INVESTIGATION INTO THE USE OF SOUTH AFRICAN CAPE ANCHOVY AND WEST COAST ROUND HERRING FOR DIRECT HUMAN CONSUMPTION FOR INCREASED FOOD AND NUTRITION SECURITY

Final report to the Water Research Commission by

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DISCLAIMER

EXECUTIVE SUMMARY

Context

South Africa and other Southern African Development Community (SADC) countries face persistent challenges of food and nutrition insecurity, especially in their low-income populations, with about 20% to 40% of the population in the region experiencing severe food insecurity. Yet, South Africa has abundant and underutilised pelagic fish resources, in particular Cape anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*), also known as West Coast round herring. In addition, these two species are currently primarily used for fishmeal and fish oil production rather than for direct human consumption. The argument being advanced in this report is that increasing the direct human utilisation of underutilised fish resources such as anchovy and West Coast round herring could positively contribute towards nutrition and protein food security in South Africa and in the SADC region as a whole.

Observably, the utilisation of processed small fish is the largest part of the edible fish product supply in most African countries. The growing number of migrants from other African countries settling in South Africa as refugees and in search of employment and opportunities has resulted in a growing market for African imported food from migrants' countries of origin. With regard to fish, these come mainly in the form of sun-dried, smoke-dried or salted-dried products – a market for processed small fish in South Africa. One group of potential consumers to target in South Africa could therefore be foreign nationals who are already used to eating such fish. Other countries in the SADC region also potentially provide a huge market for new anchovy and red-eye round herring products.

This research was part of a strategic push towards the increased utilisation of anchovy and red-eye round herring for direct human consumption through development of products aimed at the lower-income end of the market to improve food security and nutrition in this target population. The intention was to test new products in the local population and raise awareness about these products. Other possible target markets are institutional consumers such as school feeding schemes, correctional services institutions and hospitals.

Geographic areas and seasons for catching anchovy for human consumption

To determine appropriate areas and seasons for catching South African anchovy for direct human consumption, the research synthesised information on the taxonomy, distribution, biology, ecology and life history strategy of this species in South African waters; briefly described previous attempts to process South African anchovy for human consumption; described the South African small pelagic fishery in general and the directed fishery for anchovy in particular; synthesised anchovy abundance and distribution patterns derived from annual surveys to estimate the recruitment strength and total biomass of this species; and examined studies of the diets of fish, seabird and marine mammal predators of anchovy that may provide some information on seasonal variability in the occurrence, abundance and size of anchovy off the South Coast where this fishery currently does not operate. The study found that:

- Anchovy are found around the South African coast from the Orange River mouth to Gqeberha but, while they are present off the Southwestern Cape Coast and most of the South Coast throughout the year, they are typically rare or only occur in low abundance north of Cape Point in spring and summer.

- Because of their life history strategy, South African anchovy show size-based distributions with smaller (younger) fish occurring predominantly off the West Coast and larger (older) fish occurring predominantly off the South Coast.
- South African anchovy is presently only fished off the West Coast. Catches are dominated by small fish and show a strong seasonal pattern, being taken predominantly in autumn and winter (March to August).
- Studies of the diets of anchovy predators off the South Coast confirm the presence of large fish there, although various biases in those studies limit their utility for identifying seasonal patterns in anchovy abundance.

Potential and predicted climate change impacts on anchovy

Assessment of the possible impacts of climate change on South African anchovy found that:

- Predicted changes in coastal marine environments arising from climate change include increased temperatures, stratification, sea levels and extreme weather events; decreased pH and dissolved oxygen levels; and changes in circulation patterns, freshwater availability and lower trophic level (plankton) composition.
- Predicted and important near-future changes in the South African marine environment include increased sea surface temperatures (SSTs) around the entire coast, increased upwelling off the West and Southwest coasts, and increased primary production off the West Coast and in inshore waters off the Southwest and South coasts.
- Predicted climate change impacts on anchovy include changes in distribution, abundance, phenology, physiology and other biological characteristics, including body size and length at maturity.
- Despite South African anchovy being considered to have an overall "medium-low" sensitivity to climate change, warming is predicted to have a strong, negative impact on this species, with biomass reductions of around 50% projected by 2050. Projected increased upwelling may have positive or negative impacts on anchovy recruitment and hence abundance, depending on whether the timing of upwelling changes.
- The distribution of South African anchovy is strongly correlated with SSTs, and the observed change in anchovy distribution has been linked to changes in SSTs off the South Coast.

Will increased harvesting of anchovy have ecosystem impacts, including supporting the recovery of the sardine population?

South African anchovy plays a critical role in coastal ecosystems of the West, Southwest and South coasts, particularly as forage for a wide variety of fish, seabird and marine mammal predators for whom anchovy is important and sometimes dominant prey. Changes in the abundance and availability of anchovy have large impacts on such dependent predators. Additionally, it has been argued that increased harvesting of anchovy could be beneficial to the southern African sardine population, given that the two species are ecologically similar and hence compete for resources to some degree. The study found that:

- The fishery for South African anchovy is presently considered to be sustainable, but annual total allowable catches (TACs) are under-caught by some 43.9% on average (2000–2023, equivalent to ca. 190 000 t) and low exploitation rates (8.6% per year, on average) suggest that this species is under-utilised.
- Based on the Peruvian example where significant efforts were made to develop anchoveta for human consumption products (HCPs), large quantities of anchovy will not be needed for the development of HCPs from South African anchovy, at least in the short-term, and

likely also the long-term, unless multiple barriers can be overcome. In conjunction with the present under-utilisation of South African anchovy, this suggests that a fishery for this species for HCPs would likely start to use relatively small quantities (a few multiples of 10 000 t) in the near (or even mid-term) future. This is likely substantially less than the average 190 000 t of the anchovy TAC that is presently not caught, indicating that development of South African anchovy for HCPs could be accommodated without a need to increase present allowable exploitation rates of the South African anchovy. Targeting the un-caught portion of the TAC for anchovy for HCPs would be unlikely to incur substantial ecosystem impacts.

- A comparison of the population trajectories of South African anchovy and sardine shows that estimates of recruitment strength of the two species and of their total biomass are significantly and positively correlated, suggesting that the dynamics of the two species are responding to the same, likely environmental, forcing. This suggests that reducing the size of the anchovy population through increased harvesting is unlikely to have beneficial effects on the sardine population.

New anchovy and red-eye round herring products and markets for these products

The research investigated the types of new products that could be developed for direct human consumption from South African anchovy and red-eye round herring by looking into types of products and analysing the effects of hot and cold smoking on nutritional value and oxidative stability of the two species. The aim was to develop sustainable, nutrient-dense food products.

The project undertook development of the following products for direct human consumption: filleted hot-smoked anchovy; whole hot-smoked anchovy; marinated filleted anchovy; filleted hot-smoked red-eye round herrings; filleted cold-smoked red-eye round herrings; and a fish powder (as a completed food ingredient for potential fortification) made from steamed filleted red-eye round herring.

Anchovy

Anchovy is highly perishable due to its high moisture and fat content, making effective preservation critical. The research investigated the viability of long-term frozen storage of whole and filleted anchovy, combined with vacuum packaging versus aerobic packaging to ensure microbial safety and quality. Vacuum packaging did not significantly reduce microbial growth compared to aerobic packaging. This suggests that frozen storage at a temperature of –18°C is the primary preservation factor rather than the exclusion of oxygen. Both packaging environments permitted the survival of psychotropic, facultative anaerobes, which are capable of surviving in low temperatures and varying oxygen levels. Both whole and filleted anchovy stored under both packaging conditions complied with South African microbiological standards for foodstuffs (Regulation R.692),[1] specifically regarding total viable counts (TVC) and the absence of *E. coli*. The results indicate that either packaging method can sustain the production of safe anchovy products for human consumption, potentially allowing for cost-effective production for the lower-end market. However, physical quality degradation in fillets suggests that, while the product remains safe, enzymatic spoilage remains a challenge.

[1] Regulations governing microbiological standards for foodstuffs and related matters under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972).

Filleted, hot-smoked anchovy, whether stored in vacuum bags or aerobic bags, may be safe for human consumption with up to 7 days of refrigerated storage (less than 1 000 000cfu/ml). Whole hot-smoked anchovy showed higher bacterial counts compared to filleted samples, especially in terms of *Enterobacteriaceae*. This can be attributed to the gut which remained in the whole anchovy. Vacuum packaging was shown to inhibit the increase in bacterial counts from day 4 to day 7. Thus, for an extended shelf-life of smoked anchovy, vacuum packaging should be considered. Smoking increased the protein content of filleted and whole anchovy due to the concentration factor.

The nutritional content of smoked anchovy showed that smoked anchovy is an excellent source of essential omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The concentration is influenced by the smoking processing method, where EPA and DHA levels range from as low as 1 mg/g in raw anchovy to up to 13 mg/g in smoked anchovy without heads and smoked fillets.

In terms of amino acid content, the smoked anchovy contained a highly balanced profile of essential and non-essential amino acids. Key amino acids (including alanine, glycine, valine, leucine, isoleucine, proline, methionine, serine, threonine, phenylalanine, aspartic acid, glutamic acid, lysine, histidine, and tyrosine) are present in high amounts, ranging from 10 to 70 mg/g. The recommended daily allowance (RDA) for essential amino acids varies by body weight (e.g., leucine at 39–42 mg/kg, lysine at 30–38 mg/kg, and valine at 24–26 mg/kg). A standard 100 g serving of smoked anchovy provides enough essential amino acids to meet the RDA for a healthy adult weighing between 60 and 70 kg.

In terms of food safety, based on the South African Regulations relating to maximum levels of metals in foodstuffs (June 2018), the heavy metal safety profile for smoked anchovy is largely positive. Also, toxic heavy metals such as lead (Pb) tested below the maximum legal limit (0.3 mg/kg wet weight basis). While methylmercury was not determined, the total mercury (Hg) levels in raw anchovy was on average 0.013 mg/kg and ranged between 0.017 and 0.021 mg/kg for the hot-smoked anchovy products. The total arsenic (As) levels for the different anchovy products ranged between 5 and 8 mg/kg on dry weight basis across filleted and whole smoked, and raw samples. On wet weight basis, the arsenic was between 2.3 mg/kg and 3.68 mg/kg. However, the analytical method used only measured total arsenic and did not distinguish between highly toxic inorganic arsenic and relatively harmless organic arsenic, of which the latter is predominantly found in marine fish.

Red-eye round herring

The research confirms that red-eye round herring is a viable alternative to sardine for human consumption. Processing through hot- or cold-smoking effectively concentrates nutrients without degrading essential fatty acids. The antioxidant properties of the smoking process may enhance the product's shelf-life stability by preventing extensive lipid oxidation. The resulting products are rich in protein, B-vitamins, retinol, and omega-3 fatty acids, positioning them as an excellent tool for addressing nutritional insecurity in South Africa. Due to moisture content remaining above 10% (approx. 62%), the smoked products are not shelf-stable at ambient temperatures and must be kept refrigerated or frozen to ensure safety. Future research should include microbial safety testing (specifically for *Listeria* and *Clostridium*) and comprehensive sensory analysis to gauge consumer acceptance. The development of value-added products, such as instant fish soup powders incorporating red-eye round herring, should be pursued to diversify the number of market offerings.

Market research

A survey of the opinions of 1 000 people about anchovy was conducted around the general question: "Which kinds of seafood do you like?" Only 13% indicated anchovy, and of these, only 4% were from the low-income group. The most preferred seafoods were hake, tuna, and pilchards/sardines (in that order). However, the low preference for anchovy could be attributed to consumers not being familiar with it. In addition, anchovy and its products were perceived as a "low-profile" seafood and not considered by many as a food staple. It was seen as a luxury food (because of the expensive forms currently available on the retail shelves and on pizza) and, at the moment, anchovy has a low penetration into low-income households. On the positive side, anchovy was recognised as a source of essential amino acids and omega-3 fatty acids, which provides an opportunity to leverage the perception of anchovy as a health food by developing and marketing attractive affordable forms of anchovy, especially among low-income, female, and younger seafood eaters (below 50 years).

Processing guidelines

The current project has developed a basic guideline for the processing of hot- and/or cold-smoked South African anchovy and red eye round herring based on the laboratory trials that investigated the effects of smoking on the macro- and micro-nutritional content, mineral content, and microbial load of *Engraulis encrasicolus* and *Etrumeus whiteheadi*. By meticulously following these preparation steps, particularly focusing on proper evisceration and strict control of temperature (especially chilling before processing to mitigate histamine risk, followed by refrigeration of the smoked products), the hot smoking process can transform currently underutilised anchovy and red-eye round herring into nutritious, safe, and value-added products, thereby addressing the goals of increasing the availability of healthy fish protein for low-income consumers.

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Acronyms

AB	Algoa Bay
ANOVA	analysis of variance
AOAC	Association of Official Analytical Chemists
AP	aerobic packaging
API	Analytical Profile Index
at	acoustic transects
AUC	African Union Commission
a_w	water activity
BMDL	Benchmark Dose Lower Confidence Limit on Food Additives
CA	Cape Agulhas
CAB	Central Agulhas Bank
CAC	Codex Alimentarius Commission
CAF	Central Analytical Facilities, Stellenbosch University
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalVET	California vertical egg tow
CC	Cape Columbine
CD	conjugated dienes
cfu	colony-forming units
cfu/g	colony-forming units per gram
Chl a	chlorophyll a data
CI	Cape Infanta
CL	caudal length
CMIP	Coupled Model Intercomparison Project Phase
CP	Cape Point
CPS	catch per set
CPUE	catch per unit effort
CPUT	Cape Peninsula University of Technology
CV	coefficient of variation
DAFF	Department of Agriculture, Forestry and Fisheries
DEB	dynamic energy budget
DEFF	Department of Environment, Forestry and Fisheries
DHA	docosahexaenoic acid
DFFE	Department of Forestry, Fisheries and the Environment
EAB	Eastern Agulhas Bank

EBUSs	Eastern Boundary Upwelling Systems
Eddie_k	eddy kinetic energy
Ek_upw	Ekman upwelling
EoCA	east of Cape Agulhas
EPA	eicosapentaenoic acid
ER	exploitation rate
EU GDPR	European Union General Data Protection Regulation
FA	fatty acid
FAI	Forage Availability Index
FAME	fatty acid methyl ester
FAO	Food and Agriculture Organization of the United Nations
FO	frequency of occurrence
GC	gas chromatograph
GC-MS	gas chromatography-mass spectrometry
GE	George
$g.m^{-2}$	grams per square metre
GAMs	generalised additive models
GLM	general linear model
GLOBEC	Global Ocean Ecosystem Dynamics
GSI	gonadosomatic-index
HAB	harmful algal bloom
HCPs	human consumption products
HDC	histidine decarboxylase
HKB	Hondeklip Bay
HLPE	High Level Panel of Experts on Food Security and Nutrition
IBM	individual based model
ICES	International Council for the Exploration of the Sea
ICLARM	International Center for Living Aquatic Resources Management
ICMSF	International Commission on Microbiological Specifications for Foods
ICP-MS	Inductively coupled plasma mass spectrometry
IEC	International Electrotechnical Commission
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JECFA	Joint FAO/WHO Expert Committee on Food Additives (JECFA)

LDCs	least developed countries
LDL	low-density lipoprotein cholesterol
Log_chl	log of surface chlorophyll *a* concentration
LOW	low oxygen water
LSM	South African Audience Research Foundation Living Standards Measure
MAPS	Marketing All Product Survey
MARAM IWS	Marine Resource Assessment and Management Group (MARAM) International Stock Assessment Workshop (IWS), University of Cape Town.
MB	Mossel Bay
MDA	malondialdehyde
MHW	marine heat wave
MPA	marine protected areas
mtDNA	mitochondrial DNA
MUFA	high monounsaturated fatty acids
mwt	mid-water trawls
NCDs	non-communicable diseases
NEPAD	New Partnership for Africa's Development
ND	not determined
NG	no growth
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary production
OEW	optimal environmental window
OMP	Operational Management Procedure
ORM	Orange River Mouth
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-mer
PA	Port Alfred
PAHs	polycyclic aromatic hydrocarbons
PCA	principal component analysis/ plate count agar
PENM	Probabilistic Ecological Niche Model
PLAAS	Institute for Poverty, Land and Agrarian Studies, University of the Western Cape
PSJ	Port St Johns
PUCL	precautionary upper catch limit
PUFA	polyunsaturated fatty acids
RCP	Representative Concentration Pathway
RDA	recommended daily allowance
SADC	Southern African Development Community

SANHANES-1	South African National Health and Nutrition Examination Survey
SASSA	South African Social Security Agency
SD	standard deviation
SDGs	Sustainable Development Goals
SE	southeasterly
SHB	St Helena Bay
SFA	saturated fatty acids
SNPs	single nucleotide polymorphisms
SOC 2	Service Organization Control 2
SPSS	Statistical Product and Service Solutions software
SSH	sea surface height
SSP	Shared Socio-Economic Pathway
SSS	sea surface salinity
SST	sea surface temperature
STARS	sequential *t*-test analysis of regime shift
Stats SA	Statistics South Africa
SW	southwest
SWG-PEL	DFFE Small Pelagic Scientific Working Group
t	tonne
TAB	total allowable bycatch
TAC	total allowable catch
TBARs	thiobarbituric acid reactive substances
TGAM	threshold-generalised additive model
TL	total length
TNTC	too numerous to count
TVC	total viable count
µg	microgram
UNICEF	United Nations Children's Fund
UWC	University of the Western Cape
v/v	volume per volume
VP	vacuum packaging
VRBA	Violet Red Bile Agar
WAB	western Agulhas Bank
WBW	wet body weight
WFP	World Food Programme

WHO	World Health Organization
WoCA	west of Cape Agulhas
WoRMs	World Register of Marine Species
WRC	Water Research Commission
WWF	World Wide Fund for Nature
XRF	X-ray fluorescence

Contents

CHAPTER 1
INTRODUCTION, BACKGROUND, AIMS AND OBJECTIVES OF THE PROJECT AND METHODOLOGICAL APPROACH

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1.1 Sardine decline and regime shift

In recent years, surveys indicate a depleted state of the South African sardine resource, which has failed to recover since 2006 (DAFF, 2016). This resulted in the progressive reduction in total allowable catch (TAC) since 2016 to the extent that, in 2019, the TAC was only 12 250 tonnes, a reduction of about 90% on average TAC for normal years (Figure 1.1).

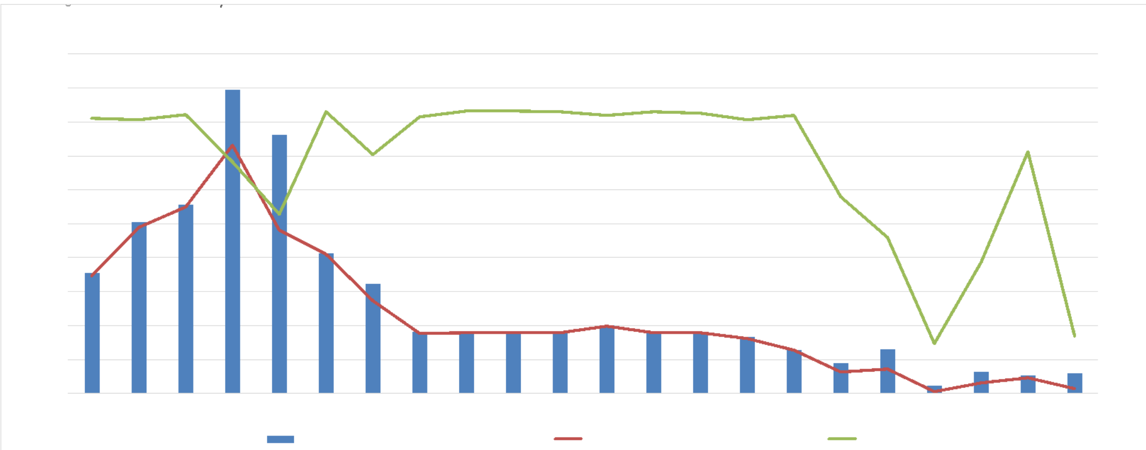

Figure 1.1. Historical sardine TAC (source: de Goede, DFFE).

Although sardine and anchovy have a migratory life history pattern, in which the adults of the two species spawn on the Agulhas Bank and the eggs and larvae are then transported to the more nutrient-rich West Coast where recruitment and feeding takes place before the spawners return to the South and East coast to complete the cycle, there appears to be a change in this stable cyclic life history pattern (van der Lingen et al., 2005) as a result of heavy fishing pressure on the west coast, environmental changes such as increased upwelling east of Agulhas (Coetzee et al., 2008; Cury et al., 2000) and/or additional climate related changes in the system (Watermeyer et al., 2016; 2018). An ecosystem-level regime shift occurred in the early 2000s and has not been reversed to date (Watermeyer et al., 2016; 2018; Blamey et al., 2012; Atkinson et al., 2012, p. 20; Howard et al., 2007). Thus, the relative abundance of the two species declined on the West Coast and increased on the South Coast.

The small pelagic industry has dealt with this variability by consolidation, diversification, range expansion (Jarre et al., 2013, Watermeyer et al., 2016) and importation of raw sardine for processing. Despite these strategies, the sardine has continued to decline, resulting in loss of employment/work hours, and other social-ecological changes. This situation in the small pelagic social-ecological system is indicative of the loss of resilience, particularly on the West

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Coast where the system appears to be in a poor state, to the extent that its resilience to large-scale change appears to have been critically compromised (Jarre et al., 2013).

Sardine (*Sardinops sagax*) and hake (*Merluccius paradoxus* and *Merluccius capensis*) contribute 70% of fish that is consumed by South Africans (WWF, 2014). Of the two, sardine has historically been the most important source of fish protein for low- and middle-income South Africans. Despite the problems being experienced with the sardine resource, other South African small pelagic marine fish species such as anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) have been largely unaffected and are currently somewhat under-utilised. For example, since the year 2000, only an average of 53% of the allocated total allowable catch for anchovy had been caught by rights holders (DAFF, 2015).

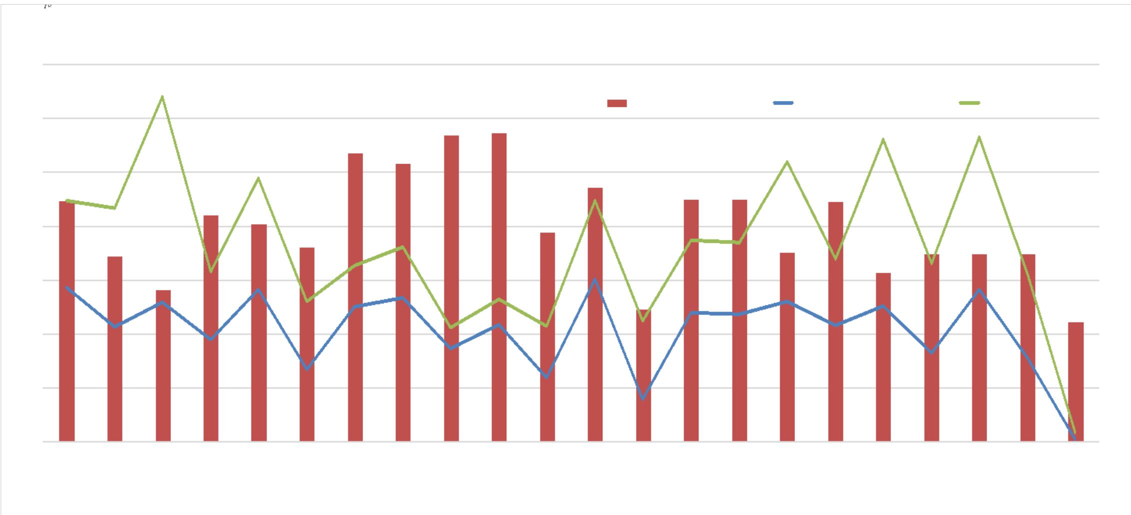

Figure 1.2. Historical anchovy TAC vs catch (source: de Goede, DFFE)

Besides not catching the entire TAC, all the anchovy harvested from South African waters is currently reduced to fishmeal and fish oil. This underutilised pelagic resource (anchovy) provides potential for an increased affordable source of fish protein for direct human consumption. Increased profitability of the anchovy-directed industry through value addition could improve the flow of revenue to the communities that could be involved in value-addition activities and hence contribute towards social-ecological viability and sustainability of the small pelagic system (Jarre et al., 2013; Paterson et al., 2010).

1.2 Food and nutrition security

Although governments globally have made great progress in fighting hunger in recent years, with 200 million fewer people being undernourished, the success in reducing micronutrient deficiency has been slow. Undernourishment disproportionately affects low-income countries (Díaz-Bonilla & Hepburn, 2016). The Sustainable Development Goals (SDGs) 2030 (in particular, Goal 2) established a new commitment for both developed and developing countries, which is to end hunger as well as all forms of malnutrition by 2030. For South Africa, increased wellness, as well as the aims to 'ensure household food and nutrition security', are milestones under the National Development Plan (National Planning Commission, 2011).

South Africa and most other Southern African Development Community (SADC) countries continue to suffer from food and nutrition insecurity (SADC, 2014). The Food and Agriculture Organization of the United Nations (FAO) has estimated that about 20% of the population in southern Africa suffers from severe food insecurity (FAO, 2017). In addition, chronic malnutrition persists in 30 to 40% of the population in most SADC countries (FAO et al., 2018). Despite South Africa being considered a "food-secure" nation producing enough calories to adequately feed its more than 60 million people (Oxfam, 2014; Stats SA, 2019), the proportion of people living below the food poverty line was 25.2% in 2015 (Stats SA, 2019), and 27% of children under five years of age were stunted (Stats SA, 2017) – a proportion that had not changed in the 20 years prior to 2017 (Jonah et al., 2018).

Fish is a rich source of easily digestible high-quality protein containing all essential amino acids; provides essential fats (e.g. long-chain omega-3 fatty acids) not found in most other protein sources; and provides vitamins (D, A and B) and minerals (including calcium, iodine, zinc, iron and selenium); is usually high in unsaturated fats and specifically the omega-3 fatty acids eicosapentaenoic (EPA) and docosahexaenoic acids (DHA) (Hoge et al., 2018; Miller et al., 2014; Tur et al., 2012; Simopoulos, 2002). Therefore, fish has many health benefits, particularly when eaten whole (FAO, 2016), which is the case in most developing countries. Even when taken in small quantities, which is the case in many developing countries, fish can have a significant positive nutritional impact on diets that are mainly plant-based (FAO, 2016; HLPE, 2014). Given these nutritional properties, fish can play an important role in correcting unbalanced diets and in countering obesity and protecting against cardiovascular diseases, which are a growing problem in South Africa (Thow et al., 2015; Shisana et al., 2013).

In 2017, the average per capita fish supply for most SADC countries (except Seychelles, Mauritius, Mozambique, Namibia and Angola) was between 7 and 8kg (FAO, 2016), which was lower than the 9.9kg average per capita consumption for Africa and much lower than the global average of 20.3kg per person per year in 2017 (FAO, 2020). The stagnant or declining production from both inland and marine capture fisheries in most SADC countries at the same time as human populations are increasing means that the per capita supply/ consumption for most of sub-Saharan Africa is likely to decline even further. The increased utilisation of the anchovy could contribute to increased supply of affordable fish protein nationally and regionally.

1.3 Ecosystem resilience

Although aquatic and terrestrial environments have an equal amount of organic matter, humans only source 3% of their total food consumption from the aquatic environment. Small pelagic fish are forage species, which means that they are at the lower level of the aquatic food chain. They are important prey of carnivorous fish species, marine mammals and marine birds. Because large (carnivorous or top predator) fish has generally greater market value, fishing nations mostly harvest the tip of the aquatic food trophic pyramid, which is inefficient and less environmentally and biologically sustainable (Garcia et al., 2012). By harvesting small (short-lived) fish that are at the lower levels of the trophic pyramid, we can increase production and sustainability since these are much more prolific in terms of fecundity and therefore abundance. In Africa, where production of the large (typically long-lived) fish species has declined, the importance of small pelagics as a source of food has increased to the extent that these now represent nearly three-quarters of total inland fish production on the continent (Kolding et al., 2017).

1.4 Past anchovy promotion initiatives

There have been some initiatives in the past to promote the use of South African anchovy for human consumption, especially in the 1980s. These foundered on a number of issues. Key problems were certain characteristics of anchovy: it is fragile when handled; it has volatile stomach contents; it has high lipid content resulting in quick oxidisation; it changes colour after processing; and it has a short shelf life. Secondly, most of the South African anchovy fishery, especially on the West Coast is a recruit fishery and therefore the size of fish that is caught is small (less than 10 cm). The adult anchovy mostly found on the South Coast of the Eastern Cape and further offshore, is bigger and would be more suitable for processing for human consumption.

A critical issue is that most past anchovy promotion initiatives for human consumption tried to produce products aimed at high-end consumer markets such as fillets, but the small average size of this fish poses challenges in that it is time-consuming (2.8 kg/ 7-hour day/ worker); has relatively low yields (32% yield from fresh to fillet); and there was lack of technical processing skills.

The current project aimed to investigate products for the lower-end market such as whole smoked fish, whole dried fish, fish paste, powdered fish, etc. By having as its objective to work on product development for the lower-end market using whole fish, the current project is different from past initiatives to promote anchovy for human consumption. By involving the public and communities in the testing and production of such new products, this could eventually create jobs and income in low-income communities and increase the chances of market penetration of new products in low-income communities.

The Peruvian experience is a good example. Peru has the world's largest anchovy resource. Until recent decades, Peruvian anchovy was almost exclusively used for fishmeal, just as is done in South Africa. Peruvians did not eat anchovy despite its abundance, health benefits and being a relatively inexpensive source of animal protein. Since 2005, anchoveta (*Engraulis ringens*) has increasingly been used for direct human consumption. The increase in direct human consumption in Peru was the result of large-scale promotion and educational campaigns, including by the President of that country.

1.5 Aims and objectives of the research

The aims and objective of the current research project were to investigate the following:

- The feasibility of utilising anchovy for direct human consumption and, if feasible, how this could be scaled-up and thereby contribute towards increased fish protein supply for the low-income population group.
- Whether diversifying from an over-dependence on sardine to increased utilisation of anchovy could improve resilience of the small pelagic fishery as a whole.
- Whether the utilisation of anchovy for human consumption could create employment, given that processing would likely be labour-intensive. The intention is to encourage small-scale processing cooperatives based in communities, which could buy the raw product for processing from industrial fishing rights holders.
- Whether increased utilisation of the anchovy could alleviate pressure on the sardine and thus contribute to its recovery, and in effect increase the resilience of the small pelagic social-ecological system.

1.6 Methodology

The research was undertaken in the Western Cape and the Eastern Cape by researchers from the University of the Western Cape (UWC),[5] Cape Peninsula University of Technology (CPUT)[6] and an independent consultant[7] (a retired scientist who previously worked on small pelagics in what is now the Department of Forestry, Fisheries and the Environment (DFFE).

The project collaborated with two private fishing companies (one in the Western Cape and another in the Eastern Cape) that have anchovy fishing rights and have an interest in the utilisation of anchovy for human consumption and the DFFE. The private companies (particularly the one based in the Western Cape) and the DFFE supplied the team with the raw anchovy for product development and content analysis. It was hoped that the private companies will pilot the scaling-up of production of the new products. During the duration of the project, postgraduate degree students were recruited to be part of the research team.

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[6] Suné Henning and Ziyanda Phike.

[7] Carl van der Lingen.

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CHAPTER 2
REPORT ON THE POTENTIAL MARKET SIZE FOR THE ANCHOVY PRODUCTS

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2.1 Introduction

This chapter reports on the potential market size for the new anchovy products. It estimates the potential size of the market for the new anchovy products that this project could develop and looks at existing knowledge of the potential markets for the new anchovy products.

2.2 Potential markets for small processed fish in Africa

Most Southern African Development Community[11] countries continue to suffer from food and nutrition insecurity (SADC, 2014). About 20% of the population in southern Africa experiences severe food insecurity[12] (FAO, 2017). In addition, chronic malnutrition[13] persists in 30 to 40% of the population in most SADC countries (FAO et al., 2018). In 2020, 21% of the population in Africa was undernourished,[14] while the figure for sub-Saharan Africa was higher at 24% (FAO, IFAD, UNICEF, WFP and WHO, 2021). This figure is likely to have increased as a result of the Covid-19 pandemic.

While annual per capita fish consumption increased steadily on a global scale (from 9kg in 1961 to 20.5kg in 2018), the increase in the least developed countries (LDCs), most of which are located in Africa, was lower – from 6.1kg in 1961 to 12.6kg in 2017. Per capita fish consumption for Africa in 2013 was 9.8kg, which was about half the global average of 19.7kg for that year (FAO, 2016; AUC-NEPAD, 2014).[15] Estimates suggest that, until 2030, the global per capita supply of fish will continue to increase in all regions except Africa, which will experience a decline of 3%. The highest growth rates are projected for Asia (9%), Europe (7%), and Latin America and Oceania (6% each) (FAO, 2020). In Africa, the per capita fish consumption is expected to decrease by 0.2% per year up to 2030 – from 10kg in 2018 to 9.8kg in 2030. The decline will be greater in sub-Saharan Africa, from 8.9kg to 8.1kg. The FAO (2020) explains that the main reason for this drop will be as a result of Africa's population growth outpacing the growth in supply, with an expected 13% increase in domestic production

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[11] SADC comprises of: Angola, Botswana, The Democratic Republic of Congo, Eswatini (formerly Swaziland), Lesotho, Madagascar, Malawi. Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe.

[12] People experiencing severe food insecurity have typically run out of food and, at worst, gone a day or more without eating. (FAO, n.d. (a)).

[13] A form of growth failure that causes both physical and cognitive delays in growth and development as a result of prolonged episodes of inadequate nutrition leading to stunting (Reinhardt & Fanzo, 2014).

[14] Undernourishment is defined as the condition in which an individual's usual food consumption is insufficient to provide the amount of dietary energy required to maintain a normal, active, healthy life. (FAO, n.d. (b)).

[15] Even then it must be noted that this increase in African countries was largely as a result of increased production of small pelagics and imports (Summance et al., 2021; FAO, 2020; Kolding et al., 2019).

over the period 2019–2030 and increased fish imports unable to meet the region's growing demand.

In 2017, the average per capita fish supply for most SADC countries (except Seychelles, Mauritius, Mozambique, Namibia and Angola) was between 7 and 8 kg (FAO, 2016), which was lower than the 9.9 kg average per capita consumption for Africa and much lower than the global average of 20.3 kg per person per year in 2017 (FAO, 2020). Table 2.1 presents the fish per capita supply for the SADC.

Table 2.1: Per capita fish supply for SADC countries

Country	**Per capita fish supply (kg/person/yr)**			
	2005	**2010**	**2015**	**2017**
Angola	12.1	14.7	14	20.2
Botswana	2.8	3.6	3.0	3.7
Democratic Republic of Congo	5.5	4.0	6.0	5.7
Lesotho	0.9	2.0	1.0	
Madagascar	7.1	6.8	6.0	
Malawi	3.6	7.0	7.0	11.6
Mauritius	17.2	22.0	23.0	24
Mozambique	5.0	8.50	18	11.4
Namibia	13.1 (2000)	11.9	13.6	13.6 (2015)
Seychelles	59.7 (2003–07)	57.4 (2009)	-	58.9
South Africa	5.0	7.5 (2009)	6.0	6.1 (2016)
Eswatini (Swaziland)	2.0	2.4	2.0	3.2
Tanzania	5.5	7.7	6.0	
Zambia	6.79	6.9	7.0	11.9
Zimbabwe	2.0	2.2	3.0	2.2

Sources of these figures are provided in the footnote[16]

The figures in Table 2.1 show that the average fish per capita supply for the SADC region remains below that for the whole of the continent and much lower that the global average. The stagnant or declining production from both inland and marine capture fisheries in most SADC countries[17] at the same time as human populations are increasing means that the per capita supply/ consumption for most sub-Saharan Africa is likely to decline further. The increased utilisation of the anchovy could contribute to an increased supply of affordable fish protein both nationally and regionally.

[16] http://www.fao.org/fishery/facp/AGO/en (Angola); http://www.fao.org/fishery/facp/20/en (Botswana); http://www.fao.org/3/a-br792e.pdf (Democratic Republic of Congo); http://www.fao.org/fishery/facp/122/en (Lesotho); http://www.fao.org/fishery/facp/129/en (Madagascar); http://www.fao.org/3/a-br797e.pdf (Malawi); http://www.fao.org/fishery/facp/137/en (Mauritius); http://www.fao.org/fishery/facp/144/en (Mozambique); http://www.fao.org/fishery/facp/147/en (Namibia); http://www.fao.org/3/a-br801e.pdf (Seychelles); http://www.fao.org/fishery/facp/202/en (South Africa); http://www.fao.org/3/a-br799e.pdf (Swaziland); http://www.fao.org/fishery/facp/215/en (Tanzania); http://www.fao.org/fishery/facp/ZMB/en (Zambia); http://www.fao.org/fishery/facp/181/en (Zimbabwe) All accessed 12 February 2018

[17] There are some water bodies where there could be increased production, but aquaculture is unlikely to make much difference in the next decade as it continues to lag behind trends in other African regions and global trends.

Food security – defined as "…a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2006, p. 1) – is fundamental for addressing all forms of malnutrition. But while food security is important, it is not sufficient on its own for achieving optimal nutrition (Hawkes, 2017). In particular, the way that food security is often interpreted as meaning the aggregate supply of food at global, regional or national level (FAO et al., 2018; Godfray et al., 2010) is problematic since this does not necessarily translate into food and nutrition security at household level. Thus, while a country might be food-secure, some of its population could be food-insecure and/or might be suffering from malnutrition due to unbalanced or unhealthy diets as a result of their inability to economically afford or physically access enough healthy food (FAO et al., 2021; Tveterås et al., 2012; Devereux, 2006; Sen, 1981).

The Food and Agriculture Organization of the United Nations (FAO, 2020) has pointed out the projected decline in per capita fish consumption in Africa raises food-security concerns because of the region's high prevalence of undernourishment and the importance of fish in total animal protein intake in many African countries. It said the decline may also weaken the ability of more fish-dependent countries to meet nutrition targets laid out in the United Nations Sustainable Development Goal 2 to achieve "zero hunger".

Increasing the utilisation of under-utilised fish resources such as anchovy could influence nutrition and food security through: stability of food supply (physical access), supply of diverse healthy food, lower food prices (affordability) and increased income (through related livelihood activities). However, these pathways largely relate to food supply and income components of food security, and do not focus on nutritional quality (Clapp, 2014), which also need to be taken into consideration (FAO et al., 2021; FAO 2017). Thus, increased utilisation of under-utilised fish could have the beneficial impacts of boosting the supply and availability of healthy foods and lowering prices through competition.

One thing that is evident is that, in most of Africa, the utilisation of small processed fish is the most important part of the supply of edible fish products (Summance, 2021; FAO, 2020; Kolding et al., 2019; Mussa et al., 2017). Recent years have seen growing numbers of migrants from other SADC countries coming into South Africa for employment opportunities and as refugees. This has resulted in a growing market for imported food from migrants' countries of origin. Increasing volumes of processed fish products of different varieties and species from various African countries are being imported into South Africa, targeting the migrant community (Jimu, 2018; Ndofor Epo, 2018). These come mainly in form of sun-dried, smoke-dried, salted-dried products such as kapenta, usipa and catfish from Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Imported African processed fish products are sold on the street, in markets and in shops that specialise in imported food from other African countries in South African cities and towns (Jimu, 2018; Ndofor Epo, 2018; Mussa et al., 2017). A market for small processed fish already exists in most of Africa and one group of potential consumers for the products being researched in the current report are foreign nationals living in South Africa who are already used to eating small processed fish. Within South Africa, the project team will test new products and raise awareness about these. The team will also target institutional consumers such school feeding schemes, correctional services institutions and hospitals for testing the acceptability and suitability of new products. Based on the feedback from the surveys, further development of the products will be undertaken and then consumer-tested again, to ensure that the new products are acceptable to potential consumers. This activity will also involve the development of processing technologies and equipment for new anchovy products.

In the 1990s, Oceana Private Company tried to process dried anchovy for export to other African countries using heated air circulation (Deon van Zyl, personal communication). Unfortunately, the project was abandoned before its potential usefulness could be evaluated. Real Fishing Private Company tried producing smoked anchovy, which was offered to people from the African diaspora living in South Africa. These products received very good feedback, but this project was also abandoned.

2.3 Beneficiary groups

Coastal communities where anchovy is fished and landed (St. Helena Bay, Gans Baai, Mossel Bay an Gqeberha) were potentially expected be the direct beneficiaries of the project in terms of knowledge and skills for processing and packing and selling new anchovy products in the long run. Low-income groups are proportionally more likely to experience malnutrition and food insecurity. Therefore, low-income groups in South Africa and in SADC could also benefit from the increased supply of affordable fish protein, livelihood activities and jobs from activities in the production value chain. The small pelagic fishing industry could benefit from the expected increased socio-ecological resilience of the small pelagic fishery.

This report will be provided to DFFE for possible policy review on fishing rights specifically for those applicants that could produce and process anchovy and red eye round herring for direct human consumption. Hopefully, this could result in anchovy and reed eye round herring being included in the list of tax-exempt foods which could help incentivise a change in fishing focus towards catching anchovy and red eye round herring for direct human consumption. In the long term, the Ministry of Health, feeding schemes, non-governmental organisations, international food relief organisations and other relevant stakeholders in the food and nutrition security field could be targeted for advocacy on the health benefits of anchovy and red eye round herring in terms of protein and other nutritional characteristics that could be suitable for dealing with malnutrition, non-communicable diseases (NCDs) and protein deficiency-related health conditions.

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CHAPTER 3
REPORT ON GEOGRAPHIC AREAS AND SEASONS FOR CATCHING SOUTH AFRICAN ANCHOVY FOR HUMAN CONSUMPTION

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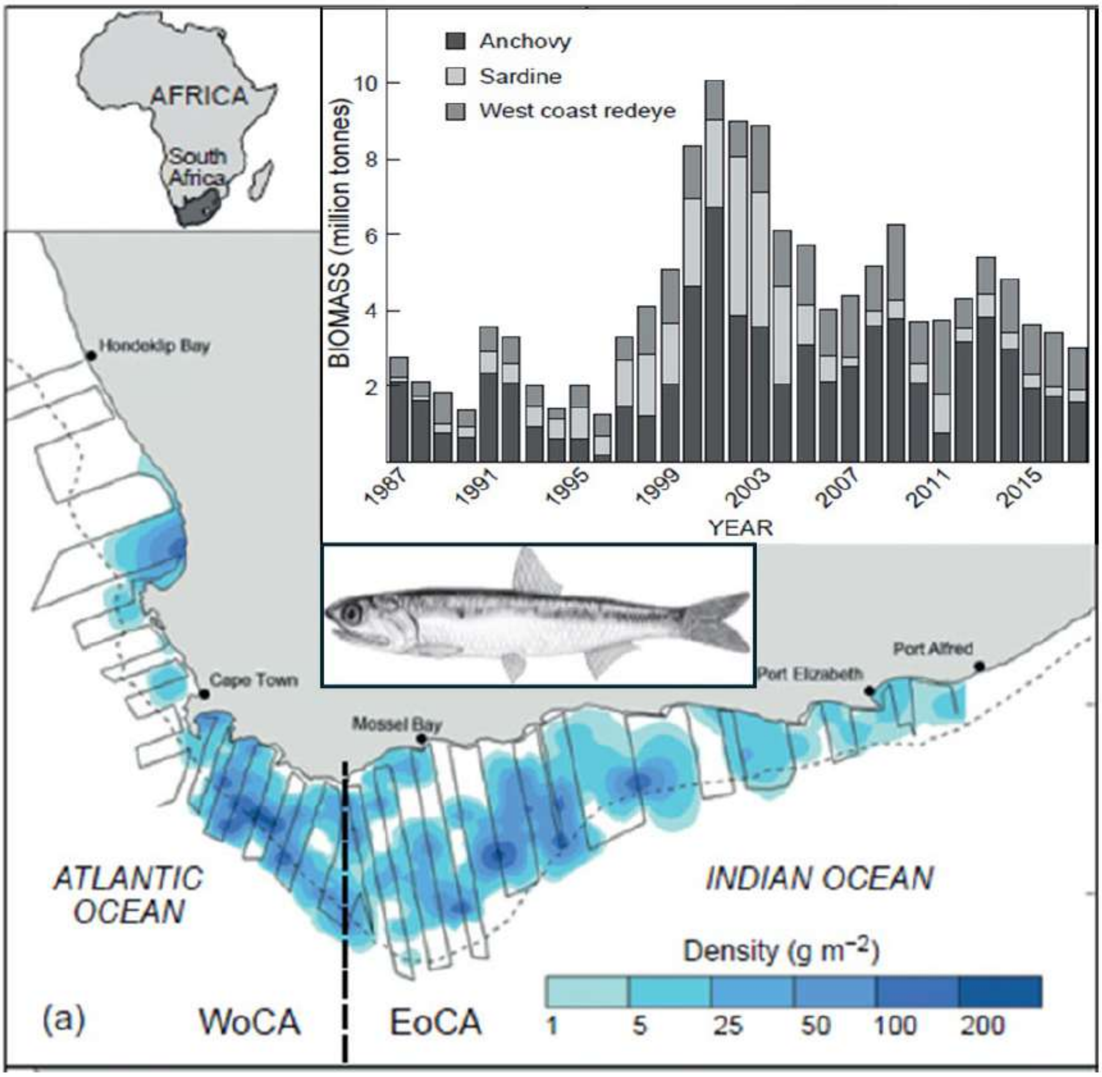

Frontispiece: Distribution of southern African anchovy *Engraulis encrasicolus* (pictured) observed during the Total Biomass Survey conducted in spring 2002 (contour map of anchovy density showing survey track (solid black lines) and the 200m depth contour (dashed black line); the thick dashed vertical line indicates the Cape Agulhas boundary between the West Coast (WoCA = west of Cape Agulhas) and South Coast (EoCA = east of Cape Agulhas)); and time series of anchovy, sardine *Sardinops sagax* and West Coast red-eye round herring *Etrumeus whiteheadi* total biomass estimated from surveys conducted between 1987 and 2017 (histogram). Image adapted from Parker et al. (2020).

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Executive summary

To determine appropriate areas and seasons for catching South African anchovy for human consumption, this report has synthesised information on the taxonomy, distribution, biology, ecology and life history strategy of this species in South African waters; briefly described previous attempts to process South African anchovy for human consumption and where this is done elsewhere; described the South African small pelagic fishery in general and the directed fishery for anchovy in particular that catches smaller (recruit) and larger (adult) fish off the West Coast and has operated for several decades; documented the abundance, distribution and fish size patterns of anchovy around the coast observed during annual Total Biomass (spring/ summer) surveys conducted over the past ten years and annual Pelagic Recruit (autumn/ winter) surveys conducted over the past five years; and examined studies of the diets of fish, seabird and marine mammal predators of anchovy off the South Coast that may provide some information on seasonal variability in the occurrence, abundance and size of anchovy in this region, given the lack of a directed fishery for anchovy there.

Key findings

- Products for human consumption that can be derived from South African anchovy include fresh or preserved (frozen, pickled, canned or dried) fillets or whole fish products which require larger fish for processing to be economically viable, as well as products such as ground dried fish, fish paste etc. which can be made from fish of any size.
- Because of their life history strategy, South African anchovy show size-based distributions with smaller (younger) fish occurring predominantly off the West Coast and larger (older) fish occurring predominantly off the South Coast.
- South African anchovy is presently only caught off the West Coast (i.e., west of Cape Agulhas) with most of the catch taken from the upper West Coast (north of Cape Columbine). The relative contribution to total annual catch taken off the Southwest Cape Coast (Cape Point to Cape Agulhas) has shown a significant long-term increase.
- South African anchovy catches off the West Coast show a seasonal pattern overall and are taken predominantly in autumn and winter (March to August), but area-specific differences in temporal catch patterns are observed and are more restricted off the upper West Coast and more spread through the year off the lower West (Cape Columbine to Cape Point) and Southwest Cape coasts.
- There is a seasonal pattern in the size of anchovy caught off the West Coast, with fish being larger in spring and summer compared to those taken in autumn and winter.
- There is a spatial gradient in the size of South African anchovy caught off the West Coast, with smaller fish caught off the upper West Coast and larger fish off the Southwest Cape Coast.
- The long-standing pelagic survey programme has shown that anchovy are distributed around the South African coast, but while they are present off the Southwest Cape Coast and most of the South Coast throughout the year, anchovy is typically rare or only occur in low abundance off the upper and lower West coasts (i.e., north of Cape Point) in spring and summer and off the eastern portion of the South Coast in autumn and winter.
- Anchovy show a gradient in size around the South African coast, being smaller off the West Coast and larger off the South Coast.
- Studies of the diets of predators that feed extensively on anchovy off the South Coast corroborate the presence of large fish there, and whereas dietary studies on African penguin, Cape fur seal and shallow water hake found little or no seasonal variation in the dietary importance of anchovy, those on Cape gannets and geelbek did, albeit with contrasting patterns. However, factors other than anchovy abundance such as the different

feeding strategies employed by different predators and the relative densities of different co-occurring prey species including preferred prey, will also impact on predator feeding patterns. This suggests caution is advisable when making assumptions about the seasonal occurrence and/or abundance of anchovy in a particular region that are based on seasonal analyses of predator diets.

Recommendations on targeting South African anchovy for human consumption

- The determination of where and when targeted fishing for anchovy for human consumption will depend on the product to be developed, given that some products require large fish whereas others do not. Because of their spatially differentiated anchovy life history strategy the seasons and areas where there is a high likelihood of catching small (<10 cm CL[19]) or large (>10 cm CL) anchovy will differ, hence recommendations for targeting small and large fish are made separately below.
- Arising from their life history strategy, and as indicated by catch patterns of the present directed anchovy fishery and observations made during both the Pelagic Recruit and Total Biomass surveys, small anchovy is available and abundant in inshore waters off the West Coast, including the western Agulhas Bank (off the Southwest Cape Coast), and are presently caught in all months of the year excluding December and January. Targeting of small anchovy for processing into products for human consumption could be undertaken from any of the designated pelagic fish landing sites on the West Coast (Lamberts Bay, Laaiplek, St Helena Bay, Saldanha Bay, Cape Town, Hout Bay, Hermanus and Gans Bay). However, and given the pulsed nature of their occurrence in waters to the north of Cape Town indicated by fishery data, fishing from harbours with easy access to the western Agulhas Bank such as Hermanus and Gans Bay would be preferrable as that would enable fish to be caught for most of the year. Targeting of smaller anchovy on the South Coast appears unlikely to be successful given their low occurrence there.
- Arising from their life history strategy, and as indicated from observations made during both the Pelagic Recruit and Total Biomass surveys, large anchovy is available and abundant in inshore waters of the western Agulhas Bank in both autumn and spring, and presumably then throughout the year. And whereas the average size of anchovy taken on the western Agulhas Bank in past decades by the present fishery is <10 cm CL, large fish are caught in most years and the average size has been close to 10 cm CL in several years, indicating that these fish are present there. Pelagic Recruit and Total Biomass surveys also show that large anchovy is also available and abundant in inshore waters along the entire South Coast to Port Alfred in spring but not in autumn, with no or few anchovy observed on the easternmost portion of the South Coast in autumn in the past five years. Studies of the diets of predators that feed extensively on anchovy off the South Coast corroborate the presence of large individuals there. However, some predators show no seasonal variation in anchovy consumption whereas others do, and factors other than anchovy abundance will also impact predator feeding patterns, suggesting caution is advisable when making assumptions about the seasonal occurrence and/or abundance of anchovy off the South Coast. Targeting of large anchovy for processing into products for human consumption could be undertaken from designated pelagic fish landing sites on the western Agulhas Bank (Hermans and Gans Bay) through the year, and likely throughout the year from Mossel Bay as well. Large anchovy would also be available in inshore waters in spring

[19] Caudal length.

(and likely summer) to vessels fishing from St Francis Bay and Gqeberha, but these fish have been absent from the Algoa Bay region during autumn/ winter in recent years.

3.1 Introduction

The Institute for Poverty, Land and Agrarian Studies at the University of the Western Cape has received funding from the South African Water Research Commission to conduct a project entitled "Investigation into use of South African anchovy for direct human consumption for increased food and nutrition security, job creation and improved socio-ecological resilience" (Project Number C2022/2023-00934). The project will report on: (i) the types and product forms of anchovy that are acceptable to consumers; (ii) the potential market size for new anchovy products; (iii) new anchovy products for human consumption; (iv) geographic areas and seasons for catching anchovy suitable for human consumption; (v) the proximate composition and mineral and fatty acid profiles of anchovy products; (vi) consumer awareness of new anchovy products; (vii) how climate change might impact anchovy and whether increased utilisation of anchovy could have ecosystem impacts, including supporting recovery of the sardine population; and (viii) the development of guidelines for handling and processing anchovy for human consumption.

This chapter is the report on point (iv) above. It comprises a desktop study that collates publicly available information to enable an assessment and identification of geographic areas and seasons that can support the sustainable harvesting of South African anchovy of a suitable size for human consumption. The report provides: (i) an overview of the taxonomy, distribution, biology, ecology and life history strategy of anchovy in South African waters; (ii) examples of instances elsewhere where anchovy is utilised for human consumption and a description of previous attempts to do this in South Africa; (iii) a description of the South African small pelagic fishery in general and the anchovy fishery in particular; (iv) information on the seasonal and spatial variability in anchovy catches off South Africa as well as on the size of anchovy caught; (v) a synthesis of anchovy abundance and distribution patterns derived from annual surveys of South African small pelagic fish resources conducted by the Department of Forestry, Fisheries and the Environment; (vi) an analysis of seasonal changes in the importance of anchovy in the diets of several marine predators including other fish species, seabirds and marine mammals off the South Coast; and (vii) conclusions and recommendations regarding where and when anchovy for human consumption should be targeted.

3.2 An overview of the taxonomy, distribution, biology, ecology and life history strategy of South African (Cape) anchovy

3.2.1 Taxonomy

Anchovy belong to the family *Engraulidae* in the order *Clupeiformes*, which also includes herrings, sardines and sprats (belonging to the family *Clupeidae*). *Clupeiformes* are small, silvery fishes that typically form (sometimes huge) schools and are found in the pelagic zone (the upper 200m of the water column) and hence are known collectively as "small pelagic fish". They are short-lived and highly fecund, feed on plankton and are preyed upon by a wide variety of predators, respond rapidly to environmental forcing, and exhibit substantial interannual variability in recruitment (the process by which new individuals are added to the population) which results in highly variable population sizes even in the absence of fishing (Peck et al., 2013; 2021). Small pelagic fish are very abundant in eastern-boundary upwelling systems like the Benguela Current ecosystem off southwestern Africa (Schwartlose et al., 1999) where they support (or used to support) moderate to large fisheries. These species also display "boom and bust” cycles in population size because of their tendency for large fluctuations in abundance and distribution in response to climate variability and their high natural mortality due to their multiplicity of predators (Rooper et al., 2024).

The anchovy off South Africa was first described as *Engraulis capensis* by JD Gilchrist in 1913, but whether this nomenclature should be used is under question. Grant et al. (2005) compared mitochondrial DNA (mtDNA) sequences from so-called “Old World” anchovy (*Engraulis australis*, *E. capensis*, *E. encrasicolus*, and *E. japonicus*) and “New World” species (*E. anchoita*, *E. mordax* and *E. ringens*) to test various hypotheses accounting for bipolar distributions (the occurrence of congeneric species that occur in the temperate zones of both the northern and southern hemispheres but not in the tropics) in this genus. Those authors reported that the genetic distance between the two Old World species in the east Atlantic (*E. capensis* in the southern hemisphere and *E. encrasicolus* in the northern) was very low compared to distances between New World species and the Old and New World groups, with such low genetic distance typical of well-differentiated populations of the same species (Grant et al., 2005). Grant and Bowen (2006) further examined mtDNA sequences from the four Old World anchovy and from *Engraulis mordax* to investigate the impacts of long-term climate oscillations on the distribution and evolution of these species in the eastern Atlantic and the eastern and western Pacific. They found that southern African anchovy had a substantially lower level of genetic diversity compared to all the other species, and that relationships among haplotypes of *E. capensis* and European anchovy *E. encrasicolus* indicate a founder event by a small number of European anchovy as the origin of the species off South Africa (Grant & Bowen, 2006).

Engraulis capensis is still considered an accepted species name by both FishBase (Froese & Pauly, 2000) and the World Register of Marine Species (WoRMS Editorial Board, 2024), but the former notes that “It hardly differs from European anchovy (*Engraulis encrasicolus*)” whilst the latter notes that “Some authors speculate this species to be identical to *E. encrasicolus*”. Apart from the work of Grant et al. (2005) and Grant and Bowen (2006), more recent work that used genomics rather than genetics has also suggested that the two species are one. Zarraonaindia et al. (2012) compared single nucleotide polymorphisms (SNPs) of *E. encrasicolus* from the entire species range (Northeast Atlantic, Mediterranean and Black seas and the Southeast Atlantic). Analysis of nuclear DNA SNPs identified two phylogroups reflecting ancient dispersals and colonisations, the first including fish from the North Sea and English Channel, the Bay of Biscay and the Mediterranean Sea, excluding the Alboran Sea (the westernmost part of the Mediterranean), and the second including South African fish, those from the Northeast Atlantic between Galicia and the Canary Islands, and the Alboran Sea. These two groups appeared to be associated with different oceanic regimes, the first inhabiting wide-shelf waters whereas the second inhabited narrow-shelf waters associated with upwelling (Zarraonaindia et al., 2012). Given the above, and the fact that the anchovy that occurs off South Africa and is called Southern African or Cape anchovy has been referred to as *Engraulis encrasicolus* in numerous publications by local scientists since the early 2000s, it will be referred to as such in this report.

3.2.2 Distribution

Because of the commercial importance of this species a substantial amount of research has been conducted on South African anchovy. This species is distributed over the continental shelf around southern Africa from Walvis Bay in Namibia to Maputo in Mozambique (Heemstra & Heemstra, 2004) and is abundant off the West and South coasts of South Africa (Figure 3.1). South African anchovy also occur off the South African East Coast, with high densities observed in the vicinity of East London[20] in research surveys conducted in the late-1980s (Armstrong et al., 1991) and in 2005 (Coetzee et al., 2010) but few fish found further north. However, anecdotal evidence of a recent increase in the abundance of South African anchovy off Durban (Guy, 2016) suggests that this species may be extending its distribution northwards along the South African East Coast.

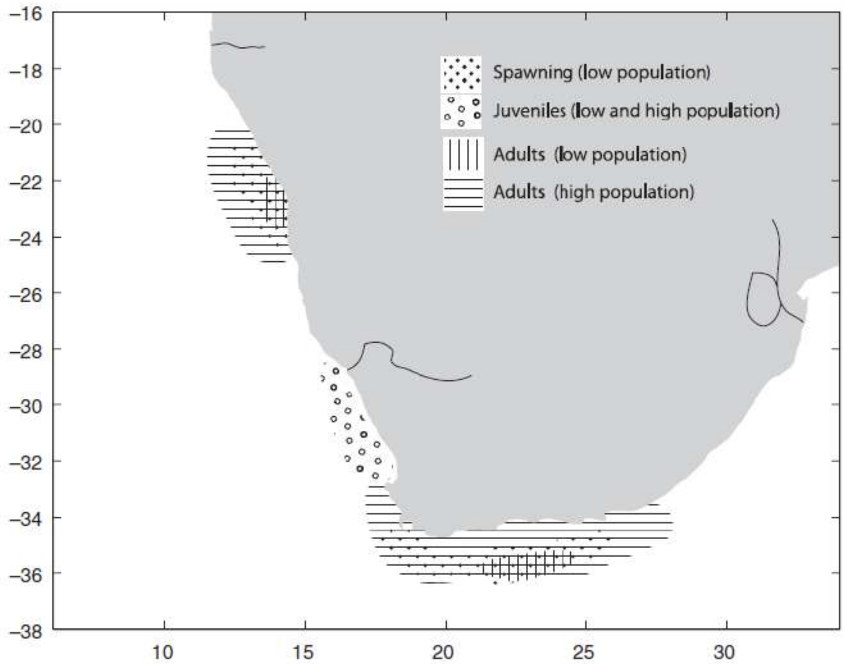

Figure 3.1: Distribution of Southern African anchovy at low and high population sizes. Adapted from Checkley et al. (2009).

3.2 3 Biology and ecology

South African anchovy are omnivorous planktivores that feed primarily on zooplankton such as large copepods and euphausiids that they capture via selective particulate-feeding (James, 1987; van der Lingen et al., 2006). This species is also able to feed on smaller prey that are entrapped by the gill rakers during filter-feeding, and juveniles off the West Coast are frequently observed to have consumed large quantities of phytoplankton captured by this feeding mode. This species produces multiple batches of eggs during their prolonged spawning season, with a new batch being spawned every 7–11 days and spawning occurring at night (Melo, 1994). Southern African anchovy become sexually mature towards the end of their first year at around 9.5 cm caudal length (Le Clus, 1979), and have a relative fecundity of 471–563 eggs per gram per spawn (or 5 600–7 800 eggs per spawning event) that increases with female size (i.e., larger fish produce more eggs per gram body weight than do smaller fish; Armstrong et al., 1988). Based on a comparison of egg distribution patterns with concurrently observed environmental parameters, anchovy in the southern Benguela appear to be more selective than sardine regarding their spawning habitat (Twatwa et al., 2005), and anchovy spawning success in terms of the number of eggs produced depends on the extent of suitable spawning habitat characterised by sea surface temperatures of 16–19°C and high copepod production levels (Richardson et al., 1998).

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[20] Renamed KuGompo City early in 2026.

Laboratory rearing experiments and analysis of daily growth rings on otoliths that are visible under electron microscopy have been used to determine the growth of South African anchovy. Larvae grew between 0.15 and 0.60 $mm.day^{-1}$ in cooler water and between 0.5 and 1.5 $mm.day^{-1}$ in warmer water (Figure 3.2, upper), reaching ca. 2.0 cm CL in the former and ca. 3.5 cm CL in the latter after 60 days (Brownell, 1983), the approximate age at which they start to metamorphose into juveniles (King et al., 1978). Post-larval growth is rapid but declines once fish have matured at a size of around 9.5 cm CL (270 days or 9 months; Figure 3.2, lower) with a maximum reported size of 14.8 cm CL and maximum estimated age of 4 years (Prosch, 1986; Waldron et al., 1989). Costalago et al. (2020) compared otolith daily growth increments from anchovy larvae sampled from the West Coast and from Algoa Bay on the Southeast Coast and showed that growth rates were higher in the latter. This is a surprising finding given the lower productivity of the Southeast Coast compared to the West Coast but indicates that Algoa Bay is a suitable nursery area for this species.

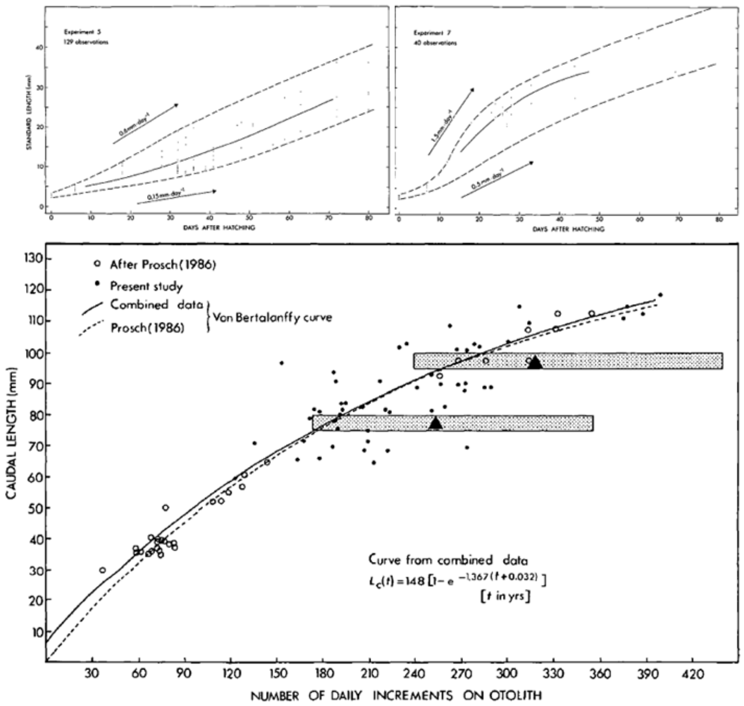

Figure 3.2: Growth of South African anchovy larvae determined during: (i) laboratory rearing experiments at 18.5–19.5°C (upper left graph) and 20.0–23.0°C (upper right graph) showing average (solid) and range (dashed lines) of caudal length (y-axes; from 0 to 40mm) against age in days (x-axes; from 0 to 80); and (ii) from counts of daily rings on otoliths (bottom graph) showing data from two studies and fitted von Bertalanffy growth curves (the triangles represent mean ages of the 75–79 and 95–99mm CL classes and the horizontal rectangles represent the range of age estimates for each CL class. Upper two plots from Brownell (1983) and lower plot from Waldron et al. (1989).

3.2.4 Life history strategy

South African anchovy spawn over the entire Agulhas Bank between Cape Point and Algoa Bay (Figures 3.1 and 3.3) during spring and early summer and in waters of 17–21°C, although eggs and larvae have been reported from as far east as the Tugela River mouth to the north of Durban (Anders, 1975; Armstrong et al., 1991; Beckley and Hewitson, 1994) and also off the West Coast to the north of Cape Columbine during years of anomalously warm waters there (van der Lingen et al., 2001; Hutchings et al., 2002; van der Lingen & Huggett, 2003).

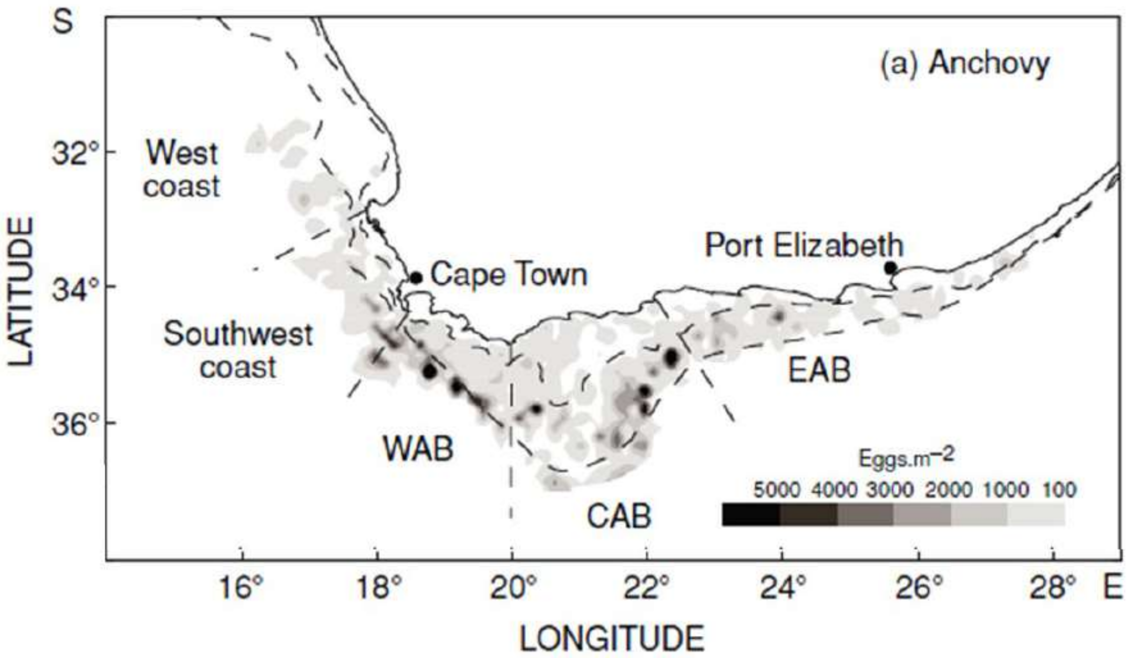

Figure 3.3: Composite distribution map (darker shading indicates higher densities) of South African anchovy egg density (eggs.m^{-2}) derived from California Vertical Egg Tow (CalVET) net samples collected during Pelagic Biomass Surveys conducted by DFFEover the period 1984–2000.[21] The five survey strata are shown (WAB, CAB and EAB are the western, central and eastern Agulhas Bank, respectively). Adapted from van der Lingen and Huggett (2003).

Surface waters on the western Agulhas Bank (WAB) show a general drift to the northwest and converge to develop into a coastal jet current that transports eggs spawned there to the productive nursery grounds off the West Coast north of Cape Columbine (Figure 3.4; Hutchings et al., 1998, 2002; van der Lingen & Huggett, 2003). Whereas some eggs spawned on the central and eastern Agulhas Bank are likely to be transported to the West Coast nursery grounds, coupled 3D hydrodynamic individual-based model simulations suggested that this is substantially less than from the WAB and that this likelihood decreases the further east eggs are spawned (Huggett et al., 2003; Mullon et al., 2003). Variability in the transport of anchovy eggs and larvae to the nursery grounds was thought to be one of the primary determinants of recruitment success (Hutchings, 1992; Hutchings et al., 1998, 2002) but productivity levels in the nursery area also play a role. Roy et al. (2001) noted that the record high anchovy recruitment observed in 2000 coincided with weak upwelling off the West Coast in December 1999 followed by moderate upwelling in January and February and then intense upwelling in March and April 2000. Those authors suggested that this temporal pattern first facilitated the successful transport of eggs and larvae to the West Coast nursery grounds during December to February and then high survival and growth rates arising from the enhanced productivity in March and April. More recently, van der Sleen et al. (2018) demonstrated a significant and positive relationship between anchovy recruitment strength and cumulative upwelling off the West Coast during summer (December to March).

[21] The name of DFFE has previously been DAFF, then DEFF.

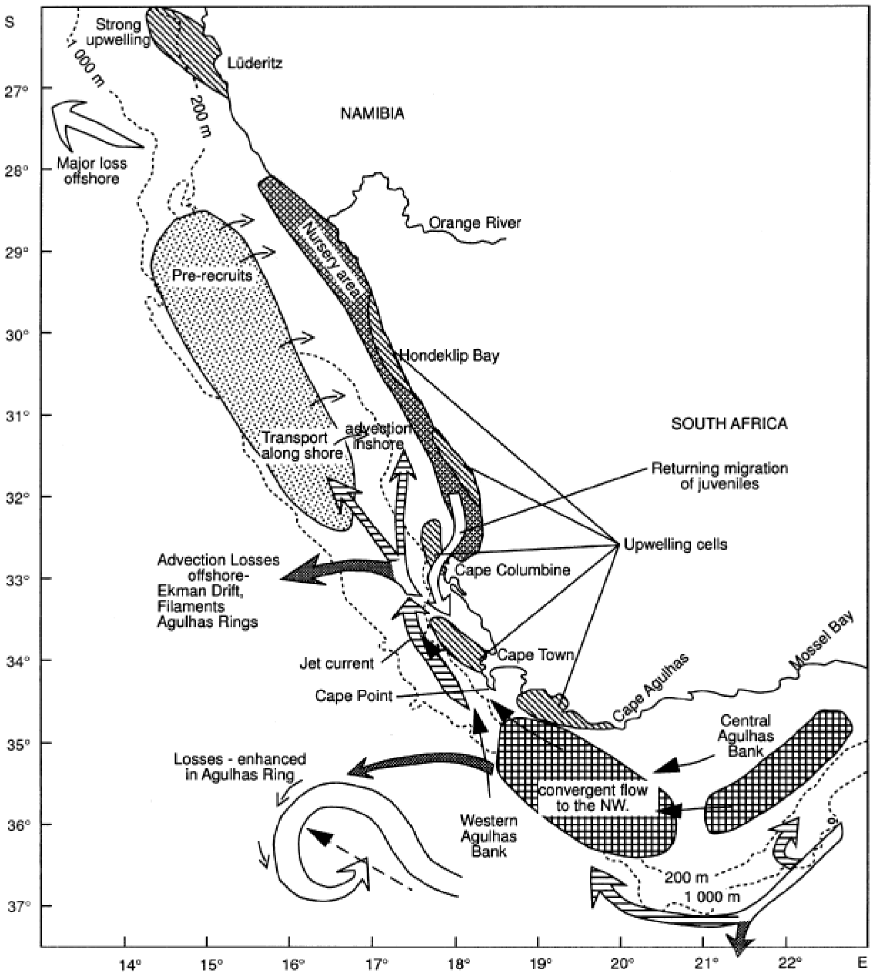

Figure 3.4: Schematic showing the present hypothesis on the life history of South African anchovy off the South African Coast. From Hutchings et al. (2002).

The early life stages of anchovy show a clear cross-shelf distribution, with the smallest fish found offshore and the largest inshore during autumn (March; Figure 3.5). Once the anchovy has metamorphosised into juveniles (at approximately 2–3 months old and 3.0–3.5 cm CL) they migrate southwards in the inshore waters of the West Coast, at which time they are targeted by the anchovy fishery. Survivors continue their migration until they reach the Agulhas Bank where they mature and reproduce.

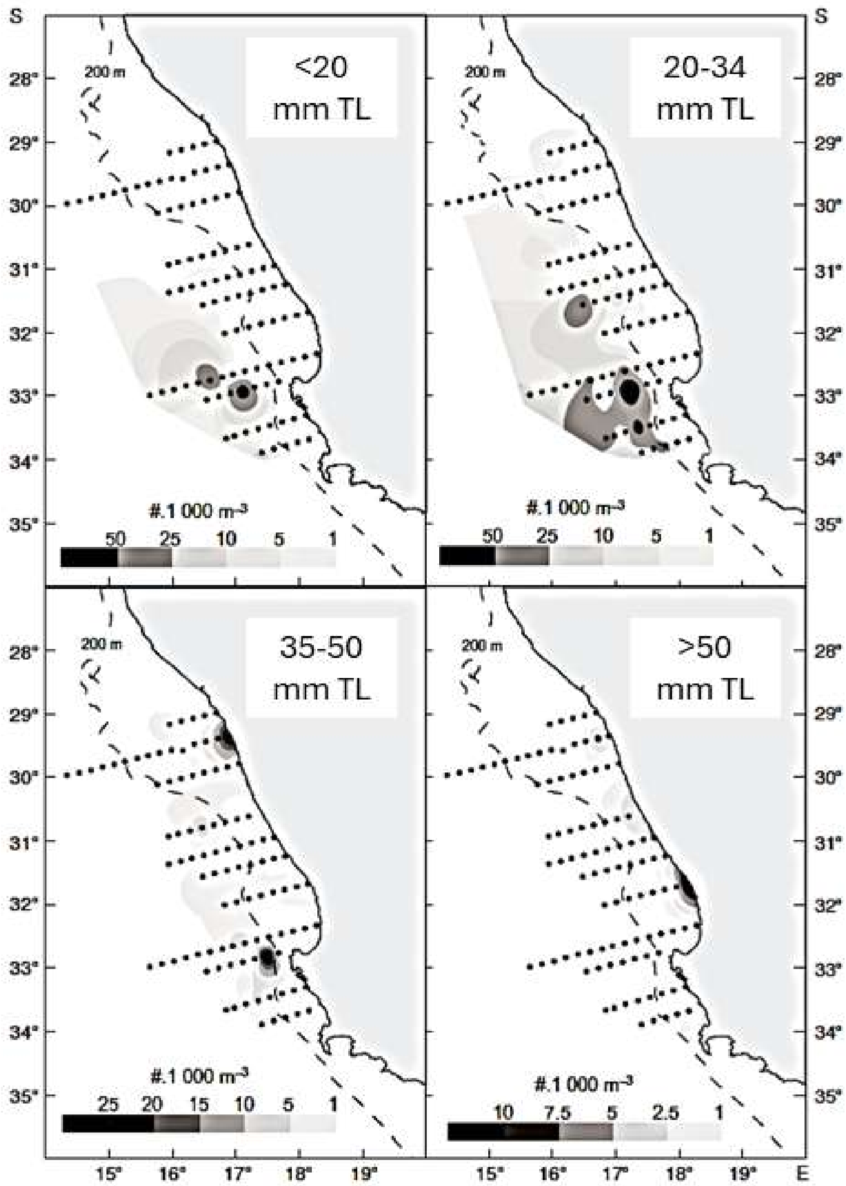

Figure 3.5: Maps showing the spatial density by size class of anchovy pre-recruits collected during a survey in March 1998. Dots indicate the positions of sampling stations; note that the density scales differ between size classes. From van der Lingen and Huggett (2003).

3.3 Utilising South African anchovy for human consumption

Anchovy has traditionally been and continue being processed for human consumption in many countries, particularly those around the Mediterranean (including Spain, France, Italy, Turkey and Greece) as well as Southeast Asia (Indonesia, Malaysia and the Philippines), the Far East (Thailand, Vietnam, Korea and Japan), and the South Asian subcontinent (India, Pakistan and Bangladesh). They are rich in macro- and micronutrients, have a well-balanced amino acid composition containing several essential amino acids, and have a high nutritive value (Kari et al., 2022). More recently, efforts to process a significant percentage of the annual catch of Peruvian anchoveta *Engraulis ringens* into products for human consumption have been made since the early 2000s. Whereas initial success was promising with up to 100 000 t of fish per annum being processed this way (Backteman, 2010) this has not been sustained for a variety of reasons including competition with similarly-priced and preferred other species such as mackerel and horse mackerel, the rapid deterioration of anchovy after capture which limits storage and transport options, and the distinct, strong flavour of anchovy that makes them relatively unpalatable and only able to be eaten in small quantities (IFFO, n.d.).

Virtually all the anchovy caught off South Africa are processed into fish meal and oil (see below) but previous attempts to process this species into products for human consumption have been made. Products such as cured anchovy, canned anchovy fillets, anchovy paste and dried anchovy were sold on the local and export markets. Unfortunately, these attempts were unsuccessful, with a decrease in the size of fish taken by the fishery that occurred in the 1980s and the manual labour required to prepare each fish individually identified as the main reason, but with product quality issues blamed on high lipid content, oxidation and rancidity also being problematic (Backteman, 2010). Despite attempts by the Fisheries Management Branch of what was then the Department of Agriculture, Forestry and Fisheries in the early 2010s to re-invigorate this programme by holding a workshop to investigate the feasibility of harvesting anchovy for human consumption (Anonymous, 2013) and subsequent recommendations targeting at-sea preservation (i.e., on ice or in refrigerated seawater) of larger fish off the South Coast in particular be investigated (van der Lingen & Hampton, 2018; Cochrane et al., 2020; van der Lingen, 2021), there has been little further development in this regard.

3.4 The South African small pelagic fishery

The South African fishery for small pelagic fishes was initiated off the West Coast in the late-1940s and initially targeted sardine (*Sardinops sagax*), Cape horse mackerel (*Trachurus capensis*) and chub mackerel (*Scomber japonicus*) using purse-seine nets (DFFE, 2021a). Declining catches of those species in the 1960s resulted in the fishery changing to smaller-meshed nets to target anchovy and this species has generally dominated landings since except from the mid-1990s to the early-2000s when large catches of sardine were taken (Figure 3.6). A third small pelagic fish, the West Coast redeye round herring (*Etrumeus whiteheadi*), is also a target of this industrial-scale fishery which is the country's largest in terms of landed mass with a long-term (1949–2022) average annual catch of 333 000t and a recent (2018–2022) average annual catch of 288 000t (Figure 3.6).

Most (around 85%) of the sardine caught is canned for human consumption and pet food whilst the remainder is frozen for bait (Coetzee et al., 2022), whereas anchovy and round herring are reduced to fish meal and oil. Because of these differences in final products the landed value of sardine is approximately five times that of anchovy and round herring (DFFE, 2021b). In addition to being the country's largest, the small pelagic fishery is also its 2nd-most valuable with a wholesale value in 2013 estimated at R1.6 billion (equivalent to around US$160 million) and employing more than 5 000 staff in 2008, including full-time sea-going and factory processing staff as well as seasonal workers (Brick & Hasson, 2016). In 2021, the wholesale value of the small pelagic catch was estimated at R5.5 billion (approximately US$300 million) and employed around 5 800 people (DFFE, 2021a).

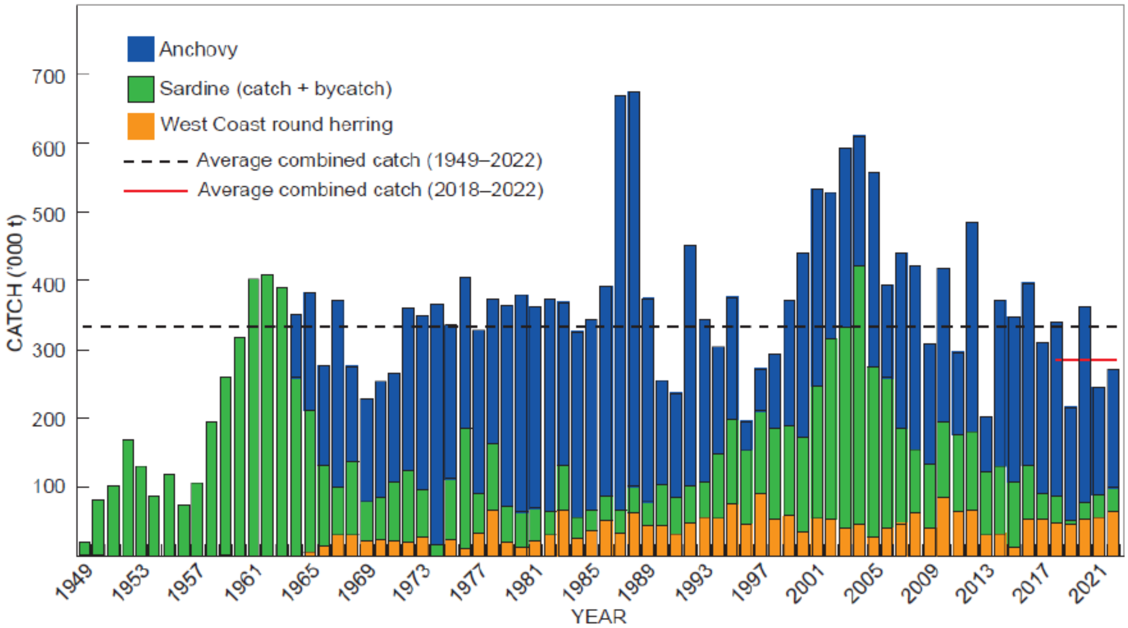

Figure 3.6: Annual combined catches of anchovy (blue), sardine (green) and West Coast round herring (orange) by the South African small pelagic fishery, 1949–2022. The long-term (entire period) average annual combined catch (dashed black line) and past five years (2018–2022) average annual combined catch (red solid line) are indicated. From DFFE (2023).

Management of the South African small pelagic fishery uses an Operational Management Procedure (OMP), an adaptive approach that uses a simulation-tested set of rules and pre-specified data, stock assessment methods and harvest control rules to set annual total allowable catch levels for anchovy and sardine, as well as annual total allowable bycatch (TAB) levels for juvenile sardine taken in anchovy-directed fishing operations and for adult sardine taken in round herring-directed fishing operations (DFFE, 2021a; van der Lingen, 2021). Rights holders in this fishery are each allocated a percentage of the TAC (and of the juvenile sardine TAB for anchovy rights holders) that is converted to an annual tonnage depending on the TAC set for that year, with those percentages being fixed for the long-term (15 year) duration of their right (DFFE, 2021a). Total annual catches of West Coast round herring may not exceed a precautionary upper catch limit (PUCL) but this resource is not allocated to individual rights holders.

3.4.1 The South African fishery for anchovy

Annual TACs for anchovy ranged between 285 000 and 573 180t over the period 2000–2022 and with an average of 409 070 ± 86 170 (std. dev.[22]) t, whereas annual anchovy catches ranged between 78 800 and 307 300t and had an average of 219 080 ± 60 540t of the same period (Figure 3.7). Anchovy catches have always been lower than the TACs during that period, sometimes substantially, with 56.1% of the TAC being caught on average each year but ranging from 17.5% (in 2013) to 91.9% (in 2000). Virtually all the anchovy catch is taken from inshore

[22] Standard deviation.

waters off the West Coast (i.e., west of Cape Agulhas), primarily in St Helena Bay but also between Cape Columbine and Cape Point, and in the Danger Point region of the southwestern Cape coast (Figure 3.8), with negligible (until very recently) landings of fish caught to the east of Cape Agulhas. Most (ca. 70%) of the anchovy caught are young-of-the-year[23] (recruits) (van der Lingen, 2021).

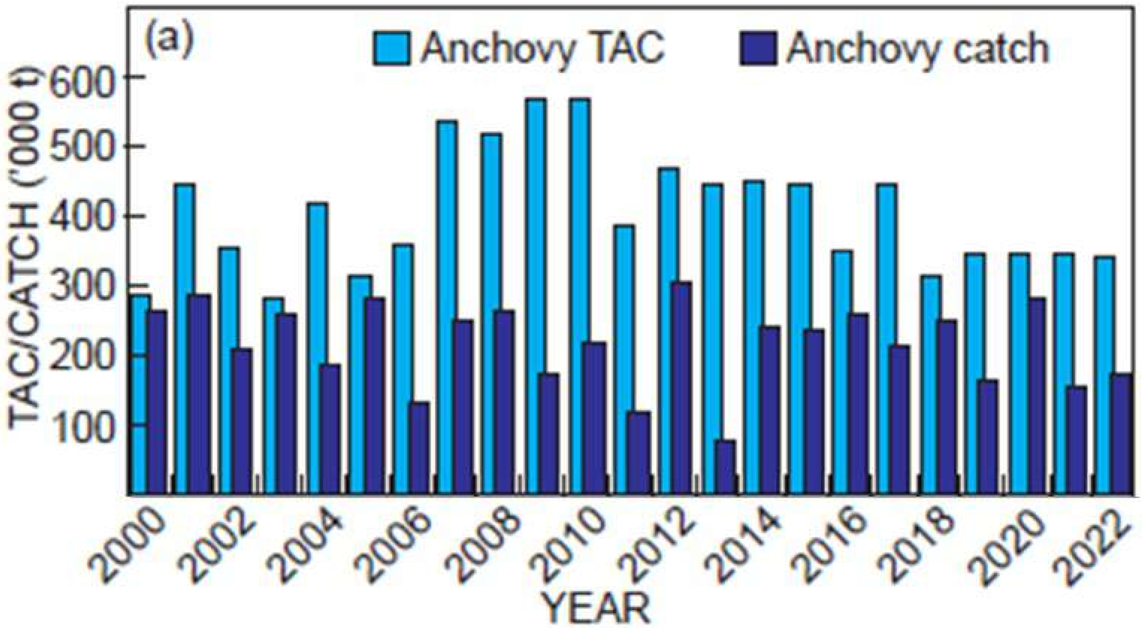

Figure 3.7: Annual total allowable catch and subsequent landings of anchovy by the South African small pelagic fishery, 2000–2022. From DFFE (2023).

[23] In their first year of life.

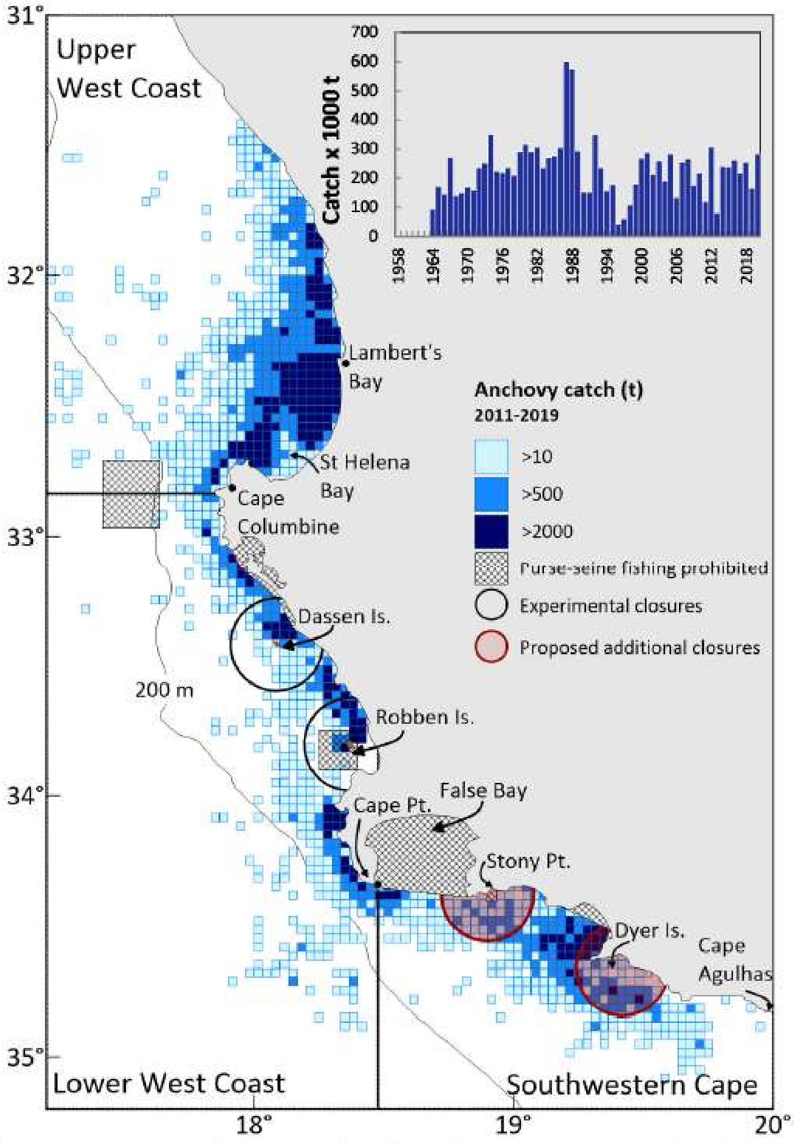

Figure 3.8: Map showing the cumulative catch of anchovy by 2-nautical-mile block over the period 2011–2019, with darker shading indicating higher catches. Marine protected areas (MPAs) and areas presently closed to purse-seine fishing (cross-hatching), and areas around African penguin mainland and island breeding colonies for which long-term closure has been proposed are indicated by circles (Dassen, Robben and Dyer islands and Stony Point). The graph shows a time-series of annual anchovy catches, 1958–2020. From DFFE (2021b).

3.4.2 Spatial and seasonal variability in anchovy catches and the size of anchovy caught

Information on spatial and temporal variability in the quantity and average size of anchovy caught by the small pelagic fishery was obtained from DFFE's Status of the South African Marine Fishery Resources Reports and from spreadsheets and documents detailing anchovy catches tabled at meetings of DFFE's Small Pelagic Scientific Working Group (SWG-PEL).

3.4.2.1 Spatial variability

Anchovy catches are composed primarily (>70%) of recruits (Fairweather et al., 2006; van der Lingen, 2021) and virtually the entire catch is taken off the West Coast (i.e., west of Cape Agulhas), albeit with substantial differences in catches taken off the upper West Coast (Pool

Area A) compared to the lower West Coast (Pool Area B) and the southwestern Cape coast (Pool Area C: Figure 3.9a). Over the period 1987–2019, annual catches of anchovy taken in Pool Area A (to the north of Cape Columbine) ranged between 16 687 and 418 662t, with an average of 129 680t, and comprised 55.6% on average of the total catch. Catches taken in Pool Area B (between Cape Columbine and Cape Point) were lower (10 364–185 692t with an average of 73 953t per year or 33.3%), and those in Pool Area C (between Cape Point and Cape Agulhas) even lower still (1 615–94 171t with an average of 23 590t or 11.1%).

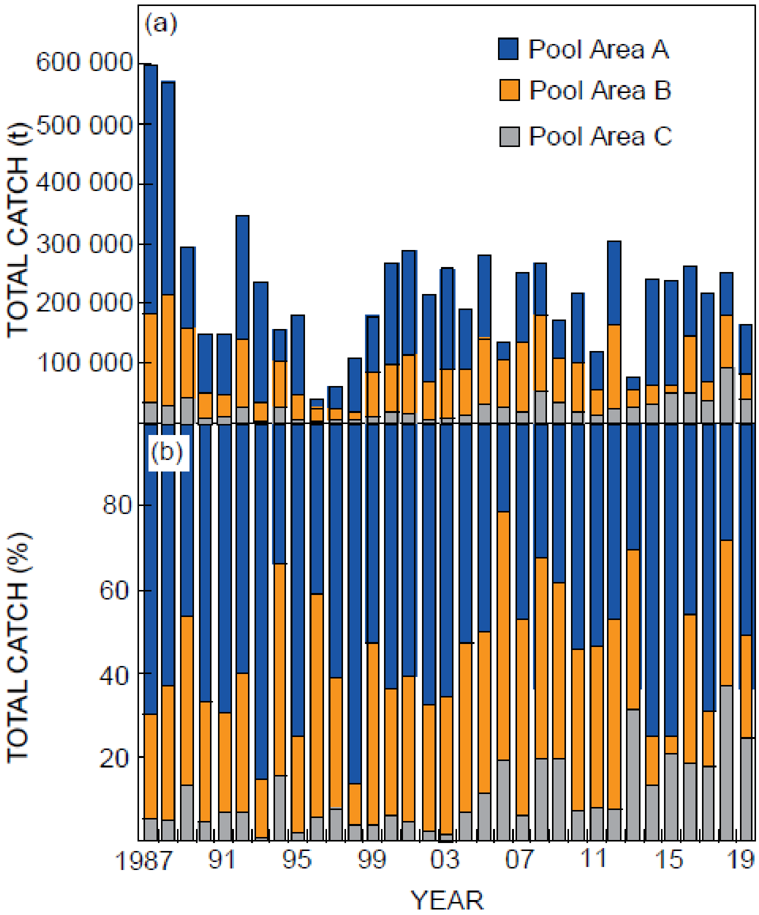

Figure 3.9: Annual absolute (tonnes; a) and relative (% of total; b) anchovy catch by Pool Area, 1987–2019. From DEFF (2020).

However, this pattern has changed in recent years, with increasing catches taken in Pool Area C: 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 between Cape Point and Cape Agulhas. 2018 was also the first year in which catches in Pool Area C (94 171t) were higher than those taken in either Pool Area A (71 253t) or B (87 882t). And whereas relative (% of total) annual anchovy catches in Pool Areas A and B showed no significant trends over time, that for Pool Area C showed a highly significant (P<0.005) positive linear trend (Figure 3.9b). Catch patterns of anchovy therefore appear to be changing and shifting southwards and eastwards, as has been seen for sardine and, to a lesser extent, round herring (Fairweather et al., 2006; Augustyn et al., 2018; van der Lingen, 2021).

3.4.2.2 *Temporal variability*

A marked seasonal pattern in anchovy catches is evident, with an autumn-winter peak that declines rapidly in spring, but large catches (>30 000t) are sometimes taken late in the season in August and September (Figure 10 upper graph). The average anchovy catch during January of recent years (2013–2022) has been <1 000t; <20 000t in February and March; >40 000t in April and May; 15 000–30 000t from June to September but declining over these four months; and <5 000t from October to December (Figure 3.10 lower graph).

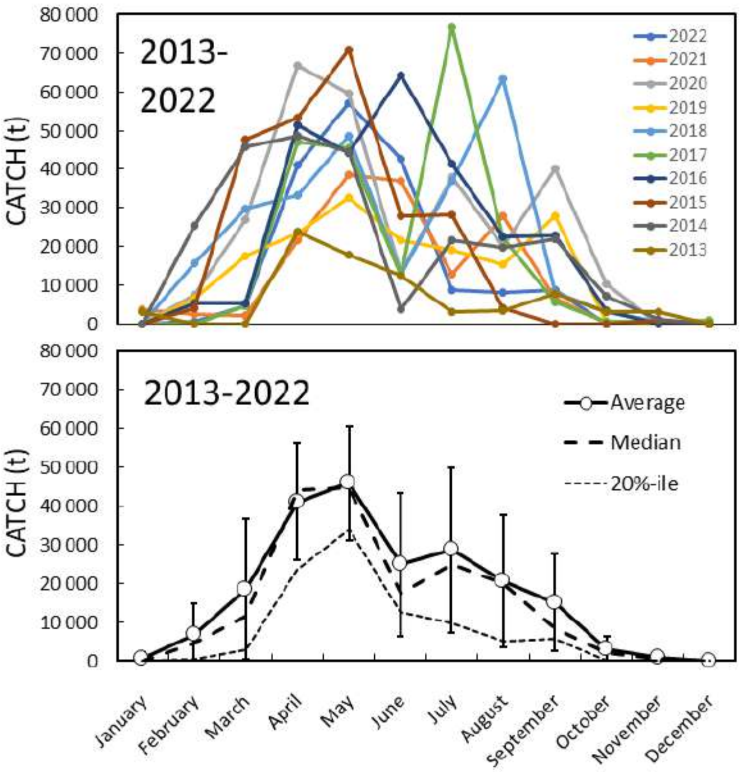

Figure 3.10: Monthly catches of anchovy per year, 2013–2022 (upper); and the average, median (50%-ile[24]) and 20%-ile catch per month over this period. From van der Lingen (2023).

Because most (typically >50%) of the annual anchovy catch is taken north of Cape Columbine in Pool Area A (Figure 3.9b), the seasonal pattern of catches in that region dominates the seasonal signal shown in Figure 10 for the entire fishery. However, there are differences in the temporal pattern of catches between the three pool areas. Anchovy catches in Pool Area A are negligible from January to March (which together account for <3.0%, on average, of annual catch there) but increase substantially in April and May (together accounting for 73.9%) before declining in June (11.3%) and being again low to negligible (<6.0%) from July to October and zero in November and December (Figure 11). Catches in Pool Area B are also negligible from January to March (<1.5%, on average, of annual catch there), start to increase in April (6.4%) and are high (ranging between 19.9 and 23.0%) from May to August, decline again in September (9.4%), and are negligible (<1.9%) in October and November, and no fish are caught in December. Catches in Pool Area C are more spread throughout the year than in the other two Pool Areas, being low (2.7%) in January, high (10.9–17.8%) from February to June

[24] Percentile.

and in September, and low again from October to December (which together account for 3.8%, on average, of annual catch (Figure 3.11).

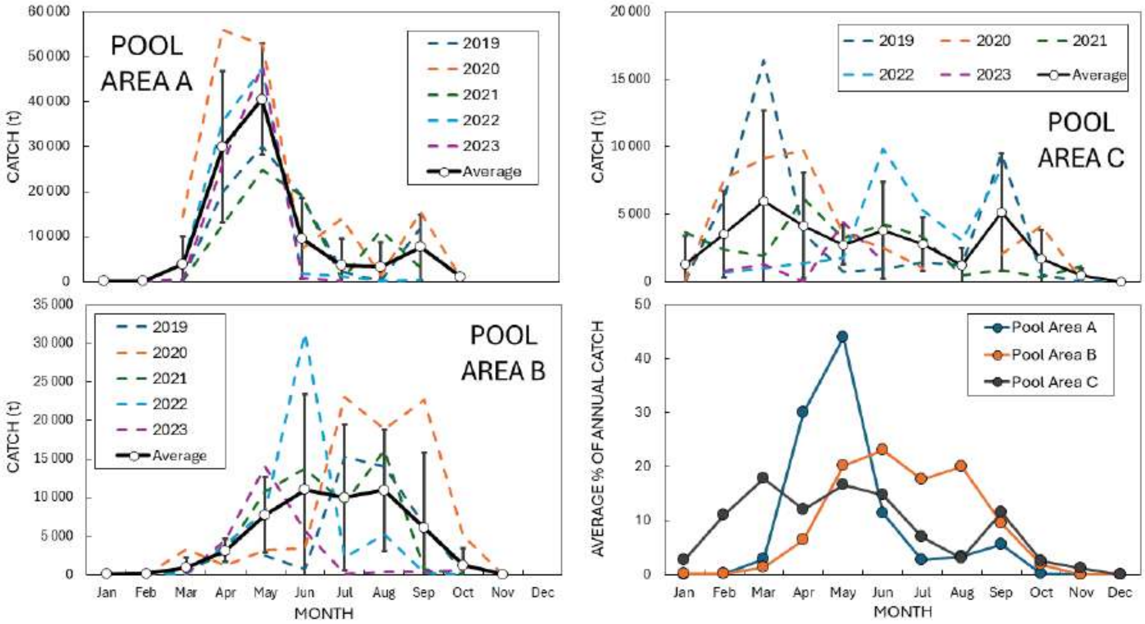

Figure 3.11: Monthly catches of anchovy per year (2019–2022; dashed lines) and the average monthly catch for this time-period (solid line) by pool area (upper and lower left plots; error bars indicate standard deviations); and the average percentage of total annual catch per month for Pool Areas A to C (lower right plot). Plots derived using data from small pelagic fish catch spreadsheets tabled at DFFE SWG-PEL meetings.

3.4.2.3 Variability in anchovy size

Fairweather et al. (2006) calculated the weighted (by catch) mean monthly and annual CL of anchovy caught from three areas off the West Coast between 1987 and 2005 and reported that, whereas this was interannually variable, a consistent pattern of larger fish being caught at the start and the end of the year was observed. Plotting the data provided in their Table 4 graphically demonstrates this pattern with mean monthly CL being >8.5 cm from January to April and again in November and December (Figure 3.12). The mean annual CL of all anchovy caught was >8.5 cm in the first three years of the time-period but below this thereafter, and anchovy increased in size from Pool Area 1 to Pool Area 3 (Figure 3.12).

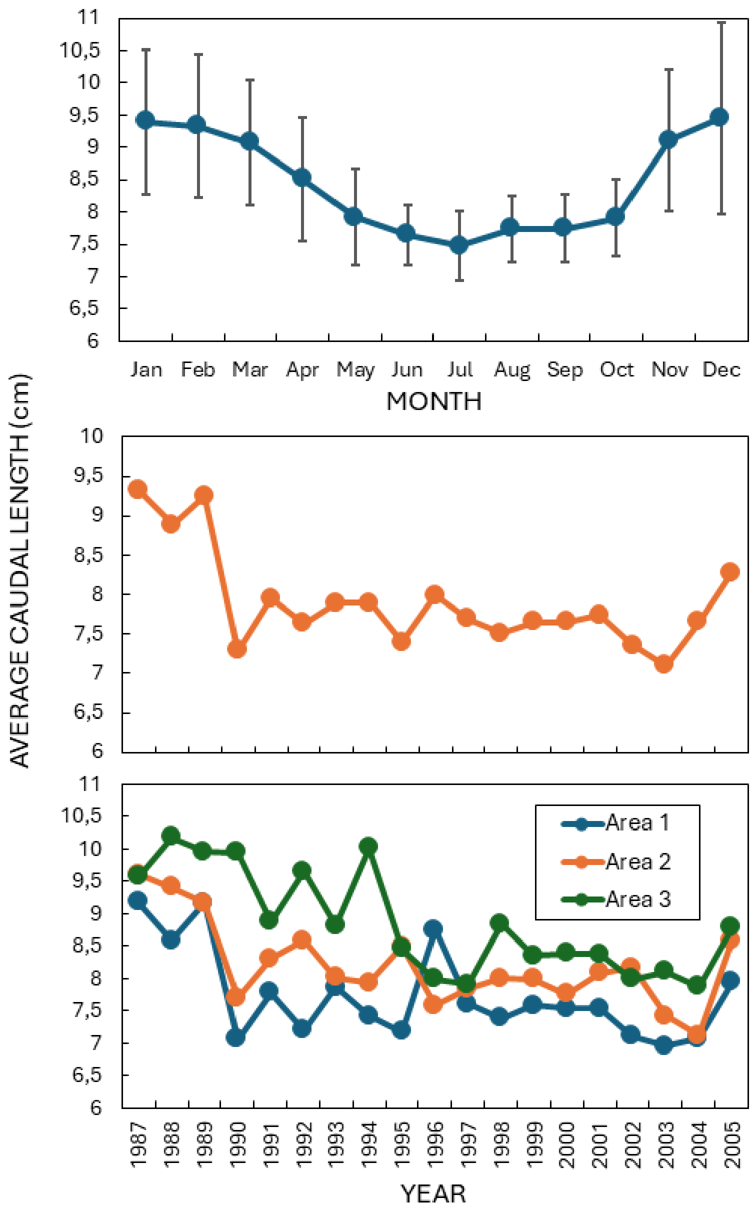

Figure 3.12: Average monthly caudal length of anchovy caught off the West Coast over the period 1987–2005 (upper panel with std. dev. values shown); average annual caudal length of anchovy caught off the West Coast over the period 1987–2005 (middle panel); and average annual caudal length of anchovy caught in each of three regions (Area 1 = Pool Area A; Area 2 = Pool Area B, and Area 3 = from Cape Point to Cape Infanta) over the period 1987–2005 (lower panel). Graphs drawn using data from Table 4 in Fairweather et al. (2006).

An updated time-series of weighted (by catch) mean annual CL of anchovy caught between 1987 and 2019 for each of three Pool Areas is shown in Figure 3.13. As reported by Fairweather et al. (2006), smaller anchovy are caught in Pool Area A (7.42 ± 0.54 cm CL) than in Pool Area B (7.80 ± 0.50 cm CL) or Pool Area C (8.42 ± 0.66 cm CL), and larger anchovy were caught at the start compared to the end of the time-series for all three Pool Areas. A significant, negative linear regression could be fitted for Pool Area B, with mean annual CL in this region declining by 0.85 cm over the 33-year time-series. Weighted mean annual CL 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.

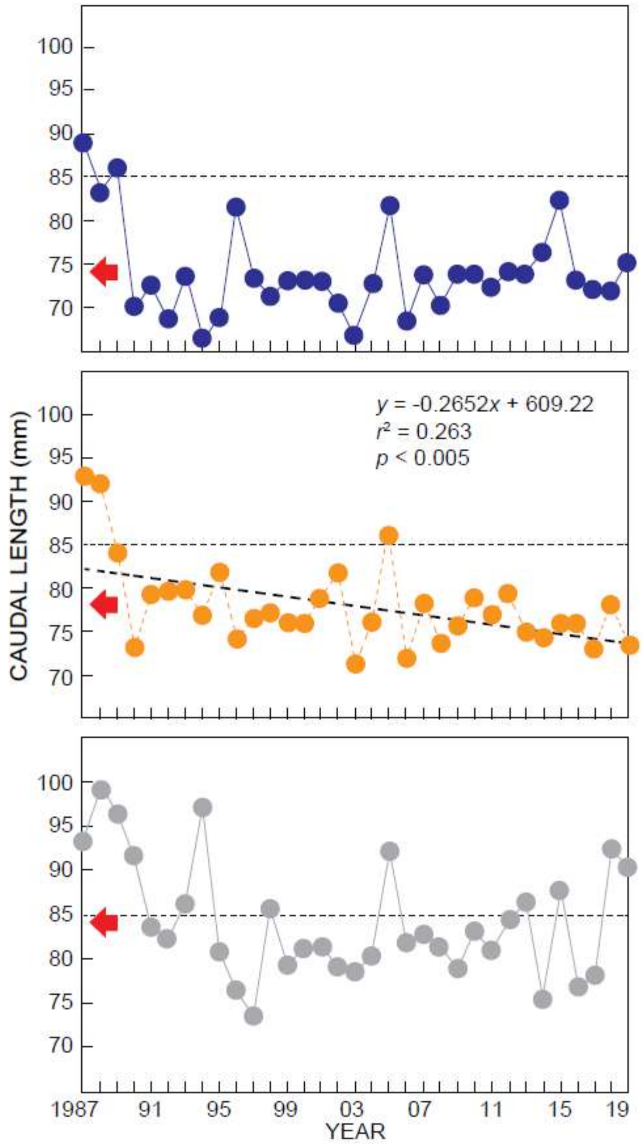

Figure 3.13: Weighted mean caudal length (mm) of anchovy caught each year in Pool Areas A (upper panel), B (middle panel) and C (lower panel) over the period 1987 to 2019. A reference line at 85mm CL is shown on all plots to facilitate comparison, the overall mean for each Pool Area is shown with red arrows on the y-axis, and the significant linear regression for Pool Area B is shown. From DEFF (2020).

3.4.3 Anchovy catches and the environment

Agenbag et al. (2003) assessed relationships between variations in anchovy (and sardine and round herring) density and the environment (mostly spatial and temporal but also including SST and SST-related variables) by comparing commercial catch per set (CPS) data as a proxy for local density with a suite of environmental variables for the period 1987–1997. They used a multivariate modelling approach that identified relationships between CPS and each environmental variable whilst accounting for covariance between environmental variables and developed a general linear model (GLM) that explained 19.6% of the variation in South African anchovy CPS (compared to 33.9% for sardine and 54.3% for round herring). Temporal variables (year, month) were the strongest predictors of anchovy CPS and whereas SST and SST-related parameters had relatively small effects on the GLM, a strong negative relationship with SSTs of >15°C was observed, indicating the tendency of anchovy to avoid higher SSTs and congregate in cool, nearshore waters.

More recently, DEFF (2020) reported on the development of a tool to optimise pelagic fishing effort by near-real time identification of high probability catch zone maps based on frontal and phytoplankton/ temperature range analytics derived using high spatial and temporal-resolution satellite observations of ocean colour and sea surface temperature. Spatially and temporally referenced catch data (haul location, date, and catch quantity) were compared to satellite-derived SST and chlorophyll a (*Chl a*) data and used to generate "heat maps" for anchovy taken to the north of Cape Town (and hence primarily juveniles) in 2012 and 2017. Most catches of anchovy juveniles in 2012 were taken in cooler waters of 13–16°C, confirming the finding of Agenbag et al (2003), and high (3–30mg m^{-3}) *Chl a* levels (Figure 3.14).

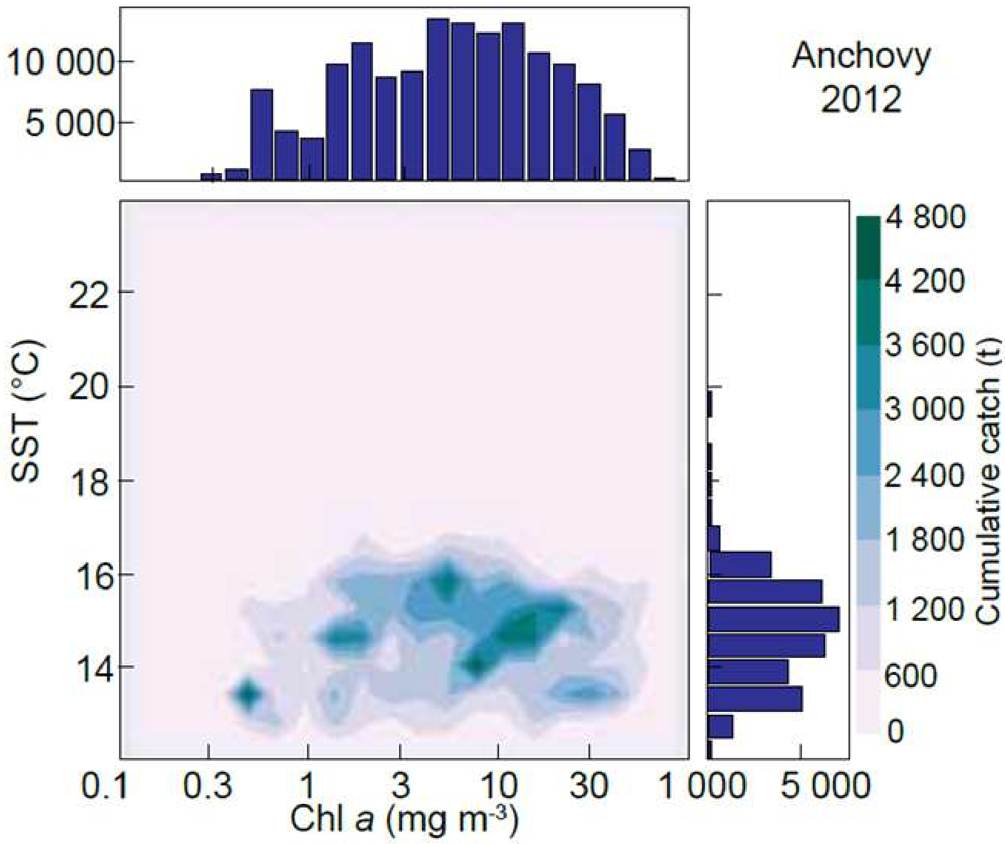

Figure 3.14: Heat map showing cumulative catch in relation to SST and *Chl a* derived from high resolution satellite imagery for anchovy catches taken to the north of Cape Town in 2012. The contour plot shows cumulative catch (tonnes; blue to green shading; colour bar on right hand side) against *Chl a* (x-axis; mg m^{-3}) and SST (y-axis; °C), and the histograms show the cumulative catch (tonnes) as a function of *Chl a* (horizontal histogram) and of SST (vertical histogram) categories. Adapted from DEFF (2020).

3.5 Anchovy abundance and distribution patterns observed during annual surveys

Hydroacoustic surveys to estimate the recruitment strength and total biomass of important small pelagic species off South Africa, including anchovy, have been conducted bi-annually since 1984. Surveys to estimate recruitment strength are targeted at young-of-the-year, conducted in autumn/winter, and cover inshore waters where juveniles are found (usually to not more than around 30 nautical miles from the coast) and do not extend to the edge of continental shelf in most parts of the survey area. In contrast, surveys to estimate total (previously called spawner) biomass are conducted in spring/ summer and cover the entire continental shelf to around 200m depth and extending to around 120 nautical miles from the coast in places. The standard area covered by the Recruit Surveys is between the Orange River mouth and Cape Infanta whereas that for Total Biomass Surveys is between Hondeklip Bay and Port Alfred, although both surveys extend further east on occasion. A description of the methodology applied during these surveys is provided by Barange et al. (1999). Essentially, they consist of transects running perpendicular to the coastline along which acoustic data are collected to estimate the biomass of small pelagic fish along each transect, and midwater trawling is aimed at acoustically detected targets to catch small pelagic fish for determination of species and size composition and the collection of biological data. These surveys provide the estimates of recruitment and total biomass for anchovy that are used as input into the population assessment model used in the OMP to recommend annual TAC levels (de Moor 2021, 2024).

Barange et al. (1999) synthesised data collected during hydroacoustic surveys of South African pelagic resources conducted in the 1980s and 1990s and showed acoustically weighted anchovy-length frequencies from Recruit and Total Biomass Surveys conducted over the period 1990–1997 as well as distribution maps by length class from all surveys conducted between 1984 and 1996. Because the Recruit Surveys only sample the inshore region, the majority of anchovy caught during surveys between 1990 and 1997 were recruits (young-of-the-year fish) of <10.5 cm CL except in 1991 and 1994 when adult fish were also caught (Figure 3.15). Recruits and adults were caught during Total Biomass Surveys in all years during that period and numerically dominated by recruits in most years except 1994, 1996 and 1997.

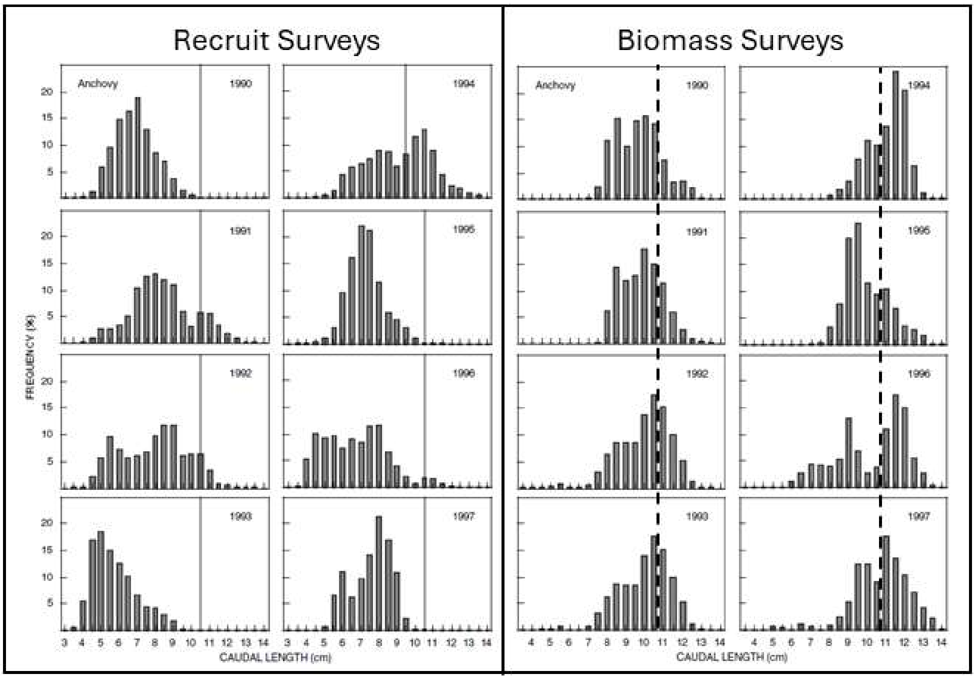

Figure 3.15: Acoustically weighted caudal length frequencies of South African anchovy caught in Recruit Survey (left) and Total Biomass Survey (right) catches, 1990–1997. Adapted from Barange et al (1999). The vertical lines shown for the Recruit Surveys indicate the cut-off caudal length (10.5 cm CL for all except 1994) applied to differentiate between recruit and adult fish in each year, and this CL is also highlighted for the Biomass Surveys.

The distribution map showing the composite occurrence of anchovy by length class derived from all (i.e. Recruit and Total Biomass) hydroacoustic surveys between 1984 and 1997 showed a clear effect of fish size on distribution patterns. Small anchovy of <10 cm TL[25] (= 8.6 cm CL) were only found off the West Coast (i.e., to the west of Cape Agulhas). Fish of 10–14 cm TL (8.6 – 12.2 cm CL) were found off both the West and South coasts, and the largest fish (>14 cm TL) were scarce off the West Coast and common off the South Coast (Figure 3.16).

[25] Total length.

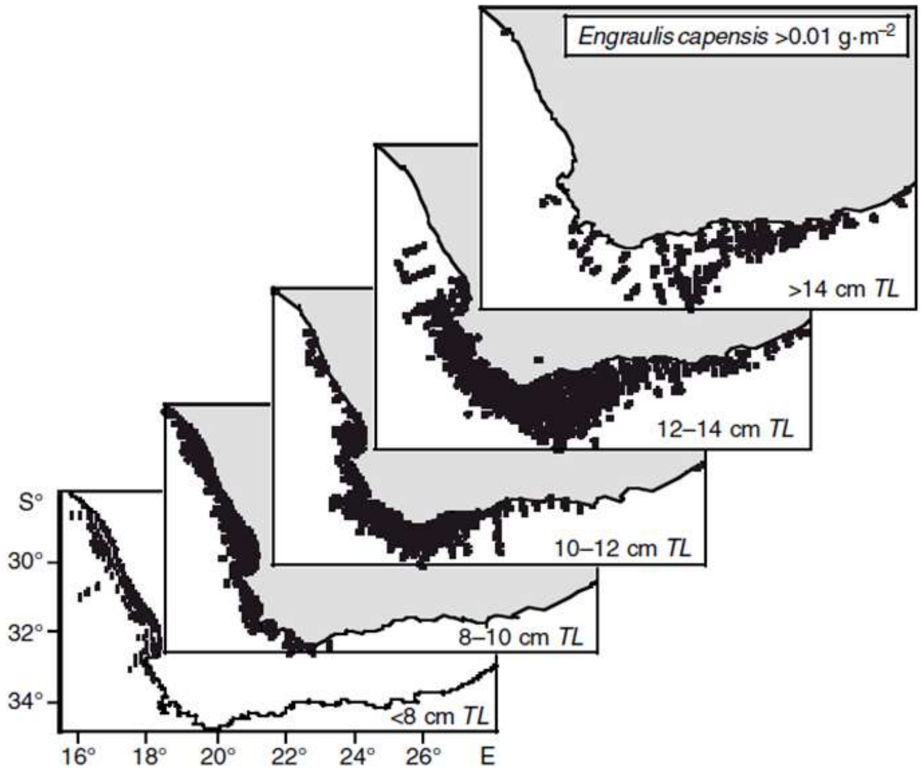

Figure 3.16: Distribution of South African anchovy by total length class derived from all hydroacoustic surveys conducted between 1984 and 1996. Adapted from Barange et al. (1999). Note that 8 cm TL = 6.8 cm CL; 10 cm TL = 8.6 cm CL; 12 cm TL = 10.3 cm CL; and 14 cm TL = 12.2 cm CL.

Information on anchovy from Total Biomass Surveys conducted over the past decade is synthesised in this report using information obtained from the DFFE Status of South African Marine Fishery Stocks and SWG-PEL reports. Whereas the design of the Recruit Surveys precludes a comprehensive and hence complete observation of anchovy distribution at that time, particularly of adult fish, information from those surveys conducted over the past five years is also presented. The dates, coverage and effort, estimated anchovy biomass and other information on Total Biomass Surveys from 2014 to 2024 are shown in Table 3.1, and the abundance and distribution maps, and stratum-specific, acoustically weighted length frequency distributions for each survey, are shown in Figures 3.17 to 3.25. Total Biomass Surveys were not conducted in 2021 and 2023 because of logistical constraints, but a survey in early (February/ March) 2024 was conducted and the estimates of all three small pelagic species were adjusted to reflect what they would have been the preceding spring (November/ December 2023) to maintain temporal consistency in the biomass time series.

Table 3.1: The start and end dates, vessel, spatial coverage and effort (# of acoustic transects (at) and # of midwater trawls (mwt)), estimated anchovy biomass within the standard (HKB to PA) area (and total area if to PSJ) and its coefficient of variation, proportion of the estimated biomass distributed east of Cape Agulhas (EoCA) and the reference for Total Biomass Surveys conducted by DFFE (previously DAFF then DEFF) between 2014 and 2024. AB = Algoa Bay; EoCA = East of Cape Agulhas; HKB = Hondeklip Bay; PA = Port Alfred; PSJ = Port St Johns.

Year	Dates	Vessel	Coverage and effort	Anchovy biomass (CV)[26]	Proportion EoCA (standard area)	Reference
2014	21/10 to 06/12	MFV *Compass Challenger*	HKB to PSJ 74 at 110 mwt	2.97 Mt (0.14) 2.97 Mt (0.14)	0.56	Mhlongo et al. (2014)
2015	19/10 to 02/12	MFV *Compass Challenger*	HKB to PSJ 74 at 136 mwt	1.94 Mt (0.16) 2.10 Mt (0.15)	0.66	Coetzee et al. (2015)
2016	25/10 to 15/12	FRS *Africana*	HKB to PA 57 at 100 mwt	1.73 Mt (0.23)	0.23	Coetzee et al. (2016)
2017	30/10 to 18/12	FRS *Africana*	HKB to PA 60 at 115 mwt	1.57 Mt (0.20)	0.48	Coetzee et al. (2017)
2018	18/10 to 01/12	FRS *Africana*	HKB to PSJ 76 at 117 mwt	1.56 Mt (0.24) 1.57 Mt (0.23)	0.77	Coetzee et al. (2018)
2019	02/11 to 17/12	FRS *Africana*	HKB to AB 58.5 at 119 mwt	0.84 Mt (0.20)	0.43	Shabangu et al. (2019a)
2020	13/11 to 19/12	FRS *Africana*	HKB to PA 52 at 96 mwt	2.56 Mt (0.16)	0.40	Coetzee et al. (2020a)
2021	No survey	No survey	No survey	No survey	No survey	No survey
2022	13/11 to 20/12	MFV *Compass Challenger*	HKB to PSJ 72 at 107 mwt	1.02 Mt (0.22) 1.02 Mt (0.22)	0.57	Coetzee et al. (2023)
2023	No survey	No survey	No survey	No survey	No survey	No survey

[26] Coefficient of variation.

Year	Dates	Vessel	Coverage and effort	Anchovy biomass (CV)[26]	Proportion EoCA (standard area)	Reference
2024	16/02 to 17/03	MFV *Compass Challenger*	HKB to PA 54 at 94 mwt	1.01 Mt (0.49) Adj. est. 0.99 Mt (0.52)	0.17	Coetzee et al. (2024)

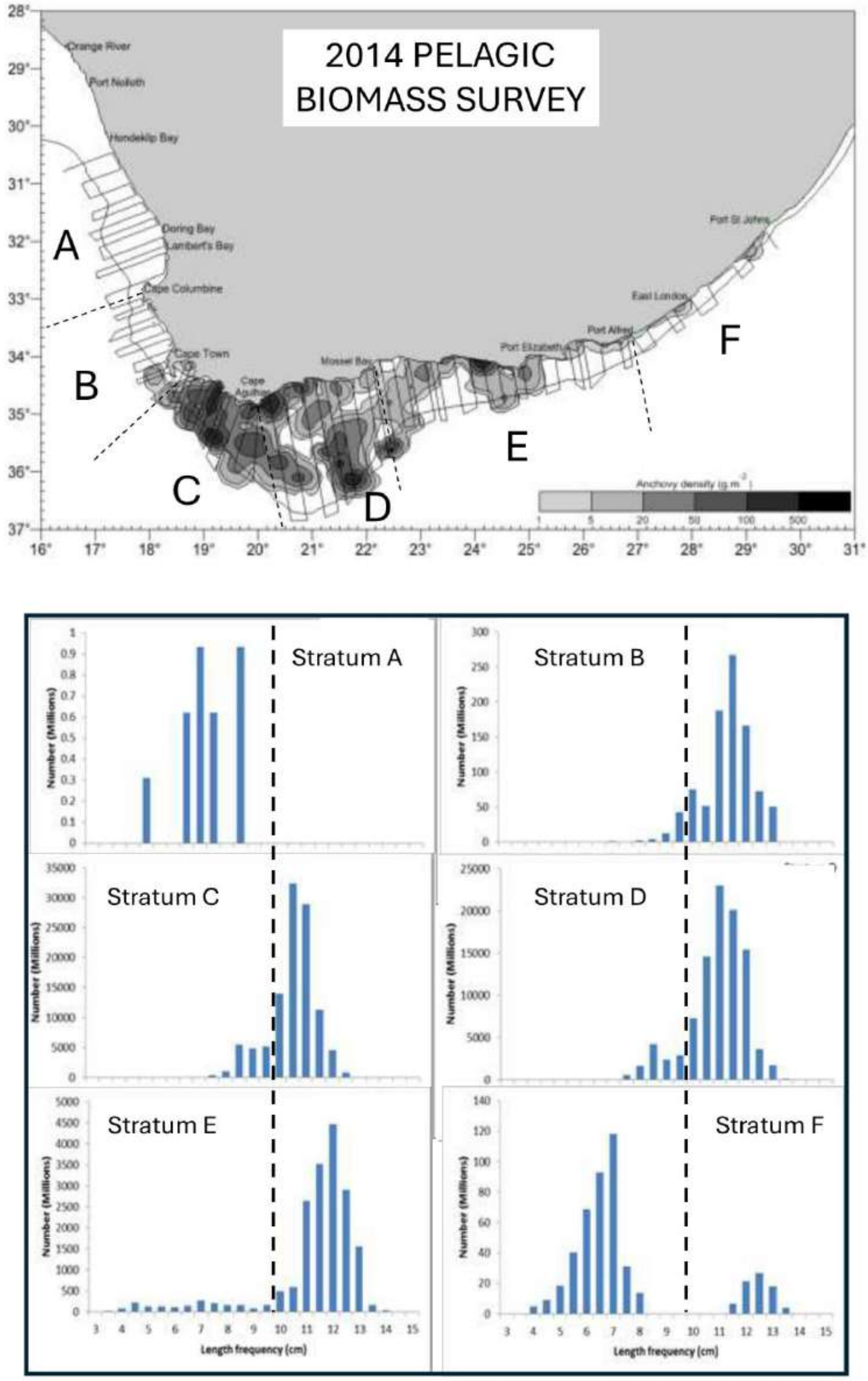

Figure 3.17: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–F; lower; histograms to the right of the vertical dashed line are >10cm caudal length) observed during the 2014 Total Biomass Survey (adapted from Mhlongo et al., 2014).

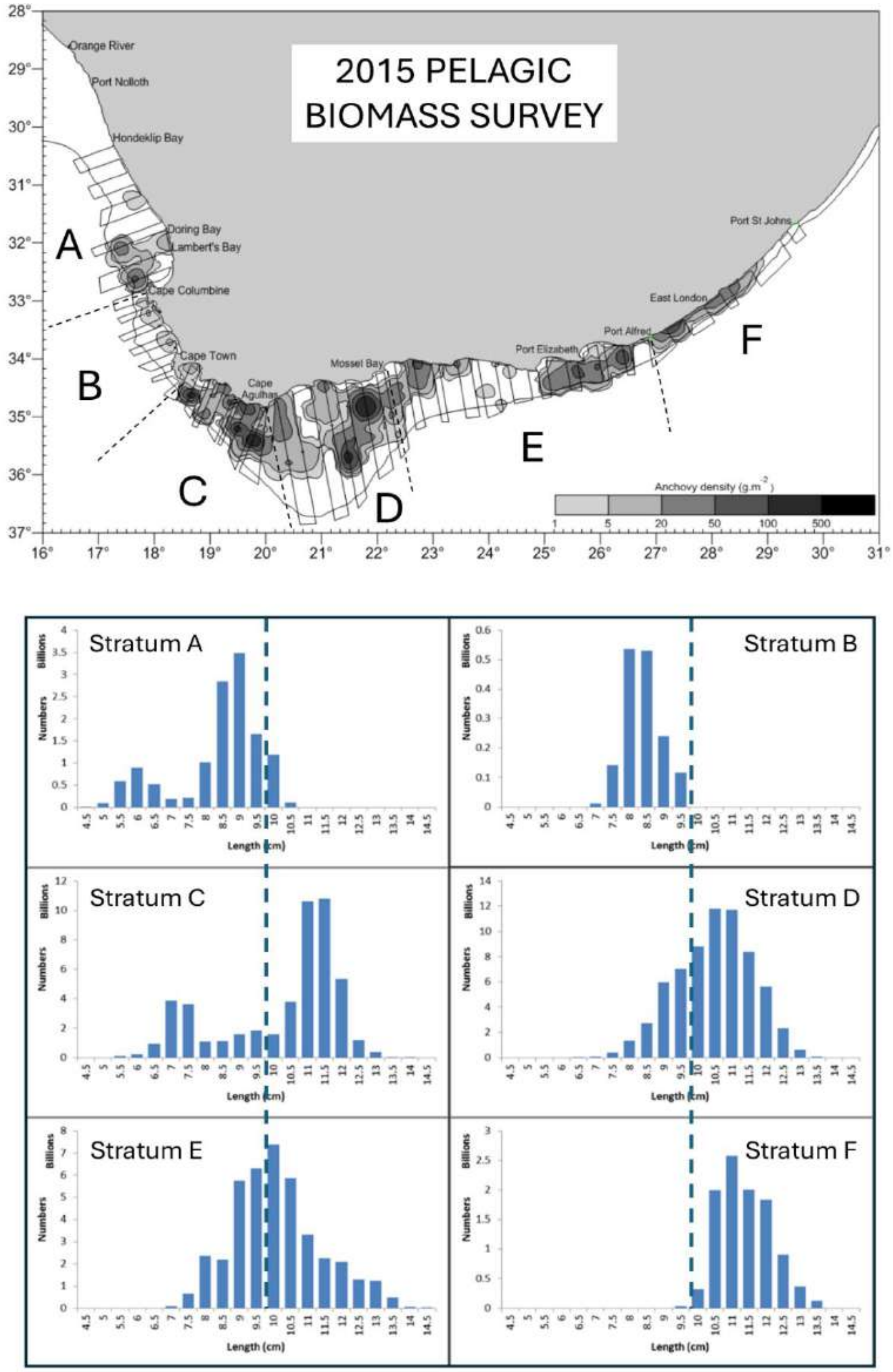

Figure 3.18: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–F; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2015 Total Biomass Survey (adapted from Coetzee et al., 2015).

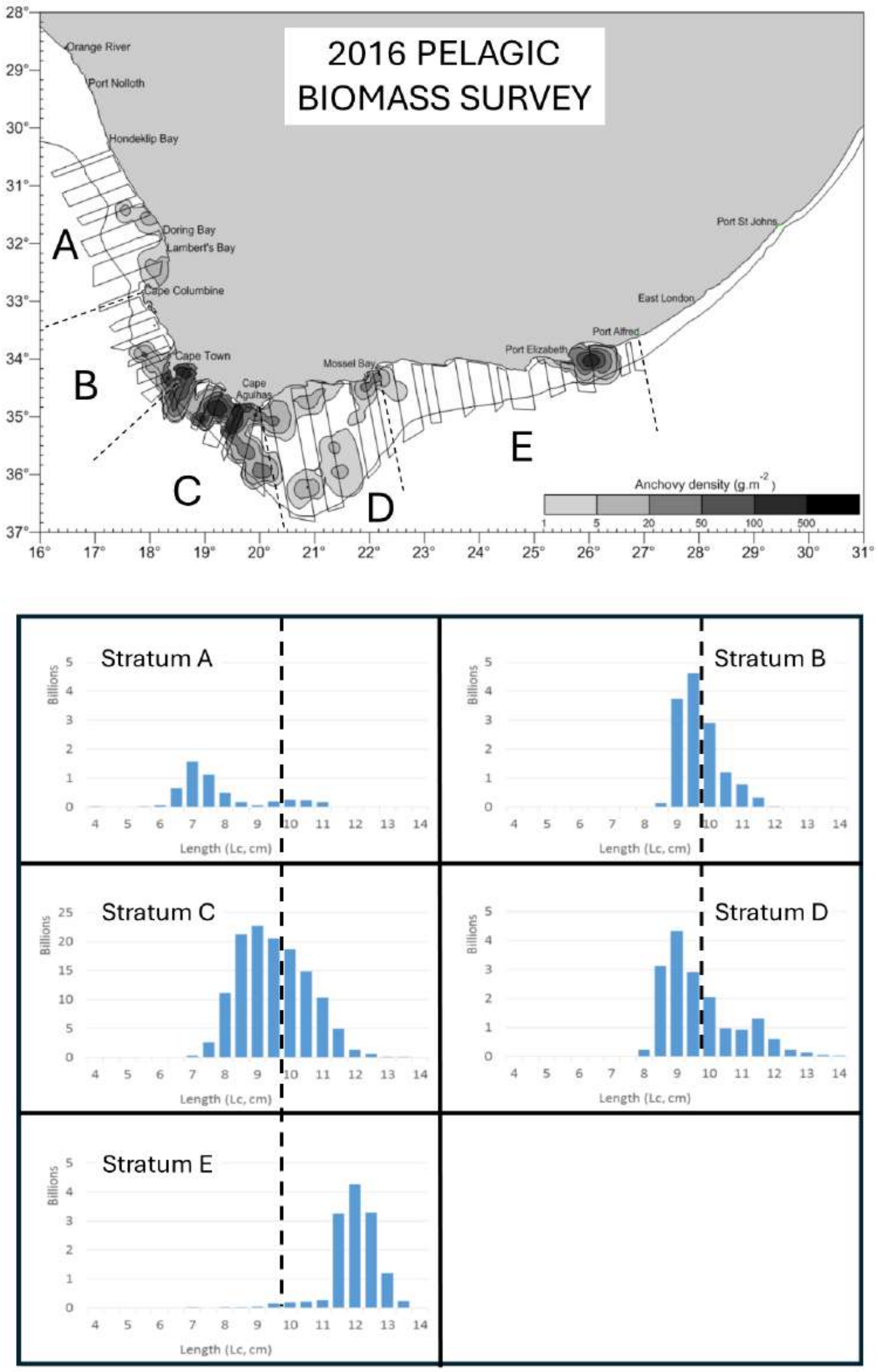

Figure 3.19: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–E; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2016 Total Biomass Survey (adapted from Coetzee et al., 2016).

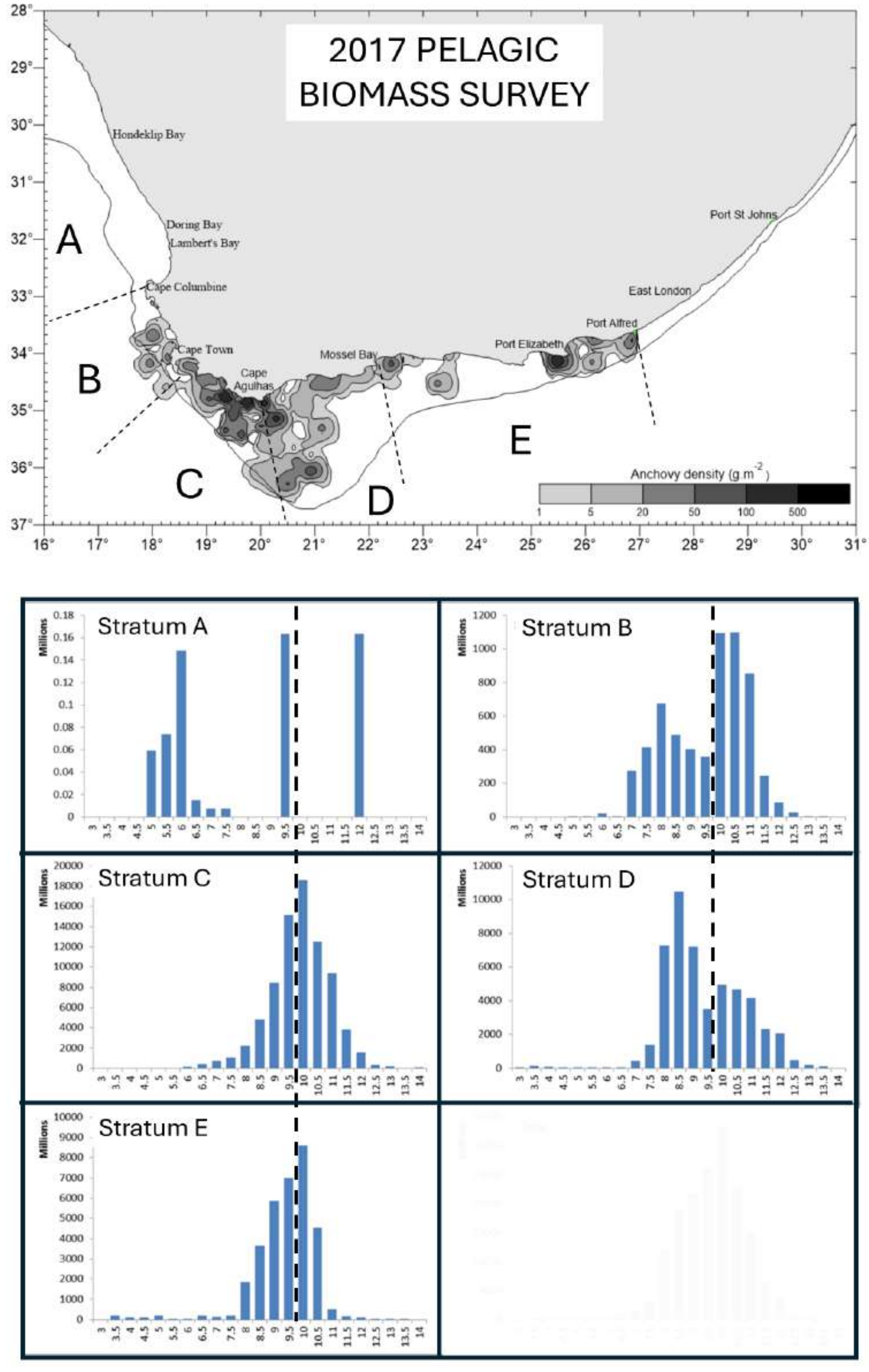

Figure 3.20: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–E; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2017 Total Biomass Survey (adapted from Coetzee et al., 2017).

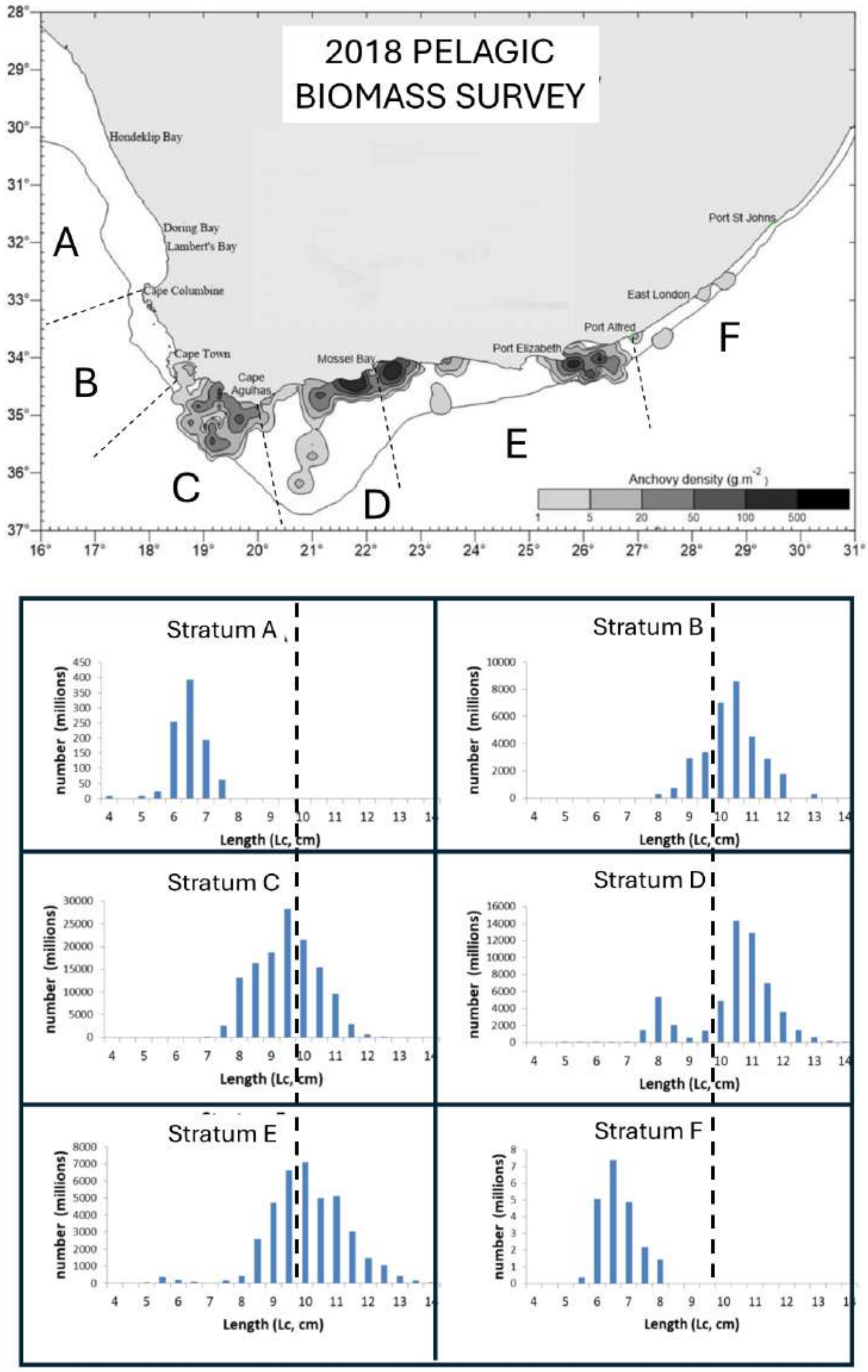

Figure 3.21: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–F; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2018 Total Biomass Survey (adapted from Coetzee et al., 2018).

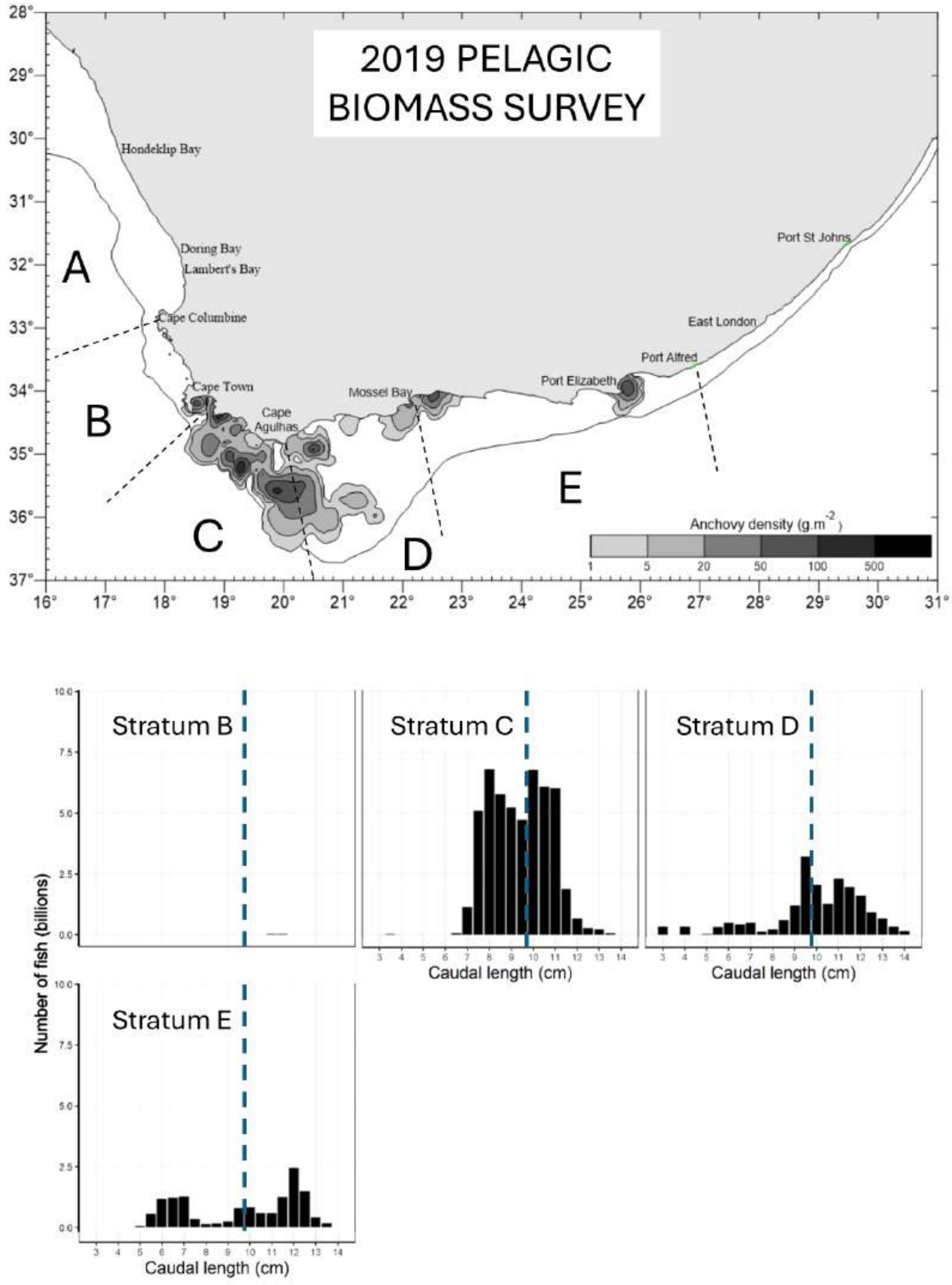

Figure 3.22: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–E; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2019 Total Biomass Survey (adapted from Shabangu et al., 2019a).

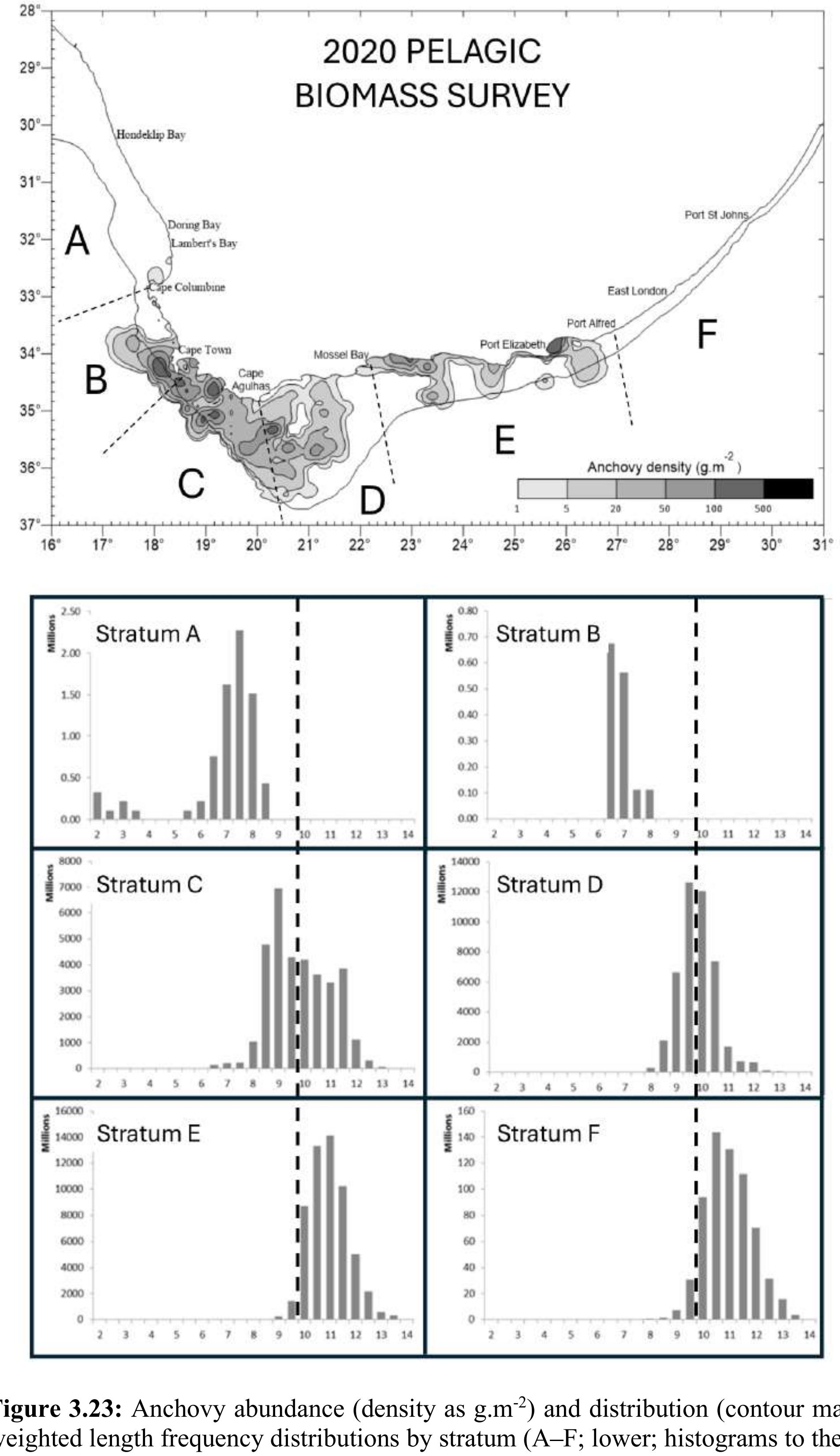

Figure 3.23: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–F; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2020 Total Biomass Survey (adapted from Coetzee et al., 2020a).

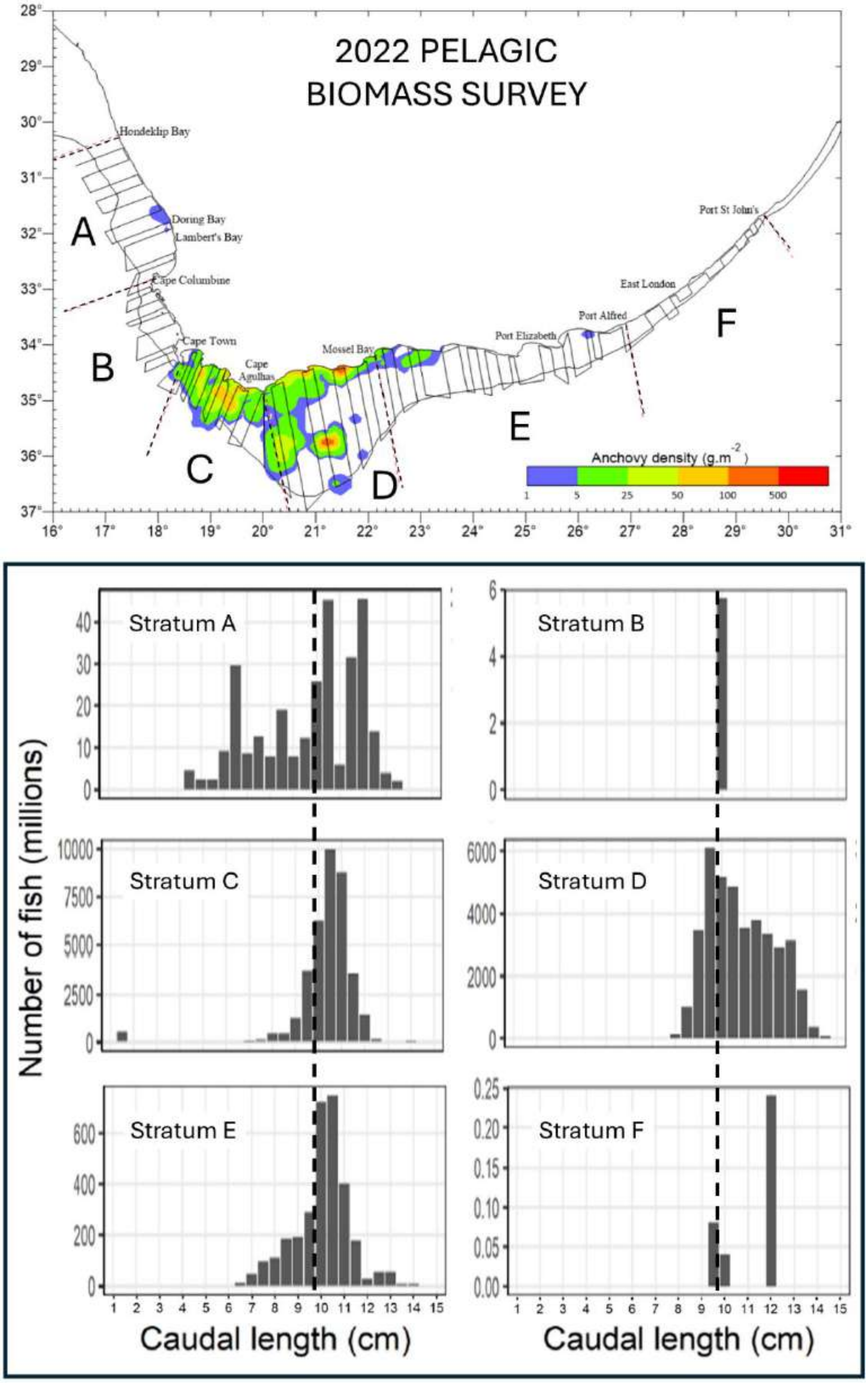

Figure 3.24: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A-F; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2022 Total Biomass Survey (adapted from Coetzee et al., 2023).

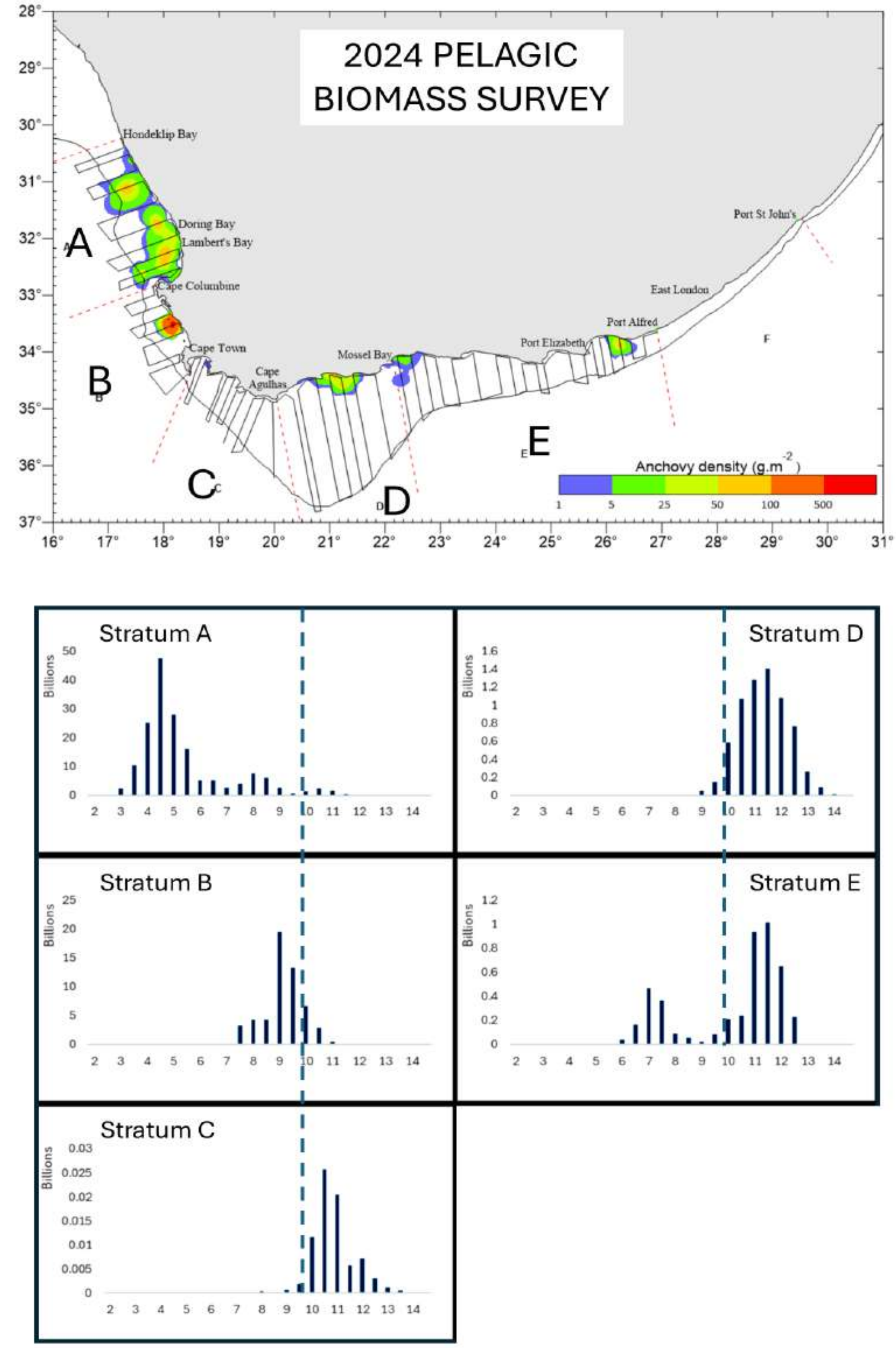

Figure 3.25: Anchovy abundance (density as g.m^{-2}) and distribution (contour map), and acoustically weighted length frequency distributions by stratum (A–E; lower; histograms to the right of the vertical dashed line are >10 cm caudal length) observed during the 2024 Total Biomass Survey (adapted from Coetzee et al., 2024).

In general, South African anchovy have been scarce off the upper West Coast to the north of Cape Columbine (Stratum A) during Total Biomass Surveys conducted in spring/ summer

(October to December) over the past decade. When they occurred there (in 2015 and 2016), they comprised low density patches of recruits (<10 cm CL) fish, resulting in low biomass (Figures 3.18 and 3.19). In contrast, during the Total Biomass Survey conducted in summer/ autumn (February/ March) of 2024 a substantial area of moderate densities of small fish that resulted in a larger biomass was recorded (Figure 3.25). Anchovy has been more common between Cape Columbine and Cape Point (Stratum B), occurring there in 2015–2017, 2020 and 2024, and comprised low- to high-density patches of both recruit and adult (>10 cm CL) fish but dominated by the former (Figures 3.18–3.20, 3.23 and 3.25). The entire western Agulhas Bank between Cape Point and Cape Agulhas (Stratum C) has typically been covered by moderate to high densities of anchovy during Total Biomass Surveys, again a mix of smaller and larger fish but dominated by adults. The almost complete absence of anchovy in Stratum C during the 2024 survey (Figure 25) is in marked contrast to all previous years of the past decade, but that survey was conducted three months later than usual.

Extensive areas of moderate to high densities of anchovy have often been observed both inshore and offshore over the central Agulhas Bank (Cape Agulhas to Mossel Bay; Stratum D) and the eastern Agulhas Bank (Mossel Bay to Port Alfred; Stratum E) during the past decade, particularly between 2014 and 2016 (Figures 3.17–3.19) and again in 2020 (Figure. 3.23) when biomass was higher and in accordance with the previously reported correlation between distributional area and biomass for this and other *Engraulis* species (Barange et al., 2009). Fish in these regions comprise both recruits and adults with the adults typically dominating, sometimes substantially (2014; Figure 3.17) but sometimes with recruits dominating (2017; Figure 3.20). High density aggregations of anchovy in the Algoa Bay area have been observed in most years. Total Biomass Surveys have extended to Port St Johns (Stratum F: Port Alfred to Port St Johns) on five occasions during the past decade, with significant quantities of anchovy found only once (in 2015; Figure 3.18) and comprised entirely of adult fish, whereas recruits dominated the small quantity of fish found in that stratum the previous year (Figure 3.17). The general pattern of an eastward increase in the size (and presumably age) of South African anchovy seen over the past decade corroborates observations reported by Barange et al. (1999) for surveys conducted between the mid-1980s and the mid-1990s.

A composite distribution map of anchovy (irrespective of size) density for the standard Total Biomass Surveys area (Hondeklip Bay to Port Alfred) derived from surveys conducted over the period 2011–2019 (Figure 3.26) clearly shows the occurrence of high-density aggregations over the entire western Agulhas Bank, along the shelf-edge of the Central and Eastern Agulhas Banks, and in inshore waters of the latter in the vicinity of Mossel Bay, Plettenberg Bay and Algoa Bay.

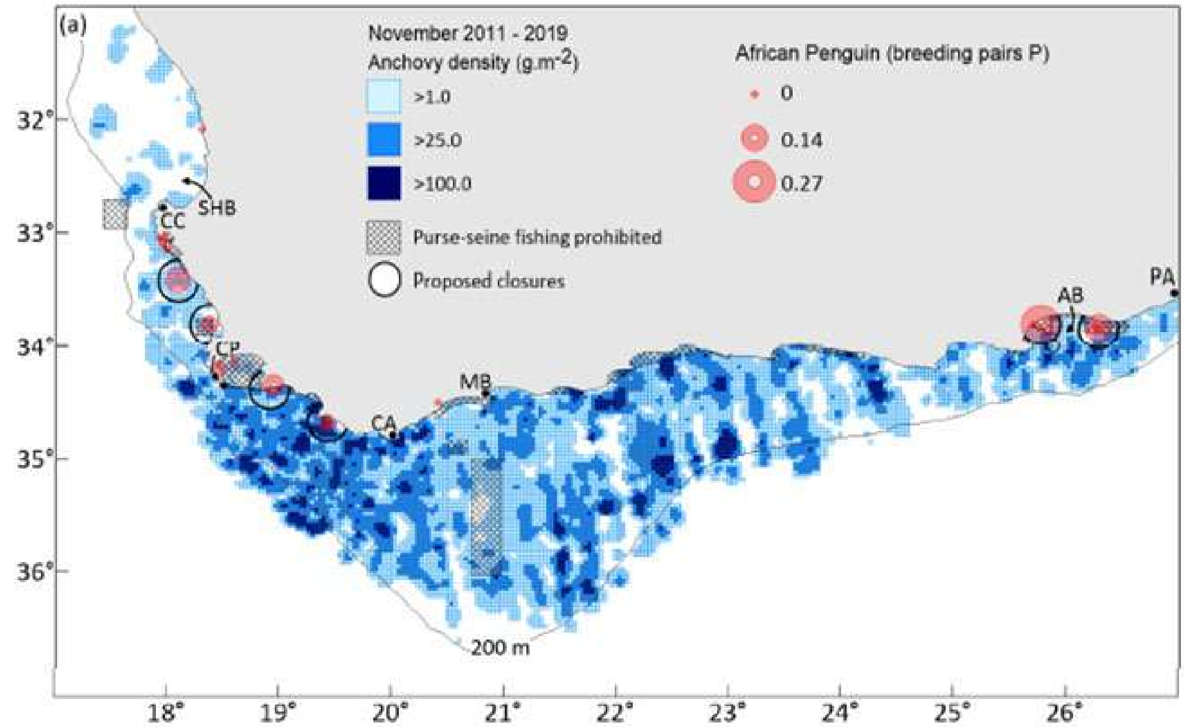

Figure 3.26: Composite distribution map of anchovy density as observed during Total Biomass Surveys conducted in spring/ summer, 2011–2019. Also shown are the locations of African penguin breeding colonies in South Africa (red circles with white centres scaled to represent the proportional contribution to the total South African penguin population (in 2019) made by that colony and the locations of proposed closures to pelagic fishing (black circles) around some colonies. Abbreviations: SHB – St Helena Bay, CC – Cape Columbine, CP – Cape Point, CA – Cape Agulhas, MB –Mossel Bay, AB – Algoa Bay, PA – Port Alfred. From DFFE (2021b).

The South African anchovy population has shown an eastward shift in its distribution over recent decades, with the relative biomass (% of total biomass) observed during Total Biomass Surveys changing abruptly in 1996 from being predominantly (>50%) to the west of Cape Agulhas (WoCA, i.e., off the West Coast) to being predominantly east of Cape Agulhas (EoCA, i.e., off the South Coast) (Roy et al., 2007). That change was correlated with an increase in the cross-shelf SST gradient EoCA observed using satellite data at a 1° by 1° resolution (Augustyn et al., 2018; Figure 3.27) that was due to cooling in the inshore region and was thought to improve feeding conditions for anchovy EoCA (Roy et al., 2007), and the eastward shift has mostly persisted since 1996 (DFFE, 2023). A recent analysis that used satellite data at a resolution of 0.05° by 0.05° and the biomass time series for the period 1984 to 2020 has shown a significant, positive correlation between anchovy relative distribution EoCA and the SST difference between coastal waters of the western Agulhas Bank and offshore waters east of Cape Agulhas (Torr, 2022).

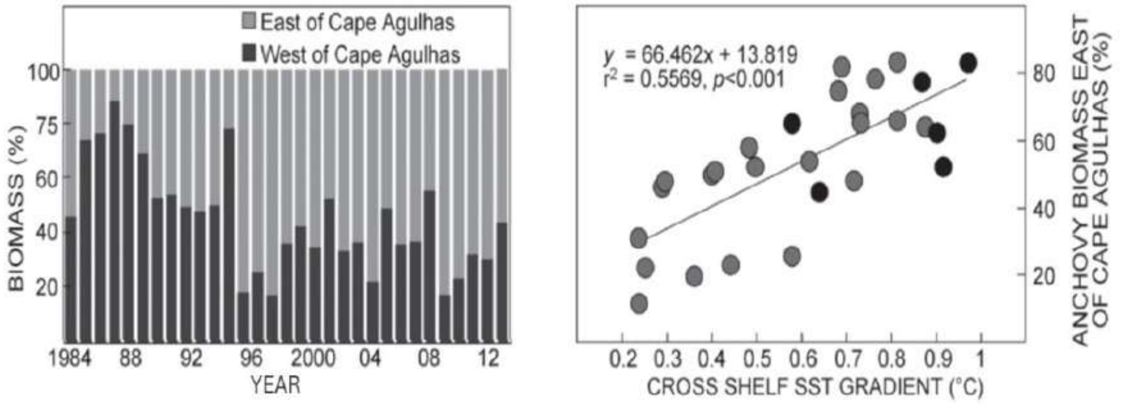

Figure 3.27: Time-series of the distribution of relative (% of total) biomass west of Cape Agulhas (WoCA) and east of Cape Agulhas (EoCA) for South African anchovy during Total Biomass Surveys, 1984–2014 (left) and scatterplot of relative (% of total) anchovy biomass EoCA and cross-shelf SST difference EoCA for the period 1984–2011 (data for 1984–2005 shown as grey circles are from Roy et al. (2007) and black circles represent data for 2006–2011) and the regression line and equation parameters are shown for the full period. Adapted from Augustyn et al. (2018).

The standard survey area (Orange River mouth to Cape Infanta) of Recruit Surveys is substantially spatially restricted compared to the Total Biomass Surveys, both across the shelf and along the shelf, although Recruit Surveys have in four of the five past years extended further east along the South Coast. During these surveys, anchovy caught in midwater trawls are defined as recruits if they are below a "cut-off" length determined using a survey-specific maturity ogive graph based on at-sea visual examination of fish gonads and their assignment to a maturity stage, whereas fish above this cut-off length are defined as adults (Geja et al., 2020). The dates, coverage and effort, estimated anchovy recruitment and other information on Recruit Surveys from 2019 to 2023 are shown in Table 3.2, and the abundance and distribution maps, and acoustically weighted length frequency distributions for each survey are shown in Figures 3.28 to 3.32.

Anchovy recruits typically comprised the majority of fish encountered during Recruit Surveys and were predominantly found off the West Coast (i.e. west of Cape Agulhas) in all years (Figures 3.28–3.32), even during surveys that extended substantially farther east than Cape Infanta (2021 and 2023; Figures 3.30 and 3.32). Adult fish were seldom found at more than low densities to the north of Cape Town and were encountered in high density patches in the inshore waters of the western Agulhas Bank and the central Agulhas Bank in all years. Interestingly, no or only low-density patches of anchovy adults were observed in the Algoa Bay area during years when the pelagic recruit survey extended to Port Alfred or further east (2021–2023; Figures 3.30–3.32), despite survey transects covering most if not all the shelf (and hence available suitable habitat) in that region.

Table 3.2: The start and end dates, vessel, spatial coverage and effort (# of acoustic transects (at) and # of midwater trawls (mwt)), estimated anchovy recruitment within the standard (ORM to CI) area (and total area if further) and its coefficient of variation, cut-off length applied to differentiate recruits from adults, and the reference for annual Recruit Surveys conducted by DFFE (previously DAFF then DEFF) between 2019 and 2023. CI = Cape Infanta; GE = George; ORM = Orange River Mouth; PA = Port Alfred; PSJ = Port St Johns.

Year	Dates	Vessel	Coverage and effort	Anchovy recruitment (billions)	Recruit cut-off length	Reference
2019	05/06-05/07	FRS *Africana*	ORM to GE 76 at 90 mwt	270.3	9.0 cm CL	Shabangu et al. (2019b)
2020	15/06-04/07	FRS *Africana*	ORM to CI 65 at 68 mwt	376.7	8.0 cm CL	Coetzee et al. (2020b)
2021	07/06-24/07	FRS *Africana*	ORM to PA 94 at 139 mwt	152.8 153.6	9.0 cm CL	Coetzee et al. (2021)
2022	30/06-29/07	MFV *Compass Challenger*	ORM to PA 80 at 97 mwt	162.9 163.3	8.0 cm CL	Coetzee et al. (2022)
2023	25/05-28/06	MFV *Compass Challenger*	ORM to PSJ 110 at 115 mwt	16.5 16.7	9.0 cm CL	Shabangu et al. (2023)

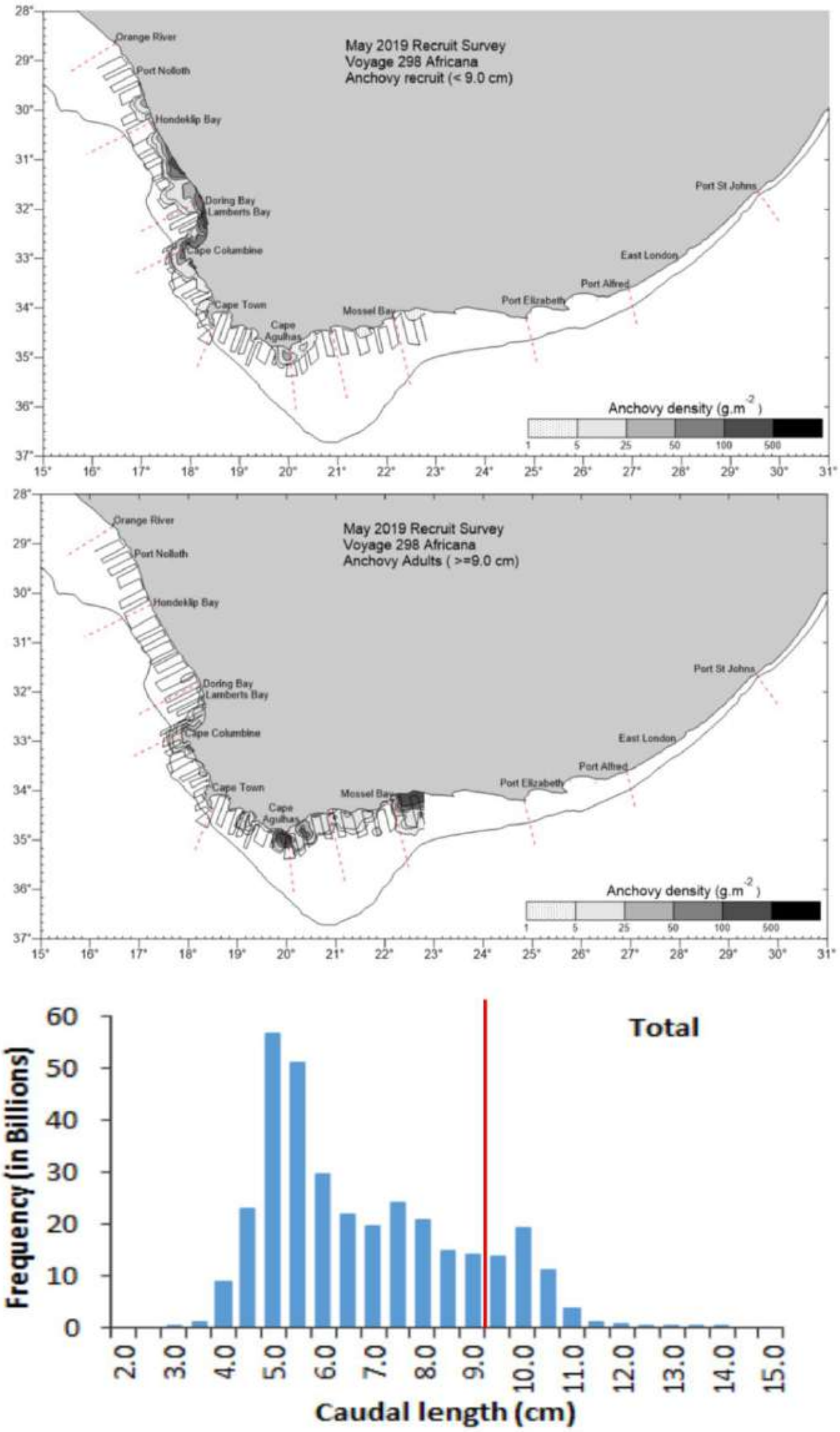

Figure 3.28: Abundance (density as g.m^{-2}) and distribution of anchovy recruits (<9.0 cm CL; upper contour map) and adults (lower contour map), and acoustically weighted length frequency distribution for the entire survey area (lower; histograms to the right of the red vertical line are >9 cm caudal length) observed during the 2019 Recruit Survey (adapted from Shabangu et al., 2019b).

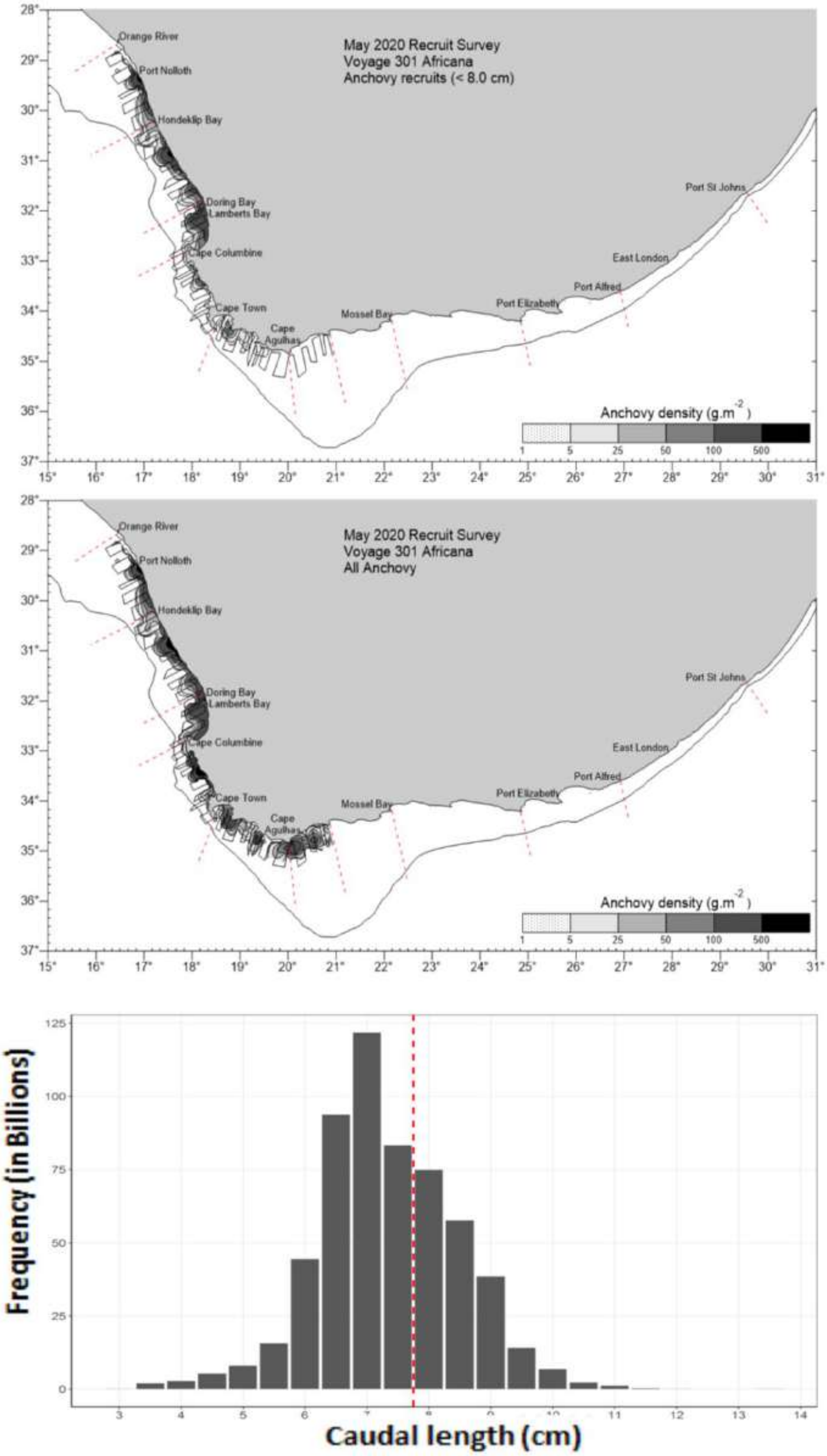

Figure 3.29: Abundance (density as g.m^{-2}) and distribution of anchovy recruits (<8.0 cm CL; upper map) and all anchovy (recruits and adults; lower map), and acoustically weighted length frequency distribution for the entire survey area (lower; histograms to the right of the red, vertical dashed line are >8 cm caudal length) observed during the 2020 Recruit Survey (adapted from Coetzee et al., 2020b).

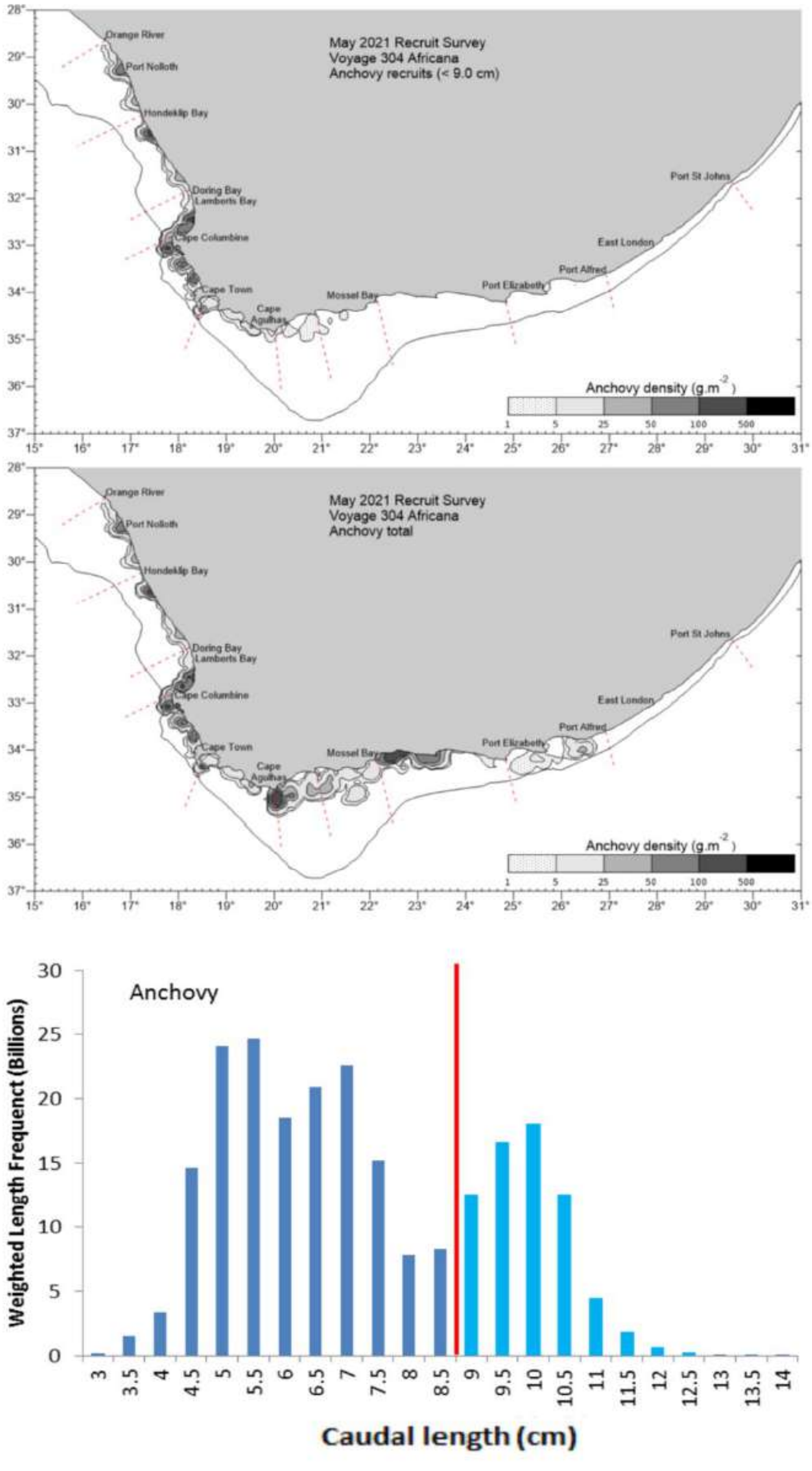

Figure 3.30: Abundance (density as g.m^{-2}) and distribution of anchovy recruits (<9.0 cm CL; upper contour map) and all anchovy (recruits and adults; lower contour map), and acoustically weighted length frequency distribution for the entire survey area (lower; histograms to the right of the red vertical line are >9 cm caudal length) observed during the 2021 Recruit Survey (adapted from Coetzee et al., 2021).

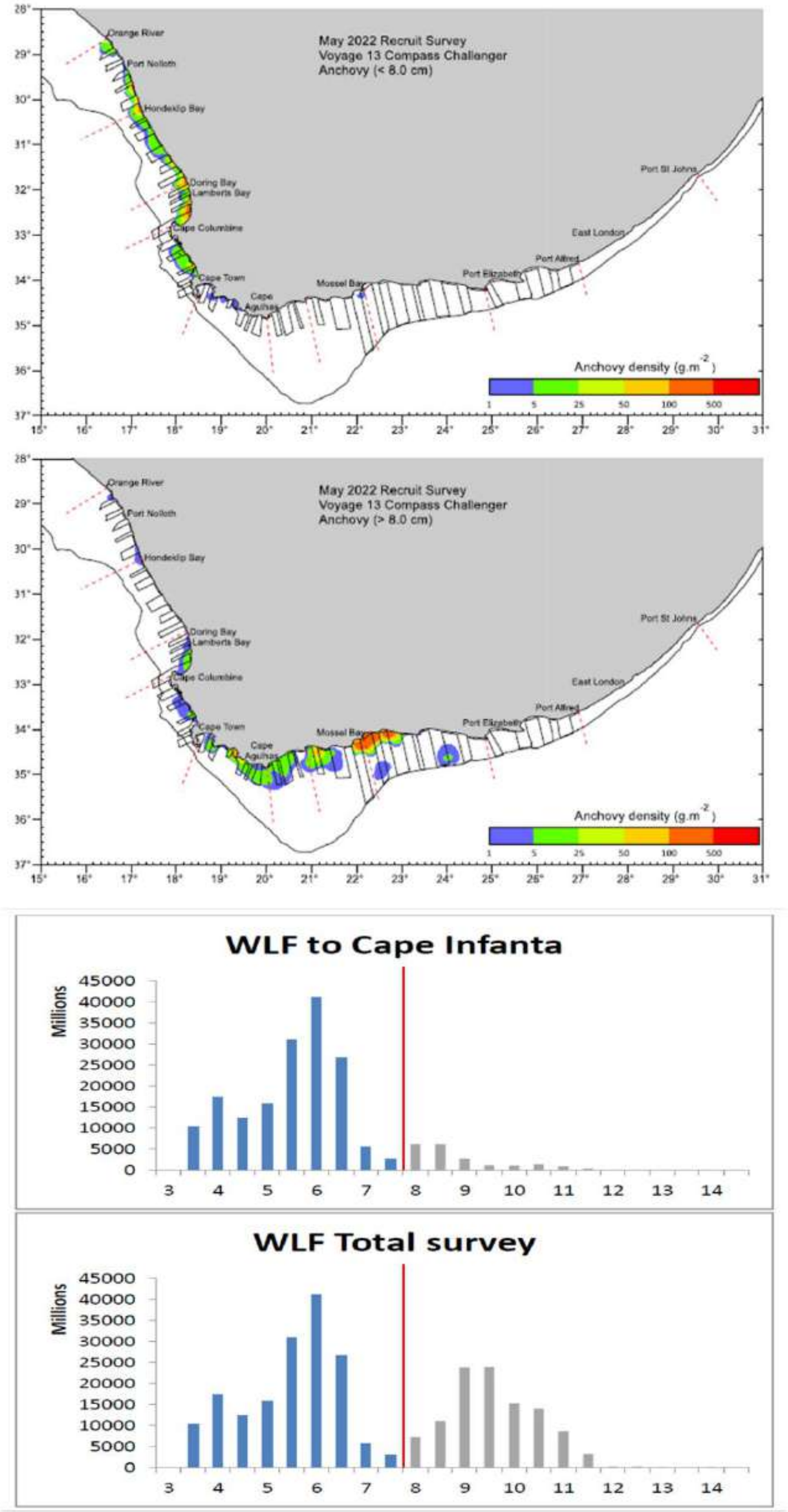

Figure 3.31: Abundance (density as g.m^{-2}) and distribution of anchovy recruits (<8.0 cm CL; upper contour map) and anchovy adults (lower contour map), and acoustically weighted length frequency distribution for the standard survey (upper histogram) and the entire survey area (lower histogram; values to the right of the red vertical line are >8 cm caudal length) observed during the 2022 Recruit Survey (adapted from Coetzee et al., 2022b).

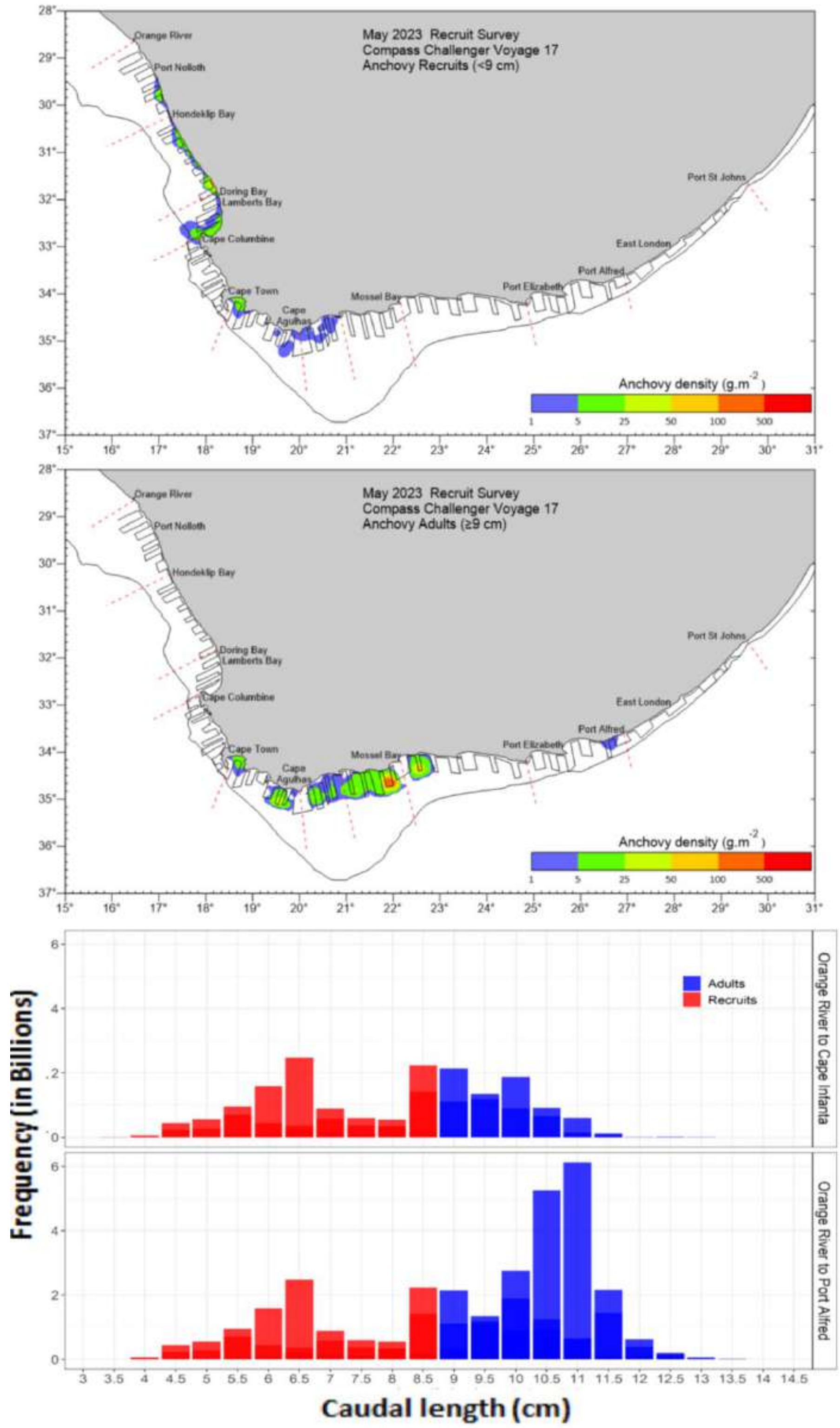

Figure 3.32: Abundance (density as g.m^{-2}) and distribution of anchovy recruits (<9.0 cm CL; upper contour map) and adults (lower contour map), and acoustically weighted length frequency distribution for the standard survey area (upper; red histograms represent recruits and blue histograms, adults) and full survey area (lower) observed during the 2023 Recruit Survey (adapted from Coetzee et al., 2023).

3.6 Seasonal changes in the importance of anchovy in the diets of fish, seabird and marine mammal predators off the South Coast

Small pelagic fishes, including anchovy, are commonly known as "forage fish" because they are preyed upon by a multitude of fish, seabird and marine mammal species and hence play a crucial role in the transfer of energy from lower trophic levels (the plankton on which they feed) to upper trophic levels (their predators), particularly in upwelling but also other systems (Cury et al., 2000; Pikitch et al., 2012; Ruzicka et al., 2024).

Some of these predators are highly dependent on small pelagic fishes, and regular analyses of the diets of such predators throughout the year can provide information on the seasonal occurrence and size of forage fish in areas that neither the commercial fishery nor research surveys cover (spatially and/or temporally). This information is available for anchovy off the West Coast because of monitoring of the fishery there, but the absence of a directed fishery for this species off the South Coast precludes this. Anchovy are important prey for a variety of predator species off South Africa including but not limited to geelbek *Atractoscion aequidens* (Griffiths, 1988; Griffiths & Hecht, 1995), shallow water hake *Merluccius capensis* (Pillar & Barange, 1993; Pillar & Wilkinson, 1995), silver kob *Argyrosomous inodorus* (Parker et al., 2020), snoek *Thyrsites atun* (Griffiths, 2002), yellowtail *Seriola lalandi* (Parker et al., 2020), African penguin *Spheniscus demersus* (Connan et al., 2016; Crawford et al., 2001, 2011; DFFE, 2021b), Cape gannet *Morus capensis* (Berruti et al., 1993; Crawford et al., 2019; Klages et al., 1992), and Cape fur seals *Arctocephalus pusilis* (David, 1987; Huisamen et al., 2012; Kirkman et al., 2007). Studies that have provided information on seasonal patterns in the importance of anchovy in the diets of predators off the South Coast are briefly described and synthesised below. It must be noted, however, that seasonal changes in dietary importance may not necessarily be due to local prey availability but may reflect preferential feeding and prey switching. For example, Cape fur seals will preferentially feed on sardine but switch to anchovy when sardines are unavailable or present at low abundance (Huisamen et al., 2012).

3.6.1 Fish

Anchovy were found to be the most important (comprising 72% by number) prey of subadult (<750mm TL) and adult geelbek in False Bay and the most important (40–70%N) prey of subadults off Port Alfred (Griffiths, 1988; Griffiths and Hecht, 1995). In the latter area, ingested anchovy had a mean size of 11.5 cm TL (10.3 cm CL) and were only recorded in geelbek stomachs between March and July, with the geelbek apparently following the anchovy offshore from autumn to winter during this period. Their absence in the diet from August to February was linked to the eastward movement in winter of small pelagic fish, principally sardine undertaking the "sardine run" but also including anchovy (Coetzee et al., 2010).

Anchovy were also a major dietary component of juvenile and subadult (<40 cm TL) shallow water hake off both the West (Pillar & Barange, 1993) and South (Pillar & Wilkinson, 1995) coasts but were substantially more important in the latter (60–75% of total dietary mass) compared to the former (10–30%). Anchovy of 8–14 cm TL (7.2–12.5 cm CL) were consumed by shallow water hake off the South Coast but there was little seasonal or spatial (both across- and alongshore) difference in the importance of anchovy to their diet.

3.6.2 Seabirds

Anchovy and sardine have long been considered the most important food items of African penguin *Spheniscus demersus* off southern Africa (Crawford et al., 2001; DFFE, 2021b and its references), with anchovy contributing 55% of dietary mass of penguins in Algoa Bay between

1979 and 1981 (Crawford et al., 2011). However, recent work using biochemical tracers (stable isotopes of carbon and nitrogen) in penguin blood and feathers to estimate dietary composition rather than traditional stomach content analyses has indicated that adult penguins in Algoa Bay target chokka squid *Loligo reynaudii* for self-provisioning in both breeding (when they feed their chicks primarily with small pelagic fish) and non-breeding seasons (Connan et al., 2016). On average, squid were estimated to contribute around 40% of the diet and sardine a similar percentage with both species showing seasonal variation in dietary importance, whereas anchovy contributed around only 10% of the diet and showed little seasonal variation in importance.

Analyses of regurgitated stomach contents of Cape gannet breeding at Lamberts Bay and Malgas Island between 1978 and 2015 showed that anchovy contributed 5–80% of dietary mass annually (Crawford et al., 2019), making its largest contribution (around 70% of total dietary mass) in April to June at Lambert's Bay and in October to December (around 50%) at Malgas Island (Berruti et al., 1993). Anchovy was also major prey item of Cape gannet sampled between 1979 and 1990 at Bird Island, Algoa Bay, comprising 60% (on average) by number of prey items consumed and contributing 24% of total prey mass there (Klages et al., 1992). Anchovy ranged between 3.0 and 17.2% and had a mean size of 12.7 cm FL[27] (2.7–15.7 and 11.6 cm CL) and showed seasonal variation in their dietary importance, contributing more to the diet (17–40% of total prey mass) during the spring/ summer breeding season (October to March) compared to the autumn/ winter non-breeding season (April to September; 0–22% mass).

3.6.3 Marine mammals

David (1987) documented the teleost portion of the diet of Cape fur seals collected at sea from the South African West (Orange River mouth to Cape Town) and South (Cape Town to Algoa Bay) coasts during the 1970s and 1980s. He reported that anchovy and Cape hakes were the most important prey species off the West Coast with each contributing 23% to seal total dietary mass there. Anchovy was again the most important teleost prey of seals off the South Coast where it contributed 17% to total dietary mass. The average size of anchovy consumed by seals off the West Coast (9.4 cm TL (8.4 cm CL) and 4.9 g WBW)[28] was substantially less than that of those consumed off the South Coast (12.7 cm TL (11.4 cm CL) and 13.3 g WBW; David, 1987). Huisamen et al. (2012) analysed scats (faeces) and the hard parts (fish otoliths and cephalopod beaks) collected from the Robberg seal colony at Plettenberg Bay on the South Coast over the period 2003–2008 to investigate the species and size composition of their diet. Anchovy was the most important dietary item in terms of percentage frequency of occurrence (31.2%) and percentage numerical abundance (55.5%) but, because of its small size (average TL estimated at 11.6 cm (= 10.4 cm CL) and wet mass of 10.2 g) compared to other species was only the 3rd most important in terms of percentage mass (15.1%). Whereas the dietary importance of anchovy did not vary between upwelling (December to May) and non-upwelling (June to November) seasons there was a significant and substantial increase in its importance over the study period, from <5% mass in 2003 and 2004 to >35% mass in 2006 and 2007. This increase was not correlated with regional or total anchovy biomass levels and likely arose from increased targeting of anchovy by seals given the decreased dietary contribution importance of

[27] Fork length

[28] Wet body weight.

sardine (their preferred small pelagic prey) over this period that arose from decreased regional and total sardine biomass levels (Huisamen et al., 2012).

3.7 Conclusions and recommendations

To determine appropriate areas and seasons for catching South African anchovy for human consumption, this report has synthesised information on:

- the taxonomy, distribution, biology, ecology and life history strategy of this species in South African waters;
- the South African small pelagic fishery in general and the directed fishery for anchovy in particular that catches smaller (recruit) and larger (adults) fish off the West Coast and has operated for several decades;
- the abundance, distribution and fish size patterns of anchovy around the coast observed during annual Recruit (autumn/winter) and Total Biomass (spring/summer) surveys of the country's small pelagic fish resources, and;
- the diets of fish, seabird and marine mammal predators of anchovy off the South Coast that may provide some information on seasonal variability in the occurrence, abundance and size of this species in this region given the lack of a directed fishery for anchovy there.

Information from the last three points above is summarised in Table 3.3.

The determination of where and when targeted fishing for anchovy for human consumption will depend on the product to be developed, given that some product types (e.g., protein meal and fish paste) do not require large fish whereas others (e.g., whole fish and fillets) do. Because of the spatially differentiated anchovy life history strategy described above, the seasons and areas where there is a high likelihood of catching small (<10 cm CL) and large (>10 cm CL) anchovy will differ, hence these are discussed separately below. Common to both, however, is the need to catch fish from vessels equipped with refrigerated seawater, ice or freezers and sufficiently close to harbours to ensure that catches will be landed in a good condition for processing.

3.7.1 Targeting small (<10 cm CL) anchovy for human consumption

Arising from their life history strategy, and as indicated by catch patterns of the present directed anchovy fishery and observations made during both the Recruit and Total Biomass surveys, small anchovy is available and abundant in inshore waters off the West Coast, including the western Agulhas Bank, and are presently caught in all months of the year excluding December and January. There is, however, marked seasonality in anchovy catches taken to the north of Cape Town which are higher in autumn (north of Cape Columbine) and winter (between Cape Columbine and Cape Point), whereas catches on the western Agulhas Bank are taken throughout most of the year.

Targeting of small anchovy for processing into products for human consumption could be undertaken from any of the designated pelagic fish landing sites on the West Coast (Lamberts Bay, Laaiplek, St Helena Bay, Saldanha Bay, Cape Town, Hout Bay, Hermanus and Gans Bay; Figure 3.33). However, and given the pulsed nature of their occurrence in waters to the north of Cape Town, fishing from harbours with easy access to the Western Agulhas Bank such as Hermanus and Gans Bay would be preferable as that would enable fish to be caught for most of the year. Targeting of smaller anchovy on the South Coast appears unlikely to be successful given their low occurrence there.

Table 3.3: A summary of spatial and temporal occurrence and fish size patterns of South African anchovy around the South African coast derived from three information sources, namely the present fishery for anchovy (West Coast only), Recruit and Total Biomass surveys (both coasts), and the diets of anchovy predators (South Coast only).

Information source	Spatial occurrence	Temporal occurrence	Fish size patterns
Fishery (West Coast only)	56% of the annual anchovy catch is taken from St Helena Bay (Pool Area A); 33% between Cape Columbine and Cape Point (Pool Area B), and 11% between Cape Point and Cape Agulhas (Pool Area C). The relative importance of anchovy catches taken in Pool Area C has shown a significant increase (from 5% to 30%) over the period 1987–2019. Anchovy are caught in cool, productive waters with SSTs of 13–16°C and moderate to high (3–20 mg.m-3) *Chl a* levels.	On average, anchovy catches are taken in a 3-month pulse between April and June from Pool Area A. On average, anchovy catches are taken in a 5-month pulse between May and September from Pool Area B. On average, anchovy catches are more evenly spread (8 months) between February and September from Pool Area C.	Overall (i.e. all pool areas), the average size of anchovy is higher (ca. 9 cm CL) in the first and last quarters of the year and lower (ca. 8 cm CL) during the middle two quarters. The average size of anchovy caught increases from north to south, being 7.4 cm CL for Pool Area A, 7.8 cm CL for Pool Area B, and 8.4 cm CL for Pool Area C. That of fish in Pool Area B has shown a significant negative trend from 1987 to 2019.

Information source	Spatial occurrence	Temporal occurrence	Fish size patterns
Surveys (West and South coasts)	Recruits (generally fish <9.0 or <10.0 cm CL) are found predominantly off the West Coast and adults predominantly off the western Agulhas Bank and the South Coast to Port Alfred.	Anchovy recruits are predominantly found off the West Coast and occasionally off the westernmost part of the South Coast in autumn/ winter but are also encountered off the West Coast in spring/ summer although typically at much lower abundances than in autumn/ winter. Adults are typically found distributed across the shelf between Cape Point and Port Alfred in spring/ summer, although they may extend further north along the West Coast in some years. Adults have shown an eastward shift in their distribution in spring/ summer over the past four decades from being predominantly (>50% of total biomass) to the west of Cape Agulhas to being predominantly to the east of Cape Agulhas. In autumn/ winter, adults are seldom found in inshore waters north of Cape Town but occur at high densities in inshore waters of the western Agulhas Bank and the central Agulhas Bank. They have been absent or present at low densities only on the eastern Agulhas Bank at this time in recent years.	Size-related anchovy distribution patterns are apparent in both Total Biomass and Recruit surveys. Fish size increases from north to south along the West Coast and from west to east along the South Coast. The smallest anchovy (2–5 cm CL) are typically found in the northern part of the West Coast and the largest (>13 cm CL) are typically found in the eastern part (Algoa Bay and eastwards) of the South Coast. On occasion, however large anchovy has been observed off the lower West Coast and small fish off the easternmost part of the South Coast.

Information source	Spatial occurrence	Temporal occurrence	Fish size patterns
Predator diets (South Coast only)	Detailed dietary studies that included analyses of seasonal variability have shown that anchovy recruits and adults are important prey of several fish, seabird, and marine mammal predators that occur on the South Coast.	Subadult geelbek off Port Alfred feed on anchovy between March and July (autumn/ winter) but not during the remainder of the year (spring/ summer). Subadult shallow water hake on the South Coast feed on anchovy throughout the year. Anchovy is less important than squid and sardine in the diet of African penguin in Algoa Bay and show little seasonal variation in dietary importance. Cape gannet breeding on Bird Island feed extensively on anchovy but more so between October and March (spring/ summer) and less so between April and September (autumn/ winter). Anchovy is important teleost prey of Cape fur seals on the South Coast, but its importance did not vary seasonally in seals at Plettenberg Bay.	Geelbek off Port Alfred consume anchovy with a mean size of 10.3 cm CL. Shallow water hake off the South Coast consume anchovy ranging in size between 7.2 and 12.5 cm CL. Cape gannet from Bird Island feed on anchovy ranging from 2.7 to 15.7 cm CL and with a mean size of 11.6 cm CL. Cape fur seals at Plettenberg Bay feed on anchovy with a mean size of 11.4 cm CL.

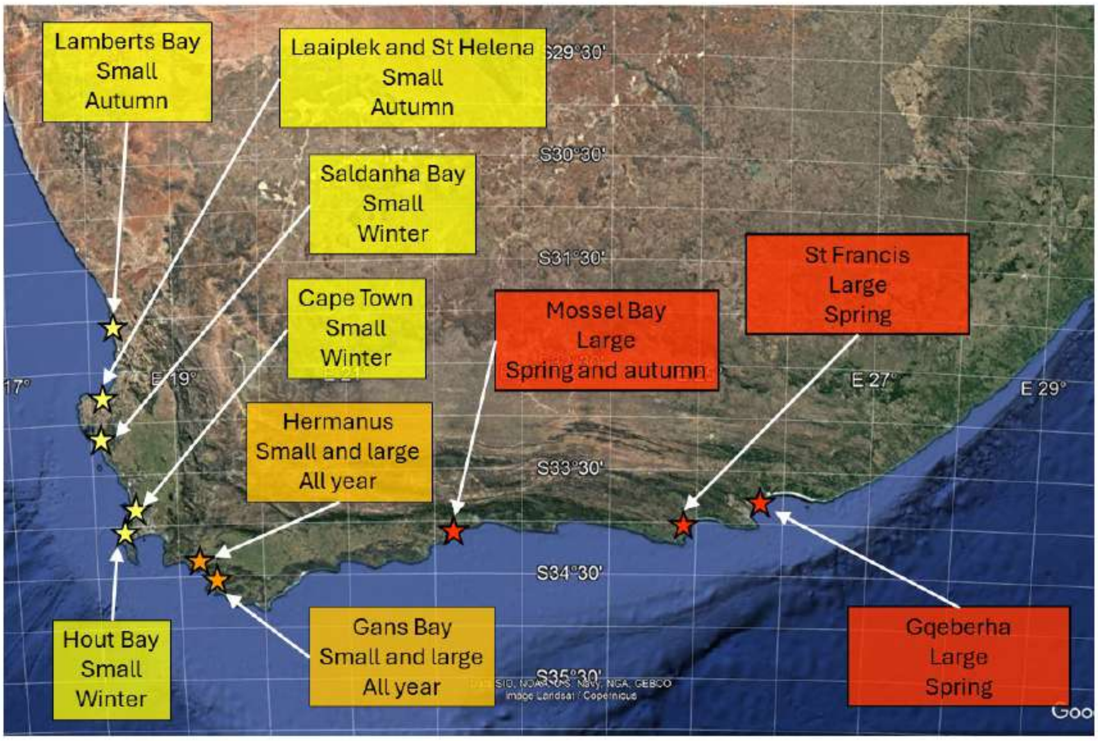

Figure 3.33: Map indicating the size category (small or large, divided at 10 cm CL) and season of likely high abundance and inshore availability of South African anchovy for each of the designated small pelagic landing sites in South Africa (as per 2024 Anchovy Fishery permit conditions).

3.7.2 Targeting large (>10 cm CL) anchovy for human consumption

Arising from their life history strategy, and as indicated from observations made during both the Recruit and Total Biomass surveys, large anchovy is available and abundant in inshore waters of the western Agulhas Bank in both autumn and spring, and presumably then throughout the year. And whereas the average size (8.4 cm CL) of anchovy taken on the western Agulhas Bank in past decades by the present fishery is <10 cm CL, large fish are caught in most years and the average size has been close to 10 cm CL in several years, indicating that these fish are present there. Recruit and Total Biomass surveys show that large anchovy is also available and abundant in inshore waters along the entire South Coast to Port Alfred in spring, but with no or few anchovy on the easternmost portion of the South Coast in autumn in the past five years.

Studies of the diets of predators that feed extensively on anchovy off the South Coast corroborate the presence of large individuals there, with the average size of fish consumed by geelbek, Cape gannet and Cape fur seals all <10 cm CL. Three of the dietary studies (on African penguin, Cape fur seal and shallow water hake) found little or no seasonal variation in the dietary importance of anchovy but those on Cape gannets and geelbek did, albeit with contrasting patterns. As indicated above, however, factors other than anchovy abundance such as the different feeding strategies employed by different predators and the relative densities of different co-occurring prey species, including preferred prey, will also impact on predator feeding patterns. This suggests caution is advisable when making assumptions about the seasonal occurrence and/or abundance of anchovy in a particular region that are based on seasonal analyses of predator diets.

Targeting of large anchovy for processing into products for human consumption could be undertaken from designated pelagic fish landing sites on the western Agulhas Bank (Hermanus and Gans Bay) throughout the year, and likely throughout the year from Mossel Bay as well (Figure 3.33). Large anchovy would also be available in inshore waters in spring to vessels fishing from St Francis Bay and Gqeberha, but have been absent there during autumn/ winter of recent years.

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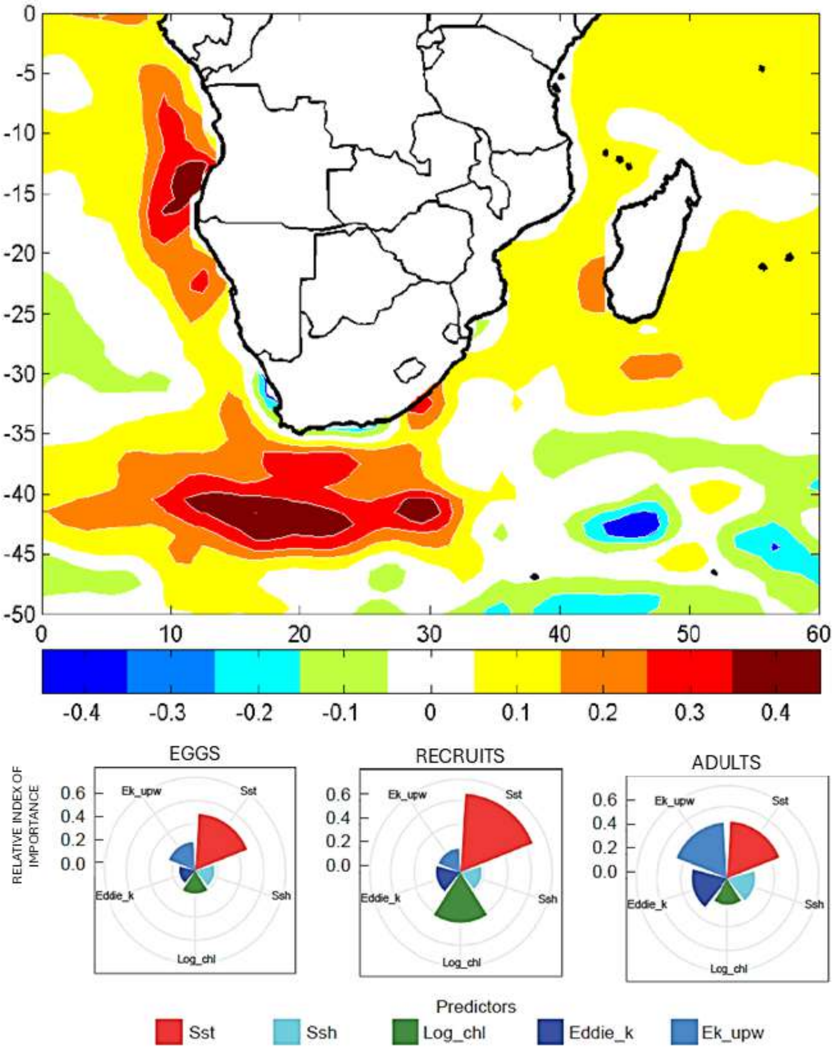
CHAPTER 4
REPORT ON HOW CLIMATE CHANGE MIGHT IMPACT ANCHOVY AND WHETHER INCREASED UTILISATION OF ANCHOVY COULD HAVE ECOSYSTEM IMPACTS INCLUDING SUPPORTING RECOVERY OF THE SARDINE POPULATION

Carl D van der Lingen[30]



Frontispiece: Linear trend of sea surface temperatures (°C per decade; yellow to red colours indicate warming and green to blue colours indicate cooling) around southern Africa from 1982 to 2016 (upper; from Rouault, 2021); and pie diagrams illustrating the relative importance of the top five environmental variables in generalised additive models relating to the distributions of anchovy eggs, recruits and adults. The sizes of environmental predictor pie slices are proportional to their relative importance in predicting the distribution of that life stage. SST = sea surface temperature; SSH = sea surface height; Log_chl = log of surface chlorophyll *a* concentration; Eddie_k = eddy kinetic energy; Ek_upw = Ekman upwelling. Adapted from DFFE (2023).

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Executive summary

To assess (i) the possible impacts of climate change on South African anchovy; and (ii) the possible ecosystem impacts of increased harvesting of anchovy including supporting recovery of the sardine population, this report has synthesised information from the literature and publicly available data on South African anchovy and sardine.

Information on and descriptions of: (i) the impacts of climate change on coastal marine ecosystems in general and South African marine ecosystems in particular; (ii) the predicted impacts of climate change on South African and other anchovy species; and (iii) environmental drivers of South African anchovy abundance, distribution, phenology, and other attributes were collated to identify the possible impacts of climate change on South African anchovy. Information on and descriptions of: (i) the ecosystem role of anchovy as predators and as prey and as mixers of the upper water column; (ii) whether utilising South African anchovy for human consumption would require an increase in exploitation rate; and (iii) anchovy-sardine interactions were collated to assess the possible ecosystem impacts of increased harvesting of anchovy, including supporting the recovery of the sardine population.

Key findings

1. Potential and predicted climate change impacts on anchovy

- Predicted changes in coastal marine environments arising from climate change include increased temperatures, stratification, sea levels and extreme weather events; decreased pH and dissolved oxygen levels; changes in circulation patterns, freshwater availability and lower trophic level (plankton) composition.
- Predicted and important near-future changes in the South African marine environment include increased sea surface temperatures around the entire coast, increased upwelling off the West and Southwest coasts, and increased primary production off the West Coast and in inshore waters off the Southwest and South coasts.
- Long-term observations of South Africa's marine environment have shown:
    - Significant increases (and some small decreases) in SSTs in different regions that are attributed to climate change.
    - A significant increase in cross-shelf SST gradients off the South Coast.
    - A significant increase in upwelling off the South Coast and a tendency to increased upwelling off the West Coast.
    - Changes in copepod abundance and species composition off both the West and South coasts that, while likely linked to environmental changes such as ocean warming, are thought to be largely driven by predation by small pelagic fishes.
    - An increase in the occurrence of harmful algal blooms (HABs) and consequent incidence of localised low oxygen water (LOW) events in coastal waters off the West and Southwest coasts, likely due to environmental (possibly climate-driven) change.
    - An increase in the severity and duration of marine heat waves (MHWs) off the West and Southwest coasts, particularly in non-upwelling localities.
    - No trends in the pH, dissolved oxygen levels, or phytoplankton biomass.
- Predicted climate change impacts on anchovy include changes in distribution, abundance, phenology and physiology and other biological characteristics including body size, length at maturity, etc).
- Despite South African anchovy being considered to have an overall "medium-low" sensitivity to climate change, warming is predicted to have a strong, negative impact on this species, with biomass reductions of around 50% projected by 2050.

- Assessments of relationships between anchovy and environmental variables have shown that:
    - Sea surface temperature is the most important environmental predictor of anchovy egg, recruit and adult distributions, and adults have shown an eastward shift in their relative distribution (% of total biomass) that is significantly correlated with cross-shelf SST gradients off the Southwest and South coasts.
    - The spatial extent of anchovy optimal habitat off the West Coast has declined since the early-2000s whereas that off the South Coast has remained stable.
    - Anchovy recruitment success is strongly dependent on the successful transport of eggs and larvae from the spawning area off the Southwest and South coasts to the nursery area off the West Coast. Recruitment is positively correlated with cumulative upwelling towards the end of the upwelling season (December and March); intense upwelling at the start of the upwelling season (October and November) is likely to have a negative impact on recruitment success. Recruitment success is also partially dependent of the biomass of spawning anchovy west of Cape Agulhas.
    - A significant decrease in the average size of anchovy caught between Cape Columbine and Cape Point may be indicative of a phenological change in the timing of peak spawning (to later in the year), or a long-term effect of warming or a decline in food quantity or quality as has been observed in anchovy populations elsewhere.

2. ***Might increased harvesting of anchovy have ecosystem impacts including supporting the recovery of the sardine population?***

- South African anchovy plays a critical role in coastal ecosystems of the West, Southwest and South coasts, particularly as forage for a wide variety of fish, seabird and marine mammal predators for whom anchovy is important and sometimes dominant prey. Changes in the abundance and availability of anchovy have large impacts on such dependent predators. Anchovy may also play a role in mixing the upper water column during spawning events.
- The fishery for South African anchovy is presently considered to be sustainable, but annual total allowable catches are under-caught by some 43.9% on average (2000-2023, equivalent to ca. 190 000t) and low exploitation rates (8.6% per year, on average) suggest that this species is under-utilised.
- Despite substantial efforts to develop human consumption products from Peruvian anchoveta (*Engraulis ringens*) made during the early-2000s, only relatively small quantities (<2% of the anchoveta TAC; typically >100 000 t) have been processed into HCPs each year since then. Barriers to increasing the quantity of anchovy processed into HCPs include a small local demand for HCPs, increased international demand for fish meal and oil, a small differential in the landing (off-vessel) price of anchoveta for HCPs or reduction, and businesses claiming to produce HCPs but instead systematically diverting anchoveta to fish meal factories, among others. These illustrate the difficulties likely to be encountered in developing anchovy HCPs in South Africa.
- A comparison of the population trajectories of South African anchovy and sardine show that estimates of recruitment strength of the two species, and of their total biomass (derived from annual surveys conducted over the past four decades), are significantly and positively correlated, suggesting that the dynamics of the two species are responding to the same, likely environmental, forcing. This is similar to observations of significant, positive correlations between deposition rates of anchovy and sardine scales in marine sediments in some other upwelling systems, and contrary to the regime shift hypothesis that posited species alternations between the two.

3. ***Implications***

- The observed eastward shift in the relative distribution of anchovy spawners appears likely to continue, under the assumptions that cross-shelf SST gradients off the Southwest and South coasts continue to increase and the relationship between anchovy relative distribution and these gradients continues to hold. Should the biomass of anchovy spawners off the West and Southwest coasts decline below ca. 750 000t, this will have a negative effect on recruitment.

- The impact on anchovy recruitment of increased upwelling off the West and Southwest coasts will depend on when the upwelling occurs: intense upwelling early in the season (spring) will likely result have a negative effect due to high advective loss of eggs and early larvae, whereas intense upwelling later in the season (summer) will likely have a positive effect.
- Increased temperatures are likely to result in decreases in anchovy body size, with attendant decreases in individual reproductive output that may impair recruitment.
- Based on the Peruvian example, large quantities of anchovy will not be needed for the development of HCPs from South African anchovy, at least in the short-term and likely also the long-term, unless multiple barriers can be overcome. This, in conjunction with the present under-utilisation of South African anchovy, suggest that a fishery for this species for HCPs would likely start use relatively small quantities (a few multiples of 10 000 t) in the near (or even mid-term) future. This is likely substantially less than the 190 000 t of the anchovy TAC on average that is presently not caught, indicating that development of South African anchovy for HCPs could be accommodated without a need to increase present exploitation rates of the South African anchovy. Targeting the un-caught portion of the TAC for anchovy for HCPs would therefore be unlikely to incur substantial ecosystem impacts.
- The observed co-variability between anchovy and sardine recruitment strength, and total biomass, suggest that increasing fishing pressure (i.e., exploitation rates) on anchovy to accommodate the development of HCPs (although this is not considered necessary for the reasons described above) appears unlikely to have beneficial effects on sardine population size.

4.1 Introduction

The Institute for Poverty, Land and Agrarian Studies of the University of the Western Cape has received funding from the South African Water Research Commission (WRC) to conduct a project entitled "Investigation into use of South African anchovy for direct human consumption for increased food and nutrition security, job creation and improved socio-ecological resilience" (Project Number C2022/2023-00934). The project will report on: (i) the types and product forms of anchovy that are acceptable to consumers; (ii) the potential market size for new anchovy products; (iii) new anchovy products for human consumption; (iv) geographic areas and seasons for catching anchovy suitable for human consumption; (v) the proximate composition and mineral and fatty acid profiles of anchovy products; (vi) consumer awareness of new anchovy products; (vii) how climate change might impact anchovy and whether increased utilisation of anchovy could have ecosystem impacts including supporting recovery of the sardine population; and (viii) the development of guidelines for handling and processing anchovy for human consumption.

This chapter is the report on point (vii) above and comprises a desktop study that has synthesised information from the literature and publicly available data on South African anchovy and sardine. Information on and descriptions of: (i) the impacts of climate change on coastal marine ecosystems in general and South African marine ecosystems in particular; (ii) the predicted impacts of climate change on South African and other anchovy species; and (iii) environmental drivers of South African anchovy abundance, distribution, phenology, and other attributes were collated were to identify the possible impacts of climate change on South African anchovy. Information on and descriptions of: (i) the ecosystem role of anchovy as predators and as prey and as mixers of the upper water column; (ii) whether utilising South African anchovy for human consumption would require an increase in exploitation rate; and (iii) anchovy-sardine interactions were collated to assess the possible ecosystem impacts of increased harvesting of anchovy including supporting the recovery of the sardine population.

Information on (i) the taxonomy, distribution, biology, ecology and life history strategy of anchovy in South African waters; (ii) the South African small pelagic fishery in general and the directed fishery for anchovy in particular, including spatial and temporal patterns in anchovy catches and fish size; (iii) abundance, distribution and fish size patterns of anchovy around the coast observed during recent annual Total Biomass (spring/ summer) surveys and Pelagic Recruit (autumn/ winter) surveys; and (iv) the diets of fish, seabird and marine mammal predators of anchovy off the South Coast have previously been provided by van der Lingen (2024).

4.2 How might likely changes in South African marine ecosystems arising from climate change impact the abundance, distribution and life cycle of anchovy?

4.2.1 Impacts of climate change on coastal marine ecosystems in general and South African marine ecosystems

Guild et al. (2025) list warming, sea level rise, ocean acidification, changes in freshwater availability and shifts in circulation and disturbance (extreme weather events) as key climate-related stressors for coastal ecosystems, with consequent ecosystem degradation and shifts toward simpler and less biodiverse states. Upwelling ecosystems are vulnerable to warming-induced stratification, altered atmospheric circulation patterns, and shifts in ocean currents, all of which can affect the intensity, location, and timing of upwelling with significant impacts for coastal ecosystems. Additionally, changes in the productivity and composition of the lower trophic levels (plankton) and changes in species distribution patterns, in conjunction with changes in physical processes referred to above, are likely to have impacts on the recruitment processes of small pelagic fish (Freon et al., 2009).

However, the complexity and inherent variability in the marine ecosystems around South Africa, particularly of physical mesoscale processes, result in a low signal-to-noise ratio that makes the detection of climate change signals difficult (van der Lingen & Hampton, 2018; Hampton et al., 2021; van der Lingen, 2021). Additionally, the difficulty of detecting long-term trends in South Africa's ocean environment that could potentially be linked to climate change is exacerbated by several other factors, including datasets of inadequate length and/or with breaks; an absence of systematic sampling and changes in methods and technology; the use of proxy measurements; and a poor understanding of natural variability (Hampton et al., 2021), as well as a limited ability to disentangle the multiple drivers of ecosystem change, specifically fishing and climate change.

Observed long-term changes in the sea surface temperatures of South Africa's oceans are considered likely due to climate change (Blamey et al., 2015; Rouault, 2021). Coastal waters off the West Coast have cooled by around 0.2°C per decade over the past four decades (Figure 4.1), particularly in autumn/ winter and possibly in response to stronger, unseasonal upwelling-favourable winds and a southward (poleward) expansion or migration of the South Atlantic Subtropical Anticyclone (also known as the South Atlantic High; Sousa et al., 2018; Blamey et al., 2021). Coastal waters off the South and Southeast coasts have also cooled, by around 0.1°C per decade. The West Coast has shown a tendency, albeit non-significant, for increased upwelling over the period 1979–2014 whereas upwelling on the South Coast has shown a significant increase over the past 35 years (Lamont et al., 2018) and localised intermittent upwelling intensity on the South Coast has also increased (Duncan et al., 2019). In contrast, coastal waters off the Transkei and KwaZulu-Natal have warmed (0.1–0.2°C per decade), particularly in spring/ summer, and the Agulhas Current – positioned at the shelf edge and an important driver of oceanic variability in the region (Augustyn et al., 2018) – has warmed by up to 0.6°C per decade (Figure 4.1), with this latter region identified as one of 23 global marine hotspots where the ocean is warming more rapidly than elsewhere (Hobday & Pecl, 2014). Because of the coastal cooling and offshore warming along the South Coast, thermal gradients across the Agulhas Bank have increased in recent decades.

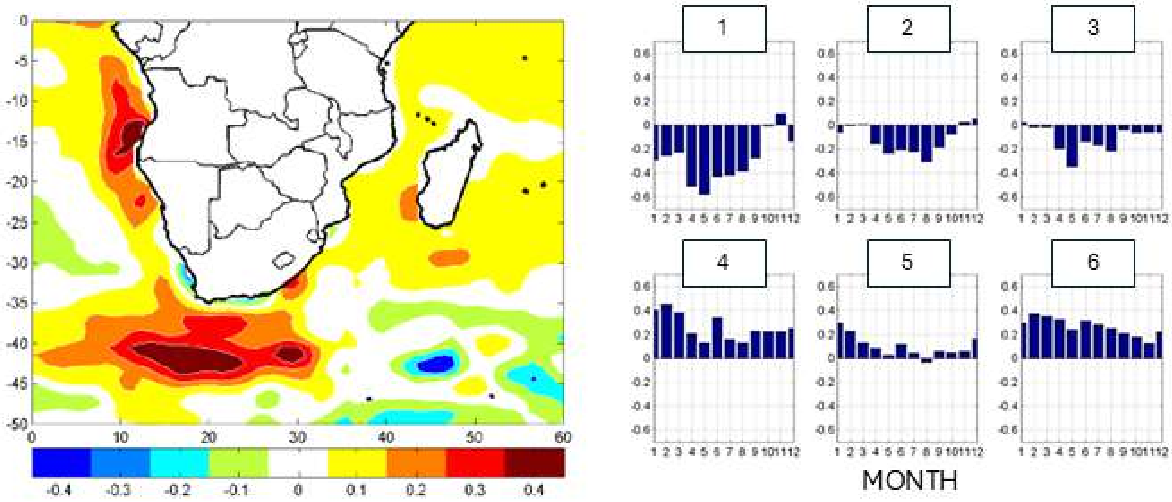

Figure 4.1: Linear trend of sea surface temperature (°C per decade; yellow to red colours indicate warming and green to blue colours indicate cooling) around southern Africa from 1982 to 2016 (left); and SST linear trend in SST around South Africa for each month of the year from 1982 to 2016 for the West Coast (1), South Coast (2), Port Elizabeth/[31] Port Alfred (3), Transkei (4), KwaZulu-Natal (5), and Agulhas Current (6). From Rouault, 2021 (updated from Rouault et al., 2010).

No long-term trends have yet been observed in the pH (Joubert, 2021), dissolved oxygen levels (Pitcher, 2021), or phytoplankton biomass (Lamont, 2021) of South Africa's oceans, although pH and dissolved oxygen levels are predicted to decrease resulting in ocean acidification and deoxygenation. Long-term changes in copepod abundance and species composition off both the West (Verheye, 2021) and South (Huggett, 2021) coasts have been observed, and whereas these may be linked to environmental changes such as ocean warming, they are thought to be largely driven by predation by small pelagic fishes. The occurrence of harmful algal blooms and consequent incidence of low oxygen water events has increased in coastal waters off South Africa's West and Southwest coasts, likely due to environmental (possibly climate-driven) change (Blamey et al., 2021). Similarly, the severity and duration of marine heat waves off South Africa's West and Southwest coasts has increased over the period 1982–2023, particularly in non-upwelling localities (Sulaman, 2023).

The winds that induce coastal upwelling are anticipated to increase under anthropogenic global warming because of the increased land-sea temperature differences arising from faster warming of the land compared to the sea (Bakun, 1990). Rykaczewski et al. (2015) examined an ensemble of 21 coupled, ocean-atmosphere models to investigate the effect of climate change on upwelling in the Eastern Boundary Upwelling Systems (EBUSs) under the Coupled Model Intercomparison Project Phase 5 (CMIP5) Representative Concentration Pathway (RCP) 8.5 (high emission) scenario. They found only limited evidence for intensification of upwelling-favourable winds or atmospheric pressure gradients in response to increasing land-sea temperature differences but consistent latitudinal and seasonal dependencies of projected changes in wind intensity associated with the poleward migration of major atmospheric high-pressure cells. Specifically, summertime winds near poleward boundaries of climatological upwelling zones were projected to intensify, while winds near equatorward boundaries were projected to weaken (Figure 4.2).

[31] Now called Gqeberha.

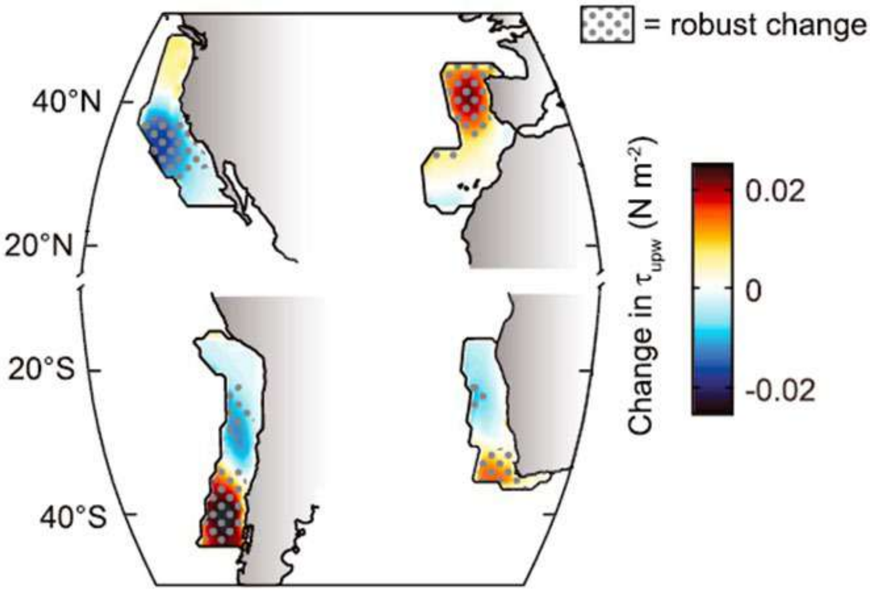

Figure 4.2: Ensemble mean plot of projected change in summertime mean wind (τupw) between 2071–2100 and 1861–1890 in each of the four EBUSs (the Benguela is at bottom right). Stippling indicates the areas of robust change across models, and the positive values consistently indicate upwelling-favourable winds. Adapted from Rykaczewski et al. (2015).

Sydeman et al. (2014), Bakun et al. (2015), Garcia-Reyes et al. (2015) and more recently Bograd et al. (2023) reviewed hypotheses of climate-driven change in the physics, biogeochemistry, and ecology of the world's eastern boundary upwelling systems (EBUSs, namely the Benguela, California, Canary, and Humboldt Current upwelling ecosystems); described observed changes over recent decades; and discussed and/or presented projected changes over the twenty-first century. All studies noted general trends toward increased upwelling in the poleward regions or EBUSs, with Bakun et al. (2015) also suggesting that EBUSs may expand polewards; mitigated warming in near-coastal regions where upwelling intensifies (and corroborating that upwelling is a key factor buffering ocean warming as noted by Varela et al., 2018); and enhanced water-column stratification and a shallowing of the surface mixed layer.

Bograd et al. (2023) used the SSP2-4.5[32] and SSP5-8.5 scenarios from CMIP6[33] to project important ocean attributes for the Benguela ecosystem overall and reported that SST would increase by 1.5 to 3.0°C by 2090 depending on emission scenario, the mixed-layer depth would remain similar or decrease by ca. 2m, dissolved oxygen at 200m depth would increase by ca. 5 to 15 mmol.m-3, and primary productivity would decrease by ca. 30 to 60 x 10-9 mmol.m-2.s-1 (Figure 4.3).

[32] Shared Socio-Economic Pathway.

[33] Coupled Model Intercomparison Project Phase 6.

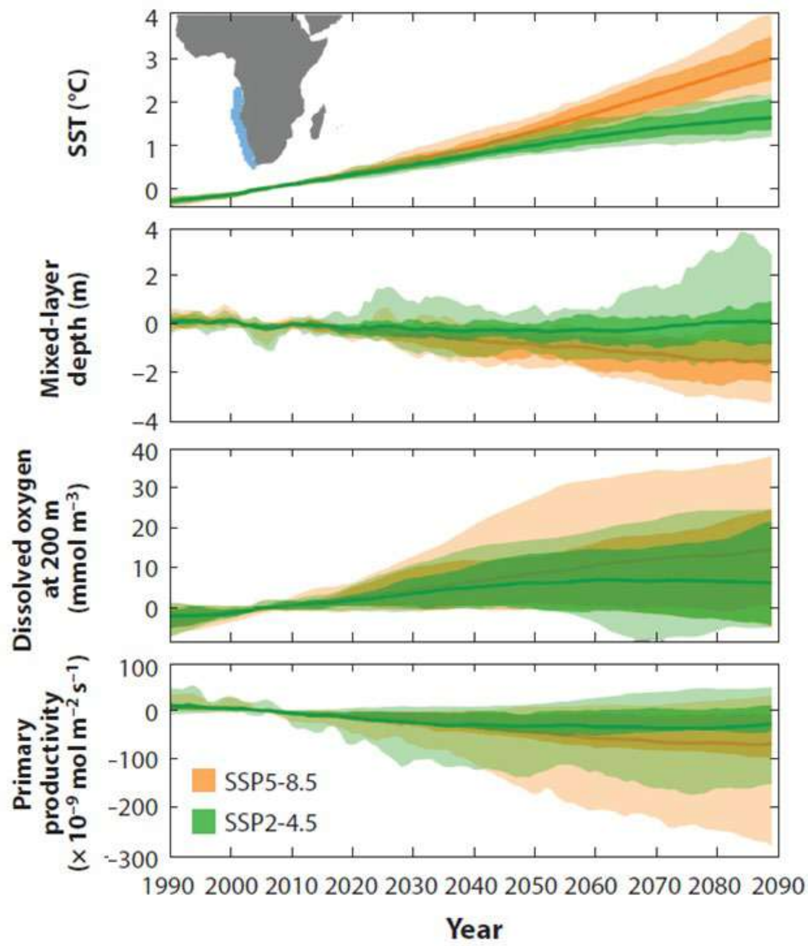

Figure 4.3: Projected twenty-first century changes in SST, mixed-layer depth, dissolved oxygen at 200m depth, and vertically integrated primary productivity of the Benguela Current upwelling ecosystem. The time series show change relative to the 1991–2020 mean, averaged over the entire ecosystem (blue region on inset map). Projections are under the SSP5-8.5 (orange) and SSP2-4.5 (green) CMIP6 scenarios, with solid lines marking the ensemble mean, and dark and light shading indicate the 25th–75th and 10th–90th percentiles, respectively. From Bograd et al. (2023).

Whereas Bograd et al. (2023) predicted an overall decrease in primary production in the Benguela during the twenty-first century, the intensification of upwelling in the poleward regions of EBUSs in the future implies increased primary production in those regions. Projections of anomalies (differences) in SST and primary productivity around South Africa (i.e., the poleward region of the Benguela EBUS) between the periods 1955–1984 and 2020–2049 that are based on model ensembles from CMIP6 (Haustfather, 2019) are shown in Figure 4 (generated from https://psl.noaa.gov/ipcc/cmip6/). Sea surface temperatures are predicted to increase by almost 1°C in all regions off South Africa by the latter period but by slightly less off the Southwest and South coasts compared to the West and East coasts in both the low-emission scenario (SSP1-2.6, which assumes warming by 2100 of around 2°C) and high-emission scenario (SPP5-8.5, which assumes warming by 2100 of around 5°C). In contrast to SST, however, primary productivity is projected to increase markedly off the West and Southwest coasts but to show little change or decrease slightly off the South and East coasts (Figure 4.4).

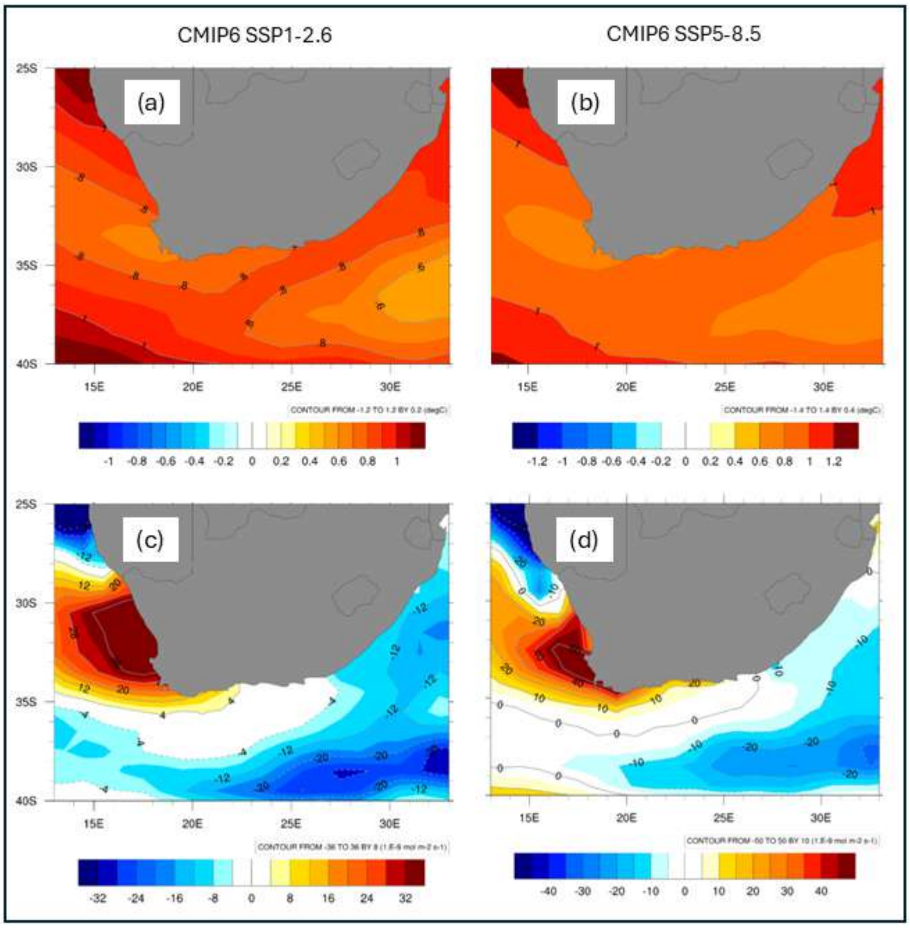

Figure 4.4: Projected model ensemble mean anomalies in SST (°C; upper panels) and primary organic carbon production by all types of phytoplankton ($1x10^{-9}$ $mol.m^{-2}.s^{-1}$; lower panels) between 2020 and 2049 (mid-point 2035) and 1955 and 1984 (mid-point 1970) for the CMIP6 SSP1-2.6 (left panels) and SSP5-8.5 (right panels) scenarios.

4.2.2 Predicted impacts of climate change on South African and other anchovy species

Because of their responsiveness to environmental forcing, small pelagic fish such as anchovy have been characterised as "excellent bio-indicators of climate-driven changes in marine systems" (Peck et al., 2013). Predicted effects of climate change on ecosystems dominated by these species include changes in distributions, changes in phenology (seasonal biological cycles such as spawning), changes in the magnitudes and sources of nutrients, ocean acidification, habitat compression due to shoaling of the thermocline (and particularly important where low oxygen waters are already close to the surface, e.g. the Humboldt Current system), changes in the productivity and composition of lower trophic levels, and changes in circulation patterns, which may impact on small pelagic fish recruitment success (Fréon et al., 2009; Checkley et al., 2017; Peck et al., 2021).

Changes in the distribution and/or range extent of anchovy species in other regions that have been attributed to climate change have been reported. These include Japanese anchovy (*Engraulis japonicus*) that showed a southward (equatorward) shift in biomass (proxied by catch locations) that was significantly correlated with water temperature (Jung et al., 2014), and the Bay of Biscay anchovy (*E. encrasicolus*) that expanded its range northward (poleward) into the English Channel (van der Kooil et al., 2024). The future states of these populations were investigated by modelling, with Jung et al. (2016) applying individual-based models (IBMs) based on a regional ocean circulation model and an Intergovernmental Panel on Climate Change (IPCC) climate change scenario and projecting a decrease of the biomass of *E. japonicus* in the Yellow Sea. Similarly, Reybaud et al. (2017) projected future distributions of *E. encrasicolus* by applying a Probabilistic Ecological Niche Model (PENM) based on SST and bathymetry optima exhibited by this species throughout its geographical range from 58°N to 38°S to SST outputs of three CMIP5 RCP scenarios (RCP2.6, RCP4.5 and RCP8.5). Their projections indicated very likely and substantial poleward shifts in the probability of anchovy occurrence in the Northern Hemisphere (Figure 4.5). Future occurrence probabilities were higher north of 48°N for all RCP scenarios, but a gradual to substantial decline in occurrence probabilities was predicted south of 48°N with the highest (reductions of 20–50%, depending on scenario) in the Benguela. The projected declines are higher in the Northern compared to the Southern Benguela but the negative outlook for both is due to the fact that the continental shelf (above or in close proximity to which anchovy and other small pelagic fishes are typically confined) does not extend beyond 37°S.

Ortega-Cisneros et al. (2018b) applied a trait-based sensitivity assessment to estimate the potential relative sensitivity to the impacts of climate change of 40 key marine species (including anchovy) in the southern Benguela. Fourteen attributes (such as fecundity and age-at-maturation, environmental tolerance ranges, and the spatial distribution of suitable habitat) that impacted the abundance, distribution and phenology (the timing of important life cycle events such as reproduction) of each species were used to estimate species' sensitivity and capacity to respond to climate change. Anchovy had an overall "medium-low" sensitivity to climate change (as did 30 other species), with the highest impact on phenology and the lowest on abundance. McClure et al. (2023) also used a trait-based assessment, and considered northern anchovy *Engraulis mordax* in the California Current Ecosystem to have a high climate exposure (due in part to its broad distribution), a low overall biological sensitivity (although considered sensitive to factors associated with changes in temperature), a high vulnerability to distributional shift, and an overall "low to moderate" climate vulnerability, similar to that assigned to South African anchovy by Ortega-Cisneros et al. (2018b).

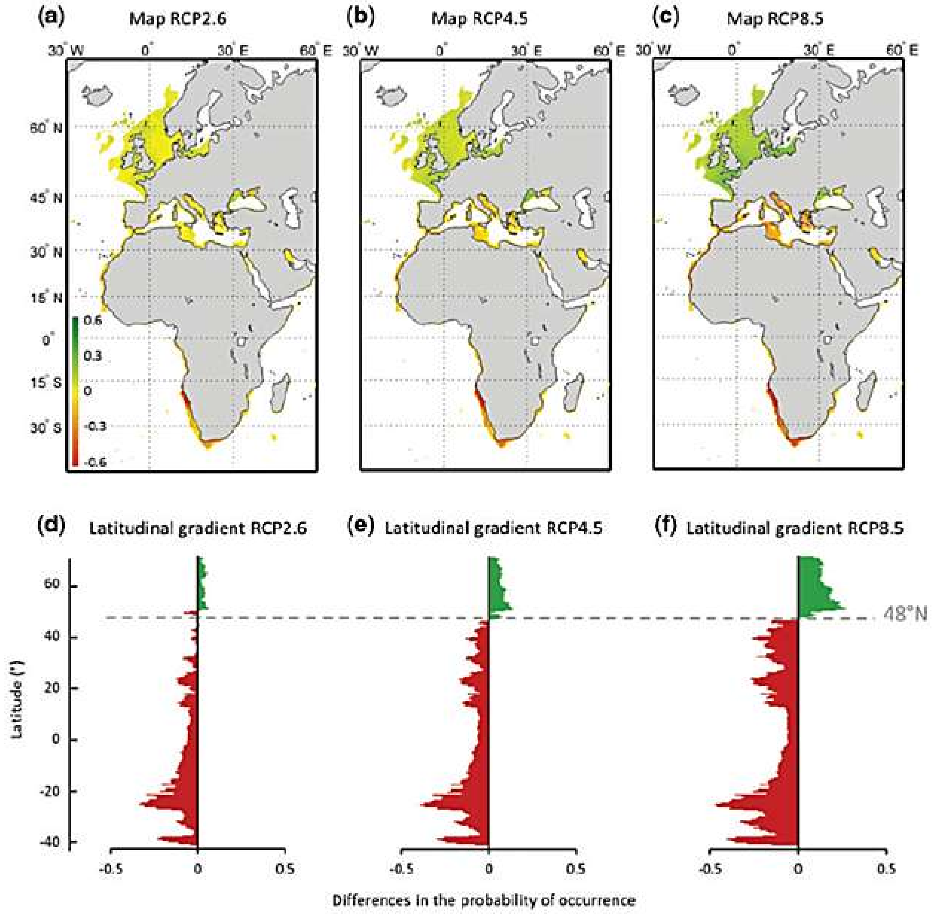

Figure 4.5: Differences (upper panels) between the current (ca. 2010) probabilities of occurrence of *E. encrasicolus* calculated from the PENM and projected occurrence for the end of the 21st century (decade 2090–2099) for (a) RCP2.6; (b) RCP4.5; and (c) RCP8.5. Latitudinal gradients (lower panels) of the differences with (d) RCP2.6; (e) RCP4.5; and (f) RCP8.5. From Reybaud et al. (2017).

Ortega-Cisneros et al. (2018a) further evaluated the effects of climate change (warming and horizontal and vertical mixing) and fishing on biota (32 functional groups or individual species, from zooplankton to top predators and including anchovy) in the southern Benguela using the Atlantis modelling platform (an end-to-end ecosystem model comprising 3D hydrodynamic and biogeochemical sub-models) coupled with climate projections (RCP 2.6 and RCP 8.5 from CMIP5) to 2050. They found warming to have the strongest (and most negative) impacts on modelled species, with anchovy being the most negatively affected under both emission scenarios and biomass reductions of 46–53% being estimated by the end of the projection period, despite its assignment of a medium-low sensitivity to climate change (see above).

A recent study used generalised additive models (GAMs) to assess the influence of several environmental variables on the distributions of eggs, recruits, and adults of anchovy (and round herring and sardine) in the Southern Benguela ecosystem (DFFE, 2023). Abundance and distribution data of these different stages were collected during routine Pelagic Recruit (recruits) and Total Biomass (adults and eggs) surveys conducted between 2000 and 2011. Selected environmental variables were those expected to respond to climate change and that can be remotely sensed, and included sea surface temperature, sea surface height, sea surface chlorophyll (*Chl a*), Ekman upwelling and eddy kinetic energy. Environmental data for the regions and periods matching the Pelagic Recruit and Total Biomass surveys of each year were collected from online sources (mostly the National Oceanic and Atmospheric Administration – NOAA) and were then mapped to the stage-specific abundance and distribution maps for GAM analyses. The relative importance of these variables in influencing fish distribution patterns was also estimated. Sea surface temperature had the highest relative importance of predictor variables for all three anchovy life stages (Figure 4.6), particularly for recruits and eggs whereas Ekman upwelling was almost as important as SST for adult distributions. Sea surface temperature was also the most important predictor for all three life stages of round herring, and for eggs and recruits of sardine (DFFE, 2023). The intraspecific differences observed suggest that different anchovy life history stages will be impacted on differently by climate change but all will respond most strongly to changes in SST. These models can be coupled with models that predict future ocean state around South Africa to indicate where, and when, particular areas may become less or more favourable to the different life stages.

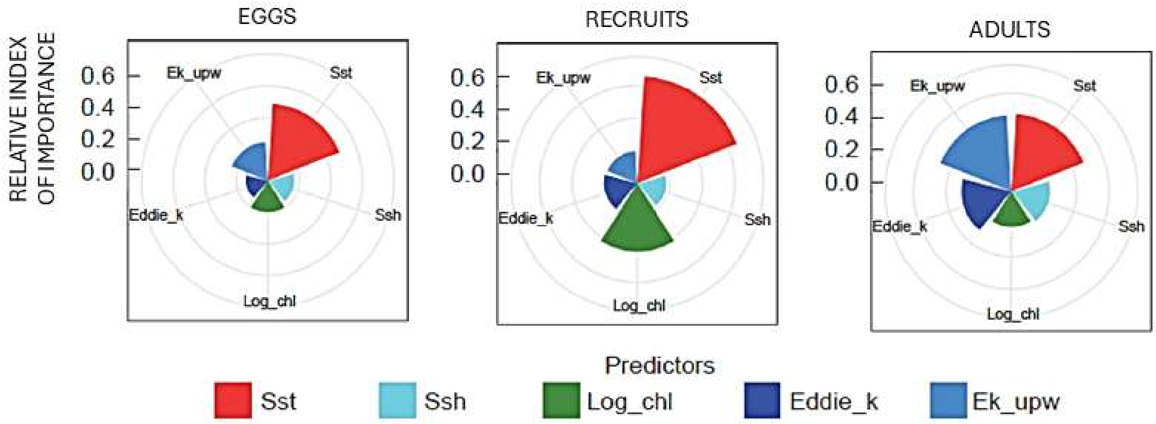

Figure 4.6: Pie diagrams illustrating the relative importance of the top five environmental variables in generalised additive models relating to the distributions of anchovy eggs, recruits and adults. The sizes of environmental predictor pie slices are proportional to their relative importance in predicting the distribution of that life stage. SST = sea surface temperature; SSH = sea surface height; Log_chl = log of surface chlorophyll *a* concentration; Eddie_k = eddy kinetic energy; Ek_upw = Ekman upwelling. Adapted from DFFE (2023).

4.2.3 Environmental drivers of South African anchovy distribution, distribution, phenology, and other attributes

South African anchovy has shown a change in its distribution over recent decades, with the relative biomass (% of total biomass) observed during Total Biomass Surveys changing abruptly in 1996 from being predominantly (>50/%) to the west of Cape Agulhas (i.e., off the West Coast) to being predominantly east of Cape Agulhas (i.e. off the South Coast; Figure 4.7a). That eastward shift in relative biomass was correlated with an increase in the cross-shelf SST gradient EoCA observed using satellite data at a 1° by 1° resolution (Roy et al., 2007; Augustyn et al., 2018; Figure 4.7b) that was due to cooling in the inshore region and was thought to improve feeding conditions for anchovy EoCA (Roy et al., 2007), and the eastward shift has mostly persisted since 1996 (DFFE, 2023). A recent analysis that used satellite data at a resolution of 0.05° by 0.05° and the biomass time series for the period 1984 to 2020 has shown a significant, positive correlation between anchovy relative distribution EoCA and the SST difference between coastal waters of the western Agulhas Bank and offshore waters east of Cape Agulhas (Torr, 2022). However, changes in sea surface temperature gradients EoCA appear to be linked to multi-decadal variability in wind, specifically a north-south migration in the large-scale wind belts (Malan et al., 2019) and hence may not be a response to climate change. However, if cross-shelf SST gradients EoCA continue to strengthen and if the relationship between this and anchovy relative distribution continues to hold, then it would be anticipated that the distribution of South African anchovy would shift away from the West Coast and toward the South Coast.

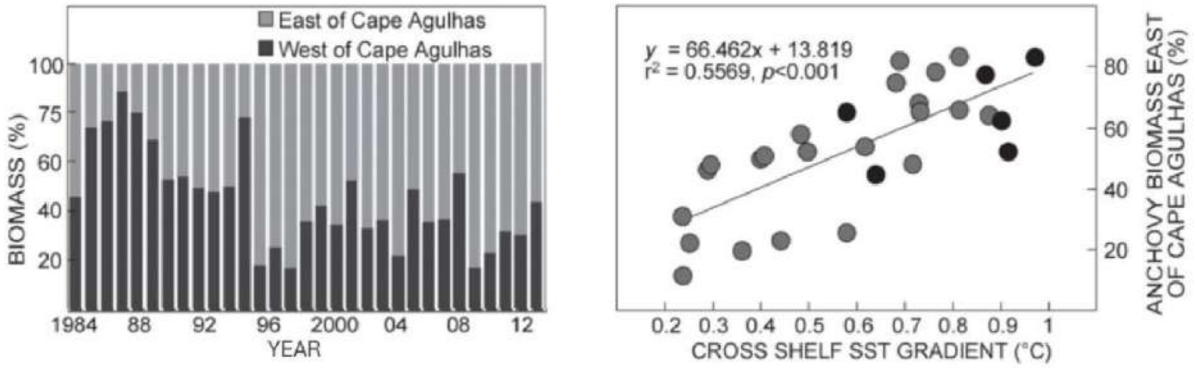

Figure 4.7: Time-series of the distribution of relative (% of total) biomass west of Cape Agulhas and east of Cape Agulhas for South African anchovy during Total Biomass Surveys, 1984–2014 (left) and scatterplot of relative (% of total) anchovy biomass EoCA and cross-shelf SST difference EoCA for the period 1984–2011 (data for 1984–2005 shown as grey circles are from Roy et al. (2007) and black circles represent data for 2006–2011) and the regression line and equation parameters are shown for the full period. Adapted from Augustyn et al. (2018).

Ramírez et al. (2022) combined spatially-explicit information on South African small pelagic fish (anchovy, round herring and sardine) densities collected during annual pelagic biomass surveys conducted over the period 1993–2018 with environmental parameters (bottom depth, SST, sea surface salinity (SSS) and net primary production (NPP)) matched to the fish density data to determine the optimal environmental ranges of each parameter for each species. Those authors then evaluated how the spatial extent of areas encompassing the optimal ranges of all four parameters for each species (used as a proxy for optimal habitat) varied temporally within the Southern Benguela (WoCA) and Agulhas (EoCA) systems. Whilst absolute values of optimal habitat differed between species, trends were similar among species but contrasted between the Southern Benguela and Agulhas systems with a general regime shift observed in 2002 in both (Figure 4.8a, b). In the Southern Benguela, the extent of optimal habitat increased from 1993 to 2002 then decreased thereafter. The opposite trend was observed for the Agulhas system, with optimal habitat availabilities decreasing until 2002, then increasingly slightly, then remaining steady thereafter.

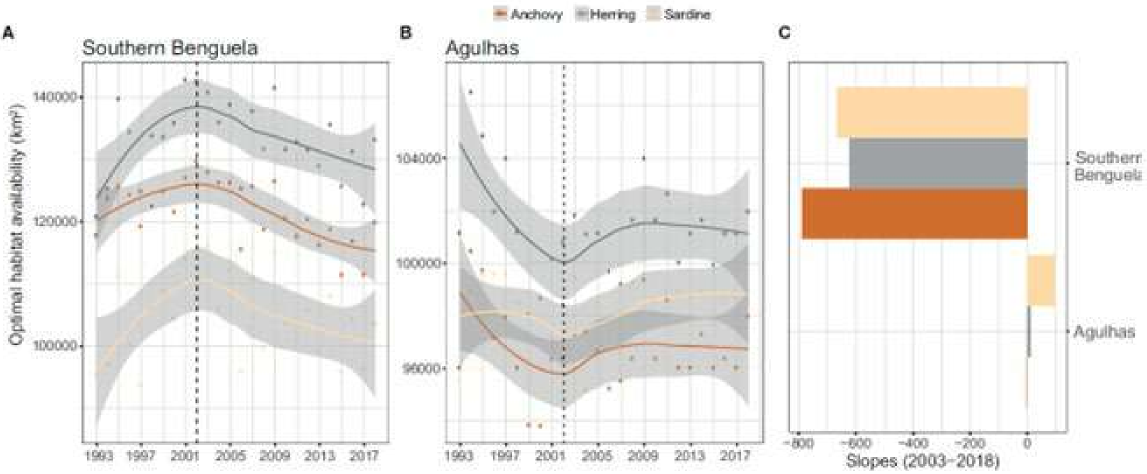

Figure 4.8: Long term (1993–2018) trends in the extent (km^2) of optimal habitat availability) for three small pelagic fish species in the Southern Benguela (A) and Agulhas (B) systems, and bar plots representing the slopes (magnitude) for the linear regressions on the long-term trends in the absolute values of optimal habitat availabilities for the period 2003–2018. From Ramírez et al. (2022).

The rate of decline in optimal habitat availability in the Southern Benguela following the regime shift (i.e., from 2003-2018) was substantially larger than the rate of increase in optimal habitat availability in the Agulhas system over this period (Figure 4.8c). However, this eastward shift in optimal habitat availability roughly corresponds with the observed changes in mean wind and upwelling off South Africa (Blamey et al., 2012), and with the eastward shifts in the distribution of anchovy (see above) and sardine (Coetzee et al., 2008; Watermeyer et al., 2016) in recent decades and with regime shifts in demersal fish assemblages (Atkinson et al., 2012).

Ramírez et al. (2022) also identified areas of persistently sub-optimal or persistently optimal areas for each species as well as areas of high cumulative fishing pressure for each species and overlaid the two to identify so-called "hotspots" where persistent sub-optimal habitat coincided with high fishing pressure and "bright spots" where persistent optimal habitat coincided with low fishing pressure (Figure 4.9). Hotspots were confined to the Southern Benguela and the intensity of the cumulative impact of climate and fishing pressure decreased from north to south for anchovy (and the other two species) with the lowest values located off the Southwest Coast. Although there is presently negligible fishing for anchovy off the South Coast the occurrence of persistently optimal habitat there suggests that area could also be a bright spot for this species.

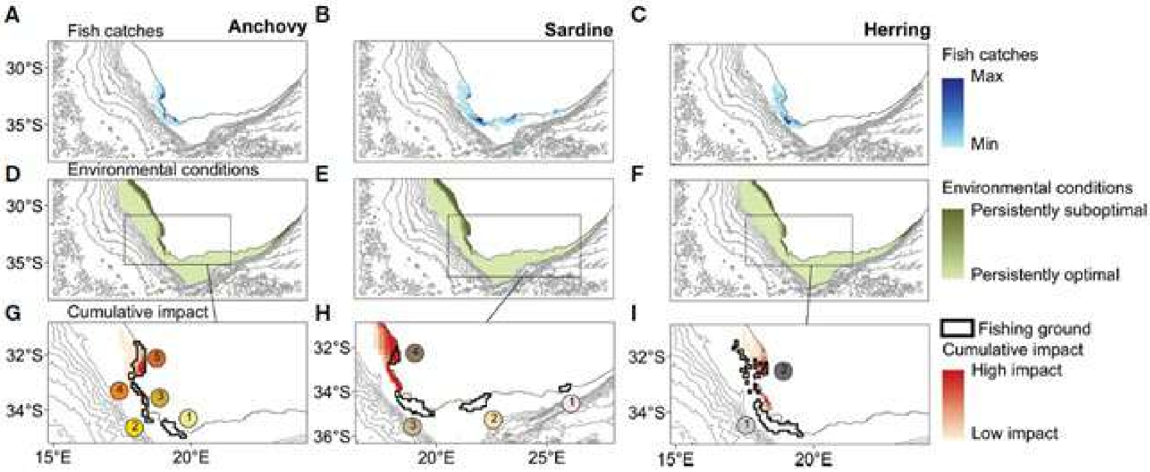

Figure 4.9: Spatially explicit information on catches of anchovy, sardine and herring (A–C) and the persistency of optimal environmental conditions (D–F) for the three species over the 2003–2018 period were overlaid to obtain a proxy for the cumulative impact of climate effects and fishing pressure on anchovy and other small pelagic fish off South Africa (G–I). From Ramírez et al. (2022).

Population size in small pelagic fishes like anchovy is strongly dependent on their recruitment success because of the typically short lifespan and early maturation exhibited by these species (Bakun, 1996; Hutchings et al., 1998; van der Lingen and Huggett, 2003, Alheit and Peck, 2019; Peck et al., 2021). In EBUSs, upwelling intensity and duration is considered an important driver of early larval survival and hence recruitment success, with a dome-shaped relationship between the two (known as the optimal environmental window (OEW) hypothesis; Cury and Roy, 1989; Figure 4.10a). Too little upwelling produces limited nutrient input that results in low primary and secondary productivity which impairs larval survival, while too much upwelling increases turbulence, which inhibits the formation of aggregations of prey on which the larvae feed, as well as increasing the advective movement of surface waters (in which the early larvae reside) away from the coast into the oceanic domain where food concentrations are again limiting. The OEW occurs at low to moderately strong upwelling (wind speeds of 5–8 $m.s^{-1}$) and when upwelled nutrients support robust phytoplankton and zooplankton communities (and hence anchovy larvae) within the coastal domain.

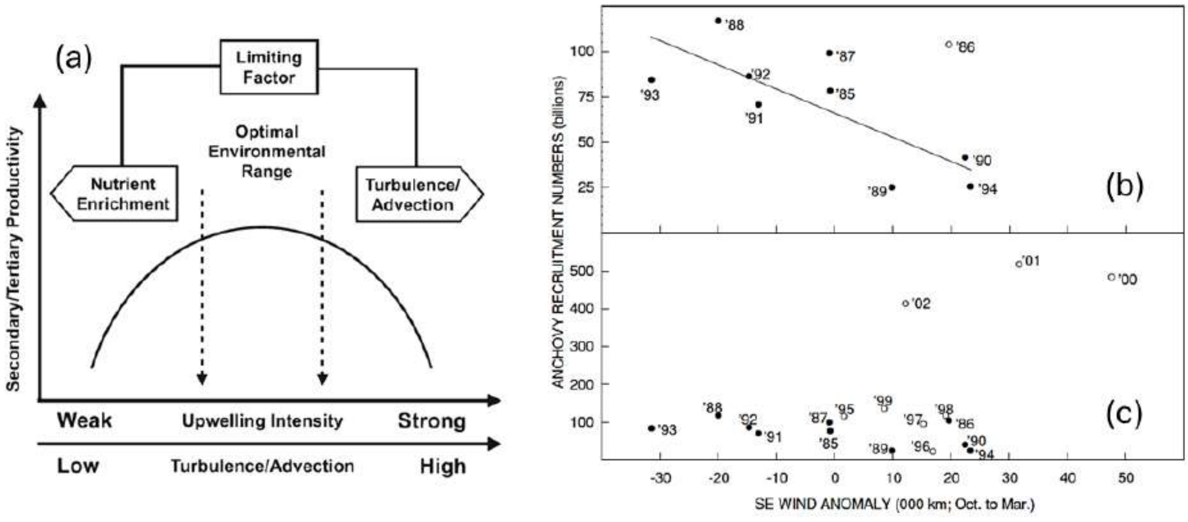

Figure 4.10: Schematic illustrating the "optimal environmental window" hypothesis relating secondary/ tertiary productivity (and hence small pelagic fish recruitment success) to upwelling intensity in upwelling areas (a; from Cury and Roy (1989)); and scatterplots of South African anchovy recruitment numbers and the southeast wind anomaly at Cape Point for the period 1985–1994 (a; note that the data-point for 1986 was not included in generating the linear regression shown) and for the period 1985–2002 (from van der Lingen and Huggett (2003)).

Given that recruits comprise the bulk (ca. 70%) of anchovy caught by the South African small pelagic fishery, a substantial amount of research effort has gone into attempts to understand variability in and the drivers of anchovy recruitment using data derived from a variety of sources (Hutchings et al., 1998). Initial modelling studies (Shannon et al., 1996) suggested that passive transport of anchovy eggs and larvae from the spawning grounds on the Southwest and South coasts to the West Coast nursery area by the so-called "jet current" flowing between Cape Point and Cape Columbine (Shelton & Hutchings, 1982) could account for a substantial proportion of interannual variability in recruitment strength. Subsequent development of coupled 3D hydrodynamic models of the Southern Benguela with individual-based particle tracking models (see Mullon et al., 2003 and its references) confirmed the importance of transport success to recruitment variability and showed that spawning during the summer months and on the western Agulhas Bank is most efficient for successful transport of spawn products to the nursery area. Observations that higher than average southeasterly (SE) winds during the October–March anchovy spawning season were followed by poor recruitment over the period 1984–1994 (Boyd et al., 1997) led to the development of a statistically significant relationship relating anchovy recruitment success to the cumulative SE wind anomaly at Cape Point (Figure 4.10b). This inverse relationship was thought to occur because more wind resulted in an offshore displacement of the jet current which increased advective loss of anchovy eggs and early-larvae. However, the addition of subsequent data to this relationship removed its significance (Figure 4.10c), with high SE anomalies (in 2000 and 2001) associated with exceptionally high recruitment success, suggesting a pattern different to that proposed under the OEW hypothesis and a more complex relationship between seasonal wind patterns and recruitment strength than previously thought.

Roy et al. (2001) examined the oceanographic environment during the 1999/2000 summer season off the West Coast of South Africa and described two major events: the first being a strong and sustained warming that occurred in mid-December and lasted for two weeks, and the second an enhanced cooling that lasted from mid- to late-summer. These two events were the result of fluctuations in wind-induced upwelling, being low for the first and high for the second, and their influence may have contributed to the high level of anchovy recruitment in 2000. Those authors proposed that a succession of weak upwelling and strong upwelling periods, and the appropriate timing of these events within the anchovy life cycle represents the canonical pattern of environmental variability for maximising anchovy recruitment success. Specifically, weak upwelling early in the season (when larvae are small and unable to swim or vertically migrate and so are confined to surface waters and thus susceptible to offshore advection) and strong upwelling late in the season (when larvae can swim and are better able to avoid advection hence can benefit from elevated production). This premise reconciled previous findings and provided a plausible explanation for the exceptional anchovy recruitment in 2000, but did not explain the high recruitment success recorded in 2001 and 2002 when oceanographic conditions were different.

van der Sleen et al. (2018) further examined the relationship between South African anchovy recruitment strength, estimated during annual recruit surveys, and coastal upwelling off the West Coast quantified using the upwelling-index time-series developed by Lamont et al. (2018). van der Sleen et al. (2018) found that cumulative December–March (i.e., later in the upwelling season as proposed by Roy et al., 2001) upwelling was significantly (r^2=0.24) and positively related to subsequent anchovy recruitment (Figure 4.11a). Integrating the upwelling index over multiple years by adding interannual autocorrelation 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 11b). 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 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 4.11c). 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 4.11d), substantially higher than the 50% threshold identified by De Oliveira and Butterworth (2005) for such predictions to have utility for management.

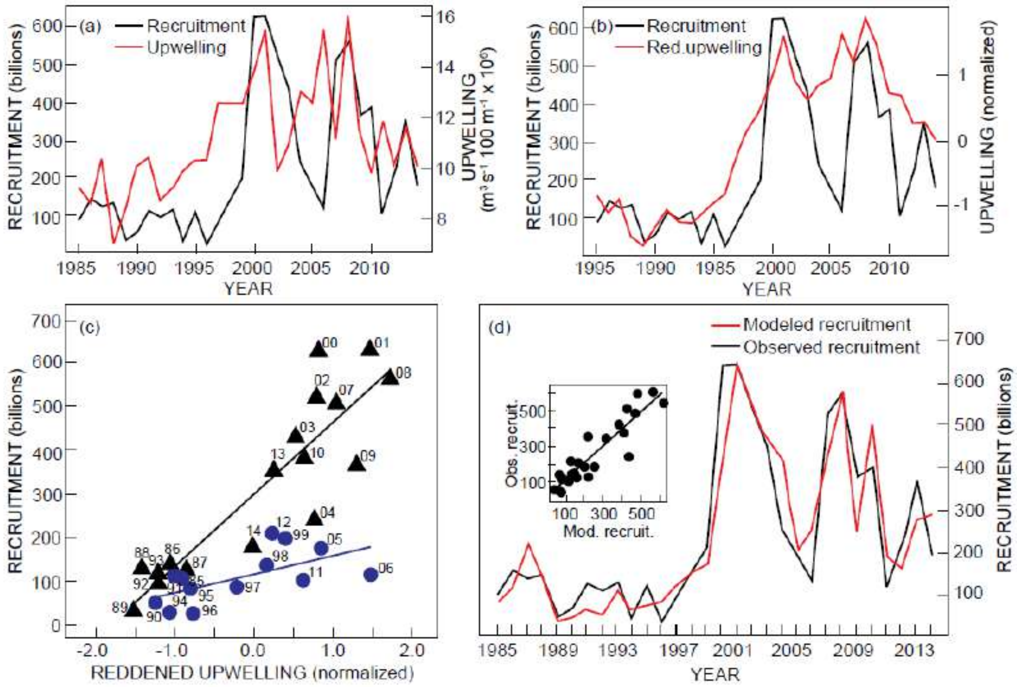

Figure 4.11: (a) Anchovy recruitment estimated from annual hydroacoustic surveys (black line) and cumulative coastal upwelling in the southern Benguela (December to March; red line) over the period 1985 to 2014; (b) anchovy recruitment (black line) and reddened cumulative coastal upwelling (December 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 DEFF, 2020, adapted from van der Sleen et al. (2018).

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, with upwelling data used with anchovy spawner biomass data to hind-cast anchovy recruitment that could be compared with survey-based observations for 2015, 2016 and 2017 and to make an actual prediction of anchovy recruitment for 2018, given that there was no Pelagic Recruitment Survey in that year (DEFF, 2020). Two (2015 and 2016) of the anchovy recruitments estimated using the van der Sleen et al. (2018) model were close (within 10%) to survey-estimated recruitment, whereas that for 2017 was substantially (65%) lower than that estimated by the survey, and hind-cast recruitment was some 15% lower on average than survey-estimated-recruitment for the three years.

In addition to likely having impacts on the anchovy distribution and abundance, climate change may also impact anchovy phenology and physiology. For example, Erauskin-Extramiana et al. (2019) analysed gonadosomatic-index (GSI) data for *Engraulis encrasicolus* in the Bay of Biscay over the period 1987–2015, a period of SST increase, and reported that the estimated date of peak spawning advanced (i.e. occurred earlier each year) at a rate of 5.5 days per decade^{-1}. This change occurred concurrent with a general increase in GSI, considered to be associated with changes in phytoplankton abundance. Those authors also used species distribution models based on anchovy egg and concurrently collected environmental data to project future distribution and abundance under the CMIP RCP8.5 scenario and estimated an increase in egg abundance of 1.1- and 2.7-fold by mid- to end-century, respectively, due to an expansion of the spawning area and higher egg densities.

Gonadosomatic-index data for South African anchovy are not available at sufficient temporal resolution to enable an assessment of whether temporal changes have occurred in their spawning peak. However, such information could be indirectly examined using data on the size of recruits taken in fishing and during annual surveys. A time-series of weighted (by catch) mean annual caudal length of anchovy caught between 1987 and 2019 for each of the three pool areas where anchovy is caught is shown in Figure 4.12. As has been previously reported (Fairweather et al., 2006), smaller anchovy is caught to the north in Pool Area A (7.42 ± 0.54 cm CL) than in Pool Areas B (7.80 ± 0.50 cm CL) or C (8.42 ± 0.66 cm CL), and larger anchovy were caught at the start compared to the end of the time-series for all three pool areas. A significant, negative linear regression could be fitted for Pool Area B, with mean annual CL in this region declining by 0.85 cm over the 33-year time-series. Weighted mean annual CL 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.

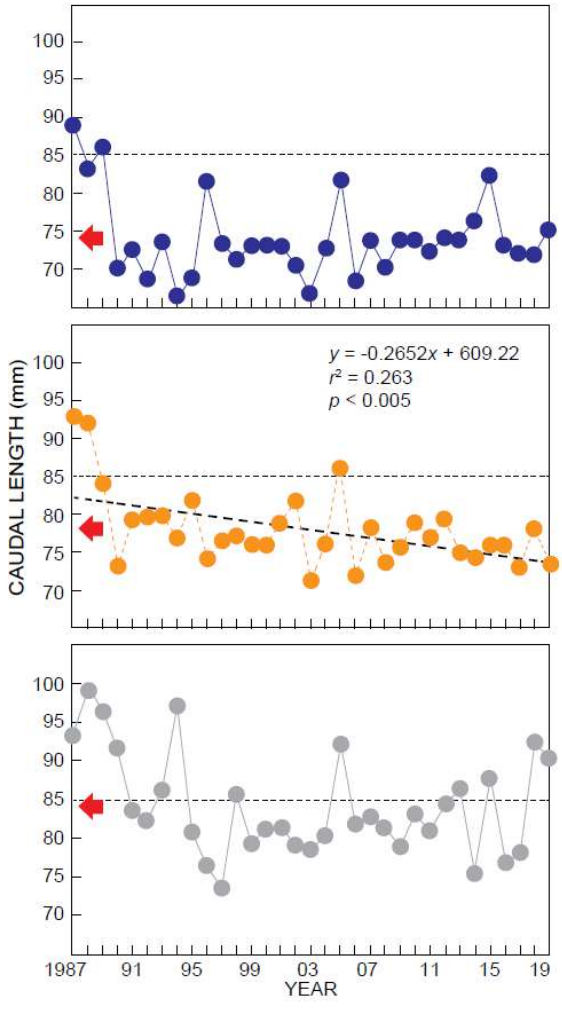

Figure 4.12: Weighted mean caudal length (mm) of anchovy caught each year in Pool Areas A (north of Cape Columbine; upper panel), B (between Cape Columbine and Cape Point; middle panel) and C (between Cape Point and Cape Agulhas; lower panel) over the period 1987 to 2019. A reference line at 85mm CL is shown on all plots to facilitate comparison, the overall mean for each Pool Area is shown with red arrows on the y-axis, and the significant linear regression for Pool Area B is shown. From DEFF (2020).

Alternatively, the time of peak spawning may have remained the same and the declines in average fish size could be due to environmental effects as has been observed for *Engraulis encrasicolus* in the Bay of Biscay (Taboada et al., 2023) and the Mediterranean (Albo-Puigserver et al., 2021). Taboada et al. (2023) reported a decline in the average body size (length and weight; Figure 4.13) and a change to a slender body shape of anchovy in the Bay of Biscay over the period 1990–2021. The declines were more rapid in recent years, and whereas anchovy abundance was strongly correlated with juvenile anchovy size (indicating density dependence), temperature was the best predictor of declines in adult size. These changes are consistent with the simultaneous, opposing effect of rising temperatures on accelerating early growth and decreasing adult size as predicted by the temperature-size rule.

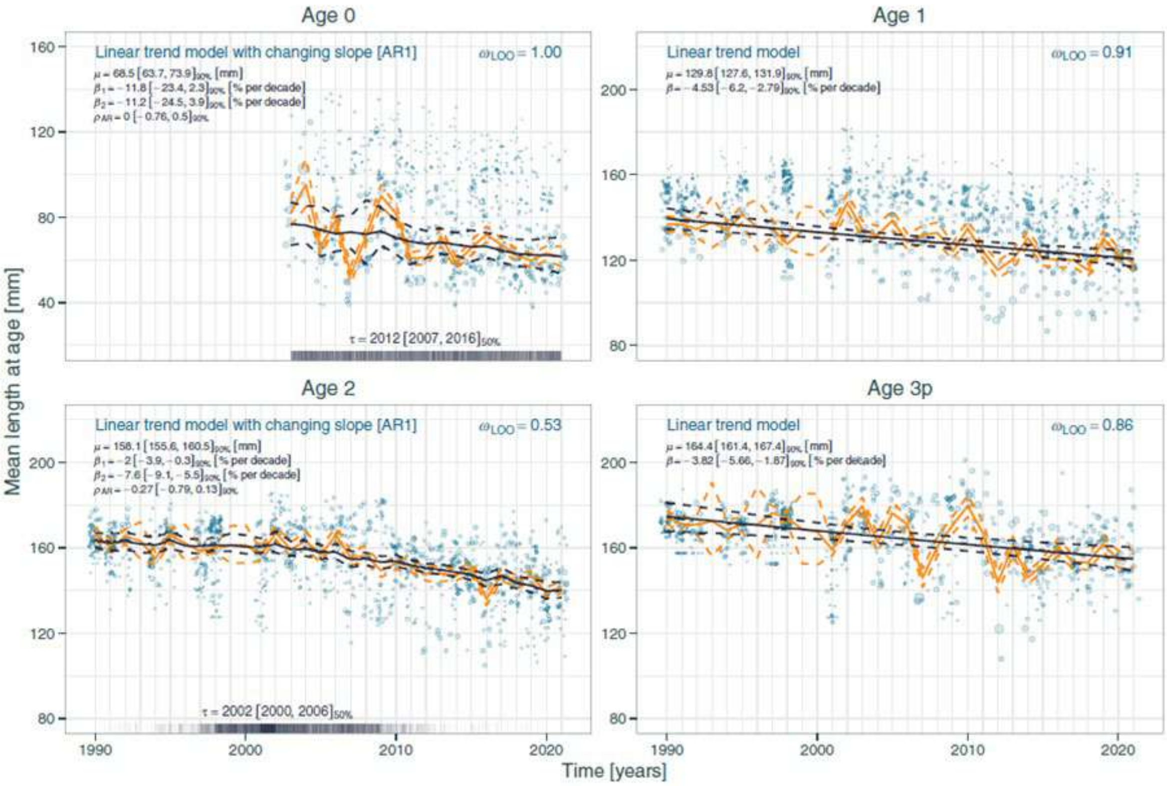

Figure 4.13: Trends in the body size at age of European anchovy *Engraulis encrasicolus* in the Bay of Biscay. Blue dots correspond to mean anchovy length per haul during research surveys and the area of each dot is proportional to anchovy relative abundance at age during each survey year in the region where each haul was towed. Each panel features the best model selected for each size metric and age class among a set of alternative hierarchical Bayesian models (labels on the top left corner of each panel detail the name of the best model and provide statistical information labels on the top right give the relative weight). Orange lines correspond to posterior estimates of the population level mean size at age during each survey year; dark blue lines give estimates based on the best fitting model; solid lines give the posterior median, and dashed lines delimit a 90% quantile-based, central interval. From Taboada et al. (2023).

Menu et al. (2022) used a bioenergetic modelling approach based on the dynamic energy budget (DEB) theory to examine assess the bottom-up hypothesis for the decline in European anchovy body size in the Bay of Biscay and northern Mediterranean and reported that two environmental parameters, namely temperature and zooplankton quality (energetic content), explained a significant part of regional differences, both of which are impacted by climate change.

Temperature and food (primary production, with possible subsequent impacts on secondary production – see below) are both predicted to increase around South Africa under climate change, and play particularly important roles in the development of early life stages and reproduction in adults of small pelagic fishes. The coastal cooling observed off the West and South coasts of South Africa and arising from intensified upwelling provides increased nutrients and better food environments for small pelagic fishes, thereby increasing larval and juvenile growth rates. However, the cool water associated with upwelling also reduces growth rates and affects reproductive output in adults. Groenewald (2021) investigated the trade-offs between temperature and food effects on the growth during the larval and recruit stages and reproductive output during the adult stage of anchovy (and sardine and round herring) in the Southern Benguela using DEB models. All three species had slower growth rates at colder temperatures. However, whereas larvae showed a trade-off between temperature and feeding effects, with slow growth rates due to cool temperatures counterbalanced by fast growth rates from enhanced food availability (Figure 4.14), this trade-off was not apparent in recruits and adults. Feeding conditions had the largest influence on growth rates of recruits and reproductive output of adults, with faster growth rates and more egg batches produced in good food conditions. Small pelagic fish produced more egg batches if good recruitment conditions were followed by good adult feeding conditions.

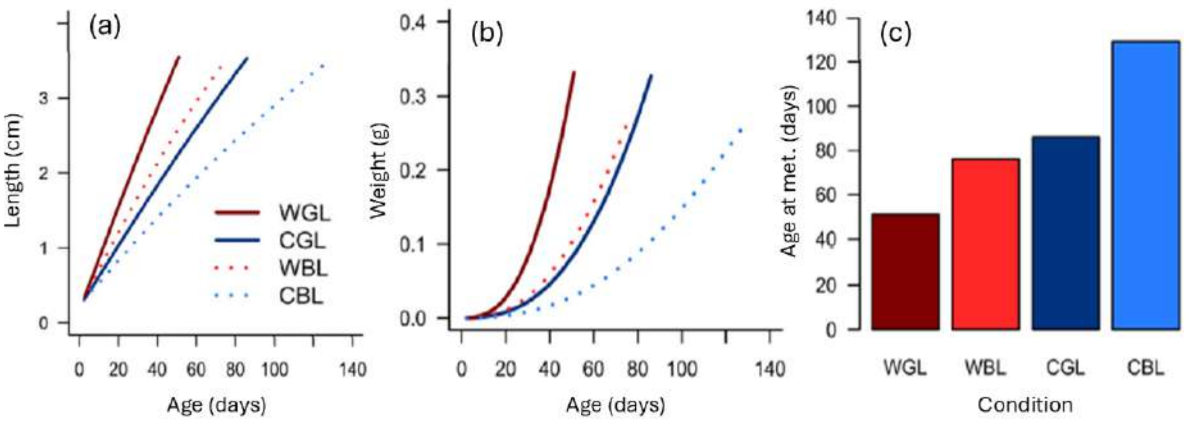

Figure 4.14: The effects of a combined temperature/food environment on the larval stages of anchovy showing (a) length (cm) at age (days), (b) weight (g) at age, and (c) the age at metamorphosis (days). The four larval food experiments are represented by colours, lines, and symbols: either cool (C, blue) or warm (W, red) water temperatures and good (G, dark colours and solid lines) or bad (B, light colours and dotted lines) food environments for larvae (L). Adapted from Groenewald (2021).

Primary production is predicted to increase off the South African West and Southwest coasts (see above), with likely increases in secondary production by zooplankton. However, it is uncertain whether the phytoplankton community composition will remain the same in the future as it is at present, given that diatoms and other larger-sized phytoplankton are projected to experience more precipitous declines in abundance than other types of phytoplankton (Marinov et al., 2010). This has implications for anchovy, given their diet of primarily large copepods and euphausiids (see below), the former of which display enhanced growth rates under diatom-dominated conditions as opposed to flagellate-dominated conditions (Walker & Petersen, 1991) and which may be food-limited when the phytoplankton community is dominated by small cells (Painting et al., 1993). In contrast, smaller copepods appear to be favoured when small phytoplankton cells predominate. Upwelling promotes the development of phytoplankton populations of high biomass that are dominated by large diatoms, whereas under stable conditions, warm temperatures and nutrient depletion of the upper layers limit diatom growth, enabling populations of small nano-flagellate to predominate (Mitchell-Innes &

Pitcher, 1992). The former environment was considered more favourable to anchovy than to sardine (which feed principally on smaller zooplankton) and the latter environment more favourable to sardine (Figure 4.15). Future increased primary production by a phytoplankton community where biomass and production remain dominated by diatoms will therefore likely be beneficial for anchovy and enhance recruitment and spawning success, whereas a phytoplankton community dominated by flagellates may impair these because of a sub-optimal feeding environment.

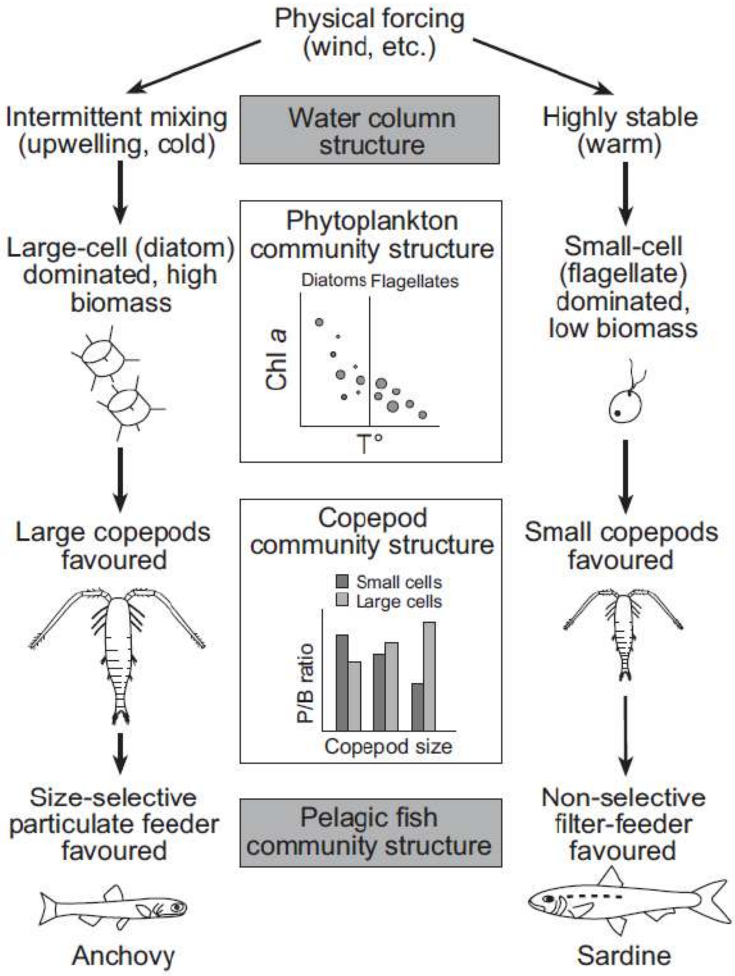

Figure 4.15: Conceptual schematic of how physical forcing may lead to environments that favour either anchovy or sardine. From van der Lingen et al. (2006a).

Predicted near-future changes in important parameters of the oceanographic environment around South Africa that will likely impact anchovy include increased SSTs around the coast and intensified upwelling and increased primary production off the West and Southwest coasts. The anticipated impacts of these on various characteristics of anchovy are synthesised in Table 4.1.

Table 4.1: Predicted near-future changes (and locations) in important oceanographic variables around South Africa and their possible/ likely impacts on South African anchovy.

Oceanographic variable	Projected change and location	Possible/ likely effects on anchovy
SST	Increase around the entire South African coast	Metabolic – decreased body size, decreased length-at-maturation
SST gradients	Increase off the South Coast	Distribution – continued eastward shift in relative distribution
Upwelling	Increase off the West and Southwest coasts	Abundance (via transport of early life history stages from spawning to nursery grounds) – dependent on when upwelling increases: early (spring) intense upwelling will likely impair recruitment whereas late (summer) intense upwelling will likely enhance recruitment
Primary production	Increase off the West and Southwest coasts	Abundance (via feeding): dependent on if and how the source of increased primary production changes: a predominantly diatom-based phytoplankton community that supports larger zooplankton will likely enhance recruitment as well as spawning success via enhanced feeding conditions whereas a predominantly dinoflagellate-based phytoplankton community that does not support larger zooplankton will likely impair recruitment

4.3 Might increased harvesting of anchovy have ecosystem impacts including supporting the recovery of the sardine population?

4.3.1 The ecosystem role of anchovy (i): Anchovy as predators and as prey

Small pelagic fishes, including anchovy, are commonly known as "forage fish" because they are preyed upon by a multitude of fish, seabird and marine mammal species and hence play a crucial role in the transfer of energy from lower trophic levels (the plankton on which they feed) to upper trophic levels (their predators), particularly in upwelling but also other systems (Cury et al., 2000; Pikitch et al., 2012; Ruzicka et al., 2024).

South African anchovy prey on both phyto- and zooplankton but obtain the majority of their dietary carbon from larger zooplankton, principally euphausiids and copepods (James, 1987). These large prey are selectively fed on by particulate-feeding, although anchovy is also capable of filter-feeding and can entrap prey down to 200µm in size (James & Findlay, 1989), and switches from filter- to particulate-feeding at a prey size of around 700µm. Their size selectivity means that anchovy can impact the size structure and species composition of the zooplankton community, as evidenced by an inverse relationship documented between the biomass of *Calanus agulhensis* (a large abundant copepod in South African waters) in St Helena Bay and anchovy recruit biomass (Hutchings et al., 2006).

Anchovy are important prey for a variety of predator species off South Africa, some of which are highly dependent on this species as well as sardine *Sardinops sagax*. Predators for which South African anchovy are important prey include (but are not limited to) geelbek *Atractoscion aequidens*, shallow water hake *Merluccius capensis*, silver kob *Argyrosomous inodorus*, snoek *Thyrsites atun*, yellowtail *Seriola lalandi*, African penguin *Spheniscus demersus*, Cape gannet *Morus capensis*, Cape cormorant *Phalacrocorax capensis* and Cape fur seal *Arctocephalus pusilis*.

Nepgen (1982) reported that anchovy were common and important prey of several important linefish species in False Bay, including geelbek (44% frequency of occurrence (FO)), silver kob (34% FO), snoek (89% FO) and yellowtail (47% FO). Griffiths (1988) and Griffiths and Hecht (1995) found anchovy to be the dominant prey of juvenile and adult geelbek in False Bay, as well as of juveniles (40–70% by number) off Port Alfred. And anchovy was also important prey of snoek in inshore waters off the West Coast (20–44% FO) but its occurrence was rare in stomachs of fish caught in offshore waters of both the West and Southwest coasts (Griffiths, 2002). Anchovy is a major dietary component of juvenile and subadult (<40 cm TL) shallow water hake off both the West (Pillar & Barange, 1993) and South (Pillar & Wilkinson, 1995) coasts, but are substantially more important in the latter (60–75% of total dietary mass) compared to the former (10–30%).

Parker et al. (2020) tested for possible functional relationships between anchovy biomass and the catch per unit effort (CPUE) of the four commercially exploited linefish species listed above (geelbek, snoek, silver kob and yellowtail). Granger causality tests (not considered suitable for accurately identifying causality in dynamic systems but applied as an exploratory analysis to identify possible causal relationships) indicated significant effects of anchovy biomass on silver kob and yellowtail CPUE. Further testing using a sequential *t*-test analysis of regime shift (STARS) indicated a relatively close (four years) temporal matching in regimes between anchovy biomass east of Cape Agulhas and yellowtail West Coast (west of Cape Point) (W) CPUE (Figure 4.16 left panel a, b). Convergent cross mapping found very little convergence ($\rho<0.2$) for the effect of anchovy on yellowtail but moderate convergence ($\rho=0.4$) for the effect of yellowtail on anchovy (Figure 4.16 right panel a). The strongest effect of anchovy on yellowtail was with a lag of −1 year, indicating true causality, albeit relatively weak according to the low convergence value. In contrast, the strongest effect of yellowtail on anchovy was with a lag of +1 year, and hence it is not causative (Figure 4.16 right panel c). The presence of both negative and positive lag values in the EoCA anchovy biomass/ yellowtail W CPUE analysis is, however, indicative of unidirectional (bottom-up) causality, whereby anchovy biomass influenced yellowtail CPUE.

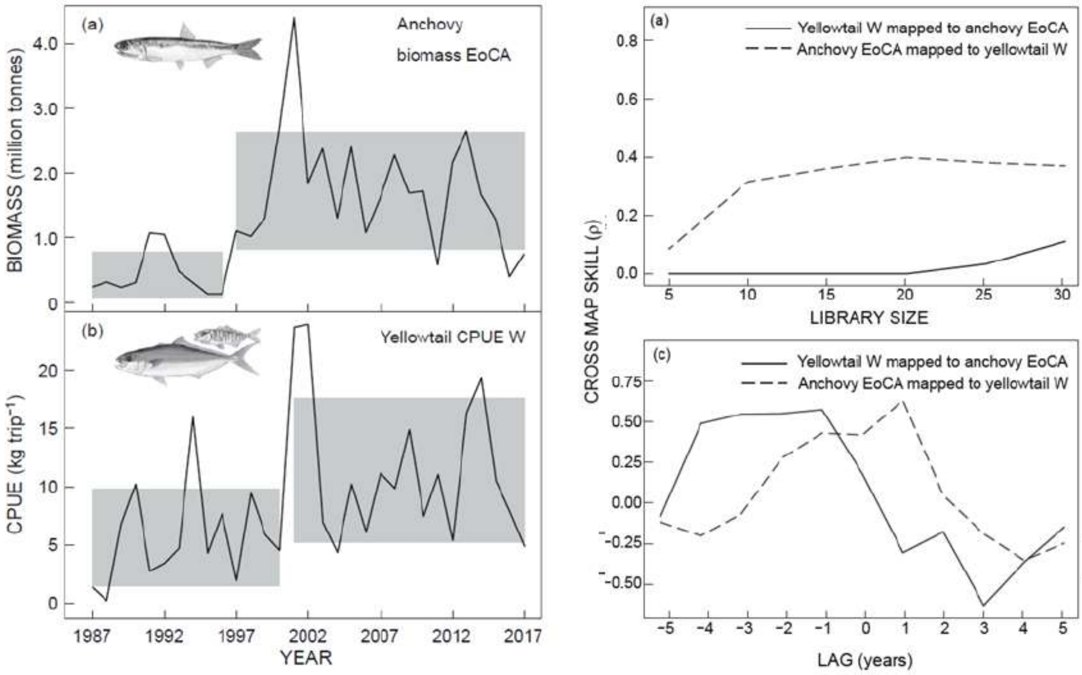

Figure 4.16: Sequential *t*-test analysis of regime shift (STARS) output plots for the comparisons of anchovy biomass EoCA / yellowtail W CPUE over the period 1987–2017 (left panel; a, b; different regimes are indicated by the grey rectangles); and results of the convergent cross mapping for the anchovy biomass EoCA and yellowtail W CPUE dataset pair (right panel; a, c), showing the cross mapping skill (ρ) as a function of (a) library size (number of years), and for each of the time lags (−5 to +5 years). EoCA = east of Cape Agulhas; W = West Coast. Adapted from Parker et al. (2020).

However, Parker et al. (2020) suggested caution is advisable when interpreting the causal bottom-up relationship between these two species because of the relatively wide interval (four years) between regime shifts and low convergence levels between anchovy biomass EoCA and yellowtail W CPUE. This was in contrast to results obtained for sardine biomass EoCA and geelbek southwest (SW) CPUE, the former of which in $year_n$ could predict the latter in $year_{n+1}$ with relatively high accuracy (r^2=0.71). This was because regime shifts in the sardine biomass EoCA and geelbek W CPUE were one year apart, the two-way causative relationship identified (as opposed to only being one-way for anchovy and yellowtail) is indicative of a classic predator-prey dynamic and provides evidence for both bottom-up and top-down control in this trophic interaction, both maximum (i.e., the time when causation is highest) cross map skill values (ρ) of the two-way relationship were negative indicating that cause preceded effect, and the maximum cross map skill value (ρ) was exceptionally high for a causal relationship examined in the natural environment.

Anchovy and sardine have long been considered the most important food items of African penguin off southern Africa (Crawford et al., 2001; DFFE, 2021 and its references), with anchovy contributing 55% of dietary mass of penguins in Algoa Bay between 1979 and 1981 (Crawford et al., 2011). However, recent work using biochemical tracers (stable isotopes of carbon and nitrogen) in penguin blood and feathers to estimate dietary composition rather than traditional stomach content analyses has indicated that adult penguins in Algoa Bay target chokka squid *Loligo reynaudii* for self-provisioning in both breeding (when they feed their chicks primarily with small pelagic fish) and non-breeding seasons (Connan et al., 2016). On average, squid and sardine were estimated to contribute around 40% each of the diet whereas anchovy contributed around only 10%. Analyses of regurgitated stomach contents of Cape gannet breeding at Lamberts Bay and Malgas Island between 1978 and

2015 showed that anchovy contributed 5–80% of dietary mass annually (Crawford et al., 2019), making its largest contribution (around 70% of total dietary mass) in April to June at Lambert's Bay and in October to December (around 50%) at Malgas Island (Berruti et al., 1993). Anchovy was also major prey item of Cape gannet sampled between 1979 and 1990 at Bird Island, Algoa Bay, comprising 60% (on average) by number of prey items consumed and contributing 24% of total prey mass there (Klages et al., 1992).

Crawford et al. (2019) analysed a 38-year time-series of data on the contributions by anchovy and sardine to the diet of Cape gannets off the West Coast collected between 1978 and 2016 using principal component analysis (PCA). Two principal components were observed in the data (Figure 4.17a), the first (PC1; which accounted for 43% of observed variance in the time-series) reflecting prey switching between anchovy and sardine whereas the other (PC2; 14%) appeared to reflect the combined availability of sardine and anchovy in the diet. PC2 was then used as a Forage Availability Index (FAI) and compared to annual estimates of the spawner biomass of anchovy and sardine off the West Coast (i.e. west of Cape Agulhas). Crawford et al. (2019) noted a change over time in the relationship between the FAI and the combined anchovy and sardine biomass WoCA from being positive until the late 1990s and abruptly switching to negative in the early 2000s and generally remaining that way thereafter (Figure 4.17b). The FAI was positively correlated with indicators of Cape gannet and Cape cormorant breeding success (Figure 4.17c, d) as well as with survival of adult penguins on Dassen and Robben islands (Figure 4.17e, f). It is worth noting, however, that annual survey-derived estimates of the combined sardine and anchovy biomass off the West Coast during the early-2000s were the highest observed to date (see Figure 7 of DFFE, 2021) when FAI values were low, and while Crawford et al. (2019) indicated that the FAI reflected a decrease in the availability (not abundance) of epipelagic fish biomass from 2000 onwards, they did not advance any hypotheses about what might have caused the change in the relationship between the FAI and fish abundance.

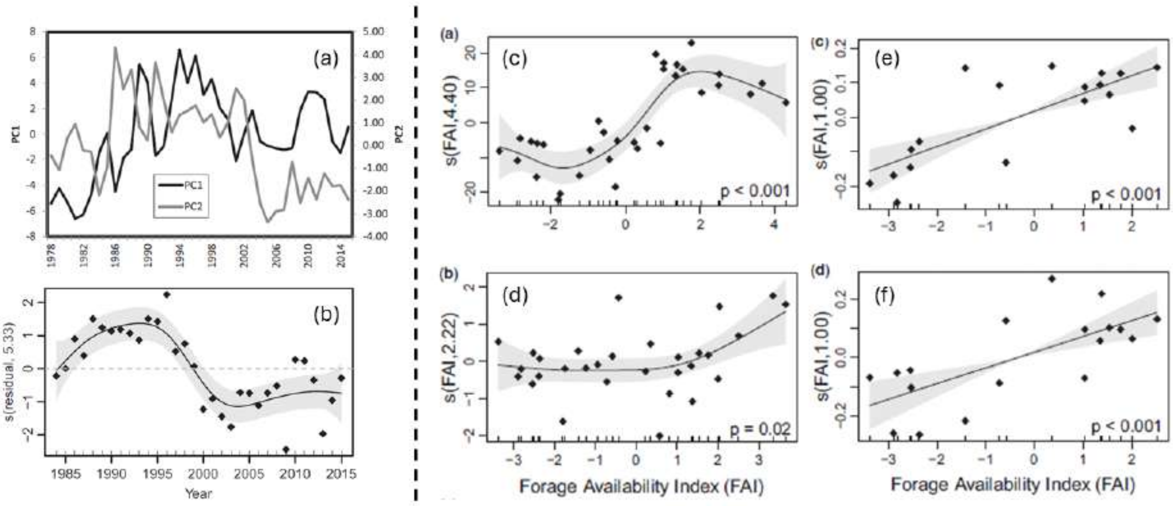

Figure 4.17: Left panel: (a) the values for PC1 and PC2 (termed the Food Availability Index (FAI)) obtained from analysis of monthly Cape gannet diet at Lambert's Bay and Malgas Islands and (b) the change over time in the relationship between the FAI and the combined biomass of anchovy and sardine off the West Coast. Right panel: the effects of the FAI on four indicators of seabird performance off the South African West Coast including (c) the number of nests at which Cape gannets were breeding between 1978 and 2016; (d) number of nests at which Cape cormorants were breeding between 1978 and 2016; and (c) and (d) apparent survival of adult African penguins at Dassen and Robben islands, respectively, between 1994 and 2012. The grey shading in (b) to (f) shows pointwise 95% confidence intervals. Adapted from Crawford et al., (2019).

David (1987) documented the teleost portion of the diet of Cape fur seals collected at sea from the South African West (Orange River mouth to Cape Town) and South (Cape Town to Algoa Bay) coasts during the 1970s and 1980s. He reported that anchovy and Cape hakes were the most important prey species off the West Coast with each contributing 23% to seal total dietary mass there. Anchovy was again the most important teleost prey of seals off the South Coast where it contributed 17% to total dietary mass. Huisamen et al. (2012) analysed scats (faeces) and the hard parts (fish otoliths and cephalopod beaks) collected from the Robberg seal colony at Plettenberg Bay on the South Coast over the period 2003–2008 to investigate the species and size composition of their diet. Anchovy was the most important dietary item in terms of percentage frequency of occurrence (31.2%) and percentage numerical abundance (55.5%) but, because of its small size compared to other species, it was only the 3rd most important in terms of percentage mass (15.1%). Whereas the dietary importance of anchovy did not vary between upwelling (December to May) and non-upwelling (June to November) seasons there was a significant and substantial increase in its importance over the study period, from <5% mass in 2003 and 2004 to >35% mass in 2006 and 2007. This increase was not correlated with regional or total anchovy biomass levels and likely arose from increased targeting of anchovy by seals given the decreased dietary contribution importance of sardine (their preferred small pelagic prey) over this period that arose from decreased regional and total sardine biomass levels (Huisamen et al., 2012).

4.3.2 The ecosystem role of anchovy (ii): Anchovy as mixers of the upper water column

In addition to the central role that anchovy (and other small pelagic fishes) play as forage for a variety of predators in marine ecosystems (see e.g., Peck et al., 2021; Mutalipassi et al., 2024), a recent study has indicated that these fish can have an impact on the vertical structure of the surface waters. Whereas wind and tides constitute the major sources of energy for ocean mixing at a global scale, it has been suggested that swimming organisms (from zooplankton to fish to marine mammals) may make a contribute a substantial energy input on regional scales, a process known as biomixing (Houghton et al., 2018; Kunze, 2019). Fernandez-Castro et al., (2022) analysed 14 days of continuously collected data at a 1 cm scale of hydrographic properties, turbulence (turbulent dissipation and mixing rates), and acoustic backscatter (as an index of plankton and fish density) at a fixed station in an embayment affected by wind-driven coastal upwelling in the Northern Canary Current upwelling ecosystem off northwest Spain. Those authors reported that turbulent dissipation was elevated 10- to 100-fold every night during due to the swimming activity of large aggregations of spawning European anchovy *Engeaulis encrasicolus*, and that turbulent mixing was invigorated concurrently to dissipation and occurred with an efficiency comparable to that of geophysical turbulence (Figure 4.18 left panel). This biomixing would increase the ability of surface waters to absorb heat in areas where anchovy is spawning, and the higher efficiency of biomixing in more-stratified waters (Figure 4.18 right panel), could also act to mitigate against the observed (and projected) stratification of ocean waters arising from climate change.

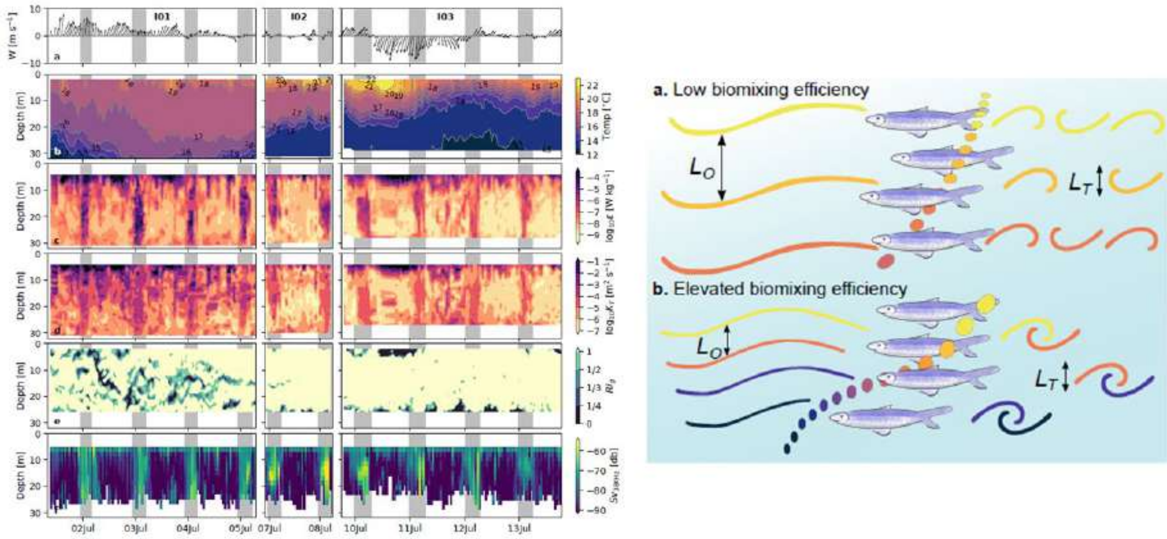

Figure 4.18: Left panel: hydrography, turbulence and mixing at a fixed locality study site showing time series of (a) local wind speed and direction, (b) hourly-mean temperature, (c) turbulent kinetic energy dissipation rate, (d) turbulent heat diffusivity, (e) gradient Richardson number, and (f) volume backscattering strength at 38 kHz (E), during the three sampling periods (I01, I02 and I03). Gray shading indicates night-time periods of biomixing by anchovy. Right panel: schematic representation of two scenarios of biophysical turbulence under weak (a) and strong (b) levels of stratification (illustrated by coloured lines and dots depicting layers of different temperature). In (a), turbulent eddies are dissipated by viscosity before producing significant mixing and biophysical mixing and are inefficient. In (b), turbulent eddies interact with the temperature/ density profile and transport heat/ mass vertically before dissipating, thus leading to an increase in the efficiency of biomixing. Adapted from Fernandez-Castro et al., (2022).

4.4 Will utilising South African anchovy for human consumption require an increase in exploitation rate?

A description of the anchovy fishery in South Africa has been provided in van der Lingen (2024; Chapter 3). This fishery is considered by the regulatory authority (DFFE) to be sustainably managed in that fishing pressure for this species is presently considered "Optimal" (DFFE, 2023) and has been "Optimal" (2010, 2012 and 2020) or "Light" (2014 and 2016) over the past 15 years. Notably, annual total allowable catch levels set for this species have not been filled for the past 23 years with 56.1% of the TAC being caught on average each year but ranging from 17.5% (in 2013) to 91.9% (in 2000; Figure 4.19).

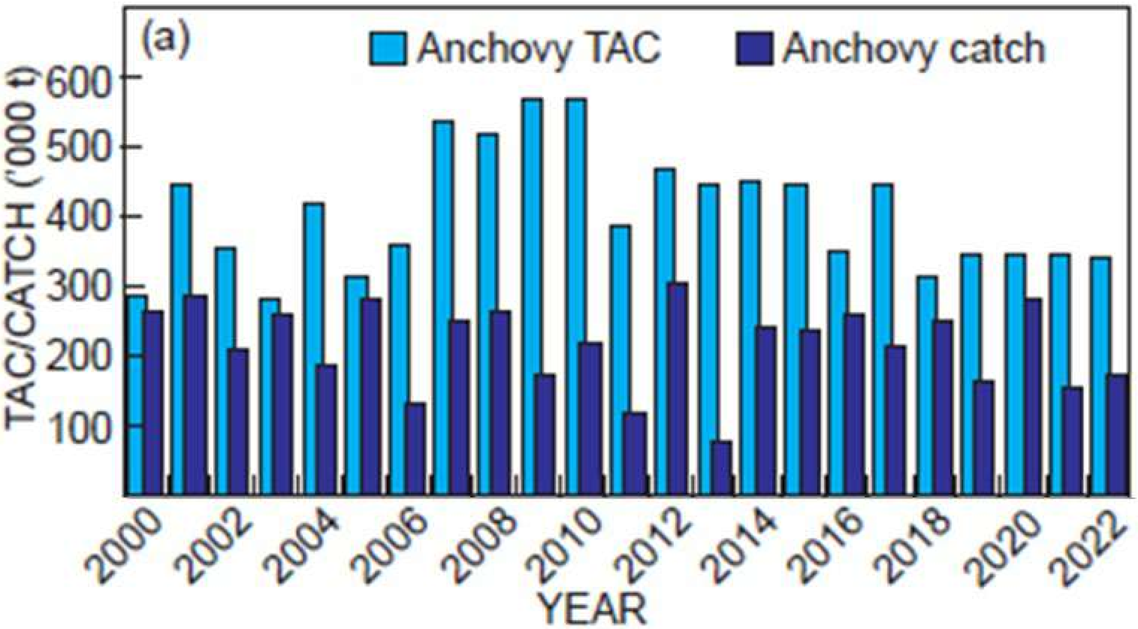

Figure 4.19: Annual total allowable catch and subsequent landings of anchovy by the South African small pelagic fishery, 2000–2022. From DFFE (2023).

Bergh (2020) collated catch and biomass data on data on other exploited anchovy stocks from the RAM Legacy Stock Assessment Database (https://www.re3data.org/repository/r3d100012095), a public database containing time-series and biological metrics from hundreds of globally distributed marine fisheries stock assessments. As such, this database provides opportunities for unique insight into population dynamics of exploited species. Bergh (2020) reported an average exploitation rate (ER; catch/ biomass) of South African anchovy of 0.086 (i.e. catch was 8.6% of biomass, on average), calculated from actual catches realised and not the TACs awarded. That author also noted that this exploitation rate was low compared to other exploited anchovy stocks, being only 33% of the median ER of 0.26 for the 16 other fisheries examined that were considered to be sustainably fished (the ERs of which ranged from 0.01 to 0.5). Bergh (2020) argued that the South African anchovy population was (and is) being under-exploited and could support higher ERs without undue risk.

However, given the historical under-catch of the South African anchovy TAC, and despite the argument that this population can support higher exploitation rates by Bergh (2020), it is necessary to consider whether increasing fishing pressure on anchovy is in fact needed to supply fish for human consumption products. Annual TACs for anchovy over the period 2000–2022 ranged between 285 000 and 573 180t and with an average of 409 070 ± 86 170 (std. dev.) t, whereas annual anchovy catches ranged between 78 800 and 307 300t and had an average of 219 080 ± 60 540t over the same period (Figure 4.20). The 43.9% (on average) of the TAC that was not taken equates to almost 190 000t, which is likely substantially more than could be used for HCPs from South African anchovy in the near (or even mid-term) future.

Substantial efforts (led by the then-President) were made in Peru in the early-2000s to process Peruvian anchoveta *Engraulis ringens*, for human consumption (Maljuf et al., 2017). Canning Peruvian anchoveta has been estimated to provide 10.8 times as many jobs per tonne as processing into fish meal and oil (Christensen et al., 2014), but only 2% of average of annual catch was processed for human consumption (mostly canning) during 2008– 2011 (Fréon et al., 2014; Figure 4.20), and this percentage has subsequently decreased (Maljuf et al., 2017).

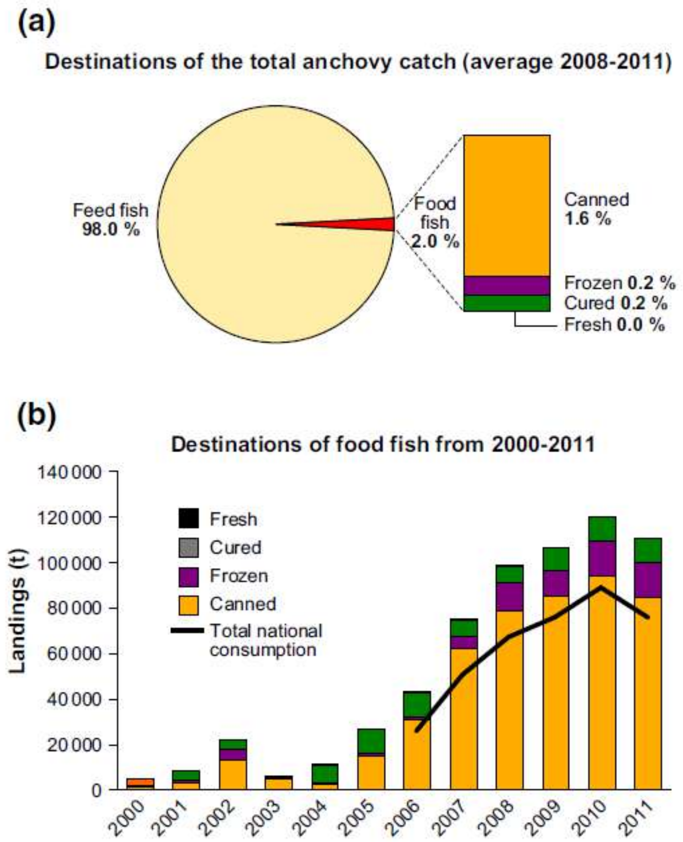

Figure 4.20: Landings of Peruvian anchoveta *Engraulis ringens* according to use, showing: (a) the share between fish reduced to fishmeal and oil (feed fish) and fish processed for human consumption (food fish) with the contributions of different HCPs also shown; and (b) trends in uses of HCPs from 2001 to 2011 with the aggregated national consumption of these products also shown. From Fréon et al., (2014).

Reasons for the decrease in the percentage of Peruvian anchoveta for HCPs include (i) decreased supply of anchoveta and increased demand for fish meal and oil; (ii) a small differential in the landing (off-vessel) price of anchoveta for HCPs or reduction, with that of the latter occasionally being higher; and (iii) little regulation or control of the artisanal fleet (required by law to only catch anchoveta for HCP) which fishes year-round and has excess capacity so frequently lands fish for reduction at a good price (Maljuf et al., 2017). Fréon et al. (2014) also list (i) national dietary habits with a preference for chicken above anchoveta reducing local demand and (ii) the recent introduction of an individual quota system that has shifted bargaining power from processors to fishers, thereby increasing competition for raw material between the feed fish industry and the food fish industry with higher prices offered by the feed fish industry due to its processing overcapacity. Additionally, life cycle assessments of different anchoveta HCPs showed that more-refined products (cured and canned) represent a much higher environmental burden than less-refined (fresh, frozen and salted) due to differences in energy consumption used in each process (Avadí et al., 2014), although how these compared to fish meal and oil products was not quantified. More recently, Carrere (2020) described three illegal mechanisms currently operating in Peru to produce fish meal for export and domestic use, including factories operating without installation permits or appropriate operating licences; businesses claiming to produce food for human consumption but instead systematically diverting anchoveta to fish meal factories; and drying fields, where anchoveta remains are dried in the sun in a labour-intensive and unsanitary way.

The 2024 catch quota for Peruvian anchovy for direct human consumption was set at 150 000t[34], only some 3% of the 2024 TAC of 4.5 million t (most of which was caught). Recent figures on realised catches of anchoveta for human consumption could not be found, but it appears that the vast majority of the Peruvian anchoveta catch is still reduced to fish meal and oil, demonstrating that converting substantial quantities of anchoveta into HCPs is not easily achieved, despite intensive effort. Additionally, developing a South African fishery for anchovy for HCPs would require substantial investment including installation of refrigerated seawater systems on anchovy vessels; developing land-based processing facilities; and expanding markets for both expensive (fillets, canned, etc) and cheap (dried, salted etc) products (Anonymous, 2013). These considerations, in conjunction with the present under-utilisation of South African anchovy as evidenced by under-caught TACs, suggest that a fishery for this species for HCPs would likely start use relatively small quantities (a few multiples of 10 000t) in the near (or even mid-term) future. This is likely substantially less than the 190 000t of the anchovy TAC on average that is presently not caught, indicating that development of anchovy for HCPs could be accommodated without a need to increase present exploitation rates of the South African anchovy.

4.5 Comparing population trajectories of anchovy and sardine

Anchovy (*Engraulis* spp.) and sardines (*Sardina pilchardus* and *Sardinops sagax*) co-exist in many of the world's large marine ecosystems, in some, dominate local fisheries landings, and together contribute a substantial portion of the global marine catch. Observations of catch data from the previous century indicated that maximum catches of anchovy and sardine had never occurred simultaneously in any one ecosystem (Lluch-Belda et al. 1989; Schwartzlose et al. 1999), and the study of fish scales preserved in anaerobic sediments from some of these regions has shown that, in the absence of fishing, the two had alternated in relative abundance over interdecadal and centennial time scales (Soutar & Isaacs, 1974; Baumgartner et al. 1992). These large-scale, long-term changes in relative abundance were termed "regime shifts" (Lluch-Belda et al. 1989, 1992) and became the subject of much investigation and discussion (Schwartzlose et al. 1999; Chavez et al., 2003). Several hypotheses were developed to account for regime shifts between anchovy and sardine, mostly concerning how these small pelagic fishes respond differently to bottom-up forcing of the ecosystem that is driven by changing basin-scale ecosystem conditions (Alheit et al., 2009; MacCall, 2009). These different responses were, for example, due to differences in the trophodynamics (van der Lingen et al., 2006a) and spawning temperature optima (Takasuka et al., 2008) of anchovy and sardines.

However, more recent analyses of scales from marine sediments (Field et al., 2009; Salvatteci et al., 2018) provide little support for the paradigm of regular alternations of anchovy and sardine within a single ecosystem. Rather, those studies emphasised the importance of regional population displacements of the two species at multidecadal time scales identified from analyses of scales collected from multiple sites (previous analyses tended to be based on a single site) that must be taken into account for the reconstruction of past fish abundance fluctuations, and that the different modes of variability in small pelagic fish abundances were consistent with paleogeographic evidence for many different climate states and modes of variability.

Estimates of the total biomass and recruitment of anchovy and sardine derived from acoustic research surveys (conducted in spring) over the past four decades are shown in Figure 4.21. Anchovy total biomass averaged 2 122 096 ± 1 331 043 (std. dev.) tonnes over this period compared to an average of 848 115 ± 957 427 tonnes for sardine, and both species showed peak biomass levels in the early

[34] https://weareaquaculture.com/news/fisheries/peru-set-anchovy-catch-quota-2024-for-direct-human-consumption.

2000s that declined swiftly (sardine) or more gradually (anchovy) to present relatively low (<25% of maximum) levels. Anchovy total biomass was higher than sardine total biomass in all but seven (1995, 1996, 1998, 2002–2004, and 2011) of the 39-year time series (Figure 4.21a).

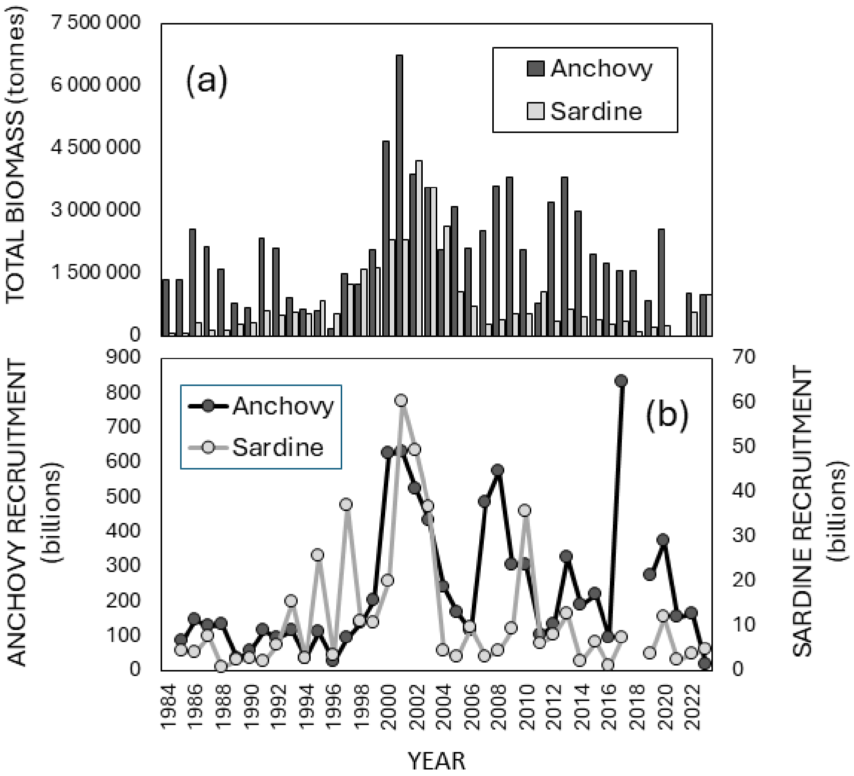

Figure 4.21: Time-series of (a) anchovy (darker histograms) and sardine (lighter histograms) total biomass (tonnes) estimated during annual pelagic biomass surveys 1984–2023, excluding 2021; and (b) anchovy (darker shading and line) and sardine (lighter shading and line) recruitment strength (billions of individuals; note the different y-axes with different scaling for each species) estimated during annual pelagic recruitment surveys, 1985–2023, excluding 2018.

Anchovy recruitment strength estimated during pelagic recruitment surveys (conducted in autumn) has been one to two orders of magnitude larger than sardine recruitment strength in any given year, and both have shown substantial interannual variability (Figure 4.21b). Estimated anchovy recruitment in 2023 was 17 billion fish, the lowest yet recorded, and whereas the figure in 2024 (56 billion fish) was somewhat higher, it was still well below the long-term average of 236 billion fish (Shabangu et al., 2024). The 2024 estimate of sardine recruitment strength (3.7 billion fish) is also below the long-term average of 11.4 billion fish.

Estimates of the total biomass and recruitment of South African anchovy and sardine from annual research surveys were compared via scatterplots to assess whether these parameters for the two species were correlated, and if so whether they showed fluctuations that were in or out of phase. Significant, positive linear regressions could be fitted to both the total biomass (Figure 4.22a) and recruitment (Figure 4.22b) data, indicating that these two species have not shown species alternations over the past four decades, and suggesting that the dynamics of the two species are responding to the same, likely environmental, forcing. This is similar to the observation of a significant, positive correlation between deposition rates of anchovy and sardine scales in sediments in the California Current reported by Field et al. (2009).

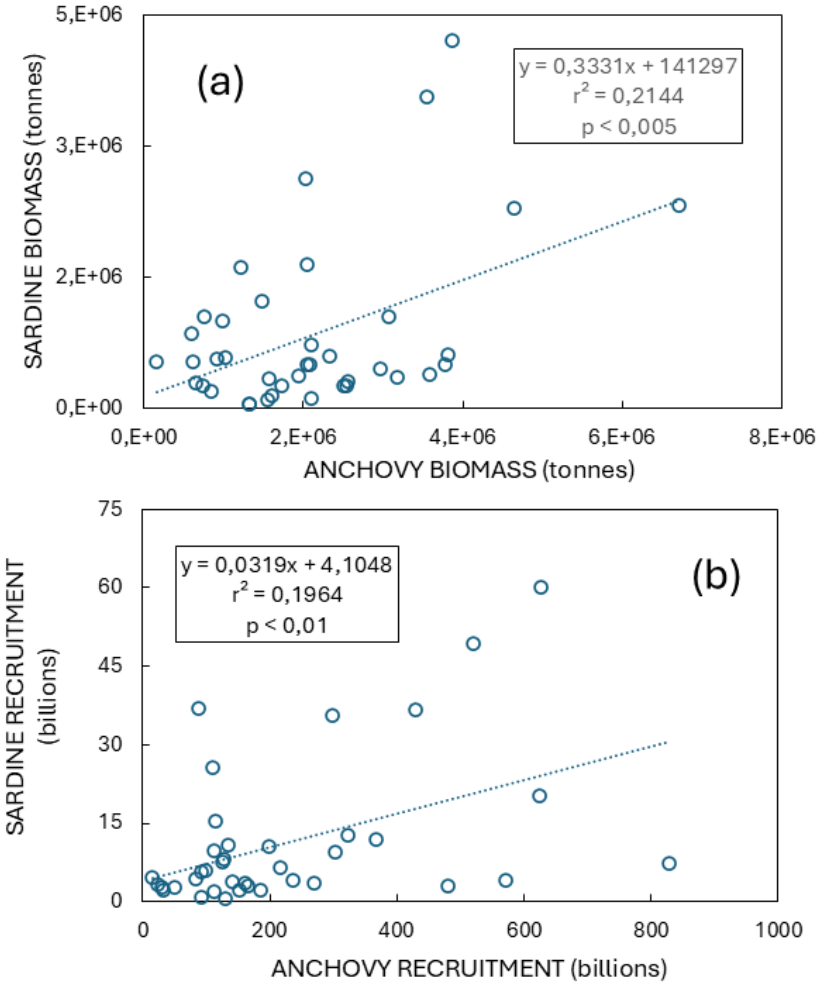

Figure 4.22: Scatterplots of (a) sardine versus anchovy total biomass, and (b) sardine versus anchovy recruitment strength, from estimates made during pelagic surveys conducted over the past four decades. The equations and statistical parameters of the fitted linear regressions are shown.

The observed co-variability in recruitment and total biomass estimates derived from annual research surveys of anchovy and sardine over the period 1985–2023, together with the findings from analyses of anchovy and sardine scales in marine sediments described above, suggests that reducing the size of the South African anchovy population by increasing fishing pressure will be unlikely to have beneficial effects on sardine population size. As had been done in South Africa, anchovy was targeted in Namibia following the sardine collapse there in the late 1960s (Beckley & van der Lingen, 1999; van der Lingen et al., 2006b). Management initiatives introduced in the early 1970s included splitting of the previously global small pelagic quota into proportions for sardine and for "other species" combined, principally anchovy and horse mackerel *Trachurus capensis*. The intention of the "other species" quota was to encourage diversification of the excess fishing effort available at that time away from sardine and, in the light of the possibility that the sardine population stock might be suffering from competition from the anchovy, it was at that time regarded desirable to subject the anchovy to heavy fishing pressure (Butterworth, 1980). However, the initially high annual catches (200 000–400 000t p.a.) of anchovy in Namibia could not be sustained and, by the late 1980s, these did not exceed 50 000t (Crawford, 2007) and have been zero or close to zero since the early 1990s (Kainge et al., 2020).

4.6 Discussion and conclusions

This chapter has synthesised information from the literature and publicly available data on South African anchovy and sardine to identify the possible impacts of climate change on South African anchovy and to assess the possible ecosystem impacts of increased harvesting of anchovy, including supporting recovery of the sardine population. Information on and descriptions of (i) the impacts of climate change on coastal marine ecosystems in general and South African marine ecosystems in particular; (ii) the predicted impacts of climate change on South African and other anchovy species; and (iii) environmental drivers of South African anchovy abundance, distribution, phenology and other attributes were collated to address the first objective. Information on and descriptions of (i) the ecosystem role of anchovy; and (ii) whether utilising South African anchovy for human consumption would require an increase in exploitation rate were collated; and (iii) a comparison of the population trajectories of South African anchovy and sardine was conducted to address the second objective.

Predicted and important near-future changes in the South African marine environment include increased sea surface temperatures around the entire coast, increased upwelling off the West and Southwest coasts, and increased primary production off the West Coast and in inshore waters off the Southwest and South coasts. Long-term observations of South Africa's marine environment have shown significant increases (and some small decreases) in SSTs in different regions, a significant increase in cross-shelf SST gradients off the South Coast, a significant increase in upwelling off the South Coast and a tendency to increased upwelling off the West Coast, all of which are attributed to climate change. An increase in the occurrence of harmful algal blooms and consequent incidence of localised low oxygen water events in coastal waters off the West and Southwest coasts, as well as an increase in the severity and duration of marine heat waves off the West and Southwest coasts, particularly in non-upwelling localities, are likely due to environmental (possibly climate-driven) change. Changes in copepod abundance and species composition off both the West and South coasts that, while likely linked to environmental changes such as ocean warming, are thought to be largely driven by predation by small pelagic fishes. No trends in the pH, dissolved oxygen levels, or phytoplankton biomass have been observed.

Predicted climate change impacts on anchovy include changes in distribution, abundance, phenology and physiology and other biological characteristics including body size, length at maturity, etc). Sea surface temperature is the most important environmental predictor of anchovy egg, recruit and adult distributions, and adults have shown an eastward shift in their relative distribution (% of total biomass) that is significantly correlated with cross-shelf SST gradients off the Southwest and South coasts. Additionally, the spatial extent of anchovy optimal habitat off the West Coast has declined since the early-2000s whereas that off the South Coast has remained stable. The observed eastward shift in the relative distribution of anchovy spawners appears likely to continue, under the assumptions that cross-shelf SST gradients off the Southwest and South coasts continue to increase and the relationship between anchovy relative distribution and these gradients continues to hold. Should the biomass of anchovy spawners off the West and Southwest coasts decline below ca. 750 000t, this will have a negative effect on recruitment.

Warming is predicted to have a strong, negative impact on the South African anchovy, with biomass reductions of around 50% projected by 2050, although warming is ameliorated to some degree in upwelling areas. Anchovy recruitment success is strongly dependent on the successful transport of eggs and larvae from the spawning area off the Southwest and South coasts to the nursery area off the West Coast and is positively correlated with cumulative upwelling towards the end of the upwelling season (December and March). Intense upwelling at the start of the upwelling season (October and November) is likely to have a negative impact on recruitment success. The impact on anchovy recruitment of increased upwelling off the West and Southwest coasts will depend on when the upwelling occurs: intense upwelling early in the season (spring) will likely result have a negative effect due to high advective loss of eggs and early larvae, whereas intense upwelling later in the season (summer) will likely have a positive effect.

Increased temperatures are likely to result in decreases in anchovy body size, with attendant decreases in individual reproductive output that may impair recruitment. A decrease in the average size of South African anchovy as a long-term effect of warming or a decline in food quantity or quality, as has been observed in anchovy populations elsewhere, appears plausible.

South African anchovy plays a critical role in coastal ecosystems of the West, Southwest and South coasts, particularly as forage for a wide variety of fish, seabird and marine mammal predators for whom anchovy is important and sometimes dominant prey, and changes in the abundance and availability of anchovy have large impacts on such dependent predators. The fishery for South African anchovy is presently considered to be sustainable, but annual total allowable catches are under-caught by some 43.9% on average (equivalent to ca. 190 000t) and low exploitation rates (8.6% per year, on average) suggest that this species is under-utilised.

Despite substantial efforts to develop human consumption products from Peruvian anchoveta made during the early 2000s, only relatively small quantities (<2% of the anchoveta TAC) have been processed into HCPs each year since then. Multiple barriers to increasing the quantity of anchoveta processed into HCPs illustrate the difficulties likely to be encountered in developing anchovy HCPs in South Africa. Additionally, it appears likely that large quantities of anchovy will not be needed for the development of HCPs from South African anchovy, at least in the short-term and likely also the long-term unless multiple barriers can be overcome. This, in conjunction with the present under-utilisation of South African anchovy, suggest that a fishery for this species for HCPs would likely start use relatively small quantities (a few multiples of 10 000t) in the near (or even mid-term) future. This is likely substantially less than the 190 000t of the anchovy TAC on average that is presently not caught, indicating that development of South African anchovy for HCPs could be accommodated without a need to increase present exploitation rates of the South African anchovy. Targeting the un-caught portion of the TAC for anchovy for HCPs would therefore unlikely incur substantial ecosystem impacts.

A comparison of the population trajectories of South African anchovy and sardine suggests that the dynamics of the two species are responding to the same, likely environmental, forcing, similar to observations of significant, positive correlations between deposition rates of anchovy and sardine scales in marine sediments in some other upwelling systems, and contrary to the regime shift hypothesis that posited species alternations between the two. The observed co-variability between anchovy and sardine population trajectories suggest that increasing fishing pressure (i.e., exploitation rates) on anchovy to accommodate the development of HCPs (although this is not considered necessary for the reasons described above) appears unlikely to have beneficial effects on sardine population size.

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CHAPTER 5
TYPES AND PRODUCT FORMS OF ANCHOVY AND RED-EYE ROUND HERRING FOR CONSUMERS

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5.0 Introduction

Fish is a rich source of easily digestible high-quality protein containing all essential amino acids; provides essential fats (e.g., long-chain omega-3 fatty acids) not found in most other protein sources; and provides vitamins (D, A and B) and minerals (including calcium, iodine, zinc, iron and selenium); is usually high in unsaturated fats and specifically the omega-3 fatty acids, eicosapentaenoic (EPA) and docosahexaenoic acids (DHA) (Hoge et al., 2018; Miller et al., 2014; Tur et al., 2012; Simopoulos, 2002). Therefore, fish has many health benefits, particularly when eaten whole (FAO, 2016), which is the case in most developing countries. Even when taken in small quantities, which is the case in many developing countries, fish can have significant positive nutritional impact on diets that are mainly plant-based diets (FAO, 2016; HLPE, 2014). Given these nutritional properties, fish can play an important role in correcting unbalanced diets and in countering obesity and protection against cardiovascular diseases, which are growing problems in South Africa (Thow et al., 2015; Shisana et al., 2013).

South Africa faces persistent challenges regarding food and nutrition insecurity, particularly within low-income populations who often have low intakes of essential fatty acids. Historically, the sardine (*Sardinops sagax*) has been a primary source of affordable marine protein, but its resources are depleting. By contrast, the red-eye round herring (*Etrumeus whiteheadi*) is an abundant, underutilised small pelagic fish species in South African waters that is primarily used for fishmeal rather than direct human consumption. Due to their high lipid content, small pelagic fish are susceptible to oxidation, which affects quality and shelf-life.

Smoking is a technique used to enhance the sensory attributes and increase the shelf-life of fish. The primary purposes of smoking fish and fish products include: 1) development of flavour, 2) preservation action, 3) creation of new products, 4) protection from oxidation and rancidity, and 5) development of colour. Smoke acts as a preservative since it inhibits microbial growth and retards fat oxidation (rancidity). Shelf-life extension of smoked fish is due to a combination of lowered water activity (a_w) and the uptake by the product of bactericidal and antioxidant components of wood smoke. Hot smoking is a traditional smoking method that uses both heat and smoke to preserve and market fish. Hot-smoked fish products have a shelf-life that varies, mostly determined by the kind of species, the amount of salt and smoke used, the degree of drying, the storage temperature, and the packing material. Fish, when properly smoked and packaged, may provide a consistent supply of dietary protein and omega-3 polyunsaturated fatty acids, improving food and nutritional security.

The current research project investigated the strategic shift towards utilising anchovy and red-eye round herring for direct human consumption, focusing on product development, nutritional analysis, food safety, and consumer acceptance to improve national food security and socio-ecological resilience. Anchovy is highly perishable due to high moisture and fat content, making effective preservation critical. This research therefore also investigated the viability of long-term frozen storage combined with vacuum packaging versus aerobic packaging to ensure microbial safety and quality for potential consumer markets.

5.1 Food products with anchovy for human consumption

Aim

The aim of this study was to investigate nutritional value, microbial and heavy metal content in terms of food safety, and product types of South African anchovy (*Engraulis encrasicolus*) for human consumption. Under this aim, there were six objectives.

Objective 1 was to perform a short literature review on potential smoked and marinated anchovy product types in South Africa.

Objective 2 was to analyse the nutrition content (proximate composition and fatty acid profile) of anchovy product types. This was a preliminary trail with the objective of evaluating the nutritional and microbiological attributes of anchovy fillets subjected to smoking processing and marinated storage in oil, respectively.

Objective 3 of the product development aspect of the project was to investigate the microbial change (food safety) and proximate composition of hot-smoked anchovy fillets, and hot-smoked whole anchovy, during a shelf-life study of 14 days, using vacuum packaging and non-vacuum packaging.

Objective 4 was to determine the proximate composition, and other micro-nutritional content (amino acids, fatty acids, and minerals) of different anchovy product types (raw anchovy, whole smoked anchovy, and smoked filleted anchovy). The health benefits associated with the consumption of omega-3 long chain polyunsaturated fatty acids have been demonstrative in many areas of human health, such as cardiovascular disease, hypertension, cognitive health, dementia, Alzheimer's disease, depression, inflammation, and visual function. The availability and consumption of fatty acid (FA) supplements, in the form of fish oil capsules, are valuable in the South African diet and contribute to public health. However, the majority of South Africans are unaware of the importance of omega-3 FA in their diet, and/or cannot afford FA supplements. Poor and lower-income consumers, especially within the Western Cape, rely on marine fish species, particularly snoek and sardines, as their sole protein and omega-3 FA source.

Objective 5 was to investigate the viability of long-term frozen storage of whole and filleted anchovy, combined with vacuum packaging versus non-vacuum packaging to ensure microbial safety and quality for potential consumer markets.

Objective 6 was to develop and taste various culinary convenience meal recipes incorporating anchovy to test consumer acceptance. The meals were evaluated using a 9-point hedonic scale for attributes such as taste, texture, aroma, appearance, and overall acceptability. Students were asked to taste the dishes and score their overall taste and acceptability.

5.1.1 Materials and methods

5.1.1.1 Material and methods for Objective 1

A short literature review was conducted, looking into product types made from anchovy, with the potential for the South African consumer.

5.1.1.2. Material and methods for Objective 2

Five variations of anchovy products were produced, three smoked and two marinated (Table 5.1). The microbiological quality of the smoked and marinated products was analysed on day 0 and day 7 of refrigerated storage at 7.4ºC. The proximate composition (moisture, ash, protein, and fat) of only the smoked anchovy samples was determined, while the fatty acid composition of the five products was determined on day 7 of refrigerated storage.

Table 5.1. Five variations of anchovy products: hot-smoked (whole and filleted) and marinated in oil (flecked)

Sample/anchovy product variation
Control sample (raw anchovy)
Whole anchovy (salted and hot-smoked)
Filleted anchovy (salted and hot-smoked)
Flecked anchovy (marinated in olive and sunflower oil)
Flecked anchovy (marinated in olive and vegetable oil)
Whole cured and hot-smoked (salted and cured for 4 weeks)

Anchovy samples were procured along the West Coast of South Africa. The fish samples were obtained from Afrofishing Pty Ltd. (Mossel Bay). Fish were covered in blue polyethylene bags, boxed and immediately frozen. The fish samples were kept frozen and transported to the Cape Peninsula University of Technology Department of Food Science and Technology laboratories where the samples were stored at -18ºC until processed and microbiological and chemical analyses commenced.

Anchovy smoked product types

The smoked products consisted of i) whole anchovy brined for 15 minutes, ii) anchovy fillets brined for 15 minutes, and iii) anchovy fillets cured/brined for 4 weeks. The smoking process for the whole and filleted anchovy is outlined in Figure 5.1. Whole and filleted samples were smoked in different batches.

Frozen anchovy was thawed at refrigerated temperatures

⇩

Whole anchovy samples were cleaned, washed, eviscerated and filleted

⇩

Whole and filleted anchovy was immersed in a brine (12.5% salt/sugar) solution for up to 15 minutes

⇩

After brining, the fish were spread on cutting boards to drain

⇩

After draining, the whole fish and fillets were spread on smoking trays and dried at 60°C for 15 minutes

⇩

Whole and filleted anchovy samples were smoked at 80°C for 20 minutes

Figure 5.1. Flow-diagram of the hot-smoking process for the three smoked anchovy products.

Filleted anchovy, salted (brined) and hot-smoked

For filleted, salted, and hot-smoked anchovy samples, the heads and guts of the anchovy samples were removed as shown in Figure 5.2. Anchovy samples were split into fillets and rinsed with tap water. The fillets were soaked for 15 minutes in a 12.5% sugar/ salt brine solution (1⁄4 cup; 62.5 ml) of salt and 1⁄4 cup (62.5 ml) of brown sugar per litre of water). The ratio of fillets to brine solution was 1:4. After 15 minutes, the fillets were dried at 60°C for 15 minutes. After drying, the fillets were smoked at 80°C for 20 minutes. Temperature and time were monitored throughout the smoking process.

(a) (b)

Figure 5.2. (a) Filleted, non-smoked anchovy and (b) filleted, hot-smoked anchovy.

Whole anchovy, salted (brined) and hot-smoked

For whole, salted, and hot-smoked anchovy samples, the heads of the anchovy samples were removed as shown in Figure 5.3. Anchovy samples were rinsed with tap water. The fillets were soaked for 20 hours in a 12.5% salt/sugar brine solution (1⁄4 cup; 62.5 ml) of salt and (1⁄4 cup; 62.5 ml) of brown sugar per litre of water. The ratio of fillets to brine solution was 1:4. After 20 hours, the fish samples were dried at 60°C for 15 minutes. After drying, the fish were smoked at 80°C for 20 minutes. Temperature and time were monitored throughout the smoking process.

(a) (b)

Figure 5.3. (a) Whole anchovy marinated in salt and sugar brine. (b) Whole hot-smoked anchovy samples after the brining step.

<u>*Hot-smoked anchovy, cured (salted and cured for four weeks)*</u>

Cured anchovy samples (Figure 5.4 a) were received from Afrofishing Pty Ltd. These samples were rinsed with clean water and dried at 60°C for 15 minutes. After drying, the samples were smoked at 80°C for 20 minutes (Figure 5.4 b). Temperature and time were monitored throughout the smoking process.

(a) (b)

Figure 5.4. (a) Samples of 4-week cured anchovy directly received from Afrofishing Pty Ltd., and (b) samples of hot-smoked, 4-week cured anchovy.

Marinated anchovy products

Two marinated products were prepared: i) raw anchovy fillets marinated in olive and sunflower oil (50/50) with garlic and parsley, and ii) raw anchovy fillets marinated in olive and vegetable oil (50/50) with garlic and parsley (Figure 5.5). For the marination process, 50 g of sea salt, 250 ml vinegar (acetic acid) and 150 ml water were used for every 1 kg of anchovy.

Filleted anchovy was rinsed with water and sprinkled with salt. The vinegar/water mixture was poured over the filleted anchovy samples and left to cure for 4–6 hours, depending on the size of the fillets. A vinaigrette was prepared with 50 ml white wine vinegar, 150 ml of extra virgin olive oil, four cloves of finely chopped garlic, three tablespoons of chopped parsley, and some cracked black pepper. The vinegar/water mixture drained and the anchovy fillets were rinsed (not soaked) with clean water and patted dry. Anchovy fillets were packed in a single layer, and the vinaigrette was poured over the fillets. Chopped parsley was sprinkled over the anchovy and were covered with clingwrap and refrigerated for 12 hours. The predicted shelf life was 3–4 weeks in the refrigerator.

(a)

(b)

Figure 5.5. Raw, eviscerated anchovy fillets: (a) in olive and sunflower oil (50/50) with garlic and parsley, and (b) marinated in olive and vegetable oil (50/50) with garlic and parsley.

Microbiological analyses

Testing for total viable counts (TVC) of microorganisms and coliform bacteria

Dilution series of up to 10^{-6} (1 000 000th dilution) were prepared for all the anchovy samples (both day 0 and day 7) using sterile Ringer's solution. TVCs of microorganisms were determined using plate count agar (PCA), and testing for Coliform was done using violet red bile agar (VRBA) media. The PCA and VRBA plates were prepared in triplicate for each dilution. TVC gives an indication of the total aerobic bacteria (both pathogens and spoilage organisms) present in the anchovy samples, while the VRBA counts give an indication of food safety by testing for coliform bacteria.

The number of colony-forming units (cfu) for all the dilutions were counted and multiplied by the dilution factor to calculate the total number of cfu cells per ml for each dilution. Results are expressed as colony-forming units per gram (cfu/g) of fish samples. Three plates per dilution were used to calculate the average cfu.

Proximate composition analyses

All proximate composition analyses were done in duplicate following Association of Official Analytical Chemists (AOAC) methods of analysis after which the average was calculated. Moisture was determined using AOAC Official Method 934.01 (2005) and ash was determined using AOAC Official Method 923.03 (2005). Protein was determined using AOAC Official Method 920.53 (2005).

Fatty acid analyses

Lipids were extracted from 2 g homogenised fish samples (as composite samples) with the use of a chloroform:methanol (1:2 v/v) solution. Heptadecanoic acid (C17:0) obtained from Sigma-Aldrich Inc. was used as an internal standard to quantify the individual fatty acids. A sub-sample of the extracted lipids was transmethylated for 2 hours at 70°C using a methanol/ sulphuric acid (19:1 v/v) solution as transmethylating agent. After cooling to room temperature, the resulting fatty acid methyl esters (FAMEs) were extracted with water and hexane. The top hexane phase was transferred to a spotting tube and dried under nitrogen. Analysis was done with the use of a Thermo Focus gas chromatograph (GC) equipped with a flame ionised detector using an SGE Australia BPX70 capillary column (60 m x 0.25 mm internal diameter, 0.25 µm film). The FAME mix was carefully prepared by weight. Each ampoule contained 10 $mg\cdot ml^{-1}$ of the FAME reference standard mixed in methylene chloride. Gas flow rates were 25 $ml\cdot min^{-1}$ for hydrogen and 2–4 $ml\cdot min^{-1}$ for the hydrogen carrier gas. The temperature programming was linear at 3.4$°C\cdot min^{-1}$, with an initial temperature of 140°C, a final temperature of 240°C, an injector temperature of 225°C, and a detector temperature of 300°C. The FAMEs were identified by comparing the retention times to those of a standard FAME mixture.[35]. Fatty acid concentrations are presented as percentages.

5.1.1.3 Materials and method for Objective 3

Anchovy samples were obtained from Afrofishing Pty Ltd. (Mossel Bay). Fish were covered in blue polyethylene bags and immediately frozen. The fish samples were kept frozen and transported to the Cape Peninsula University of Technology Department of Food Science and Technology laboratories where the samples were then stored in a freezer at -18˚C until subjected to processing, microbiological and chemical analysis. One batch of each of all four variations of hot-smoked anchovy products were produced (whole smoked in vacuum bags; filleted smoked in vacuum bags; whole smoked in sterile, aerobic bags; and filleted smoked in sterile aerobic bags) (Table 5.2). Microbiological quality (total TVC and coliforms) of the smoked whole and filleted samples was analysed during refrigerated (0–4ºC) shelf-life storage of 14 days. Microbial analyses were done on day 0, 1, 4, 7, 10 and day 14. The proximate composition (total moisture, ash, protein, and fat) of the smoked anchovy samples was determined on day 0, following AOAC official methods of analysis.

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[35] Sigma-Aldrich Supelco 37 Component FAME Mix, 10 $mg\cdot ml^{-1}$ in CH_2Cl_2, Catalogue Number 47885-U.

Table 5.2. Four variations of hot-smoked anchovy products refrigerated at 0–4ºC for 14 days

Treatments/anchovy products and packaging types
Control sample (raw anchovy, whole without head and tail
Hot-smoked whole anchovy without head and tail packaged in vacuum bags
Hot-smoked filleted anchovy without head and tail packaged in vacuum bags
Hot-smoked whole anchovy without head and tail packaged in sterile sample bags
Hot-smoked filleted anchovy without head and tail packaged in sterile sample bags

<u>Anchovy smoked products</u>

The smoked products consisted of (i) whole anchovy without head and tail brined for 90 minutes; and (ii) anchovy fillets brined for 15 minutes. Hot smoking commenced as outlined in Figure 5.1.

<u>Filleted anchovy, salted (brined) and hot-smoked</u>

The head and tail were removed before filleting the anchovy (Figure 5.6). Anchovy samples were split into fillets (flecked) and rinsed with tap water. The fillets were soaked for 15 minutes in a 12.5% salt/sugar brine solution (1⁄4 cup; 62.5 ml) of salt and (1⁄4 cup; 62.5 ml) of brown sugar per litre of water. The ratio of fillets and brine solution was 1:4. After 15 minutes, fish were dried at 65°C for 15 minutes. After drying, the fillets were smoked at 80°C for 20 minutes in a small smoker. The temperature and time were monitored throughout the smoking process.

(a) (b)

Figure 5.6. (a) Filleted, unsmoked anchovy and (b) filleted, hot-smoked anchovy.

<u>Whole anchovy, salted (brined) and hot-smoked</u>

For the whole hot-smoked anchovy samples, the head and tail of the anchovy samples were removed as shown in Figure 5.7. Anchovy samples were rinsed with tap water and then soaked for 90 minutes in a 12.5% salt/sugar brine solution (1⁄4 cup; 62.5ml) of salt and brown sugar (1⁄4 cup; 62.5ml) of per litre of water. The ratio of whole anchovy and brine solution was 1:4. After 20 hours, fish were dried at 65°C for 15 minutes. After drying, the whole anchovy was smoked at 80°C for 20 minutes. The temperature and time were monitored throughout the smoking process.

(a) (b)

Figure 5.7. (a) Whole unsmoked anchovy and (b) whole hot-smoked anchovy.

Microbiological analyses

Testing for the TVCs of microorganisms and coliform bacteria

Dilution series of up to 10^{-6} (1 000 000th dilution) were prepared for all the anchovy samples using sterile Ringer's solution. TVCs of microorganism were determined using PCA, and testing for coliforms was done using VRBA media. The PCA and VRBA plates were prepared in triplicate for each dilution. For all the dilutions, plates with a cfu number between 25 and 250 were counted and multiplied by the dilution factor to calculate the total number of cells (cfu) per ml for each dilution. Three plates per dilution were used to calculate the average cfu. The TVC gives an indication of the total aerobic bacteria (both pathogens and spoilage organisms) present in the anchovy samples, while the VRBA counts give an indication of food safety in terms of coliform bacteria.

Proximate composition

All proximate analyses were determined in triplicate and the average value was calculated as a percentage. Moisture was determined using AOAC Official Method 934.01 (2005) and ash was determined using AOAC Official Method 923.03 (2005). Protein was determined using the Kjeldahl method (AOAC Official Method 920.53 (2005)). Fat was determined using AOAC Official Method 920.53 (2005). Carbohydrates were calculated by difference (subtraction).

5.1.1.4 Materials and methods for Objective 4

Sample preparations

Samples of frozen anchovy were received from Mossel Bay during November 2025 and were smoked during November/December 2025. The following types of anchovy products were prepared (Figure 5.8).

- Three batches of hot-smoked whole anchovy without head.
- Three batches of hot-smoked anchovy fillets.
- Three batches of hot-smoked whole anchovy with head.

Samples were vacuum packaged and stored at -18ºC until analysed.

Figure 5.8. Demonstration of the smoking process, followed by vacuum packaging of samples for chemical analyses.

Fatty acid analyses

Fatty acid composition was done at the Central Analytical Facilities (CAF) at Stellenbosch University. Lipids were extracted from 2 g homogenised fish samples with the use of a chloroform/ methanol (1:2 v/v) solution. Heptadecanoic acid (C17:0) obtained from Sigma-Aldrich was used as an internal standard to quantify the individual fatty acids. Analysis was done with the use of a Thermo Focus gas chromatograph equipped with a flame ionised detector using an SGE Australia BPX70 capillary column (60 m x 0.25 mm internal diameter, 0.25 µm film). The FAMEs were identified by comparing the retention times to those of a standard FAME mixture. Fatty acid concentrations are presented at percentages.

Amino acid composition

The analyses were done at CAF, Stellenbosch University.

Major and trace elements (mineral content and heavy metals)

Analytical work was conducted at the ICP-MS[36] & XRF[37] Unit of CAF. The trace elements Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Sb, Hg and Pb were analysed on an Agilent 7900 quadrupole ICP-MS instrument equipped with a High Matrix Introduction and a 4th generation Octopole Reaction System to remove polyatomic interferences from the analytes of interest. All analytes were measured in He collision mode, while H_2 reaction gas was used for Se. The elements Na, Mg, K, Ca, and P were analysed on a Thermo ICAP 6200 ICP-AES instrument with Charge Injection Device solid state detector.

5.1.1.5 Materials and methods for Objective 5

Sample preparations

Frozen, whole anchovy were received from the Department of Forestry, Fisheries and the Environment. The fish were kept frozen at -18ºC until processed and analysed. Fish were randomly assisted to four groups of treatment: whole vacuum packaged, whole aerobic packaged, filleted vacuum packaged, and filleted aerobic packaged. The anchovy was thawed, the head, viscera, and bones were removed, and the fish were filleted. The fillets were then packaged in two conditions: vacuum packaging (VP) and aerobic packaging (AP). Each package contained three to five fillets that were randomly selected to avoid sampling bias, and this represented one composite sample. Each type of treatment contained three replicates for analyses.

The packaged samples were kept frozen at -18ºC for nine months before microbial analysis commenced. Before every experimental run, a standardised thawing method was used to prepare samples to be used in the microbial enumeration. In particular, samples were removed from frozen storage and placed into refrigeration (4˚C) around 24 hours preceding testing to allow gradual thawing under controlled conditions. This is in accordance with international processing standards for fishery products which suggest chilling using refrigeration to avoid growth of microbes and maintain the integrity of the sample (ISO, 2024; ICMSF, 2002).

Microbiological analysis

Standard plate count was used to assess microbiological quality of the anchovy samples. A 1:10 initial dilution was prepared by placing 10 g of fish sample into 90 ml of sterile peptone water. Tenfold dilutions were subsequently made to a final dilution of 10^{-6}. Total viable counts were determined by PCA. Each dilution was pour-plated onto duplicate plates of PCA and incubated at 37˚C for 48 hours. Colonies on the plates were manually counted and the results tabulated as colony-forming units per gram of fish. VRBA was used to enumerate colonies of coliforms. Each dilution (1ml) was plated in duplicates and incubated at 37˚C for 48 hours. Coliform colonies were tabulated as cfu/g. To establish whether the coliforms found on the VRBA plate from both the aerobic and vacuum sample were Gram-negative, colonies from the VRBA plates were stained using to the Gram's staining method. The slides were then observed under the microscope to determine whether they were Gram-positive or Gram-negative. Gram-negative colonies were isolated using streak plate methods for an Analytical

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[36] Inductively coupled plasma mass spectrometry.

[37] X-ray fluorescence.

Profile Index (API) test using API strips and applying the manufacturer's instructions. For the API test, a bacterial suspension was made by using a sterile loop to remove bacteria from an isolated colony from each of the three incubated petri dishes into a tube containing 5 ml ringer's buffer solution. The tube containing the suspension was then vortexed. API strips were inoculated with the suspension. The strips were covered and placed in the incubator for 24 hours. After the incubation period ended, the strips were observed and identified and interpreted with the help of the API 20E booklet.

5.1.1.6 Materials and methods for Objective 6

Students developed various convenience meal recipes incorporating anchovy to test consumer acceptance. The anchovy was kept whole and frozen until used for the recipe development. Frozen anchovy was thawed at refrigerated temperatures before being cleaned (heads, tails and guts removed). The meals were evaluated using a 9-point hedonic scale for attributes such as taste, texture, aroma, appearance, and overall acceptability. Students were asked to taste the dishes and score the overall taste and acceptability.

5.1.2 Results and discussion

5.1.2.1 Results for Objective 1

<u>Anchovy products that could be suitable for the South African market</u>

Based on work done by other researchers, the following products have potential in the South African market.

1. Smoked anchovy sausages (Baltaci et al., 2020). This product has potential in South Africa since sausage (and boerewors, a specific type of South African sausage) is a common and familiar product in South Africa. Sausage is preserved with salt and vinegar and packed in sausage casing. Therefore, developing a sausage from anchovy will need to investigate some of these aspects.
2. Hot-smoked anchovy/ anchovy fillets (in oil) (Laso et al., 2017). This type of product has potential in South Africa because of its longer shelf-life potential and versatility as ingredient in meals.
3. Hot-smoked anchovy fillets in liquid smoke flavouring (Çakir & Ayvaz, 2020). Fillets are common in South Africa, especially in the restaurant sector. Also, imported anchovy was common until a few years ago. Although filleting of anchovy is laborious since it is a small fish, the research team would like to investigate this product. The labour-intensity means that this type of product has job creation potential.
4. Cold smoked anchovy. This type of product typically requires longer brining times, and longer smoking times, but at lower temperatures. Hot-smoked products are typically easier to prepare in a shorter time and with better shelf-life potential without refrigeration (Nandari et al., 2020).
5. Smoked anchovy nuggets (Alcicek & Atar, 2011).

Numbers 4 and 5 on the list above are products that could potentially be like bokkom[38] bites (Figure 5.9), which is already a familiar product within communities living along the West Coast of South Africa. Bokkoms are made from harders (i.e., mullet, *Chelon richardsonii*, also called a harder mullet). A specific artisanal fishing community of women in St Helena Bay sell bokkom biltong (Figure 5.9). There is potential to prepare anchovy in a similar manner to produce anchovy bites. However, product development will be required to determine the correct salt concentration and drying

[38] Salted and air dried harder.

time to produce a product of acceptable water activity, food safety, shelf-life, and consumer acceptance.

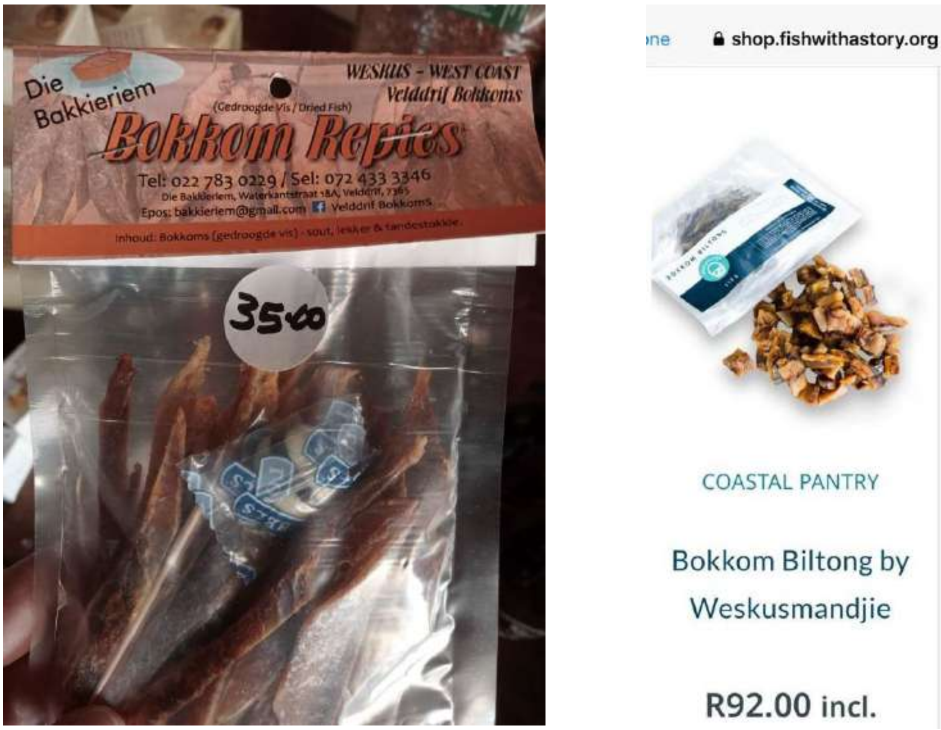

Figure 5.9. Examples of bokkom bites. Small fishing communities prepare bokkom bites by salting and drying mullet (*Chelon richardsonii*).

Anchovy products that could be suitable for the growing African market

In most of Africa, the utilisation of small processed fish forms a major part of the edible fish product supply (Summance, 2021; FAO 2020; Kolding et al., 2019; Mussa et al., 2017). Real Fishing (a collaborating company on this project) has been exporting increasing amounts of anchovy to several African countries, mostly in frozen form (personal communication, Redah de Maine, Gqeberha, 22 August 2023). The increase in the utilisation of anchovy is influenced by the fact that people in most African countries are already used to eating whole small fish in various forms (Summance et al., 2021). The decline in fish production against growing populations in most southern African countries provides a potential export market for anchovy. In this context, anchovy exports are contributing towards nutrition and food security through stability of food supply (physical access); supply of diverse healthy food, lower food prices (affordability); and increased income (through related livelihoods). Thus, increased utilisation of anchovy will have the impact of boosting supply, availability and lowering prices of healthy foods through competition in importing countries. Recent years have seen growing numbers of migrants from other SADC countries into South Africa for employment opportunities and as refugees. This has resulted in a growing market for imported food from migrants' countries of origin. Increasing volumes of processed fish products of different varieties and species from various African countries are being imported into South Africa, targeting the migrant community (Jimu, 2018; Ndofor Epo, 2018). These come mainly in the form of sun-dried, smoke-dried, salted-dried products from kapenta, usipa and catfish from Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Imported processed fish products are sold on the street, at markets and in shops in South African cities that specialise in imported food from African countries (Jimu, 2018; Ndofor Epo, 2018; Mussa et al., 2017). Thus, a market for small processed fish already exists in most of Africa, and within South Africa, one group of potential consumers to target are foreign nationals living in South Africa who are already used to eating small processed fish.

5.1.2.2 Results for Objective 2

<u>Microbial results for hot-smoked anchovy and marinated anchovy product types</u>

Tables 5.3 and 5.4 summarise the results for the microbial analysis (TVC and coliforms, respectively) for the smoked and marinated anchovy samples at day 0 and day 7, respectively. As expected, the bacterial load (both TVC and coliforms) for the raw samples were higher at both day 0 and day 7, compared to the smoked samples. The 4-week cured and hot-smoked samples also showed high bacterial load. These samples also had a noticeable rancid smell and taste.

The effects of brining and hot smoking on the microbial load over a refrigerated period of 7 days are evident for the whole and filleted samples as the bacterial load decreased from day 0 to day 7. The marinated samples had a relatively high count of coliforms on day 7, indicating the importance of hygiene and evisceration, and the limited shelf-life of these types of products.

Table 5.3. Results for microbial TVC of six anchovy samples on day 0 (i.e., directly after processing) and day 7

Sample	**#Colony forming units (cfu) per ml per dilution**					
	10^{-1}	**10^{-2}**	**10^{-3}**	**10^{-1}**	**10^{-2}**	**10^{-3}**
	Day 0			**Day 7**		
Control sample (raw anchovy)	TNTC*	192	34	TNTC*	NG**	NG
Whole anchovy (salted and hot-smoked)	50	11	NG	TNTC*	NG**	NG
Filleted anchovy (salted and hot-smoked)	TNTC	2	NG	TNTC	NG	NG
Anchovy (marinated in olive & sunflower oil)				2	NG	NG
Anchovy (marinated in olive & vegetable oil)				1	NG	NG
Hot-smoked (salted and cured for 4 weeks)	112	13	NG	TNTC	1	NG

**TNTC = Too numerous to count*

***NG = No growth*

#*Average of three plates per dilution factor*

Table 5.4. Results for microbial coliforms analysis of six anchovy samples plated on VRBA media for day 0 and day 7

Sample	#Colony forming units (cfu) per ml per dilution					
	10^{-1}	10^{-2}	10^{-3}	10^{-1}	10^{-2}	10^{-3}
	Day 0			**Day 7**		
Control Sample (raw anchovy)	TNTC	TNTC	100	TNTC	NG	NG
Whole anchovy (salted and hot-smoked)	TNTC	57	31	TNTC	15	NG
Filleted anchovy (salted and hot-smoked)	TNTC	25	NG	TNTC	4	NG
Anchovy (marinated in olive & sunflower oil)				TNTC	58	3
Anchovy (Marinated in olive & vegetable oil)				TNTC	65	NG
Hot-smoked (salted and cured for 4 weeks)	TNTC	TNTC	TNTC	TNTC	TNTC	NG

**TNTC = Too numerous to count*

***NG = No growth*

#Average of three plates per dilution factor

Proximate composition results

As expected, smoking reduced the moisture content and increased the protein and ash content of smoked anchovy samples (Table 5.5). The 4-week, hot-smoked samples had the highest ash content due to the long period of curing in salt (i.e., increasing the sodium/mineral content of the fish product). The protein content of the 4-week, hot-smoked samples was higher compared to the brined and hot-smoked samples due to the lower moisture content of these samples. The 4-week curing process greatly reduces the moisture content of cured fish products. It is difficult to compare the percentage of protein between the whole and filleted, brined, and hot-smoked samples without the total (crude) fat content per sample (this was not determined for this trial). One would expect the total percentage protein for the whole and filleted, brined, and hot-smoked samples to be similar, since the moisture and ash percentages are very similar.

Table 5.5. Proximate composition of smoked anchovy samples as a function of hot smoking

Sample	Proximate component		
	% protein	% moisture	% ash
Control sample (raw anchovy)	ND	79.44	1.10
Whole anchovy (salted and hot-smoked)	15.38	54.63	8.92
Filleted anchovy (salted and hot-smoked)	23.73	56.53	7.06
Hot-smoked (salted and cured for 4 weeks)	36.11	39.34	24.03

Proximate composition of the oil marinated samples was not determined.

Total fat was not determined.

ND = Not determined

Fatty acid results

As expected, raw anchovy has a relatively high docosahexaenoic acid (DHA, C22:6n-3) content. The fatty acid composition of the brined, and hot-smoked samples was observably different from the oil-marinated samples (Table 5.6). This can be explained by the difference in FA composition between fish on the one hand and olive and vegetable oil on the other. The 4-week cured hot-smoked samples showed a difference in FA content compared to the other samples. The 4-week cured hot-smoked samples showed a reduction in total saturated fatty acids (SFA), and an increase in polyunsaturated fatty acids (PUFA). It was also interesting to notice the increase in EPA and DHA for these samples. This might explain the higher level of rancidity observed in these samples.

Stearic acid (C18:0) may slightly lower LDL[39] (unhealthy) cholesterol or has a neutral effect on human cardiovascular health. As such, it may be healthier than many other saturated fatty acids. Research shows that the human body partly converts stearic acid to oleic acid, a healthy unsaturated fat. Curing of anchovy fish for 4 weeks, followed by hot smoking, reduced the percentage of stearic acid compared to raw and whole hot-smoked (only brined) anchovy samples (Table 5.6).

The high monounsaturated fatty acids (MUFA) and PUFA content of the oil-marinated samples are due to the addition of the olive and/or vegetable oil.

[39] Low-density lipoprotein cholesterol.

Table 5.6. Fatty acid composition (%) of the five variations of anchovy products (smoked and oil-marinated) on day 7 of refrigerated storage

Fatty acid (FA) (%)	Control Sample (raw anchovy)	Whole anchovy (salted and hot-smoked)	Filleted anchovy (salted and hot-smoked)	Anchovy (Marinated in olive & sunflower oil)	Anchovy (Marinated in olive & vegetable oil)	Hot-smoked (salted and cured for 4 weeks)
Saturated fatty acids (SFA) %						
C8:0 Octanoic acid	7.53	ND	9.22	1.17	1.41	4.64
C10:0 Decanoic acid	0.99	ND	1.02	0.10	0.15	0.63
C11:0 Undecanoic acid	12.93	ND	13.51	1.44	2.08	8.65
C12:0 Dodecanoic acid	1.47	ND	0.94	0.04	0.17	0.76
C13:0 Tridecanoic acid	13.61	ND	13.13	1.43	2.05	9.21
C14:0 1.62Myristic	2.89	ND	2.26	0.21	0.15	4.59
C15:0 Pentadecylic	11.03	ND	10.49	1.11	1.62	7.51
C16:0 Palmitic acid	13.37 Similar to olive oil	ND	18.17	12.00 Olive oil range 9–12% Fregapane et al. (2010); Amaral et al. (2010)	12.18	17.31
C18:0 Stearic acid	7.06	ND	8.20	3.16 Olive oils range between 2 and 5% Amaral et al. (2010)	3.51	6.25
C20:0 Arachidic	0.71	ND	0.42	2.87	2.62	0.79
C22:0 Behenic	0.00	ND	0.00	0.20	0.22	0.00
C24:0 Lignoceric	0.19	ND	0.20	0.07	0.08	0.37
Total SFA	64.26		68.35	22.63	24.82	55.79
Monounsaturated fatty acids (MUFA)						

Fatty acid (FA) (%)	Control Sample (raw anchovy)	Whole anchovy (salted and hot-smoked)	Filleted anchovy (salted and hot-smoked)	Anchovy (Marinated in olive & sunflower oil)	Anchovy (Marinated in olive & vegetable oil)	Hot-smoked (salted and cured for 4 weeks)
C14:1 Myristoleic	0.84	ND	0.35	0.05	0.07	0.32
C15:1 cis-10-Pentadecanoic acid	0.44	ND	0.00	0.00	0.00	0.10
C16:1 Palmitoleic	4.71	ND	1.23	0.80	0.79	4.12
C18:1n-9(t) Elaidic	0.89	ND	1.64	0.00	1.65	0.31
C18:1n-9(cis) Oleic acid	0.96	ND	1.04	48.30 Olive oil is high in this FA acid	45.76	2.76
C18:1n-7	1.87	ND	0.61	0.10	0.00	1.90
C20:1	1.29	ND	0.00	0.19	0.25	0.09
C22:1n-9	0.15	ND	0.00	0.00	0.00	0.44
C24:1	0.58	ND	0.21	0.00	0.00	0.17
Total MUFA	11.20		4.97	49.43 Range between 42 and 83% Amaral et al. (2010)	48.46	9.99
Polyunsaturated fatty acids (PUFA)						
C18:2n-6 Linoleic acid	5.67	ND	5.24	25.70 Olive oils range between 3 and 5% Amaral et al. (2010)	23.87	3.86
C18:3n-6 g-Linolenic	0.00	ND	0.00	0.12	0.12	0.00
C20:2	2.96	ND	2.93	0.28	0.45	1.98

Fatty acid (FA) (%)	Control Sample (raw anchovy)	Whole anchovy (salted and hot-smoked)	Filleted anchovy (salted and hot-smoked)	Anchovy (Marinated in olive & sunflower oil)	Anchovy (Marinated in olive & vegetable oil)	Hot-smoked (salted and cured for 4 weeks)
C20:3n-6	0.35	ND	0.31	0.00	0.00	0.16
C22:4n-6	0.17	ND	0.00	0.00	0.00	0.45
C22:5n-6	0.28	ND	0.27	0.00	0.00	0.90
C20:3n-3	0.22	ND	0.45	0.00	0.00	0.84
C20:5n-3 EPA eicosapentaenoic	1.04	ND	1.47	0.07	0.07	3.19
C22:6n-3 DHA docosahexaenoic	6.07	ND	6.66	0.57	0.69	17.80
Total PUFA	16.49		17.35	26.75	25.25	29.18
Total n-3	7.32	ND	8.58	0.64	0.81	21.83
Total n-6	9.17	ND	8.76	26.11	24.44	7.35
N6/N3 ratio	1.31	ND	1.50	52.92	36.63	0.34

ND = Not determined

Data is from one set of samples.

5.1.2.3 Results for Objective 3

Microbial results

As expected, the total number of organisms increased from day 1 to day 7 for all four product types and both packaging types (vacuum vs. non-vacuum) (Table 5.7) in refrigerated storage. Results in Tables 5.7 and 5.8 indicate that the total number of organisms (TVC and coliforms were more than 1 million cells/ml (2.44×10^6 and 4.60×10^6 cfu/ml, respectively) at day 7 of refrigerated storage for the whole smoked anchovy stored in vacuum bags. On day 4, the counts were more than 1 000 per ml.

According to Regulation 692[40] (Amendment 5 May 2000): Regulations governing microbiological standards for foodstuffs and related matters in the Foodstuffs, Cosmetics and Disinfectants Act (1972, Act No. 54) cooked fish should not contain more than 100 000 cfu per gram (i.e., 1×10^5 cfm/ml). Filleted smoked anchovy, in overall, showed lower total number of organisms during refrigerated storage in both vacuum and non-vacuum sealed packaging, as compared to whole smoked anchovy. Smoked fillets showed a lower cfu/ml count at day 4, compared to the whole samples. Whole, hot-smoked samples in aerobic (non-vacuum) packaging had TVC (1.23×10^5 cfu/ml) just above the government recommended value of less than 1×10^5 cfu/ml, making these samples unsuitable for human consumption at 4 days of refrigerated storage.

For the coliform counts (i.e., representing Enterobacteriaceae), the whole, hot-smoked samples showed higher values compared to the filleted samples (Table 5.8). These higher counts were for both vacuum and non-vacuumed samples. According to Regulation 692, cooked fish should not contain more than 1 000 cfu/100g (10 cfu/g) of tested sample. In this study, the coliform counts for all samples were more than 1 000 cfu/g, indicating a high level of coliform contamination on days 4 and 7. This may be attributed to the quality of the raw fish samples, where many of the samples were damaged due to improper handling during harvesting activities. In the case of the whole samples, the high coliform count could be attributed to the gut not being removed from the samples before the brining and smoking processing steps.

Table 5.7. Results (cfu/g) for the #average TVC for four anchovy products and two packaging combinations at days 0 (i.e., directly after processing) 1, 4, and 7 during refrigerated storage (0–4ºC)

Shelf-life day	Smoked fillet vacuum	Smoked fillet non-vacuum	Smoked whole vacuum	Smoked whole non-vacuum
Day 0	*NG	NG	NG	NG
Day 1	NG	NG	NG	NG
Day 4	7.00×10^3	1.14×10^4	1.75×10^4	1.23×10^5
Day 7	1.03×10^4	1.15×10^4	2.44×10^6	9.00×10^3

**NG = No growth*

#Average of three plates per dilution factor

[40] Regulations governing microbiological standards for foodstuffs and related matters under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972).

Table 5.8. Results (cfu/g) for the #average Coliforms counts of four anchovy product samples during shelf-life storage from day 0 (i.e., directly after processing) day 1, 4, and 7 at refrigerated storage (0–4ºC) for vacuum and non-vacuum packaging, respectively

Shelf-life day	Smoked fillet vacuum	Smoked fillet non-vacuum	Smoked whole vacuum	Smoked whole non-vacuum
Day 0	*NG	NG	NG	NG
Day 1	NG	NG	NG	NG
Day 4	6.90×10^3	1.80×10^4	2.74×10^4	1.53×10^5
Day 7	9.50×10^3	9.60×10^3	4.60×10^6	1.02×10^4

**NG = No growth*

#Average of three plates per dilution factor

Proximate composition results

The average (of three replicate analyses, not three batches) proximate composition of smoked fillets, smoked whole anchovy, and raw whole anchovy, are summarised in Table 5.9. The smoking process reduced the moisture content, while concentrating the protein and ash in both the fillets and whole smoked samples. The smoking process did not have a large effect on the fat content of the anchovy. Smoked fillets shoved a lower fat content (2.22% ± 0.96) compared to the smoked and raw whole anchovy.

The whole hot-smoked samples showed a high ash content (8.92% ± 0.44). This could possibly be assigned to the gut still part of the sample. Smoked fillets and whole samples had higher ash contents compared to raw samples. This can be attributed to the presence of salt (NaCl) from the brining step in the smoking process.

Table 5.9. Average (± standard deviation) for proximate composition (% moisture, fat, protein, ash, and carbohydrates) of smoked fillets, smoked whole anchovy, and raw whole (without head and gut) anchovy

Sample	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrates (%)
Smoked fillets	49.27 ± 0.11	2.22 ± 0.96	42.33 ± 0.54	5.67 ± 0.49	0.78 ± 0.78
Smoked whole	56.03 ± 0.82	2.84 ± 1.28	35.40 ± 0.63	8.92 ± 0.44	ND
Raw whole	70.95 ± 1.04	2.89 ± 0.74	18.11 ± 0.04	2.71 ± 0.12	5.33 ± 1.94

ND = not detected

5.1.2.4 Results for Objective 4

For a more comprehensive discussion about the data for Objective 4, the researchers are in the process of writing a manuscript of publication in a scientific journal.

Fatty acid composition

In summary (Figure 5.10), palmitic acid (C:16) was highest in concentration (between 16 and 24 mg/g) for raw and smoked samples, with no significant difference between the three types of hot-smoked anchovy products (whole with heat, whole without head, and fillets). This is followed by myristic acid (C14, between 5 and 9 mg/g) and palmitoleic acid (C16:1, between 6 and 10 mg/g). EPA (C20:5n3) and DHA (C22:6n3) ranged from 1 to 13 mg/g. The following fatty acids range from 2 to 5 mg/g: stearic acid (C18), C18:1-cis, and C20:1. The other fatty acids ranged below 1 mg/g. Except for C24, where hot-smoked fillets were significantly lower (0.13 ± 0.01 mg/g) than whole fish without the head (0.16 ± 0.01 mg/g), but not from whole with head (0.26 ± 0.04 mg/g), there were no significant differences in fatty acid content between the three hot-smoked types of anchovy products.

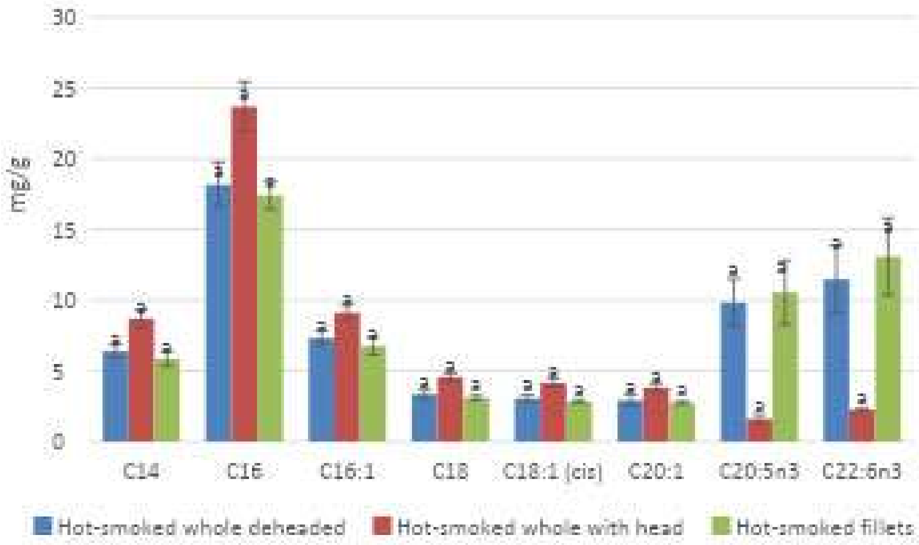

Figure 5.10. Major fatty acid (mean ± standard deviations, mg/g) content for hot-smoked whole (with and without head, i.e., de-headed), and hot-smoked filleted anchovy. [a]Values with a different superscript are significantly different (P<0.05).

Amino acid composition

In summary, for raw (whole, de-headed) and smoked anchovy (with head, without head, and fillets) the amino acids ranged from 10 to 70 mg/g for alanine, glycine, valine, leucine, iso-leucine, proline, methionine, serine, threonine, phenylalanine, aspartic acid, glutamic acid, lysine, histidine, and tyrosine. The amino acids cysteine and cystine ranged from 2 to 7 mg/g for hot-smoked fillets, whole without head, and whole anchovy with head attached (Figure 5.11), with no significant (P>0.05) difference between the three types of anchovy products. For several of the amino acids (alanine, glycine, proline, serine, and tyrosine), there were significant differences (P<0.05) between hot-smoked anchovy with the head and those samples without the head, whole not statistically different from the hot-smoked fillets.

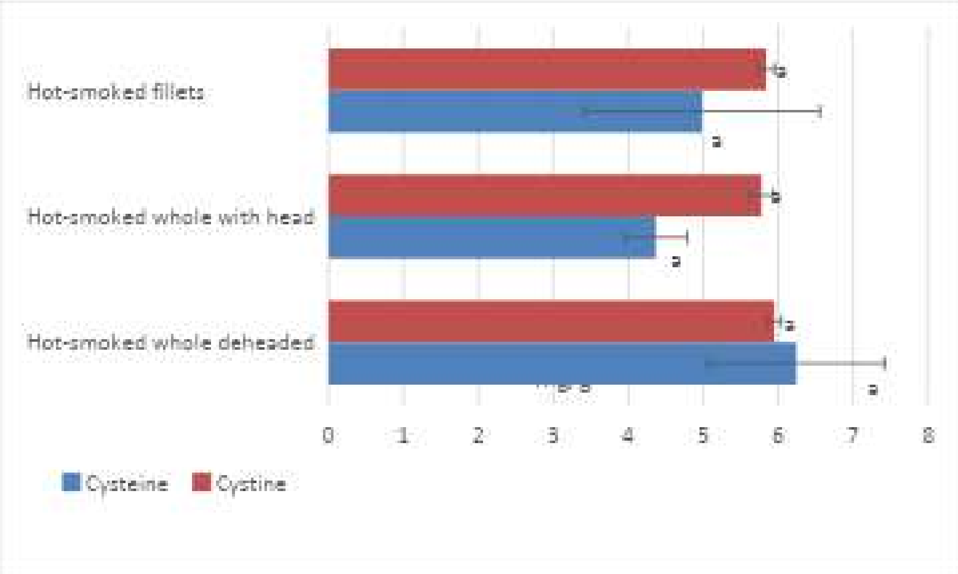

Figure 5.11. Cystine and cysteine (mean ± standard deviations, mg/g) content for hot-smoked whole (with and without head), and hot-smoked filleted anchovy. [a]Values with a different superscript are significantly different ($P<0.05$).

Mineral and heavy metals content

For the minerals Ca, K, P, Mg, Na, (Figure 5.12), K, P and Ca showed significant differences between the three types of hot-smoked products (fillets vs. whole without head vs. whole with head intact on dry weight basis).

In terms of heavy metals, regulation 588[41] regulates maximum levels of metals in foodstuffs. In summary for the smoked anchovy products, on a dry weight basis (mg/kg), cadmium (Cd), mercury (Hg), and lead (Pb) were below the regulatory limits.

Arsenic (As) was above 3 000 µg/kg on dry weight basis. Arsenic ranged from 5 000 to 8 000 µg/kg for raw, whole smoked (with and without head), and smoked fillets. Note that the method used to quantify arsenic did not distinguish between inorganic (iAs) and organic arsenic, thus giving indication of total arsenic.

[41] Regulation 588, 15 June 2018, made under the Foodstuffs, Cosmetics and Disinfectants Act (Act 54 of 1972).

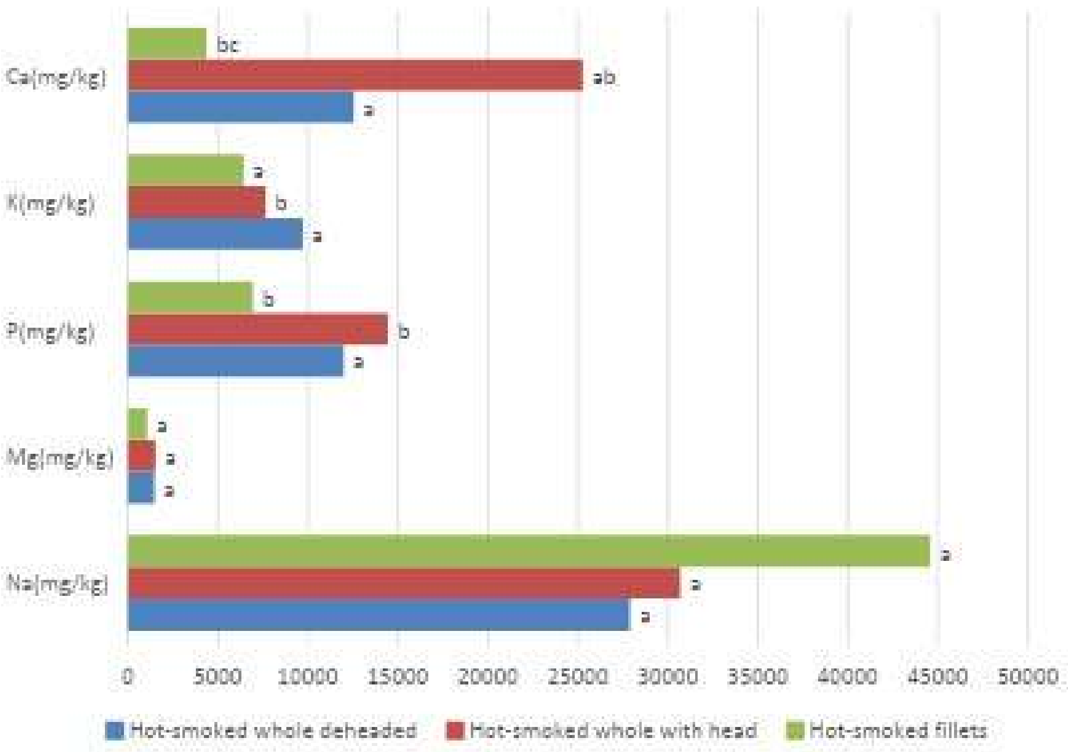

Figure 5.12. Mineral content (mean mg/kg on dry weight basis) for hot-smoked whole (with and without head), and hot-smoked filleted anchovy. [abc]Values with a different superscript are significantly different ($P<0.05$).

5.1.2.5 Results for Objective 5

<u>Total plate count (TVC)</u>

The effects of packaging type on TVCs were evaluated for aerobic and vacuum packaged storage whole frozen anchovy. The results are presented in Table 5.10. It was found that aerobic packaged anchovy had higher $\log_{10}$ cfu/ml, but it was not significantly higher (P>0.05) in comparison to the vacuum packaged samples. This was to be expected since exposure to oxygen favours the growth of aerobic spoilage microorganisms, such as *Pseudomonas* and *Shewanella* species (Salem et al., 2018). Using SPSS,[42] both the one-way analysis of variance (ANOVA) and student T-test showed that there was no significant difference (P=0.779) in the TVC counts between the aerobic and vacuum packaged whole frozen anchovy samples.

[42] Statistical Product and Service Solutions software.

Table 5.10. Total viable counts (Log_{10} cfu/g) for aerobic and vacuum packaged whole anchovy samples as means ± standard deviation

Packaging type	Total viable count (Log_{10} cfu/g)	N	P-value
Aerobic	4.15 ± 0.68^a	4	0.779
Vacuum	4.01 ± 0.62^a	4	

[a]Values within a row with different superscripts are significantly different (P<0.05)

For the filleted samples, the log_{10} cfu/g data (Table 5.11) indicated that TVC and coliform counts were similar across treatments (P>0.05).

Table 5.11. Mean ± standard deviation of total viable counts (TVC) (log_{10} cfu/g) for vacuum packaging (VP) and aerobic packaging (AP) filleted frozen anchovy samples

Parameter	Treatment	n	Mean ± SD log_{10} cfu/g	DF	P-value
PCA	VP	3	4.12 ± 0.03	4	0.512
	AP	3	4.01 ± 0.26		

n = number of independent trials per treatment; df = degrees of freedom; p-value indicates the probability that differences between treatments occurred by chance (P>0.05 is considered not significant).

Values are presented as mean ± standard deviation. Independent t-tests were performed to assess statistical differences; no significant differences were observed between packaging types.

Coliform count and API results

The results of the coliform counts (cfu/g) for the whole anchovy samples are presented in Table 5.12. The data shown in the table are below the international standard of 25–250 cfu to demonstrate results of the coliform count. Most of the dilutions exhibited fell outside this standard, i.e., no growth. The coliform counts were therefore not statistically analysed using SPSS. Qualitative assessment indicated generally low levels of coliform across both package treatments, with no discernible pattern identified that would suggest any noteworthy impact of packaging type on coliform growth under the conditions investigated in the study.

Table 5.12. Coliform counts per plate and means values (cfu/g) for whole anchovy samples stored under aerobic and vacuum packaging at frozen (–18ºC) conditions

Packaging type	Trial	Dilution	Plate 1	Plate 2	Mean cfu/g
Aerobic	1	10^{-1}	15	7	11
	2	10^{-1}	6	2	4
	3	10^{-1}	1	1	1
	4	10^{-1}	G-w/yellow	G-w/yellow	-
Vacuum	1	10^{-2}	NG	2	2
	2	10^{-1}	6	7	6.5
	3	10^{-1}	G-w/yellow	G-w/yellow	-
	4	10^{-1}	3	16	9.5

G-w/yellow indicates there were no countable colonies, but the media had a yellow colour.

For the filleted samples, there was also no significant difference in coliform counts (Table 5.13) between the vacuum and aerobic packaged samples.

Table 5.13. Mean ± standard deviation of coliforms ($\log_{10}$ cfu/g) for vacuum packaging (VP) and aerobic packaging (AP) filleted frozen anchovy samples

Parameter	Treatment	N	Mean ± SD	DF	P-value
Coliforms	VP	3	3.14 ± 0.5	4	0.294
	AP	3	2.75 ± 0.26		

n = number of independent trials per treatment; t = t-test statistic; df = degrees of freedom; p-value indicates the probability that differences between treatments occurred by chance (P>0.05 considered not significant).

Values are presented as mean ± standard deviation. Independent t-tests were performed to assess statistical differences; no significant differences were observed between packaging types. The very slightly higher numbers among the whole and filleted vacuum packaged samples indicate that although vacuum packaging decreases the availability of oxygen, it can produce conditions conducive to the survival of some facultative anaerobes, including *Enterobacter* species.

Once the incubation period of the API strips ended, they were observed for colour changes. After consulting the API booklet, it was found that the colony extracted from the aerobic packaged whole anchovy sample contained *Serrata plymuthica*, whereas the vacuum whole sample contained *Enterobacter amnigenus*. These results were in line with previous studies reporting low coliforms numbers in frozen fish due to low water activity and nutrient availability. This suggests that both storage methods were found to be effective in inhibiting coliform proliferation. However, vacuum packaging did not fully limit coliform growth.

Microbiological testing of the raw whole anchovy confirms compliance with the most stringent requirements of R.692, governing microbiological standards for foodstuffs for TVC and absence of *E. coli*. The TVC of both the aerobic and vacuum packaging were confirmed to be below the legal limit of 10^6 cfu/g TVC for uncooked fish and is an acceptable overall microbial load. Furthermore, it was concluded that *E. coli* was not present in the samples. Therefore, the regulatory requirement of "Presumptive *Escherichia coli* shall not be found in 10 grams" (Reg. 6(2)(e)) was met. Based on the TVC parameters measured and the established lack of *E. coli*, the product was within specification.

The API results for the filleted anchovy showed that the isolated colonies from the VRBA plates were found to be *Serratia fonticola* or *Klebsiella pneumoniae* for the AP samples, and *Klebsiella oxytoca* for the VP samples. These organisms are facultative anaerobic species, as they can survive in both the presence and absence of oxygen, hence their existence in both the types of packaging. The results of microbial identification served as important information on the types of bacteria that remained following prolonged freezing as well as brief examination of the filleted South African anchovy (*Engraulis encrasicolus*). The suspected isolates, *Serratia fonticola*, *Klebsiella pneumoniae*, and *Klebsiella oxytoca* are all Gram-negative, rod-shaped organisms that are facultative anaerobes (i.e., able to grow in the presence and absence of oxygen). *Klebsiella oxytoca* is a ubiquitous species of water and soil and has recently been detected in aquatic organisms, such as fish, presumably due to the high environmental adaptability and the wide range of metabolic functions (Ni et al., 2021). The members of *Klebsiella* are usually mucoid colonies due to the polysaccharide capsule that makes them resistant to the drying and stress factors (e.g., freezing) (Cortes-Sanchez et al., 2025). *Serratia* species are also haploithiobacilli, commonly found isolated in water, soil and fish surfaces; *S. fonticola* has been regarded as a food spoiling bacterium as well as an infrequent opportunistic pathogen (*Serratia fonticola*). Since these bacteria occur naturally in the water, it is possible that they were colonised by the fish in its natural habitat or in the water applied in processing. These are not normally aggressive and harmful spoilage bacteria, but they may be found in some of the niches of fish. *Enterobacteriaceae* (*Klebsiella* and *Serratia*) are frequently higher in the gastrointestinal tract, skin mucous and surfaces in direct water contact (i.e., gills) of fish. In a study of freshwater fish, *Klebsiella* spp. and other *Enterobacteriaceae* were detected in the intestinal contents more than in the muscle tissue (Rawash et al., 2019). These bacteria can be introduced into muscle tissue (the fillets) during filleting and handling by gut contents, surface mucus or processing water. When in the fillet, they may grow slowly in low temperature (particularly under frozen conditions), but can produce extracellular enzymes (proteases, lipases) or slime which slowly degrades fish tissue and adds to softening, mucous, or a gravy-like exudate. *Serratia* is especially a recognised spoiler in fish (e.g., *S. fonticola* in Atlantic horse mackerel) with a tendency to produce proteolytic enzymes. Meanwhile, biofilm or slime is also produced by *Klebsiella* species in times of stress, and this can also further weaken texture or serve as a form of slow metabolic activity (Cortes-Sanchez et al., 2025).

In terms of the results of the Gram-stain, homogenous pink to reddish, rod-shaped cells are the morphology that should have been observed in Gram-negative *Enterobacteriaceae*. The absence of Gram-positive organisms could be attributed to the fact that either those bacteria were frozen and therefore inactivated over time, or that they were never present in large quantities to start with. This further makes the argument that only those that could withstand the stress (cold, freezing, low nutrients) survived to the present. As facultative anaerobes, *Klebsiella* and *Serratia* can survive in low oxygen conditions, and this can explain the presence of both in the vacuum (low oxygen) and aerobic packaging. Their capacity to survive in different oxygen concentrations makes them more resistant in packaged fish, particularly at times when growth conditions are not favourable for fast-growing strict aerobes. The lack of Gram-positive in the samples indicates that either the Gram-positive were inhibited through prolonged freezing, or they were not present in high populations in the first place. This observation shows that the one that survived was largely the flora that could withstand the environmental pressure like cold and freezing temperatures and a lack of nutrients.

Overall, the microbial analysis, along with the results of Gram staining, suggests the predominance of psychrotropic Gram-negative bacteria in the aquatic environment that can survive frozen storage. Notably, no new or virulent contaminants were added to the food during either vacuum or aerobic packaging, and the preservation methods did not lead to any external contamination of the instruments but preserved the existing microbial community. All these findings point to the conclusion that the microbial populations that could be found are explained by handling and environmental exposure.

5.1.2.6 Results for Objective 6

Below is a summary of culinary recipes incorporating anchovy from frozen format. The sensory overall acceptability score is out of 9 based on a 9-point hedonic scoring sheet.

High-acceptance recipes

- *Anchovy and dumpling bake*: This dish, consisting of baked anchovy and vegetables topped with dumplings and cheddar cheese, received the highest taste score of 8.31 out of a possible top score of 9 and scored well across all sensory categories.
- *Creamy tomato and anchovy pasta* (Figure 5.13): This anchovy-infused pasta dish developed for local preferences achieved a high overall acceptability score of 7.5.

Figure 5.13. Creamy tomato and anchovy pasta.

- *Light and bright anchovy-corn soup*: This thick vegetable broth featured anchovy fillets and corn kernels. Notably, it was served with croutons made from anchovy and mielie meal bread, demonstrating the versatility of anchovy in baked goods. It received an overall acceptability score of 7.4.
- *Mediterranean anchovy-infused spaghetti* (Figure 5.14): This dish balanced anchovy flavour with tomato and vegetables, achieving an overall acceptability score of 7.4.

Figure 5.14. Mediterranean anchovy-infused spaghetti.

- *Anchovy frikkadels (meatballs) with pasta* (Figure 5.15): This dish of meatballs made with anchovy and flavoured with tomato achieved an overall acceptability score of 7.4.

Figure 5.15. Anchovy meatballs with pasta.

Moderate-acceptance recipes

- *Curry dishes*: Recipes such as "Anchovy curry and rice" and "Anchovy & vegetable curry" received lower scores compared to the pasta and baked dishes, with overall acceptability ratings ranging between 6.0 and 6.07. The taste score for the standard curry was 5.36, indicating a mixed consumer response to this specific flavour profile.

Other recipes tested

- *Spaghetti with anchovy, garlic, and herb crumb* (Figure 5.16): This convenient meal paired anchovy fillets with chargrilled vegetables and cheese (overall score: 6.9).

Figure 5.16. Spaghetti with anchovy, garlic, and herb crumb.

- *Creamy mushroom and anchovy puttanesca* (Figure 5.17). This pasta dish with smoked paprika, anchovy puttanesca sauce, penne pasta and cream had an overall score of 7.0 out of 9.

Figure 5.17. Creamy mushroom and anchovy puttanesca with penne pasta.

- *Anchovy pasta bake* (Figure 5.18): Despite receiving high scores for taste (7.50) and texture (7.81), the summary data indicates this recipe was "Not included" in the final selection, unlike all the others that were marked as "Included".

Figure 5.18. Anchovy pasta bake.

5.1.3 Conclusions and recommendations for section 5.1

The microbiological results from this preliminary study on hot-smoked and marinated anchovy showed that the processes of marinating raw anchovy in oil and spices seems to not be an effective method for prolonging the shelf-life of raw anchovy. This type of product would be more applicable in a restaurant and/or catering scenario. The filleted and hot-smoked anchovy product showed the best potential as a safe product for human consumption up to 7 days of refrigerated storage.

Anchovy that was cured for 4 weeks and then hot-smoked showed an increase in polyunsaturated fatty acids compared to anchovy that was not cured for 4 weeks. It would be advisable to measure the level of fat oxidation during a shelf-life study of the products evaluated in this preliminary trial.

Filleted, hot-smoked anchovy, stored in vacuum and aerobic bags, respectively, may be safe for human consumption up to 7 days of refrigerated storage (less than 100 000 cfu/g TVC). Whole hot-smoked anchovy showed higher bacterial counts compared to filleted samples, especially in terms of coliforms. This can be attributed to the gut which remained in the whole anchovy, whereas in the filleted samples, the gut was rinsed away with water during the filleting process. It would be advisable to repeat the study using a higher salt concentration for the whole anchovy to reduce the bacterial load of whole smoked anchovy. Vacuum packaging of hot-smoked anchovy was shown to inhibit the increase in bacterial counts between day 4 and day 7. Vacuum packaging could therefore be considered to extend the shelf-life of smoked anchovy.

Hot smoking increased the protein content of filleted and whole anchovy due to the concentration factor. Hot-smoked anchovy maintained a highly balanced profile of essential and non-essential amino acids, with no significant deterioration in the amino acid content between the raw and smoked products. The fatty acid profile was well-preserved during the thermal processing of hot smoking, showing that smoked anchovy is an excellent source of essential omega-3 fatty acids. Hot smoking successfully concentrated the levels of eicosapentaenoic acid and docosahexaenoic acid. While raw anchovy had lower concentrations, the fat extracted from the hot-smoked samples contained about 9.84 to 10.54 mg/g of EPA and 11.48 to 13.08 mg/g of DHA. Hot smoking significantly increased the ash (mineral) content of the anchovy compared to raw samples, which is largely attributed to the moisture loss and the absorption of salt (NaCl) during the brining process. Specific minerals like potassium (K), phosphorus (P), and calcium (Ca) showed significant variations depending on whether the smoked product was a fillet, whole with the head, or whole without the head. The mineral safety profile for the hot-smoked anchovy was largely positive.

In terms of microbial safety and total bacterial counts in whole and filleted anchovy stored under vacuum packaged and aerobic packaged, frozen conditions, both packaging types for the whole anchovy samples were below the acceptable limit of 10^5 cfu/g TVC, as defined in the South African regulations for frozen fish. Both packaging techniques permitted psychrotropic, Gram-negative bacteria such as *Klebsiella* and *Serratia*, that are normally linked with the aquatic environment and can endure low-temperature storage, to survive.

The most viable processing method identified was filleting, brining, and hot smoking the anchovy, which produced a product safe for human consumption between to 4 to 7 days under refrigerated storage. The smoking process also successfully concentrated the protein content of both filleted and whole anchovy. By contrast, marinating raw anchovy in oil and spices was found to be ineffective for prolonging shelf-life, making this method more applicable for immediate use in catering or restaurant settings.

Regarding storage and packaging, the study found that for long-term frozen storage (–18°C), both vacuum and aerobic packaging successfully kept total bacterial counts below the legal South African safety limit of 10^5 cfu/g TVC. There was no significant difference between the two packaging types in controlling microbial survival under frozen conditions. While psychrotrophic, Gram-negative bacteria like *Klebsiella* and *Serratia* survived, their numbers remained within an acceptable range, proving that freezing itself, rather than oxygen restriction via vacuum packaging, is the primary factor for preserving the fillets.

5.2 Food products with red-eye round herring for human consumption

Aim

The aim of this research project was to investigate the viability of red-eye round herring product types for human consumption. This project investigated the effects of hot and cold smoking on its nutritional value and oxidative stability of red-eye round herring fillets (Objective 1), as well as the potential of a fish powder made from steamed red eyer round herring fillets (Objective 2).

Objective 1

The primary aim of this study was to investigate the effects of hot- and cold-smoking processing on the proximate, vitamin, and fatty acid compositions, and lipid oxidation of red-eye round herring fillets.

Specific objectives:

- To evaluate the proximate composition (moisture, protein, ash, and fat) of raw and smoked red-eye round herring (flecked).
- To determine the baseline fatty acid composition of raw *E. whiteheadi*.
- To investigate the effects of hot- and cold-smoking processes on the fatty acid profile, specifically essential omega-3 fatty acids.
- To assess the effects of smoking processes on lipid oxidation using thiobarbituric acid reactive substances (TBARs) and conjugated dienes (CD) assays.
- To assess the vitamin (Vitamin A, B1, B2 and B3) content of hot and cold smoked red-eye round herring (flecked).

Objective 2

To conduct a preliminary investigation of the incorporation of a fish powder made from steamed red-eye round herring fillets (Figure 5.19) to create value-added dry foods. This objective focused on recipe formulations.

Figure 5.19. Red-eye round herring in powder form.

5.2.1 Materials and methods

5.2.1.1 Material and methods for Objective 1

Sample collection and preparation

E. whiteheadi samples (10–15 cm in size) were sourced from the Department of Forestry, Fisheries, and the Environment from the Mossel Bay coastline. Fish were eviscerated (guts, head, and backbone removed) and prepared as "flecked" fillets (fillets attached to one another).

Smoking protocols

Hot smoking: Samples were brined (15% NaCl for 10 minutes), dried at 45°C for 35 minutes, and smoked at 75°C for 20 minutes (Figure 5.20).

Figure 5.20. Hot-smoked red-eye round herring fillets.

Cold-smoking: Samples were brined (15% NaCl for 10 minutes), dried at 27°C for 40 minutes, and smoked at 30°C for 60 minutes (Figure 5.21).

Figure 5.21. Cold smoked red-eye round herring fillets.

The hot- and cold-smoking processing were performed using a Junior Butcherquip smoker with French oak wine barrel sawdust.

Proximate analysis

Moisture, ash, and protein were determined using ISO and AOAC standard methods.

Fatty acid analysis

Fatty acid methyl esters were quantified using gas chromatography-mass spectrometry (GC-MS) following modified AOCS methods.

Lipid oxidation

Oxidation was evaluated using the TBARS assay (measuring malondialdehyde, a secondary oxidation product) and conjugated dienes (measuring primary oxidation) via spectrophotometry.

Vitamins

Additional analysis included inductively coupled plasma mass spectrometry for heavy metals and standard lab assays for vitamins A and B-series.

Statistical analysis

Data was analysed using SPSS to determine significant differences between smoking treatments (P<0.05).

5.2.1.2 Materials and methods for Objective 2

An instant fish soup powder (Figure 5.22a) and a seed baked biscuit (Figure 5.22b), were developed to serve five people for general tasting to determine how much they liked these products.

Formulation

The soup recipe relied heavily on the fish powder as a protein base, incorporating about 90g of red-eye round herring powder (*Etrumeus whiteheadi*). Thickening and flavouring agents including cornstarch, vegetable stock powder, tomato powder and leek powder. A spice blend comprising onion, garlic, black pepper, coriander and paprika was added.

Figure 5.22. An instant soup and a seed baked biscuit containing red-eye round herring fish powder as an ingredient.

5.2.2 Results and discussion

5.2.2.1 Results for Objective 1

For a more comprehensive discussion about the results summarised below, the researchers are in the process of writing a manuscript for publication in a scientific journal.

Proximate composition

Both hot and cold smoking significantly reduced moisture content from ~71% (raw) to ~62–63% (smoked), resulting in a concentration of nutrients. Protein content increased significantly from 22.87% in raw fish to 27.87% in cold-smoked samples. The fish is classified as "medium fat", with crude fat ranging between 4.51% and 5.05%, showing no statistically significant change across treatments.

Fatty acid profile

The fatty acid profile was well-preserved despite thermal processing. Docosahexaenoic acid (DHA) was the most abundant fatty acid (~25%), followed by palmitic acid (~23%) and eicosapentaenoic acid (~11%). There were no significant losses of EPA or DHA expressed as a percentage composition due to smoking. A 100 g portion of smoked product exceeds the recommended daily allowance of 500 mg for combined DHA and EPA.

Lipid oxidation

Raw samples exhibited significantly higher TBARs values (0.25 µmol MDA[43]/g) compared to hot-smoked (0.14 µmol MDA/g) and cold smoked (0.13 µmol MDA/g) smoked samples.

The conjugated dienes values were slightly higher in hot-smoked samples (indicating some early-stage oxidation due to heat), but differences were not statistically significant.

[43] Malondialdehyde.

Smoked samples contained Vitamin A (Retinol) ranging from 11.5 to 31.6 µg/100 g, and notable amounts of Vitamins B1 (ranging from 0.16 to 0.23 mg/100 g), B2 (ranging from 0.62 to 0.33 mg/100 g), and B3 (ranging from 12 to 30 mg/100 g).

The study established that *E. whiteheadi* is a nutrient-dense source of high biological valued protein and essential omega-3 fatty acids. Contrary to the hypothesis that heat processing might degrade lipids, the smoking process demonstrated a protective effect. The significantly lower TBARs values in smoked samples suggest that phenolic compounds present in the wood smoke acted as antioxidants, scavenging free radicals and retarding secondary oxidative rancidity. This indicates that smoking not only enhances flavour but significantly improves the oxidative stability of the fish compared to raw frozen storage. While hot smoking caused minor initial oxidation (higher CD values), the overall lipid quality remained high.

5.2.2.2 Results for Objective 2

In both the soup and biscuit, the fish powder provided a pleasant umami taste to the products. The fish powder shows potential as ingredient for the fortification of different food products. Further development of the fish powder in terms of quality and shelf stability is required.

5.2.3 Conclusions and recommendations for section 5.2

The research confirms that red-eye round herring is a viable alternative to sardine for human consumption. Processing through hot- or cold-smoking effectively concentrates nutrients without degrading essential fatty acids. The antioxidant properties of the smoking process may enhance the product's shelf-life stability by preventing extensive lipid oxidation. The resulting products are rich in protein, B-vitamins, retinol, and omega-3 fatty acids, positioning them as an excellent tool for addressing nutritional insecurity in South Africa.

Due to moisture content of hot and cold smoked red-eye round herring fillets remaining above 10% (approximately 62%), the smoked products are not shelf-stable at ambient temperatures and must be kept refrigerated or frozen to ensure safety. Alternatively, the smoking process could be adjusted to lower the moisture content. Future research should investigate the ideal smoking parameters to ensure at moisture content of 10% in red-eye round herring fillets

Future research should also include microbial safety testing (specifically for *Listeria* and *Clostridium*) and comprehensive sensory analysis to gauge consumer acceptance.

The creation of an instant soup powder from red-eye round herring confirms the potential for processing these small pelagic fish into shelf-stable, nutrient-dense powdered ingredients. Future research for the development of value-added products, such as instant fish soup powders incorporating red-eye round herring in the form of a powder, should be pursued to diversify market offerings. Comprehensive shelf-life studies, food safety analysis, and sensory analysis of the fish powder is recommended for future studies.

5.3 Overall conclusions and recommendations

From strategic context and viability collectively, the research projects investigated and positively reported on the scientific and commercial viability of utilising South African anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) for direct human consumption. Faced with the depletion of traditional sardine resources and persistent malnutrition in South Africa, these projects successfully demonstrated that these underutilised pelagic species could serve as sustainable, safe, and nutrient-dense alternatives for the lower-to-middle income (LSM[44] 4–7) markets. The red-eye round herring powder is a more expensive product with the potential as ingredient for fortification (animal amino acids, omega-3 fatty acids, and minerals) in multiple food product formulations (for example, instant soup and baked biscuits).

The investigation into the frozen storage of anchovy yielded critical cost-saving insights for the industry. Contrary to the assumption that vacuum packaging is superior for microbial control, the research established that there is no statistically significant difference ($P>0.05$) in TVCs or coliform presence between vacuum and aerobic packaging after long-term frozen storage. Both methods maintained microbial loads well within regulatory safety limits ($<10^5$ cfu/g for TVCs) and showed the absence of *E. coli*. However, while microbial safety is assured under both conditions, the presence of psychrotrophic facultative anaerobes (e.g., *Klebsiella oxytoca*, *Serratia* spp.) and physical deterioration in fillets suggests that frozen storage at –18°C is the primary preservation factor, rather than oxygen exclusion. Consequently, processors can potentially utilise less expensive aerobic packaging for frozen distribution without compromising food safety, provided the cold chain is strictly maintained.

The study on *Etrumeus whiteheadi* established it as a high-quality, medium-fat fish offering high biological value protein (up to 27.87%) and significant levels of essential fatty acids. Crucially, the research demonstrated that thermal processing via hot- and cold-smoking does not degrade the fatty acid profile; rather, it effectively concentrates nutrients due to moisture loss. Furthermore, smoking provided a significant technological advantage by improving lipid stability. Smoked samples exhibited significantly lower TBARs values compared to raw frozen samples, indicating that phenolic compounds in wood smoke act as antioxidants, retarding lipid oxidation and extending shelf-life. With a 100g portion exceeding recommended daily intakes for EPA and DHA, smoked red-eye round herring is validated as a nutritionally superior product for food security initiatives.

Bridging the gap between scientific analysis and consumer plates, the product development phase proved that these species are highly acceptable when integrated into culturally relevant convenience meals.

- Anchovy: Sensory evaluation revealed high acceptance for anchovy-based dishes, with the "Anchovy and dumpling bake" achieving a taste score of 8.31 out of possible 9, and pasta dishes scoring consistently high (7.4–7.5/9). This confirms that "hiding" or incorporating anchovy into savoury bases overcomes potential barriers regarding the fish's strong flavour or appearance.
- Red-eye round herring: The successful formulation of an instant fish soup powder demonstrates the species' versatility as a fortifying ingredient for dry goods, offering a potential protein source for food-insecure populations. However, future research into the shelf-life of the fish powder is crucial, in addition to product development using the fish powder as a fortification ingredient. The full nutritional content (proximate composition, mineral and vitamin content, and fatty acid profile) of the developed fish powder from red-eye round herring is something that needs to be determined and documented in future research projects.

This chapter research report provides a comprehensive "boat-to-plate" solution for the South African small pelagic fishery. It confirms that (1) expensive vacuum packaging is not strictly necessary for the safety of frozen bulk anchovy, (2) smoking effectively preserves the nutritional integrity and stability of red-eye round herring, and (3) value-added culinary applications (convenience meals and powders) achieve high consumer acceptance. These findings support the diversification of the fishery

[44] South African Audience Research Foundation Living Standards Measure.

sector, offering tangible pathways to improve national nutrition security, create jobs in processing, and reduce reliance on diminishing sardine stocks.

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[45] Polycyclic aromatic hydrocarbons.

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CHAPTER 6
CONSUMER PERCEPTION AND AWARENESS OF ANCHOVY PRODUCTS IN SOUTH AFRICA

Dr Suné Henning,[46] Ziyanda Phike,[47] and Prof. Mafaniso Hara[48]

6.1 Introduction

This chapter reports on an investigation into the perceptions of South African consumers about anchovy products with the aim of gauging the size of the market for potential anchovy products. Traditionally, anchovy has been used mainly as the protein ingredient in animal feed rather than for direct human consumption. It has also been observed that good quality anchovy products are extremely expensive and the few entry-level products that did exist have been discontinued. Thus, a nationwide survey was conducted to determine the perception and understand attitudes and awareness towards seafood (fish), in particular, anchovy products within the South African seafood eating community in order to understand the level of consumer interest in anchovy products.

6.2 Methodology

Regarding anchovy products, the specific questions were: Are they aware of anchovy? If yes, are they positively or negatively predisposed towards them? What are the perceived advantages and disadvantages of eating anchovy? If they are open to a new anchovy product, what in their diet do they think it might replace? How do they feel about smoked and pickled products? Would the proposed product replace something in their current diet? When might they eat it? How? These questions were answered in a structured quantitative way via an online survey, with behind-the-scenes design ensuring that respondents only saw questions that were relevant to them. For example, if respondents indicated that are not aware of what an anchovy is, they were not asked follow up questions about anchovy, e.g., if they were open to eating anchovy or not. Those respondents who indicated they currently eat anchovy saw a follow-up question establishing what kind of anchovy products they eat.

Smartphone penetration is high and rising in South Africa, even in low-income communities. According to MAPS,[49] a nationally representative sample of adult South Africans, overall smartphone penetration currently stands at 73.8%, and at 63.9% for people living in a household with a combined income of less than R5 000, i.e., two out of three people from low-income households have access to an internet-enabled smartphone on which they can participate in an online survey. This means the anchovy-based products proposed in the current project have the potential to be marketed to an audience beyond high-income communities. A broader cross-section of South Africans can therefore be reached by distributing a survey via social media such as Facebook.

Since the survey was only available online, it excluded people who are **not** active online. Reaching people who are not active online is prohibitively expensive (from R300 per face-to-face interview). The research team accepted the trade-off of a cost-effective online survey which reflects the broad spectrum of people who are active online versus the extremely expensive and time-consuming approach of including people who are not active online with face-to-face surveys.

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[49] The Marketing All Product Survey of the Marketing Research Foundation.

An online questionnaire (Appendix 2) was designed using Alchemer to assess copy of consumer behaviour and attitudes toward anchovy and distributed via Facebook (Figure 6.1). To attract participants, three R1 000 Takealot vouchers were randomly given away to participants. Data obtained was analysed using Alchemer. Alchemer is highly committed to data privacy and protection and claims ISO/IEC 27001[50] certification, SOC2[51] Type 2 certification, as well as compliance with the EU GDPR.[52]

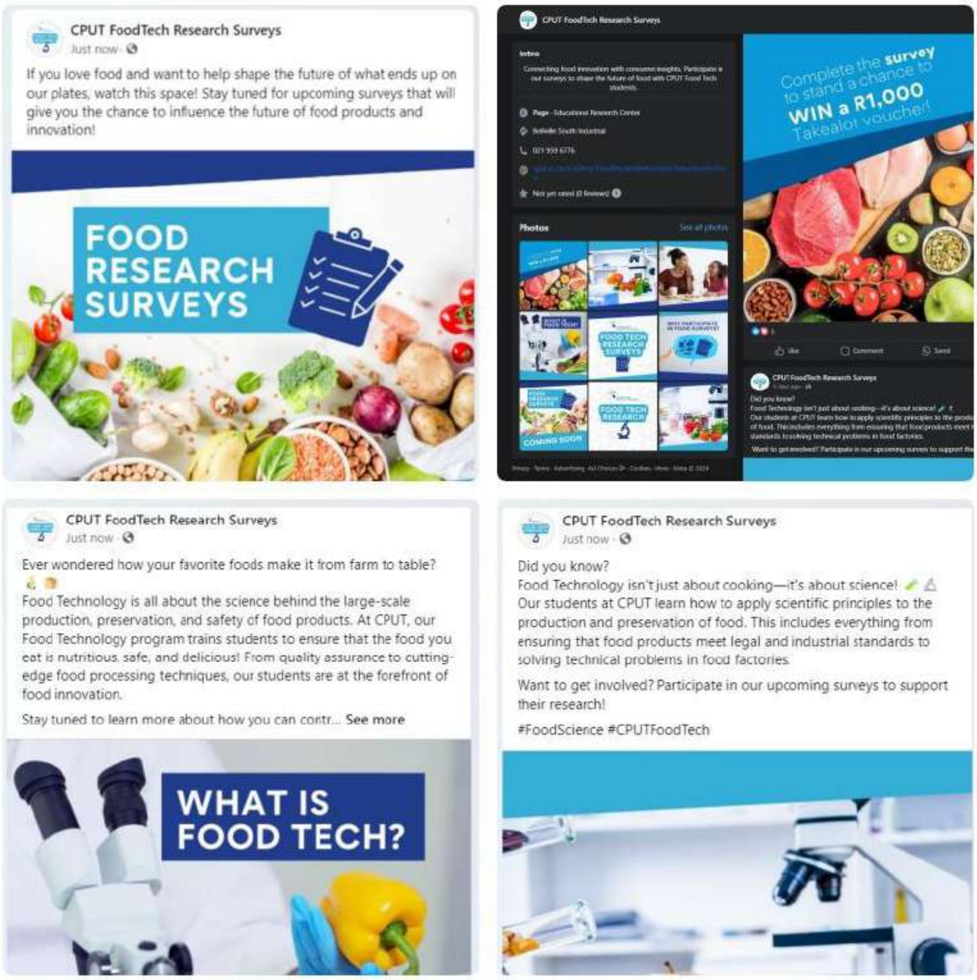

Figure 6.1. Composite image of anchovy survey on Facebook during August 2024.

A quantitative approach was followed for the answers from the members of the public to generate sufficiently large samples of respondents for sub-analysis within the overall sample.

Fishing industry stakeholders could answer questions like:

- What are the challenges to delivering quality anchovy for processing?
- How can the supply and processing of anchovy be optimised?

[50] International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 27001:2022 – Information security, cybersecurity and privacy protection — Information security management systems — Requirements.

[51] Service Organization Control 2.

[52] European Union General Data Protection Regulation.

- What is your opinion of the viability of an affordable anchovy-based product?
- What else does a supplier of anchovy products for human consumption need to understand about the supply chain?

The survey responses were compared across these sub-groups. Further, to smooth out the expected sample skews (women and younger people generally make up disproportionately large percentage of online survey respondents), the data will be weighted back to the profile of people who are active online.[53]

6.3 Results, conclusions and recommendations

Summary of 2024 anchovy consumer awareness study

In summary, about 1 000 people across South Africa completed the anchovy survey. For the questions about "Which of these kinds of seafood do you like?", 13% of the participants indicated anchovy, of which 4% fell within the low-income group (Figure 6.2). The most preferred seafood was hake, tuna, and pilchards/sardines. Anchovy was one of the least "liked" seafood products, however, this could be attributed to consumers not being familiar with anchovy, since it is a very expensive and is perceived as a luxury product that is mainly used on pizzas (Figures 6.3 and 6.4).

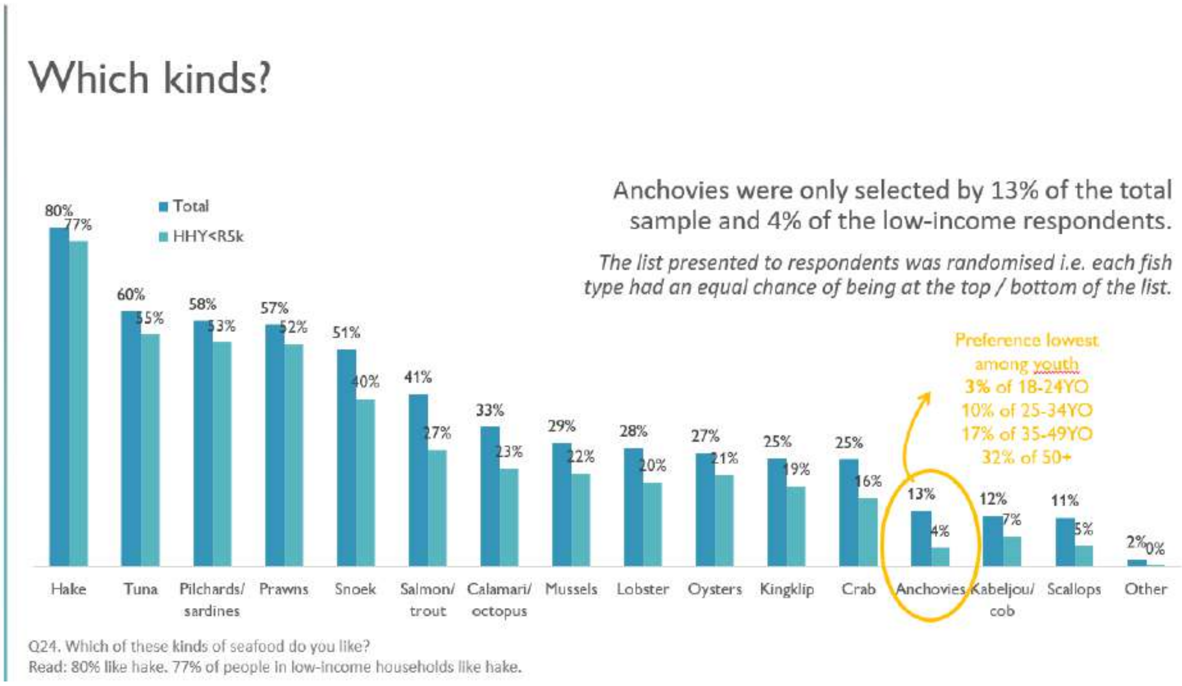

Figure 6.2. Thirteen percent of participants indicated that they like anchovy.

[53] The 'active online' filter is applied to the MAPS profile for weighting because the survey is only available online, and therefore by definition it is limited to people who are active online.

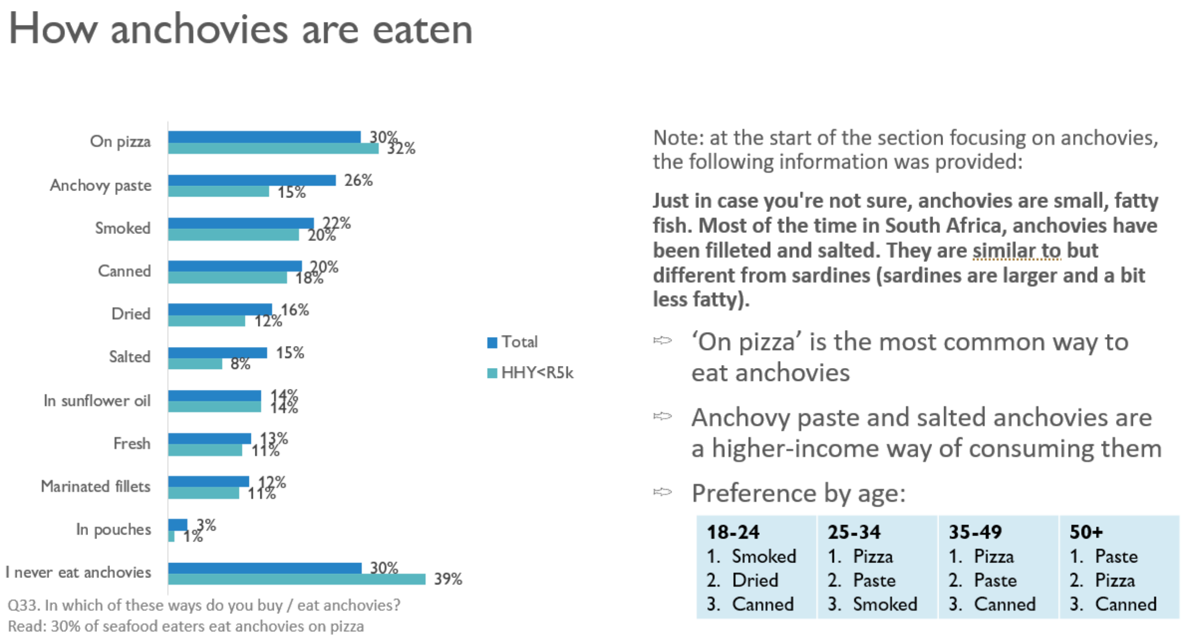

Figure 6.3. In the anchovy survey, 30% of the participants who indicated that they eat seafood said that they consume anchovy on pizza.

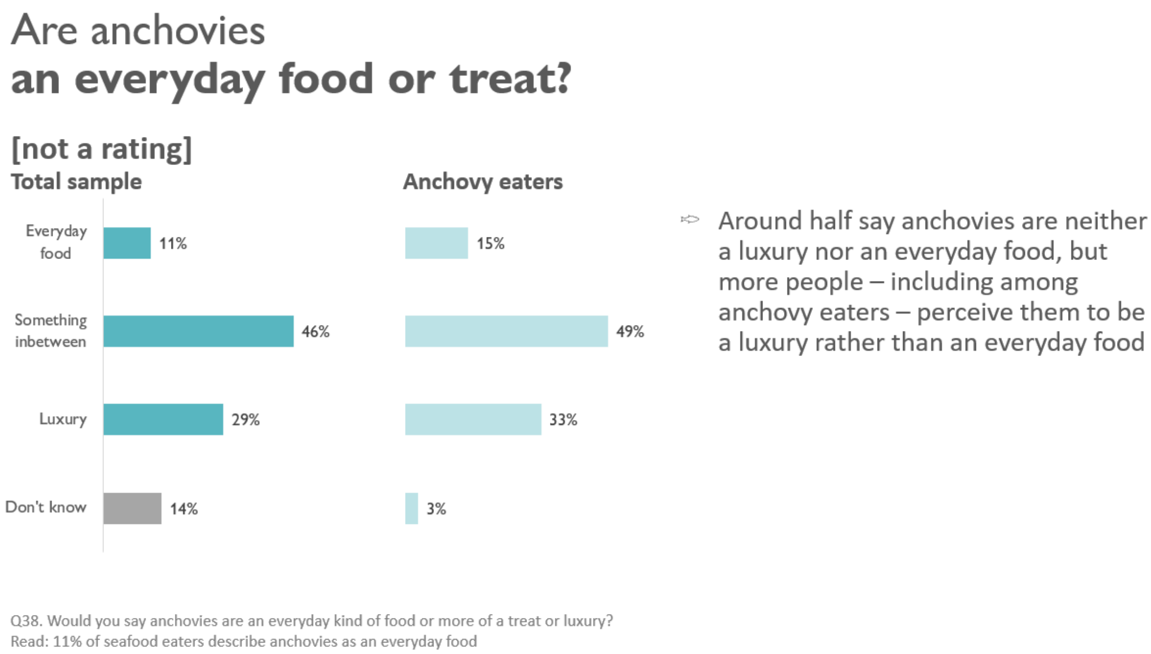

Figure 6.4. Many seafood eaters (30%) perceive anchovy as a luxury food.

However, in summary (Figure 6.5) anchovy and anchovy products are perceived as a "low-profile" seafood not considered by many as a food staple. It is seen as a luxury food (because of the expensive forms currently available on the retail shelves) and has a low penetration value into low-income households. There are many other attractive alternative seafood products. However, on the positive side, anchovy is recognised (as is fish generally) as a source of essential amino acids and omega-3 fatty acids. There is an opportunity to leverage the perception of the high cost of healthy food by developing, and marketing attractive affordable forms of anchovy to consumers, especially among low-income, female, and young-of age seafood eaters.

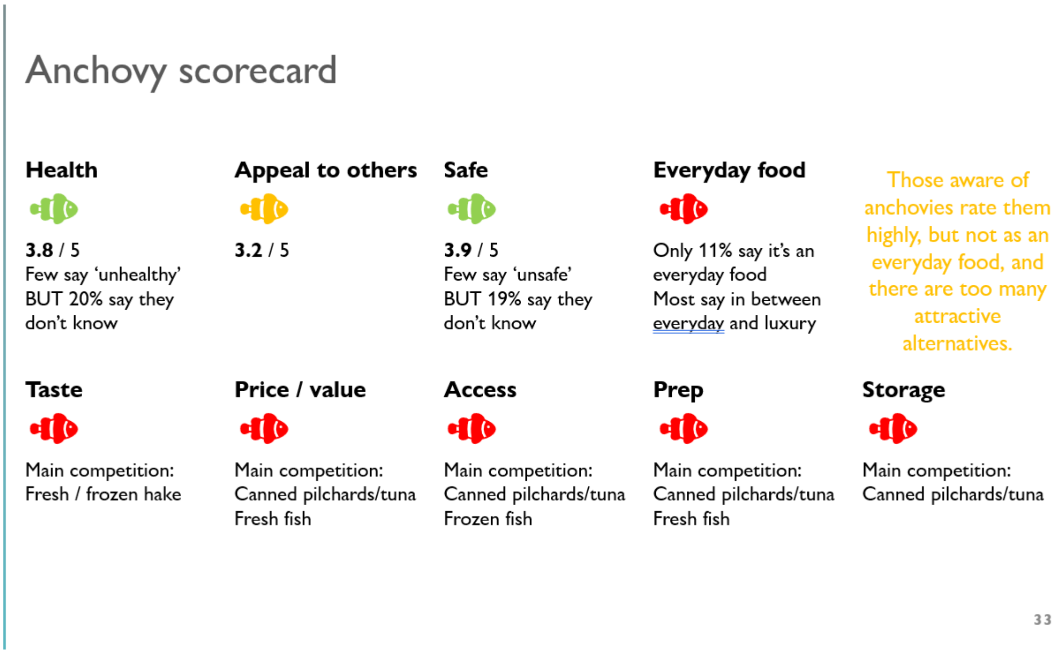

Figure 6.5. In summary there are challenges and opportunities for new, affordable anchovy products in South Africa.

CHAPTER 7
GUIDELINES FOR HOT AND/OR COLD SMOKING OF SOUTH AFRICAN ANCHOVY (*ENGRAULIS ENCRASICOLUS*) AND RED-EYE ROUND HERRING (*ETRUMEUS WHITEHEADI*)

Dr Suné Henning[54] and Prof. Mafaniso Hara[55]

This document is a basic guideline for the processing of hot and/or cold smoked South African anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) based on laboratory trials that investigated the effects of smoking on the macro- and micro-nutritional content, mineral content, and microbial load of *E. encrasicolus* and *E. whiteheadi*.

7.1 Hot smoking of anchovy (*Engraulis encrasicolus*)

7.1.1 Introduction: The value proposition (The "why")

Smoking is a highly effective technique used to enhance the sensory attributes and significantly increase the shelf-life of fish products due to the anti-microbial and antioxidant effects of phenolic compounds in the smoke.

Hot smoking is a process in which fish is smoked at an appropriate combination of temperature and time sufficient to cause the complete coagulation of the proteins in the fish flesh (CAC, 2024). Hot smoking is generally sufficient to kill parasites, to destroy non-sporulated bacterial pathogens, and to injure spores that are of concern for human health.

7.1.2 Key purposes of smoking

The primary objectives of smoking fish are multi-faceted, encompassing both preservation and product quality enhancement:

i. Flavour development: Smoking imparts desirable flavours to the product.
ii. Preservation action: Smoke acts as a preservative by inhibiting microbial growth and retarding fat oxidation (rancidity). Shelf-life extension results from a combination of lowered water activity (a_w) and the uptake of antioxidant and bactericidal components from the wood smoke.
iii. Product creation: It enables the creation of new products.
iv. Protection: It helps protect the product from fat oxidation.
v. Colour development: Smoking contributes to the desired colour of the final product.

7.1.3 Nutritional benefits of anchovy

Anchovy is a small, fatty fish that offer substantial nutritional advantages, positioning them as an excellent candidate for value-added products like hot-smoked fish. A study by Henning (2021–2025, unpublished data) showed the following nutritional benefits of smoked anchovy products:

- High-quality protein and amino acids: Fish is a rich source of easily digestible, high-quality protein containing all essential amino acids. Hot smoking increases the protein content due to the reduction of moisture (a concentration effect).
- Essential fatty acids: Anchovy is generally rich in essential fats, particularly long-chain omega-3 fatty acids: eicosapentaenoic acid (EPA, C20:5n-3) and docosahexaenoic acid

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(DHA, C22:6n-3). These fatty acids are vital for health, supporting cardiovascular health, cognitive function, and mitigating inflammation.

- Micronutrients: Anchovy provides essential vitamins (A, B, and D) and minerals such as calcium, iodine, zinc, iron, and selenium.
- Consumer perception: Anchovy is generally rated as healthy by South African consumers (1 000 responses from study in 2024, Henning et al. 2024–2025) who have an opinion, with an average rating of 3.8/5 (seafood eaters) to 3.9/5 (anchovy eaters), where 5 is "super-healthy" (Henning et al. 2024–2025a). A significant proportion of seafood eaters (30%) who consume anchovy reported eating them primarily on pizza. Furthermore, many seafood eaters perceive anchovy as a luxury food**,** which is likely due to the expensive forms currently available in retail (e.g., fillets costing over R100). There is an opportunity to leverage the general perception that healthy food is expensive by developing and marketing attractive, affordable forms of anchovy.

7.1.4 Processing method: Hot smoking anchovy fillets (the "how")

Hot smoking is a traditional method utilising both heat and smoke. Processing anchovy into fillets before smoking offers better microbial control compared to smoking the whole fish.

7.1.4.1 Pre-processing steps

Sourcing raw material

Anchovy, typically small fish ranging between 8 and 14 cm in length, should be sourced. If not processed immediately, they should be kept frozen (e.g., between –17°C and –20°C) until use.

Quality of raw material

The quality of anchovy delivered from the fishing vessels is critically important for food safety and the feasibility of further processing for human consumption. It has been observed and reported (Henning et al., 2024–2025b) that the quality of anchovy samples received from industry and/or the Department of Forestry, Fisheries, and the Environment is questionable, often due to damage (fish without heads and/or catch holes in fish bodies and/or belly contents spilling out). This damage is expected because the South African anchovy is small (ranging between 8 and 14 cm in length) and is caught in large nets during trawling, and primarily meant for fishmeal or fish oil production. The fact that it is for fishmeal or fish oil production means it does not have to be landed in prime condition.

Damaged fish (or fish in a bad state) are detrimental to safety because:

- Damage to fish due to improper handling during harvesting is a likely cause of high *Enterobacteriaceae* (coliform) counts in processed products.
- The primary problem with anchovy, historically, has been its fragility in handling, which also includes the high lipid content that leads to quick oxidation and a short shelf-life.
- Damaged fish in combination with improper refrigeration on trawlers will lead to high levels of histamine production due to microbial growth (CAC, 2020; FAO/WHO, 2018). Histamine production occurs when spoilage bacteria, migrating from the fish's skin, gills or gut, produce the histidine decarboxylase (HDC) enzyme. The HDC enzyme reacts with the naturally occurring amino acid free histidine, converting it into the toxic metabolite histamine. The presence of hazardous levels of histamine is generally a result of gross time-temperature abuse during handling and storage. Bacterial growth and histamine formation accelerate exponentially under unrefrigerated conditions, typically occurring at temperatures above 25°C for more than six hours.

Once histamine is produced no means of processing – including freezing, cooking, smoking, or drying – can reduce or break down histamine.

It is therefore important to only use only good quality anchovy as raw material. Following the guidelines for handling and processing anchovy for human consumption from boat to shelf is extremely important for food safety compliance. The aim is to use fish from vessels equipped with on-board refrigeration (such as refrigerated seawater, ice, or freezers) that are sufficiently close to harbours to ensure that catches will be landed in a good condition for processing.

Preparation

7.1.4.2 Flecked fillets (fillets that stay attached to one another):

- Remove the heads and guts (evisceration).
- Split the anchovy open and rinse thoroughly with tap water (Figure 7.1). The removal and rinsing of the gut help reduce bacterial load, especially *Enterobacteriaceae*.

Figure 7.1. Anchovy fillets as flecked fish.

7.1.4.3 Whole fish without head

For whole fish, remove the head and rinse the fish with clean water.

7.1.4.4 Brining/ salting for flavour and preservation

Salting is the process of treating fish with salt of food grade quality to lower water activity (a_w) in fish flesh and to enhance flavour by any appropriate salting technology (e.g., dry salting, brining, injection salting). For this guideline, brining is used to salt the anchovy fillets.

A 12.5% salt/sugar solution comprising of 1/4 cup (62.5 ml) of salt and 1/4 cup (62.5 ml) of brown sugar per litre of water was prepared. The purpose of the sugar is for colour production and flavour development during the smoking step.

- Soak the flecked fillets for 15 minutes in the brine at room temperature. Maintain a ratio of fillets to brine solution of 1:4 (Figure 7.2).
- Soak the whole fish (not eviscerated, without head) for 20 hours in the brine solution at refrigerated temperatures (Figure 7.3).

Figure 7.2. Salt anchovy flecked fillets for 15 minutes in the brine at room temperature.

Maintain a ratio of fillets to brine solution of 1:4.

Figure 7.3. Salt whole (not eviscerated, without head) anchovy fillets for 20 hours in the brine at refrigerated temperature. Maintain a ratio of fillets to brine solution of 1:4.

7.1.5 Smoking-drying process flow

The following parameters are based on experimental trials for filleted and whole (without head) anchovy (Figure 7.4) using a Model J536 Junior Butcherquip smoker.

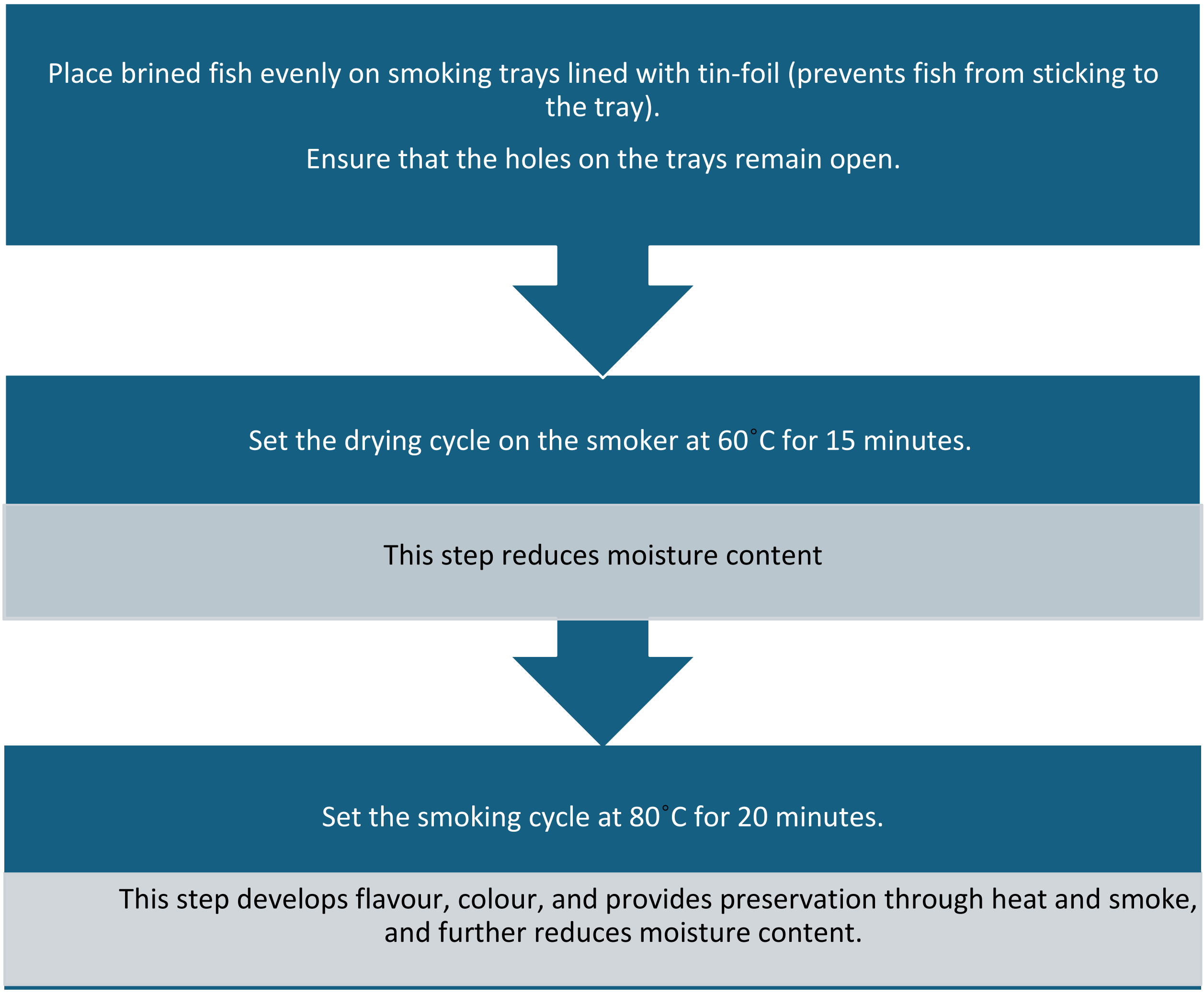

Figure 7.4. Process flow diagram for hot-smoked flecked filleted and whole anchovy.

Smoke-drying is a process in which fish is treated by combined smoking and drying steps to such an extent that the final product can be stored and transported without refrigeration (Figure 7.5) and to achieve a a_w of 0.75 or less (10% moisture content or less), which is necessary to control bacterial pathogens and fungal spoilage (CAC, 2024).

(a) (b)

Figure 7.5. (a) Flecked filleted and (b) whole (not eviscerated, without head) hot-smoked anchovy.

In a trial where whole (eviscerated and without head and tail) anchovy was brined for 10 minutes in 15% brine (only NaCl), followed by drying at 45ºC for 30 minutes, and hot-smoked at 75ºC for 15 minutes, the a_w was between 0.80 and 0.82, with a moisture content between 49 and 55%. Based on these results, the hot-smoked whole anchovy product should be kept refrigerated (CAC, 2024). In the case where the products are dried further to a moisture content of 10% or less, the final product could be stored and transported without refrigeration (CAC, 2024).

7.1.6 Food safety and quality assurance

Proper handling is critical as anchovy is fragile and has high lipid content resulting in quick oxidation, and possess volatile stomach contents. Frozen samples of final products should be thawed at refrigeration temperatures to maintain quality and safety.

7.1.6.1 Microbial control

- Removing the guts (evisceration) is important for hygiene and is essential, especially when processing whole fish, as high counts of *Enterobacteriaceae* (coliforms) are often attributed to gut contents.
- Filleted, brined, and hot-smoked anchovy showed the best potential as a safe product for human consumption during refrigerated storage (e.g., up to 7 days) when using undamaged raw fish.
- To extend the shelf-life of smoked anchovy, vacuum packaging (Figure 7.6) could be considered, as studies indicate it may inhibit the increase in bacterial counts during refrigerated storage of 7 days. However, the presence of *Clostridium botulinum* in vacuum-sealed smoked fish products must be monitored.

Toxins of *Clostridium botulinum* are not allowed in smoked fish, smoke-flavoured fish and smoke-dried fish products (CAC, 2024). The formation of *Clostridium botulinum* toxin can be controlled through an application of a combination of science-based options such as packaging type, storage temperature, and a_w, e.g. by use of salt in the water phase. Countries where the products are to be consumed may allow these products in an uneviscerated state or may require evisceration, either before or after processing, in such a way as to minimise the risk of *Clostridium botulinum* (CAC, 2024).

Figure 7.6. Vacuum packaged hot-smoked whole and filleted anchovy.

Storage temperature: At temperatures below 3ºC and frozen temperatures (< or equal to –18ºC), *Clostridium botulinum* cannot produce toxins. The product can be packaged aerobically or vacuum sealed. Temperature monitoring is crucial when storing smoked anchovy at 3ºC or below. It is important to note that toxin production can take place after a smoked product is thawed. It is therefore important to add labelling information about the need for the consumer to keep the product frozen, to thaw it under refrigeration, and to use it immediately after thawing.

7.1.6.2 Histamine risk management

Histamine formation is a significant food safety risk associated with anchovy.

- Histamine is produced when fish is not properly iced immediately after capture or when the cold chain is not maintained until landing.
- Once histamine has been produced, no processing method (including freezing, cooking, or smoking) can reduce or break down histamine.
- Histamine levels in foodstuffs are regulated under the Foodstuffs, Cosmetics and Disinfectants Act which states that histamine content of 10 mg/100 g (100 ppm) indicates decomposition and if more than 20 mg/100 g the product is unfit for human consumption. The Codex Alimentarius Commission CXS 311-2013 standard for smoke-dried fish (CAC, 2024) indicates that a product may not contain histamine that exceeds 20mg/100g of fish flesh in any sample unit tested. This applies specifically to species of *Engraulidae* (i.e., anchovy).

7.1.6.3 Heavy Metal Monitoring

Trace element analysis of South African anchovy (Table 7.1) found that toxic heavy metals tested (chromium, copper, zinc, cadmium, mercury, and lead) were below the relevant South African maximum limits.

Total arsenic (As) for the hot-smoked anchovy samples was detected in the range of 5 000 to 8 000 µg/kg (on a dry weight basis) in raw and smoked samples. It should be noted that the method used quantifies total arsenic and does not distinguish between inorganic and organic arsenic. The key concern lies in the fact that arsenic is commonly regulated by its highly toxic inorganic (iAs) form. Because the research method available in South Africa can only measure total arsenic (which includes the much less harmful organic forms typically found in seafood), the result of 5 000 to 8 000 ug/kg dry weight basis may not accurately reflect a public health risk. The health risk may be negatable since the non-toxic organic arsenic (mostly arsenobetaine) typically makes up most of the arsenic in fish and seafood, often ~80–99% of total arsenic, with inorganic arsenic *(As^{3+}/As^{5+})* generally being a minor component (< 10% of total arsenic). This pattern is widely reported across fish and shellfish samples globally.

Joint FAO/WHO Expert Committee on Food Additives (JECFA) set a Benchmark Dose Lower Confidence Limit ($BMDL_{0.5}$) of 3 µg inorganic arsenic per kg body weight per day for small increases in lung cancer risk (Mania et al., 2015). Many regulatory exposure assessments assume that inorganic arsenic from fish is a small fraction of total arsenic intake given typical ratios and therefore contributes only modestly to total risk. **Even where total arsenic in fish may be elevated relative** to other foods, inorganic arsenic in fish products is very low – often near detection limits (<**0.025–**0.05 mg/kg) and usually well below levels that would trigger safety concerns under current benchmarks. Surveys of dietary exposure show that inorganic arsenic intake from fish is a very small percentage of the total health risk threshold when compared with the $BMDL_{0.5}$ (e.g., <1% of $BMDL_{0.5}$ average intake in some studies). Because inorganic arsenic is the form associated with toxicity, and because it is a small fraction of arsenic in fish, eating fish does not generally pose a significant arsenic-related health risk at normal consumption levels.

It is important to note that the heavy metal (or metallic element) content found in fish is significantly influenced by a combination of natural and anthropogenic (human-caused) environmental factors, as well as the biological characteristics of the fish itself. The metal content of fish is like a detailed, location-specific report card of their environment. It reflects both the natural "ingredients" present in the ocean water (especially those brought up by deep-sea upwelling) and the "waste products" from human industry and agriculture that enter the marine system, all magnified or diluted depending on the species' position in the food web and its individual life cycle.

Table 7.1. Means (± standard deviation) heavy metals (µg/kg dry weight) in raw and hot-smoked flecked fillets and whole anchovy without the head (as processed according to the hot smoking protocol outlined in this document)

Product type	**Toxic heavy metals (µg/kg dry weight)**						
	Chromium (Cr)	**Copper (Cu)**	**Zinc (Zn)**	**Cadmium (Cd)**	**Mercury (Hg)**	**Lead (Pb)**	**Arsenic (As)**
Raw without head	330.14±59.70	4633.57±277.98	51779.98±1068.03	677.19±113.19	42.85±7.38	79.63±25.44	8371.73±401.43
Hot-smoked: Whole without head	219.84±77.77	4417.66±137.78	48260.58±2151.63	384.41±105.76	44.77±1.49	28.40±5.09	7480.32±200.51
Hot-smoked: fillets	498.86±295.39	4515.03±409.30	35358.68±4141.89	152.68±49.89	42.49±2.83	33.38±46.86	5562.94±324.93

7.1.7 *Nutritional composition data (as % of product or concentration in mg/g)*

The hot-smoked processing of anchovy results in concentrated nutritional content due to moisture loss.

7.1.8 *Moisture content of hot-smoked anchovy products*

Hot smoking reduces the moisture content (Table 7.2) of filleted and whole anchovy products. According to CAC (2024), the process of smoke drying fish must reduce the moisture content to 10% (or less) for a final product to be stored and transported without refrigeration.

Hot-smoked anchovy flecked fillets produced according to the protocol outlined in this document has potential shelf-life extension of up to 7 days under refrigeration. It is not suitable for storage at ambient temperatures.

Table 7.2. Moisture composition of hot-smoked filleted and whole (not eviscerated and without head) anchovy samples

Product type	% Moisture content
Control Sample (raw anchovy)	79.44
Whole anchovy (without head, salted and hot-smoked)	54.63
Filleted anchovy (salted and hot-smoked)	56.53

7.1.9 *Amino acid content in smoked anchovy products (fillets vs. whole without head)*

There are nine essential amino acids that the human body cannot synthesise and must be obtained through diet: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. Fish is recognised as a rich source of easily digestible high-quality protein that contains all the essential amino acids, making it valuable for human health, growth, and development.

According to a South African survey (Henning et al. 2024–2025a) about consumer perceptions about fish and seafood, 53% of the 1 000 respondents believe amino acids are healthy, and that fish is widely recognized as the best source of essential amino acids. A total of 86% of respondents mentioned it as a top three source, far exceeding eggs (45%) or red meat (30%). An unpublished 2024 study by Henning into the micro-nutritional content of hot-smoked anchovy products (fillets vs. whole fish without the head) demonstrated a wide range of amino acids present in hot-smoked samples, including lysine, histidine, valine, leucine, isoleucine, methionine, threonine, phenylalanine, aspartic acid, glutamic acid, and tyrosine, with concentrations generally ranging between 10 and 70mg/g (Table 7.3). Notably, lysine content reached 63.84±4.97 mg/g in hot-smoked fillets. Research has indicated that hot smoking generally results in an increase in the overall amino acid content between raw and hot-smoked whole anchovy (without head).

Table 7.3. Mean (± standard deviation) essential amino acids (mg/g) in raw and hot-smoked flecked fillets and whole anchovy without the head

Product type	Essential amino acid (mg/g)								
	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophane	Valine
Raw without head	28.95±2.83	12.14±0.67	20.74±0.75	66.51±0.32	11.76±0.59	14.23±0.83	18.63±1.75	ND	14.83±0.78
Hot-smoked: Whole without head	28.92±2.36	16.08±0.94	27.01±1.70	70.31±7.33	16.10±1.06	17.65±1.63	23.21±1.58	ND	18.91±0.85
Hot-smoked: fillets	24.32±1.82	13.74±2.52	23.74±3.92	63.84±4.97	14.01±2.31	15.91±3.13	16.99±1.81	ND	16.85±2.99

ND = not detected

7.1.10 Key fatty acid content (in mg/g)

Anchovy is highly valued for its fatty acid profile, particularly omega-3 fatty acids. Hot smoking increased the EPA and DHA (Table 7.4) content compared to raw anchovy.

Table 7.4. Means (± standard deviation) essential fatty acids (mg/g) for raw, and hot-smoked whole (without head) and flecked filleted anchovy samples

Fatty acid (mg/g)	Raw whole Without heat	Hot-smoked Whole without head	Hot-smoked fillets	Notes
Palmitic acid (C16:0)	21.22±1.56	18.18±1.57	17.41±1.00	Most abundant fatty acid and saturated fatty acids.
Myristic acid (C14)	7.32±0.53	6.40±0.45	5.85±0.53	Second most abundant SFA.
Stearic acid (C18)	3.95±0.38	3.35±0.31	3.10±0.17	Stearic acid may have a neutral or slightly lowering effect on LDL cholesterol.
Palmitoleic acid (C16:1)	7.22±0.62	7.33±0.48	6.75±0.62	Most abundant monounsaturated fatty acids (MUFA).
EPA (C20:5n3)	1.33±0.87	9.84±1.67	10.54±2.25	Omega-3 fatty acid (a PUFA). Essential fatty acid.
DHA (C22:6n3)	1.53±0.72	11.48±2.40	13.08±2.72	Omega-3 fatty acids (a PUFA). Essential fatty acid.

DHA – Docosahexaenoic acid EPA – Eicosapentaenoic acid

PUFA – Polyunsaturated fatty acids SFA – Saturated fatty acids

MUFA – Mono-unsaturated fatty acids

7.1.11 Conclusions

By meticulously following these preparation steps – focusing particularly on proper evisceration and strict control of temperature (especially chilling before processing to mitigate histamine risk, followed by refrigeration of the smoked products) – the hot smoking process transforms underutilised anchovy into a nutritious, safe, and value-added product, addressing the goals of increasing the availability of healthy fish protein for consumers.

7.2 Guideline document: Hot and cold smoking of red-eye round herring (*Etrumeus whiteheadi*)

7.2.1 Introduction: The strategic importance (the "why")

Red-eye round herring (*Etrumeus whiteheadi*) is a promising, abundant species in the South African pelagic fishery that is consistently among the highest landed tonnages. Historically, however, this species has been largely unaffected by conservation concerns and remains somewhat underutilised, predominantly being used for fishmeal and crude fish oil production. Investigating processing methods like smoking is crucial for transforming this underutilised resource into a viable, stable food product for direct human consumption, particularly given the decline of the sardine resource, which was historically important for the low- and middle-income South African population.

7.2.2 Nutritional value of **Etrumeus whiteheadi**

Fish are classified as either fatty (>10% fat), medium fat (5–10% fat), low fat (2–4% fat) or lean (<2% fat) according to the percentage fat in the muscle (Koubaa et al., 2010; Huynh & Kitts, 2009). *E. whiteheadi* is a small pelagic species that was shown (unpublished data, Henning, 2025) to be a low- to medium-fatty fish (5.05 ± 1.58% crude fat), and rich in high biological value protein. Like other small pelagic fish, it is a crucial source of essential fatty acids and protein.

7.2.3 Benefits of smoke processing

Smoking serves multiple objectives for fish processing:

- Shelf-life extension and preservation due to lowered a_w and the uptake of bactericidal and antioxidant components from the wood smoke.
- Enhancement of sensory attributes, including the development of flavour and colour.
- Protection against fat oxidation (rancidity). Notably, preliminary results indicate that smoking treatments (hot and cold) result in lower levels of secondary lipid oxidation (TBARs values) compared to raw samples, suggesting an antioxidant effect from the wood smoke that protects lipids.

Cold smoking is a process of treating fish with smoke using a time/temperature combination that will not cause significant coagulation of the proteins in the fish flesh but that will cause some reduction of the water activity (CAC, 2024).

7.3 Processing methods: Hot and cold smoking (the "how")

The following hot and cold smoking processing protocols (summary in Figure 7.7) for smoking *E. whiteheadi* were developed based on the protocol for hot smoking South African anchovy (Section 1 above).

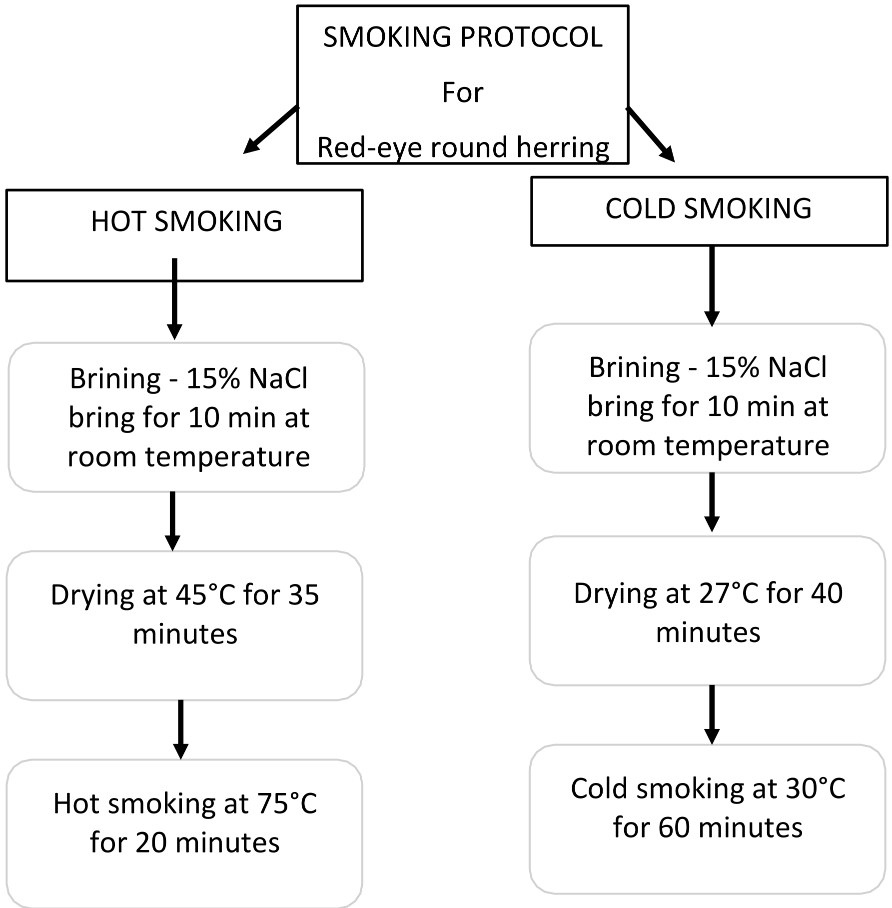

Figure 7.7. Summary of hot and cold smoking process flow for flecked red-eye round herring (eviscerated, without head and tail).

7.3.1 Pre-processing and preparation

Sourcing raw material

E. whiteheadi samples, ranging from 10–15 cm in size (Figure 7.8), are typically supplied frozen and should be semi-thawed before preparation of evisceration and flecked (filleting the fish in such a way that the fillets stay attached to one another).

Figure 7.8. Whole raw red-eye round herring.

7.3.2 Preparation

All fish must be eviscerated to remove the guts for food safety reasons. Frozen fish should be thawed at refrigerated temperatures. Remove the head, tail, backbone and guts, and fleck the fish to create flecked fillets (Figure 7.9).

Figure 7.9. Raw flecked red-eye round herring prepared for hot and/or cold smoking on smoking racks lined with tin foil.

7.3.3 Salting/brining

Prepare a brine solution of 15% NaCl. The ratio of fish to brine should be 1:2 when placing the flecked fish into the brine. Soak the eviscerated flecked fillets for 10 minutes at room temperature.

7.4 Hot smoking protocol

Hot smoking is a traditional method which uses both heat and smoke to preserve fish (Table 7.5).

Table 7.5. Hot smoking protocol for red-eye round herring flecked fillets using a Model J536 Junior Butcherquip smoker

Processing step	Details	Temperature (ºC)	Duration (minutes)	Notes/Preparation
1. Arrangement	Fleck the fish and arrange evenly onto a smoking tray.	N/A	N/A	Allows for equal distribution of smoke.
2. Drying	Place trays in the smoker (Junior Butcherquip model J536).	45°C	35 minutes	Reduces moisture content in preparation for smoking.
3. Hot Smoking	Introduce smoke using wood sawdust (e.g., LK's French oak wine barrel sawdust).	75°C	20 minutes	Applies heat and smoke for flavour and preservation.

Hot-smoked red-eye round herring, smoked according to the above protocol (Table 7.5), obtained a pale and dark brown colour (Figure 7.10) and moisture content of 63.23±3.21%.

Figure 7.10. Hot-smoked flecked red-eye round herring.

7.5 Cold smoking protocol

Cold smoking utilises lower temperatures than hot smoking, but the smoking step is for a longer period (Table 7.6).

Table 7.6. Cold smoking protocol for red eye round herring flecked fillets using a Model J536 Junior Butcherquip smoker

Step	Detail	Temperature	Duration	Notes/Preparation
1. Arrangement	Arrange the fish evenly on trays.	N/A	N/A	N/A
2. Drying	Dry the fish to reduce surface moisture.	27°C	40 minutes	Lower temperature requires slightly longer drying time compared to hot smoking.
3. Cold Smoking	Introduce smoke (e.g., using French oak wine barrel sawdust).	30°C	60 minutes	Longer smoking time at lower temperature.

Cold-smoked red eye round herring, smoked according to the above protocol (Table 7.6), obtained a golden-brown to dark colour (Figure 7.11) and moisture content of 61.97±0.58%.

Figure 7.11. Cold smoked flecked red-eye round herring.

7.6 Food safety and quality assurance

E. whiteheadi is a small pelagic fish, and like anchovy, it is highly susceptible to lipid oxidation due to its elevated lipid content and near-neutral pH. Maintaining quality and safety is paramount during pre-processing, smoking, and storage of the final product.

7.6.1 Microbial and histamine considerations

While specific microbial and histamine testing for smoked *E. whiteheadi* is a component of planned future research, general safety practices for small pelagic fish apply:

- ***Evisceration:*** Removal of guts is a general hygienic practice to reduce the bacterial load.
- ***Histamine risk:*** Histamine is a significant risk in small pelagic fish like anchovy, and its formation is irreversible by any processing method once it has been formed. Although not specifically documented for *E. whiteheadi*, strict cold chain management immediately post-capture is critical to prevent histamine formation. Histamine production occurs when fish are not properly iced immediately after capture, or when the cold chain is not maintained until the fish is landed. South African Regulation 692 for histamine is regulated under the Foodstuffs, Cosmetics and Disinfectants Act, Regulations Governing Microbiological standards for Foodstuffs and related matters. According to this regulation, histamine should not exceed 20 mg/100 g. At this level it will be unsafe for human consumption. A level of 10 mg/100 g (equivalent to 100 ppm) is an indication of decomposition.

The CAC (2024) specifies a maximum histamine level of 20 mg/100g**.**

7.6.2 Lipid oxidation control

A major advantage of smoking *E. whiteheadi* is the effects of the smoke on fat stability:

- ***Antioxidant effect of smoke:*** Smoked samples showed significantly lower values of secondary oxidation markers (TBARs) compared to the raw control. This suggests that phenolic compounds from the wood smoke act as free-radical scavengers, suppressing the late-stage oxidation process (conversion of primary products into malondialdehyde).
- ***Early oxidation:*** Hot smoking, which uses higher temperatures, caused slightly higher (though not statistically significant) accumulation of primary oxidation markers.

Conjugated dienes values are consistent with the idea that heat can initiate lipid oxidation. However, the wood smoke mitigated subsequent degradation.

7.6.4 Storage

After smoking, the fish should be weighed, vacuum sealed, and frozen (e.g., at −40˚C for analysis) to maintain stability.

7.6.5 Moisture content

Hot and cold smoking reduced the moisture content (63.23 ± 3.21% and 61.97 ± 0.58%) of flecked red-eye round herring compared to raw samples (Table 7.7). The reduction in moisture content is a functional outcome of the smoking process (which typically combines salting, drying, heating, and smoking steps) and is critical for preservation. The extension of shelf-life in smoked fish is attributed to a combination of lowered a_w and the uptake of antimicrobial and antioxidant components from the wood smoke.

The global CAC standard (2024) specifies a maximum moisture content for a particular category of smoked fish intended for ambient storage. For products classified as “smoke-dried fish”, the process must reduce the moisture content to such an extent that the final product can be stored and transported without refrigeration. To achieve this level of preservation and control against bacterial pathogens and fungal spoilage, the standard requires a water activity of 0.75 or less (which corresponds to a moisture content level of 10% or less).

Table 7.7. Means (± standard deviations) for moisture content (g/100g) of raw, hot-smoked, and cold-smoked flecked fillets of red-eye round herring

Component (g/100g)	**Raw *E. whiteheadi***	**Hot-smoked *E. whiteheadi***	**Cold-smoked *E. whiteheadi***
Moisture content	71.27 ± 0.64 (Highest)	63.23 ± 3.21	61.97 ± 0.58

7.7 Nutritional composition data

7.7.1 Proximate composition

Smoking causes expected changes in the macro-nutrient profile due to moisture loss (the concentration effect). There were no significant proximate differences observed between hot and cold smoked red-eye round herring samples (Table 7.8). Smoking significantly reduced moisture while increasing protein, dry matter, and ash content compared to raw fish. Smoking had no significant effect (P>0.05) on the crude fat content of raw red-eye round herring.

Table 7.8. Means (± standard deviations) for proximate composition (g/100 g) of raw, hot-smoked, and cold-smoked flecked fillets of red-eye round herring

Proximate component (g/100 g)	**Raw *E. whiteheadi***	**Hot-smoked *E. whiteheadi***	**Cold-smoked *E. whiteheadi***
Moisture	71.27 ± 0.64 (Highest)	63.23 ± 3.21	61.97 ± 0.58
Protein	22.87 ± 0.68 (Lower)	27.63 ± 2.80 (Higher)	27.87 ± 0.46 (Highest)
Ash	1.66 ± 0.10 (Lower)	4.70 ± 0.63 (Higher)	4.74 ± 0.63 (Higher)
Crude fat	5.05 ± 1.58	4.51 ± 0.55	4.96 ± 0.60

7.7.2 Essential fatty acid content

In a study following the smoking protocols as set out in this document for red-eye round herring, showed that the fatty acid content generally remained largely unchanged (Table 7.9) across raw and hot and cold smoked red-eye round herring fillet samples, demonstrating that smoking did not significantly degrade these beneficial compounds. *E. whiteheadi* contains significant levels of long-chain omega-3 fatty acids, crucial for human health. Red-eye round herring fillets are high in docosahexaenoic acid (DHA).

Table 7.9. Means (± standard deviations) for essential fatty acids (%) component of raw, hot-smoked, and cold-smoked red-eye round herring flecked fillets

Fatty Acid Composition (% of total FA)	**Raw *E. whiteheadi***	**Hot-smoked *E. whiteheadi***	**Cold-smoked *E. whiteheadi***
DHA (C22:6n-3)	25.49 ± 4.14	25.66 ± 0.31	22.70 ± 2.25
EPA (C20:5n-3)	10.48 ± 1.74	10.97 ± 1.02	11.11 ± 0.55
Palmitic acid (C16:0, SFA)	23.90 ± 0.46	23.24 ± 0.28	23.20 ± 0.40
Alpha-linolenic acid (C18:3n-3)	0.73 ± 0.17	0.63 ± 0.13	0.62 ± 0.14

Fatty Acid Composition (% of total FA)	**Raw *E. whiteheadi***	**Hot-smoked *E. whiteheadi***	**Cold-smoked *E. whiteheadi***
∑ PUFA	42.93 ± 2.36	43.05 ± 1.36	40.63 ± 1.61
∑ Omega-3 FA	38.85 ± 2.72	38.93 ± 0.86	36.07 ± 1.94
∑ Omega-6 FA	4.43 ± 0.39	4.12 ± 0.51	4.56 ± 0.60
∑ SFA	36.06 ± 0.41	36.34 ± 0.16	36.52 ± 1.03

DHA – Docosahexaenoic acid EPA – Eicosapentaenoic acid
PUFA – Poly-unsaturated fatty acids SFA – Saturated fatty acids

Key points on the fatty acid content of red-eye round herring processed according to the smoking protocols as described in this document are as follows:

- Docosahexaenoic acid (DHA, C22:6n-3) is the most abundant PUFA in red-eye round herring fillets (raw and smoked).
- Eicosapentaenoic acid (EPA, C20:5n-3) constitutes 10 to 11% of total FA in raw and smoked red-eye round herring fillets.
- A 100 g portion of smoked *E. whiteheadi* will exceed the recommended daily intake of 500 mg of DHA and EPA.

7.8 Conclusions

The hot and cold smoking of *E. whiteheadi* yields a highly valuable, protein-rich, and omega-3 fatty acid dense food source. Due to the high level of moisture in the smoked products, final products should be kept refrigerated for food safety reasons.

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CHAPTER 8
SUMMATIVE SYNTHESIS

8.1 Context for utilisation of anchovy for direct human consumption

South Africa faces persistent challenges with regard to food and nutrition insecurity, especially in the low-income population, who often have low intakes of essential fatty acids. Similarly, Southern African Development Community countries[56] continue to suffer from food and nutrition insecurity, with about 20% of the population in the region experiencing severe food insecurity. In addition, chronic malnutrition persists in 30 to 40% of the population in most SADC countries.

Although the sardine (*Sardinops sagax*) has historically been a primary source of affordable fish protein in South Africa, its productive availability within South Africa waters has declined in the last two decades. By contrast, the anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) remain abundant, and much of the annual total allowable catch (for anchovy) and precautionary upper catch (for red-eye round herring) limits have been underutilised. Also, the two species are currently primarily used for fishmeal and fish oil production rather than for direct human consumption. Increased catches of under-utilised fish resources such as anchovy could positively influence nutrition and protein food security through: stability of supply (physical access), increased supply of diverse fish food, lower food prices (affordability) and increased income (through related livelihoods). Thus, increased utilisation of under-utilised fish resources could have the impact of boosting supply and availability and lowering prices of fish protein.

An important observation is that, in most of Africa, the utilisation of processed, small fish forms the major part of the edible fish product supply. Recent years have seen growing numbers of migrants from other African countries coming into South Africa for employment opportunities and as refugees. This has resulted in a growing market for imported food from migrants' countries of origin. Increasing volumes of processed fish products of different forms and varieties from various African countries are being imported into South Africa, targeting the migrant community. With regard to fish, these come mainly in the form of sun-dried, smoke-dried or salted-dried products, meaning a market for processed, small fish already exists. Therefore, within South Africa, one group of potential consumers to target could be foreign nationals who are already used to eating such fish.

This research was part of the strategic push towards the increased utilisation of anchovy and red-eye round herring for direct human consumption through development of products aimed at the lower-end market to improve food security and nutrition. The intention was to test the new products among the local population and raise awareness about these. Other possible markets are institutional consumer groups such as school feeding schemes, correctional services and hospitals. Apart from the potential South African market, other countries within

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[56] The SADC comprises of: Angola, Botswana, The Democratic Republic of Congo, Eswatini (formerly Swaziland), Lesotho, Madagascar, Malawi. Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe.

the SADC region also provide for a huge potential market for the new anchovy products. Exports of frozen anchovy by some South African companies attest to this.

8.2 Areas and seasons for catching anchovy for human consumption
Geographic distribution and seasonality

To determine appropriate areas and seasons for catching South African anchovy for human consumption, this research synthesised information on the taxonomy, distribution, biology, ecology and life history strategy of this species in South African waters; briefly described previous attempts to process South African anchovy for human consumption and where this is done elsewhere; described the South African small pelagic fishery in general and the directed fishery for anchovy in particular that catches smaller (recruit) and larger (adult) fish off the West Coast where it has operated for several decades; documented the abundance, distribution and fish size patterns of anchovy around the coast observed during annual Total Biomass (spring/summer) surveys conducted over the past ten years and annual Pelagic Recruit (autumn/winter) surveys conducted over the past five years; and examined studies of the diets of fish, seabird and marine mammal predators of anchovy off the South Coast that may provide some information on seasonal variability in the occurrence, abundance and size of anchovy in this region, given the lack of a directed fishery for anchovy there.

Key findings

- Products for human consumption that can be derived from South African anchovy include fresh or preserved (frozen, pickled, canned, or dried) fillets or whole fish products which require larger fish for processing to be economically viable, as well as products such as ground dried fish, fish paste, etc. which can be made from fish of any size.
- Because of their life history strategy, South African anchovy show size-based distributions with smaller (younger) fish occurring predominantly off the West Coast and larger (older) fish occurring predominantly off the South Coast.
- South African anchovy is presently only caught off the West Coast (i.e., west of Cape Agulhas) with most of the catch taken from the upper West Coast (north of Cape Columbine). The relative contribution to total annual catch taken off the Southwest Cape Coast (Cape Point to Cape Agulhas) has shown a significant long-term increase.
- South African anchovy catches off the West Coast show a seasonal pattern overall and are taken predominantly in autumn and winter (March to August), but area-specific differences in temporal catch patterns are observed and are more restricted off the upper West Coast and more spread through the year off the lower West (Cape Columbine to Cape Point) and Southwest Cape coasts.
- There is a seasonal pattern in the size of anchovy caught off the West Coast, with fish being larger in spring and summer compared to those taken in autumn and winter.
- There is a spatial gradient in the size of South African anchovy caught off the West Coast, with smaller fish caught off the upper West Coast and larger fish off the Southwest Cape Coast.
- The long-standing pelagic survey programme has shown that anchovy is distributed around the South African coast, but whilst they are present off the Southwestern Cape Coast and most of the South Coast throughout the year, anchovy are typically rare or only occur in low abundance off the upper and lower West coasts (i.e. north of Cape Point) in spring and summer and off the eastern portion of the South Coast in autumn and winter.
- Anchovy show a gradient in size around the South African coast, being smaller off the West Coast and larger off the South Coast.

- Studies of the diets of predators that feed extensively on anchovy off the South Coast corroborate the presence of large fish there, whereas dietary studies on African penguin, Cape fur seal and shallow water hake found little or no seasonal variation in the dietary importance of anchovy, while those on Cape gannets and geelbek did, albeit with contrasting patterns. However, factors other than anchovy abundance such as the different feeding strategies employed by different predators and the relative densities of different co-occurring prey species including preferred prey, will also impact predator feeding patterns. This suggests caution is advisable when making assumptions about the seasonal occurrence and/or abundance of anchovy in a particular region that are based on seasonal analyses of predator diets.

8.3 Climate change factors

Information on and descriptions of (i) the impacts of climate change on coastal marine ecosystems in general and South African marine ecosystems in particular; (ii) the predicted impacts of climate change on South African anchovy and other anchovy species; and (iii) environmental drivers of South African anchovy abundance, distribution, phenology, and other attributes, was collated to identify the possible impacts of climate change on South African anchovy.

Key findings

Potential and predicted climate change impacts on anchovy

- Predicted changes in coastal marine environments arising from climate change include increased temperatures, stratification, sea levels and extreme weather events; decreased pH and dissolved oxygen levels; changes in circulation patterns, freshwater availability and lower trophic level (plankton) composition.
- Predicted and important near-future changes in the South African marine environment include increased sea surface temperatures around the entire coast, increased upwelling off the West and Southwest coasts, and increased primary production off the West Coast and in inshore waters off the Southwest and South coasts.
- Long-term observations of South Africa’s marine environment have shown:
    - Significant increases (and some small decreases) in SSTs in different regions that are attributed to climate change.
    - A significant increase in cross-shelf SST gradients off the South Coast.
    - A significant increase in upwelling off the South Coast and a tendency to increase upwelling off the West Coast.
    - Changes in copepod abundance and species composition off both the West and South coasts that, while likely linked to environmental changes such as ocean warming, are thought to be largely driven by predation by small pelagic fishes.
    - An increase in the occurrence of harmful algal blooms and consequent incidence of localised low oxygen water events in coastal waters off the West and Southwest coasts, likely due to environmental (possibly climate-driven) change.
    - An increase in the severity and duration of marine heat waves off the West and Southwest coasts, particularly in non-upwelling localities.
    - No trends in the pH, dissolved oxygen levels, or phytoplankton biomass.
- Predicted climate change impacts on anchovy include changes in distribution, abundance, phenology and physiology and other biological characteristics including body size, length at maturity, etc).

- Despite South African anchovy being considered to have an overall “medium-low” sensitivity to climate change, warming is predicted to have a strong, negative impact on this species, with biomass reductions of around 50% projected by 2050.
- Assessments of relationships between anchovy and environmental variables have shown that:
    - Sea surface temperature is the most important environmental predictor of anchovy egg, recruit and adult distributions, and adults have shown an eastward shift in their relative distribution (% of total biomass) that is significantly correlated with cross-shelf SST gradients off the Southwest and South coasts.
    - The spatial extent of anchovy optimal habitat off the West Coast has declined since the early-2000s whereas that off the South Coast has remained stable.
    - Anchovy recruitment success is strongly dependent on the successful transport of eggs and larvae from the spawning area off the Southwest and South coasts to the nursery area off the West Coast. Recruitment is positively correlated with cumulative upwelling towards the end of the upwelling season (December and March); intense upwelling at the start of the upwelling season (October and November) is likely to have a negative impact on recruitment success. Recruitment success is also partially dependent on the biomass of spawning anchovy west of Cape Agulhas.
    - A significant decrease in the average size of anchovy caught between Cape Columbine and Cape Point may be indicative of a phenological change in the timing of peak spawning (to later in the year), or a long-term effect of warming or a decline in food quantity or quality as has been observed in anchovy populations elsewhere.

8.4 Could increased harvesting of anchovy have ecosystem impacts including supporting the recovery of the sardine population?

Information on and descriptions of: (i) the ecosystem role of anchovy as predators and as prey and as mixers of the upper water column; (ii) whether utilising South African anchovy for human consumption would require an increase in exploitation rate; and (iii) anchovy-sardine interactions, was collated to assess the possible ecosystem impacts of increased harvesting of anchovy including supporting recovery of the sardine population.

Key findings

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South African anchovy play a critical role in coastal ecosystems of the West, Southwest and South coasts, particularly as forage for a wide variety of fish, seabird and marine mammal predators for whom anchovy is important and sometimes dominant prey. Changes in the abundance and availability of anchovy have large impacts on such dependent predators. Anchovy may also play a role in mixing the upper water column during spawning events.

- The fishery for South African anchovy is presently considered to be sustainable, but annual TACs are under-caught by some 43.9% on average (2000– 2023, equivalent to ca. 190 000t) and low exploitation rates (8.6% per year, on average) suggest that this species is under-utilised.
- Despite substantial efforts to develop human consumption products from Peruvian anchoveta (*Engraulis ringens*) made during the early-2000s, only relatively small quantities (<2% of the anchoveta TAC; typically >100 000t) have been processed into HCPs in each subsequent year. Barriers to increasing the quantity of anchoveta processed into HCPs include a small local demand for HCPs, increased international demand for fish

meal and oil, a small differential in the landing (off-vessel) price of anchoveta for HCPs or reduction, and businesses claiming to produce HCPs but instead systematically diverting anchoveta to fish meal factories, among others. These illustrate the difficulties likely to be encountered in developing anchovy HCPs in South Africa.

- A comparison of the population trajectories of South African anchovy and sardine show that estimates of recruitment strength of the two species, and of their total biomass (derived from annual surveys conducted over the past four decades), are significantly and positively correlated, suggesting that the dynamics of the two species are responding to the same, likely environmental, forcing. This is similar to observations of significant, positive correlations between deposition rates of anchovy and sardine scales in marine sediments in some other upwelling systems, and contrary to the regime shift hypothesis that posited species alternations between the two.

8.5 Implications

- The observed eastward shift in the relative distribution of anchovy spawners appears likely to continue, under the assumptions that cross-shelf SST gradients off the Southwest and South coasts continue to increase and the relationship between anchovy relative distribution and these gradients continues to hold. Should the biomass of anchovy spawners off the West and Southwest coasts decline below ca. 750 000t, this will have a negative effect on recruitment.
- The impact on anchovy recruitment of increased upwelling off the West and Southwest coasts will depend on when the upwelling occurs: intense upwelling early in the season (spring) will likely have a negative effect due to high advective loss of eggs and early larvae, whereas intense upwelling later in the season (summer) will likely have a positive effect.
- Increased temperatures are likely to result in decreases in anchovy body size, with attendant decreases in individual reproductive output that may impair recruitment.
- Based on the Peruvian example, large quantities of anchovy will not be needed for the development of HCPs from South African anchovy, at least in the short-term and likely also the long-term unless multiple barriers can be overcome. This, in conjunction with the present under-utilisation of South African anchovy, suggest that a fishery for this species for HCPs would likely start to use relatively small quantities (a few multiples of 10 000t) in the near (or even mid-term) future. This is likely substantially less than the 190 000t of the anchovy TAC on average that is presently not caught, indicating that development of South African anchovy for HCPs could be accommodated without a need to increase present exploitation rates of the South African anchovy. Targeting the un-caught portion of the TAC for anchovy for HCPs would therefore unlikely incur substantial ecosystem impacts.
- The observed co-variability between anchovy and sardine recruitment strength, and total biomass, suggest that increasing fishing pressure (i.e., exploitation rates) on anchovy to accommodate the development of HCPs (although this is not considered necessary for the reasons described above) appears unlikely to have beneficial effects on sardine population size.

8.6 Product development, product characteristics and markets for new anchovy and red-eye round herring products

This research investigated the viability of anchovy and red-eye round herring for human consumption by analysing the effects of hot and cold smoking on nutritional value and oxidative stability of the two species, with the aim of developing sustainable, nutrient-dense food products**.**

The project undertook development of the following products for direct human consumption: filleted hot smoked anchovy, whole hot smoked anchovy, marinated filleted anchovy, filleted hot smoked red-eye round herring, filleted cold smoked red-eye round herring, and a fish powder (as a completed food ingredient for potential fortification) made from steamed filleted red-eye round herring.

Anchovy

Anchovy is highly perishable due to high moisture and fat content, making effective preservation critical. The research investigated the viability of long-term frozen storage of whole and filleted anchovy, combined with vacuum packaging versus aerobic packaging to ensure microbial safety and quality for potential consumer markets. Contrary to the initial hypothesis, vacuum packaging did not significantly reduce microbial growth compared to aerobic packaging for long-term frozen storage of whole and filleted anchovy. This suggests that frozen storage at temperature of –18°C is the primary preservation factor rather than the exclusion of oxygen. Both packaging environments permitted the survival of psychrotrophic, facultative anaerobes (such as *Enterobacter*, *Serratia*, and *Klebsiella* species), which are capable of survival in low temperatures and varying oxygen levels. Both whole and filleted anchovy stored under both packaging conditions complied with South African microbiological standards for foodstuffs (Regulation R.692), specifically regarding TVCs and the absence of *E. coli*. The results indicate that either packaging method can sustain the production of safe anchovy products for human consumption, potentially allowing for cost-effective production for the lower-end market. However, physical quality degradation in fillets suggests that while safe, enzymatic spoilage remains a challenge.

Filleted, hot smoked anchovy, stored in vacuum and aerobic bags, respectively, may be safe for human consumption up to 7 days of refrigerated storage (less than 1 000 000 cfu/ml). Whole hot-smoked anchovy showed higher bacterial counts compared to filleted samples, especially in terms of *Enterobacteriaceae*. This can be attributed to the gut which remained in the whole anchovy, whereas in the filleted samples, the gut was rinsed away with water during the filleting process. Vacuum packaging has shown to inhibit the increase in bacterial counts from day 4 to day 7 of refrigerated storage. Thus, for an extended shelf-life of smoked anchovy, vacuum packaging should be considered. Smoking increased the protein content of filleted and whole anchovy due to the concentration factor.

The nutritional content of smoked anchovy was investigated, and results showed that smoked anchovy is an excellent source of essential omega-3 fatty acids, particularly eicosapentaenoic acid and docosahexaenoic acid. The fat extracted from the smoked samples contained 9 to 10 mg/g of EPA and 11 to 13 mg/g of DHA. The concentration is influenced by the smoking processing method, where EPA and DHA levels range from as low as 1 mg/g in raw anchovy to up to 13 mg/g in smoked anchovy without heads and smoked fillets. Dietary recommendations for European adults suggest a combined intake of between 250 and 500 mg/day of EPA and DHA for cardiovascular health. Because the preformed EPA and DHA from fish are readily available for human metabolism, consuming even modest portions of smoked anchovy or fillets can significantly contribute to meeting these daily targets.

In terms of amino acid content, the smoked anchovy contained a highly balanced profile of essential and non-essential amino acids. Key amino acids (including alanine, glycine, valine, leucine, isoleucine, proline, methionine, serine, threonine, phenylalanine, aspartic acid, glutamic acid, lysine, histidine, and tyrosine) are present in high amounts, ranging from 10 to 70mg/g. The recommended daily allowance for essential amino acids varies by body weight (e.g., leucine at 39–42mg/kg, lysine at 30–38mg/kg, and valine at 24–26mg/kg). A standard 100g serving of smoked anchovy provides enough essential amino acids to meet the RDA for a healthy adult weighing between 60 and 70kg.

In terms of food safety, based on the South African Regulations relating to maximum levels of metals in foodstuffs (June 2018), the heavy metal safety profile for smoked anchovy is largely positive. Toxic heavy metals such as lead (Pb) tested below the maximum legal limit (0.3 mg/kg wet weight basis) with average values of 0.013 mg/kg for smoked samples and 0.024 mg/kg for raw samples (based on wet weight basis). While methylmercury was not determined, the total mercury (Hg) levels in raw anchovy was on average 0.013 mg/kg and ranged between 0.017 and 0.021 mg/kg for the hot-smoked anchovy products. The total arsenic (As) levels for the different anchovy products ranged between 5 (for hot-smoked) and 8 mg/kg (for raw) on dry weight basis across filleted and whole smoked, and raw samples. On wet weight basis, with hot-smoked anchovy having a water content on average of 54% (based on proximate composition) across whole and filleted hot-smoked product types, the arsenic was between 2.3 mg/kg and 3.45 mg/kg, and 3.68 mg/kg for the raw samples. However, the analytical method used only measured total arsenic and did not distinguish between highly toxic inorganic arsenic and relatively harmless organic arsenic, of which last mentioned is predominantly found in marine fish.

Red-eye round herring

The research confirms that red-eye round herring is a viable alternative to sardine for human consumption. Processing through hot- or cold-smoking effectively concentrates nutrients without degrading essential fatty acids. The antioxidant properties of the smoking process may enhance the product's shelf-life stability by preventing extensive lipid oxidation. The resulting products are rich in protein, B-vitamins, retinol, and omega-3 fatty acids, positioning them as an excellent tool for addressing nutritional insecurity in South Africa. Due to moisture content remaining above 10% (approx. 62%), the smoked products are not shelf-stable at ambient temperatures and must be kept refrigerated or frozen to ensure safety. Future research should include microbial safety testing (specifically for *Listeria* and *Clostridium*) and comprehensive sensory analysis to gauge consumer acceptance. The development of value-added products, such as instant fish soup powders incorporating red-eye round herring, should be pursued to diversify market offerings.

8.7 Market research

A survey of 1 000 people on their opinion about anchovy was conducted by a professional market research company around the general question: "Which kinds of seafood do you like?"

Only 13% indicated anchovy and, of these, only 4% were from the low-income group. The most preferred seafoods were hake, tuna, and pilchards/ sardines (in that order). However, the low preference for anchovy could be attributed to consumers not being familiar with anchovy. In addition, anchovy and anchovy products were perceived as a "low-profile" seafood and not considered by many as a food staple. It was seen as a luxury food (because of the expensive forms currently available on the retail shelves and on pizza) and, at the moment, anchovy has a low penetration into low-income households. On the positive side, anchovy was recognised as a source of essential amino acids and omega-3 fatty acids, which provides for an opportunity to leverage the perception of anchovy as a health food by developing, and marketing attractive affordable forms of anchovy, especially among low-income, female, and young-of-age seafood eaters.

The project has developed a basic guideline for the processing of hot- and/or cold-smoked South African anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) based on the aforementioned laboratory trials that investigated the effects of smoking on the macro- and micro-nutritional content, mineral content, and microbial load of *E. encrasicolus* and *E. whiteheadi*. By meticulously following these preparation steps, focusing particularly on proper evisceration and strict control of temperature (especially chilling before processing to mitigate histamine risk, followed by refrigeration of the smoked products), the hot smoking process can transform the currently underutilised anchovy and red-eye into a nutritious, safe, and value-added product, thereby addressing the goals of increasing the availability of healthy fish protein for low-income consumers.

CHAPTER 9
CONCLUSIONS

From strategic context and viability collectively, the research project investigated and reported on the scientific and commercial viability of utilising South African anchovy (*Engraulis encrasicolus*) and red-eye round herring (*Etrumeus whiteheadi*) for direct human consumption. Faced with the depletion of traditional sardine resources and persistent malnutrition in South Africa, the research findings demonstrate that these underutilised pelagic species could serve as sustainable, safe, and nutrient-dense alternatives for the lower-to-middle income (LSM 4–7) markets. The red-eye round herring powder is a product with the potential as an ingredient for fortification in multiple food product formulations (for example, instant soup and baked biscuits).

The determination of where and when targeted fishing for anchovy for human consumption will depend on the product to be developed, given that some products require large fish whereas others do not. Because of their spatially differentiated anchovy life history strategy the seasons and areas where there is a high likelihood of catching small (<10 cm CL) or large (>10 cm CL) anchovy will differ.

Arising from their life history strategy, and as indicated by catch patterns of the present directed anchovy fishery and observations made during both the Pelagic Recruit and Total Biomass surveys, small anchovy are available and abundant in inshore waters off the West Coast, including the western Agulhas Bank (off the Southwest Cape Coast), and are presently caught in all months of the year excluding December and January. Targeting of small anchovy for processing into products for human consumption could be undertaken from any of the designated pelagic fish landing sites on the West Coast (Lamberts Bay, Laaiplek, St Helena Bay, Saldanha Bay, Cape Town, Hout Bay, Hermanus and Gans Bay). However, and given the pulsed nature of their occurrence in waters to the north of Cape Town indicated by fishery data, fishing from harbours with easy access to the Western Agulhas Bank such as Hermanus and Gans Bay would be preferable as that would enable fish to be caught for most of the year. Targeting of smaller anchovy on the South Coast appears unlikely to be successful given their low occurrence there.

Based on their life history strategy, large anchovy is available and abundant in inshore waters of the western Agulhas Bank in both autumn and spring, and presumably then throughout the year. And whereas the average size of anchovy taken on the western Agulhas Bank in past decades by the present fishery is <10 cm CL, large fish are caught in most years and the average size has been close to 10 cm CL in several years, indicating that these fish are present there. Pelagic Recruit and Total Biomass surveys also show that large anchovy is also available and abundant in inshore waters along the entire South Coast to Port Alfred in spring but not in autumn, with no or few anchovy observed on the easternmost portion of the South Coast in autumn in the past five years.

Studies of the diets of predators that feed extensively on anchovy off the South Coast corroborate the presence of large individuals there. However, some predators show no seasonal variation in anchovy consumption whereas others do, and factors other than anchovy abundance will also impact predator feeding patterns, suggesting caution when making assumptions about the seasonal occurrence and/or abundance of anchovy off the South Coast. Targeting of large anchovy for processing into products for human consumption could be undertaken from designated pelagic fish landing sites on the western Agulhas Bank (Hermans and Gans Bay) throughout the year, and likely throughout the year from Mossel Bay as well. Large anchovy would also be available in inshore waters in spring (and likely summer) to vessels fishing from St Francis Bay and Gqeberha, but these fish have been absent from the Algoa Bay region during autumn/ winter of recent years.

The investigation into the frozen storage of anchovy yielded critical cost-saving insights for the industry. Contrary to the assumption that vacuum packaging is superior for microbial control, the research established that there is no statistically significant difference ($P>0.05$) in total viable counts or coliform presence between vacuum and aerobic packaging after long-term frozen storage. Both methods maintained microbial loads well within regulatory safety limits ($<10^6$ CFU/g for TVC) and ensured the absence of *E. coli*. However, while microbial safety is assured under both conditions, the presence of psychrotrophic facultative anaerobes (e.g., *Klebsiella oxytoca*, *Serratia* spp.) and physical deterioration in fillets suggests that frozen storage at −18°C is the primary preservation factor, rather than oxygen exclusion. Consequently, processors can potentially utilise less expensive aerobic packaging for frozen distribution without compromising food safety, provided the cold chain is strictly maintained.
The study on *Etrumeus whiteheadi* established it as a high-quality, medium-fat fish offering high biological value protein and significant levels of essential fatty acids. Crucially, the research demonstrated that thermal processing via hot and cold smoking does not degrade the fatty acid profile; rather, it effectively concentrates nutrients due to moisture reduction. Furthermore, smoking provided a significant technological advantage by improving lipid stability. Smoked samples exhibited significantly lower TBARs values compared to raw frozen samples, indicating that phenolic compounds in wood smoke act as antioxidants, retarding lipid oxidation and extending shelf-life. With a 100 g portion exceeding recommended daily intakes for EPA and DHA, smoked red-eye round herring is validated as a nutritionally superior product for food security initiatives.

Bridging the gap between scientific analysis and consumer plates, the product development phase proved that these species are highly acceptable when integrated into culturally relevant convenience meals. Sensory evaluation of anchovy revealed high acceptance for anchovy-based dishes, with the "Anchovy and dumpling bake" achieving a taste score of 8.31 out of a possible 9, and pasta dishes scoring consistently high (7.4–7.5/9). This confirms that "hiding" or incorporating anchovy into savoury bases overcomes potential barriers regarding the fish's strong flavour or appearance.

Regarding red-eye round herring, the successful formulation of an instant fish soup powder demonstrates the species' versatility as a fortifying ingredient for dry foods, offering a potential protein source for food-insecure populations. However, future research into the shelf-life of the fish powder is crucial, in addition to product development using the fish powder as a fortification ingredient. The full nutritional content (proximate composition, mineral and vitamin content, and fatty acid profile) of the developed fish powder from red-eye round herring is something that needs to be determined and documented in future research projects.
This research provides a comprehensive "boat-to-plate" solution for the South African small pelagic fishery. It confirms that (1) expensive vacuum packaging is not strictly necessary for the safety of frozen bulk anchovy, (2) smoking effectively preserves the nutritional integrity and stability of red-eye round herring, and (3) value-added culinary applications (convenience meals and powders) have great potential for high consumer acceptance. These findings support

the diversification of the fishery sector, offering tangible pathways to improve national nutrition security, create jobs in processing, and reduce reliance on diminishing sardine stocks.

APPENDIX 1: PROJECT DELIVERABLES

The table below lists the final project deliverable numbers, their short descriptions and dates of delivery

No.	Description	Target date
1	Report on types and product forms of anchovy acceptable to consumers	30 Sep 2022
2	Report on the potential market size for the new anchovy products	31 Jan 2023
3	Report on new anchovy products for human consumption	31 Aug 2023
4	Report on geographic areas and seasons for catching anchovy suitable for human consumption	31 Jul 2024
5	Report on content proximate composition, mineral and fatty acid profile of anchovy products	30 Nov 2024
6	Report on consumer awareness of the new anchovy products	15 Dec 2024
7	Report on whether increased utilisation of anchovy could support recovery of sardine	30 Apr 2025
8	Guidelines for handling and processing of anchovy for human consumption	31 Dec 2025
9	Final Report	28 Feb 2026

APPENDIX 2: SURVEY INSTRUMENT USED TO INVESTIGATE CONSUMER PERCEPTIONS

Food survey

Hello!

This is a survey about food and how and what people like you eat. It should take you less than 20 minutes to complete. We hope you enjoy it!

You'll need to give us your name and contact details if you'd like to be entered into the lucky draw, but that is the only way in which your info will be used.

Once the survey has closed (in about one week's time), a lucky draw will be held and three people will each win a R1,000 Takealot voucher.

Before we begin, we just need to find out a bit about you and make sure you're not allergic to any of the products we're interested in (otherwise we'd be wasting your time).

1) Which of these age categories do you fall into?*

( ) Age 17 or younger **[close]**

( ) 18-24 ( ) 25-29 ( ) 30-34

( ) 35-39 ( ) 40-49 ( ) 50-59 ( ) 60+

2) Where are you based? *

( ) In South Africa

( ) Somewhere else **[close]**

3) Are you allergic to any of these products?*

[ ] Dairy products (milk / cheese / yoghurt etc.)

[ ] Seafood, fish, shellfish, etc. **[close]**

[ ] Nuts

[ ] None of these

Page exit logic: Skip / Disqualify LogicIF: ((#1 Question "Which of these age categories do you fall into?" is one of the following answers ("Age 17 or younger") OR #2 Question "Where are you based? " is one of the following answers ("Somewhere else")) OR #3 Question "Are you allergic to any of these products?" is one of the following answers ("Seafood, fish, shellfish, etc.")) THEN: Disqualify and display: "Sorry, you do not qualify to take this survey. We need to hear from adults age 15+ who live in South Africa and who AREN'T allergic to seafood products. But thanks for being willing to take our survey! "

SHOPPING FOR FOOD

4) Where do you and your household generally shop for food?

[ ] Supermarkets like Shoprite, SPAR, Boxer, Makro, Game, Checksave

[ ] Wholesalers like Jumbo, Kit Kat, cash & carry stores

[ ] Spaza stores, township supermarkets

[ ] Online e.g. Pick n Pay's website

[ ] Delivery apps like Checkers Sixty60, Pick n Pay asap!, OneCart

[ ] Factory outlets and farm shops

[ ] Specialist stores like delis, greengrocers, butchers, fish shops

[ ] Health shops like Wellness Warehouse, Clicks

[ ] Garage shops, convenience stores

[ ] Markets that sell fresh food e.g. vegetables, fish

[ ] Somewhere else: ____*

THE FOOD YOU EAT

5) How healthy would you say the food you eat is in general? Please use a scale from 1 to 5 where 1 means you don't think your food is healthy at all and 5 means you think the food you eat is perfectly healthy. Please be honest :-)

( ) 1 - I don't think the food I eat is healthy at all to ( ) 5 - the food I eat is super-healthy + ( ) I don't know.

6) How easy is it for you to find healthy food? Please use a scale from 1 to 5 where 1 means it's really difficult and 5 means it's really easy.

( ) 1 - really difficult to ( ) 5 - really easy + ( ) I don't know

7) How affordable is healthy food for you? Please use a scale from 1 to 5 where 1 means it's very expensive and 5 means it's very affordable.

( ) 1 - very expensive to ( ) 5 - very affordable + ( ) I don't know

UNPACKING 'HEALTHY'

8) Which of the following would you describe as 'healthy'? You can choose as many options as you like.

[ ] Omega-3 fatty acids [ ] Essential amino acids

[ ] Probiotics [ ] 100% plant-based diet

[ ] Protein powders [ ] Collagen

[ ] Red meat [ ] Chia seeds

[ ] Cannabis oil [ ] Homeopathic remedies

[ ] All of the above

[ ] None of the above

[ ] I don't know

Logic: Hidden unless: #8 Question "Which of the following would you describe as 'healthy'? You can choose as many options as you like." is not one of the following answers ("None of the above","I don't know")

Piping: Piped Values From Question 8. (Which of the following would you describe as 'healthy'? You can choose as many options as you like.)

9) Which of them do you personally consume?

[ ] None of them

10) Would you say you know what 'essential amino acids' are? We're just interested; it's not a test :-)

( ) I know exactly what essential amino acids are

( ) I know a little about essential amino acids

( ) I don't know much at all about essential amino acids

( ) I know nothing about essential amino acids

Validation: Max. answers = 3 (if answered)

Logic: Show/hide trigger exists. Hidden unless: #10 Question "Would you say you know what 'essential amino acids' are? We're just interested; it's not a test :-) " is one of the following answers ("I know exactly what essential amino acids are","I know a little about essential amino acids","I don't know much at all about essential amino acids")

11) Which of these would you say are the best sources of essential amino acids? Please choose up to three.

[ ] I don't know

[ ] Red meat [ ] Fish [ ] Supplements

[ ] Quinoa [ ] Eggs [ ] Tofu

[ ] Cheese [ ] Edamame [ ] Legumes [ ] Seeds

Logic: Hidden unless: #11 Question "Which of these would you say are the best sources of essential amino acids? Please choose up to three." is not exactly equal to ("I don't know")

Piping: Piped Values From Question 11. (Which of these would you say are the best sources of essential amino acids? Please choose up to three.)

12) Which of them do you personally consume?

[ ] None of them

13) Would you say you know what 'omega-3 fatty acids' are? Again, we're just interested; it's not a test :-)

( ) I know exactly what omega-3 fatty acids are

( ) I know a little about omega-3 fatty acids

( ) I don't know much at all about omega-3 fatty acids

( ) I know nothing about omega-3 fatty acids

Validation: Max. answers = 3 (if answered)

Logic: Show/hide trigger exists. Hidden unless: #13 Question "Would you say you know what 'omega-3 fatty acids' are? Again, we're just interested; it's not a test :-) " is one of the following answers ("I know exactly what omega-3 fatty acids are","I know a little about omega-3 fatty acids","I don't know much at all about omega-3 fatty acids")

14) Which of these would you say are the best sources of omega-3 fatty acids? Please choose up to three.

[ ] I don't know

[ ] Oily fish like sardines, mackerel, salmon [ ] Flaxseed

[ ] Supplements [ ] Chia seeds [ ] Walnuts

[ ] Soybeans [ ] Omega-3 enriched eggs [ ] Spinach

[ ] Brussels sprouts [ ] Oysters [ ] Fortified margarine

Logic: Hidden unless: #14 Question "Which of these would you say are the best sources of omega-3 fatty acids? Please choose up to three." is not exactly equal to ("I don't know")

Piping: Piped Values From Question 14. (Which of these would you say are the best sources of omega-3 fatty acids? Please choose up to three.)

15) Which of them do you personally consume?

[ ] None of these

16) Would you say you know what protein is? We're just interested; it's not a test :-)

( ) I know exactly what protein is

( ) I know a little about protein

( ) I don't know much at all about protein

( ) I know nothing about protein

Validation: Max. answers = 3 (if answered)

Logic: Hidden unless: #16 Question "Would you say you know what protein is? We're just interested; it's not a test :-) " is one of the following answers ("I know exactly what protein is","I know a little about protein","I don't know much at all about protein")

17) Which of these would you say are the best sources of protein? Please choose up to three.

[ ] I don't know

[ ] Eggs [ ] Almonds

[ ] Chicken / turkey breast (white meat) [ ] Lean red meat

[ ] Fish [ ] Shellfish

[ ] Quinoa [ ] Cottage cheese

[ ] Plain yoghurt [ ] Milk

[ ] Lentils [ ] Chickpeas

[ ] Peanut butter [ ] Tofu

[ ] Pumpkin seeds [ ] Protein powders

FOOD PRIORITIES

18) When it comes to deciding what to eat, different people prioritise different things. Which of these would you say is your MAIN priority?

( ) Fresh fruit

( ) Fresh vegetables

( ) Carbs like bread, pasta

( ) Food that gives you energy

( ) Food that makes you feel full

( ) Protein-rich food

( ) Iron-rich food

( ) Food that is affordable

( ) Food that tastes delicious

( ) Food that is easy to prepare

( ) Food that my kids like

( ) I don't know / I don't prioritise anything

Piping: Piped Values From Question 18. (When it comes to deciding what to eat, different people prioritise different things. Which of these would you say is your MAIN priority?)

19) And what would you say is your NEXT biggest priority?

( ) Don't know / I don't have any other priorities

Piping: Piped Values From Question 19. (And what would you say is your NEXT biggest priority?)

20) And what would you say is your NEXT biggest priority?

( ) Don't know / I don't have any other priorities

Piping: Piped Values From Question 20. (And what would you say is your NEXT biggest priority?)

21) And what would you say is your NEXT biggest priority?

( ) Don't know / I don't have any other priorities

THE FOOD YOU EAT

22) Which of these do you eat or drink at least once a week?

[ ] Fresh milk / cheese / yoghurt / cottage cheese

[ ] Fermented milk products amasi / kefir / mageu

[ ] Eggs

[ ] Red meat (e.g. beef)

[ ] White meat (e.g. chicken, pork)

[ ] Fish (e.g. tuna, sardines, pilchards, anchovies, hake, salmon, etc.)

[ ] Shellfish (e.g. mussels, shrimp, oysters)

[ ] Beans, lentils, soya

[ ] Oats, quinoa

[ ] Protein powder / supplements

[ ] Nuts, peanut butter

[ ] Pumpkin seeds

[ ] None of these

Piping: Piped From Question 22. (Which of these do you eat or drink at least once a week?)

In an average week, how many times do you have each of these?

	Once	2 or 3 times	Most days	Every day	It depends

FOCUS ON SEAFOOD

23) Let's focus on seafood. Seafood includes fish like sardines, snoek, hake, pilchards, salmon, kabeljou, anchovies, tuna, etc. and also includes shellfish like crab, prawns, mussels, calamari, etc.

How do you feel about seafood in general?

( ) I love all kinds of seafood

( ) I like most seafood

( ) I like some seafood

( ) I don't like most seafood

( ) I don't like any seafood at all **[SKIP TO TYPES]**

24) Which of these kinds of seafood do you like?

[ ] Tuna [ ] Pilchards / sardines [ ] Hake

[ ] Salmon / trout [ ] Anchovies [ ] Calamari, octopus

[ ] Prawns [ ] Lobster [ ] Snoek

[ ] Kabeljou / cob [ ] Kingklip [ ] Mussels

[ ] Oysters [ ] Crab [ ] Scallops

[ ] Other: _____________*

25) What 'format' of seafood do you like?

[ ] Canned [ ] Fresh (to be cooked at home)

[ ] Frozen & processed e.g. hake fillets, fish fingers [ ] Frozen & whole

[ ] Salted and dried (e.g. bokkoms) [ ] Smoked

[ ] Pickled / marinated [ ] Sushi [ ] Paté

[ ] Spread / paste [ ] Fish oil [ ] Other: _______*

26) What kind of packs do you like to buy your seafood products in?

[ ] Canned [ ] Pouch [ ] Box

[ ] Bottle [ ] Plastic container [ ] As little packaging as possible

[ ] I don't personally ever buy seafood products

FOCUS ON A FEW TYPES OF SEAFOOD

Validation: Max. answers = 3 (if answered)

27) In this list of products, which would you say are the three TASTIEST? You can choose up to three.

[ ] Canned tuna [ ] Canned pilchards in sauce

[ ] Canned sardines in oil [ ] Anchovies

[ ] Fresh fish [ ] Frozen hake

[ ] Mussels [ ] None of them are tasty

[ ] I don't know

28) In this list of products, which would you say are the three best in terms of PRICE AND VALUE FOR MONEY? You can choose up to three.

29) In this list of products, which would you say are the three that are the EASIEST TO FIND when you want to buy them? You can choose up to three.

30) In this list of products, which would you say are the three that are the EASIEST or most CONVENIENT TO PREPARE A MEAL WITH? You can choose up to three.

31) In this list of products, which would you say are the three that are the EASIEST or most CONVENIENT TO STORE AT HOME? You can choose up to three.

Flavoured products

32) You can get 'plain' seafood products, where it's just the seafood, no flavours, sauces, etc. or more recently you can get seafood products that come in new and different flavoured sauces, like curry sauce, or there are green peppers or olives added, or something else has been done to it before it is sold to you. How do you feel about new sauces and flavours and added things like this?

( ) I can't stand it - give me the plain version

( ) I'm not sure about new flavours and versions

( ) I quite like new flavours and versions

( ) I absolutely love the new flavours and versions

FOCUS ON ANCHOVIES

Just in case you're not sure, anchovies are small, fatty fish. Most of the time in South Africa, anchovies have been filleted and salted. They are similar to but different from sardines (sardines are larger and a bit less fatty).

33) In which of these ways do you buy / eat anchovies?

[ ] I never eat anchovies **[SKIP TO Q35]**

[ ] On pizza [ ] Marinated fillets [ ] In sunflower oil [ ] Anchovy paste

[ ] Smoked [ ] Salted [ ] Dried [ ] Fresh

[ ] Canned [ ] In pouches [ ] Other: __________*

34) How often do you eat anchovies?

( ) At least a few times a week ( ) About once a week

( ) A few times a month ( ) About once a month

( ) Less often

35) How would you rate anchovies in terms of how healthy they are for you?

( ) 1 Very unhealthy to ( ) 5 Super-healthy + ( ) Don't know

36) How would you rate anchovies in terms of their appeal to other people in general?

( ) 1 No-one likes anchovies to ( ) 5 Everyone loves anchovies + ( ) Don't know

37) How would you rate anchovies in terms of how safe they are to eat?

( ) 1 They can easily cause sickness to ( ) 5 They're perfectly safe to eat + ( ) Don't know

38) Would you say anchovies are an everyday kind of food or more of a treat or luxury?

( ) Everyday food ( ) Treat or luxury ( ) Somewhere in between ( ) Don't know

DEMOGRAPHICS

Almost done! Please tell us a little about yourself so we can do some analysis across different groups of people (e.g. men vs women, older people vs younger people, etc.) and don't forget to leave your details if you want to be entered into the lucky draw.

39) Are there any things on this list that you can't or choose not to eat?

[ ] Red meat [ ] All meat including chicken

[ ] Eggs [ ] Dairy products

[ ] Nuts [ ] No, I eat everything

40) Do you identify as ...*

( ) Female ( ) Male ( ) Self-described: ____________ ( ) Prefer not to say

41) Which of these best describes your employment status? The options may not match you perfectly – please choose the closest description.*

( ) Learner at school ( ) Studying at a tertiary institution

( ) Working full-time ( ) Working part-time

( ) Homemaker ( ) Retired

( ) Unemployed (looking for work)

42) How many people (including kids) live in your household, on average?

( ) 1 (it's just me) ( ) Me + 1 other person

( ) Me + 2 or 3 other people ( ) Me + 4 or more other people

43) Are their kids in your household?

( ) Yes ( ) Sometimes ( ) No

44) Which of these do you have in your home?

[ ] Fridge [ ] Microwave oven [ ] Stove [ ] Oven [ ] None of these

45) How would you describe the area where you live?*

( ) City or town centre / business district ( ) Suburb ( ) Township ( ) Rural area

46) What is your approximate household income in an average month? This is the total of all the money all the income earners in your household make, before tax or any deductions. This could be salaries, wages, grants, child support, interest on investments. We just need your best guess. *

( ) Less than R5,000 per month ( ) R5,000 - R9,999 ( ) R10,000 - R19,999

( ) R20,000 - R29.999 ( ) R30,000 - R49,999 ( ) R50,000 - R99,999

( ) R100,000 or more per month ( ) I prefer not to say

47) What kind of income does your household rely on?

[ ] Salary or salaries [ ] Wage or wages

[ ] Self-employment / income from a business [ ] Pension / retirement income

[ ] SASSA grant/s [ ] Other income e.g. investments, rental income

[ ] Contributions from other people / family members

48) Which province do you live in?*

( ) Eastern Cape + which city ( ) Free State + which city

( ) Gauteng + which city ( ) KwaZulu-Natal + which city

( ) Limpopo + which city ( ) Mpumalanga

( ) North West ( ) Northern Cape

( ) Western Cape + which city

55) Would you like to enter the lucky draw?*

( ) Yes please! ( ) No thanks

56) Please tell us how to get hold of you if you're a lucky winner. Your personal details will not be used for any other purpose.*

First name, Surname, Daytime cell number, E-mail address

Thank You! Thank you for taking our survey. We really appreciate your input.

APPENDIX 3: OVERALL CAPACITY BUILDING REPORT

Name	Degree	Research topic
Ziyanda Phike	PhD Food Science and Technology	Influence of feed modification on biochemical, physical chemical and sensory attributes of farmed Mozambique tilapia (*Oreochromis mozambicus*)
Thokozani Lumbo	MSc Food Science and Technology	Impact of cold- and hot-smoking on microbial and chemical quality of vacuum-packed anchovy
Dylan-Jordan Engelbrecht	BSc Food Science & Technology	Effects of frozen storage on the microbial load of whole anchovies (*Engraulis encrasicolus*) stored under vacuum vs. aerobic conditions
Itumeleng Malemoga	BSc Food Science & Technology	The effects of vacuum vs. aerobic packaging on the microbial quality of frozen filleted South African anchovies
Realeboha Lesedi Nkoe	BSc Biotechnology and Consumer Science	Proximate, fatty acid composition and lipid oxidation of hot vs. cold-smoked red-eye round herring

APPENDIX 4: LIST OF PUBLICATIONS

AUTHOR / CO-AUTHOR	TITLE OF PUBLICATION
Dr Carl van der Lingen	Fany Sardenne, Jean-Marie Munaron, Yonela Geja, Enora Jaffrezic, Marie Vagner, Laure Pecquerie and **Carl van der Lingen**. 2026. Long-chain omega-3 fatty acids and metallic elements in small pelagic fish from South Africa from a human consumption perspective. *Journal of Food Composition and Analysis*, 152, April 2026, 109018. doi:https://doi.org/10.1016/j.jfca.2026.109018