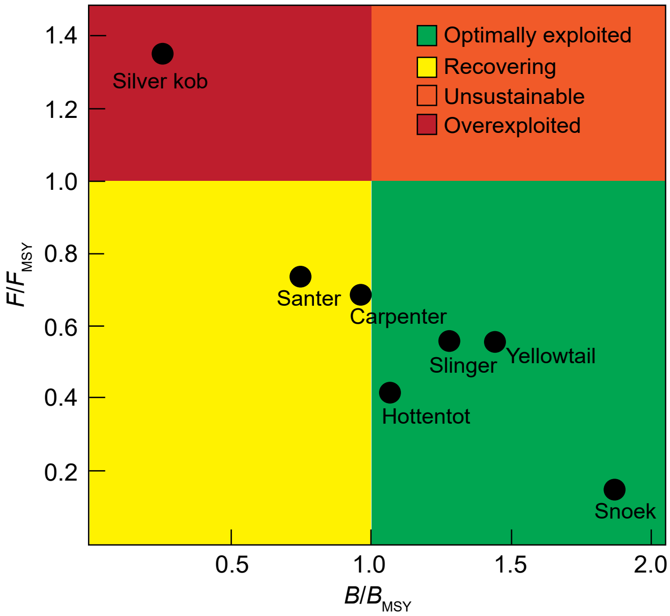


Figure 25: Kobe phase plot summarising the stock status estimates of fishing mortality relative to F_{MSY} and biomass relative to B_{MSY} for linefish species. Only results from stock assessments conducted by DEFF's Linefish Scientific Working Group (LSWG) in 2017 are included

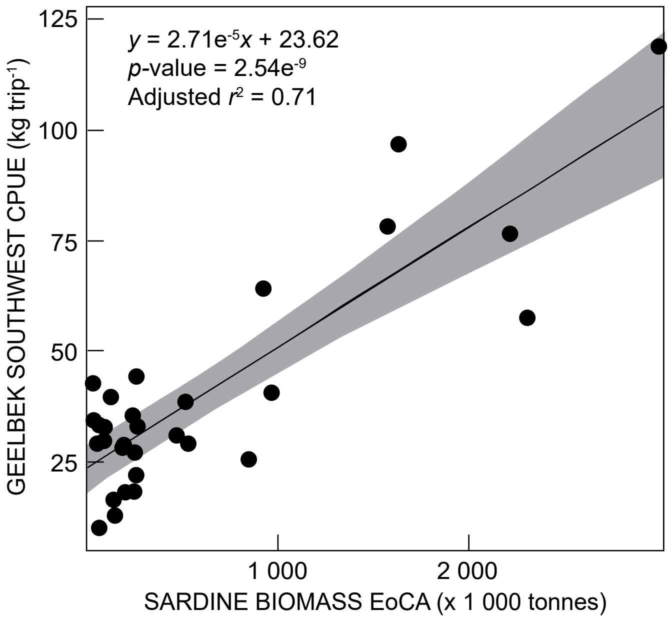


Figure 26: Scatterplot of geelbek southwest CPUE in year$_{n+1}$ plotted against sardine biomass east of Cape Agulhas (EoCA) (x 1 000 t) in year$_{n}$, with the fitted linear regression, its associated statistical parameters and 95% confidence interval shown in grey

dependence of many predatory species on small pelagic fish as forage. A functional relationship between sardine and geelbek (Figure 26) indicates that low levels of sardine biomass east of Cape Agulhas have a negative impact on geelbek CPUE in the southwest region in the following year. It is postulated that the juvenile geelbek survival rate is dependent on sufficient availability of prey, i.e. local sardine biomass. This dependency eventually manifests in geelbek CPUE in the southwest region after a minimum lag of one year, when the juvenile geelbek first recruit into the linefishery.

As many as 80 species caught in the linefishery are associated with estuaries and rely on these for feeding, refuge or reproduction. Consequently, the wellbeing of these fish stocks is linked to the ecological status of the estuaries. Reduced or regulated freshwater input, coastal development and pollution are altering estuarine habitats and threatening the wellbeing of dependent fish populations.

Conservation awareness among recreational anglers has increased dramatically in recent years. Many anglers now practice 'catch and release' and competitive angling formats are constantly adapting to minimise fish mortalities. That said, the number of recreational anglers remains high (in excess of 650 000 individuals) and a recent study found that although captured fish are often released, there may still be significant (up to 20% observed) post-release mortality due to barotrauma and hook damage.

Further reading

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Table 6: Annual total allowable effort (TAE) and activated commercial linefish effort per management zone from 2006 to 2019

Total TAE boats (fishers). Upper limit: 455 boats or 3 450 crew.			Zone A: Port Nolloth to Cape Infanta		Zone B: Cape Infanta to Port St Johns		Zone C: KwaZulu-Natal	
Allocation	455 (3 182)		301 (2 136)		103 (692)		51 (354)	
Year	Allocated	Activated	Allocated	Activated	Allocated	Activated	Allocated	Activated
2006	455	385	301	258	103	78	51	49
2007	455	353	301	231	103	85	51	37
2008	455	372	301	239	103	82	51	51
2009	455	344	300	222	104	78	51	44
2010	455	335	298	210	105	82	51	43
2011	455	328	298	207	105	75	51	46
2012	455	296	298	192	105	62	51	42
2013	455	289	301	189	103	62	51	38
2014**	455	399	340	293	64	58	51	48
2015**	455	356	340	291	64	61	51	45
2016**	455	378	340	274	64	59	51	45
2017**	455	329	340	232	64	60	51	37
2018**	455	324	340	232	64	50	51	42
2019**	455	306	340	218	64	50	51	38

** In the finalisation of the 2013 commercial Traditional Linefish appeals, the effort apportioned for the small-scale fisheries sector was allocated to the commercial sector. All the small-scale Rights were considered to be activated on allocation

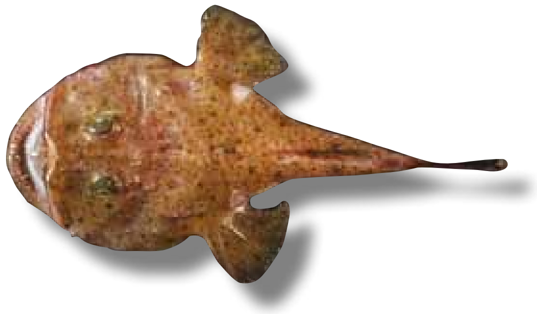
Table 7: Annual catch (t) of the eight most important linefish species for the period 1985–2018

Year	Snoek	Yellowtail	Kob	Carpenter	Slinger	Hottentot seabream	Geelbek	Santer
1985	1 063	324	1 504	588	312	399	152	73
1986	3 143	817	2 016	768	268	811	262	99
1987	5 642	809	1 902	831	246	915	436	99
1988	4 919	722	1 822	877	132	953	482	57
1989	4 039	868	2 097	775	199	739	810	60
1990	7 892	585	2 540	1 228	262	542	513	86
1991	6 556	542	2 082	1 210	249	522	457	89
1992	5 692	591	1 799	873	305	496	530	114
1993	2 948	888	1 867	695	298	614	610	124
1994	7 759	868	1 348	638	217	815	468	82
1995	9 618	801	1 422	758	235	252	396	85
1996	7 063	497	1 415	879	179	276	384	80
1997	6 623	488	1 471	841	128	322	524	68
1998	7 872	565	1 331	518	114	408	684	64
1999	8 348	339	1 026	574	160	270	467	60
2000	6 543	320	1 093	441	186	234	894	75
2001	6 839	327	831	285	139	109	395	69
2002	3 837	242	784	231	101	79	315	48
2003	4 532	329	544	177	88	106	513	48
2004	7 278	883	720	228	184	254	672	87
2005	4 787	739	647	184	169	168	580	84
2006	3 529	310	800	159	192	87	419	79
2007	2 765	478	841	265	157	128	448	84
2008	5 223	313	715	226	194	120	403	82
2009	6 322	330	884	282	186	184	495	66
2010	6 360	171	838	263	180	144	408	69
2011	6 205	204	625	363	214	216	286	62
2012	6 809	382	441	300	240	160	337	82
2013	6 690	712	313	481	200	173	263	84
2014	3 863	987	289	522	201	192	212	74
2015	2 104	609	246	522	186	143	244	69
2016	1 681	475	277	713	211	211	250	66
2017	1 888	361	199	820	215	188	148	72
2018	2 095	654	213	728	174	215	214	69

Table 8: Detailed status of the South African linefish resources assessed by the Linefish Scientific Working Group in 2017

	Carpenter	Hottentot seabream	Santer	Silver kob	Slinger	Snoek	Yellowtail
Stock Assessment	2017	2017	2017	2017	2017	2017	2017
MSY	1.004 t (807.5–1 319)	446.2 t (298.7–657.4)	147.7 t (111.1–199.4)	784.7 t (557.7–1 196)	347.5 t (273.7–521.5)	24 396 t (16 060–42 422)	1 087 t (757.2–2 613)
Total yield for stock	812.4 t (2015)	196.35 t (2015)	69.3 t (2015)	295.38 t (2015)	241.8 t (2016)	6 674.8 t (2015)	748.5 t (2016)
Relative biomass	B_{2015}/B_{MSY} = 0.96	B_{2015}/B_{MSY} = 1.07	B_{2015}/B_{MSY} = 0.75	B_{2015}/B_{MSY} = 0.26	B_{2015}/B_{MSY} = 1.28	B_{2015}/B_{MSY} = 1.87	B_{2015}/B_{MSY} = 1.44
Relative fishing mortality	F_{2015}/F_{MSY} = 0.69	F_{2015}/F_{MSY} = 0.42	F_{2015}/F_{MSY} = 0.74	F_{2015}/F_{MSY} = 1.35	F_{2015}/F_{MSY} = 0.56	F_{2015}/F_{MSY} = 0.15	F_{2015}/F_{MSY} = 0.56
Summary	Carpenter was severely overfished prior to 2000 which resulted in stock decline. However, results from all scenarios in the current assessment indicate that the carpenter stock is rebuilding following many years of decreased fishing mortality ($F < F_{MSY}$). The current biomass is estimated as 38% (25–53%) of the unfished biomass level and the stock is considered optimally exploited. Further recovery is expected under current fishing mortality levels.	Results from the base case scenario indicate a 90.1% probability that the hottentot stock is above the target biomass (B/B_0 = 0.4) and that the stock is being fished below F_{MSY}. The most pessimistic scenario estimates this probability to be marginally less (89.6%) and the most optimistic approaches certainty (99.7%). The stock could likely sustain an increase in fishing mortality of approximately 20% without there being a significant risk of overexploitation.	Results from the base case scenario indicate a 34% probability that the santer stock is above the target biomass (B/B_0 = 0.4) and that the stock is being fished below F_{MSY}. It must be noted that the base case is the most pessimistic of the four scenarios produced, and the remaining three scenarios estimate this probability to be between 82% and 89%. The results imply the santer stock is rebuilding and should reach B_{MSY} by 2021 if current catch levels are maintained. It is unlikely that the stock could currently sustain an increase in fishing mortality without there being a significant risk of overexploitation. Increases in annual catch should be avoided until the biomass target B_{MSY} is reached.	The results are explicit in that all four scenarios indicate a 100% probability that the silver kob stock is severely depleted and continues to be overexploited. The current biomass was estimated as 10.4% (5–17%) of the unfished biomass level. According to the LMPI the silver kob stock has collapsed. Overfishing, and subsequent stock depletion, of silver kob occurred prior to 1987 and despite there having been a trend towards reduced fishing mortality since 1991, this decrease has not been sufficient to initiate stock rebuilding.	Results from the base case scenario indicate a 83% probability that the slinger stock is above the target biomass (B/B_0 = 0.4) and that the stock is being fished below F_{MSY}. The remaining three scenarios suggest this probability ranges from 39% to 98%. There is little evidence to suggest slinger is overexploited and the stock could potentially sustain a 5% increase in fishing mortality without there being a significant risk of overexploitation.	The results are explicit in that all four scenarios indicate that there is a 100% probability that snoek has been fished below F_{MSY} for the entire assessment period. There is no anecdotal evidence or data to suggest that snoek has been overexploited over the last Century and snoek biomass has been increasing for the past 10 years. In contrast, linefish catch in 2014 was unusually low and the 2015 catch was the lowest ever recorded in the linefishery - despite relative consistency in annual offshore trawl catches over the same period. The linefishery targets the nearshore component of the snoek stock, which is renowned for inter-annual variability. This variability is seemingly driven by resource availability and, to a lesser extent, the market price - as opposed to overall biomass. Snoek is the single largest component of the linefishery and has the capacity to sustain increased fishing mortality. However, the current TAE framework of the linefishery is restrictive in that introducing more participants to the fishery is the only viable means of increasing harvest, assuming current fishers make full use of their Right. This would likely have negative impacts, such as increased sector competition and unsustainable exploitation of other species during periods when snoek is unavailable to the linefishery.	According to the base case scenario, there is a 70.8% probability that the yellowtail biomass is above the target reference point. However, annual catch has exceeded sustainable levels at regular intervals (e.g. 1989, 1993/4, 2004, 2014). This assessment is characterised by an unusually high degree of uncertainty in biomass and harvest (*F*) estimates as a result of inter-annual variability in CPUE and catch data, which must be acknowledged in the associated scientific recommendations. The remaining three model scenarios in the JABBA-Select assessment suggest that the probability of yellowtail being overexploited is low - between 5.9% and 32.8%. A conservative sustainable yield estimate for this stock would be approximately 700 tonnes per annum. Annual catches exceeding 850 tonnes are not sustainable.

Monkfish



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

The most common monkfish species occurring in southern African waters is *Lophius vomerinus*, commonly known as the Cape monkfish or devil anglerfish (the latter name referring to the modified dorsal spine near the front of the head that the fish uses as a lure to attract prey). Monkfish are well camouflaged predators characterised by an unusually wide mouth with numerous sharp teeth, a large head and a relatively small body. They live a sedentary life, lying on the seabed and often burrowing under the surface sediment while awaiting potential prey (Figure 28). Their diet comprises primarily other demersal fish species and crustaceans. *Lophius vomerinus* occur on both the West and South coasts of southern Africa, their

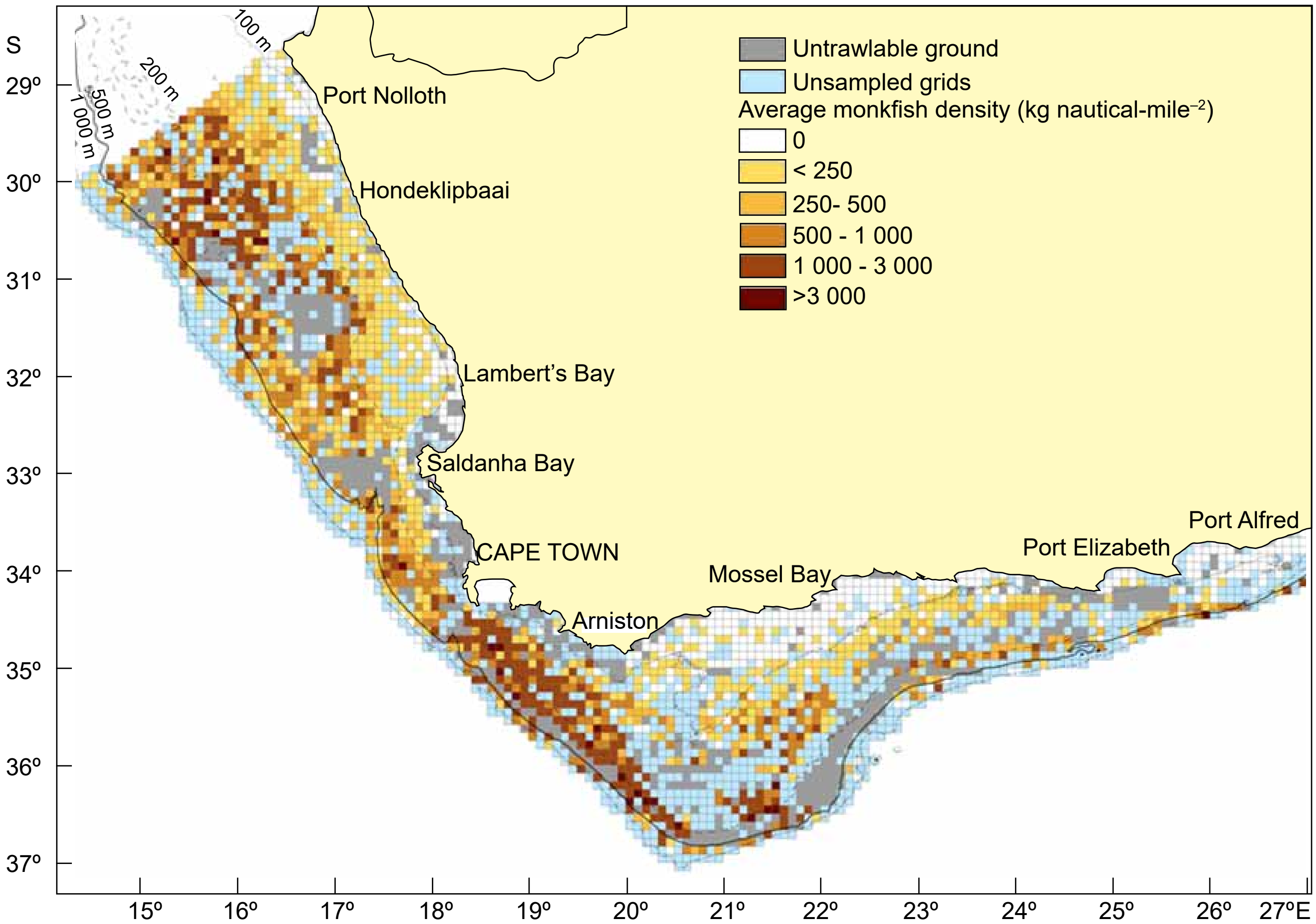


Figure 27: Distribution of Cape monkfish *Lophius vomerinus* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical mile^{-2}) are averages over all survey stations within each survey grid block

distribution extending from KwaZulu-Natal (KZN) in South Africa to northern Namibia. They occur at depths ranging from about 50 m to 1 000 m (Figure 27) and larger individuals tend to be found deeper and further offshore.

The lifespan of Cape monkfish is approximately 17 years, with fish reaching up to 1 m in length. The peak spawning period is in September, based on trends in the female gonadosomatic index (GSI; the weight of the gonads relative to whole body weight). The length at 50% maturity does not differ markedly between the sexes and is estimated to be approximately 37 cm, corresponding to an age of about six years for both sexes.

The species is a high-value product, often marketed as "mock crayfish". Monkfish is caught almost exclusively as by-catch during hake- and/or sole-directed fishing by the hake trawl fishery, both deep-sea and inshore sectors. Catches are made predominantly on the West Coast.

History and management

Annual catches of monkfish in the hake trawl fishery fluctuated around 4 700 t over the period 1974 to 1994, and subsequently increased to a peak of over 10 000 t in 2001 (Figure 29). The increased catches raised concerns of overexploitation and efforts were directed at assessing the status of the resource to establish a basis for sustainable management. An initial attempt to apply a modified version of a hybrid age-structured surplus production model was unsuccessful as the model failed to converge due to the uninformative nature of the data. Subsequently a coast-disaggregated replacement yield (RY) approach was employed, the results of which indicated that annual catches should not exceed 7 300 t. A precautionary upper catch limit (PUCL) was formally introduced into the demersal trawl fishery permit conditions in 2006 and remains the primary means of regulating catches of monkfish. The initial PUCL in 2006 was set at a level of 7 000 t per annum. However, this was generally exceeded during the early years of its implementation (Figure 29), largely due to difficulties associated with real-time monitoring and management. Effective co-management procedures have been developed and implemented over time, and catches subsequent to 2011 have generally been well below the PUCL (Figure 29).

The RY analysis is generally updated every two years. Although the 2011 RY assessment suggested that the PUCL could be increased to 8 300 t, this increase was delayed until the 2013 fishing season while improved monitoring of catches

Figure 28: A monkfish in its natural habitat. Photograph courtesy of SAEON

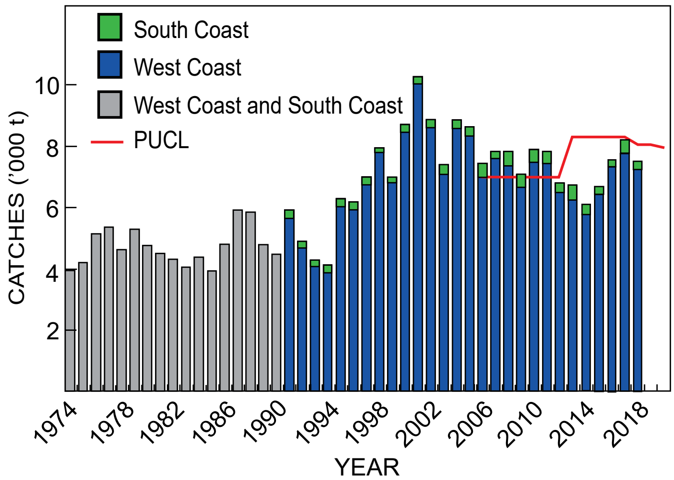


Figure 29: Annual catches (tonnes) of Cape monkfish made by the hake trawl fishery for the period 1974–2018, and the precautionary upper catch limit (PUCL) that was introduced in 2006. Catches subsequent to 1990 can be split by coast

and implementation of a co-management procedure with the hake-trawl-industry associations were being developed. Updated assessments conducted in 2013 and 2015 provided no grounds to alter the PUCL and it was consequently maintained at 8 300 t (Figure 29) for the 2014 to 2016 fishing seasons. The assessment conducted in 2017, however, resulted in RY estimates of 7 652 t and 402 t for the West Coast and South Coast components of the resource, respectively. Based on these results, the PUCL for the 2018 and 2019 fishing seasons was set at 8 054 t.

Research and monitoring

Abundance estimates for monkfish (Figure 30) are derived from demersal trawl research surveys conducted using the swept-area method. These surveys are designed to estimate the abundance of hakes, although data on other demersal species, including monkfish, are collected. The surveys also provide length-frequency data and biological information on sex, maturity, age, body condition and diet. A detailed description of the demersal trawl surveys is provided in the Cape hakes section. Commercial landings of monkfish from the hake demersal trawl fleets are also monitored.

Morphometric and meristic analyses on Cape monkfish indicated potential stock structuring between the West and South coasts. However, this hypothesis was not supported by genetic evidence derived from an analysis of allozyme markers and uncertainty regarding monkfish stock structure still remains. A research project investigating stock structure of monkfish using parasites as biotags is ongoing.

Current status

The most recent assessment of the monkfish resource was conducted in 2019, again using a coast-disaggregated RY approach applied to data ending in 2018. The resultant RY estimates ranged from 7 814 tonnes to 8 252 tonnes across both coasts (Table 9), depending on assumptions regarding the overall catchability (q) of the demersal surveys that provide the fishery-independent abundance data. The base-case model (q = 1.0) indicated that while the resource has shown marginal increases on the West Coast (Figure 31), the increase is not as

Table 9: Maximum likelihood estimates of coast-specific replacement yield (RY, tonnes) for the South African Cape monkfish resource for different assumed values of survey catchability (*q*) from the 2019 updated assessment. The associated log likelihood (-lnL), asymptotic normal 90% confidence intervals (90% CI, upper and lower) and the CV (%) corresponding to each estimate are also shown

q	West Coast				South Coast			
	-lnL	RY(t)	CV(%)	90%CI	-lnL	RY(t)	CV(%)	90%CI
0.7	-31.1	7 884	1.8	7 618, 8.132	-13.1	368	30.0	158, 565
1.0	-30.3	7 629	1.3	7 456, 7.814	-13.0	343	22.4	196, 480
1.3	-28.4	7 484	1.0	7 345, 7.632	-12.9	330	17.8	218, 435

apparent as in previous years. The South Coast component of the resource appears to remain stable. The results of the base-case model were used to set the PUCL for the 2020 fishing season at 7 972 tonnes.

Ecosystem interactions

South Africa has committed to implementing an ecosystem approach to fisheries management (EAF). This approach extends fisheries management beyond the traditional single-species approach to the entire marine ecosystem. In 2006, the permit conditions for all sectors in the hake fishery contained a specific "ecosystem impacts of fishing" section for the first time.

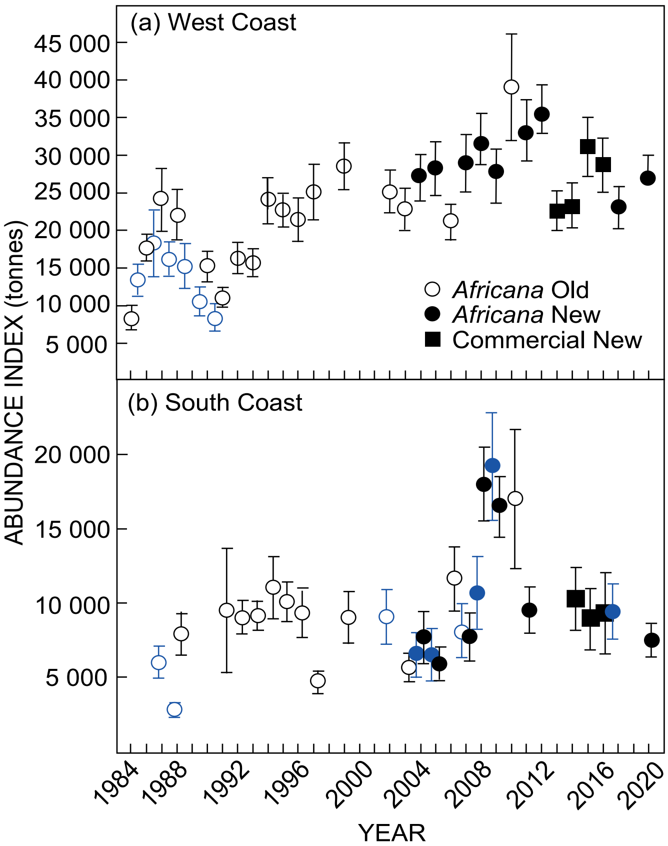


Figure 30: Cape monkfish abundance estimates (tonnes ± 1 SE) derived from fishery-independent swept area demersal surveys. Estimates are illustrated by coast for the various vessel-gear combinations. Summer (West Coast) and autumn (South Coast) surveys are indicated with black symbols, while winter (West Coast) and spring (South Coast) surveys are indicated with blue symbols. Note that surveys that only extended to the 200-m isobath have been excluded from the figures and that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability. *Africana* = research vessel FRS *Africana*, Commercial = commercial fishing vessel

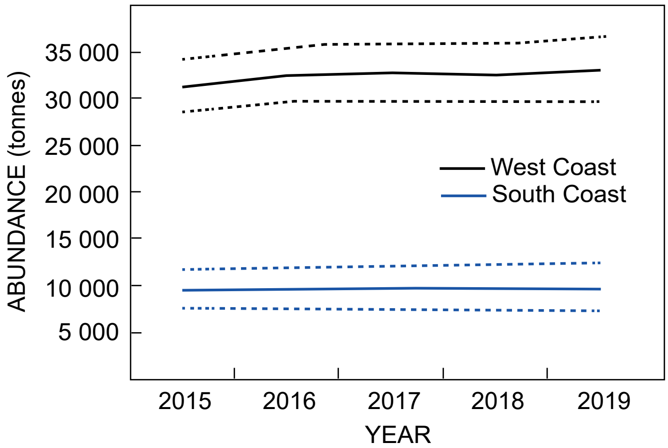


Figure 31: Median annual estimates of abundance and associated 90% probability intervals per coast for monkfish for the most recent 5 years derived from Bayesian analyses

Given that monkfish are taken as bycatch in the hake fishery, these conditions would also apply to this species (see section on Cape hakes).

Further reading

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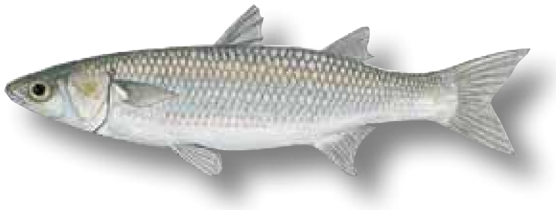
Useful statistics

Annual catches of monkfish (tonnes) made by the hake trawl fishery for the period 1974–2018, and the precautionary upper catch limit (PUCL) that was introduced in 2006. Catches prior to 1990 cannot be separated by coast. WC = West Coast, SC = South Coast

Year	WC	SC	Total	PUCL	Year	WC	SC	Total	PUCL
1974			3 920		1997	6 723	235	6 958	
1975			4 190		1998	7 766	137	7 903	
1976			5 110		1999	6 805	145	6 950	
1977			5 350		2000	8 440	227	8 667	
1978			4 590		2001	10 035	222	10 257	
1979			5 260		2002	8 638	242	8 880	
1980			4 736		2003	7 049	328	7 377	
1981			4 478		2004	8 545	274	8 819	
1982			4 287		2005	8 294	312	8 606	
1983			4 009		2006	6 973	443	7 416	7 000
1984			4 369		2007	7 568	220	7 788	7 000
1985			3 893		2008	7 329	470	7 799	7 000
1986			4 785		2009	6 594	461	7 055	7 000
1987			5 901		2010	7 453	397	7 850	7 000
1988			5 812		2011	7 392	399	7 791	7 000
1989			4 754		2012	6 461	303	6 764	7 000
1990			4 433		2013	6 209	491	6 700	8 300
1991	5 593	290	5 883		2014	5 767	315	6 082	8 300
1992	4 646	212	4 858		2015	6 428	244	6 972	8 300
1993	4 051	198	4 249		2016	7 338	214	7 552	8 300
1994	3 853	236	4 089		2017	7 787	422	8 209	8 300
1995	6 008	238	6 246		2018	7 253	255	7 508	8 054
1996	5 900	239	6 139		2019				8 054

Netfish



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
					Harders
Fishing pressure	**Unknown**	**Light**	**Optimal**	**Heavy**	
				Harders	

Introduction

There are a number of active beach-seine and gillnet fisheries throughout South Africa. By far the biggest are the fisheries for harders (or mullet) *Chelon richardsonii*, with 28 beach-seine and 162 gillnet Right Holders operating on the West Coast from Port Nolloth to False Bay. This fishery is managed on a total allowable effort (TAE) basis with a fixed number of operators in each of 15 defined areas. Permits are issued solely for the capture of harders, St Joseph *Callorhynchus capensis* and species that appear on the 'bait list'. The exception is False Bay, where Right Holders are also allowed to target linefish species that they have traditionally exploited. All evidence points towards the harder resource being overexploited, and sector conflict arises due to real and perceived impacts on linefish resources from associated bycatch. Excessive effort granted under Interim Relief as well as a substantial illegal component, which in most years equals or exceeds legal catches of harders, results in negative perceptions of management and negates most attempts to rebuild these stocks.

History and management

Beach-seine nets were introduced into the Cape during the mid-1600s and gillnets in the late 1800s. The main beach-seine targets then were large linefish species, in particular white steenbras *Lithognathus lithognathus* and white stumpnose *Rhabdosargus globiceps*. The advent of gillnets in the 1800s saw effort directed at geelbek *Atractoscion aequidens*, with reports of gillnets being strung between Robben Island and the mainland to intercept shoals of these fish moving along the West Coast. Harders were largely used for fertiliser, salted to victual passing ships and to feed farm labourers including slaves. Abolishment of slavery in the 1800s saw many "fishing rights" transferred to former slaves and indentured labourers, many of whose descendants are active in the fishery in the present day.

Until 2001, some 450 licensed permit-holders used about 1 350 nets, and an unknown number (perhaps a further 100) used another 400 nets illegally. The vast majority of these fishers were not reliant on netfishing but were occupied with this activity for a short period over the summer and autumn months, and either had other occupations such as teaching or farming, or spent the rest of the year in other branches of the fishing industry, such as the pelagic, rock lobster and linefish (snoek and hottentot seabream) fisheries. Many of the participants (including crew members) had retired from fishing activities and participated in the netfishery to supplement incomes and food supplies. Many, both historically advantaged and disadvantaged, were desperately poor and were employed seasonally as crew or factory workers. Overall, there was an excess of effort in the fishery. Many only went to sea a few times each year, catching small quantities of fish. They went to sea when they heard from the active participants about harders being plentiful. They then flooded the few small factories with fish, which maintained the price but refused to take any more fish than could be processed or sold fresh. This extra effort interfered considerably with the viability of the regular full-time fishers.

Back then, approximately 6 000 t were landed per annum by the beach-seine and gillnet fisheries. The gillnet fishery accounted for, on average, 3 250 t of harders, 650 t of St Joseph and 130 t of bycatch consisting of at least 27 species. Illegal gillnetting landed approximately 100 t of houndshark *Mustelus mustelus* and 50 t of linefish (mostly galjoen *Dichistius capensis*). Beach-seine permit-holders landed approximately 1 950 t of harders and in excess of 200 t of bycatch, also predominantly linefish.

Back then, the beach-seine and gillnet fisheries were seldom generating more than R20 million annually. Most of the operators were running at a loss of between 20 and 60%, especially in over-subscribed areas. The financial loss experienced by most fishers also indicated the part-time or "recreational" nature of many of the participants. Indeed, in the Berg River estuary, fewer than 4% of interviewed original permit-holders regarded themselves as netfishers and were either retired or employed elsewhere in other fishing sectors and various jobs.

It was evident that the beach-seine and gillnet fisheries were operating at a loss brought about by effort subsidisation, unfair competition between part-timers and *bona fide* fishers, and declining catches due to overfishing. Consequently, from

2001 onwards, Rights were allocated to those reliant on the fishery, and the numbers of legal beach-seine operations were reduced from around 200 to 28 and gillnet operations from just over 1 500 to 162.

Prior to this reduction in effort, size-frequency distributions of the harders caught suggested that the stock was overexploited on a local and national scale, with a strong negative correlation between effort (number of nets) and the size of fish caught. The allocations of medium- and long-term Rights saw the removal of part-timers from the beach-seine and gillnet fisheries. The 80% reduction in the number of net permits amounted to an effective 40% reduction in fishing effort, the target set by the Minister in 2001 to facilitate rebuilding of the harder stock.

Also relevant was the linefish bycatch, most of which was composed of species assessed as being overexploited or collapsed. In turn, most of the catches of overexploited or collapsed species were juveniles below the minimum legal size, i.e. before they were recruited into the linefishery and before they were able to reproduce, thus considerably compromising replenishment of linefish stocks. In turn, most of the targeted species are estuary-dependent, requiring estuarine nursery areas for their early life-history stages. Recognising that estuarine gillnetting was severely compromising the nursery function of estuaries and impacting negatively on the fisheries for many other species, the management policy was to phase out all estuarine gillnets in the long-term. This was implemented in all estuaries with the exception of the Olifants River estuary on the West Coast.

More recently, in 2010, by order of the Equality Court, three Interim Relief gillnet exemptions were issued to 15 fishers in Langebaan and two beach-seine exemptions in Struisbaai and Simonstown. The latter was awarded to more than 50 fishers who failed to fish due to inter-crew conflict and lack of a catch agreement between them. The Struisbaai exemption was awarded despite there being no TAE to the east of Cape Hangklip, this specifically due to the unsustainable bycatch of linefish there. The three shared gillnet exemptions in Langebaan have contributed to an escalation in fishing effort in an area where the TAE had already been exceeded. The nett result has been more than a 50 % increase in gillnet fishing effort with growth overfishing and a 10% and 20% decline in the average size of harders in Saldhana Bay and Langebaan Lagoon, respectively, and collapse of that population or stock (see current status, below). FRAP (fishing Rights allocation process) 2015 and the small-scale implementation were intended to see these fishers formally incorporated into the beach-seine and gillnet fishery within the limits of the TAE, thus reducing effort in an attempt to arrest the decline in growth rate. This management intervention to rebuild the stock never materialised.

Research and monitoring

Fishery-dependent data sources consist of ongoing measurement of length frequency, observer data, compulsory monthly catch returns by Right Holders and intermittent net- and linefishery surveys. The most important of the fishery-dependent data sources (and now historical reference) was the National Linefish Survey, as this provided comparable and combined catch, effort, compliance and socio-economic information for the beach-seine and gillnet fisheries, as well as the commercial, recreational and small-scale (including subsistence) linefisheries. It has not been possible to repeat this survey, however, since 1995.

Fishery-independent data are currently collected through sampling estuarine and surf-zone fish assemblages to ascertain the links between environmental and fishery variables and juvenile recruitment. Sample fish densities are compared across estuaries and surf-zones in relation to the different levels of fishing and environmental variables, such as freshwater inflow, in each of these systems. From these data, a predictive capability that can be incorporated into existing linefish stock assessment models will be developed. This is a relatively novel approach as the existing assessments are largely based on adults caught by the fishery and often ignore the anthropogenic and environmental influences experienced by fish in their earlier life-history stages. In all, 22 high-priority estuaries have been monitored once to four times annually from 2001 onwards, until the present.

In addition, recruitment sampling is complemented by netting with gillnets of identical mesh-size and dimensions to those used by the commercial and illegal fisheries to provide catch estimates independently of those unobtainable from the illicit gillnet fishery. Fishery-independent size frequency information, which allows comparison between areas with different levels of fishing effort, is validated by size-frequency distributions from the observer programmes. Past work shows that this approach provides a good indication of the status of local populations and the stock as a whole, as there is a strong negative correlation between the level of netfishing effort and average fish size.

Current status

Prior to the reduction in effort implemented after 2001, size frequency distributions of the harders caught suggested that the stock was overexploited on a local (netfish area) and national scale. There was a strong negative correlation between effort (number of nets) and the size of fish caught. This was not surprising considering that effort ranged from 0.5 nets per kilometre of coastline in Langebaan to 15 nets per kilometre in St Helena Bay. Also relevant was the linefish bycatch, most of which comprised species regarded as overexploited or collapsed. Furthermore, most of this catch comprised juveniles below minimum legal size, i.e. before they were recruited into the linefishery and before they were able to reproduce and thus contribute to replenishment of the linefish stocks.

There was some evidence, albeit briefly, for recovery of the harder stock in some areas. For example, in the Berg River estuary, continued monitoring before and after effort reduction indicated a recovery in the numbers and size of harders and bycatch species such as elf *Pomatomus saltatrix*. An increase in the numbers and mean size of harders caught in St Helena Bay was also reported by fishers and observers employed at that time. This success was, however, short-lived, as observer and compliance data indicated that the illegal gillnet fishery in the Berg River estuary soon escalated. These data suggest that at least 400 t are harvested illegally from the Berg River estuary, alone, each year. A total reduction of 600 t in reported catches by the legal fishery in the sea strengthens the veracity of this and highlights the predicted impact of this recruitment and growth overfishing on the legal fishery.

To reiterate, the area-specific beach-seine and gillnet fisheries are assessed on an ongoing basis by monitoring changes in size frequency distributions, catch per unit effort (CPUE), total catch, and species composition from fishery-independent surveys and, for a brief three years, from one observer based at the centre of the industry in St Helena Bay. These data and the nature of the fishery indicate that formal area-specific stock assessments are integral to providing scientific advice on the TAE. This was most evident for harder *Chelon richardsonii* in Langebaan and Saldanha where a 50% increase in gillnet fishing effort over and above the TAE was followed by a >40% drop in CPUE and a 15–20% decline in the average size of harders caught.

Consequently, an assessment of the Saldanha and Langebaan harder gillnet fishery was conducted in 2019. The per-recruit assessment applied looked at changes in sex ratio, mean length (mm) and standardised CPUE. Analyses of sex ratios over time indicated a significant switch between two periods (1998–2002 and 2017), from a predominantly female- (larger individuals) to a male- (smaller individuals) biased population (1.7 males: 1 female). Three period-specific length frequency distributions of commercial catch of *C. richardsonii* (1998–2002, 2009–2011 and 2017) indicated a reduction in mean total length (TL) of 36.5 mm over time (Figure 32). The standardised CPUE of harder for the period 2008–2016 declined, indicating a reduction in relative abundance of *C. richardsonii* of approximately 30% over this time (Figure 33). A spawner-biomass-per-recruit model revealed that the stock is heavily depleted, with the stock currently collapsed and at only 24% of estimated pristine spawner biomass or breeding potential (Figure 34), a level at which recruitment is likely to be seriously impaired.

The multifaceted diagnostic assessment approach applied to the Saldanha and Langebaan harder gillnet fishery highlights several characteristics of overfishing. Together, the change in sex-ratio and reduction in both CPUE and mean TL characterise an overexploited fishery. These negative results are likely due to the combined effects of the TAE being exceeded by 50%, illegal catches occurring in the Restricted and Sanctuary zones of the Langebaan MPA, and fishers reducing mesh size to maintain catch rates.

Exacerbating the problem was an anomalous series of 1-in-50-year floods in quick succession on the South and West coasts in 2013–2014, followed by the severe 1-in-100-year drought since then, which considerably reduced juvenile recruitment into estuaries and ultimately into fisheries, over the last six years. This had a negative impact on the adult stocks of harders and many other estuary-associated species, including dusky kob *Argyrosomus japonicus*, elf *Pomatomus saltatrix* and white steenbras *Lithognathus lithognathus*. Ultimately, the impact on the beach-seine and gillnet fisheries will depend on the linkages between the South, East and West coast populations of these species

Ecosystem considerations

Obvious from the above is that environmental drivers also play a role in harder growth, which varies between estuaries, islands and the nearshore, and between the cool West and warm-temperate South coasts of South Africa. The sex ratios of harders in estuaries and the nearshore, subject to low fishing pressure, are skewed towards females and may be as much as 9 females: 1 male in some localities. This contrasts with fished areas where sex ratios are skewed towards males or the gender parity of 1 female: 1 male around the offshore islands. Spawning occurs in the nearshore throughout the summer but with early and late season peaks. Females and males grow at the same fast rate to maturity during the first year, whereupon female growth slows considerably and that of males becomes negligible. Females attain larger size-at-age in all regions and habitats. South Coast female fish are larger than West Coast ones and estuary female fish are larger at age than those in the sea. Females from islands on the West Coast appear to grow faster than those from the nearshore. Observed differences in growth are likely attributable to the interplay between harder life-history strategies and response to the environment and fishing. Females grow larger than males and continue to grow after maturity to maximise reproductive output. South Coast fish are larger than West Coast ones due to the West Coast net fisheries catching larger fast-growing fish (and females), thereby selecting for slow growth. Warmer temperatures and higher productivity in the South Coast nearshore may also play a role. Similarly, favourable environmental conditions and lower fishing intensity around the

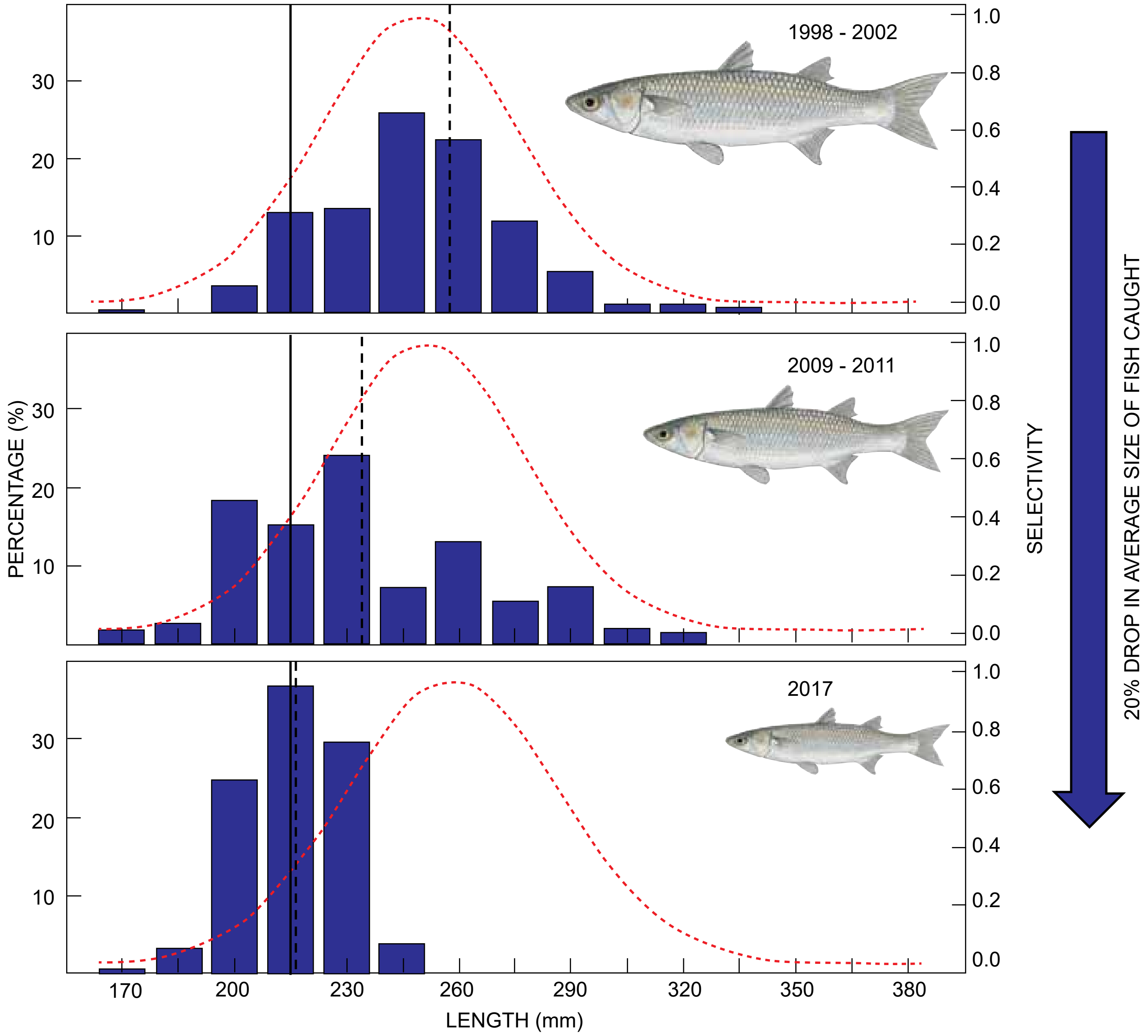


Figure 32: Length-frequency distributions of *Chelon richardsonii* caught in Saldanha and Langebaan by the commercial gillnet fishery fleet for three different time-periods. The solid vertical line represents length-at-50% maturity (215 mm total length [TL]) and the dotted vertical line is the mean TL for that length-frequency series. The bell-shaped selection curve is the selectivity of the gillnets that were deployed during that particular time-series. After Horton et al. (2019). For comparison, the harder pictures are to scale and illustrate the average size in each of the time-series

offshore islands and in estuaries may account for the faster growth and larger fish there.

Ecosystem interactions

Estuaries and freshwater flow

All South African estuaries are important nurseries for exploited marine and estuarine species before they recruit into marine fisheries, and more than 90% of the beach-seine and gillnet catch comprises estuary-associated species. This is illustrated by the declines in the *Chelon richardsonii* stock and marine gillnet fishery catches on the West Coast, which have been directly attributed to recruitment overfishing in the legal and illicit Olifants River and Berg River estuary gillnet fisheries. Fishing aside, the health of estuarine habitat determines juvenile fish recruitment, survival and ultimately catches in the sea. Estuarine health is largely driven by catchment management and the quantity and quality of fresh water reaching the estuary and sea. Reductions in freshwater flow are accompanied by declines in primary production, shrinkage of the warm-water plume entering the sea, narrowing of the stream channel, and an overall reduction in available habitat and refugia and loss of estuary nursery function for juvenile fish.

There are only nine estuaries on the West Coast, of which only three, the Orange, Olifants and Berg, are large and permanently open to the sea. Overall, there has been an approximate 40–80% reduction in freshwater flow and a 60% loss of floods to these estuaries. Climate change, increased hydropower demands and freshwater abstraction, will see these losses be even greater in the future. In the present

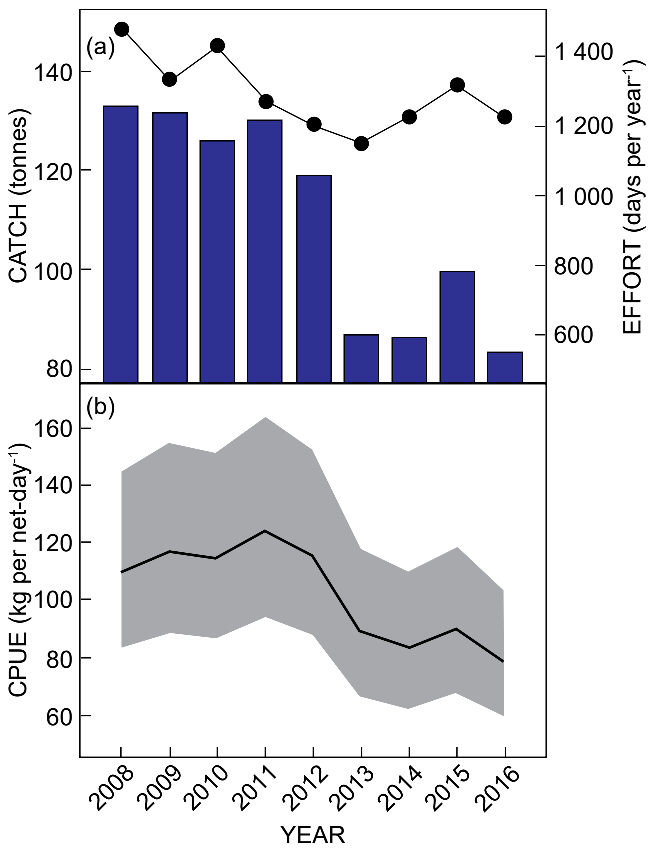


Figure 33: (a) The annual total catch (t) (shaded bars) and fishing effort (days year^{-1}) (line) of *Chelon richardsonii* by the commercial net fishery in Saldanha Bay and Langebaan, and (b) the standardised CPUE (kg trip^{-1}) estimates (±95% CI) of the commercial *Chelon richardsonii* net fishery in Saldanha Bay and Langebaan derived from mandatory catch records between 2008 and 2016. After Horton et al. (2018)

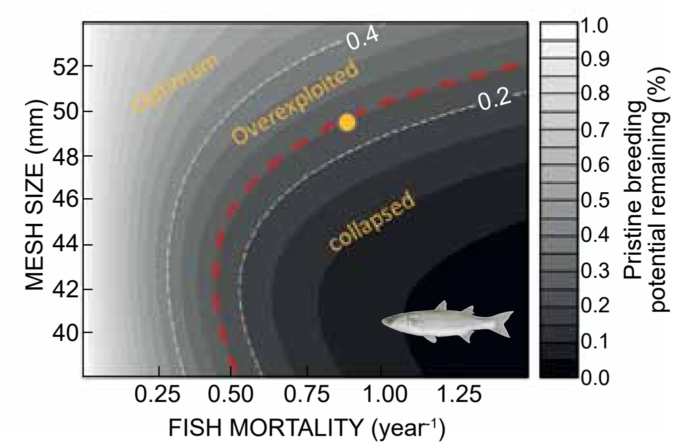


Figure 34: An isopleth illustrating the response of the percentage of spawner-biomass-per-recruit (SBR) to unexploited levels (SB_0) of *Chelon richardsonii* according to varying levels of fishing mortality (*F*, year^{-1}) and different combinations of mesh sizes (mm). Critical reference depletion points (SB_{40} and SB_{20}) are represented by dashed white lines. The current SBR is denoted by ○; SBR depletion = 0.245, F_{curr} = 0.881 year^{-1}. After Horton et al. (2019)

day, juveniles of obligate estuary-dependent fish such as springer/flathead mullet *Mugil cephalus* and white steenbras *Lithognathus lithognathus* in West Coast estuaries have declined in abundance to <10% of reference (pristine level) and are likely to decline to <5% under future flow projections. Partially estuarine-dependent fish, most importantly harders, the mainstay of the netfishery, have estuarine juvenile populations that are now at 60% of pristine levels.

Range expansions and shifts in abundance

Range expansions and/or shifts in abundance have been documented for more than 50 nearshore and estuarine fish in our waters over the past 30 years. Most of these shifts can be attributed to various global and climate change drivers, including changes in rainfall, freshwater flow, wind regimes, water chemistry and catchment and sea temperatures. Until recently, most of these shifts in southern Africa have been of tropical, subtropical and warm-temperate fish moving south and west to the cool-temperate biogeographical region, ostensibly due to warming there. However, there are more and more instances of cool-temperate fish expanding northeastward and westward into the warmer bioregions. By example, there are about 12 species of mullet occurring in our coastal waters, only one cosmopolitan, and the rest with their core range in each of their preferred bioregions. Tropical/warm-temperate groovy mullet *Chelon dumerili* from the East Coast have increased from less than 10% to more than 30% of total mullet abundance in Cape South Coast estuaries over the past 25 years. Similarly, freshwater mullet *Pseudomyxus capensis*, originally limited to the Southeast and East Coast, have expanded past Cape Agulhas, are abundant in Table Bay estuaries and now also occur in the Orange River estuary on the West Coast. Harder *Chelon richardsonii* are cool-temperate fish and comprise 98% of mullet biomass on the West Coast and until recently about 90% of that on the South Coast. They have dropped to 50–70% of mullet abundance on the cool- and warm-temperate South Coast but increased from less than 1% to 5–10% of that in the warm-temperate/subtropical transition zone of the East Coast. Similarly, *C. richardsonii* have increased from about 10% to more than 30% of mullet biomass in the warm-temperate/subtropical region of northern Namibia and southern Angola.

Bird, seal, shark, cetacean interactions and bycatch

Concerns around frequent, excessive gillnet catches of 100 or more penguins *Spheniscus demersus* around Dassen and Robben Islands prompted management intervention in the late 1990s. Gillnet fishers were setting their nets across penguin approaches because of the guano slicks on which harders feed. Gillnet exclusion zones now prohibit gillnets being set within 1–2 km of each island.

High bird-bycatch mortality, especially in unattended nets, led to legislation and permit conditions that prohibit unattended gillnets (either set or drift). The most vulnerable species are crowned cormorant *Microcarbo coronatus* and penguins in the sea, and African darters *Anhinga rufa*, reed cormorants *Microcarbo africanus* and great crested grebes *Podiceps cristatus* in the estuarine environment. More recently, an upsurge in poaching with gillnets has been accompanied by an increase in the retention of bird bycatch for food and African and Asian "traditional medicine" trade. This may need management intervention in the future.

Seal depredation of catches is frequent in the beach-seine and gillnet fisheries. Catch loss is similar in both fisheries but damage to beach-seine nets is negligible compared to the costly repairs or replacement of gillnets. Fishers are permitted to request management authorities to cull problem animals but this rarely happens, and is usually limited to the Olifants Estuary. Some fishers successfully use bullwhips to keep seals away from their nets. There are limited seal mortalities, mostly of pups, in the beach-seine and St Joseph gillnet fishery.

Cetacean bycatch and mortality, especially of Heaviside's dolphin *Cephalorhynchus heavisidii*, has long been a problem with the larger-mesh set nets used to target St Joseph and with the illegal galjoen gillnet fishery. Up until the 1980s most cetaceans caught, sometimes through targeted sets, were kept and eaten. These mortalities occurred mainly in the Cape Columbine region. Consequently, since 1999 there has been an effective 25 km exclusion zone for the gillnet fishery from North Head Saldhana Bay to Cape Columbine.

Shark interactions with the netfishery range from being taken as bycatch to depredation of catches by sevengill cowsharks *Notorynchus cepedianus* and bronze whalers *Carcharhinus brachyurus*. Despite claims to the contrary, white shark*Carcharodon carcharias* do not home in on beach-seine net activity in False Bay thereby posing a safety risk to beach-goers. Analysis of more than 11 000 catch records suggest that these sharks actively avoid beach-seine nets once set. Beach-seine fish-spotters in False Bay are used as auxiliary shark-spotters at Fish Hoek and Simon's Town and were consulted on the design and deployment of the bather protection "shark exclusion net" at Fish Hoek beach. The design and deployment of the exclusion net is strictly to rules that prevent interference with beach-seine operations and target species (e.g. yellowtail *Seriola lalandi*) in Fish Hoek Bay.

Further reading

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Oysters

Stock status	Unknown (KwaZulu-Natal and Southern Cape)	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	**Unknown**	**Light**	**Optimal** (KwaZulu-Natal)	**Heavy** (Southern Cape)	

Introduction

The Cape rock oyster *Striostrea margaritacea*, which is targeted in this fishery, has an extensive geographic distribution and occurs on rocky reefs from Cape Agulhas to Mozambique. These oysters are found in the intertidal zone down to about 6 m water depth. The Cape rock oyster occurs naturally and is sold in South African restaurants. Another species that is available in restaurants is the Pacific oyster *Crassostrea gigas*, which is imported and used widely in marine aquaculture. Cape oysters along the KwaZulu-Natal (KZN) coast have been found to take 33 months (almost three years) to reach marketable size (60 mm right-valve length). Oysters are broadcast spawners, and those along the KZN coast spawn throughout the year, with peaks during spring and summer.

Harvesting takes place during spring low tides and has traditionally been restricted to the intertidal zone. In recent years, however, this has gradually been expanded towards the fringes of the subtidal zone (see below). Oysters are dislodged from rocks by means of a pointed steel crowbar (oyster pick). Harvesters are allowed to wear a mask, snorkel and weight-belt, and commonly use an oyster pick to dislodge oysters from the rocks. The use of fins and artificial breathing apparatus is not allowed. No harvesting is permitted from the subtidal beds, which are considered to seed the intertidal oyster reefs.

History and management

The commercial fishery for oysters dates back to the late 19th Century. Prior to 1998, a handful of individuals (less than 8

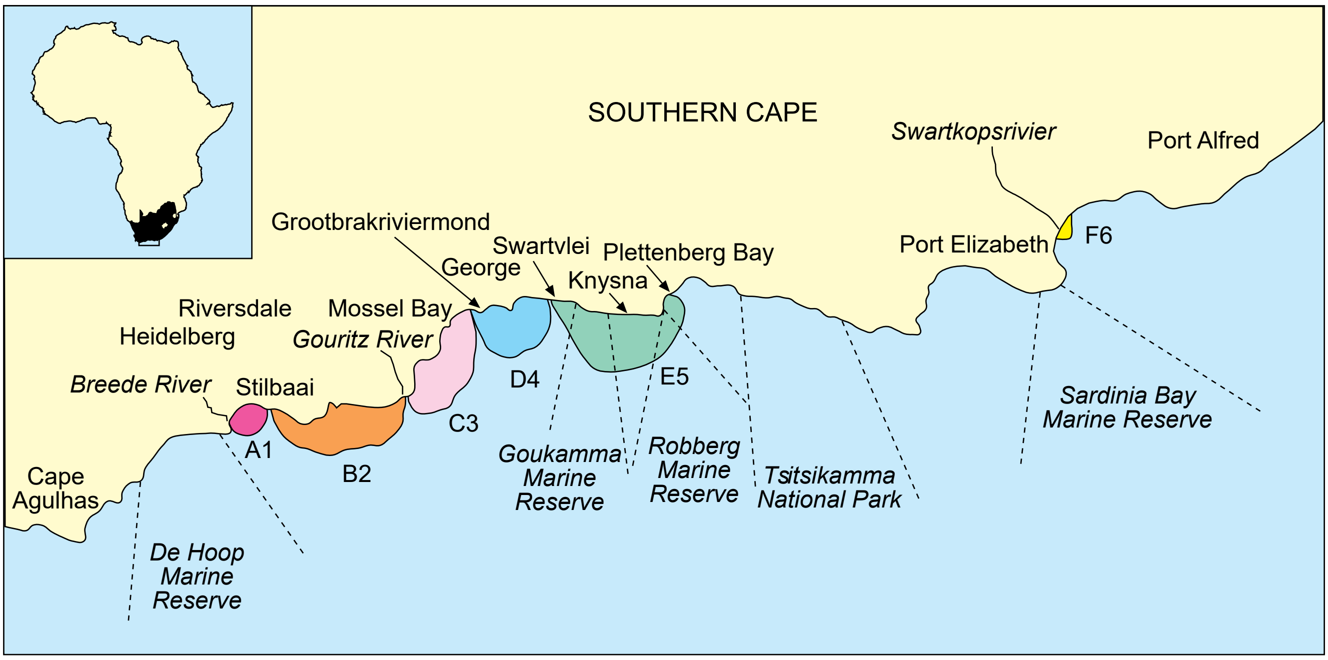

Figure 35: Oyster fishery in Port Elizabeth and the Southern Cape. The colour-coded areas indicate dedicated oyster-collection zones

people) held concessions to harvest oysters and employed large numbers of "pickers" to assist with collections. In 2002, Rights were redistributed and medium-term (4-year) Rights were allocated to 34 Right Holders, the majority of whom held limited commercial Rights and were allowed to work with up to three pickers each. A few Right Holders held full commercial Rights and were allocated a maximum of 10 pickers each. In total, 114 pickers were permitted to harvest oysters during this period.

In the 2006 Rights allocation process, the sector was further transformed and 3-year commercial Rights were allocated to 121 individuals. A large number of pickers were accommodated in this process, the idea being that pickers were granted Rights as a means of empowering those who were dependent on oyster harvesting for their livelihood. In this system, Right Holders were required to harvest the oysters themselves and were no longer allocated additional effort (pickers) to assist with harvesting. In 2013, the "fishing rights allocation process' (FRAP 2013) for this fishery started and, after an appeal process, confirmed the previous number of harvesters and their split across the four fishing areas (Figure 36) in 2015. In 2017, 73 Rights were allocated to the new small-scale sector, leaving 72 Rights for allocation to the commercial sector. During all the allocation changes in recent years, the TAE and its split between areas remained constant (see Useful Statistics).

The oyster fishery was previously managed as two separate fisheries related to their areas of operation, namely the Southern Cape Coast and the KZN Coast. Since 2002 the oyster fishery has been managed as a national fishery. Under the new management system, four commercial oyster-harvesting areas were officially recognised, namely the Southern Cape, Port Elizabeth, KZN North and KZN South (Figures 35 and 36). Regional differences regarding regulations and harvesting patterns have been retained.

Research and monitoring

Research on the oyster resource has begun only recently. Since oysters are of relatively low value in comparison to other commercially exploited species, in the past the fishery was not prioritised in terms of research effort and management attention. The consequence is that the total allowable effort (TAE) for the oyster fishery is currently determined according to historical effort levels and not on the basis of the assessed stock or status of the resource.

Initiatives are underway to improve the quality of catch and effort data, and towards undertaking resource assessments. Current research on oysters is therefore focused on developing appropriate methods for assessing the oyster resource, given that the patchy distribution and cryptic nature of oysters make accurate sampling of this resource in the intertidal zone exceedingly difficult. Once the method is refined and a reliable index of oyster abundance is obtained, improved scientific advice on sustainable harvesting levels will be able to be provided.

Due to the uncertain status of the resource, and evidence of overexploitation in the Southern Cape, this region has been prioritised for research efforts aimed at establishing indices of

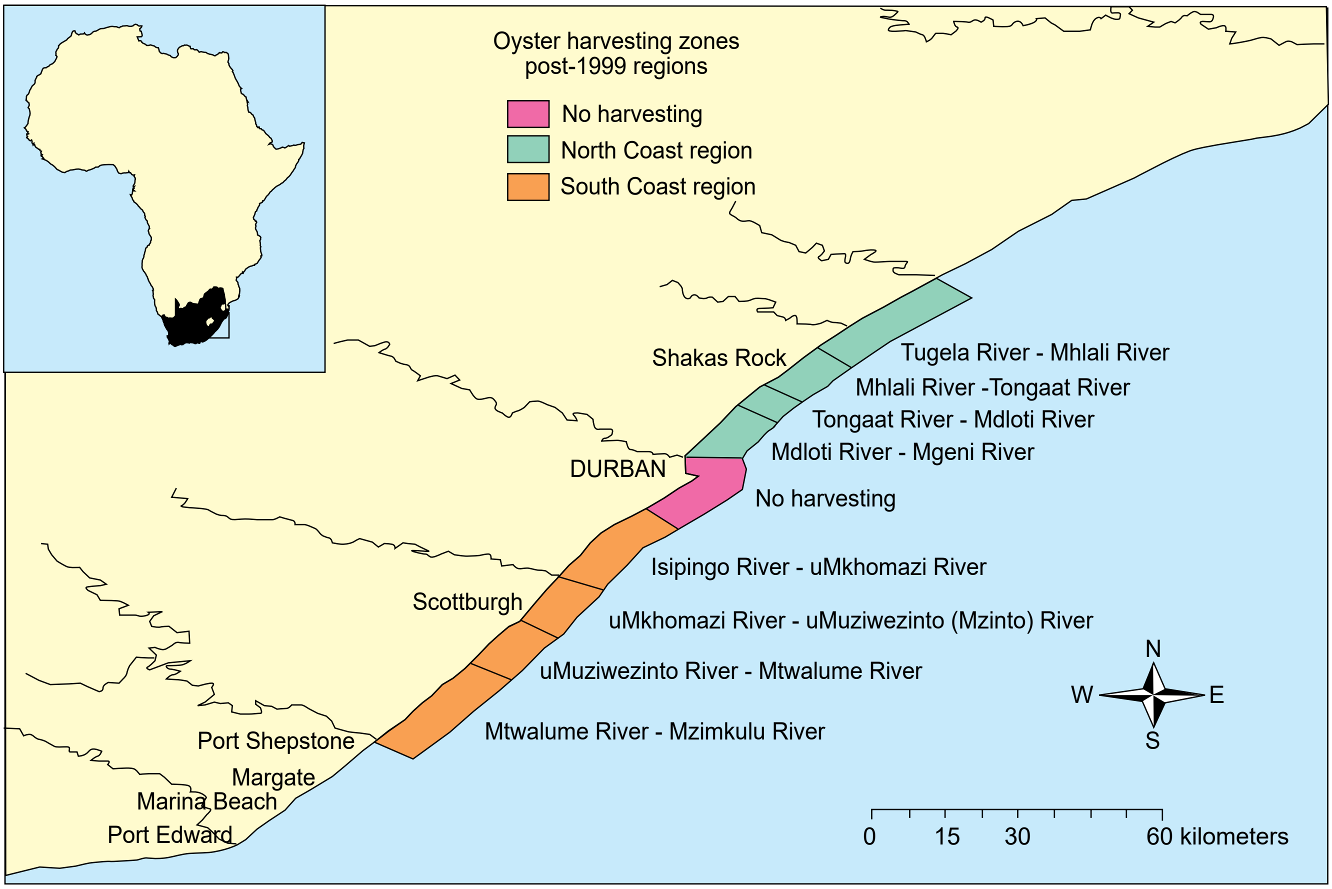

Figure 36: Oyster fishery in KwaZulu-Natal (re-zoning of South Coast included)

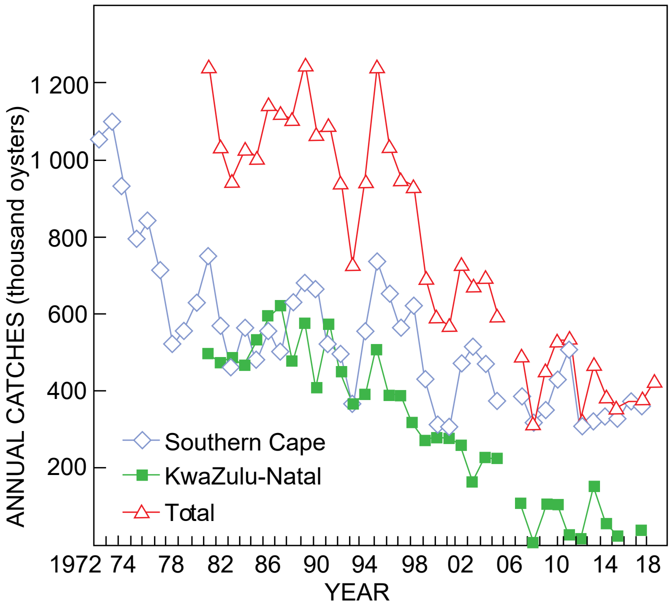

Figure 37: Total number of oysters harvested from the Southern Cape and KwaZulu-Natal coasts from 1972 to 2018

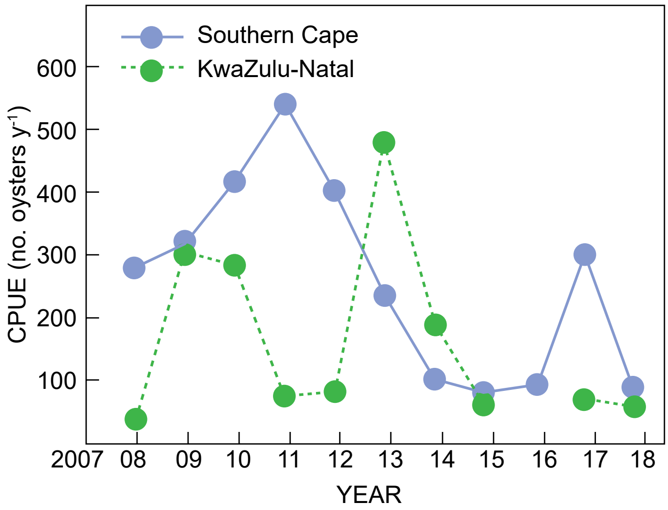

Figure 38: CPUE data calculated from catch data (see Figure 37) for oysters harvested commercially per annum from 2008 to 2018

abundance, estimating density and population size structure, and determining a more accurate TAE. Research and monitoring in KZN is carried out by the Oceanographic Research Institute (ORI) under contract to the Branch: Fisheries Management with the purpose of providing information on which to base recommendations for this region of the coast.

Current status

Currently, the overall TAE is 145 pickers. In the last five years, however, on average only 60% of Right Holders have actively fished in all areas. The status quo is being maintained until further data become available.

Total catches between 2002 and 2005 were between approximately 600 000 and 730 000 oysters, the majority of which were harvested in the Southern Cape (Figure 37). Data for 2006 are not available because catch reporting was poor on account of the new Rights allocation and the change of Right Holders. The low catches in KZN in 2008 (3 491 individuals) was an exception, caused mainly by problems during the permit processing. Since 2009, total catch has stabilised at above 350 000 oysters. It is noteworthy, however, that these come mainly from the Southern Cape because catches in KZN are at very low levels and have declined consistently during the last two decades (Figure 37). This is thought to be caused by reduced effort (non-activation of permits), poor catch reporting (especially along the KZN South Coast) or a decline in resource availability. Further research is required for an updated assessment.

The oyster resource along the KZN coast is considered to be fully exploited. Resource assessments undertaken in 2006 during a research project outsourced to ORI showed that, although the oyster stocks had declined since 1980, they were stable or showed only a slight decline for approximately 20 years prior to the study. As mentioned above, however, harvesting figures have declined more recently.

In the Southern Cape there is concern that the intertidal zone is being denuded of oysters as a result of being over-harvested. Surveys undertaken between 2000 and 2004 that measured oyster density and size composition suggested that the intertidal component of the oyster stock along the Southern Cape Coast appeared to be overexploited. Moreover, there have been reports of divers illegally harvesting oysters from subtidal "mother beds".

Catch per unit effort (CPUE) data for the Southern Cape oyster fishery fluctuated strongly from 2008 (Figure 38) and are considered unsuitable for the purposes of stock assessment. The status of this resource thus remains uncertain.

Ecosystem interactions

The harvesting of rock oysters involves the direct picking of individual organisms from the rocks, and the use of diving masks by pickers allows more-precise fishing, thereby reducing the potential for dislodgement of non-target species. Oyster harvesting is therefore considered to have minimal significant disturbance on the surrounding biological communities, although research is required to substantiate this view.

Further reading

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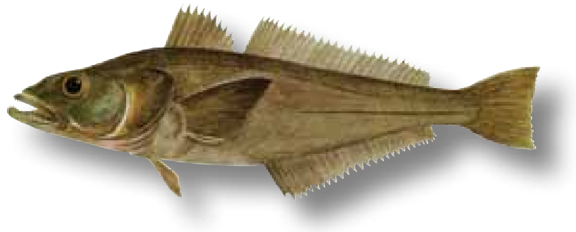
Useful statistics

Total allowable effort (TAE) (number of pickers) and total catch (number of oysters) for the oyster fishery for the period 2002 to 2017

	Southern Cape and Port Elizabeth		KwaZulu-Natal	
Year	TAE	Catch	TAE	Catch
2002	105	471 360	40	257 238
2003	105	511 946	40	163 357
2004	105	468 485	40	227 067
2005	105	373 322	40	222 864
2006	105	–	40	–
2007	105	387 831	40	105 552
2008	105	315 807	40	2 796
2009	105	350 853	40	103 684
2010	105	426 649	40	102 168
2011	105	508 422	40	24 928
2012	105	311 186	40	13 695
2013	105	320 312	40	149 863
2014	105	327 120	40	52 620
2015	105	330 392	40	20 833
2016	105	374 698	40	–
2017	105	368 270	40	34 171
2018	105	373 306	40	54 131

Patagonian toothfish



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

Patagonian toothfish *Dissostichus eleginoides*, (Figure 39) belong to the family Nototheniidae, a family of fish that occurs in the Southern Ocean. Unlike other species in the family, Patagonian toothfish appear to lack antifreeze molecules in the blood and are consequently not found in waters colder than 2° C. They are slow-growing, reaching sexual maturity at about 90 to 100 cm (9 to 10 years old) and attain a maximum total length of over 200 cm. Patagonian toothfish occur at depths between 70 and 1 600 m around sub-Antarctic Islands and seamounts, mainly between 40° S and 55° S. A longline fishery for this species has developed in the South African exclusive economic zone around the Prince Edward Islands (PEI-EEZ).

Patagonian toothfish fetch a high price on markets in the United States and Japan and have consequently been the target of extensive fishing, primarily using longline gear. As a large part of their distribution is on or around remote seamounts and islands where surveillance is difficult, they have been subjected to substantial illegal, unreported and unregulated (IUU) fishing. The implementation of a catch-documenting scheme that enables buyers to identify product from legal fisheries has led to a marked reduction in levels of IUU fishing. Fisheries for Patagonian toothfish are further characterised by losses through marine mammals (mostly killer whales *Orcinus orca*) taking fish off the lines (termed "depredation"). In some fisheries this depredation can be substantial. During a single fishing trip in the PEI-EEZ, it was estimated to represent a loss of as much as 80% of the catch on a single day, and 30% to 50% of the catch during that trip.

Most of the Patagonian toothfish distribution falls within the area managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). As an original member of CCAMLR, South Africa remains committed to its objectives, and has voluntarily applied the CCAMLR conservation measures (CMs) within the PEI-EEZ. According to CCAMLR CM 32-01 "the fishing season for all Convention Area species is 1 December to 30 November the following year"; thus a split-year fishing season applies within the PEI-EEZ.

Figure 39: A Patagonian toothfish *Dissostichus eleginoides*, with an individually-numbered tag inserted just below the dorsal fin

History and management

An experimental fishery for Patagonian toothfish in the PEI-EEZ was initiated in October 1996. Five Permit Holders participated in the experimental fishery from its inception until 30 November 2005. In 2006, the experimental fishery was converted to a commercial fishery through the allocation of five long-term fishing Rights. At the start of the commercial fishery there were two active vessels, one representing the largest Right Holder and a second, larger vessel operating for a consortium of the other four Right Holders. The consortium soon withdrew their vessel from the fishery, advising that fishing was uneconomical due to poor catch rates and high losses to marine mammals. Consequently, only a single vessel operated in the PEI-EEZ from 2006 until the consortium re-introduced a second vessel into the fishery in late 2010.

Various gear configurations have been employed to exploit the resource since the inception of the fishery. At the commencement of the fishery in the 1990s, the primary fishing gear employed was a form of longline known as an "autoline", with a few vessels using the Spanish double-line system. Apart from a brief period (2004–2005) when one vessel deployed pots, the period from 2000 onwards was characterised by an increasing shift to the use of Spanish longlines, and autolines were eventually phased out altogether by 2008 (Figure 40). Another shift in the gear employed began with the introduction in 2008 of a modified longline gear, the trotline, which appreciably decreases the loss of catch to marine mammal depredation and has a higher retention of large fish. Use of this gear has subsequently increased to the extent that no Spanish longline gear has been used subsequent to the 2012/2013 fishing season (Figure 40). These gear changes have complicated the assessment of the status of the resource (see below), and hence its management. An experiment to calibrate catch rates between Spanish longlines and trotlines was

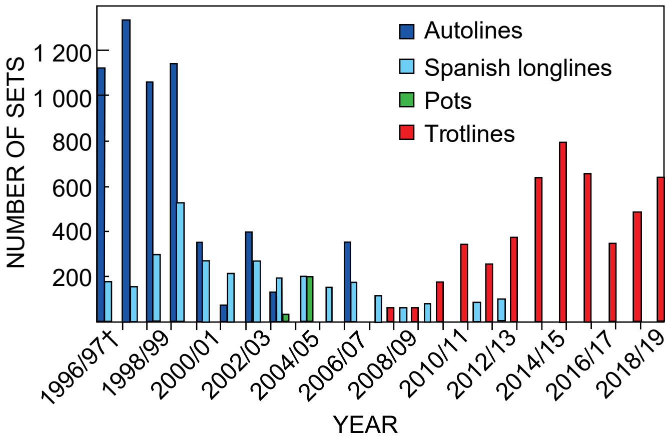


Figure 40: Number of sets deployed per fishing season in the Prince Edward Islands EEZ. Data are shown for pot lines and for three different longline gear configurations deployed in the fishery over time. † Note that data for the 1996/97 season include fishing during the months of October and November 1996

initiated in the 2011/2012 season and continued through to the end of the 2012/2013 fishing season. Currently, trotlines are the only gear deployed in this fishery.

During the two years prior to the start of the experimental fishery the Patagonian toothfish resource in the Prince Edward Islands area was subjected to heavy exploitation by a fleet of illegal vessels that ranged throughout the Southern Ocean. The estimated IUU catch during those initial two years was more than double the total legal catch taken over the subsequent 20 years. The IUU activity in the area declined in response to reduced catch rates and the establishment of the legal fishery, and the last recorded IUU activity in the PEI-EEZ was the sighting of a single vessel in 2004. Although there has been no indication of IUU activity since 2004, there is a possibility that IUU activity could go undetected because of the limited presence of legal vessels in the PEI-EEZ. Consequently, assessments of the PEI toothfish resource conducted prior to 2013 assumed a continued, constant IUU take of 156 t per annum (i.e. the same level as that estimated in 2004) over the period 2005 to 2009. On the basis of information that subsequently became available, recent assessments of the resource (2013 onwards) have assumed no IUU catches in the PEI-EEZ after 2005.

Regulation of the fishery was initiated in the 1996/97 season with a 2 500 t total allowable catch (TAC) (Figure 41), but this was increased to 3 000 t for the 1997/98 season to promote year-round presence in the PEI-EEZ in an effort to deter IUU fishing activity. The TAC was reduced to 2 750 t for the 1998/99 and 1999/2000 seasons, and then further reduced to 2 250 t for the 2000/01 season, since resource indicators (catch per unit effort [CPUE]) suggested that sustainable harvest levels had been greatly reduced due to illegal catch levels. The first assessment of the status of the resource was conducted in 2001 and used an age-structured production model (ASPM) that was based on CPUE data derived from Spanish longline sets. The results of the assessment indicated severe depletion of the stock, which led to a decrease in the TAC to 600 t for the 2001/02 season. At its October 2002 meeting, the CCAMLR Scientific Committee suggested that a TAC of not more than 400 t would be appropriate for the 2002/03 season. In consultation with industry representatives, a compromise was reached between the 400 t suggested by CCAMLR's Scientific Committee and the 600 t TAC that was set in the 2001/02 season. This compromise was firstly to demonstrate South Africa's commitment to CCAMLR, and secondly to provide sufficient catch to maintain a year-round legal fishing presence in the PEI-EEZ as a means of deterring further IUU fishing in the area. The TAC was thus set at 500 t for the 2002/03 season and maintained at that level for the 2003/04 fishing season.

The ASPM was extended to incorporate catch-at-length (CAL) data as a basis for TAC recommendations in 2003. Despite refinements to the model, the two primary resource-monitoring indices (CPUE and CAL) yielded conflicting estimates of resource status. While the CPUE data indicated that the resource was severely depleted, the CAL data suggested that the situation was less serious. Attempts to reconcile these two indices were unsuccessful. These circumstances led to major difficulties in making scientific recommendations for appropriate catch limits for this resource, and a pragmatic approach was adopted that led to a reduction in the TAC to 450 t for the 2004/05 season. The consortium of four Right Holders withdrew their vessel in 2006 due to economic pressures, leaving only a single Right Holder, with an allocation of 27% of the TAC, active in the fishery. Consequently the TAC was maintained at 450 t per annum until 2010 when the consortium of four Right Holders re-entered the fishery. The annual catches over the 2006 to 2010 period were well below the TAC (Figure 41) as a result of only one Right Holder being active in the fishery.

An updated analysis of the status of the resource incorporating additional catch data (2007–2010) was conducted in September 2011. The analysis was complicated by the gear change (Spanish longline to trotline) in the fishery in recent years that had compromised the only index of abundance, namely the time-series of commercial CPUE. Depending on the data and approach used in the analysis, standardised CPUE dropped

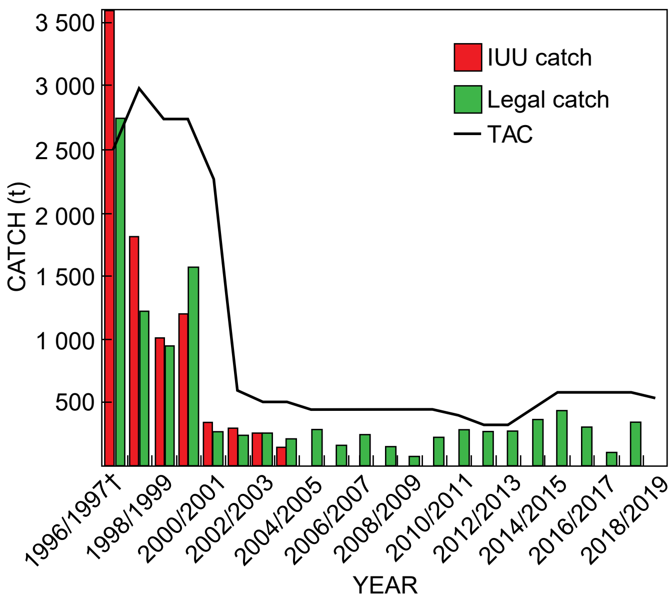


Figure 41: Catches (tonnes) of Patagonian toothfish estimated to have been taken from the Prince Edward Islands EEZ. Catches are split into those from the legal fishery and estimates of illegal (IUU) catches.
† Note that data for the 1996/97 season include legal catches during the months of October and November 1996, and that the estimated IUU catch during this period was in excess of 21 000 tonnes

by between 16% and 34% in 2010 relative to preceding years. On the basis of these results, the TAC for the 2011/12 fishing season was reduced by 20% from the 2010/11 level to 320 t, and this level was maintained for the 2012/13 season, pending further work on calibrating the Spanish longline and trotline CPUE indices.

A research strategy was implemented during the 2011/12 and 2012/13 fishing seasons with the objective of calibrating the trotline CPUE against that for Spanish longline. The strategy involved operators deploying paired sets of both Spanish longline and trotline gear in close spatial (3 nautical miles) and temporal (2 weeks) proximity to each other in order to compare catch rates obtained with the two gear types. The data collected during this exercise enabled the calculation of a calibration factor for the two gear types, which could then be applied to the general linear mixed model (GLMM)-standardised CPUE time-series for each gear type to obtain a calibrated overall "longline" CPUE abundance index for the entire duration of the legal fishery.

The assessment of the Prince Edward Islands toothfish resource was updated during 2013 to take account of further catch, GLMM-standardised CPUE and catch-at-length information that had become available for the years 2007 to 2013. The assessment allowed for three fleets to accommodate data from the pot fishery that operated in 2004 and 2005 and the trotline fishery since 2008, in addition to the Spanish longline operations. Results from the updated model indicated that the resource was healthier than has been suggested in previous assessments, yielding estimates of current depletion (spawning biomass relative to pre-exploitation levels) ranging from 43% to 87% depending on various assumptions of recruitment variability and pre-exploitation abundance. Based on these results, the TAC for the 2013/14 fishing season was increased to 500 t.

In addition to updated catch data and the improved standardised CPUE index of abundance, the 2014 assessment-model update involved several improvements over previous assessments. Tag-recapture data (Table 10) were incorporated for the first time, and a new basis for estimating the extent of depredation by cetaceans was used. The updated model yielded a changed perception of depletion, with estimates ranging from 55% to 60% of the average pre-exploitation spawner biomass. Although projections using the assessment model indicated that the resource would increase in abundance under catches of up to 700 t per annum, the poor fits to longline CPUE data, coupled with uncertainties regarding the stock-recruit relationship, led to the decision to set the TAC for the 2014/15 season at 575 t, with further increases dependent on a review of updated datasets. The TAC was subsequently maintained at this level until the 2018/19 season due to concerns related to the declining trotline CPUE index despite projections from assessments indicating that the TAC might be safely increased to some extent. The 2018 update of the assessment was conducted in circumstances where the trotline CPUE had continued to decline, and used a new basis to estimate the extent of cetacean depredation. The assessment yielded a somewhat more pessimistic perception of resource status than did that conducted in 2017, and projections under a suite of alternative scenarios of future resource dynamics indicated that a 5.5% reduction in the TAC (to 543 tonnes) for the 2019/20 fishing season would be appropriate.

Table 10: Number of Patagonian toothfish tagged and released per year in the Prince Edward Islands EEZ, and the number of tagged fish recaptured per year

Season	Released	Recaptured
2004/2005	175	4
2005/2006	179	4
2006/2007	120	7
2007/2008	141	13
2008/2009	74	1
2009/2010	131	9
2010/2011	206	8
2011/2012	162	12
2012/2013	253	25
2013/2014	386	52
2014/2015	458	35
2015/2016	317	10
2016/2017	125	5
2017/2018	362	8
2018/2019†		
Grand Total	3 279	193

† Up to 22 February 2019

Research and monitoring

Catch and effort data are reported by the fishing vessels on a set-by-set basis (i.e. per longline deployed). In compliance with CCAMLR conservation measures, there is 100% observer coverage in this fishery. Catch and effort records and observer reports are submitted to CCAMLR.

Some toothfish were tagged during 2005 as a trial, and a tagging program was initiated in 2006. Vessels are required to tag and release one fish per tonne of catch (in line with CCAMLR Conservation Measure 41-01). Fish should be selected at random for tagging (every 100th fish, for example) so that a range of sizes is tagged. However, fishermen tend to select the smaller fish to tag because they are less valuable and are easier to handle – it is difficult to bring a large (70 kg) fish onboard without using a gaff and thereby injuring the fish. A tag-overlap statistic has been developed by CCAMLR to measure the degree to which the length distribution of tagged fish matches that of all fish caught, and a requirement for a tag-overlap statistic in excess of 60% was introduced. These regulations have resulted in a marked improvement in the size range of tagged fish. To date 3 279 fish have been tagged and 193 have been recaptured (Table 10).

About 88% of recaptures of tagged toothfish have been within 10 nautical miles of the tag-and-release locations. This observation suggests that toothfish do not move between seamounts and hence could be susceptible to serial depletion. If this was the case, then standardising the CPUE over a large area would mask the serial depletion and lead to an artificially stable CPUE trend.To address this concern, a new CPUE standardisation was developed during 2014, using a finer spatial scale for fishing areas. The results did not support the hypothesis of serial depletion and showed no evidence of systematic shifts in fishing effort over time, but did show a larger decline in CPUE over the last five years than that estimated by previous standardisations.

Efforts are being directed at continuing work on developing an operational management procedure (OMP) to enhance effective management of the resource and fishery. Efforts

Table 11: Estimates of resource status provided by the base-case model and two sensitivity runs developed during the 2019 assessment. Results arising from the application of the 2018 base case are also shown

Parameter	Description	2018 base case	2019 base case	2019 intermediate case	2019 pessimistic case
K^{sp}	Pre-exploitation spawning biomass (t)	27 726	25 582	22 458	13 115
MSY	Maximum sustainable yield (t)	1 162	1 077	946	554
B^{sp}_{2019}/K^{sp}	Depletion in 2019	0.377	0.397	0.360	0.193
B^{sp}_{2020}/K^{sp}	Depletion in 2020	-	0.374	0.336	0.161
B^{sp}/B_{MSY}	Spawning biomass relative to B_{MSY}	1.538	1.520	1.365	0.655

are also being directed at attempting to improve estimates of depredation by marine mammals, which is currently a major source of uncertainty in the assessment process.

Current status

While considerable progress has been made during 2019 on developing an operational management procedure (OMP) for the PEI Patagonian toothfish resource, this work has not yet advanced to the point where such an OMP can be used as a basis for recommending TACs. The ASPM assessments conducted in 2019 used data extending from 1996 (the start of the fishery) to the end of the 2018 fishing season within a similar framework to that used in recent years, but assumed that a small amount of cetacean depredation also occurs from trotlines (previous assessments assumed no cetacean depredation from trotlines). The assessment was conducted in circumstances where the trotline CPUE index of abundance had increased to some extent. The 2019 base-case assessment model and many of the sensitivity runs estimated the resource to be at a depletion level (current spawning biomass relative to pre-exploitation biomass) in the 36–40% range in median terms. Forcing the model to fit the trotline CPUE indices yielded depletion estimates of about 19%, but this required an assumption of probably unrealistically high levels of tag loss to better fit the tag-recapture data. Confronted with this uncertainty, a suite of three assessment model variants (Table 11, Figure 42) was selected to encompass “optimistic”, “intermediate” and “pessimistic” scenarios in further analyses evaluating the impacts of various management options. The 2019 base-case model was selected as the “optimistic” scenario, while the “pessimistic” model assumed a tag loss of 0.50 in order to achieve a satisfactory fit to the tag-recapture data. The “intermediate” scenario used a model that assumed a tag-recapture reporting rate of 80%. Evaluation of projected resource status under a range of future catches indicated that a precautionary approach should be adopted in recommending the TAC for the 2020 fishing season. While somewhat *ad hoc*, a reduction that equated to half of the maximum interannual TAC decrease constraint that is being considered in the new OMP (15%) was considered to be a suitable trade-off until that OMP is put in place (hopefully during 2020). The reduction of 7.5% from the 543 tonnes TAC implemented for the 2018/19 season yielded a TAC for the 2019/20 season of 502.3 tonnes.

Ecosystem interactions

South Africa has voluntarily undertaken to implement the CCAMLR conservation measures within the PEI-EEZ. These include 100% observer coverage, move-on rules to limit by-catch and specifications for mandatory bird-scaring lines (tori lines). In addition, the total catch of rat-tails *Macrourus* spp. and skates (Rajiidae) may not exceed 16% and 5%, respectively, of the toothfish TAC.

Since 2010 the total catch per fishing season for rat-tails has ranged between 7 and 28 t and for skates between 0.1 and 3 t. There have been no reported seabird mortalities for the past three years.

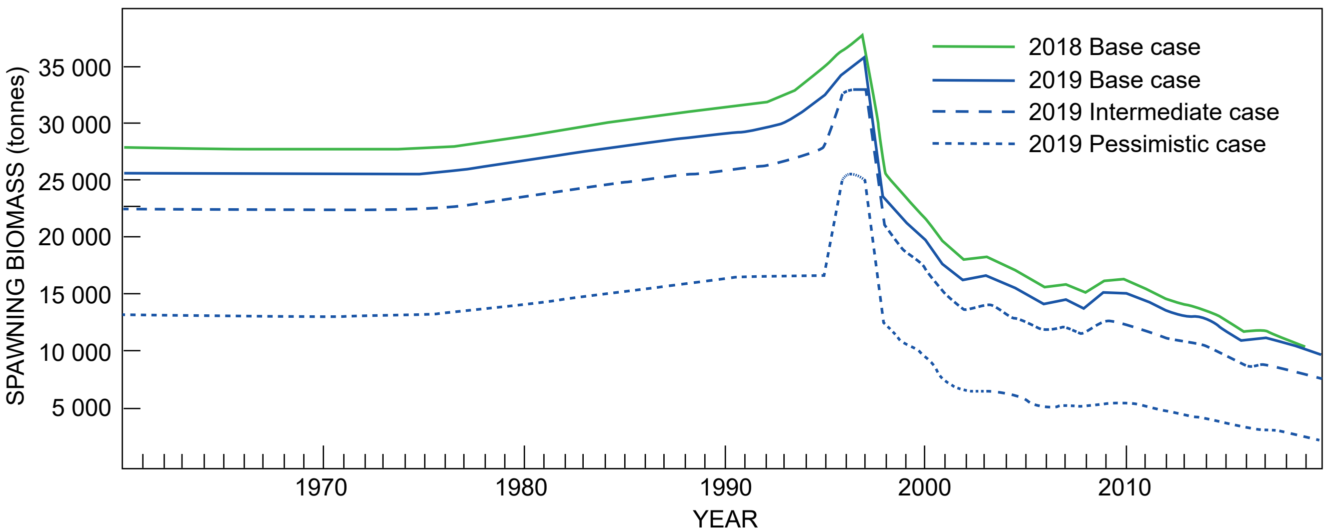


Figure 42: Spawning biomass trajectories estimated by the 2019 assessments. Results are shown for the base-case model (reflecting an “optimistic” scenario) and the “intermediate” (assumes a tag-reporting rate of 0.8) and the “pessimistic” (assumes a tag loss rate of 0.5) models. The results arising from application of the previous (2018) base-case model are also shown

A marine protected area (MPA) in the PEI-EEZ that contains a no-take area within 12 nautical miles of Prince Edward and Marion Islands, and three limited-access areas, was promulgated in 2013. The MPA is primarily aimed at protection of biodiversity.

Further reading

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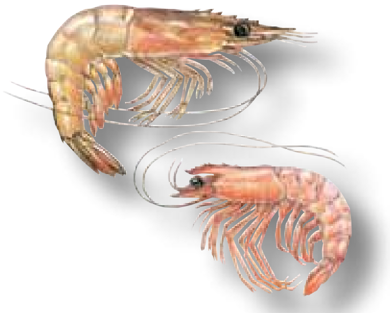
Useful statistics

Catches (tonnes) of Patagonian toothfish estimated to have been taken from the Prince Edward Islands EEZ and the total allowable catch (TAC) limit.

Fishing season	Legal catch			Illegal	Total	TAC (t)
	Longline	Pot	Trotline			
1996/97†	2 754.9			21 350	24 104.9	2 500
1997/98	1 224.6			1 808	3 032.6	3 000
1998/99	945.1			1 014	1 959.1	2 750
1999/00	1 577.8			1 210	2 787.8	2 750
2000/01	267.8			352	619.8	2 250
2001/02	237.3			306	543.3	600
2002/03	251.1			256	507.1	500
2003/04	182.5	34.3		156	372.8	500
2004/05	142.6	141.9			284.5	450
2005/06	169.1				169.1	450
2006/07	245.0				245.0	450
2007/08	88.8		56.4		145.2	450
2008/09	41.8		30.7		72.5	450
2009/10	49.2		174.6		223.7	450
2010/11	1.0		290.4		291.4	400
2011/12	52.4		223.5		276.2	320
2012/13	49.7		215.6		265.3	320
2013/14			366.9		366.9	450
2014/15			431.3		431.3	575
2015/16			298.0		298.0	575
2016/17			110.8		110.8	575
2017/18			342.7		342.7	575
2018/19						543

† Note that data for the 1996/97 season include catches during the months of October and November 1996

Prawns



Stock status	Unknown	Abundant	Optimal (Deep-water)	Depleted (Shallow-water)	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

The KwaZulu-Natal prawn-trawl fishery consists of two components: a shallow-water (5–40 m) fishery on the Thukela Bank and at St Lucia in an area of roughly 500 km^2, and a deep-water fishery (100–600 m) between Cape Vidal in the north and Amanzimtoti in the south, covering an area of roughly 1 700 km^2 along the edge of the continental shelf. Species captured in the shallow-water trawl fishery include white prawns *Fenneropenaeus indicus* (80% of the prawn catch), brown prawns *Metapenaeus monoceros* and tiger prawns *Penaeus monodon*. The abundance of shallow-water prawns on the fishing grounds is highly variable between years, depending on recruitment. Shallow-water prawns have a 1-year lifespan and the juvenile stages are spent in estuaries; recruitment therefore depends on rainfall and river run-off.

Species captured in the deep-water sector include pink and red prawns *Haliporoides triarthrus* and *Aristaeomorpha foliacea*, langoustines *Metanephrops mozambicus* and *Nephropsis stewarti*, rock lobster *Palinurus delagoae* and red crab *Chaceon macphersoni*. These deep-water species are longer-lived than those found in the shallow-water component and do not depend on an estuarine juvenile stage.

History and management

Management of the fishery is via effort-control which is effected by limiting the number of vessels allowed to operate in the two sectors of the fishery. The two major management challenges facing the fishery are mitigation of bycatch and setting total allowable effort (TAE) levels that reflect the high interannual variability of the shallow-water resource. Closed shallow-water fishing seasons are used to reduce bycatches of juvenile linefish. It is important to note that many vessels fish in KZN only when prawns are abundant, but then re-locate to other areas (such as Mozambique) in periods when yields in KZN decline and the operation becomes uneconomical. Historically, the nominal fishing effort in the KZN prawn-trawl fishery has remained virtually unchanged since 1993, although many of the vessels operate in KZN waters only occasionally. The number of vessels active in the fishery is currently largely dependent on economic factors, with only four vessels active in 2018 (one more than in the years before). Recruitment failure on the Thukela Bank as a result of inadequate river run-off has severely impacted the shallow-water fishery in recent years. The opening of the mouth of the St Lucia estuary in 2012 due to good rains in the catchment area was expected to have a positive effect on shallow-water prawn landings in 2013. However, no effort was directed in the shallow-water areas (<100 m depth) in the years 2013 to 2018. The small landings of white prawn recorded for these years (Table 12) derive from trawls made just inside the deep-water zone. The status of the shallow-water species can only be ascertained once trawling effort is directed at this zone, or research surveys are able to be conducted.

Research and monitoring

There is ongoing research on the bycatch of this fishery and the fishery is monitored by observers. The collection of data is, however, patchy and not comprehensive. In the absence of suitable biological data (growth rate, size at sexual maturity) on the various species targeted by this fishery, annual catch and effort data were used as input to a Schaefer surplus production model in order to produce a preliminary stock assessment. Initially, the landing (discharge) data were examined for suitability, but these were excluded because, based on the information recorded in the landing records, it was not possible to split the effort data (number of trawling days based on dates of the trip) into shallow- and deep-water sectors. There were also anomalous catch values, which may have resulted from the possible inclusion of landing data based on fishing in Mozambique. There were also numerous trips for which no dates were available. The catch and effort data which were finally used were those provided by skippers on the daily trawl-drag sheets, and which spanned the period from 1990 to 2006. Annual estimates of total catch were based on the annual sum of the total combined catch per trawl of four deep-water target species (pink prawn, langoustine, deep-water crab and deep-water rock lobster).

A range of surplus production models was therefore applied to the catch and catch per unit effort (CPUE) data for the KZN crustacean trawl fishery in 2009. This included a simple equilibrium model, fitting data separately to the Schaefer

Table 12: Total catches of the KZN prawn trawl fishery in the various species groups

		Total catch (t)						
		Inshore fishery		Offshore fishery			Both fisheries	
Year	TAE (no. of permits)	Shallow-water (all prawns)	Deep-water (all prawns)	Langoustine	Red crab	Rock lobster	Landed bycatch	Total catch
1992		87	112	70	187	31		
1993		52	166	83	138	33		
1994		47	65	46	79	10		
1995		23	106	60	108	11	34	342
1996		53	80	58	82	10	24	307
1997		15	79	78	114	10	21	317
1998		90	72	49	100	6	22	338
1999		72	124	49	73	8	28	354
2000		107	142	76	53	10	34	422
2001		63	103	80	54	8	4	313
2002		93	102	56	28	9	10	298
2003		29	162	60	40	5	91	387
2004		40	116	42	24	4	82	308
2005		33	140	42	31	4	88	339
2006		21.3	123	49	31	4.7	47	276
2007	7	17.6	79.2	53.2	24.1	5.3	46.9	226.3
2008	7	9.2	104.6	31.4	17.0	4.7	34.9	201.8
2009	7	7.7	196.7	59.8	20.9	9.7	53.4	267.8
2010	7	7.3	172	51.2	23.2	22	69.4	345.1
2011	7	9.6	150.1	79.2	19.7	22.7	63.2	344.5
2012	7	7.6	153.4	81.6	21.6	18.5	71.4	354.1
2013	7	1.7	103.3	61.5	12.0	8.1	34.4	221.0
2014	7	0.3	149.6	56.2	11.5	4.9	25.2	247.7
2015	7	0.4	228.8	62.7	52.7	6.4	35.1	386.1
2016	7	1.5	160.5	35.9	42.5	4.3	24.8	269.5
2017	7	2.4	272.4	65.5	82.6	9.5	35.0	467.4
2018	7	2.1	287.6	108.9	104.6	7.4	54.7	565.3

and Fox equations (on all four deep-water species combined and then individually). Unrealistically high levels of both maximum sustainable yield (MSY) and the fishing mortality that would produce this yield (F_{MSY}) were obtained. Data were therefore fitted to both simple and complex non-equilibrium surplus production models (Schaefer, Fox and Pella-Tomlinson), also resulting in unrealistic estimates of MSY and F_{MSY}. The inability of the models to produce reasonable estimates of MSY and F_{MSY} is probably a consequence of the time-series of data only commencing several years after the fishery began. Consideration will be given to utilising alternative methods of stock assessment for this fishery in future.

Current status

The fishery is regarded as optimally exploited although there is a need for more and better data collection and systematic research on the biology of the various prawn species and bycatches. The fishing effort in the KZN prawn trawl fishery has remained virtually unchanged since 1993, although many of the vessels operate in KZN waters only occasionally (only four vessels were active in the KZN fishery).

Catches of shallow-water prawns strongly reflect annual recruitment from estuaries, and a predictive equation relating historical river flows to shallow-water prawn catch on the Thukela Bank was developed for the 1988–2000 period by the then Department of Water Affairs and Forestry. Very low catches in recent years (Figure 43a) are attributed to drought conditions and the closure of the mouth of the St Lucia estuary by a sandbar. Recruitment of juvenile prawns from the estuary to the Thukela Bank has therefore been blocked, leading to recruitment failure on the Thukela Bank in the last 10 years. This has severely impacted on the shallow-water fishery and resulted in historically low catches since 2013 of 0.3 to 2.4 t, compared with, for example, a catch of 107 t in 2000 (Table 12). As a consequence, it has been recommended that the exploitation levels be retained at the current level, but that fishing on the Thukela Bank be restricted to between March and August.

Trends in catches in the deep-water fishery relate both to abundance and targeting practices, where specific depths or substratum types are selected to achieve a desired species mix or highest economic value. Landings of deep-water prawns increased from a low level of 79.2 t in 2007 to a peak of nearly 200 t in 2009, and has been around 150 t in three of the past four years, confirming an overall increase in catch since 2007 (Figure 43b). Langoustine catches have remained relatively stable recently at between 51 and 82 t, whereas catches of rock lobster declined dramatically from 23 t in 2011 to only 5 t in 2014. Catches of red crab also decreased sharply, from 19.7 t in 2011 to 11.5 t in 2014, the lowest since the time-series began in 1992 (Table 12).

More than 75% (by mass) of the total catch of both fisheries is discarded at sea because it has little commercial value (such as some cephalopods, many species of bony fish, sharks and rays, and lower-value crustaceans) but a substantial amount of bycatch is also landed. The mitigation of this bycatch is a huge challenge and an aim of the management of this resource. One measure taken is the closure of the shallow-water fishing season to March–August to reduce bycatches of linefish species, especially juveniles. There is ongoing research on the bycatch

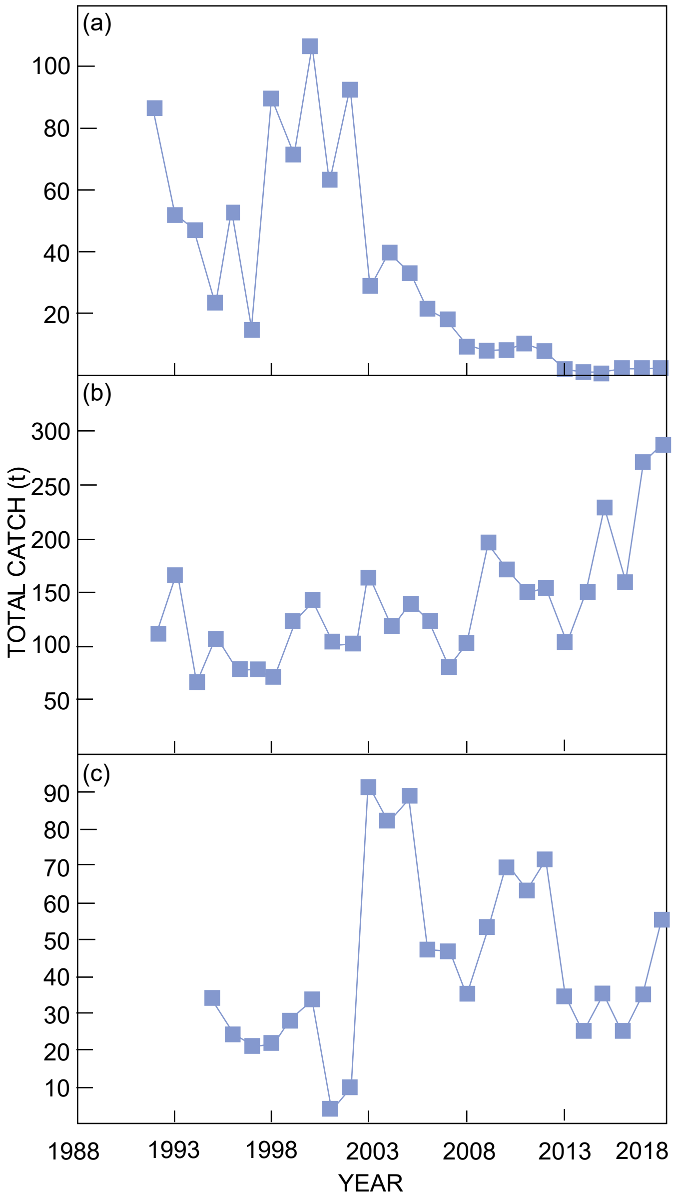


Figure 43: Total annual catches of (a) shallow-water prawns, (b) deep-water prawns and (c) landed bycatch in KwaZulu-Natal for the period 1992 to 2018

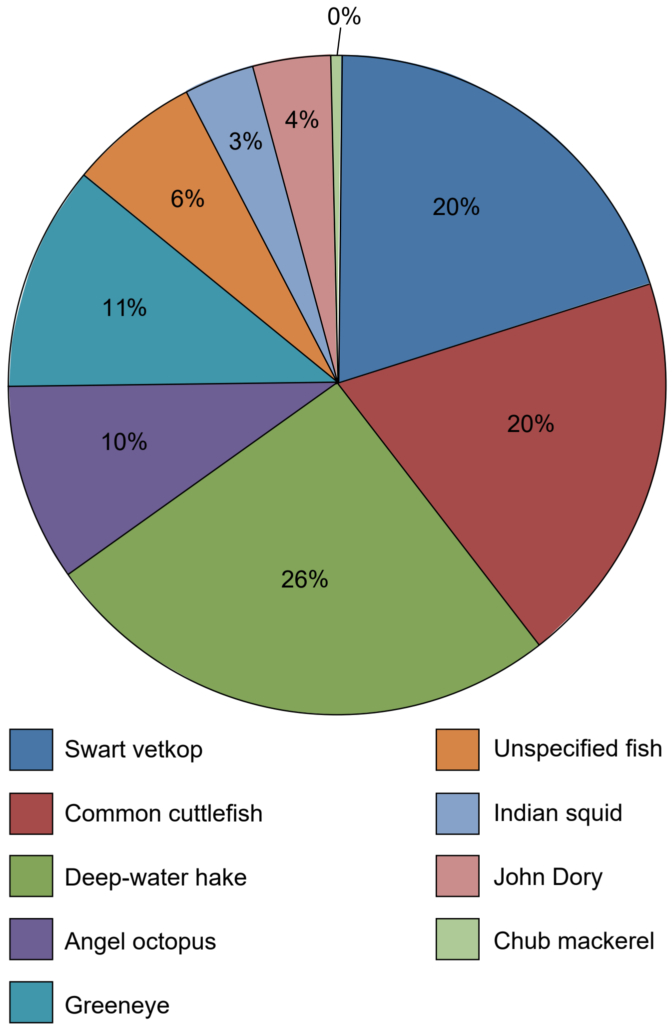


Figure 44: Species composition (by mass) of landed bycatch in KwaZulu-Natal for the 2018 fishing season

composition of this fishery but more knowledge on their biology is needed to develop further mitigation strategies. The amount (Table 12; Figure 43c) and composition (Figure 44) of landed bycatch shows marked seasonal fluctuation. Of the 35 t of bycatch landed in 2017, the majority were fish (65%) and the remaining 35% molluscs. More than 70% of the fish bycatch consisted of three species: swart vetkop *Cubiceps baxteri*, deep-water hake *Merluccius paradoxus* and greeneye *Chlorophthalmus punctatus*. The mollusc bycatch consisted of the three cephalopod species: common cuttlefish *Sepia officinalis vermiculata*, Natal deep octopus *Velodona togata* and Indian squid *Loligo duvauceli*.

Ecosystem interactions

The prawn fisheries take high amounts of bycatch. The fishing season for the shallow-water fishing grounds (Thukela Bank) is therefore restricted to March–August to protect juvenile fish species that are important to the linefishery. Further research is currently being carried out with the aim to mitigate the impact of the fishery.

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Seaweeds

Stock status	Unknown	Abundant Non-kelps	Optimal Kelp	Depleted	Heavily depleted
Fishing pressure	**Unknown**	**Light** *Gelidium*	**Optimal** Kelp	**Heavy**	

Introduction

The South African seaweed industry is based on the commercial collection of kelps and the red seaweed *Gelidium*, and small quantities of several other species. All commercially exploited seaweeds are found between the Orange (Northern Cape) and Mtamvuna (Eastern Cape) rivers. In the Western Cape and Northern Cape, the South African seaweed industry is currently based on the collection of beach-cast kelps and harvesting of fresh kelps. In the past, beach-cast gracilarioids (agar-producing red seaweeds of the genera *Gracilaria* and *Gracilariopsis*) were collected in Saldanha Bay and St Helena Bay, but there has been no commercial activity there since 2007. *Gelidium* species are harvested in the Eastern Cape.

The sector is small compared to many other fisheries, but is estimated to be worth at least R40 million annually and to provide at least 350 jobs. Much of the harvest is exported for the extraction of gums. The international seaweed industry is controlled by large international companies that can manipulate prices. Marketing of these raw materials is complicated and requires overseas contacts to sell seaweed or to obtain a good price. As a result, returns for South African companies that do not process locally may be marginal, and they often stockpile material while negotiating prices.

Collection and drying of seaweed is a low-tech activity, while secondary processing is more technical. Extraction and manufacture of end-products (e.g. plant-growth stimulants, alginate, agar, or carrageenan) is technical and expensive, but although only plant-growth stimulants are currently produced (from kelp) in South Africa, production of other extracts should be encouraged because of potentially higher earnings.

Fresh kelp is now harvested in large quantities (about 5 000 t fresh weight per annum) in the Western Cape as feed for farmed abalone. This resource, with a market value of over R6 million, is critically important to local abalone farmers. Fresh kelp is also harvested for high-value, plant-growth stimulants that are marketed internationally and nationally.

History and management

Commercial interest in South African seaweeds began during World War II, when various potential resources were identified, but commercial exploitation only began in the early 1950s. The South African industry has historically been based almost entirely on three groups of seaweeds: the kelps *Ecklonia maxima* and *Laminaria pallida*, several species of the red seaweed *Gelidium*, and the red seaweeds *Gracilaria* and *Gracilariopsis* (together referred to as "gracilarioids").

The coastline between the Orange and Mtamvuna rivers is divided into 23 seaweed Rights areas (Figure 45). In each area, the Rights to each group of seaweeds (e.g. kelp, *Gelidium*, or gracilarioids) can be held by only one company, to prevent competitive overexploitation of these resources. Different companies may hold the Rights to different resources in the same area.

Management of most seaweed resources is based on total allowable effort (TAE), except for fresh kelp, for which a maximum sustainable yield (MSY) is set in annual permit conditions. The commercial season for permits and reporting of seaweed harvests is from 1 April of year 1 to 31 March of year 2.

Kelps

Until the mid-1990s, kelp use in South Africa was restricted to the collection, drying and export of beach-cast kelp for the

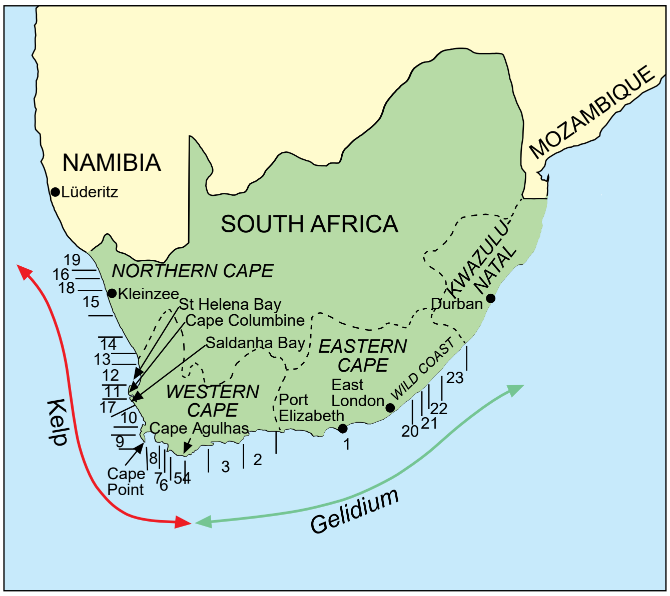

Figure 45: Map of seaweed Rights areas in South Africa

extraction of alginate, a colloid used in the food and chemical industries. Annual yields varied with international market demands, but peaked in the mid-1970s, with maxima of around 5 000 t dry weight. Since then yields of <1 000 t dry weight per annum have been more usual (Table 13).

Since the early 1980s, a local company has been producing a liquid plant-growth stimulant from *Ecklonia maxima* and marketing this nationally and internationally. A second local company now produces a similar extract that is used in South Africa.

The growth of abalone farming in South Africa since the early 1990s has led to increasing demands for fresh kelp as feed. In 2018 a total of 4 803 t of fresh kelp fronds was supplied to farmers. Demand for kelp as feed is currently centred around the two nodes of abalone farming activity, at Cape Columbine and the area between Danger Point and Hermanus. Kelp harvesters are supplied with a "kelp harvesting manual", which sets out best practices to ensure sustainability.

Gelidium

Gelidium species contain agar, a commercially valuable colloid with many food and cosmetic uses, and the only medium for cultivating bacteria in medical pathology. The *Gelidium* resource in South Africa comprises *G. pristiodes*, *G. pteridifolium* and *G. abbottiorum*, all most abundant in the Eastern Cape (seaweed Rights areas 1, 20, 21, 22 and 23; Figure 45), where they have been harvested from intertidal areas since the mid-1950s. Yields, which come almost entirely from area 1, vary with demand but are usually about 120 t dry weight annually. Since 2010 there has been little or no harvesting from areas 20, 21, 22 and 23 because of low prices for some of the species and access and security problems on the Wild Coast (i.e. northern part of the Eastern Cape coast).

Gracilarioids

Gracilarioids produce agar of a lower quality than that from *Gelidium*. Only Saldanha Bay (seaweed Rights area 17) and St Helena Bay (areas 11 and 12 in part) contain commercially viable amounts of these seaweeds. Only beach-cast material may be collected commercially, because harvesting of the living beds is not sustainable. In Saldanha Bay, large yields (>1 000 t dry weight, annually) were obtained until the ore jetty and breakwater were built in 1974, after which yields fell dramatically. Occasional small wash-ups are obtained in St Helena Bay. Since 2001, total annual yields of gracilarioids ranged from zero to a few hundred tonnes dry weight, and the resource is regarded as unreliable. No gracilarioids have been collected commercially since 2008.

Other resources

Other seaweeds have been harvested commercially on occasion, including *Porphyra*, *Ulva*, *Gigartina* species and *Mazzaella*. However, local resources of these species are small by international standards and harvesting has not been economically viable. Nevertheless, there is potential for local use of some species, for example in food products.

Research and monitoring

It is not practical to monitor the amounts of kelp cast up on beaches along the approximately 1 000 km of the West Coast where they occur. Collection of beach-cast kelp has no impact on the living resource and is driven by market demands. Monthly returns are, however, submitted and monitored.

Estimates of kelp biomass are based on infrared aerial imagery, GIS mapping and diver-based sampling. Monthly harvest of fresh kelp is checked against the prescribed MSY as set in annual permit conditions. Kelp beds in the two main nodes of harvesting (Gansbaai and Jacobsbaai) are monitored each year, when densities of kelps are determined during diving surveys at each of two permanent locations in each area. Every two years, the same methods are used to monitor kelp beds at Port Nolloth, Kleinzee, Hondeklip Bay and Doring Bay. Values are compared with baseline data from previous surveys. In addition, periodic inspections of selected kelp beds are made

Table 13: Annual yields of commercial seaweeds in South Africa, 2001–2018, by calendar year. "Kelp beach cast" (column 4) refers to material that is collected in a semi-dry state, whereas "kelp fresh beach cast" (column 6) refers to clean wet kelp fronds that, together with "kelp fronds harvest" are supplied as abalone feed. "Kelp fresh beach cast" was only recorded separately since 2003. NB – from 2012, the commercial "season" for permits and monthly reporting of seaweed harvests was changed from a calendar year to 1 March of year 1 to end February of year 2

Year	*Gelidium* (kg dry weight)	*Gracilaria* (kg dry weight)	Kelp beach cast (kg dry weight)	Kelp fronds harvest (kg fresh weight)	Kelp fresh beach cast (kg fresh weight)	Kelp for hormone extraction (kg fresh weight)
2001	144 997	247 900	845 233	5 924 489	0	641 375
2002	137 766	65 461	745 773	5 334 474	0	701 270
2003	113 869	92 215	1 102 384	4 050 654	1 866 344	957 063
2004	119 143	157 161	1 874 654	3 119 579	1 235 153	1 168 703
2005	84 885	19 382	590 691	3 508 269	126 894	1 089 565
2006	104 456	50 370	440 632	3 602 410	242 798	918 365
2007	95 606	600	580 806	4 795 381	510 326	1 224 310
2008	120 247	0	550 496	5 060 148	369 131	809 862
2009	115 502	0	606 709	4 762 626	346 685	1 232 760
2010	103 903	0	696 811	5 336 503	205 707	1 264 739
2011	102 240	0	435 768	6 023 635	221 138	1 617 975
2012	117 149	0	1 063 233	6 092 258	1 396 227	1 788 881
2013	106 382	0	564 919	5 584 856	253 033	2 127 728
2014	75 900	0	775 625	4 555 704	244 262	1 610 023
2015	95 200	0	389 202	3 974 100	249 014	1 930 654
2016	102 500	0	411 820	4 044759	100 018	2 166 293
2017	102 802	0	482 082	3 254 561	63 276	3 001 611
2018	89 253	0	540 498	4 803 358	552 691	1 886 691
Total	1 931 800	633 089	8 657 065	24 005 312	3 619 304	6 525 434

from the surface and by divers. Current research aims to improve our understanding of kelp biology in order to manage the resource better.

Assessment of the gracilarioid resource is performed on an *ad hoc* basis because only beach-cast seaweed is collected and there is therefore no direct effect on the living resource.

The harvesting and biology of *Gelidium pristoides* in area 1 of the Eastern Cape were comprehensively researched in the 1980s. Current monitoring is by annual inspections of certain harvested and non-harvested shores in that area, and annual biomass and density measurements at two permanent study sites. Catch returns are also monitored to ensure that yields do not exceed historical levels; if they did, further inspections and monitoring would be necessary. The *Gelidium pristoides* resources in areas 20-23 (former Transkei) have never been quantified. Although currently unexploited, they may become commercially relevant with small-scale fisheries allocations, and will require study. Other seaweed resources are assessed on an *ad hoc* basis as the need arises.

Current status

Kelps

There are 13 areas in which kelp Rights were held in 2018.

Yields of dry beach-cast kelp totalled 540 t in 2018 (Table 13). A further 100 t wet weight of fresh beach-cast kelp was supplied to abalone farms, together with 4 044 t wet weight that was harvested directly as abalone feed. These yields have remained fairly steady over the past three years. Substantial harvests for abalone feed were obtained in areas 5, 6, 7 and 11. Although there are more than five abalone farms in the Gansbaai–Hermanus area, they are supplied by four Rights areas (areas 5, 6, 7 and 8), with a substantial potential MSY between them.

In some areas, harvests (Table 13) were well below MSY (Table 14). The under-harvest is a result of lower demand for kelp in some areas and/or the use of alternative abalone feeds, and is not a reflection of the status of the resource in those areas. This substantial and potentially harvestable biomass ("spare" MSY) would allow for the expansion of abalone farms in such areas. Since the reassignment of four of the concession areas (areas 5, 8, 15 and 16) to the small-scale fisheries sector in 2016, no kelp harvesting has been undertaken in these areas. This has negatively impacted nearby abalone farms, which have been forced to use an artificial feed for their abalone.

In areas 6 and 9, the production of plant-growth stimulant by Kelpak and Afrikelp used a combined 1 887 t of fresh kelp in 2018. The status of kelp resources therefore varies geographically: from well/almost completely exploited in some areas to almost completely unexploited in others.

Monitoring, visual inspections and reports from Right Holders show that the kelp resource is stable and healthy.

Gelidium

All of the *Gelidium* that were collected are from area 1, where *G. pristoides* now comprises almost all of the harvest. The other species, which used to comprise most of the harvest in areas 20-23, now fetch low prices on Asian markets. Catch returns from area 1 (89 t dry weight) were lower than in the recent past, mainly because of reduced demand. Inspections and measurements done in February and May 2018 indicate very healthy *G. pristoides* populations, with density and biomass values well within normal limits.

Table 14: Maximum sustainable yield (MSY) of harvested kelp for all areas for 2018 season (1 March 2018 – 28 February 2019). *Note: In Areas 5 and 6a only non-lethal harvesting of fronds is allowed.

Area number	Whole kelp (t fresh weight)	Kelp fronds (t fresh weight)
5	0*	2 625
6a*	0*	4 592
6b	174	87
7	1 421	710
8	2 048	1 024
9	4 159	2 080
10	188	94
11	3 085	1 543
12	50	25
13	113	57
14	620	310
15	2 200	1 100
16	620	310
18	2 928	1 464
19	765	383
Total	18 371	16 404

Gracilarioids

Biomass of this unreliable resource varied during 2018, and only sporadic wash-ups were observed in Saldanha Bay. These periodic fluctuations appear to have natural causes and have been recorded before. This resource must at present be regarded as commercially unreliable, despite such occasional wash-ups.

Other seaweed resources

Despite some commercial interest in *Ulva* and *Porphyra* in areas 11 and 12, where research demonstrated small but viable resources, no further developments have taken place.

Seaweed resources in general, with the exception of gracilarioids, are in a good state. None are over-exploited, some (kelp in a few Rights areas) are close to optimal exploitation, and some are under-exploited.

Ecosystem interactions

In the case of *Gelidium pristoides* in area 1, which makes up the bulk of the *Gelidium* harvest, considerable research has shown that harvesting, as currently practised, has negligible ecosystem effects.

Ecosystem effects of kelp harvesting have been dealt with in a few studies, and are the subject of ongoing research. Results so far indicate that they are slight; harvesting never exceeds natural mortality (about 10% of biomass), recovery of beds is rapid, and previous research showed no measurable effects on plants and animals living under the kelp canopy. Current studies are examining possible climate change interactions.

Climate change

The only recorded seaweed distributional change, in South Africa, is the eastward movement of the large kelp *Ecklonia* *maxima* that forms extensive forests along the South African West Coast and parts of the South Coast. During the 1950s, *E. maxima* was only recorded up to Suiderstrand (130 km east of Cape Town) but can now be found 70 km further east at De Hoop Nature Reserve. The kelp bed there is now well established and fairly significant. Recent research using repeat photography has shown that the abundance of *E. maxima* is also increasing within its distribution range. This range extension and increase in abundance have been ascribed to cooling of inshore sea temperatures in the region. Repeat sampling of other seaweed species have not shown any similar distributional changes.

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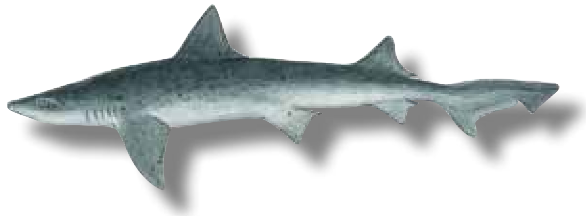
Sharks



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
		Slime skate Spearnose skate Biscuit skate St Joseph	Smoothhound Blue	Yellowspot skate	Oceanic whitetip Great hammerhead Twineye skate Soupfin Shortfin mako
Fishing pressure*	**Unknown**	**Light**	**Optimal**	**Heavy**	
		Yellowspot skate Slime skate Oceanic whitetip Hammerhead		Biscuit skate Spearnose skate Requiem Soupfin Smoothhound Blue Shortfin mako St Joseph Twineye skate	

*Fishing pressure is across multiple fisheries

Introduction

With 204 species recorded, South Africa has one of the most diverse chondrichthyan (sharks, rays and chimaeras, henceforth "shark") faunas in the world. Many species are caught in its fisheries in appreciable quantities. The majority of the 99 species that have been reported from 12 of the 22 recognised fisheries constitute incidental bycatch. Less than 10 species are purposefully targeted by the shark-directed demersal longline fishery and by parts of the line- and netfisheries as they are commercially valuable with significant markets. Catches can be substantial, in particular in the pelagic longline fishery where shortfin mako sharks *Isurus oxyrinchus* and blue sharks *Prionace glauca* are utilised to subsidise tuna catches during times when tuna are not available on the fishing grounds. In other fisheries, sharks form part of the unwanted bycatch and are discarded (dead or alive) at sea if not valuable or marketable The high level of diversity and endemism engenders South African responsibility in conserving and managing sharks that occur in South African waters and protecting those that enter South African waters periodically. South Africa is a signatory to the United Nations Food and Agricultural Organization (FAO) Committee on Fisheries (COFI) Code of Conduct for Responsible Fisheries. Within this framework South Africa has adopted a National Plan of Action for Sharks (NPOA-Sharks) to ensure the conservation and management of sharks and their long-term sustainable use. South Africa has well-developed fisheries-management systems in place for most of its fisheries, and challenges with regard to the sustainable management and conservation of sharks have largely been identified.

The NPOA-Sharks broadly guides the research and monitoring efforts for sharks caught in South African fisheries. It was finalised in 2013 and provides information on the status of chondrichthyans in South Africa. It examines structure, mechanisms and regulatory frameworks related to research, management, monitoring and enforcement associated with shark fishing and trade of shark products in the South African context. A review of the plan was completed in 2018. Most-notable progress was made in the area of shark assessments, with comprehensive assessments completed for smoothhound sharks *Mustelus mustelus* and soupfin sharks *Galeorhinus galeus*, and trend and status analysed for a further 19 species. Limited progress was made with regard to capacity and infrastructure and regulatory tools, a consequence of lack of capacity in enforcement and compliance, attrition of government funding and poor co-ordination of management across multiple fishing sectors. The NPOA-Sharks will be formally updated, with the intention of completion by 2021. The Minister of Environment, Forestry and Fisheries, Ms Barbara Creecy, has appointed an Expert Panel on Sharks to review the management and conservation of the species by South Africa to be updated by 2021.

The nine-member Panel comprising national and international experts will review South Africa's National Plan of Action for the Conservation and Management of Sharks (NPOA Sharks) over a three-month period to determine whether the Plan is effective and where improvements need to be made. It will recommend actions needed to properly manage and conserve all shark species found along the South African coast, and to guide their long-term sustainable use.

History and management

Inshore/demersal sharks

In South Africa, inshore demersal shark species (i.e. species living close to the seafloor) such as smoothhound sharks, soupfin sharks and a number of smaller requiem (carcharhinid) sharks are mainly caught in three commercial fisheries, namely the demersal shark longline fishery, the inshore trawl fishery and the commercial linefishery. The demersal shark longline fishery is the only sector that consistently targets demersal sharks. Targeted catches in the linefishery are sporadic, depending on the availability of more-valuable target species and seasonal aggregations of sharks, whereas the inshore trawl fishery catches sharks as bycatch. None of the commercial fisheries are currently limited by shark species-specific management measures such as size- or bag limits, but shark-specific regulations exist in the following commercial fisheries: demersal shark longline, large-pelagic longline and beach-seine and gillnet.

The shark longline sector formally commenced in 1991 when 30 permits were issued initially to target both demersal and pelagic sharks (pelagic sharks are those living in the water column, often occurring further offshore). In 2005 the dual targeting of demersal and pelagic sharks under the same permit was discontinued and the sector became an exclusive demersal shark longline fishery reduced to eleven Right Holders in 2004 and just six in 2006. The demersal shark longline fishery is permitted to operate in coastal waters from the Orange River on the West Coast to the Kei River on the East Coast, but fishing rarely takes place north of Table Bay. Vessels are typically <30 m in length and use nylon monofilament Lindgren Pitman spool systems to set weighted longlines baited with up to 2 000 hooks (average = 917 hooks). The fishery operates in waters generally shallower than 100 m, and uses bottom-set gear to target predominantly soupfin sharks and smoothhound sharks. Following an initial period of adjustment to catching and marketing demersal sharks, catches of soupfin and smoothhound sharks started increasing in 2006, and reporting became more reliable. As the majority of Right Holders own additional Rights in other fisheries, the number of active vessels fluctuates over the year but rarely exceeds four vessels operating at the same time. Annual landings have fluctuated widely due to variation in demand and price. Rights are due to be re-allocated during the fishing Rights allocation process (FRAP) 2021.

The long history of the commercial linefishery can be traced back to fishing activities of the European seafarers in the 1500s, with the first fishing restrictions imposed in 1652. The commercial linefishery is the oldest sector to have targeted sharks in South Africa; commercial-scale exploitation of sharks began in the 1930s around traditional fishing villages in the Western Cape. This fishery used handlines and targeted inshore demersal sharks for their livers to be used in the production of Vitamin A oil. By the 1940s, catches of soupfin sharks had declined (Davies 1964) as targeting shifted. To date, this Western Cape soupfin fishery has not recovered to historical catch levels. To compensate for declining catch rates of high-value linefish species, a rapid increase was seen in shark catches between 1990 and 1993. After 2000, species-specific reporting came into effect and sharks continued to constitute a large proportion of the livelihood of these fishers around South Africa, with the establishment of a number of dedicated shark processing facilities. Shark catches by the linefishery since the 1990s have typically fluctuated in response to the availability of higher priced linefish species and market influences. Species targeted include soupfin sharks, smoothhound sharks, dusky sharks *Carcharhinus obscurus*, bronze whaler sharks *C. brachyurus*, and various skate species. The fishery is described in detail in the linefish section of this report.

The inshore trawl fishery targets shallow-water Cape hake *Merluccius capensis* and Agulhas sole *Austroglossus pectoralis* between Cape Agulhas and the Great Kei River, but takes a substantial bycatch of soupfin and smoothhound sharks. The fishery is described in detail in the Agulhas sole section of this report.

The estimated combined soupfin and smoothhound catch of the demersal shark longline fishery, the inshore trawl fishery and the commercial linefishery is shown in Figure 46, where catches have been upscaled to round weight following the algorithms developed by the Department's Linefish Stock Assessment Task Team.

To inform discussions about future management recommendations for sharks caught in the above fisheries, it is important to understand the relative impact of the targeted demersal longline fishery relative to trawl and linefish catches of the main species. Overall, the commercial linefishery takes the largest proportion of soupfin catches, with an average of 66% of catches between 2007 and 2016 (range 45% to 77%). The demersal shark longline fishery takes the largest proportion of smoothhound catches, with an average of 63% between 2007 and 2016 (range 35% to 80%).

A directed gillnet fishery for ploughnose chimaeras, locally referred to as the St Joseph *Callorhinchus capensis*, is confined to the South African West Coast and is managed as part of the netfishery, with strict gear and effort limitations (see netfish section of this report).

Offshore/pelagic sharks

The South African large pelagic longline fishery was commercialised in 2005. As above, in 2005 the shark longline sector was split into a demersal shark longline component, which predominantly targets soupfin and hound sharks, and a pelagic shark longline component (consisting of seven vessels), which predominantly targets shortfin mako and blue

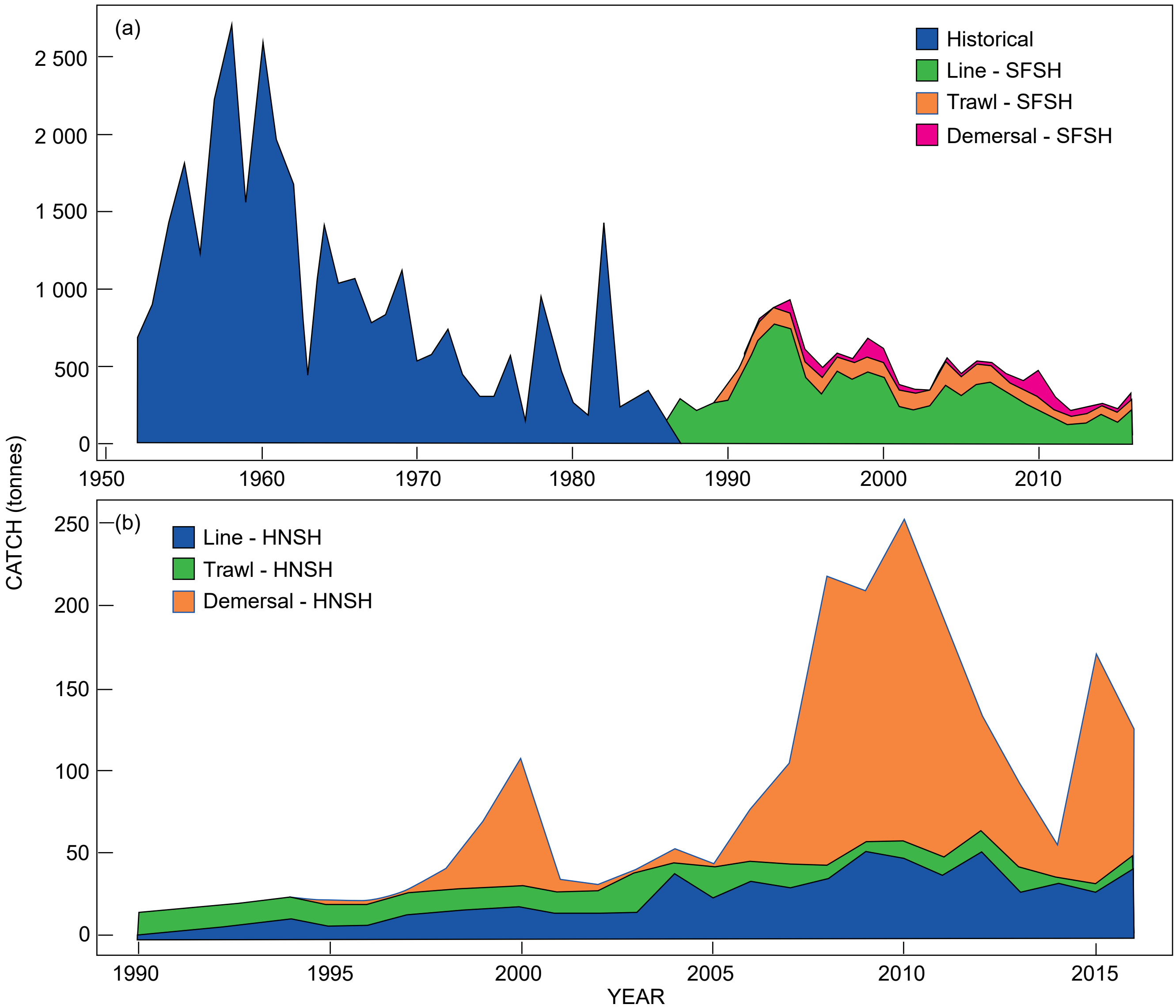


Figure 46: Total catch of (a) soupfin shark *Galeorhinus galeus* (SFSH) and (b) smoothhound shark *Mustelus mustelus* (HNSH) between 1950 and 2016 and 1990 and 2016, respectively, for the inshore trawl fishery, the demersal shark longline fishery and the commercial linefishery. Catches were raised from dressed weight to total weight using the de la Cruz (2015) raising factors of 1.42 for HNSH and 1.52 for SFSH

sharks. This fishery was split as a precursor to phasing out the targeting of pelagic sharks due to concern over the local stock status of some species. The pelagic shark fishery operated under exemptions from 2005 until March 2011, when South Africa incorporated the pelagic shark fishery into the tuna/swordfish longline fishery. Six of the seven shark exemption-holders were issued with tuna/swordfish Rights in March 2011. Under these Rights, a precautionary upper catch limit (PUCL) of 2 000 t dressed weight of all sharks has been set. Should this limit be reached in a given season, fishing in the large pelagic fishery would close. These vessels are undergoing a phase-out period to reduce shark catch and improve tuna and/or swordfish catch performance. Pelagic sharks are now considered bycatch in the large pelagic longline fishery. Progressively more stringent measures have been applied to limit the shark catch since 2013, as sharks were designated as bycatch in the policy for this fishery. Measures include the ban of wire-trace, the prohibition of finning at sea (sharks have to be landed with their fins attached), the implementation of a mandatory observer coverage of 20% stratified across vessels and seasons, and the restriction of targeting to less than 50% shark catch per season. Vessels that catch more than 60% sharks in any quarter are required to have 100% observer coverage thereafter.

Fishing takes place within the entire exclusive economic zone (EEZ) and beyond, out of three main harbours; Richards Bay, Port Elizabeth and Cape Town. Large pelagic species targeted by South African fleets are highly migratory and their distributions span multiple EEZs. Consequently these resources are managed by Regional Fisheries Management Organizations (RFMOs): specifically, the International Commission for the Conservation of Atlantic Tunas (ICCAT); the Indian Ocean Tuna Commission (IOTC); and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). South Africa is obligated to adhere to RFMO resolutions, management advice and requests, particularly in relation to overexploited stocks, to ensure their sustainability. Providing RFMOs with accurate and complete data is extremely important for regional stock

assessments conducted by the RFMO working parties. These assessments ultimately inform TAE/TAC allocations. The permit conditions relating to bycatch of pelagic sharks, seabirds, turtles and marine mammals must satisfy international best practices and require strict enforcement. It is essential for South Africa to demonstrate it is implementing all current requirements necessary to reduce ecosystem effects of the fishery on threatened and endangered species.

In response to sustainability concerns expressed by the RFMOs, CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) and the IUCN (International Union for Conservation of Nature), South Africa has prohibited the retention of thresher sharks (genus *Alopias*), hammerhead sharks (genus *Sphyrna*), oceanic whitetip sharks *Carcharhinus longimanus*, porbeagle sharks *Lamna nasus*, silky sharks *Carcharhinus falciformis* and dusky sharks *Carcharhinus obscurus*, which resemble silky sharks.

Research and monitoring

Half of the 204 chondrichthyan species that occur in southern Africa are impacted by fisheries, ranging from recreational angling to industrialised fishing such as trawling and pelagic longline fishing. The most-recent collated estimate of the dressed catch of chondrichthyans across all fisheries in South Africa was 2 300 t in 2016.

Accurate information on the species and their fisheries is vital in order to develop appropriate management strategies. Consequently, a number of research-related issues were identified in the South African NPOA-Sharks of 2013, namely data and reporting, classification and assessment of species, and optimum use.

Data and reporting

Data and reporting involves all processes relating to improving data from fisheries-dependent and -independent sources. This includes improved identification of sharks reported by fishers in logbooks, collection of fisheries-independent data by observers, and improving understanding of total catch and discards across fisheries. A fundamental step in the management of chondrichthyan fisheries was identifying which species are under threat; prior to the publication of the NPOA-Sharks, such a list did not exist. Collaborations between international research groups, national research groups and DEFF resulted in the publishing of a comprehensive list of chondrichthyans occurring in southern Africa (204 species). Through various international collaborations, samples from DEFF have been provided to researchers at the Pacific Shark Research Center in a concerted effort to resolve taxonomic uncertainties within various groups of chondrichthyans in South Africa. Following the development of a list of chondrichthyans occurring in southern Africa, a review of catch data of all chondrichthyans by all fishing sectors suggests that a total of 99 species are impacted by fisheries in South Africa

One of the major limitations when attempting to quantify fisheries impacts on sharks is generic reporting. Sharks are often misidentified or are identified to genus level only (e.g. “smoothhound sharks” or “dogsharks”) or even to superorder level (e.g. “skates and rays” [Batoidea]). A shark, ray and chimaera identification guide has been developed to improve data collection at a species level for all fisheries, and will be updated, printed and distributed to the fisheries.

Of particular importance to the assessment of species is the development of conversion factors between different length and weight metrics. Efforts by the Department have focused thus far on the two commercially most-valuable inshore species, soupfin and smooothhound sharks, and conversion factors between different length measurements, as well as from length to weight, have been developed.

Classification and assessment of species

As outlined in the NPOA-Sharks, classification and assessment of shark species involves the following; addressing gaps in life-history knowledge, investigating stock delineation of key sharks, investigating key uncertainties in movement and distribution across RFMO regions, and addressing the lack of formal assessments.

Life history

In order to conduct comprehensive assessments, the following life-history parameters are required as direct input into stock assessment models: maximum age, growth rate, size at maturity and fecundity. In addition, the development of useful management interventions such as area and seasonal closures requires life-history information such as mating behaviour, sexual segregation, pupping and the use of nursery grounds. A gap-analysis of sharks caught in South Africa indicated that of the 99 shark species impacted by fisheries, comprehensive life-history information as required for a full stock assessment exists for only 15%.

Genetics

Stock delineation was investigated for the top three commercial species; smoothhound, soupfin and blue sharks, through collaborations with the Molecular Breeding and Biodiversity Group at Stellenbosch University and the Research Center for Biodiversity and Genetic Resources, Portugal. Genetic studies indicate the likely existence of two inter-oceanic populations of the smoothhound shark *M. mustelus* at the Atlantic/Indian Ocean boundary and one panmictic population of soupfin sharks. The different patterns of gene flow might be attributed to the species-specific habitat preferences and movement patterns of these species and has significant potential implications for fisheries management. Blue sharks, on the other hand, are much more widely distributed. Although they are currently managed by different RFMOs related to different ocean basins, it is likely that there are shared stocks of blue sharks that straddle various RFMO regions, with gene flow occurring at a global scale. Through local collaboration at Stellenbosch University, substantial headway has also been made with DNA barcoding (molecular species identification) of some taxonomically challenging groups such as catsharks. These studies will form the platform for a newly developed Forensics Unit that will be used for analyses of suspected prohibited and CITES (Appendix I and II) listed species from police confiscations and illegal operations

Movement

Many sharks are highly mobile and some species exhibit large-scale movement, including transoceanic migrations. Movement studies are currently being undertaken on smoothhound sharks, soupfin sharks, blue sharks and shortfin mako sharks. Research conducted by the Department on smoothhound sharks in Langebaan Lagoon has shown that these commercially valuable species spend a large proportion of their time within the confines of the local marine protected area (MPA). These sharks use the MPA for reproduction and feeding, and also as a nursery ground. Occasionally they leave the protection of the MPA and then become available to fishing. The existence of eight other MPAs within the distribution of the smoothhound shark could provide considerable benefits to the fishery in the form of spill-over if nursery areas are contained within the MPAs. It is also likely that various existing MPAs also provide protection for various chondrichthyans.

South Africa's geographic location is such that the IOTC/ICCAT boundary is incorporated in its EEZ at 20° E, approximately offshore of Cape Agulhas. The broad continental shelf in this region is known as the Agulhas Bank, a renowned fishing region that exhibits high productivity and diversity as a result of the temperate Atlantic and subtropical Indian oceans meeting. As such, many large-pelagic species aggregate on the Agulhas Bank, attracting relatively high fishing pressure. A significant proportion of South Africa's large-pelagic catch statistics consist of catches from this area. The presence of an RFMO management boundary creates a number of reporting issues, and catch data from fishing trips which straddle the IOTC/ICCAT boundary line might include erroneous statistics that are an artefact of the boundary. The investigation of transboundary movements has been identified as a priority for chondrichthyans within the South African NPOA-Sharks.

Results from pelagic-shark satellite tagging studies and population genetics indicate that blue sharks move freely between the Atlantic and Indian oceans, suggesting the existence of a single southern stock/global stock of the species. This strongly corroborates genetic studies. This research has also highlighted the existence of a nursery ground for blue sharks off southern Africa in the cool Benguela/warm Agulhas Current transition zone. Ongoing research is also investigating the existence of a nursery area for shortfin mako sharks on the shelf-edge of the Agulhas Bank. A total of 19 juvenile sharks have been tagged in the area and the movement data are currently being analysed. These findings will potentially have significant implications for stock assessments conducted by RFMOs. For example, an interrogation of shortfin mako catch data on the IOTC/ICCAT RFMO boundary has highlighted potential RFMO reporting concerns. Specifically, these include the artificially high inter-annual variability and the potential for inconsistent catch trends associated with stocks that transition across the RFMO boundary. These trends may influence the outcome of stock assessments that include South African catch statistics. This is particularly true for shortfin mako, as South Africa is a major contributor to total catch in the IOTC area, being responsible for approximately 32% of all reported catches in the area. It is possible that similar movements occur in other large-pelagic species. South Africa is well placed geographically to further investigate the movement patterns of large-pelagic species with a view to understanding stock separation between the Indian and Atlantic oceans.

Assessments

Two new assessment methods developed for the use of data-poor resources such as sharks were developed at DEFF: Just Another Bayesian Biomass Assessment Model (JABBA) and Just Another Redlist Assessment (JARA). Whereas JABBA is

Table 15: Summary of the decline (%) and probabilities for rates of population decline falling within any of the threat criteria of the IUCN Red List: Least Concern (LC%), Vulnerable (VU%), Endangered (EN%) and Critically Endangered (CR%). The most-probable status based on criteria A2–4 is assigned based on the category containing the highest posterior probability, with the exception that VU is also selected in cases where LC obtained the highest probability, but it is <50%. All probabilistic statements are based on an evaluation time-frame of 27 years (1991–2017)

Species name	Common name	Decline%	LC%	VU%	EN%	CR%	Status
Leucoraja wallacei	Yellowspot skate	-37.9	31.4	35.1	31.8	1.6	VU
Dipturus pullopunctatus	Slime skate	79.8	99.6	0.3	0	0	LC
Raja ocellifera	Twineye skate	-64.7	6.3	11.6	60.4	21.7	EN
Rostroraja alba	Spearnose skate	8	83.1	13.6	3.3	0	LC
Raja straeleni	Biscuit skate	-18.6	70.5	25.5	3.8	0.1	LC
Dasyatis chrysonota	Blue stingray	-54.7	16.4	14.5	49.7	19.4	EN
Myliobatis aquila	Eagle ray	-20.3	50.9	25.2	23.2	0.8	LC
Callorhinchus capensis	St Joseph	39.7	97.2	1.8	0.9	0	LC
Acroteriobatus annulatus	Lesser guitarfish	-82.9	1	1.6	23.2	74.1	CR
Mustelus palumbes	Whitespotted smoothhound	12.3	98.1	1.9	0.1	0	LC
Mustelus mustelus	Smoothhound shark	14.4	78.8	14.1	7.1	0	LC
Galeorhinus galeus	Soupfin shark	-47.6	16.8	28.9	53	1.3	EN
Halaelurus natalensis	Tiger catshark	-45.4	23.3	22.3	47.8	6.6	EN
Scyliorhinus capensis	Yellowspotted catshark	-19.8	52.3	26.9	20.6	0.2	LC
Haploblepharus edwardsii	Puffadder shyshark	-56.8	11.8	17	58.4	12.8	EN
Holohalaelurus regani	Izak spotted shyshark	31.3	96.7	3.1	0.2	0	LC
Holohalaelurus punctatus	African spotted shyshark	66.4	95	4.1	0.9	0	LC
Squalus acutipinnis	Shortnose spiny dogfish	-15.7	76.2	22.4	1.4	0	LC
Squalus margaretsmithae	Smith's dogfish shark	144.3	96.1	2.8	1.1	0	LC
Squalus bassi	Shortspine spiny dogfish	73.4	96	3.2	0.8	0	LC
Pliotrema warreni	Sixgill sawshark	61.5	90.6	6.8	2.5	0.1	LC

a comprehensive stock assessment model using abundance indices and fisheries data, JARA only uses abundance indices and translates results into the IUCN Red List framework. To date, JABBA has been used for assessment of shortfin mako and blue sharks at IOTC and ICCAT as well as a number of tuna and tuna-like species at RFMO level. JABBA has also been used for comprehensive assessments of two demersal shark species in South Africa (see details below, Table 15), as well as internationally. JARA, as well as data from South Africa, has been used to inform international IUCN red listing of 14 pelagic sharks and 21 inshore southern African chondrichthyans (see below, Table 15). In addition, a further 28 southern African species of chondrichthyans were assessed for the IUCN Red List using national expertise.

Optimum use

Research on optimum use of chondrichthyan resources is related to potential health risks associated with their consumption, full utilisation of shark catches, and traceability from catch to sale. Several DEFF collaborations with SA research institutions, such as the Department of Food Science, University of Stellenbosch, resulted in a number of studies investigating the heavy metal accumulation and toxicity of several marine fishes, including sharks. These studies indicated that, in general, large sharks are not safe for consumption and the related low economic value of sharks of over 12 kg formed the basis for slot-limit recommendations of 70 to 130 cm total length for demersal sharks caught in the commercial linefish and demersal shark longline fisheries. In addition, low reported catches of other species (<10 t), such as broadnosed sevengill sharks, *Notorynchus cepedianus*, in conjunction with their low value, facilitated their addition to the prohibited list in the demersal shark longline fishery. Lastly, with the aim of full utilisation of sharks as noted under the NPOA-Sharks, the large pelagic tuna fleet was required as of 2017 to land sharks with fins naturally attached.

Current status

Inshore/demersal sharks

Sharks have life-history characteristics that make them vulnerable to overexploitation. Long lifespans, low fecundity and complex migration patterns make successful fisheries management challenging. These attributes result in low productivity (rates of increase) and low resilience to fishing mortality and sharks can withstand only modest levels of fishing without depletion and stock collapse. The risk of overfishing is exacerbated by the disaggregation of catches across many fisheries and the resultant uncertainty in catch and effort time-series. The first comprehensive assessments of soupfin and smoothhound sharks were conducted in July 2019. The assessment input data included standardised abundance indices from fishery-independent demersal trawl surveys (1990–2016) and catch estimates from the demersal trawl fishery, the demersal shark longline fishery and the commercial linefishery. The Bayesian state-space surplus production model, JABBA, was applied to fit the catch and abundance time-series of soupfin and smoothhound sharks (Figure 47). All assessment scenarios indicated a >99% probability that soupfin is fished unsustainably. Biomass in 2016, the terminal year of the time-series, was estimated at 13% of carrying capacity and 25% of the biomass at maximum sustainable yield. At the

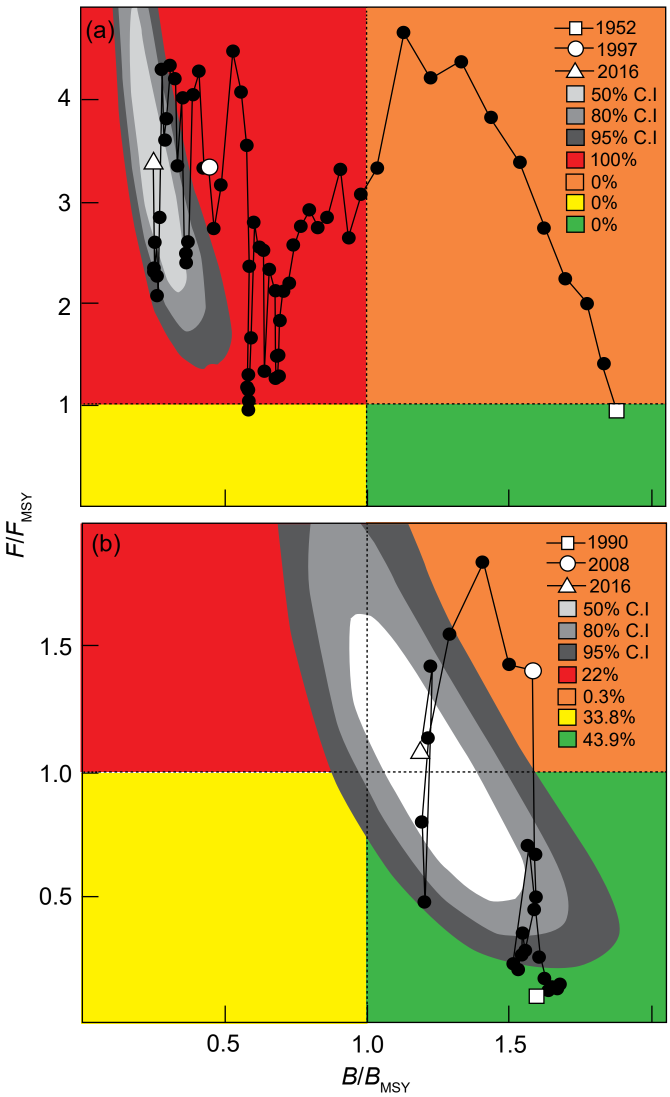


Figure 47: Kobe plot summarising the stock status estimates of fishing mortality relative to F_{MSY} and biomass relative to B_{MSY} for (a) soupfin sharks *Galeorhinus galeus* and (b) smoothhound sharks *Mustelus mustelus*

current catch level (329 t), depletion is projected to continue and result in commercial extinction of soupfin before 2055 with more than 97.5% probability. Given these results, urgent steps are required to reduce fishing mortality for soupfin sharks (Figure 47).

The smoothhound shark biomass, on the other hand, is still above the biomass at maximum sustainable yield, but the stock is fished at unsustainable levels. Projections into the future predict a stock decline at current fishing levels and steps ought to be taken to reduce fishing mortality for smoothhound sharks across all fisheries. It is advisable that the various sectors be restricted to similar degrees, although it should be noted that the bulk of the catch is taken by the demersal shark longline fishery. Fishing mortality needs to be reduced to below 75.0 t to stem the stock decline.

In addition to the assessments of smoothhound and soupfin sharks, trend analyses for chondrichthyan species off the South and West coasts of South Africa were completed as part of a workshop hosted by the IUCN Shark Specialist Group,

using the Bayesian state-space tool, JARA. Seven species were classified as threatened, with one Critically Endangered, five Endangered and one Vulnerable, whereas the remainder of the species were Least Concern. Overfishing has been identified as a concern for three of the seven threatened species, including yellowspot skate *Leucoraja wallacei*, twineye skate *Raja ocellifera* and soupfin shark, with the latter result aligning with results from comprehensive stock assessments. The negative assessments for the remaining four species are likely due to a shift in abundance, given the spatial nature of the data underpinning the JARA assessments.

Offshore/pelagic sharks

Assessments of pelagic sharks are conducted at RFMO level, with input from national scientists. The most recent assessment of shortfin mako shark by the ICCAT in 2017 indicated that the stock has collapsed in the North Atlantic and that, despite the considerable uncertainty around current biomass estimates of the South Atlantic stock, fishing mortality in the South Atlantic likely exceeds sustainable levels. Partially in response to the lack of progress at the 2018 ICCAT Commission with regard to shortfin mako management, the species has now been included in CITES Appendix II, which has ramifications for the large-pelagic longline fishery. The status of shortfin mako sharks in the Indian Ocean is largely unknown due to large uncertainty in reported data.

The most recent stock assessment for blue sharks in the ICCAT region was completed in 2015. Bayesian state-space surplus production model estimates were less optimistic than previous models and predicted that the stock could be overfished and that overfishing could be occurring. Considering the uncertainty in stock status results for the South Atlantic stock of blue sharks, the Committee strongly recommended that a precautionary approach be taken. For the IOTC region of competence, the blue shark was assessed in 2017 as not overfished or subject to overfishing. However, a large degree of uncertainty around data suggested that continuing catches at current levels will result in overfishing in the near future. As a result of this assessment, a reduction in catches of at least 10% was recommended.

Ecosystem interactions

Inshore/demersal sharks

Ecosystem interactions of shark fisheries are sometimes difficult to isolate, given that, in addition to being targeted in certain fisheries, chondrichthyans are caught as bycatch species in a suite of fisheries. The catches themselves are often considered to represent ecosystem interactions of those fisheries; an example is the large-pelagic tuna longline fishery covered below.

The demersal shark longline fishery targets soupfin and smoothhound sharks but markets most species caught, including skates, with the exclusion of those on the prohibited list. Ecosystem considerations for the demersal shark longline fishery include potential incidental catches of prohibited species such as white sharks *Carcharodon carcharias* and red steenbras *Petrus rupestris*. No mitigation measures are currently in place. Only two white sharks have been reported in logbooks by this fishery. Although no mandatory observer coverage is in place for this fishery, a brief observer programme was in place between 2008 and 2009. During these trips no significant bycatch of threatened species was observed. Electronic monitoring services (EMS) are being investigated for use in this fishery. Due to the gear used in the fishery, there are no catches of birds, mammals or turtles.

Offshore/pelagic sharks

A fundamental ecosystem consideration for South African large pelagic fisheries is the incidental catch of seabirds and marine turtles, including species that have an IUCN Red List status of Near Threatened, Vulnerable, Endangered or Critically Endangered. It is important to note that a number of international global environmental accords (e.g. Convention on Migratory Species [CMS], Agreement on the Conservation of Albatrosses and Petrels [ACAP], and the Convention on Biological Diversity [CBD]), as well as numerous fisheries agreements, obligate signatory States to provide protection for these species. The status of seabirds is affected by a range of factors, with fisheries bycatch being amongst the important ones. Permit conditions include management measures to reduce the mortality of seabirds, turtles and marine mammals. References to procedures for the handling and safe release of seabirds and turtles in the longline permit conditions are aligned with the aforementioned agreements.

South Africa has been collecting data on seabird interactions with its pelagic longline fishery since 1998. South Africa published its NPOA for seabirds in 2008 (NPOA-Seabirds 2008). The NPOA-Seabirds specifies a maximum mortality rate of 0.05 birds/1 000 hooks, and lays out bycatch mitigation measures for use in longline fishing.

South Africa has introduced a number of bird mitigation measures through permit conditions since the start of its pelagic longline fishery, including no daylight setting in conjunction with the compulsory flying of tori-lines or line weighting, and the use of thawed bait to improve sink rates. South Africa does not consider the use of line shooters or offal discard management to be useful in reducing seabird incidental mortality. Furthermore, South Africa (with the Albatross Task Force of BirdLife South Africa) developed a management plan in 2008 to reduce seabird bycatch in its longline fishery. This plan includes two seabird bycatch limits per vessel per year. The first limit stipulates that, once a vessel reaches 25 birds killed in a year, it must adopt additional mitigation measures; it has to fly a second tori line and it has to place additional weights on each branchline. If the vessel reaches the second limit of 50 seabird mortalities, the Department will review compliance with mitigation measures before deciding whether to permit further fishing by that vessel.

Since 2014, several species of chondrichthyans have been listed in CITES Appendix II. These include the oceanic whitetip shark *Carcharhinus longimanus*, three species of hammerhead sharks (scalloped *Sphyrna lewini*, great *S. mokarran*, and smooth *S. zygaena*), porbeagle shark *Lamna nasus*, mobulid rays, silky shark *C. falciformis* and thresher sharks *Alopias* spp. As described above, the shortfin mako shark was added to the list of species in CITES Appendix II, which has severe implications for the large-pelagic longline fishery. International trade of products (i.e. fins/flesh and gillrakers) of species listed in CITES Appendix II requires an import/export permit from the Department, a CITES permit, also from the Department, and a Non-Detrimental Finding (NDF) certificate provided by an RMFO from the area of capture. The latter is available for a limited number of species, and will not be issued for species such as the oceanic whitetip, rendering such species effectively CITES Appendix I-listed, whereby trade is not allowed. Prior to the listing of shortfin mako sharks, all CITES Appendix II-listed pelagic sharks were caught infrequently and were moved to the non-retention lists. Shortfin mako shark fins are the second-most-traded shark fins in and out of South Africa, and hence the risk of contravention of CITES Appendix II conditions is high. On the 26th November 2019, South Africa issued a reservation against the listing of mako sharks on CITES. As such, until the reservation is withdrawn, South Africa will be treated as a non-party to the Convention regarding their trade.

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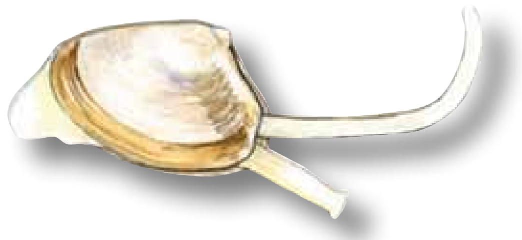
Small invertebrates and new fisheries



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
	White mussel Octopus East Coast round herring				
Fishing pressure	**Unknown**	**Light**	**Optimal**	**Heavy**	
		Octopus East Coast round herring	White mussel		

White mussels

White mussels of the species *Donax serra* are found in the intertidal zone of sandy beaches. They occur from northern Namibia to the Eastern Cape of South Africa. Their abundance is highest along the West Coast because of the higher plankton production there, compared with the rest of the South African coast, which is associated with upwelling of the Benguela Current.

The fishery for white mussels started in the late 1960s as part of the general commercial bait fishery and was suspended in 1988 when the bait Rights were revoked. Subsequent to stock assessments conducted in 1988/1989, harvesting of white mussels was retained as a commercial fishing sector and limited to seven areas along the West Coast (Figure 48). Surveys conducted in the 1990s showed that commercial catches amounted to less than 1% of the standing biomass in the relevant areas, and the resource was considered under-exploited.

Prior to 2007, each Right Holder was limited to a monthly maximum catch of 2 000 mussels. However, data from the fishery were unreliable, due to under-reporting and difficulties with catch monitoring, and hence catch limits were not considered to be an adequate regulatory tool to manage this fishery. As of October 2006, the monthly catch limit was lifted with the aim of removing constraints. Since 2007 the commercial sector has been managed by means of a total allowable effort (TAE) allocation of seven Right Holders (a Right Holder may have up to seven "pickers"), each harvesting within only one of the seven fishing areas along the West Coast. In 2013, the fishing Rights allocation process (FRAP 2013) for this fishery started and new Rights were granted in addition to those of some of the previous Right Holders. After an appeal process, 26 commercial Rights were confirmed in 2015, until December 2020. Each Right Holder was allocated a specific number of pickers. Some Right Holders are not allowed to employ pickers.

In the decades preceding the 1990s, commercial catches declined continuously (Figure 49). Increases in commercial

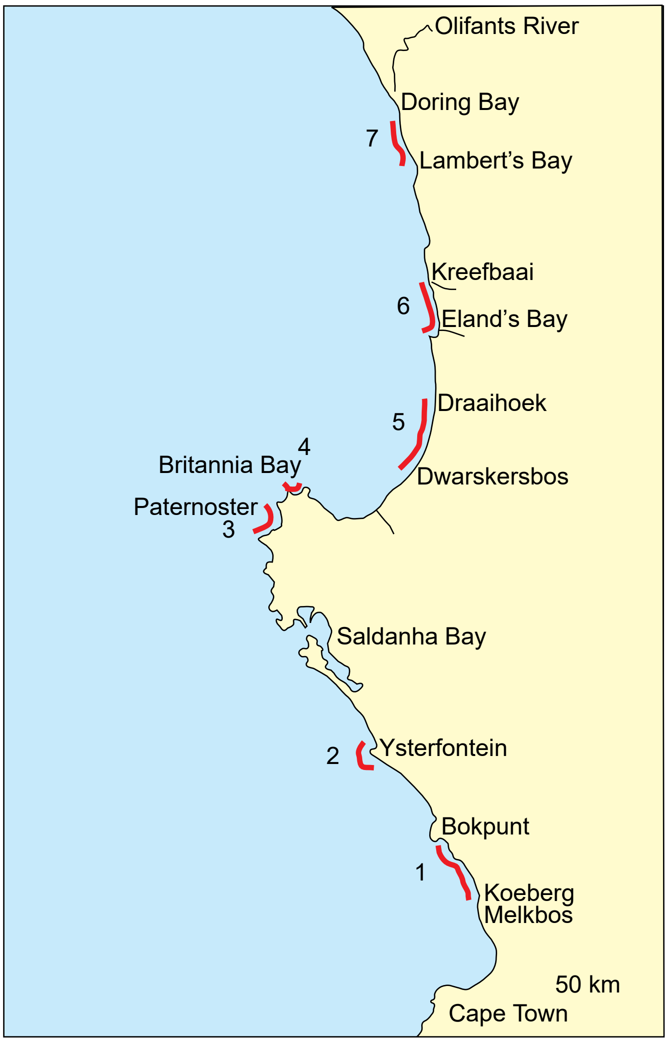


Figure 48: Areas allocated for commercial harvesting of white mussel *D. serra* along the West Coast of South Africa

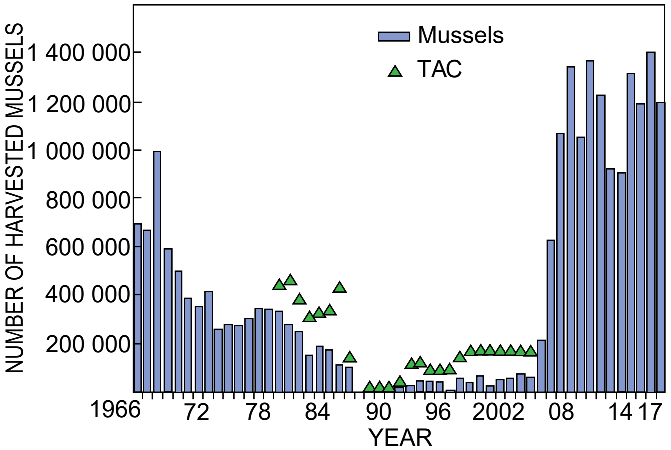


Figure 49: TAC and yield (total number) of white mussels harvested commercially per annum, 1966–2018

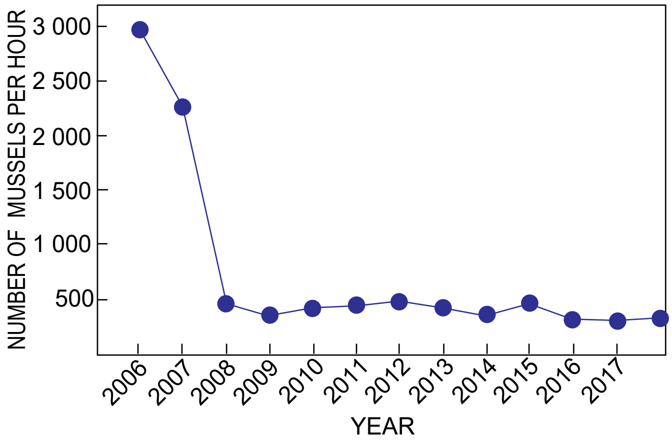


Figure 50: CPUE data calculated from catch data (see Figure 49) for mussels harvested commercially from 2006 to 2018

catches after 2006 can be attributed to the lifting of the commercial upper catch limit. The result was an improvement in the reliability and quality of catch data. Therefore, CPUE data were calculated from 2006 onwards, with the exception of 2006 and 2007, when person-hours were probably still under-reported. Recently, CPUE has remained relatively stable overall at between 300 and 500 mussels per hour harvested (Figure 50).

The Interim Relief sector was started in 2007. During the 2013/2014 season, 1 995 Interim Relief permits were issued for the Western and Northern Cape combined. This sector is subject to a limit of 50 mussels per person per day. The recreational sector is also limited by a daily bag limit of 50 mussels per person per day. For all sectors, a minimum legal size of 35 mm applies.

In the early 1990s, research on white mussels was confined to a few *ad hoc* area-specific stock assessment surveys which were carried out in response to requests for commercial permits. Fishery-independent surveys, aimed at providing information that can be used to assess the stocks, have been conducted since September 2007 and data are being collected in order to provide insights into the abundance of the white mussel resource on an area-by-area basis.

However, it is still too early for a comprehensive assessment of this resource. In addition to the fishery-independent surveys, commercial catch data are also required in setting the TAE. The lifting of the commercial upper catch limit in 2006 led to a steep increase in the number of white mussels collected by this sector over the last few years (Figure 49). In addition, the development of a bait market in Namibia in recent years has created a greater demand for the resource. It should be noted that not all the areas allocated are being harvested, and that the largest component of the overall catch of white mussels is that of the recreational sector, but these catches are not monitored. There are also information gaps regarding the level of exploitation by Interim Relief harvesters and the levels of illegal take. On account of irregularities, and despite the improvement post-2006, the catch-and-effort data are still considered to be unreliable. The current research programme will help to gather sufficient data to allow for proper assessment of the white mussel resource in the medium term. Comprehensive fishery-independent surveys are required in each of the areas and these surveys will take at least 3–5 more years to yield sufficient information for meaningful assessment. Therefore, uncertainty remains regarding the current status of the white mussel resource.

Octopus

Octopus are commercially fished in many parts of the world, including Australia, Japan, Mauritania and countries in Europe and South America. Markets for octopus exist in countries where this resource is considered a delicacy, for example Japan, China, Portugal, Spain and Greece. However, there is currently no commercial octopus fishery in South Africa and the local market for this product is very small. The common octopus *Octopus vulgaris* is the most sought-after octopus species internationally. It has a southern African distribution from Lüderitz (Namibia) on the West Coast to KwaZulu-Natal (approximately at Durban) on the East Coast. It occurs from intertidal rock pools down to depths of over 200 m, and inhabits various substrata including shell, gravel, sand and reef. Traditionally, octopus has been harvested primarily for subsistence purposes and as bait. A pilot study to investigate the potential of a commercial fishery for octopus paved the way for a 5-year experimental pot-fishery between October 2004 and September 2009. Difficulties caused by: (i) gear loss and damage from rough seas; (ii) vandalism and theft; and (iii) access to suitable vessels and equipment, resulted in this exploratory fishery yielding insufficient information to assess the feasibility of establishing a commercial fishery. Lessons learned during these attempts, however, were used in initiating and developing a further 5-year exploratory fishery, which commended in 2012.

At the end of this second 5-year exploratory period, a proper scientific evaluation of the fishery still could not be made because of insufficient data received, due to: (i) little or no fishing; (ii) gear losses in some areas; and (iii) environmental conditions (e.g. extended periods of red tide). The Department thus extended this exploratory fishery for another three years. This new period commenced in 2019.

The exploratory fishery for octopus aims to improve performance by participants by introducing greater flexibility with regard to the experimental design. Sixteen fishing areas have been designated. The sampling protocol makes provision for

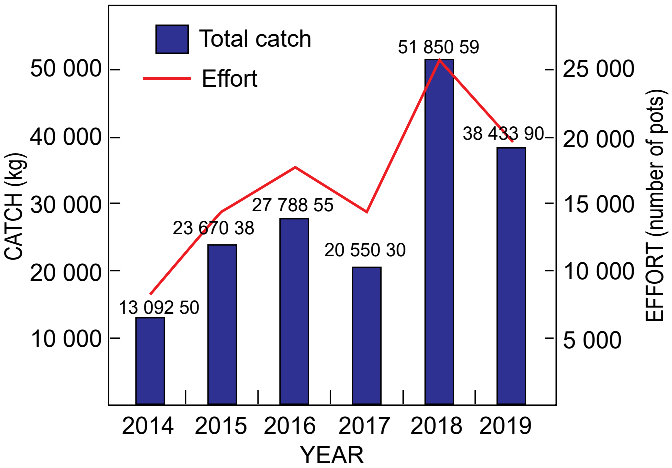


Figure 51: Total annual octopus catch (whole weight) and effort (numbers of pots retrieved)

participants to set and retrieve an average of 3–5 lines per day, with 50–100 Ivy Blue pots per line, resulting in a potential maximum of 500 pots being set per day. However, with three trigger traps per cradle and each line carrying 40 cradles, the total number of pots set per fishing day could be up to 600 (if the Australian trigger traps are used). Previous restrictions on pot-type have also been removed, so that participants may use whichever pot design is most appropriate to their own operations. On retrieval of each line, octopus in each pot are recorded separately, and any bycatch identified and counted.

Catches increased gradually from 13.1 t in 2014 to 51.85 t in 2018 (Figure 51). Catches subsequently dropped to 38.43 t in 2019 due to a temporary suspension of the fishery. The drop in total annual catch in 2017 is likely due to a lower number of pots hauled in that year (14 436 pots) compared to 2016 (17 887 pots). The high catches in 2018 and 2019 reflect an increasing trend in the efficiency of fishing gear, a better understanding of the fishing environment and the improvement of fishing skills. Access to adequate financial resources remains a challenge in this fishery, however, and is the main contributor to slow progress in the current dispensation. Out of 10 successful applicants, only five operators were able to activate their permits and begin fishing, and of this number only three permit-holders fish on a regular basis. In effect, of the 16 designated fishing areas, only three are being fished regularly, with data being retrieved most consistently from the False Bay area.

East Coast round herring (KwaZulu-Natal)

Two species of round herring of the genus *Etrumeus* occur in South African waters. The West Coast round herring *E. whiteheadi* is distributed from Walvis Bay (Namibia) to East London and is targeted by the purse-seine fishery for small pelagic species off the West Coast (see 'Small pelagic fish' section of this report). The East Coast round herring *E. wongratanai* (formerly known as *E. teres*) is distributed from East London to warm subtropical waters north of Durban and is targeted by an exploratory fishery. Landed fish are sold as bait and can attain prices in the region of R5.00 each.

Initial attempts in the late 2000s to catch East Coast round herring using a small purse-seiner proved unsuccessful, but fish can be caught using jigging from small craft (inflatables and sea kayaks) and three permits in this exploratory fishery have been granted annually from 2013 onwards. Participants are limited to a precautionary upper catch limit (PUCL) of 50 t each per annum, and permit conditions include the reporting of catch-and-effort data. Permit-holders typically also record the length and weight of around 100 fish caught per month and retain subsamples of fish for further analysis by DEFF staff, although these are not permit requirements.

Almost all of the exploratory fishing via jigging has been in the region of Scottburgh on the KZN South Coast. Effort, catch and catch per unit effort (CPUE) data from 451 fishing trips over the period January 2013 to July 2017 (there was no fishing for the remainder of 2017) have been collated and are shown at a monthly resolution in Figure 52. Trips ranged between 0.75 and 7 h in duration, with an average of 3.66 h, and almost all started in the early morning. Fishing effort was relatively high during the initial three years of the fishery (2013–2015; Figure 52a) but declined somewhat subsequently, both in terms of the number of hours fished per month and the number of months that fishing occurred. Catches (Figure 52b) were also higher during the first three years (respectively 14 175 fish or 842 kg, 24 745 fish or 1 333 kg, and 13 279 fish or 630 kg for 2013, 2014 and 2015) compared to the last two years (3 925 fish or 225 kg and 3 100 fish or 162 kg for 2016 and 2017, respectively). A similar reduction in CPUE between the first three and the last two years of this fishery was also observed (Figure 52c). The derivation of average monthly values of effort, catch and CPUE for the full 5-year time-series shows that, whereas some fishing effort was expended each month (on average, although not necessarily in each year; Figure 52d), catch (Figure 52e) and CPUE (Figure 52f) showed a clear seasonal cycle and were elevated during the middle of the year (April–September) with a peak in winter and average catch rates of just over 50 fish h^{-1} in July and August.

These annual catch levels (a total of 3.2 t to date for the period 2013–2017) are extremely low compared to the single biomass estimate (around 13 000 t) for this species obtained during a research survey conducted off the East Coast in 2005, and indicate that present, legal jig-fishing pressure is light and unlikely to be prejudicial to the resource. Catch levels from un-regulated jigging, which does occur, are unknown. The low catches made by Right Holders in the exploratory fishery also suggest that the present precautionary upper catch limit (PUCL) of 50 t per Right Holder per annum is too high, and could be substantially reduced without compromising the viability of individual Rights. The small quantities taken also indicate that access to this exploratory fishery can be broadened. The economic viability of this fishery has yet to be properly assessed but the input costs are likely low, particularly for operators fishing from kayaks that do not use any fuel. The product is in high demand, does not require further processing and apparently sells for a high unit (individual-fish) price in its landed state. Although sustained fishing by exploratory Right Holders suggests that the fishery is economically viable, the reduction in effort and CPUE during the past two years is of concern.

A length-frequency distribution derived from over 4 000 East Coast round herring measured by Right Holders (Figure 53a) shows that caught fish ranged from 120 to 248 mm caudal length (CL), with the majority between 170 and 200 mm CL, and with an average size of 178 mm CL (SD 20 mm) and an average wet body weight of 50 g (Figure 53b). Average monthly

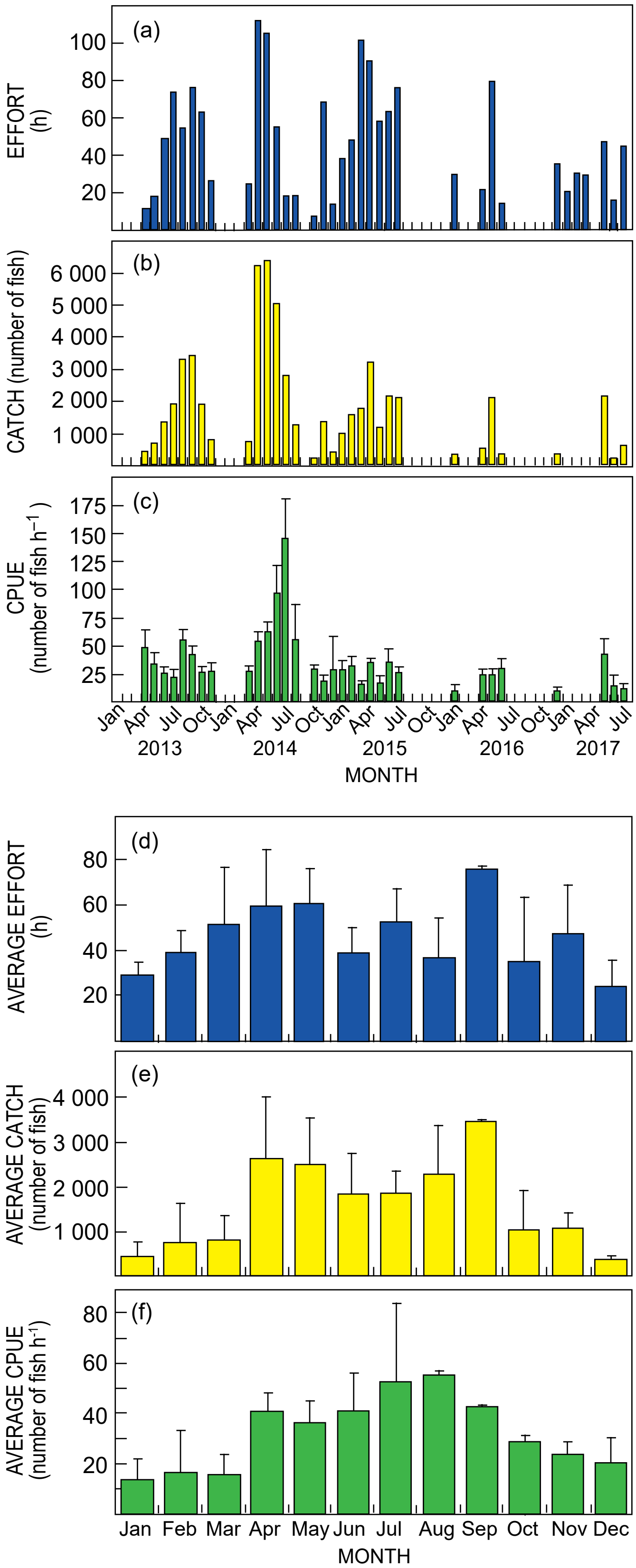


Figure 52: Time-series plots showing (a) monthly effort (total numbers of hours); (b) monthly catch (total numbers of fish); and (c) average (+1 SE) monthly CPUE (fish h^{-1}) over the period January 2013 to July 2017 for the exploratory fishery for East Coast round herring; and average (+1 SE) monthly (d) effort (hours); (e) catch (number of fish); and (f) CPUE (fish h^{-1}) over the full time-period

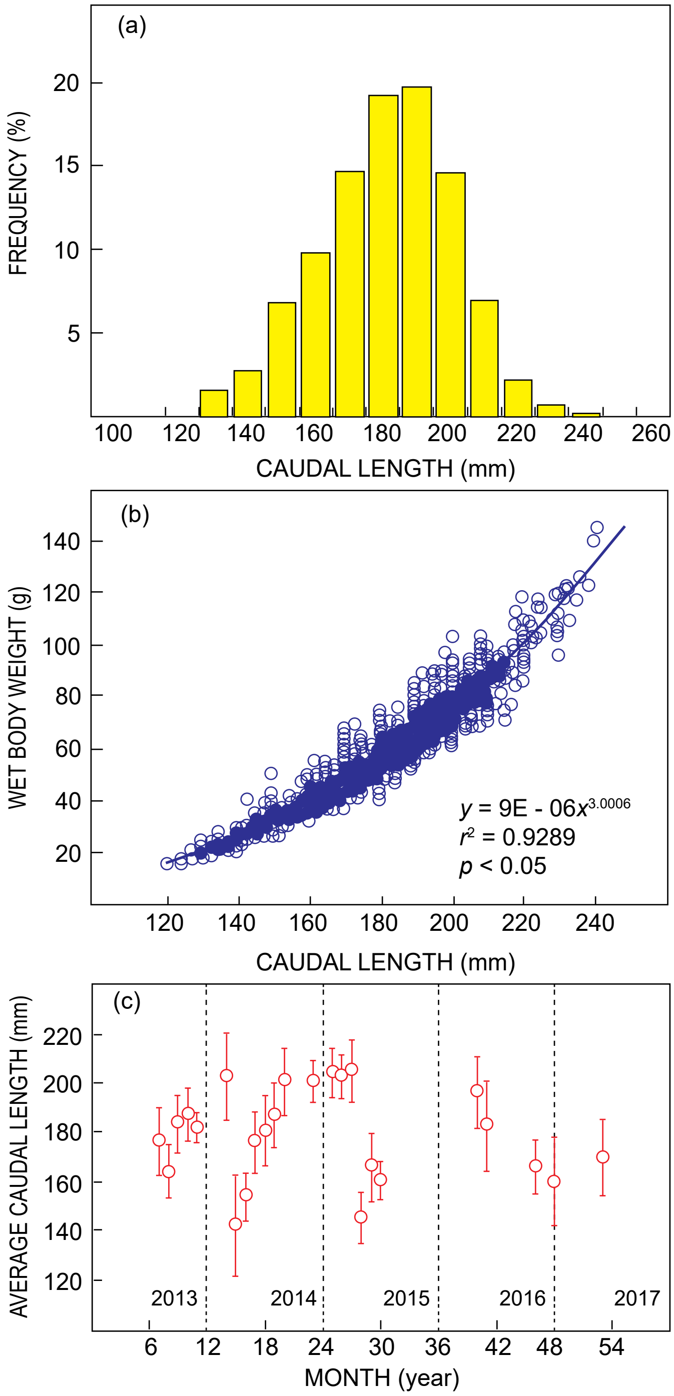


Figure 53: (a) Caudal length frequency distribution; (b) caudal length-weight scatterplot and fitted regression; and (c) average monthly caudal length (with standard deviation) of 4 019 East Coast round herring caught and measured by Right Holders in the exploratory fishery for this species over the period 2013 to 2017

CL values (Figure 53c) tended to be lower in the winter compared to the summer (although this was not always the case, e.g. 2016), suggesting that fish recruit to the fishery in winter and towards the end of their first year.

Biological data collected from subsamples of East Coast round herring kindly supplied by Right Holders have shown that *Etrumeus wongratanai* is a short-lived species that reaches a maximum age of 3 years; grows rapidly to between 100 and

160 mm CL in its first year and attains a maximum observed length of 248 mm CL, with females growing faster and attaining a larger size than males. It attains 50% sexual maturity in its 2nd year and at sizes of 163 mm CL for females and 145 mm CL for males; reproduces between June and December (which corroborates data from ichthyoplankton sampling off KZN); and feeds primarily on eucalanoid copepods and fish larvae, with fish size and seasonal effects on prey composition apparent. This represents new knowledge on a previously poorly-researched fish.

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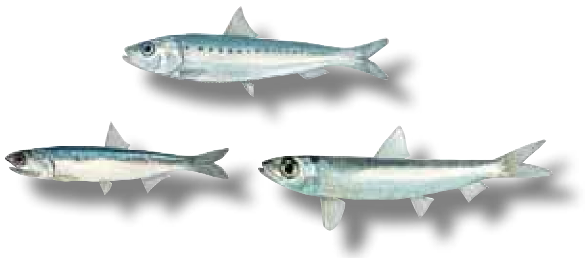
Small pelagic fish (sardine, anchovy and round herring)



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
		West Coast round herring	Anchovy	Sardine	
Fishing pressure	**Unknown**	**Light**	**Optimal**	**Heavy**	
		West Coast round herring	Anchovy Sardine		

Introduction

Forage fish of the order Clupeiformes occur in continental shelf waters between Hondeklip Bay on the West Coast and Durban on the East Coast. They generally exhibit schooling behaviour, have a small body size with rapid growth rates, have short life spans and exhibit strong population responses to environmental variability which results in large natural fluctuations in abundance over space and time even in the complete absence of fishing. Abundant small pelagic forage fish off the coast of South Africa include anchovy *Engraulis encrasicolus*, sardine *Sardinops sagax* and West Coast round herring (or redeye) *Etrumeus whiteheadi*, and these three species generally account for more than 90% of the total pelagic purse-seine catch. Long-term changes in the relative abundance of anchovy and sardine, over decadal and centennial time-scales, have been observed both locally and worldwide. Changes in the abundance of the two species are generally associated with variability in their recruitment, owing to changing environmental factors that affect, amongst others, transport of eggs and larvae, and feeding conditions. These characteristics also render small pelagic fish resources susceptible to those impacts of climate change that result in changed circulation patterns, altered composition and productivity of lower trophic levels, and the distribution of marine organisms – all of which are likely to exacerbate recruitment variability.

Pelagic fish resources are important to the country for several reasons. Firstly, the purse-seine fishery in which they are caught is South Africa's largest fishery in terms of landed mass and second only to the hake fishery in terms of value. Secondly, pelagic fish are an important and high-quality source of protein. Anchovy and round herring are mostly reduced to fish meal and oil in industrial-scale factories and used as a protein supplement in agri- or aqua-feeds. Sardine is mainly canned for human and pet consumption, with a small amount packed whole for bait or as cutlets for human consumption. Thirdly, the pelagic fishery employs a large workforce in fishing and related industries. Finally, pelagic fish occupy a key position in the marine food web where they are the link that transfers energy produced by plankton to large-bodied predatory fish, seabirds, and marine mammals. In this role, forage fish species can and do have major effects on higher trophic levels as well as on lower trophic levels, and variability in forage fish abundance is likely to propagate throughout the entire ecosystem.

Because animals and humans alike depend on forage fish, it is important to manage the fishery that targets them in a manner that accounts for their high degree of variability and importance to the ecosystem. This is so because of the potentially severe risks of local depletion of forage fish for dependent species such as seabirds, particularly in years of low fish abundance in certain areas. However, an often-overlooked fact is that whereas forage fish abundance influences higher trophic levels, the predation pressure exerted by these predators also has a controlling influence on the abundance of forage fish, given that they are the food source for many predators. Estimates of forage fish losses to predation are typically much higher on average than losses to fisheries, yet the assumption is often made that fishing is the main driver of reduced forage fish biomass.

Although it remains difficult to disentangle the impacts of fishing and natural processes at relevant time-scales in extremely complex marine ecosystems, excessive fishing is likely to disrupt important trophic interactions, particularly at low levels of forage fish abundance. Furthermore, predation pressure is likely to increase too as forage fish abundance declines, at least until a new predator-prey equilibrium is established. Fisheries management responses to such declines in forage fish abundance should therefore be precautionary to limit the risk that abundance falls below levels at which future recruitment

is compromised and/or the ecosystem is markedly impacted, while at the same time having regard for the important socio-economic role of the commercial fisheries that depend on forage fish.

History and management

The first pelagic fishing operations began in South Africa in 1935, but commercial operations only started in 1943 in the St Helena Bay area 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. Sardine, horse mackerel *Trachurus capensis* and chub mackerel *Scomber japonicus* dominated pelagic catches in the early years. Annual sardine catches increased rapidly from less than 200 000 t in the 1950s to more than 400 000 t in the early 1960s, whereas annual horse mackerel catches, which had peaked at around 120 000 t by the mid-1950s, decreased to less than 30 000 t annually by the end of the 1960s. Similarly, annual chub mackerel catches that peaked at almost 130 000 t in 1967 decreased markedly by the mid-1970s. As sardine, horse mackerel and chub mackerel stocks started collapsing in the mid- to late-1960s, the fishery changed to using smaller-meshed purse-seine nets to target juvenile anchovy, which dominated catches and largely sustained the South African purse-seine fishery for the next 30 years. Anchovy catches peaked at around 600 000 t in the late 1980s then subsequently decreased to a low of 40 000 t in 1996. Catches of sardine gradually increased throughout the 1990s under a conservative management strategy and reached 374 000 t in 2004 following a rapid increase in sardine population size, particularly on the South Coast. Anchovy catches also recovered quickly during the early-2000s, resulting in total pelagic landings in excess of 500 000 t per annum between 2001 and 2005. Round herring catches have been reported since the mid-1960s but have never exceeded 100 000 t or dominated the pelagic landings, despite several attempts by the pelagic industry to increase catches of this species.

A prolonged period of low sardine recruitment since 2004 resulted in a rapid decline in the size of the sardine stock with sardine catches dropping to levels in the order of 90 000 t between 2008 and 2014 and to less than 40 000 t in 2017 and 2018. The sardine catch in 2019 of only 2 100 t is the lowest recorded over the past 70 years. The current low sardine catches 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 local catches remain at these low levels.

Owing to this rapid decline in sardine catches, anchovy catches again dominate the fishery, with average catches of around 220 000 t between 2000 and 2018; however, the 2019 anchovy catch of around 165 000 t was the lowest recorded since 2013.

Historically, the fisheries for sardine and anchovy were managed separately in South Africa. The South African anchovy fishery has been regulated using an operational-management-procedure (OMP) approach since 1991. This adaptive management system is designed to respond rapidly to major changes in resource abundance without increasing risk. The first joint anchovy-sardine OMP was implemented in 1994, with subsequent revisions. The joint anchovy-sardine OMP is needed because sardine and anchovy school together as juveniles, resulting in the bycatch 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 the sustainable utilisation of both resources. Total allowable catches (TACs) for both species and a total allowable bycatch (TAB) for juvenile sardine are set at the beginning of the fishing season, based on results from the total biomass survey of the previous November. However, because the anchovy fishery is largely a recruit fishery, the TAC of anchovy and the juvenile sardine TAB are revised mid-year following completion of the recruitment survey in May/June.

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. Even though these formulae are also conditioned on low probabilities that the abundances of these resources drop below levels at which successful future recruitment might be compromised, now that the sardine biomass has dropped below that threshold, the primary and overriding consideration becomes assisting its speedy recovery, while still having consideration for the socio-economic implications associated with any TAC recommendation.

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 differing productivity characteristics. The model of two sardine components, a western component assumed to be distributed west of Cape Agulhas and a southern component distributed 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 and that future sardine population growth is mainly dependent on West Coast recruitment. OMP-18 therefore includes spatial management components which limit the amount of sardine that can be caught west of Cape Agulhas. Formal spatial management was implemented for the first time in 2019, with each sardine Right Holder constrained to take a maximum of 43% of their sardine allocation off the West Coast.

Some other key differences between OMP-14 and OMP-18 include a reduction in the maximum anchovy TAC from 450 000 t to 350 000 t, to reflect the maximum catch which the anchovy fishery is expected to be able to achieve at this time given fishmeal processing and environmental limitations; the implementation of a minimum directed sardine TAC of 10 000 t, to reflect the expectation that the directed fishery would never be closed completely in practice, and a reduction in the maximum directed sardine TAC from 500 000 t to 200 000 t, reflecting the low expectancy in the near future for another large pulse in sardine biomass (and therefore catches) as occurred around the turn of the century. Furthermore, the directed sardine TAC is now recommended based only on the November hydro-acoustic estimate of sardine biomass, with no mid-season adjustment as per OMP-14 (this as the mid-season sardine recruitment estimate is considered too imprecise [particularly when sardine abundance is low as recently] to be used reliably to adjust the TAC).

OMP-18, as with previous OMPs, also includes agreed procedures for deviating from the OMP-calculated TACs and TABs in the event of Exceptional Circumstances (ECs) when application of the TAC generated by the OMP is considered to be inappropriate. Such a deviation may occur, for example, when an observed survey biomass falls outside the range of biomass distributions simulated during the development of the OMP. ECs were declared for sardine in 2019 and have been declared for both sardine and anchovy in 2020 on this basis; consequently, OMP-18 cannot be applied routinely at this stage. Conservative interim TACs for anchovy and sardine have been recommended for 2020 until such time as biomass projections from updated assessments for both resources are available.

Research and monitoring

Ongoing research on a number of issues that have an impact on the sustainable use and management of small pelagic fisheries off the coast of South Africa includes regular monitoring of pelagic fish abundance, development and revision of management procedures, and investigation into, amongst others, population structure, biology and ecology, catch patterns, distribution and behaviour of key species.

The biomass and distribution of anchovy and sardine, but also of other schooling pelagic and mesopelagic 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. These surveys, which have been conducted since 1984, comprise a summer total biomass survey and a winter recruit survey. Data for the estimation of a number of other key biological measurements needed as input into the OMP and information pertaining to the environment are also collected during these surveys. Given the fluctuating nature of the abundance of pelagic fish species, these surveys continue to provide estimates that are far more reliable than those that would have been obtained through mathematical estimation from commercial catch data only, and have enabled optimal use of these resources at times of high biomass while offering protection to them at low biomass levels.

This time-series of biannual biomass estimates was unfortunately disrupted in 2018 owing to the unavailability of the research vessel FRS *Africana* and funding to charter an alternative vessel to conduct the pelagic recruit survey. The loss of this survey has had far-reaching consequences both for setting the 2018 final anchovy TAC and for our understanding of the status of the anchovy and sardine resources. Only a conservative mid-year revision of the 2018 anchovy TAC was possible, based on mathematical projections of recruitment, and the missing anchovy recruitment estimate has added additional uncertainty to the stock assessment models which are now required for short-term projections in the face of ECs having been declared for anchovy and sardine.

Data on catch statistics, including landed mass, species composition, and catch position and date, are obtained from the pelagic fishery. Samples from commercial catches are processed to obtain the length frequency distributions of harvested fish that are required as input in the species-specific population dynamics models, in addition to other data on biological characteristics such as sex and gonad maturity stage, and fish condition. The current absence of official scale-monitors at offloading factories is, however, of great concern and potentially compromises the quality of reported landing statistics. Initial investigations have suggested that bycatches of sardine in both the anchovy and round herring fisheries may have been under-reported in the absence of scale-monitors. This has serious consequences for the sustainable management of these resources and attention to this matter is urgently needed.

Whereas most (80%) of the TAC for anchovy was taken in 2018 this has not been the case in many years since 2000. The direct and indirect factors impacting the small pelagic fishery and influencing its ability to fully utilise the anchovy TAC were described in the Status of the South African Marine Fishery Resources 2016 report, but continued anchovy under-catch has prompted the need for an assessment of spatial and temporal variability in anchovy catches over past decades.

Anchovy catch locations have been reported by pelagic fishing block (PFB; 10 x 10 nautical mile blocks covering the South African continental shelf) since 1987. PFBs are grouped into five Pool Areas (A = north of Cape Columbine; B = Cape Columbine to Cape Point; C = Cape Point to Cape Agulhas; D = Cape Agulhas to Mossel Bay; and E = Mossel Bay to Algoa Bay). Given that negligible quantities of anchovy are caught east of Cape Agulhas, analyses of spatial and temporal variability in anchovy catches were restricted to data from Pool Areas A–C, only. Absolute annual anchovy catches per Pool Area were compiled from landings data, and time-series showing these absolute catches, as well as relative (percentage of the total annual catch) catches from each of the three Pool Areas, are shown in Figure 54.

The few years of high (>250 000 t) anchovy catches in the late-1980s declined rapidly to very low (<50 000 t) catches in the mid-1990s before stabilising at between 130 000 t and 200 000 t from 2000 (except for 2013) onwards (Figure 54a). The typical pattern is that most (55.6 ± 16.3% on average) of the annual anchovy catch has been taken in Pool Area A, less in Pool Area B (33.3 ± 12.9%), and least in Pool Area C

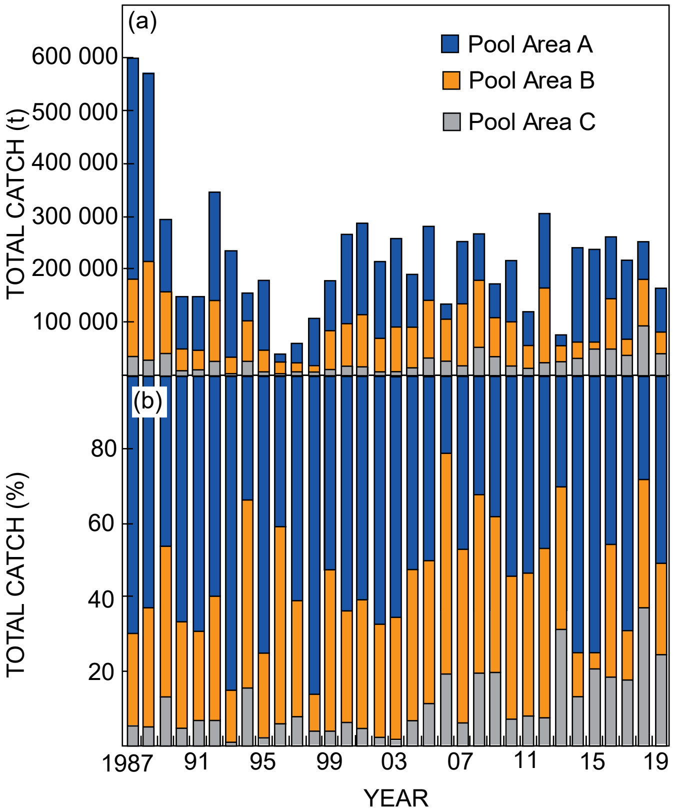


Figure 54: (a) Annual absolute (tonnes) and (b) relative (% of total) anchovy catch by Pool Area, 1987-2019

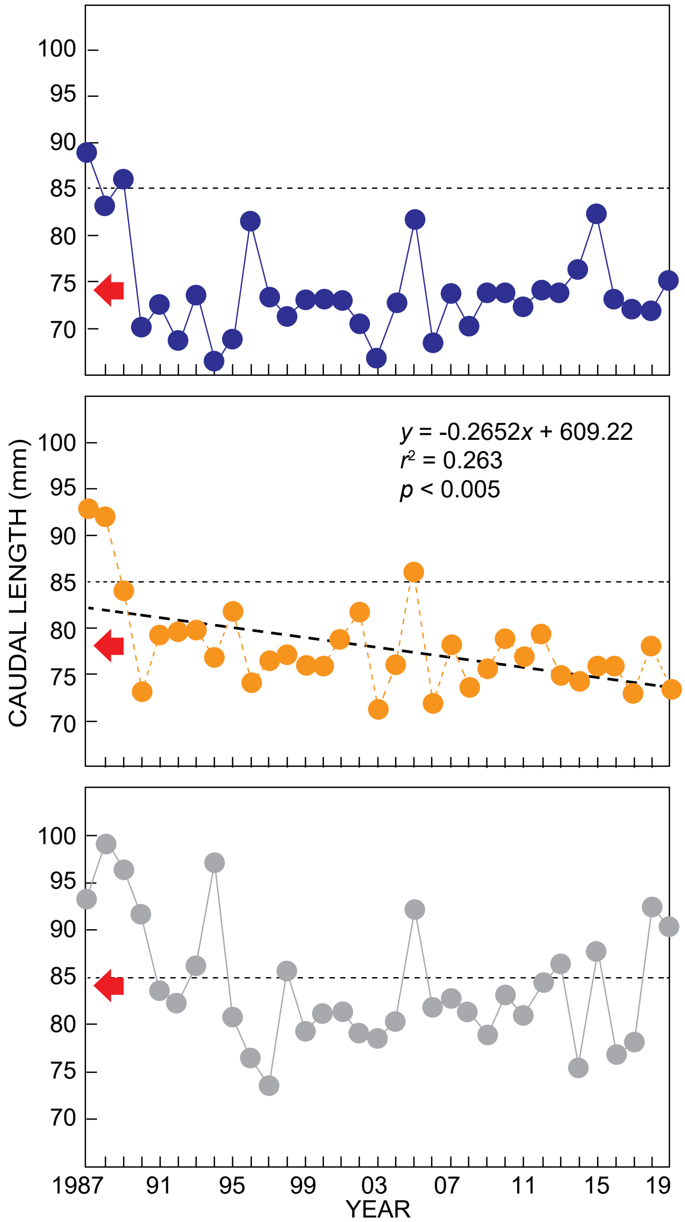


Figure 55: Weighted mean caudal length (mm) of anchovy caught each year in Pool Areas A (upper panel), B (middle panel) and C (lower panel) over the period 1987 to 2019. A reference line at 85 mm CL is shown on all plots to facilitate comparison, the overall mean for each Pool Area is shown with an arrow on the y-axis, and significant linear regressions are shown

(11.1 ± 8.8%). This pattern appears to be changing in recent years, however, particularly with regard to Pool Area C which has shown increased relative catches in the past decade and in which over a third (37.2%) of the anchovy caught in 2018, and just under one quarter (24.5%) of anchovy caught in 2019, were taken (Figure 54b). 2018 is also the first year in which catches in Pool Area C (94 171 t) were higher than those taken in either Pool Area A (71 253 t) or B (87 882 t). And whereas relative (% of total) annual anchovy catches in Pool Areas A and B show no significant trends through time, that for Pool Area C shows a highly significant ($p < 0.005$) positive linear trend. Catch patterns of anchovy therefore appear to be changing, as has been seen for sardine, and to a lesser extent round herring.

In addition to examining spatial variability in anchovy catch patterns, length frequency data from sampled anchovy catches were used to derive annual catch length frequency (LF) distributions by raising each observed (or assumed) LF by catch size. A "weighted mean length" was then derived for each Pool Area for each year from these raised length frequencies by summing the product of each size class and its proportional contribution across all length classes, and these are shown in Figure 55.

On average, smaller anchovy are caught in Pool Area A (74.2 ± 5.4 mm CL) than in Pool Areas B (78.0 ± 5.0 mm CL) or C (84.2 ± 6.6 mm CL). Larger anchovy were caught at the start compared to the end of the time-series for all three Pool Areas, and a significant ($p < 0.005$) linear regression could be fitted for Pool Area B, with weighted mean length in this region declining by 8.5 mm over the 33-year time-series. Weighted mean length also shows a declining trend in Pool Area C, but this is not significant and appears to have reversed in 2018 and 2019. These declining trends may be an indication of a shift in the timing of peak spawning to later in the year, resulting in later recruitment and hence smaller recruits being available to the fishery.

Staff from the Chief Directorate: Fisheries Research and Development of the Department are collaborating with researchers from the Council for Scientific and Industrial Research (CSIR) to develop a Fisheries Decision Support Tool (DeST) to optimise fishing effort across a range of fishery sectors. This work is being conducted as part of the National Oceans and Coasts Information Management System (OCIMS) for South Africa that was recently initiated by the Department of Environment, Forestry and Fisheries (DEFF) and the Department of Science and Technology (DST). The Fisheries DeST focuses primarily on developing Potential Fishing Zone (PFZ) information and identifying high probability catch zone maps based on frontal and phytoplankton/temperature range analytics that are derived using high spatial- and temporal-resolution satellite observations of ocean colour and sea surface temperature. Initial investigations are focussing on pelagic fisheries, but there is also scope for assessing similar options for demersal fisheries.

Spatially and temporally-referenced (haul location and date) historical catch data for directed sardine, anchovy and round herring in 2012 were compared to satellite-derived SST and chlorophyll *a* (Chl *a*) data for those places and times during that year. Those data were used to generate heat maps (Figure 56) for directed sardine catches taken off the West Coast (i.e. west of Cape Agulhas, predominantly on the western Agulhas Bank but also between Cape Point and Lambert's Bay) and South Coast (off Mossel Bay and Port Elizabeth), juvenile anchovy taken to the north of 34° S (Cape Town), and round herring caught off the West Coast. Similar heat maps using SST gradients for 2012, and for SST, SST gradient and Chl *a* for 2017, have also been derived but are not shown here.

The heat maps, as anticipated, show interspecific differences in environmental conditions where maximum catches of small pelagic fishes are achieved. The bulk of directed sardine caught off both the West and South Coasts in 2012 was taken in warmer waters of 16-20 °C and moderate (1–3 mg m-3) Chl *a* levels; most catches of anchovy juveniles in 2012 were taken in cooler waters of 13–16 °C and high (3–30 mg m-3) Chl *a* levels; and the bulk of round herring catches were tak-

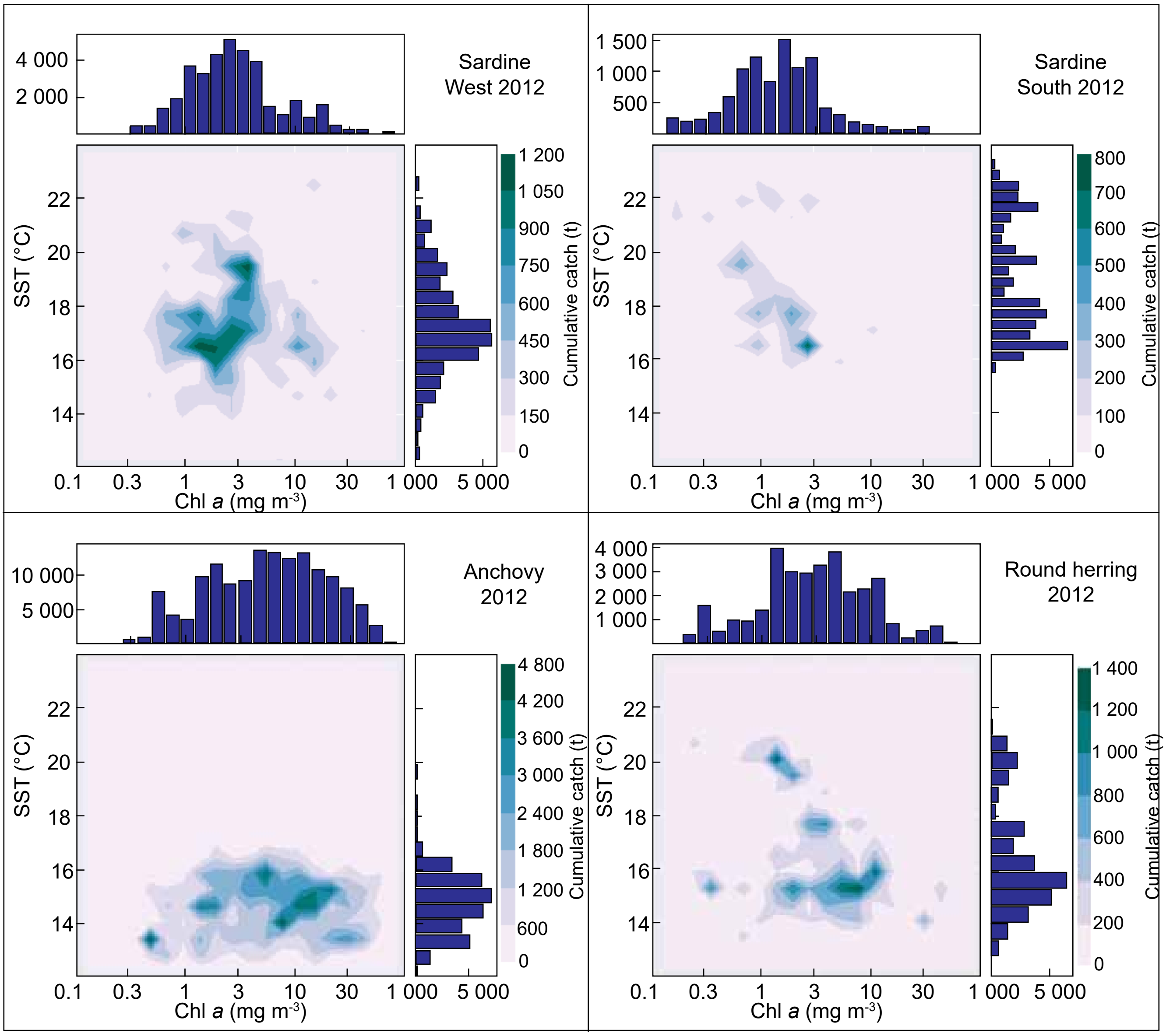


Figure 56: Heat maps showing cumulative catches in relation to SST and Chl *a* derived from high resolution satellite imagery for directed sardine catches taken off the West and South Coasts (top panels), juvenile anchovy catches taken to the north of 34° S (bottom left panel) and round herring catches taken off the West Coast (bottom right panel), in 2012. Each panel shows a contour plot of cumulative catches (tonnes; blue to green shading; colour bar on right hand side) against Chl *a* (*x*-axis; mg m^{-3}) and SST (*y*-axis; °C) and histograms of the cumulative catch (tonnes) as a function of Chl *a* (horizontal histogram) and of SST (vertical histogram) categories. Plots courtesy of Drs M Smith and S Bernard (CSIR); note that whereas both the *x*- and *y*-axes of the heat maps are to the same scale the *y*-axes of the various catch histograms are not to the same scale

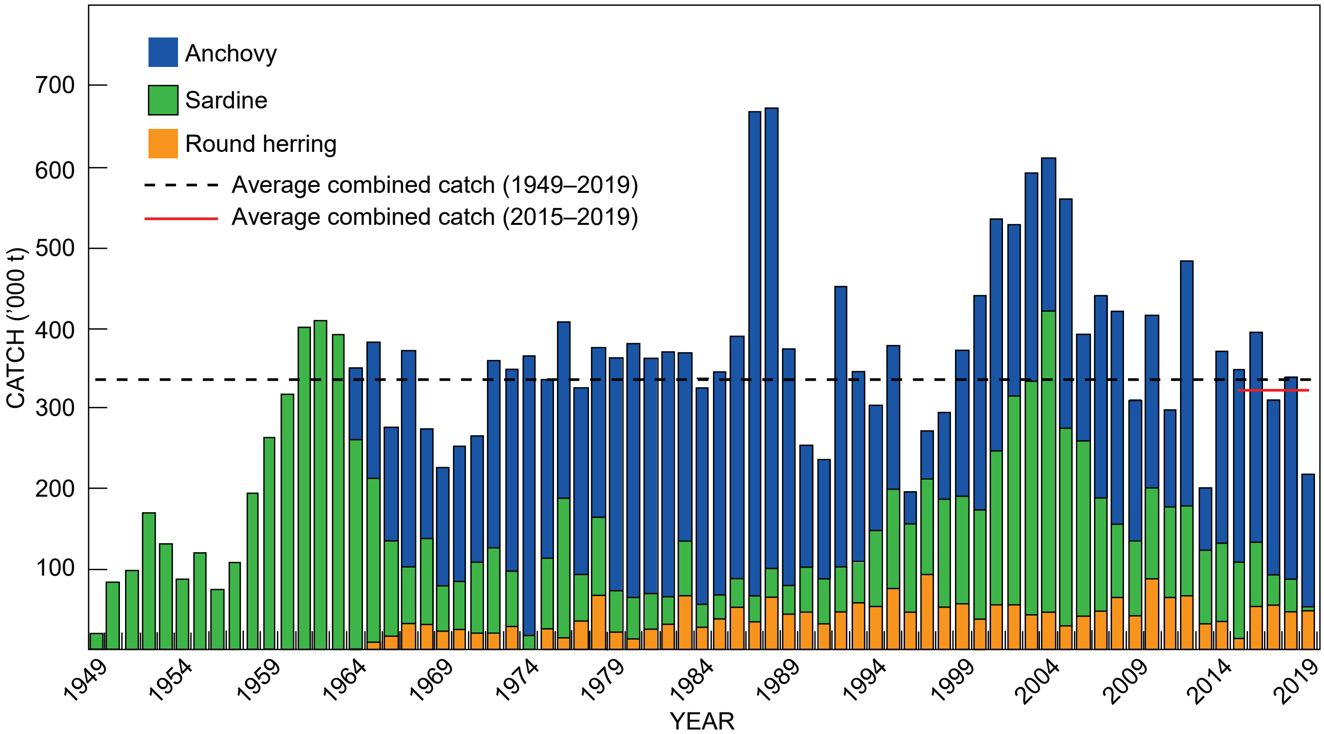


Figure 57: The annual combined catch of anchovy, sardine and round herring. Also shown is the average combined catch since the start of the fishery (1949-2019; black dashed line) and for the past five years (2015-2019; red solid line)

en in intermediate waters of 15–18 °C and moderate to high (1–10 mg m^{-3}) Chl *a* levels but also in warm water of ~20 °C and moderate Chl *a* levels. There was little difference in the heat maps for directed sardine taken off the West and South Coasts in 2012. Further work will involve determining the optimal combination of ocean observations (possibly including surface wind and current data in addition to SST, SST gradient and Chl *a* data) for predicting high probability catch zones for small pelagic fish. This combination will then be applied to "test" years (not used in the analysis) to compare the spatial and temporal co-occurrence of predicted and realised high probability catch zones. Ultimately, high probability catch zone maps will be made available in near-real-time primarily for industry use, but can also be used for historical analyses for research and management purposes.

Current status

Annual TACs and landings

The total combined catch of anchovy, sardine and round herring landed by the pelagic fishery has decreased by 45% from 395 000 t in 2016 to just 219 000 t in 2019, due mainly to a substantial decrease in the catch of anchovy from 262 000 t in 2016 to only 166 000 t in 2019. Despite this decline, the average combined catch over the last five years of 322 000 t is only slightly lower than the long-term (1949–2019) average annual catch of 334 000 t (Figure 57). The utilisation of the anchovy TAC allocated for most years since 2000 remains low, with only 56% of the TAC being caught on average since 2000 (Figure 58a). Although a record high recruitment was estimated during the 2017 recruit survey (see below), that record recruitment did not translate into increased catches in subsequent years. An interim precautionary anchovy TAC of only 100 000 t has been awarded for 2020, owing to the recent decline in anchovy biomass and the declaration of ECs for this species.

The directed sardine catch in 2016 was 63 000 t, decreasing to an all-time low of 2 100 t in 2019 (Figure 58b). In 2019, the directed sardine TAC was only 12 000 t, as a result of ECs having been declared for sardine at the end of 2018. This decreased TAC reflects the depleted state of the sardine resource, which has failed to recover from a prolonged period of poor recruitment since 2004. An interim precautionary TAC of 10 000 t has been allocated for 2020, with not more than 3 000 t of that TAC to be caught west of Cape Agulhas.

Sardine bycatch, which includes juvenile sardine caught with anchovy, adult sardine, and round herring as well as adult sardine caught with round herring, ranged from 17 000 t in 2016 to 3 000 t in 2019 (Figure 58c). The levels of sardine bycatch are substantially less than that allowed for in recent years – mainly reflecting the low level of sardine biomass measured in 2017–2019. This under-catch of the sardine TAB is encouraged because the OMP, whilst making provision for occasional high bycatch levels, assumes that the TAB will be under-caught on average. Furthermore, industry has also put in place measures to avoid areas with high bycatches of sardine to improve the chances of a recovery in the size of the adult sardine population.

The catch of West Coast round herring has remained relatively stable, averaging at 51 000 t since 2016, which is similar to the 2000–2019 average annual catch (Figure 58d). These recent catches, however, are only half of the 100 000 t precautionary upper catch limit (PUCL) recommended for this resource and reflects the difficulty of catching this species with purse-seine nets. Increased utilisation of the West Coast round herring resource is encouraged and attempts to improve catch rates with the use of midwater trawling have not been successful to date.

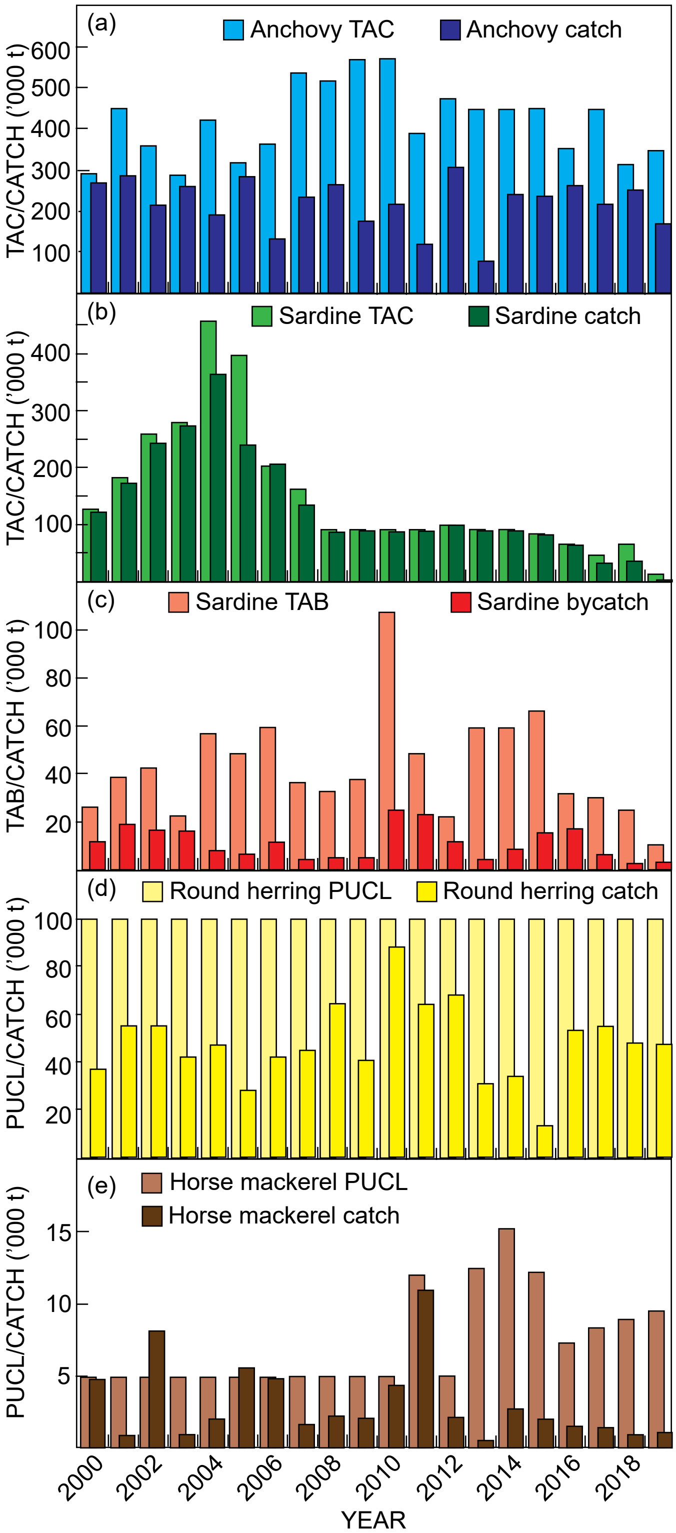


Figure 58: Total allowable catches (TACs), total allowable bycatch (TAB) and precautionary upper catch limits (PUCLs), and subsequent landings of each by the South African pelagic fishery for (a) anchovy, (b) directed sardine, (c) sardine bycatch, (d) round herring and (e) horse mackerel, 2000–2019

Bycatches of juvenile horse mackerel have been low in recent years (<2000 t) and well below the three-year PUCL of 12 000 t, despite the precautionary reduction in the $PUCL_3$ from 15 589 to 12 000 t in 2016 (Figure 58e). This three-year rule, whereby the PUCL over any consecutive three-year period totals to 12 000 t, has allowed for increased flexibility and increased bycatches of horse mackerel in years when horse mackerel recruitment is high and incidental bycatch with anchovy is unavoidable.

An annual PUCL for mesopelagic fish of 50 000 t was introduced in 2012, following increased catches of lantern- and light fish by the experimental pelagic trawl fishery in 2011, when just over 7 000 t of these species were landed. A resumption of the trawl experiment in 2018 resulted in mesopelagic catches of 5 800 t and 3 500 t in 2018 and 2019, respectively. The relatively high costs associated with this experiment, coupled with the recent downturn in the anchovy and sardine fishery, has led to the applicant not pursuing this any further. The Department remains desirous of continuing this experimental fishery as well as the exploratory trawl fishery for anchovy and West Coast round herring aimed at improving utilisation of these resources off the South Coast, especially given the current depleted state of the sardine resource.

Recruitment strength and adult biomass

Anchovy recruitment measured in 2016 was considerably lower than the long-term average and almost half that measured in 2015. This was followed by a record high anchovy recruit estimate of 830 billion fish in 2017 (Figure 59a). Fish sampled during this survey on average weighed about 1.4 g less than those sampled during the preceding two years and not many of them appeared to have survived subsequent to the survey, with the adult anchovy biomass in 2017 and 2018 remaining relatively stable at around 1.5 million t. The recent decrease of close to 50% in the adult anchovy biomass from 1.5 million t in 2018 to only 0.84 million t in 2019, despite reasonable recruitment in 2019, is a cause for concern and updated anchovy assessments indicate below-average recruitment for the past five years, possibly indicative of a regime shift and/or increased natural mortality.

Sardine recruitment has remained very low. The lowest recruit estimate in 30 years of <1 billion fish in 2016 was followed by an estimate of 7 billion fish in 2017 and 4 billion fish in 2019 (Figure 59b). Given this sustained below-average recruitment, the adult sardine biomass decreased further to only 91 000 t in 2018. A slight increase to 190 000 t in 2019, although encouraging, has not provided sufficient motivation to set aside low-biomass ECs provisions for this species and necessitates continued precautionary management.

Recent West Coast round herring recruitment estimates remain far above the long-term average of 11 billion fish (Figure 59c). The 2019 West Coast round herring recruit estimate was the second highest on record and resulted in a 60% increase in the biomass of adult West Coast round herring from 1.4 million t in 2018 to 2.3 million t in 2019.

Shifts in the distribution both of anchovy and sardine adults that have previously been reported on (see Status of the South African Marine Fishery Resources Reports of 2012, 2014 and 2016) continue to be monitored. The abrupt eastward shift of anchovy that occurred in 1996 still persists and seems to have intensified in recent years (apart from 2018), with an average of 37% of the adult anchovy biomass observed in the area to the west of Cape Agulhas since 1996 compared to 64% on average in the years preceding the shift (Figure 60a). Given the recent decline in the size of the anchovy population, the biomass of anchovy in this western area has declined to

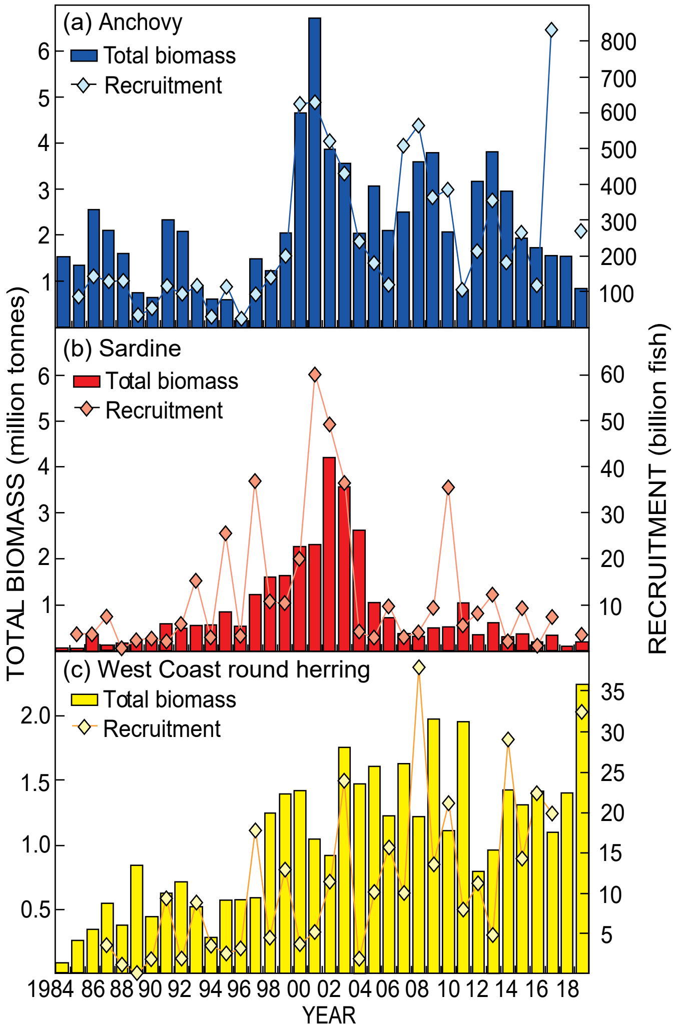


Figure 59: Time-series of acoustically-estimated recruitment strength and total biomass of (a) anchovy, (b) sardine and (c) West Coast round herring, 1984–2019

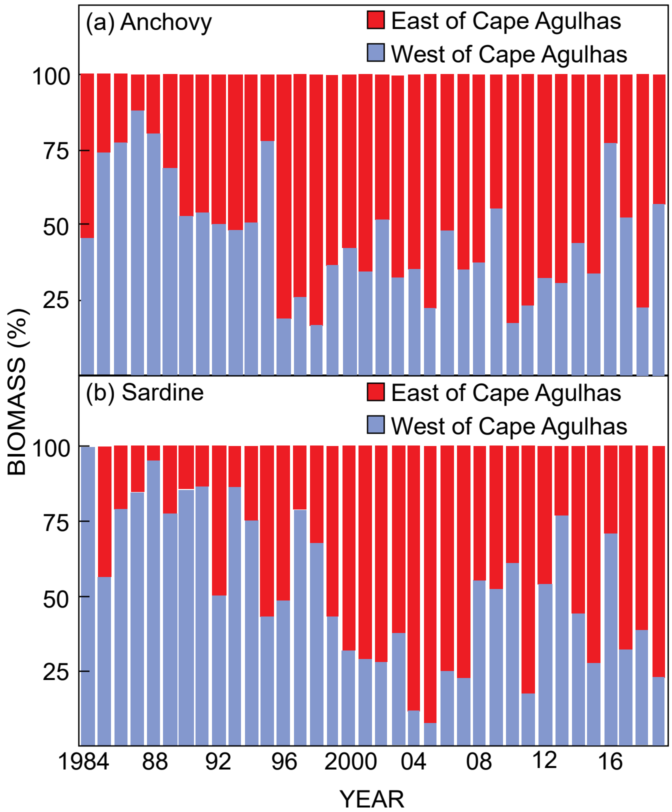


Figure 60: Percentage of the adult (a) anchovy and (b) sardine biomass found to the west and east of Cape Agulhas, 2000–2019

<500 000 t, a level far below that observed from 2012 to 2016. The percentage of the sardine biomass found in the area to the west of Cape Agulhas remains highly variable but has decreased considerably in recent years. Around 71% (180 000 t) of the sardine biomass was found in the area to the west of Cape Agulhas in 2016 (Figure 60b), but this percentage decreased to 32% in 2017 and subsequently to only 23% (44 000 t) in 2019. This decrease in the biomass of sardine to the west of Cape Agulhas is likely to compromise future recruitment, given reduced transport of eggs and larvae to the West Coast nursery area from sardine spawning on the South and East Coasts.

Ecosystem interactions

The primary approach that has been used to limit catches of forage fish is Rights-based management with specifie annual TACs. Incorporation of ecosystem considerations and the development of ecosystem-based management is undertaken through the revised operational management procedure OMP-18.

OMP-18 was simulation-tested to ensure certain probabilities that sardine and anchovy abundances would not drop below specified thresholds. That OMP was also tested using parameters denoting risk to the African penguin *Spheniscus demersus* population. Penguins were chosen as a key predator species for consideration because they feed predominantly on sardine and anchovy and because of their conservation status, which is of concern due to appreciable reductions in their numbers at the major breeding colonies over recent years and their listing as Endangered by the IUCN. As part of the implementation of an ecosystems approach to fisheries (EAF) in South Africa's fishery for small pelagic fish, a model of penguin dynamics has 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 could be evaluated. This study suggested that fishing is likely to have a relatively small impact on penguins, especially when compared with uncertainties that arise from the variable spatial distribution of the sardine population. Recent OMP-18 performance statistics indicate that even with zero sardine catch, penguin numbers are expected to decline. Under OMP-18 harvest control rules, the rate of decline in penguin moulters would be an annual 10.9% over the next five years, compared to 9.5% if there was no sardine fishing. The lower realised sardine biomass in recent years would, however, be expected to result in more pessimistic rates of decline under both catch and no-catch scenarios

Penguins are potentially also sensitive to changes in pelagic fish abundance and distribution as a consequence of their land-based breeding sites and their limited foraging range (< about 20 km) during breeding. Additional measures to possibly restrict fishing in close proximity to penguin breeding colonies were initiated in 2009. Results from experimental closure of areas to fishing around some important seabird breeding colonies (islands) in an attempt to assess the impact of localised fishing effort on the breeding success of these birds are now available. Whereas there remains debate about the appropriateness of some of the methods of analysis applied to these data, and the conclusions which can be drawn from the results, they do indicate that although certain island closures may help reduce the rate of decline of the penguins, they would not be sufficient to stop it. Appropriate management recommendations in this regard are expected prior to the start of the 2021 fishing season.

Additionally, central to the development of OMP-18 was the consideration of harvest strategies that include spatial management of sardine, given the likely existence of two or more local stocks of this resource. Such spatial management, which is now being formally implemented to limit catches of sardine in the area to the west of Cape Agulhas, potentially also has the associated benefit of preventing local forage fish depletion and heightened competition between dependent predators and the fishing industry on the West Coast.

Further reading

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Useful statistics

Pelagic fish catches and TACs/TAB/PUCLs, 1990–2019 (x 1 000 tonnes)

	Catch									TAC/TAB/PUCL						
Year	Anchovy	Total sardine	Directed sardine	Bycatch sardine	Horse mackerel	Chub mackerel	Round herring	Meso-pelagic fish	TOTAL	Anchovy TAC	Sardine directed TAC	Sardine TAB	Round herring PUCL	Horse mackerel PUCL	Meso-pelagic PUCL	TOTAL TAC, TAB and PUCL
1990	152	57	42	15	8	0	46	1	263	150	42	0	0	0	0	192
1991	151	53	40	13	1	10	34	1	249	150	37	0	0	0	0	187
1992	349	55	34	21	2	0	48	1	455	350	32	0	0	0	0	382
1993	236	51	30	21	12	0	57	1	357	360	27	0	0	0	0	387
1994	156	95	50	44	8	2	54	1	316	150	50	45	0	0	0	245
1995	178	121	77	44	2	3	77	1	382	210	75	42	0	0	0	327
1996	41	108	79	29	19	1	47	0	216	70	76	29	0	0	0	175
1997	60	119	92	27	13	4	92	0	289	60	88	50	0	0	0	198
1998	108	133	109	24	27	0	53	7	327	175	106	35	0	0	0	316
1999	180	132	118	14	2	0	59	0	373	231	136	26	0	0	0	393
2000	267	135	124	12	5	0	37	0	445	291	126	38	0	5	0	460
2001	288	192	173	19	1	0	55	0	535	451	182	50	0	5	0	688
2002	213	261	245	16	8	0	55	0	537	360	258	54	0	5	0	677
2003	259	290	274	16	1	0	43	0	593	282	250	44	100	5	0	681
2004	190	374	366	8	2	0	47	0	614	423	457	69	100	5	0	1 054
2005	283	247	240	6	6	0	28	0	564	297	397	60	100	5	0	859
2006	134	217	206	11	5	0	42	0	398	362	204	71	100	5	0	743
2007	253	140	135	5	2	0	48	0	443	537	162	49	100	5	0	853
2008	266	91	86	5	2	1	64	0	424	518	91	38	100	5	0	752
2009	174	94	89	5	2	1	40	0	312	569	90	43	100	5	0	808
2010	217	112	88	25	4	1	88	0	423	573	90	115	100	5	0	883
2011	120	112	89	23	11	0	65	7	315	390	90	54	100	12	0	646
2012	307	109	98	12	2	0	68	0	487	473	101	27	100	5	50	756
2013	79	92	88	4	1	0	31	0	203	450	90	66	100	12	50	769
2014	240	98	89	9	3	1	34	0	376	450	90	66	100	15	50	771
2015	238	95	80	15	2	1	14	0	350	450	83	73	100	12	50	769
2016	262	80	63	17	2	4	54	0	401	354	65	45	100	12	50	626
2017	217	37	31	6	1	2	55	0	314	450	45	41	100	8	50	694
2018	253	38	35	3	1	2	48	6	348	315	65	37	100	9	50	576
2019	165	5	2	3	1	4	47	3	230	350	12	11	100	9	50	532

South Coast rock lobster

Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

South Coast rock lobsters *Palinurus gilchristi* are endemic to the southern coast of South Africa, where they occur on rocky substrata at depths of 50–200 m. The fishery operates between East London and Cape Point and up to 250 km offshore along the outer edge of the Agulhas Bank, and fishing gear is restricted to longlines with traps. It is the second-largest rock lobster fishery in South Africa and is capital-intensive, requiring specialised equipment and large, ocean-going vessels.

Products (frozen tails, whole or live lobster) are exported to the USA, Europe and the Far East. Sales are affected by seasonal overseas market trends and competition from other lobster-producing countries. High prices on international markets and the increase of the Rand to Dollar exchange rate make the sector lucrative. Prices for commodities fluctuate and the sales prices in the USA are currently the equivalent of R440–R600 per kg tail mass.

Longline trap-fishing is labour intensive and as such each boat requires approximately 30 officers and crew. The total sea-going complement of the fleet is about 300 individuals, nearly all previously disadvantaged. In addition to sea-going personnel, the sector employs approximately 100 land-based factory (processing) and administrative personnel, also mostly previously disadvantaged people. The total export value in 2012 was approximately R320 million.

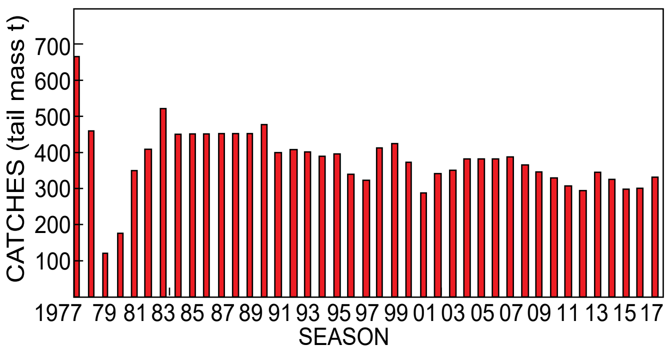

Figure 61: Annual catches of South Coast rock lobster from 1977 to 2018. Note that 1977 refers to the 1977/78 season, etc

History and management

The South Coast rock lobster was first described in 1900 and was recorded occasionally in trawler catches for sole at a depth of about 70 m. The commercial fishery commenced in 1974, after the discovery of concentrations of rock lobsters on rocky ground at a depth of around 110 m off Port Elizabeth. Numerous local and foreign fishing vessels converged on the fishing grounds, giving rise to the expansion of the fishery. However, foreign fishing vessels were withdrawn from the fishery in 1976, when South Coast rock lobster was recognised as a species occurring wholly within South African waters. From 1977 onwards, the sector operated solely as a local commercial fishery.

The fishery has a management history stretching back to 1974. The fishery was regulated initially by limiting the number of traps permitted per vessel. Catches and catch rates declined significantly between 1977 and 1979 (Figures 61 and 62). The introduction of management measures such as reduction of effort and catches during the early 1980s resulted in some resource recovery (Figures 61 and 62). An annual total allowable

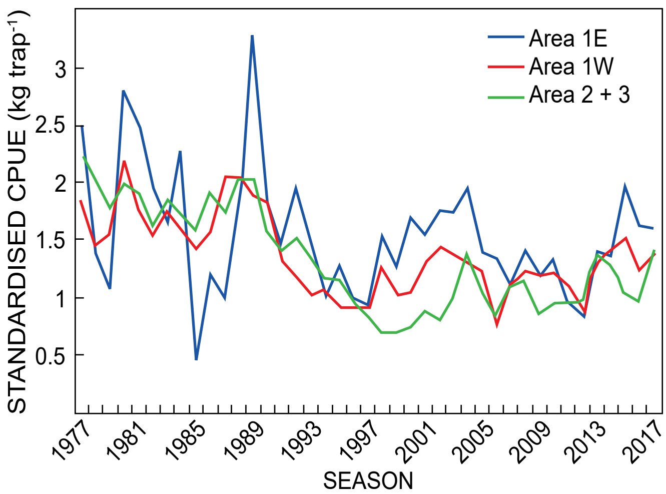

Figure 62: South Coast rock lobster catch per unit effort (CPUE) by area from 1977 to 2018. Note that 1977 refers to the 1977/78 season, etc

Table 16: South Coast rock lobster historical records of TAC, TAE, catch and standardised CPUE by area

Season	TAC (tonnes tail mass)	TAE (allocated seadays)	Standardised CPUE (kg trap^{-1})		
			Area 1E	Area 1W	Area 2 & 3
1977/1978			2.53	1.85	2.23
1978/1979			1.42	1.46	2.00
1979/1980			1.07	1.57	1.77
1980/1981			2.80	2.20	2.01
1981/1982			2.49	1.76	1.90
1982/1983			1.96	1.56	1.60
1983/1984			1.65	1.75	1.85
1984/1985	450		2.30	1.61	1.71
1985/1986	450		0.45	1.42	1.60
1986/1987	450		1.22	1.58	1.93
1987/1988	452		0.99	2.05	1.74
1988/1989	452		1.78	2.06	2.04
1989/1990	452		3.29	1.88	2.04
1990/1991	477		1.87	1.83	1.59
1991/1992	477		1.45	1.35	1.42
1992/1993	477		1.98	1.15	1.53
1993/1994	477		1.45	1.03	1.37
1994/1995	452		1.01	1.08	1.17
1995/1996	427		1.28	0.91	1.15
1996/1997	415		1.00	0.91	0.95
1997/1998	402		0.92	0.91	0.85
1998/1999	402		1.54	1.27	0.69
1999/2000	377		1.26	1.03	0.68
2000/2001	365	2 339	1.71	1.05	0.74
2001/2002	340	1 922	1.54	1.32	0.89
2002/2003	340	2 146	1.77	1.46	0.80
2003/2004	350	2 038	1.74	1.38	1.00
2004/2005	382	2 089	1.97	1.30	1.38
2005/2006	382	2 089	1.39	1.22	1.05
2006/2007	382	2 089	1.34	0.78	0.83
2007/2008	382	2 089	1.09	1.09	1.11
2008/2009	363	2 675	1.42	1.24	1.15
2009/2010	345	2 882	1.17	1.18	0.85
2010/2011	328	2 550	1.37	1.22	0.94
2011/2012	323	2 443	0.96	1.09	0.95
2012/2013	326	2 250	0.86	0.90	0.97
2013/2014	342	2 536	1 41	1.30	1.41
2014/2015	359	2 805	1.36	1.43	1.28
2015/2016	341	2 858	1.97	1.50	1.04
2016/2017	332	2 029	1.63	1.24	0.96
2017/2018	321	2 148	1.61	1.38	1.41

catch (TAC) was introduced in 1984, based on the performance of the fishery in the previous years. The TAC and limited entry stabilised the sector until the 1993/94 season (Figure 61), and a more rigorous procedure for stock assessment was developed in 1994.

The fishing season for South Coast rock lobster is year-round, extending from 1 October to 30 September of the following year. The management strategy is a combination of TAC and total allowable effort (TAE). The TAC limits the total catch and is based on an annual resource assessment, whereas the TAE is measured in fishing days allocated to each vessel. A vessel may fish until its fishing days expire or its quota is filled, whichever occurs first. The number of days spent at sea by each vessel is monitored. Catches may be offloaded only in the presence of Fishery Control Officers, and are weighed at designated offloading points. Skippers must, at the conclusion of each trip, provide the Department with accurate daily catch statistics.

The scientific recommendations for catch limits are based on an operational management procedure (OMP) which was introduced in 2008 and modified ("re-tuned") in 2010. A full review of the OMP was completed in 2014 (designated OMP-2014) and was used to provide the scientific recommendations for the 2015/16 to 2018/19 seasons.

A full OMP review was completed in 2019 (OMP-2019). This was used to determine the TAC and TAE for the 2019/20 season and will be used in the subsequent three fishing seasons. The objective of this OMP is to increase the spawning biomass of the resource by 30% over the 20-year period from 2006 until 2025, while restricting inter-annual TAC fluctuations to a maximum of 5%.

Research and monitoring

The stock assessment model used for South Coast rock lobster (an age-structured production model [ASPM]) is based, *inter*

alia, on size and age composition of the catch, somatic growth rates, and population size estimates. A tagging programme supplies the critical growth and population size estimates, as well as estimates of migration.

Scientific observers are deployed aboard commercial South Coast rock lobster fishing vessels. These observers primarily collect data relating to catch composition, take biological measurements (length, sex and reproductive state), estimate catch and effort, report on gear used, observe fishing practices such as discarding, dumping and bycatch, and also record the areas where fishing takes place. The data are utilised in the annual stock assessment used to determine the TAC. Observers also tag lobsters during commercial fishing operations, and information from recaptured tagged lobsters is returned by commercial fishers, with details of the date and location of recapture. Tagging covers as wide an area and range of size classes as possible.

Commercial CPUE data are captured from landing slips. These provide input data (CPUE and landings) for TAC and TAE management.

New research planned for this resource aims to use baited "video fishing" techniques to offer a standardised, non-extractive methodology for estimating relative abundance and observing the behaviour of South Coast rock lobster. Precise and accurate length and biomass estimates will also be recorded by paired stereo-cameras. The baited underwater video camera traps will be used to monitor the effect that bycatch species have on catch rates, the fate of bait and other bycatch and discards, and to help measure metabolic rates, swimming speed and foraging behaviour of South Coast rock lobsters.

The feasibility of introducing a fisheries independent survey to track status indicators for this resource is being investigated.

The effect of benthic environmental factors on daily catches of South Coast rock lobster have not been investigated to date. However, new research is directed at elucidating these relationships.

Current status

In 1977–1979/80, fishing effort and catches increased above sustainable levels (Figures 61 and 62), and thereafter the catches declined rapidly to 122 tonnes tail mass (Figure 61). The decline in catches was partly as a result of the withdrawal of the foreign vessels from South African waters in 1976, and also overfishing. By the end of the 1970s, several of the remaining local fishing vessels were forced out of the fishery by low catch rates. Gradual recoveries of catches between 1980 and 1984 and stable catch rates during that time were accompanied by a resurgence of interest in the fishery by fishers who had previously withdrawn. In response to the possibility of overfishing, a TAC was introduced into the fishery in 1984, and quotas were allocated to companies that were active in the fishery. This measure effectively limited the number of participants in the fishery.

The TAC restricted total catches to 450 t tail mass (970 tonnes whole mass) per year (Table 16); fluctuations in the TAC up to 1994 included the addition of 2 t (tail mass) for research purposes in the 1988/89 fishing season, and the addition of 25 t in 1990/91. The latter increase was justified by the inclusion of a previously unfished area off the Eastern Cape coast after 1990. The TAC remained stable at 477 t up to the 1993/94 fishing season.

Resource assessments introduced in 1993–1994 indicated that an annual catch of 477 t could not be sustained. Consequently, a programme of annual TAC reductions was initiated in 1994–1995, reducing the TAC in steps of 25 t per year. The 2001 assessment of the resource indicated that the reductions had, however, failed to impact significantly on the trend of declining abundance.

The exploitable biomass is currently around 30% – and spawner biomass is around 29% – of pre-fished levels.

Ecosystem interactions

There are no major ecosystem issues that require urgent attention in this fishery at present. However, the spatial and temporal distribution of berried females should be investigated to allay concerns regarding the vulnerability of these females under current fishing practices.

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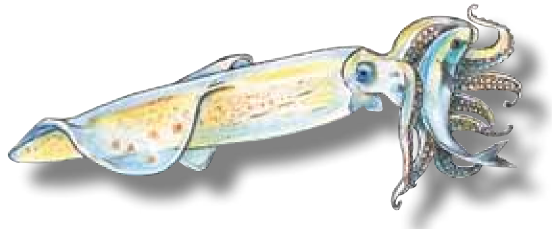
Squid



Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

The Cape Hope squid *Loligo reynaudii*, locally known as 'chokka', is an ubiquitous loligonid squid that occurs around the southern African coast from Namibia to the Wild Coast off the Eastern Cape (Figure 63). It is fast-growing, reaching reproductive size in approximately one year or less and its total lifespan is less than two years. Maximum observed mantle lengths are 48 cm for males and 28 cm for females. Spawning occurs throughout the year with a peak in summer, and its distribution is governed largely by environmental conditions. Spawning occurs on the seabed, mostly in inshore areas of less than 60 m depth, and occasionally in deeper waters. Their chief prey items are fish and crustaceans, but they also sometimes feed on other cephalopods, and cannibalism is fairly frequent. The abundance of squid fluctuates widely, mainly due to bio-

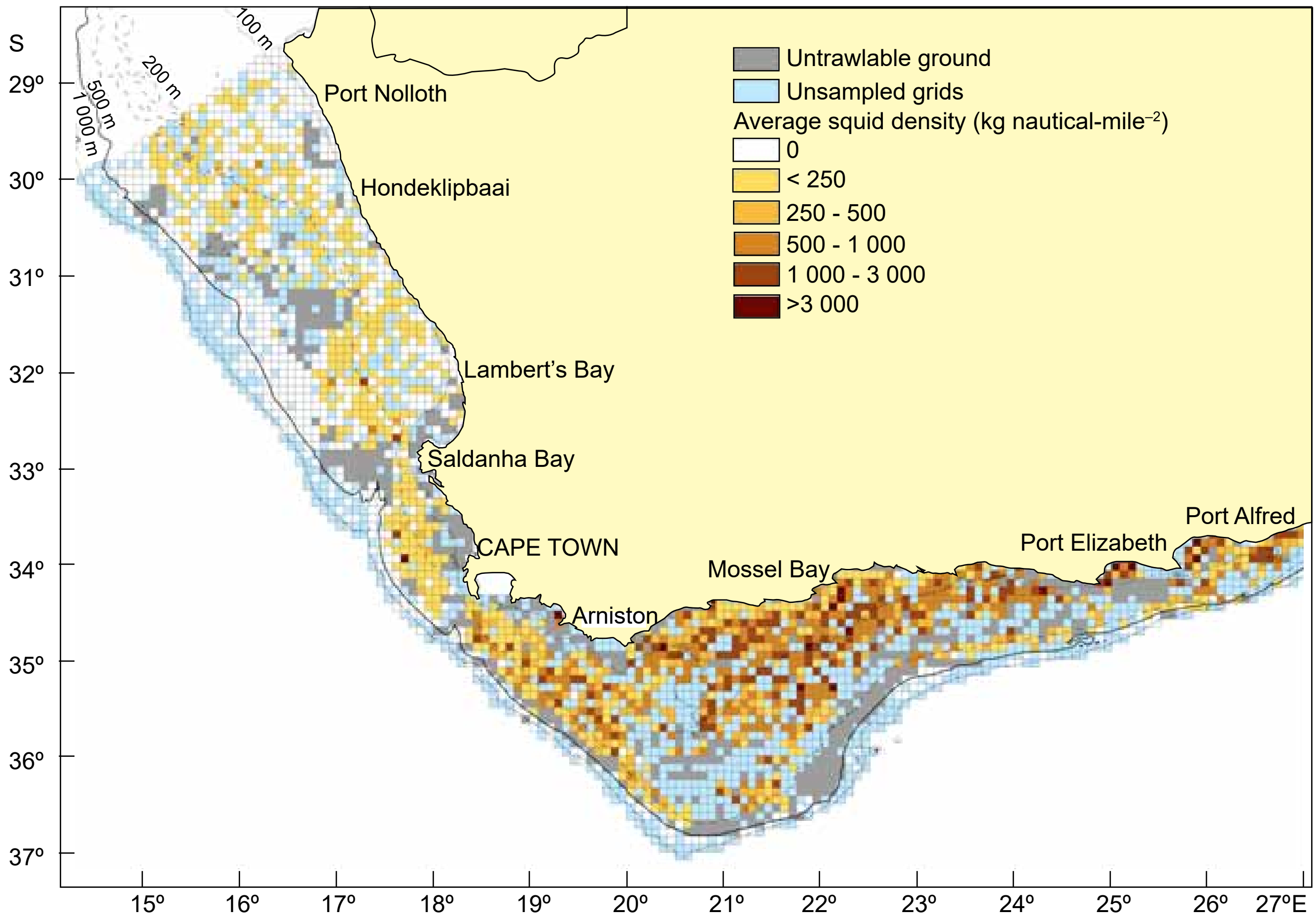


Figure 63: Distribution of chokka squid *Loligo reynaudii* in South African waters, as derived from fishery-independent demersal research surveys. Densities (kg nautical-mile^{-2}) are averages over all survey stations within each survey grid block over the period 1985–2017 (note there was no survey in 2018)

logical factors such as spawning distribution and survival rates of hatchlings and juveniles, and environmental factors such as temperature, currents, turbidity and macro-scale events such as *El Niños*.

Chokka squid is the target of a dedicated commercial jig fishery that operates between the Cape of Good Hope and Port Alfred. The squid fishery is fairly stable and provides employment for approximately 3 000 people locally. The fishery is believed to generate in excess of R480 million in a good year and is South Africa's third largest fishery in monetary terms. Chokka are mostly frozen at sea in small blocks. They are landed mainly between Plettenberg Bay and Port Alfred and exported whole to European countries, most notably Italy. Squid are also used as bait by linefishers. Apart from the directed fishery, squid are also caught as bycatch in the hake-directed demersal trawl fishery.

History and management

In the 1960s and 1970s the squid resource was heavily exploited by foreign fleets, predominantly from the Far East. Foreign fishing activity was gradually phased out in the late 1970s and early 1980s following South Africa's declaration of an exclusive fishing zone (EFZ) in 1977. Since then, squid and other cephalopods have continued to be caught by South African trawlers as bycatch. Over the last decade, the squid bycatch in the demersal trawl fishery has fluctuated between 200 and 800 t annually (Figure 64).

A commercial jig fishery for squid was formally established in 1984. Hand-held jigs are used to catch squid, making this a particularly labour-intensive fishery. Between 1986 and 1988 a licensing system was introduced with a view to limiting the number of boats participating in the fishery. Catches in the 1990s ranged between 1 900 and 7 400 t, and in the 2000s between 2 600 and 13 900 t. In 2004 the jig fishery registered its highest catch of just below 14 000 t (Figure 64). Catch data indicate an increase in jig catches over the period 2001 to 2004, followed by catches stabilising at approximately 9 000 t between 2005 and 2008, and then increasing again to just over 10 000 t in 2009 and 2010 (Figure 64). Annual catches in both the jig and trawl fisheries declined after 2010, reaching a level in 2013 that was almost the lowest since the inception of the commercial jig fishery. It is encouraging to note that this declining trend subsequently reversed, increasing to over 13 000 t in 2018.

The fishery is effort-controlled and was historically capped at a maximum of 2 422 crew, with the number of vessels commensurate with the number of persons permitted to fish. The current recommended total allowable effort (TAE) is 295 000 person-days. A mandatory five-week closed season (October—November each year) has been implemented since 1988, with the intention of minimising the disturbance to spawning squid and improving recruitment the following year. Furthermore, an additional closed season (in the range of three to five months duration) has been implemented since 2014 to guard against the TAE being exceeded.

The current management objective for the squid fishery is to cap effort at a level which secures the greatest catch, on average, in the longer term without exposing the resource to the threat of reduction to levels at which future recruitment success might be impaired or catch rates drop below economically viable levels.

Research and monitoring

Biomass estimates of chokka squid (as well as accompanying size structure and biological information) are derived from data collected on demersal swept-area research surveys conducted on the West Coast in summer each year and on the South Coast in autumn each year (and also in spring in some years). Interpretation of the trends in the time-series of abundance estimates (Figure 65) is complicated by the changes in the gear and vessels employed during the surveys (see the section on Cape hakes for details). The data obtained from surveys conducted with different gear and vessels are not directly comparable, and any apparent trends in the time-series should be viewed with caution pending the development of reliable calibration factors for the various vessel-gear combina-

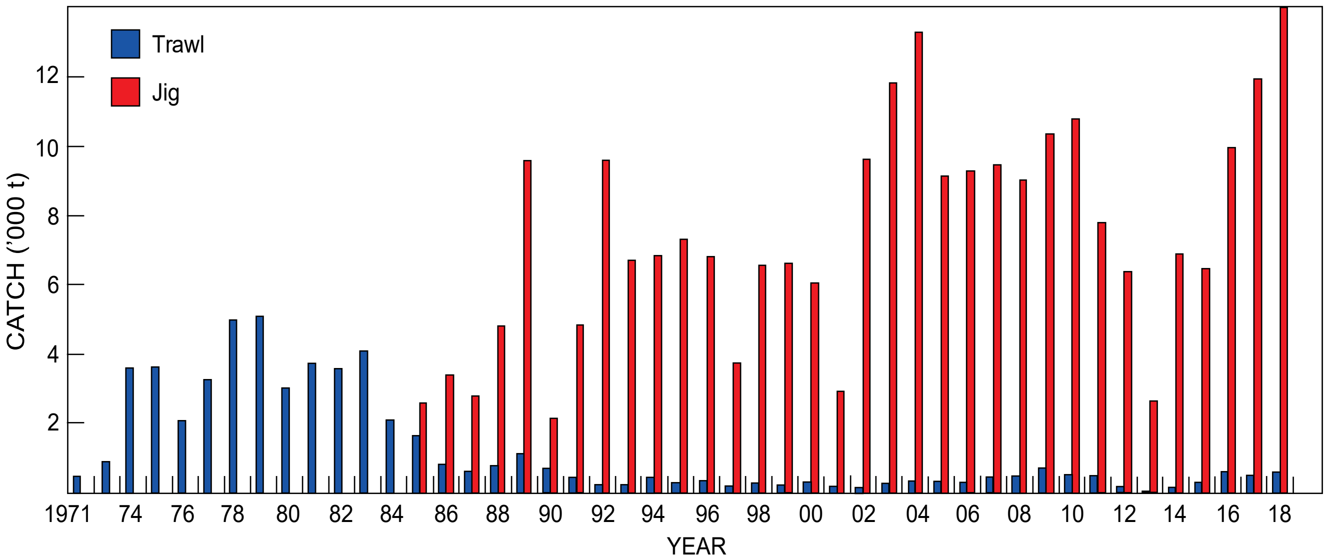


Figure 64: Annual catch (trawl- and jig-caught) squid off South Africa, 1971-2018. Trawl data are from external sources 1971–1982, and from the DEFF demersal database 1983–2018. Commercial jig catch data are from the South African Bureau of Standards (SABS) as provided by Industry for the period 1985-2006, and the National Regulator for Compulsory Standards (NRCS) for the period 2007-2018

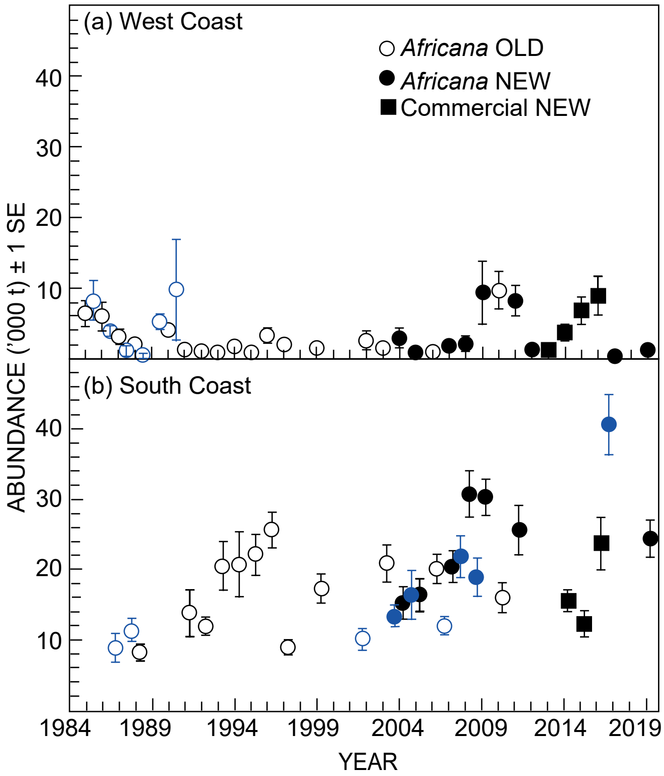


Figure 65: Chokka squid abundance estimates (tonnes ± 1 SE) derived from fishery-independent swept area demersal surveys. Estimates are illustrated by coast for the various vessel-gear combinations. Summer (West Coast) and Autumn (South Coast) surveys are indicated with black symbols, while Winter (West Coast) and Spring (South Coast) surveys are indicated with blue symbols. Note that surveys that only extended to the 200 m isobath have been excluded from the figures and that estimates across the vessel-gear combinations cannot be directly compared due to differences in catchability

tions. Although data from both the autumn and spring surveys are used in assessments of the resource, the spring surveys provide the most useful indication of spawning stock abundance, given that these surveys are conducted just prior to peak spawning season.

Catch and effort data are collected on a regular basis from the commercial jig fishery and additional landings data are available from the National Regulator for Compulsory Specifications (NRCS) - formerly the South African Bureau of Standards (SABS) (Figure 64). In the past, squid data were recorded along with catches of linefish, and stored in the National Marine Linefish System. In 2006, a new logbook was introduced specifically for the squid fishery, allowing for the recording of more-detailed catch-and-effort information, and the data are now stored in a dedicated database.

Chokka squid is one of the best-researched squid species in the world and aspects of its early life history and adult ecology are relatively well known. However, capacity constraints within the Department have slowed research efforts considerably. Current research is conducted on the age and growth of squid, possible changes in biological characteristics of squid over time, genetics of adults (stock identity), environmental influences on stocks, acoustic mapping of inshore spawning grounds,

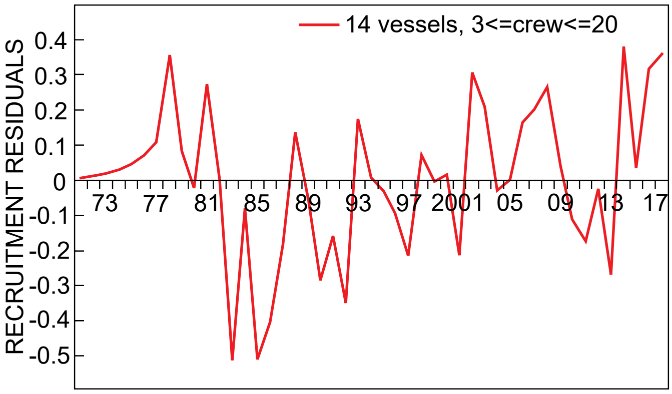


Figure 66: Recruitment residuals from 1971–2017. (NB derived from 14 vessels and restricted to records where 3<=crew<=26)

use of acoustics as a method of surveying squid egg beds, and investigating the potential damage of different anchor systems on squid spawning grounds and squid egg beds. Following the marked decline of the squid resource in 2013, an initiative was launched that was entitled Sustainable Oceans, Livelihoods and food Security Through Increased Capacity in Ecosystem research in the Western Indian Ocean (SOLSTICE-WIO). SOLSTICE is a four-year collaborative Global Challenge Research Fund project that seeks to address key environmental and anthropogenic factors controlling the ecosystem dynamics of the Agulhas Bank. Results from the study are expected to provide some indication of the reasons for the 2013 decline and are to be published in the special edition of a reputable scientific journal. The special edition will be published in October of 2021 and information therein should assist in enhancing the management of this resource.

In 2013, exploratory fisheries for a number of other squid species were initiated, although they are yet to be fully implemented. The species include three ommastrephids (*Todarodes angolensis*, *Todaropsis eblanae* and *Ommastrephes bartramii*), one loligonid (*Uroteuthis duvauceli*) and one thysanoteuthid (*Thysanoteuthis rhombus*).

Current status

A biomass-based stock assessment model is applied to assess the status of the squid resource. The most recent assessment was conducted in 2019 and indicated a more positive outlook of resource status than did the 2016 assessment. As a result, the Department's Squid Scientific Working Group recommended that the TAE could be increased from 270 000 person-days to 295 000 person-days for the 2019 fishing season. Above-average recruitment had been observed over the period 2002–2009, but then declined to below-average levels over the period 2010–2013, before showing an improvement in 2014 (Figure 66). The assessment indicated a period of declining abundance over the period 2009–2014, since then biomass has shown an increasing trend (Figure 67), and the stock was estimated to be at about 41% of pre-exploitation levels in 2015. The 2010–2013 decline in recruitment may be related to possible environmental anomalies over the 2012–2014 period, given that other species on the South Coast showed similar declines in catch rates during this period.

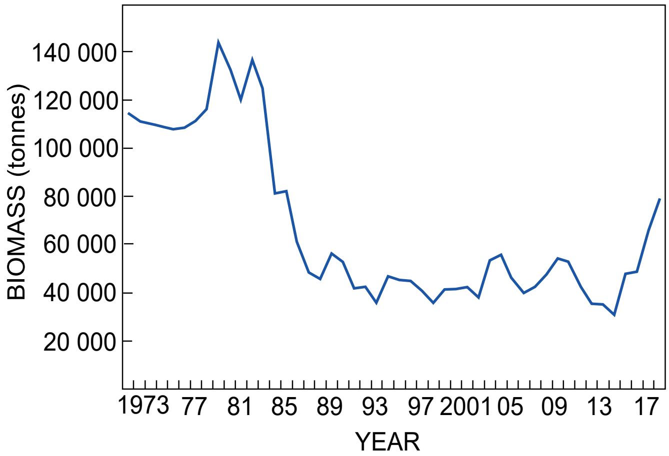


Figure 67: Estimated begin-year biomass in tonnes from 1971 to 2018. (NB derived from 14 vessels and restricted to records where 3<=crew<=26)

Ecosystem interactions

The South African chokka squid fishery employs hand-held jigs, mainly targeting aggregations of spawning adult squid. This method selectively targets the desired species. There is little to no bycatch in this fishery and jigs have little impact on the environment. Some damage to the seabed and squid eggs may occur during deployment, adjustment and retrieval of anchors. A study to evaluate the impact of different anchoring systems on squid eggs and the seabed is currently being planned. Chokka squid is currently listed as green (most sustainable choice from the healthiest and most well-managed fish populations) under WWF's SASSI (South African Sustainable Seafood Initiative) assessment.

Further reading

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Useful statistics

Total squid catches from commercial jig and as bycatch from trawl, as well as squid total allowable effort (TAE) (2003–2019). Note that trawl bycatch data differ from those previously reported due to ongoing validation and correction of historical data

Year	Squid jig catches	Squid landings as bycatch from hake trawl	Squid TAE
2003	11 820	340	2 423 unrestricted crew* 41 restricted crew*
2004	13 261	391	2 423 unrestricted crew* 41 restirted crew*
2005	9 147	373	2 423 unrestricted crew* 22 resricted crew*
2006	9 291	358	2 423 crew or 138 vessels, whichever occurred first
2007	9 438	496	2 422 crew or 136 vessels, whichever occurred first
2008	9 021	528	2 422 crew or 136 vessels, whichever occurred first
2009	10 341	759	2 422 crew or 136 vessels, whichever occurred first
2010	10 777	574	2 422 crew or 136 vessels, whichever occurred first
2011	7 796	460	2 422 crew or 136 vessels, whichever occurred first
2012	6 392	227	2 422 crew or 136 vessels, whichever occurred first
2013	2 664	61	2 422 crew or 136 vessels whichever occurred first
2014	6 907	213	TAE or 250 000 person days
2015	6 479	333	TAE of 250 000 person days
2016	9 952	642	TAE of 250 000 person days
2017	11 919	558	TAE of 270 000 person days
2018	13 444	630	TAE of 270 000 person days
2019	6 689		TAE of 295 000 person days

*NB Unrestricted permits applied to Right Holders who were not restricted to fishing in any particular area, whereas restricted permits applied to Right Holders who were only allowed to fish off the former Ciskei (in the Eastern Cape Province). Restricted permits were eventually phased out of the fishery from 2006

Tunas and swordfish

Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
			Albacore (Ind. and Atl.) Yellowfin (Atl.) Bigeye (Ind.) Swordfish (Ind.)	Yellowfin (Atl.)	Southern bluefin (Ind. and Atl.) Yellowfin (Ind.) Bigeye (Atl.)
Fishing pressure	**Unknown**	**Light**	**Optimal**	**Heavy**	
			Albacore (Ind. and Atl.) Yellowfin (Atl.) Swordfish (Ind. and Atl.) Southern bluefin (Ind. and Atl.)	Yellowfin (Ind. and Atl.) Bigeye (Atl.) Bigeye (Ind.)	

Introduction

Large pelagic fish resources in the waters around South Africa comprise a number of tuna species exploitable in quantities suitable for commercial operations. The common commercial species include albacore *Thunnus alalunga*, yellowfin *Thunnus albacares*, bigeye *Thunnus obesus* and southern bluefin *Thunnus maccoyii* tunas, and swordfish *Xiphias gladius*. In addition, blue *Prionace glauca* and shortfin mako *Isurus oxyrinchus* sharks are abundant in South African waters. All these species are highly migratory and their distributions span across multiple exclusive economic zones (EEZs) as well as the high seas of all oceans, except southern bluefin tuna, which is confined to the southern hemisphere.

Given their wide-ranging distribution, fisheries for large pelagic fish and their management are international, and participation is regulated through the tuna Regional Fisheries Management Organizations (RFMOs). For management purposes, a single southern bluefin tuna stock, straddling all oceans, is considered. Single stocks of yellowfin tuna and bigeye tuna are also assumed for the entire Atlantic Ocean, and likewise the Indian Ocean is considered to have one stock each of yellowfin, bigeye and albacore tuna. Two different stocks, i.e. a North stock and a South stock, separated at 5° N, are recognised in the Atlantic Ocean for albacore tuna, swordfish, and blue and shortfin mako shark. A management boundary separates the Indian and Atlantic oceans at 20° E, though there is concern over its bio-geographical validity for tuna and the extent to which tuna, billfishes and pelagic shark populations straddle this boundary.

South Africa has two commercial fishing sectors that target tuna and tuna-like species in the Atlantic and Indian oceans. These sectors are the tuna pole-line (TPL) or ‘baitboat’ and the large pelagic longline (LPL) fisheries. Additionally, the boat-based commercial linefishery catches tuna opportunistically and the boat-based recreational anglers undertake game fishing for tuna and sailfishes. TPL fishing, from three main centres, i.e. Richards Bay, Port Elizabeth and Cape Town, takes place throughout the entire EEZ and beyond. Albacore tuna is predominantly caught on pole and is traditionally the main target species of the South African TPL fleet, which operates in waters up to 1 000 km off the South and West coasts of South Africa and off Namibia, from October to May. When available in the inshore regions, yellowfin tuna, predominantly caught with rod and reel, is the second-most important species targeted by this sector. The TPL fishery also catches bigeye tuna, southern bluefin tuna and skipjack in smaller volumes. The use of two gears in this fishery – pole to catch albacore and rod and reel to catch yellowfin tuna – was recognised and incorporated into the naming of this fishery as the TPL fishery. This fishery may not retain any incidentally caught swordfish, billfishes or sharks. Southern bluefin tuna, bigeye tuna, yellowfin tuna and swordfish are the main targeted species in the LPL fishery, with albacore tuna, blue sharks and shortfin mako sharks being

the main bycatch species. This fishery also catches a number of other pelagic and epipelagic species, including billfishes and pelagic shark species, in smaller quantities.

History and management

Large pelagic longline fishing for tuna dates back to the early 1960s, when South African longline vessels targeted southern bluefin tuna and albacore off the Western Cape coast. Poor market conditions, however, led to a rapid decline in this fishery during the mid-1960s. Foreign vessels, mainly from Japan and Taiwan, continued to fish in South African waters from the 1970s until 2002 under a series of bilateral agreements. Thirty experimental LPL permits were issued to South Africans in 1997 in an attempt to revive the local tuna fishery. Catches were, however, dominated by swordfish during this experimental phase.

The South African LPL fishery was formalised in 2005, with the issuing of 18 swordfish-directed and 26 tuna-directed fishing Rights valid for a period of 10 years. At the same time, nine vessels were exempted, in terms of section 81 of the Marine Living Resources Act (MLRA; Act No. 18 of 1998), to exclusively fish for pelagic sharks until March 2011. During a mini Rights allocation process in 2011, this pelagic shark fishery was incorporated into the tuna/swordfish longline fishery. In 2015, a decision was taken to no longer refer to the fleet as having two different fishing strategies, tuna-directed and swordfish-directed, since the fishing behaviour of the local fleet had been shifting from exclusive swordfish targeting to including tunas and sharks. Since then the fishery has been referred to as the large pelagic longline fishery and includes vessels that target tunas and swordfish and take sharks as bycatch. South Africa allocated 60 new fishing Rights in this fishery in 2017, for a period of 15 years. Although the fishing grounds just outside South Africa's EEZ are hotspots for international longline fishing fleets, the current South African LPL fleet remains under-capitalised. The primary target species are southern bluefin tuna, yellowfin tuna, bigeye tuna and swordfish. This fishery may no longer target sharks, a practice further discouraged in 2017 with the banning of the use of wire traces. Until very recently, however, a small component of the fleet continued to target sharks, with blue and shortfin mako sharks accounting for more than 95% of the total landings of some vessels. To restrict directed fishing of sharks further, the proportion of sharks in the catch of each vessel has been limited to a maximum of 60% per quarter and less than 50% per annum since 2019.

The South African TPL fishery started in the late 1970s and initially targeted yellowfin tuna, but switched back to its traditional albacore target species when yellowfin moved out of Cape waters in 1980. Since then, albacore has made up the bulk of the catch, with annual catches varying between 2 000 and 4 000 t in recent years. South Africa's TPL fishery is one of four major fisheries in the South Atlantic that contribute to the region's albacore catches; the remaining three fisheries that target albacore include Namibia's bait-boat fleet and the longline fleets of Brazil and Chinese Taipei. Although tuna generally occur in mixed-species shoals, bigeye tuna and skipjack tuna are typically caught only in low volumes. During occasional "good years", higher-value yellowfin tuna becomes available to the fishery, with catches in the order of 1 000 t substantially increasing the profit margin of this fishery.

Initially managed under the linefishery, the TPL fishery has been recognised as a separate sector since 2003. In 2005, the Department allocated 191 commercial TPL fishing Rights, thereby authorising 198 vessels (greater than 10 m in length) and more than 2 600 crew to target tuna using the pole method, for a period of 10 years. On average, 130 vessels were active over the period 2005–2013. During the 2013 fishing Rights allocation process (FRAP 2013), 163 fishing Rights and 165 vessels gained access. The long-term Rights have again been allocated for a period of 10 years and a new Rights allocation process (FRAP 2020/21) has commenced for re-allocation in 2021. Due to the seasonality of the TPL fishery, fishers also have access to snoek *Thyrsites atun* and yellowtail *Seriola lalandi*. However, the traditional linefish sector also relies on these species for the majority of their catch. An assessment of yellowtail conducted in 2017 suggests that the stock is currently not being subjected to overfishing, but trajectories indicate rapid stock declines can be expected if annual catches exceed 650 t. Consequently, TPL access to yellowtail is currently managed by means of a bag limit of 10 fish per person per trip.

Three RFMOs manage South Africa's large pelagic fish resources; i.e. (i) the International Commission for the Conservation of Atlantic Tunas (ICCAT), (ii) the Indian Ocean Tuna Commission (IOTC), and (iii) the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). The CCSBT has the sole mandate for the management of southern bluefin tuna. South Africa is obliged to adhere to the Conservation and Management Measures (CMMs) of the RFMOs to ensure sustainability of stocks. Providing RFMOs with accurate and complete data is extremely important for regional stock assessments conducted by the RFMOs. These assessments ultimately inform total allowable effort (TAE) and total allowable catch (TAC) allocations. The permit conditions relating to bycatch of pelagic sharks, seabirds, turtles and marine mammals must satisfy international best practices and require strict enforcement. It is essential for South Africa to demonstrate that it is actively implementing all requirements necessary to reduce ecosystem effects of the fishery on threatened and endangered species. With the exception of southern bluefin tuna, managed by the CCSBT, all catches of tuna and tuna-like species to the west of 20° E fall under ICCAT whereas catches to the east of 20° E fall under the IOTC. This leads to the peculiar situation where, for example, yellowfin tuna caught in the Atlantic is considered optimally exploited, but overfished just a few kilometres further to the east. TAC quotas are allocated by ICCAT to South Africa for albacore (4 400 t) and swordfish (1 001 t) in the Atlantic. Currently, however, South Africa is far from attaining any of these quotas. The IOTC does not yet manage the Indian Ocean stocks by way of TAC quota allocations. Instead, South Africa has an effort limitation (TAE) of 50 vessels above 24 m ("length overall", LOA) in the IOTC's Area of Competence. South Africa became a full member of the CCSBT in February 2015. This resulted in a sequentially increased TAC of southern bluefin tuna quota for South Africa from a mere 40 t to 160 t in 2016 and to 450 t for 2017–2020. The opportunity to catch larger quantities of this extremely valuable tuna, combined with the current under-utilisation of quotas for other important target species, emphasises the substantial development potential of South Africa's large pelagic fisheries sector, as perhaps the most promising in terms of landed value.

Research and monitoring

Fisheries and observer data

Being a full member of the three RFMOs obligates South Africa to submit a wide range of fisheries statistics and reports to ICCAT, IOTC and CCSBT annually. The two key sources of mandatory information are catch statistics in the form of logbooks from the LPL and TPL sectors, and the LPL observer data. Information submitted to the regional management bodies include: number and estimated capture (round and dressed weight for each species) of all fish caught (from logbooks of Right Holders for both sectors); the geographical coordinates (1°×1° fishing blocks); gear used; and bait used (live bait, fresh or frozen). Scale measurements of the landed (or factory) weight of fish caught has recently also been included, and these data will be used to report more accurate nominal weight in future. In addition, Right Holders in the LPL fishery have been required to complete daily logs of catches since 1997. The logbook records: the catch locations; number of hooks; time of setting and hauling; bait used; number and estimated weight of retained species; as well as data for bycatch (seabirds, turtles and sharks). Identification guides on tunas, common bycatch species, sharks, billfish, seabirds and turtles are issued to all active vessels to facilitate reporting.

Recognising the importance of the observer programme in ensuring that vessels comply with bycatch (sharks, seabirds and turtles) mitigation measures, as well as catch and size limits for target and bycatch species, South Africa has implemented an on-board observer programme for the LPL fishery since 1998. Although the government-funded programme came to an end in March 2011, industry-funded observer coverage has continued to comply with RFMO requirements. The foreign-flagged vessels, which fish under joint-venture charter agreements, are required to carry an observer for all of their trips. Observer coverage of local vessels has been included in the permit conditions and has been steadily increased. The observer effort for the LPL fishery had improved from just two observed trips in 2016 to 15 observed trips in 2017, which had resulted in an increase from 2% to 8.5% coverage of the longline effort in the Atlantic. In 2018, the number of observed trips was further increased to 24 trips, while the total observer coverage of hooks set remained similar to 2017 (8.4%) due to a higher proportion of trips covering smaller vessels that typically have fewer sea days. To improve the spatiotemporal observer coverage further, South Africa is aiming to increase its overall observer coverage to 20% per quarter. To achieve this, the current LPL permit conditions now require permit holders to carry one or more scientific observers on board their vessels on a minimum of one fishing trip per quarter to ensure monitoring of 20% of all fishing days in each quarter. Vessels that exceed a 60% shark bycatch limit per quarter will also have to carry an observer on board for the remainder of the fishing season.

The small size of the South African TPL bait-boat vessels (average 16 m LOA) precludes the accommodation of an on-board observer. As the majority of the vessels offload their catch at night, there is limited capacity within the permanent Departmental monitoring and compliance staff to monitor every discharge as required, limiting the collection of size frequencies and the verification of logbook information to a subset of the effort. The Department's shore-based observer programme that monitored vessel offloads in port ended in March 2011. Although the programme has not yet been re-established, specifications developed for the new programme include comprehensive monitoring of all the large pelagic fisheries operating around South Africa.

Abundance indices and stock assessment

Catch per unit effort (CPUE) indices are commonly used to track the abundance of large pelagic species in the absence of fisheries independent surveys, which are not possible for these wide-ranging species. Over the past four years, South Africa has made significant progress in developing models to standardise tuna pole and longline catch and effort data that account for targeting (as opposed to bycatch), individual vessel characteristics and spatial effects. For the ICCAT region, South African presented standardised CPUE indices for albacore and yellowfin tuna from the tuna pole fleet, as well as swordfish, shortfin mako and bigeye tuna from the longline fleet. For the IOTC region, standardised CPUE indices were provided for swordfish, based on domestic vessel catch and effort, and for the two tropical tuna species, bigeye and yellowfin tuna, based on catch and effort data from joint-venture vessels. The suitability of these standardised indices for use in stock assessments was extensively reviewed during a number of ICCAT and IOTC scientific meetings. As a result, the South African swordfish CPUE indices were included as key abundance indices in the assessment models for Atlantic and Indian Ocean swordfish and thus contributed to management advice by ICCAT and IOTC, respectively. The TPL albacore CPUE index

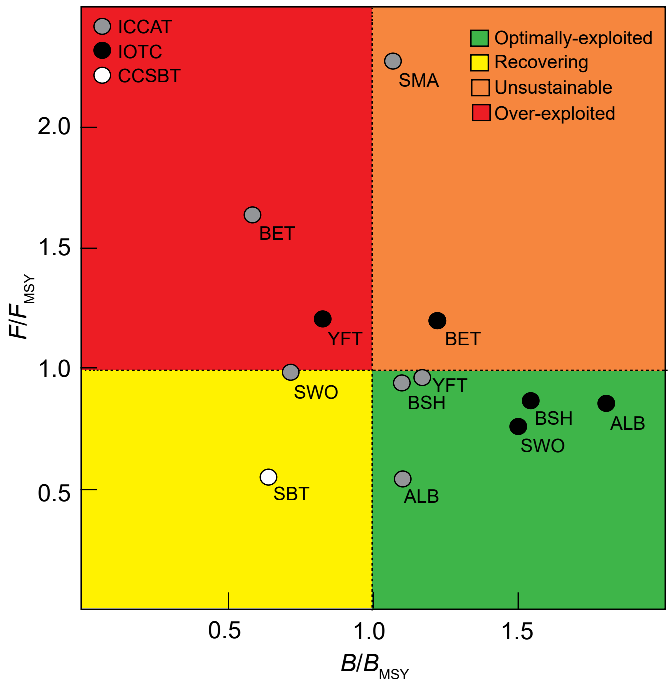

Figure 68: Kobe plot summarising the most-recent stock status estimates of fishing mortality relative to F_{MSY} and biomass relative to B_{MSY} for large pelagic species targeted by the South African longline and tuna pole-line fishery. Only results from formal stock assessments conducted by ICCAT (Atlantic), IOTC (Indian Ocean) or CCSBT (Southern Ocean) are included. ALB: Albacore; YFT: yellowfin tuna; BET: bigeye tuna; SBT: southern bluefin tuna; SWO: swordfish; BSH: blue shark; SMA: shortfin mako shark. Note that "Biomass" (B) in the plot can reflect exploitable biomass, spawning biomass, total reproductive output or pupping stock fecundity, depending on the type of model used to estimate stock status

was also considered and included as input for the 2020 South Atlantic albacore assessment. Yellowfin tuna and bigeye tuna CPUE indices were, however, not deemed suitable as direct stock assessment inputs given their small spatial representation of the catch area. Similarly, the shortfin mako CPUE index should currently not be included in stock assessment models because the majority of available catch and effort records occur in an area straddling the ICCAT/IOTC 20° E boundary, a known juvenile aggregation area, and because regional assignment of this boundary stock is very uncertain. South Africa intends to improve the standardisation of CPUE indices of both the tuna pole fleet and the tuna/swordfish longline fleet further for contribution to future stock assessment sessions of tunas, swordfish and sharks.

South Africa has been actively participating in the regional stock assessments of several large pelagic species since 2017. South African government scientists have been leading the development and implementation of the open-source modelling framework JABBA (Just Another Bayesian Biomass Assessment). JABBA has been widely applied in stock assessments of highly migratory species (sharks, tuna, and billfishes) around the world, including: the 2017 North and South Atlantic shortfin mako shark assessments; the 2017 ICCAT South Atlantic swordfish assessment; the 2018 ICCAT blue marlin assessment; the 2018 ICCAT bigeye tuna assessment; the 2019 white marlin assessment; and the 2019 yellowfin tuna assessment. JABBA is published as a peer-reviewed open-access publication and distributed through the global open-source platform GitHub where it is accessible at https://github.com/JABBAmodel for free. In 2019, the ICCAT Secretariat presented materials to the Working Group of Stock Assessment Methods (WGSAM) for the inclusion of JABBA into the ICCAT stock assessment software catalogue. This included comprehensive documentation, source codes, user manuals, vignettes, and references. After review, the WGSAM agreed unanimously to include JABBA in the ICCAT software catalogue (https://github.com/ICCAT/software/wiki/2.8-JABBA).

Bycatch and its mitigation

Scientists from the Department, together with other national scientists from countries operating pelagic fleets south of 25° S, participated in the First Regional Bycatch Pre-assessment Workshop held in early 2017. This workshop was part of a collaborative process to bring national scientists together, and where appropriate and requested, to help build capacity of national scientists to undertake a global bycatch analysis. In 2018, scientists from DEFF and NOAA (US National Oceanic and Atmospheric Administration) participated in the Seabird Bycatch Small Working Group Meeting hosted by BirdLife SA under the Common Oceans project to explore alternative techniques for estimating bird encounters and overall captures from observer and effort data. In February 2019, South Africa participated in the final workshop of the Common Ocean Seabird Bycatch Project, hosted by BirdLife South Africa. Delegates collaborated by sharing observer data on seabird bycatch and applied spatial models, including the Spatially Explicit Fisheries Risk Assessment (SEFRA), to estimate seabird bycatch of pelagic longline fisheries operating south of 25° S. Delegates from CCSBT member states, including South Africa, Japan, New Zealand, South Korea and Australia, continued to collaborate on a follow-up analysis using the SEFRA model to improve total seabird bycatch estimates and risk characterisation at the species level. The Department's scientists were also part of a multi-national group from Atlantic coastal states, including Brazil, Uruguay, South Africa and Portugal, that investigated the effect of seabird bycatch mitigation from analyses of the largest multinational observer dataset. The Department also reviewed the National Plan of Action for Sharks (NPOA-Sharks) in 2018 and presented its findings to the IOTC Working Party for Ecosystems and Bycatch. These inputs are being considered in the current revision of the NPOA. Finally, the Department's scientists participated in a multi-national research project to assess the extent of turtle-bycatch by longline fisheries in the Atlantic. Results are expected in mid-2020.

Current status

Stock assessments and country allocations for the Atlantic and Indian Ocean stocks of tuna and tuna-like species are the responsibility of ICCAT and the IOTC, whereas CCSBT conducts the stock assessments for southern bluefin tuna. South Africa contributes abundance indices (standardised CPUE) (Figure 68, Appendix 1) a as critical inputs for the stock assessments of South Atlantic albacore and South Atlantic and Indian Ocean swordfish. As mentioned above, South Africa has been actively participating in the stock assessments of several species since 2017, following the rapid uptake of the South African stock assessment software JABBA by ICCAT and IOTC.

Yellowfin tuna

The most recent stock assessment for yellowfin tuna, conducted by ICCAT in 2019, indicated that the spawning stock biomass (SB) of yellowfin tuna in the Atlantic Ocean was just above that which would produce a maximum sustainable yield (MSY) and estimates suggested that maintaining catch levels at the current TAC of 110 000 t were sustainable. However, the 2018 catch was estimated to be four times higher at 423 815 t and at these catch levels the stock will be driven into an overfished state. Increased harvests on smaller yellowfin tuna have negative consequences for the long-term sustainability of the stock. A stock assessment carried out in 2018 for yellowfin tuna in the IOTC area of competence estimated the spawning stock biomass in 2017 to be 30.0% of the unfished levels (see Useful Statistics). In terms of this assessment, the spawning stock biomass in 2017 was below the level that would produce MSY (SB_{2017}/SB_{MSY} = 0.83; 95% CI [0.74–0.97]) and the fishing mortality was 20% higher than that required to reach MSY (F_{2017}/F_{MSY} at 1.20; 95% CI [1.00–1.71]). Caution is required, however, in the interpretation of this assessment outcome because it does not fully account for uncertainty in the spatial representation of the CPUE data, estimated catch data, length frequency information and bias in tagging information. A new stock assessment was therefore carried out in 2019, but due to the complexity of the work, lack of agreement on key model aspects and time constraints during the meeting, new management advice has not yet been provided. As a result, the 2018 assessment continues to be the basis for stock status determination and further detailed management advice remains outstanding. On the weight-of-evidence available, based on data up to 2017, the yellowfin tuna stock is determined to be overfished and subjected to overfishing.

Albacore

ICCAT conducted a full southern Atlantic albacore stock assessment in 2016, using a broad range of methods and including data up to 2015. The majority of assessment model scenarios suggested that the stock is neither overfished nor subjected to overfishing. Projections at a level consistent with the 2016 TAC (24 000 t) showed that the probability of this stock being in the green quadrant of the Kobe plot (spawning stock biomass is above SB_{MSY} and fishing mortality is below F_{MSY}) by 2020 is 63%. A new assessment for this stock is scheduled for 2020. In the Indian Ocean, the albacore stock is most likely not overfished and overfishing is not occurring, according to results of the most recent 2016 stock assessment. However, a high degree of uncertainty exists about the total catch that this stock can sustain.

Swordfish

Swordfish stock assessments conducted by ICCAT in 2017, from two separate models, produced consistent results indicating that the South Atlantic swordfish stock is overfished and that overfishing is occurring or that fishing mortality is close to the maximum fishing mortality that the stock can withstand. A TAC of 14 000 t was set in 2018. The most recent stock assessment conducted by IOTC in 2017 determined that this swordfish stock was not overfished nor subject to overfishing. It was noted, however, that the most recent catches are much higher than can be sustained by the stock.

Bigeye tuna

In the Atlantic Ocean, the bigeye tuna stock has been exploited by three major gear-types (longline, bait boat and industrial purse-seine fisheries) and by many countries throughout its distributional range. Catches peaked in 1994 at about 135 000 t but have since been gradually declining. In 2001 the catch fell below 100 000 t and the catch for 2014 is estimated at 72 585 t. In the period 2010–2014, landings of bigeye tuna caught by longline fleets represented 48%, those caught by purse-seine fleets represented 37%, and those caught by bait-boat fleets represented 15% of the total catch by weight on average. The 2018 Atlantic bigeye tuna stock assessment results provided coherent evidence, with a 99% probability, that the stock is overfished and that overfishing is occurring. Reported catches far exceed the TAC and projections from the different assessment model scenarios indicate that, at current catch levels, the TAC of 65 000 t is unlikely to facilitate rebuilding. In 2019 a new stock assessment was carried out for bigeye tuna in the IOTC area to update the stock status previously determined in 2016. This estimated the 2018 spawning stock biomass to be 31% of the unfished levels and 22% (18–81%) higher than that required to achieve MSY. Based on the pessimistic outlook, South Africa led the negotiations during the 2019 ICCAT Commission and managed to get consensus on a wide range of measures to stop overfishing of bigeye tuna. These include a reduction of total catch and a reduction of effort related to fish aggregating devices (FADs), including a closed season for fishing on FADs and a restriction in FAD numbers.

Southern bluefin tuna

The most recent stock assessment of the southern bluefin stock was conducted in 2017 at the Extended Scientific Committee (ESC) of CCSBT. This stock assessment suggested that, although current spawning stock biomass is estimated at 13% of the unfished biomass, fishing mortality is sufficiently low to promote further rebuilding. The 2019 ESC meeting advised that the 2019-reconditioned operating models (for testing of candidate management procedures) suggest the spawning stock biomass in 2018 to be 17% of the initial biomass (15–21%). Based on the positive outlook, the recommended TAC for 2020 and the 2018–20 quota block remains set at 17 647 t.

Ecosystem considerations

The unique geographical position of South Africa's large pelagic fishing grounds, in proximity to large seabird breeding colonies in the Southern Ocean and at the boundary of two large marine ecosystems, gives rise to a rich and diverse megafauna and increased potential for fishery-related impacts on these. Interactions between fishing vessels and seabirds, turtles, sharks and mammals are common and not necessarily a reflection of fishing pressure, but rather a consequence of fishing taking place in a global pelagic biodiversity hotspot.

Extensive research and subsequent management advice have contributed to mitigating the bycatch of seabirds, turtles and marine mammals in the pelagic longline fishery. The most frequently caught seabird bycatch species, all of which are either Near Threatened, Vulnerable or Endangered, are the white-chinned petrel *Procellaria aequinoctialis* and albatrosses, the most common being the shy-type (mostly white-capped *Thalassarche steadi*, black-browed *T. melanophrys* and Indian yellow-nosed albatrosses *T. carteri*). Leatherback *Dermochelys coriacea* and loggerhead *Caretta caretta* turtles are the most common turtle species caught as bycatch.

South Africa is regarded as a global leader, amongst developing states, in bycatch mitigation for longline fisheries and has, in the last few years, consistently been among a handful of countries that are compliant with all bycatch-related conservation measures imposed by the three tuna RFMOs. South African longline observer coverage is amongst the highest of all longline fleets in the world and the resulting data are subsequently used to refine bycatch mitigation measures and to investigate their impact.

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Useful statistics

Table A: Total catch (t) and number of active domestic and foreign-flagged vessels for 2005 to 2018. Figures for sharks denote dressed weight.

Year	Bigeye tuna	Yellowfin tuna	Albacore	Southern bluefin tuna	Swordfish	Shortfin mako shark	Blue shark	Number of active vessels	
								Domestic(*)	Foreign-flagged
2005	1 077.2	1 603.0	188.6	27.1	408.1	700.1	224.6	13 (4)	12
2006	137.6	337.3	122.9	9.5	323.1	457.1	120.7	19 (4)	0
2007	676.7	1 086.0	220.2	48.2	445.2	594.3	258.5	22 (5)	12
2008	640.3	630.3	340.0	43.4	397.5	471.0	282.9	15 (4)	13
2009	765.0	1 096.0	309.1	30.0	377.5	511.3	285.9	19 (4)	9
2010	940.1	1 262.4	164.6	34.2	527.8	590.5	311.6	19 (5)	9
2011	906.8	1 181.7	338.7	48.6	584.4	645.2	541.6	16 (6)	15
2012	822.0	606.7	244.6	78.8	445.3	313.8	332.6	16	11
2013	881.8	1 090.7	291.1	50.9	471.0	481.5	349.0	15	9
2014	543.8	485.8	113.8	31.2	223.1	609.6	573.4	16	4
2015	391.7	551.4	153.0	36.6	307.0	768.2	523.7	22	4
2016	301.6	438.5	84.5	38.2	233.1	869.5	526.6	20	3
2017	452.8	374.4	172.7	98.6	194.2	750.6	558.0	22	3
2018	423.4	423.6	238.8	180.8	238.6	613.8	592.7	26	3

*Pelagic shark vessels, included in total

Table B: Total catch (t) and number of active vessels in the tuna pole-line sector for 2005 to 2018

Year	Albacore	Yellowfin tuna	Snoek	Yellowtail	Skipjack tuna	Bigeye tuna	Number of active vessels
2005	3 149.4	975.0	193.4	13.8	0.9	1.7	111
2006	2 526.6	978.9	118.0	1.4	0.0	1.0	116
2007	3 681.0	945.2	79.5	19.2	0.2	20.5	128
2008	2 189.9	347.8	313.7	13.0	3.6	22.9	109
2009	4 795.3	223.8	186.2	33.4	4.0	37.9	118
2010	4 272.8	177.2	476.8	41.2	1.6	12.6	108
2011	3 346.8	629.5	163.8	26.9	5.4	35.5	111
2012	3 619.6	165.6	180.1	27.5	8.0	13.2	119
2013	3 488.8	374.5	620.5	18.2	2.6	125.8	106
2014	3 526.4	1 308.2	266.9	11.1	4.6	43.3	94
2015	3 969.3	790.0	332.6	199.4	2.2	50.7	93
2016	2 029.7	543.0	219.3	12.0	1.6	9.3	99
2017	1 791.5	212.4	453.7	21.3	0.7	21.4	95
2018	2 498.5	232.9	774.6	10.0	1.5	20.2	94

APPENDIX 1a: Detailed status of large pelagic resources and allocations by RFMOs

	Albacore		Yellowfin tuna		Bigeye tuna		Swordfish		Southern bluefin tuna
	Atlantic Ocean	Indian Ocean	Atlantic Ocean	Indian Ocean	Atlantic Ocean	Indian Ocean	Atlantic Ocean	Indian Ocean	Atlantic and Indian Ocean
Stock Assessment	2016 (2020)	2016	2019	2018	2018	2019	2017	2017	2017
MSY	25 901 t (15 270–32 768)	38 800 t (33 900–43 600)	121 298 t (90 428–267 350)	403 000 t (339 000–436 000)	76 232 t (72 664–79 700)	87 000 t (75 000–108 000)	14 570 t (12 962–16 123)	31 590 (26 300–45 500)	-
Total yield for stock	13 677 t) (2016)	35 996 t (2016)	423 815 t (2018)	409 101 t (2017)	73 366 t (2018)	93 515 t (2018)	10 404 t (2018)	39 777 t (2016)	18 222 t (2018)
RFMO TAC	24 000 t	-	110 000 t	-	62 500 t	1.20 t (0.70-2.05) 1.22 t (0.82-1.81)	14 000 t	-	17 647 t (2018-2020)
Quota allocation to South Africa	4 400t (+1 100 t under age)	-	-	-	-		1 001 t	-	450 t
Relative biomass	B_{2015}/B_{MSY} = 1.10 (0.51 – 1.80)	SB_{2014}/SB_{MSY} = 1.80 (1.38–2.23)	B_{2018}/B_{MS} = 1.17 (0.75–1.62)	SB_{2017}/SB_{MSY} = 0.83 (0.74–0.97)	B_{2017}/B_{MSY} = 0.59 (0.42–0.80)	SB_{2018}/SB_{MSY} = 1.22 (0.82–1.82)	B_{2015}/B_{MSY} = 0.72 (0.53–1.01)	B_{2015}/B_{MSY} = 1.50 (1.05–2.45)	SB_{2018}/SB_{MSY} = 0.64 (0.47– 0.91)
Relative fishing mortality	F_{2014}/F_{MSY} = 0.54 (0.31–0.87)	F_{2014}/F_{MSY} = 0.85 (0.57–1.12)	F_{2018}/F_{MSY} = 0.96 (0.56–1.5)	F_{2017}/F_{MSY} = 1.20 (1.00–1.71)	F_{2017}/F_{MSY} = 1.63 (1.14–2.12)	F_{2018}/F_{MSY} = 1.20 (0.70–2.05)	F_{2015}/F_{MSY} = 0.98 (0.70–1.36)	F_{2015}/F_{MSY} = 0.76 (0.41–1.04)	F_{2018}/F_{MSY} = 0.55 (0.41–0.74)

APPENDIX 1b: Large pelagic shark species.

	Blue shark		Shortfin mako shark	
	Atlantic Ocean	Indian Ocean	Atlantic Ocean	Indian Ocean
Stock Assessment	2015	2017	2017 (2019)	2017 (2019)
MSY	Unknown	33 000 t (29 500-36.600)	Unknown	Unknown
Total yield for stock	24 077 t (2016)	Estimated catch 54 735 t (2015) Reported catch 32 312 t (2016)	2 641 t (2016)	1 631 t (2016)
RFMO TAC	-	-	-	-
Quota allocation	-	-	-	-
Relative biomass	B_{2013}/B_{MSY} = 1.15* (0.78–1.29)	B_{2015}/B_{MSY} = 1.54 (1.37–1.72)	B_{2015}/B_{MSY} = 0.07 (0.65–1.75)	Unknown
Relative fishing mortality	F_{2013}/F_{MSY} = 0.60 (0.01–1.19)	F_{2015}/F_{MSY} = 0.87 (0.67–1.10)	F_{2015}/F_{MSY} = 2.27 (0.86–3.67)	Unknown
RFMO summary and recommendations	Estimates obtained with the *Bayesian state-space surplus production model formulation should be considered more reliable than other Bayesian production models. These were less optimistic, predicting that the stock could be overfished and overfishing could be occurring. Considering the uncertainty in stock status results for the South Atlantic stock of blue sharks, the Committee strongly recommends that the Commission considers a precautionary approach for this stock. If the Commission chose to use the same approach taken for the North Atlantic stock, the average catch of the final five years used in the assessment model (28 923 t for 2009–2013) could be used as a limit.	Even though the blue shark in 2017 is assessed to be not overfished nor subject to overfishing, maintaining current catches is likely to result in decreasing biomass and the stock becoming overfished and subject to overfishing in the near future. If the Commission wishes to increase the probability of maintaining stock biomass above MSY reference levels ($B>B_{MSY}$) over the next 8 years, then a reduction of a least 10% in catches is advised. The stock should be closely monitored. Mechanisms need to be developed by the Commission to improve current statistics, by ensuring CPCs comply with their recording and reporting requirement on sharks, so as to better inform scientific advice in the future.	For the South Atlantic stock of shortfin mako, the estimates of unsustainable harvest rates appear to be fairly robust at this stage whereas the biomass depletion and B/B_{MSY} estimates must be treated with extreme caution. Given the uncertainty in stock status, the large fluctuations in catch, the high intrinsic vulnerability of this species, and the depleted status for the North Atlantic stock, the Committee recommends that until this uncertainty is reduced, catch levels should not exceed the minimum catch in the last five years of the assessment (2011–2015; 2 001 t).	A precautionary approach to the management of shortfin mako shark should be considered by the Commission. Mechanisms need to be developed by the Commission to ensure CPCs comply with their recording and reporting requirement on sharks, so as to better inform scientific advice.

West Coast rock lobster

Stock status	Unknown	Abundant	Optimal	Depleted	Heavily depleted
Fishing pressure	Unknown	Light	Optimal	Heavy	

Introduction

The West Coast rock lobster fishery is the most important rock lobster fishery in South Africa due to its high market value (more than R500 million per annum) and its importance in providing employment for over 4 200 people from communities along the West Coast. West Coast rock lobster is a cold-water temperate spiny lobster species occurring from Walvis Bay in Namibia to East London in South Africa. In South Africa, the commercial fishery operates between the Orange River mouth and Danger Point in waters up to 100 m in depth. This slow-growing species inhabits rocky areas and exhibits a seasonal inshore-offshore migration governed by its biology and environmental factors. Currently the resource is harvested by hoop nets from "bakkies" (small wooden rowing boats) in the nearshore region up to one nautical mile offshore and by offshore trap vessels operating in water depths greater than 100 m. The resource in the nearshore region is also harvested by recreational fishers and small-scale or subsistence fishers operating exclusively in the nearshore region during the summer months.

The invasion of West Coast rock lobsters into the traditional abalone fishing zones east of Cape Hangklip marked the onset of an eastward shift in lobster distribution. Commercially viable quantities of lobster in this area resulted in the opening of three new lobster fishing areas (areas 12–14; Figure 69). As a result, the fishery on the West Coast, which historically landed the bulk (60%) of the lobster catch, now lands only 40% of the total catch annually. This decline in catch has had a devastating effect on coastal communities, with economic hardships experienced by most fishers on the West Coast. In the face of resource decline, an operational management procedure (OMP) was developed which aims to rebuild the stock to sustainable levels.

History and management

The commercial harvesting of West Coast rock lobster commenced in the late 1800s, and peaked in the early 1950s, yielding an annual catch of 18 000 t. Lobsters were predominantly caught with hoop nets prior to the 1960s and from 1965 more-efficient traps and motorised deck boats were also used. Average catches declined by almost half to 10 000 t during the 1960s and continued to decline sharply to around 2 000 t in recent years. The decline in catches is believed to be due to a combination of changes in fishing methods and efficiency, changes in management measures, over-fishing, environmental changes, and reduced growth rates.

A number of management measures have been put in place during the history of the fishery. A minimum size limit was introduced in 1933 (89 mm carapace length), which protected a large proportion of the slower-growing female component of the population, and a tail-mass production quota was imposed in 1946. However, catches declined sharply during the 1950s, particularly in the northern areas, in response to overfishing. A minimum legal size limit of 76 mm carapace length was implemented in 1959, after which the average catch increased to around 10 000 t until the mid-1960s. However, catches declined again from 1966 and continued to decline during the 1970s, when a minimum legal size limit of 89 mm carapace length was implemented. In 1979, the tail-mass production quota was replaced by a whole-lobster quota, which led to the introduction of the total allowable catch (TAC) management system in the early 1980s.

Under the TAC management system, annual catch limits were subdivided for the 10 traditional West Coast fishing areas (Figure 69, zones A-D). A new fishing ground in False Bay (zone E) was opened in 1987, and zone F was opened in 1999 following the eastward shift in distribution of lobster towards the area east of Cape Hangklip. Currently the stock is managed on a per zone (super-area) basis. The resource in zones A, E and F are exclusively harvested by fishers operating with hoop nets in the nearshore region.

Other management controls applied included protection of females with eggs (berried females) and soft-shelled lobsters, a closed winter season, and a daily bag limit for recreational fishers. Average annual catches stabilised at around 3 500 to 4 000 t until 1989 when the resource started to decline further. This continued decline in the resource during the 1990s and early 2000s was attributed to mass strandings of lobster and reduced growth caused by low oxygen events along the West Coast. During this period the size limit was decreased from 89 to 75 mm carapace length to reduce mortalities resulting from discards of undersized lobsters. By 1996 catches had declined to their lowest levels of 1 500 t and showed no marked signs of recovery.

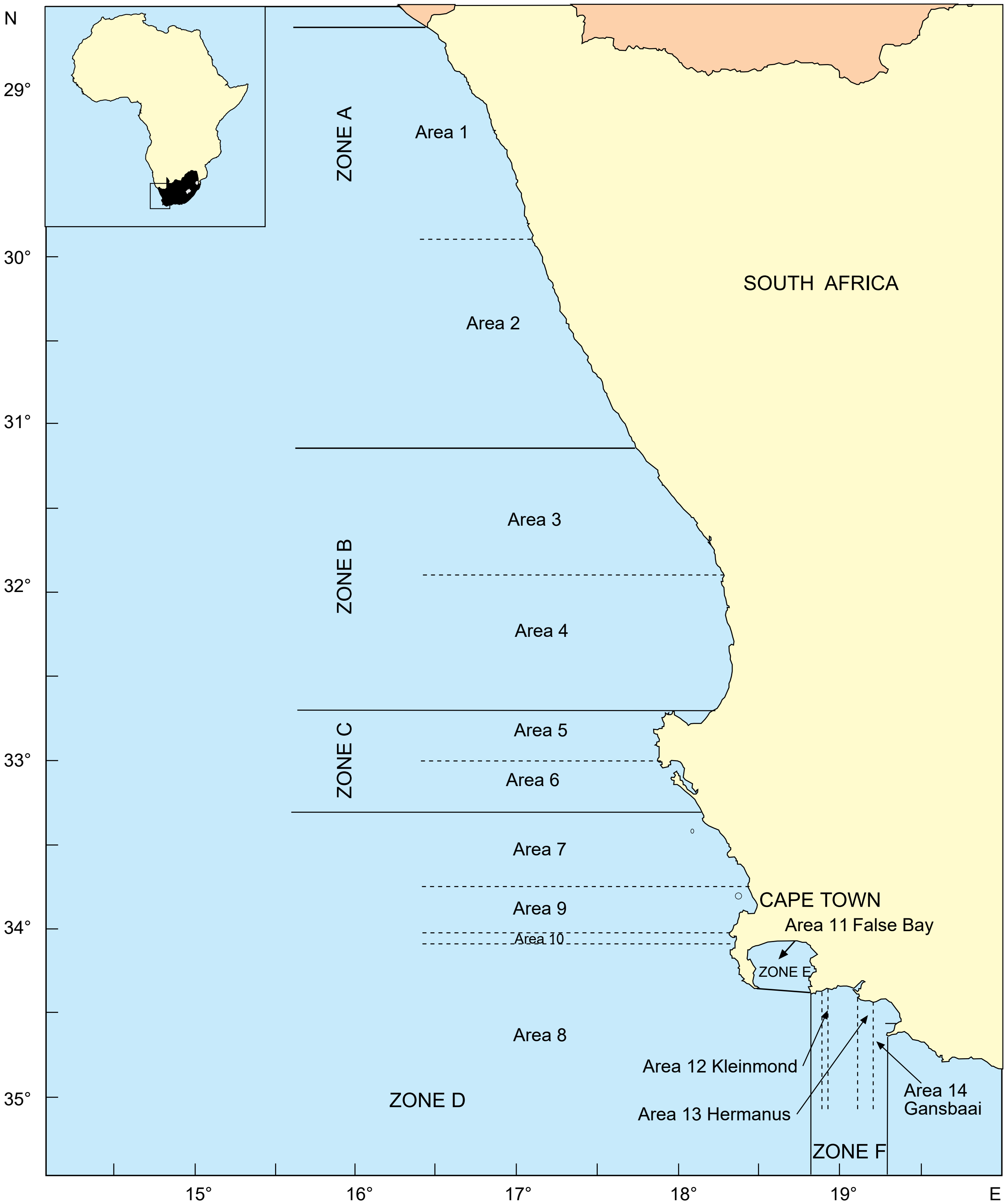

Figure 69: West Coast rock lobster fishing zones and areas. The five super-areas are: areas1–2, corresponding to zone A; areas 3–4, to zone B; areas 5–6, to zone C; area 7, being the northernmost area within zone D; and area 8+, comprising area 8 of zone D as well as zones E and F

In the face of decreases in growth rates, catch rates and biomass, an OMP was implemented in 1997 in an attempt to rebuild the resource to more-healthy levels (defined as pre-1990). Since then, scientific recommendations for TACs for the West Coast rock lobster resource have been based on OMPs. These calculate sustainable catch limits each year, in a manner that incorporates updated information from resource-monitoring data, according to formulae pre-agreed by scientists, managers and stakeholders and adopted by the Branch Fisheries Management as the accepted management basis for the fishery concerned. The OMP for West Coast rock lobster has since been revised on four occasions: in 2000, 2003, 2007 and 2011. In 2013/14, Exceptional Circumstances arose in super-area 7 following a large decline in abundance there, necessitating the development of an interim approach to provide a TAC recommendation for the 2013/14 fishing season which was consistent with the intent of the rebuilding plan inherent in OMP-2011 (35% recovery in the 2006 male biomass above 75 mm carapace length by 2021, in median terms). A new OMP (OMP-2015) was developed and adopted to provide the scientific recommendations for TACs for the West Coast rock lobster resource for the 2015/16 season and the following three seasons.

In 2016, updated assessments, together with a re-appraisal of estimates of the extent of and trends in poaching, were conducted as part of the standard process of monitoring the performance and continued appropriateness of the OMP. The assessments showed results for resource status that were appreciably worse than anticipated, particularly for super-area 8+ (the Cape Peninsula area extending to east of Hangklip). This, together with revised estimates of poaching (which suggested a doubling over the previous three years), resulted in invoking the Exceptional Circumstances rules of the OMP which necessitated the suspension of use of the formulae to calculate the TAC, and reliance instead on (effectively) constant catch projections as a basis to develop TAC recommendations in line with the Exceptional Circumstances provisions. These projections indicated that the recovery target for the resource of a 35% increase in the 2006 abundance by 2021 (the agreed recovery target incorporated in the OMP) could not be achieved, even if the legal fishery was closed until the 2021 target year. It was therefore recommended that this target be revised downward to a 7% increase, and that the necessary substantial TAC reductions be implemented to achieve this target. The 7% figure reflected a trade-off between achieving at least some resource recovery, while maintaining some fishing activities for socio-economic reasons. Based on this revised target, the TAC recommended for the 2016/17 season was 1 270 t and 790 t for the 2017/18 season. This phased-reduction approach was recommended as a means to reduce socio-economic disruption. In addition, it was recommended that an effort-reduction strategy based on reducing the fishing-season length be implemented in order to assist with reducing the unacceptably high levels of poaching. However, the TAC for the 2016/17 season was set at the same level as for the 2015/16 season (1 924 t), and the recommended effort limitation strategy was not implemented.

Research and monitoring

Research and monitoring of West Coast rock lobster continues to provide and improve essential data inputs for assessing the sustainability of the stock, its management and setting annual catch limits for the fishery. Indices of abundance such as catch per unit effort (CPUE) derived from the fishery-independent monitoring survey (FIMS) and commercial catch-statistics (Figures 70 and 71), annual assessments of somatic growth rate (Figure 72), and estimates of recreational and Interim Relief catch, are used as input data to the OMP assessment model.

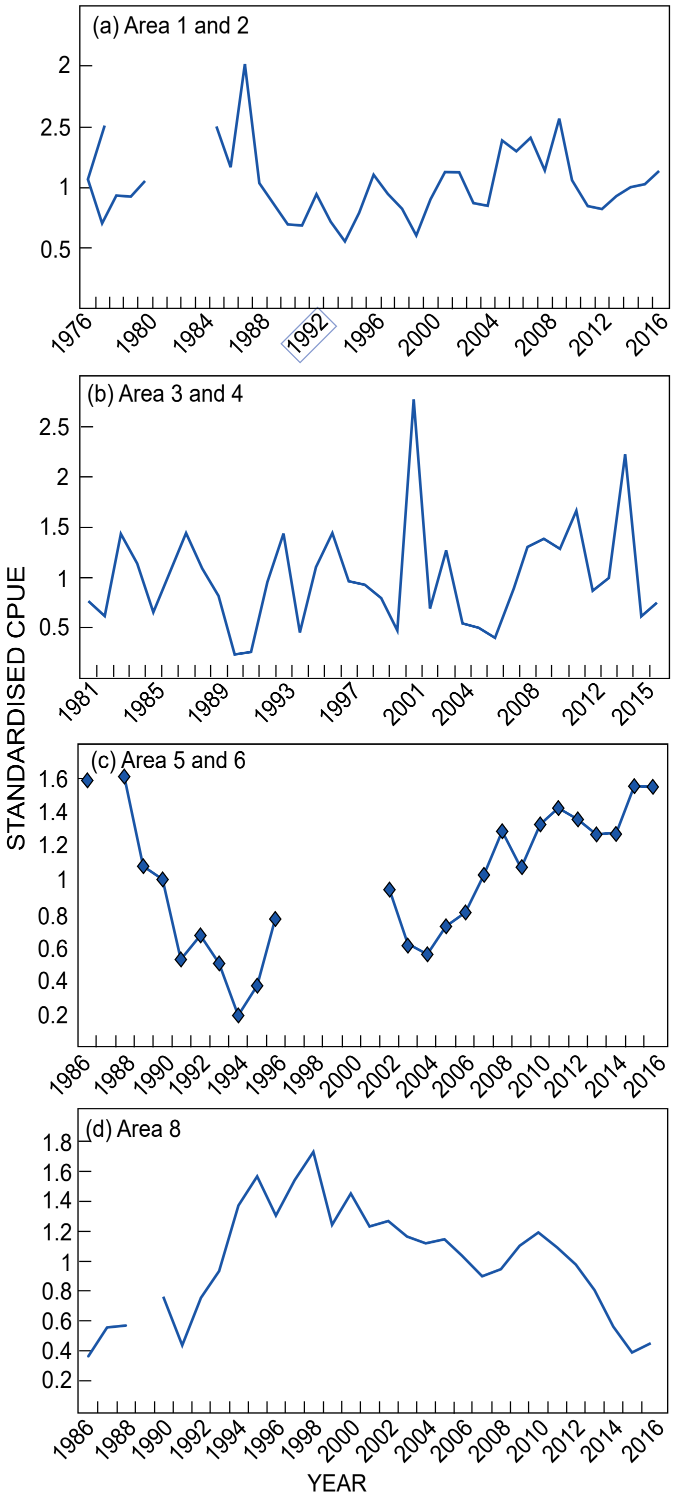

Figure 70: Standardised hoopnet CPUE indices per area (each index has been standardised to its mean)

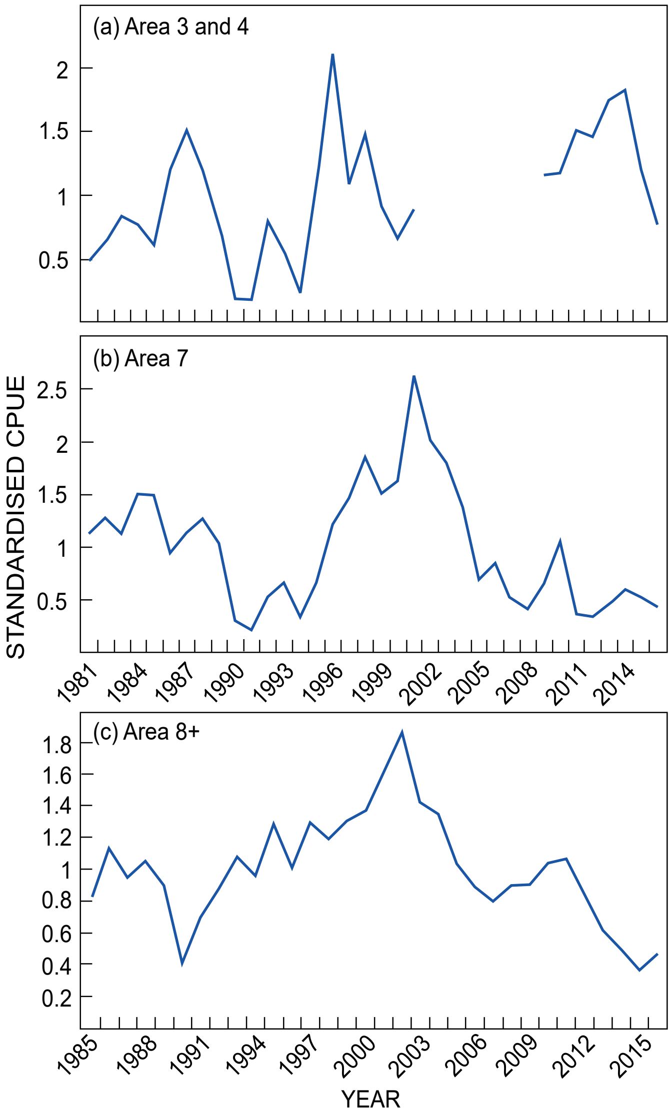

Figure 71: Standardised trap CPUE indices per area (each index has been normalised to its mean)

Catch monitors record fishing effort and catch landed by commercial nearshore and offshore Right Holders and Interim Relief fishers on landing slips after each fishing trip. Recreational catch is estimated from catch and fishing effort statistics reported during an annual recreational telephonic survey.

Growth of West Coast rock lobsters is monitored by tagging pre-moult male lobsters (>75 mm carapace length) along the West Coast from July to November. Growth increment and release-recapture times are incorporated into a "moult probability growth model" to estimate the growth per moult cycle.

Information on sex, reproductive state, size frequency and bycatch are also recorded during fisheries independent monitoring surveys and ship-based observer monitoring surveys on board commercial vessels. These statistics are used to derive abundance indices of subadult and legal-sized male and female (>75 mm carapace length) lobsters which are used as inputs into the size-structured assessment model. This information, together with environmental data, is also used in providing ongoing scientific advice for management of the resource. Historical fisheries-independent survey data and analysis methods have recently been re-checked, and changes in

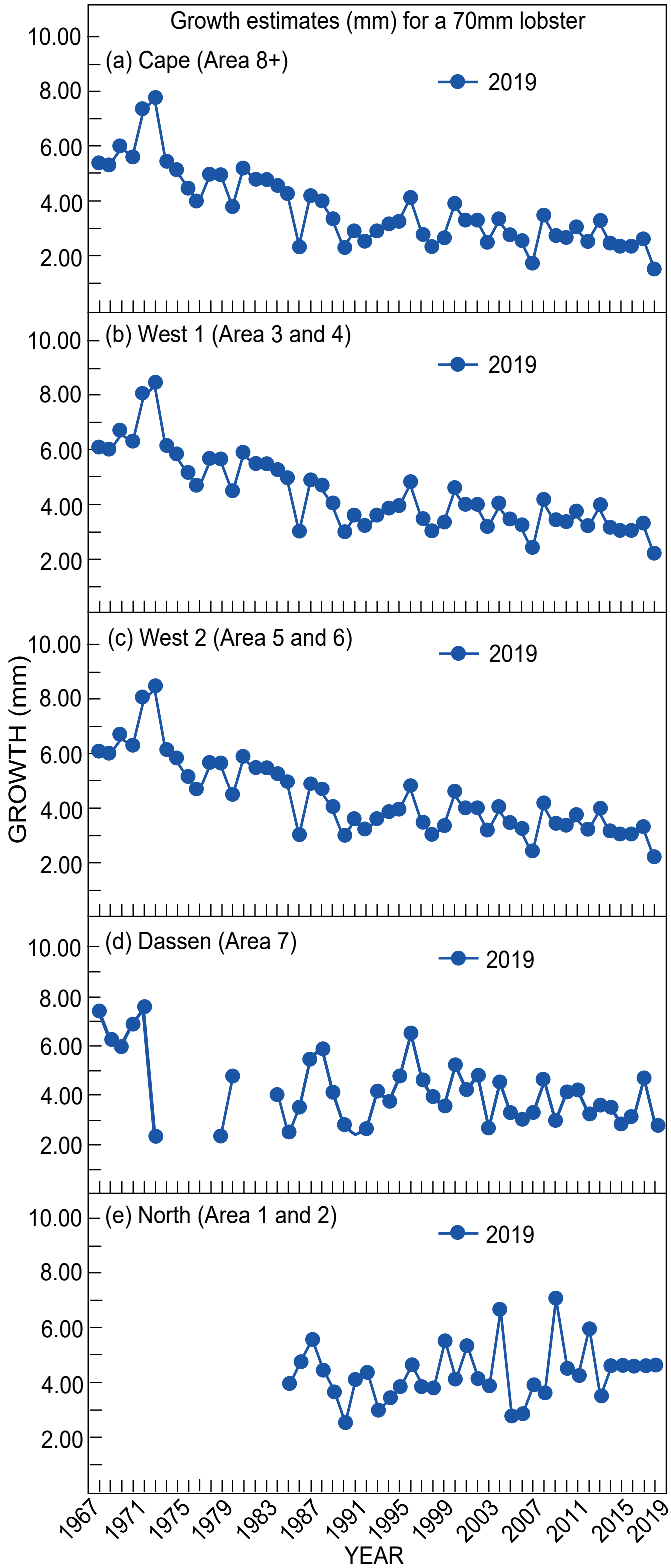

Figure 72: Somatic growth trends per area

weather conditions, most notably wind, have been identified as a source of variation in CPUE. The associated effects of changes in bottom-oxygen levels, temperature and current speed on catch rates is also currently being investigated.

The OMP assessment model provides projections of future biomass under the assumption that future recruitment and growth will follow trends similar to those observed in the past. New research projects are being developed to provide improved indices of future recruitment, growth and catch to refine OMP projections of future biomass. Studies on the recruitment of post-larval and juvenile lobster have been initiated to establish a long-term index of pre-recruit abundance that could potentially be used in predicting future recruitment and catch (6-7 years in advance). The function of internal energy sources in regulating growth and reproduction in females is also under investigation, to formulate energy-growth-reproduction conversion factors for predicting future trends in growth and reproductive potential.

Current status

In the absence of an updated assessment in 2017, the nominal (and standardised where available) data relating to the indices (commercial CPUE, somatic growth rate, FIMS and compliance data related to poaching) were used to ascertain whether there was any evidence of meaningful change in resource status having occurred since the full assessment completed in 2016. These were used to check whether there was any compelling evidence to invalidate the 2016/17 assessment and the associated projections, which had provided the basis for the TAC recommendations made in 2016. Absence of such evidence justified the continued use of these projections as the basis to provide TAC recommendations for the 2017/18 season, and a TAC of 790 t was therefore recommended. The TAC for the 2017/18 season was, however, again set at the same level as for the 2015/16 season (1 924 t) with an effort-limitation strategy amended to four months being implemented. Results from an updated assessment conducted in 2018 indicate that, similar to the situation in 2016, the Exceptional Circumstances provisions of OMP-2015 still apply as super-area 8+, in particular, remains at a much lower level than anticipated at the time whenOMP-15 was adopted. The current male biomass above 75 mm carapace length is estimated to be 15 500 t, or only some 1.8% of the corresponding pristine level.

Ecosystem interactions

Bycatch is not an issue of concern in this fishery. There are, however, negative interactions between lobster fishing gear (traps, ropes and buoys) and whales, with entanglements reported each season. The reported number of these incidents has reduced over the past few seasons as a result of an awareness programme directed at encouraging lobster-trap fishers not to leave excess trap rope untied during fishing operations.

The general decline in lobster abundance (especially in shallow reef areas) and the eastward distributional shift in the lobster population have been linked to the decline in the numbers and breeding success of the Endangered bank cormorant, which relies on West Coast rock lobsters as a major food source. In the late 1980s/early 1990s there was a major eastward shift in lobster distribution, including the movement of lobster into the area east of Cape Hangklip (or zone F in Figure 69) with major implications for the benthic ecology in that area. Recent studies have shown, however, that the situation in this area is stable, with no further eastward movement.

Further reading

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Useful statistics

Total allowable catch, fishing sector landings and total landings for West Coast rock lobster.

	TAC (t)					
Season	Global TAC	Offshore allocation	Nearshore allocation	Interim Relief	Recreational	Total catch[3]
1998/1999	2 300	1 780			258	2 051
1999/2000	2 156	1 720		145	291	2 152
2000/2001	2 018	1 614		230	174	2 154
2001/2002	2 353	2 151		[1]	202	2 410
2002/2003	2 957	2 713		[1]	244	2 706
2003/2004	3 336	2 422	594	[1]	320	3 258
2004/2005	3 527	2 614	593	[1]	320	3 222
2005/2006	3 174	2 294	560	[1]	320	2 291
2006/2007	2 857	1 997	560	[2]	300	3 366
2007/2008	2 571	1 754	560	[2]	257	2 298
2008/2009	2 340	1 632	451	[2]	257	2 483
2009/2010	2 393	1 632	451	180	129	2 519
2010/2011	2 286	1 528	451	200	107	2 208
2011/2012	2 426	1 541	451	251	183	2 275
2012/2013	2 276	1 391	451	251	183	2 308
2013/2014	2 167	1 356	451	276	83.5	1 891
2014/2015	1 800.85	1 120.25	376.1	235.3	69.2	1 688
2015/2016	1 924.08	1 243.48	376.1	235.3	69.2	1 524.4
2016/2017	1 924.08	1 204.48	376.1	274.3[4]	69.2	1 564.3
2017/2018	1 924.08	994.784	305.7	554.4[5]	69.2	1 355.7

[1] No Interim Relief allocated
[2] Interim Relief accommodated under Recreational allocation
[3] Total catch by all sectors
[4] Includes 39 t allocated to N Cape small-scale fishers (SSF)
[5] Includes 248.7 t allocated to SSF Offshore and 70.4 t to SSF Nearshore

RESEARCH HIGHLIGHTS

Climate change and marine fisheries and aquaculture

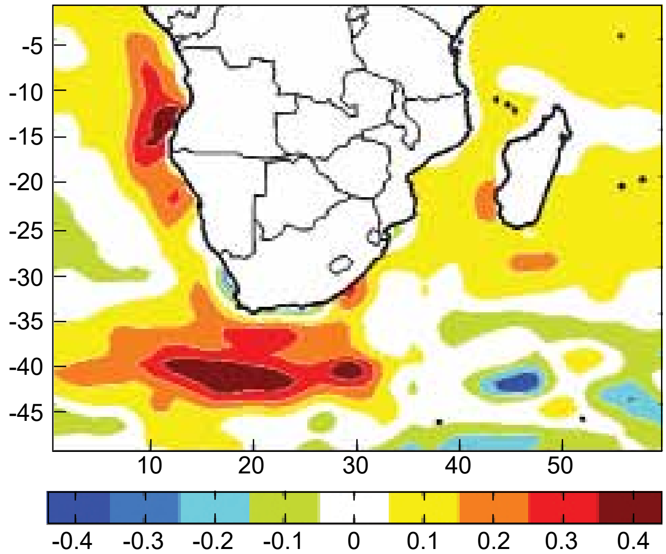

Figure 73: Linear trend of sea surface temperature from 1982 to 2016 in degrees per decade. Image from Rouault (2017) – Coastal climate change and variability in the Benguela Current System from 1982 to 2016. See Hampton et al. (2017c)

As a signatory to climate change-specific international agreements, South Africa's then-Department of Agriculture, Forestry and Fisheries (DAFF) effected institutional arrangements resulting in the inclusion of Fisheries as a sector requiring a national development plan. An *ad hoc* team of scientists within the Branch: Fisheries Management of the Department was appointed to address all climate-change related issues within the sector, forming the Fisheries Climate Change Task Team (FCCTT). The team is currently composed of four scientists from the Chief Directorate: Fisheries Research and Development — Dr Jean Githaiga (Chair), Dr Carl van der Lingen, Dr Steve Lamberth and Dr Dawit Yemane; and two scientists from the Chief Directorate: Marine Aquaculture and Economic Development — Dr Grant Pitcher and Ms Michelle Pretorius.

In June 2015, an internal workshop was held to assess the vulnerability to climate change of all fisheries falling within the scope of the scientific working groups of the Branch, including the marine aquaculture sector. The workshop was set up and convened by the FCCTT, as the first step in the process of developing a Climate Change Adaptation and Mitigation Plan (CCAMP) for marine fisheries and aquaculture. Results showed that the sectors most vulnerable to climate change appeared to be the linefish and small pelagic fisheries. A third sector, aquaculture, was selected because of its unique challenges and its potential for growth.

Concurrent to the development of CCAMP, several scientists from the Branch and from the then-Department of Environmental Affairs (DEA) collaborated in writing a book chapter on South Africa in the publication "The impacts of climate change on marine fisheries and aquaculture and their adaptations". Apparent changes in oceanography off the South African coast, such as increased intensity and variability of coastal upwelling in the last two decades, and increased SSTs off the East Coast (Figure 73), and their potential impact on fisheries for small pelagics, linefish, squid and West Coast rock lobster, as well as the aquaculture industry, were considered. Several adaptation measures were discussed and some specific proposals for identified sectors considered.

In the CCAMP, specific adaptation measures were identified for the fisheries and sectors rated as most vulnerable to climate change (small-scale linefishery, small pelagic fishery, and marine aquaculture). The Branch proceeded with developing a more-detailed CCAMP specifically for the marine-fisheries and marine-aquaculture sectors, through broader discussions at a workshop convened in October 2016. A number of interested and affected parties were invited and were consulted on possible adaptation measures for fisheries already included in the current CCAMP, as well as those not yet considered. The final process was to select and prioritise those adaptation measures for the short, medium and long term.

The emission of greenhouse gases (GHGs) by the marine fisheries and marine aquaculture sectors is currently small in comparison to other South African economic sectors. Several measures for reducing GHG emissions in marine capture fisheries can be applied and are discussed in the CCAMP.

A further workshop was held at the Sea Point Research Aquarium from 14 to 16 March 2017 to solicit views from as wide a scientific audience as possible to: (i) increase the amount of information available to the FCCTT to facilitate further development of the Fisheries CCAMP; and (ii) provide a broad geographical and multidisciplinary foundation for the longer-term objective of developing a national research response to the effects of climate change on South Africa's marine environment and on the industries, communities and individuals dependent on it.

Going forward, the Branch should strengthen its capability to monitor fish stocks effectively through resource surveys and through the continued collection of adequate catch data from commercial and small-scale fishers to assess the size and distribution of resources and to monitor changes in all key parameters of exploited fish populations. Furthermore, the Branch should retain the capacity (or at least access to it) to carry out state-of-the-art mathematical modelling of fish population dynamics using survey estimates of exploited stocks, catch and effort data, and parameters that characterise the marine ecosystem.

Another important requirement is to continue, and expand, research on models that require limited data, since it is likely that the available data for many of the potential new target species will be very limited. The Branch should also collect relevant oceanographic data, and ensure adequate monitoring of oceanographic trends, especially in areas where large changes and major impacts on fisheries are taking place, such as the South Coast and in many inshore zones. Bioclimatic modelling to predict distribution shifts in response to changes in the environment should also be a priority.

The marine aquaculture sector should expand its research on the range of species suitable for the sector, consider predictions of future changes such as temperature and ocean acidification, monitor the occurrence of disease, and carry out additional research relevant to the sector.

Creating awareness of climate change is a priority, and climate change should be highlighted through events such as workshops and seminars organised in partnership with all relevant entities.

In terms of policy updates, climate change and response measures should: (i) be included in the Marine Living Resources Act (MLRA); (ii) form part of the fishing Rights allocation process (FRAP); and (iii) be included in other policies such as the Aquaculture Policy Framework for South Africa.

Revisions of the MLRA should include the enabling of greater flexibility, since climate change impacts on economically important resources will require rapid impact redress.

The draft Policy for Exploratory Fisheries should be finalised and implemented, since opportunities for new fisheries, which could arise from changing distributions of species, ought to be properly and systematically addressed, as should the Inland Fisheries Policy, currently under development.

The Small Scale Fisheries Policy makes reference to possible impacts of environmental and climate change on coastal communities but makes no recommendations on how these impacts should be addressed. The Branch should enhance climate change awareness in the Small-Scale Fisher Co-operatives, and promote specific adaptation measures in affected co-operatives.

The CCAMP for the marine fisheries and marine aquaculture sectors will be further developed into a more detailed and comprehensive plan for the Branch: Fisheries Management, which will include specific recommendations on implementation. A monitoring and evaluation (M&E) unit for marine fisheries and marine aquaculture should be set up within the Branch.

Figure 74: Commercial line-fish boats on the slipway at Arniston. Increased storminess has seen a significant decline in sea-days on the Cape South Coast over the past four decades

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Predicting recruitment strength of South African anchovy from upwelling indices

The Cape anchovy *Engraulis encrasicolus* is an important target of the country's purse-seine fishery, with annual landings of this species averaging around 220 000 t since the turn of the Century (see 'Small pelagic fish' section of this report). The bulk (>70%) of anchovy caught are juvenile fish of around 6 months old (also known as recruits) that are taken between April and September in inshore waters, primarily from St Helena Bay to Cape Point, with the remainder of the catch consisting of mostly adult fish taken year-round on the western Agulhas Bank between Cape Point and Cape Agulhas. Anchovy catches are reduced to fishmeal and fish oil for use in agri- and aqua-feeds.

Anchovy are short-lived, grow rapidly and mature at the end of their first year, and spawn in spring and summer on the Agulhas Bank between Cape Point and Port Alfred. Individual-based models coupled with 3D hydrodynamic models of the region have indicated that a significant portion of anchovy eggs spawned to the west of Cape Agulhas are transported by a shelf-edge jet current to the West Coast nursery grounds (Huggett et al. 2003). In contrast, only a small fraction of those spawned to the east of Cape Agulhas are transported westwards and anchovy recruitment is considered to come primarily from spawning on the western Agulhas Bank (Hutchings et al. 1998; Figure 75). Once arrived in the West Coast nursery area, anchovy early stages benefit from the high productivity there to develop and grow, before migrating southwards to the spawning grounds during autumn and winter, at which time they are targeted by the fishery.

Because the anchovy fishery harvests primarily recruits, and because anchovy recruitment strength is unknown at the start of the year when catch allocations are announced, an initial total allowable catch (TAC) for this species is set at the start of the fishing season in early-January. The initial TAC is based on the total anchovy biomass observed during the Pelagic Biomass Survey at the end of the preceding year and assuming that average recruitment will occur, but to counter possible poor recruitment the TAC is then scaled down by a factor of 0.85 (de Moor et al. 2011). A final TAC is set following the mid-year (June/July) Pelagic Recruit Survey during which actual anchovy recruitment strength is estimated; the final TAC cannot be less than the initial TAC and is occasionally substantially higher. The anchovy final TAC has typically been under-caught in recent years, with only 56%, on average, taken each year since 2000. Several reasons for this under-catch have been suggested, including reduced processing capacity and a changed behaviour of anchovy that has reduced their availability to the fishery, but a likely reason is also the short time-period between the announcement of the final TAC (typically early-August) and the time when anchovy are no longer available off the West Coast (typically late-September), particularly when the final TAC is significantly higher than the initial TAC.

It has previously been estimated that the average annual catch of Cape anchovy could be increased by as much as 48% if precise predictions of anchovy recruitment could be made at the start of the fishing season, or by 21% if predictions were made by March (Cochrane and Starfield 1992). Given this potential, significant effort to develop environmental predictors of Cape anchovy recruitment strength was made during the 1990s (e.g. Cochrane and Hutchings 1995; Korrûbel et al. 1998; Painting and Korrûbel 1998; Miller and Field 2002; van der Lingen and Huggett 2003). However, none of these attempts provided sufficiently accurate predictors (i.e. able to explain >50% of the total variation in anchovy recruitment strength; De Oliveira and Butterworth 2005) to warrant their inclusion in the current management procedure used for the anchovy fishery.

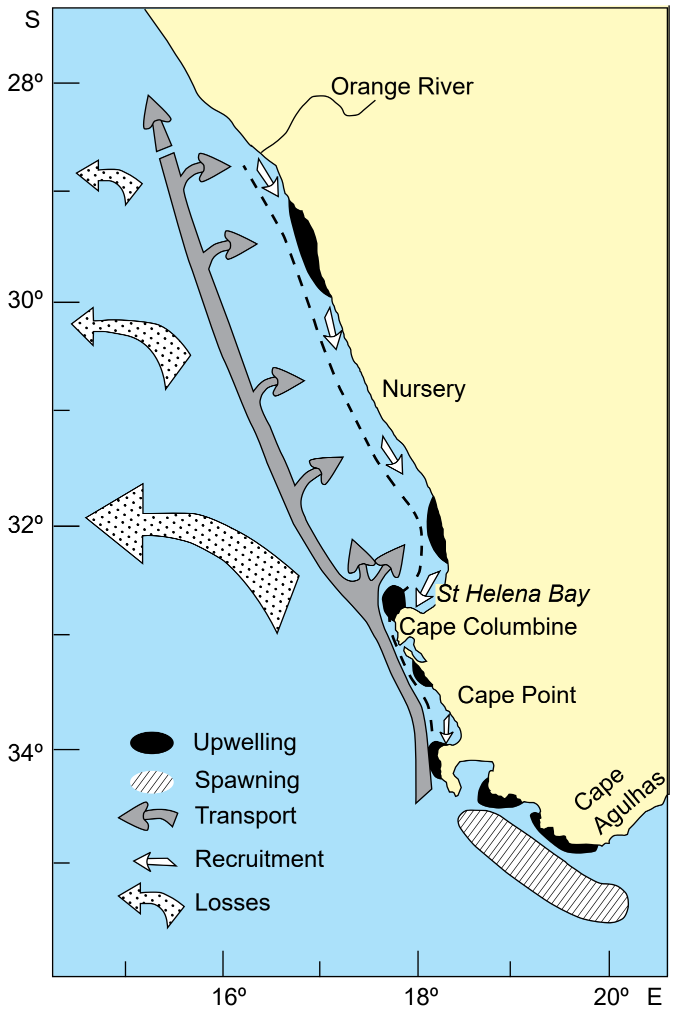

Figure 75: Schematic of the anchovy life-history cycle (from Hutchings et al. 1998; reproduced with permission)

Research into recruitment variability of Cape anchovy has again been initiated as part of the collaborative and multidisciplinary California-Benguela Joint Investigation (CalBenJI) Programme between scientists from South Africa and the United States of America (see http://www.faralloninstitute.org/calbenji-about) that aims to assess how climate change may impact these upwelling ecosystems. As part of the CalBenJI programme, van der Sleen et al. (2018) investigated the relationship between Cape anchovy recruitment strength, estimated during annual recruit surveys, and coastal upwelling off the West Coast, quantified using a recently-developed upwelling-index time-series derived using satellite measurements of wind made by the National Centres for Environmental Prediction (Lamont et al. 2018).

Van der Sleen et al. (2018) found that cumulative December–March upwelling was significantly ($r^2 = 0.24$) and positively related to subsequent anchovy recruitment (Figure 76a), and that integrating the upwelling index over multiple years by adding autocorrelation (a technique known as reddening), in order to account for potential "carry-over" effects from previous years, improved the relationship, such that 55% of the total variation in observed recruitment was accounted for (i.e. $r^2 = 0.55$; Figure 76b). Further analysis used a threshold-generalised additive model (TGAM) to assess whether the relationship between recruitment and upwelling changed at some level of a threshold variable, with year and anchovy spawner biomass estimated west of Cape Agulhas (WoCA) during the Pelagic Biomass Survey of the preceding year included as variables. Whereas the nature of the recruitment-upwelling relationship did not change as a function of calendar year, it did change for anchovy spawner biomass WoCA, with the slope of the relationship between recruitment and integrated, cumulative upwelling being markedly higher when anchovy spawner biomass WoCA was greater than 0.74 million tonnes (Figure 76c). This was attributed to the higher biomass WoCA resulting in more eggs being spawned where they would be efficiently transported to the nursery area, whereas a lower biomass WoCA would result in relatively few eggs being spawned there and hence transported to the nursey area. By combining the two linear regressions into a single model, van der Sleen et al. (2018) were able to account for 82% of the variability in observed anchovy recruitment (Figure 76d), substantially higher than the 50% threshold identified by De Oliveira and Butterworth (2005) for such predictions to have utility for management. Given this, van der Sleen et al. (2018) suggested that their findings could be used in management of the anchovy fishery by increasing/decreasing the scale-down factor applied to the initial TAC when the anchovy biomass WoCA was

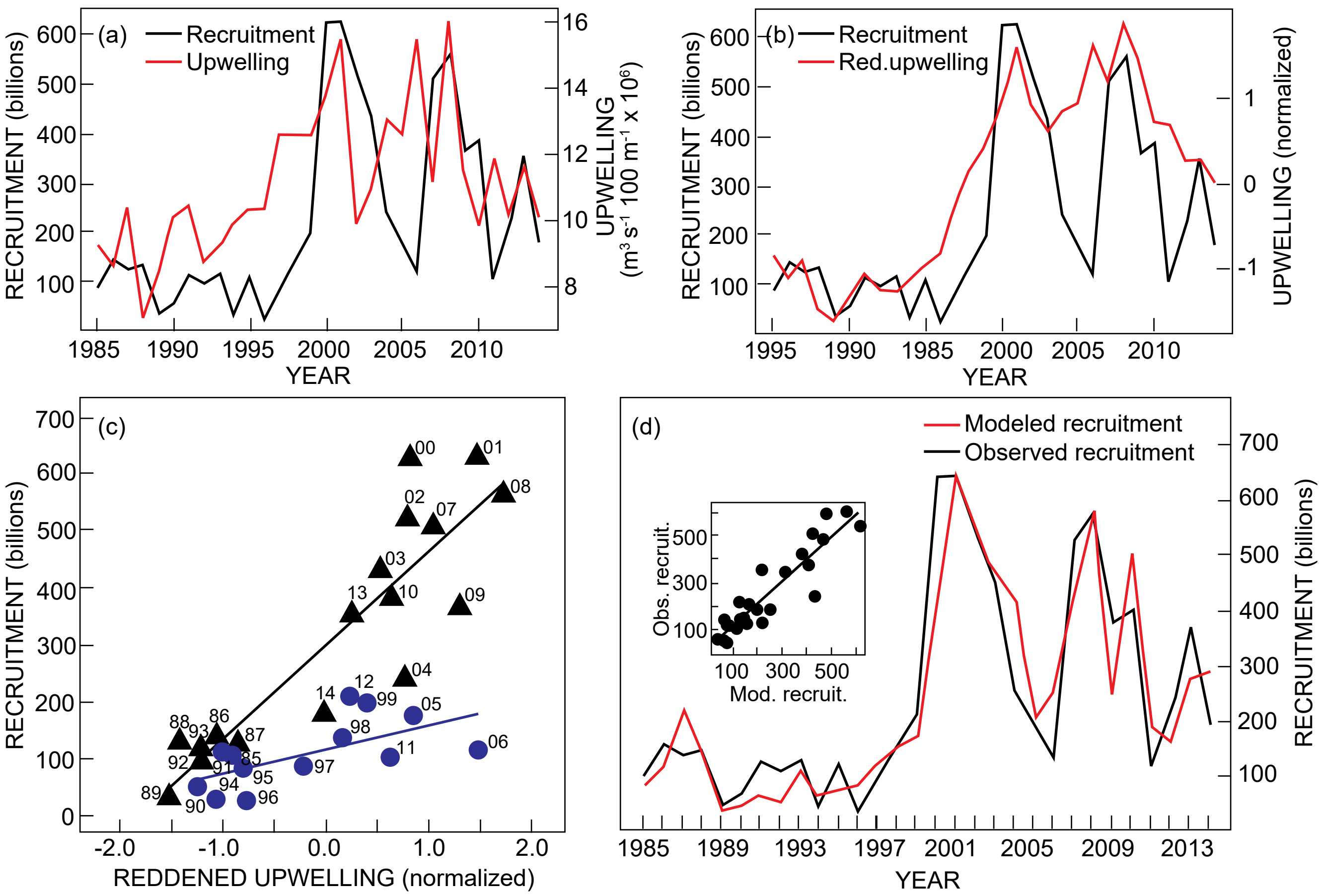

Figure 76: (a) Anchovy recruitment estimated from annual hydroacoustic surveys (black line) and cumulative coastal upwelling in the southern Benguela (December to March; red line) over the period 1985 to 2014; (b) anchovy recruitment (black line) and reddened cumulative coastal upwelling (December to March; red line); (c) two (black line and black triangles; and blue line and blue circles, respectively) linear anchovy recruitment-upwelling relationships identified in the non-additive TGAM with the calendar year of each point shown; and (d) modelled (using the two relationships from the TGAM) anchovy recruitment (red line) and observed anchovy recruitment (black line) with the inset showing the correlation between modelled and observed recruitment (from van der Sleen et al. 2018; reproduced with permission).

above/below the 0.74-million-tonne threshold level. This could be done immediately following the Pelagic Biomass Survey and hence before the start of the anchovy fishing season, or some months later once the wind data for December to March had been analysed and incorporated into the upwelling index, which would be in April at the earliest and around the start of the anchovy fishing season.

The analysis by van der Sleen et al. (2018) used data for the period 1985–2014, and the continued collection of wind and anchovy recruitment and biomass data since has enabled testing of the relationship between the two as proposed by van der Sleen et al. (2018), an important and necessary step if that relationship is to be utilised for management purposes. Wind data were collected as described by Lamont et al. (2018) and the upwelling index time-series updated to March 2018 (T Lamont, Department of Environment, Forestry and Fisheries, Cape Town, pers. comm.), and those data were then used with anchovy spawner-biomass data to hind-cast anchovy recruitment that could be compared with survey-based observations for 2015, 2016 and 2017 (P van der Sleen, Karlsruhe Institute of Technology, Rastatt, Germany, pers. comm.). In addition, an actual prediction of anchovy recruitment for 2018 was made, given that there was no Pelagic Recruitment Survey in that year. The upwelling-model-derived recruitment (*Upwell-recruit*), recruitment estimated during recruit surveys (*Survey-recruit*), and recruitment estimated from an updated anchovy assessment model (*Assess-recruit*) that uses data from both recruitment (winter) and biomass (spring) surveys in addition to commercial catch data and is considered to provide the most accurate reflection of the population dynamics of this species (de Moor 2020), are compared in Table 17.

Two (2015 and 2016) of the anchovy recruitments estimated using the model of van der Sleen et al. (2018) were close (within 10%) to survey-estimated recruitment, and one (2016) was close (within 10%) to assessment-model-estimated recruitment, indicating some utility of this approach for incorporation into management procedures for the anchovy fishery. The hind-cast upwelling-model-recruitment for 2017 was substantially (65%) lower than that estimated by the survey but moderately close (within 38%) to assessment-model-estimated recruitment for that year. This mismatch for 2017 may be because recruitment in that year, which was the highest-yet survey estimate since 1985, was outside the range of values used in the original analysis. Alternatively, recruitment in 2017 may have been over-estimated during the survey, as suggested by the anchovy-assessment model. The upwelling-model-predicted recruitment for 2018 was substantially (3×) higher that that estimated by the assessment model. Upwelling-model-estimated recruitment was some 15% lower on average than survey-estimated-recruitment for the three years (2015–2017) for which comparative data exist, and the former was some 79% higher on average than assessment-model-estimated recruitment for the four-year (2015–2018) period. The relatively close match between upwelling-model and survey estimates of recruitment is encouraging. However, the difference between upwelling-estimated and assessment-model-estimated recruitment is too large to permit incorporation of such recruit predictions into management procedures at present and further testing using data from more years is needed.

Table 17: Comparison of upwelling-model-estimated (hind-cast for 2015–2017 and predicted for 2018 as per van der Sleen et al. 2018), survey-estimated, and assessment-model-estimated recruitment (in May; de Moor 2020) of Cape anchovy (in billions), 2015–2018

Year	Upwelling-model-estimated recruitment (*Upwell-recruit*)	Survey-estimated recruitment (*Survey-recruit*)	Assessment-model-estimated recruitment (*Assess-recruit*)	Comment
2015	289.0	262.7	152.3	Good match (differ by +10%) between *Upwell-recruit* and *Survey-recruit*; poor match (differ by +90%) between *Upwell- recruit* and *Assess-recruit*
2016	127.9	118.1	141.7	Good match (differ by +8%) between *Upwell-recruit* and *Survey-recruit*; good match (differ by -10%) between *Upwell-recruit* and *Assess-recruit*
2017	293.4	830.2	213.3	Poor match (differ by -65%) between *Upwell-recruit* and *Survey-recruit*; moderate match (differ by +38%) between *Upwell-recruit* and *Assess-recruit*
2018	352.6	No survey	117.4	No comparison with survey possible; very poor match (differ by +200%) between *Upwell-recruit* and *Assess-recruit*

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Notes