Climate change impacts on a dominant species: dinoflagellate blooms and sardine in the southern Benguela

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Some predicted effects of climate change on marine ecosystems

- Increasing sea temperature
- Increasing sea level
- Increasing extreme weather events
- Decreasing dissolved oxygen
- Decreasing pH
- Changes in salinity
- Changes in circulation patterns
- Changing species distributions
- Increasing harmful algal blooms (HABs)
Harmful Algal Blooms

Favourable conditions of light, nutrient availability (eutrophication) and warm stratified waters can trigger algal blooms, typically (but not always) dominated by dinoflagellates (red tides)

Pose threats to human health (toxic seafood, respiratory and skin irritation from red-tide aerosols)

Fish kills (directly via toxicity and indirectly via anoxia following bloom decay) and marine mammal strandings; negative impacts on aquaculture

Apparent increase in frequency, severity and geographic distribution of HABs worldwide has prompted international cooperation on HABs
HABs in the southern Benguela

HABs common in the southern Benguela, predominantly non-toxic Dinophycae

Most dinoflagellate blooms west of Cape Agulhas, typically during Jan-May; spatial difference in species composition

Toxic species cause mass mortalities of fish, shellfish, marine mammals and seabirds

Paralytic (PSP) and Diarrhetic Shellfish Poisoning (DSP) common

Harmful effects of high biomass, non-toxic blooms include marine organism mortality arising from hypoxia or anoxia, and mechanical or physical damage

What does this have to do with sardine?

Reported dinoflagellate-dominated red tides (1989-1997)

Species composition (1989-1997)

Pitcher and Calder (2000)
The Cape Town sardine run of late-2011 (i)

Sardine very close inshore and/or washed up from several localities around Cape Town during early to mid-November 2011; “trapped close to beach by seals”, “feebly swimming and dying” and “thin and weak”; and “seabed littered with dead pilchards”. Fish preyed upon by seals, seabirds and humans.

Thought by some to be due to “cold shock”; by others linked to bloom of *Gonyaulax polygramma* extending from St Helena Bay to Walker Bay.
DAFF acoustic survey conducted every spring to estimate abundance and map distribution of sardine, anchovy and redeye round herring.

Fish biological data (length, weight, age, reproductive state, condition etc) collected.

Also abiotic data and phyto-, zoo- and ichthyoplankton samples.
2011 Pelagic Spawner Biomass survey – fish (ii)

Length-weight relationships determined for each species and used to calculate condition factor:

CF = observed weight/expected weight

Spatial distribution of mean CF plotted

**Average Condition Factor: Redeye**

- **Above-average**
- **Below-average**

Size proportional to deviation from average

**Anchovy**

- $y = 0.0135x^{2.8475}$
- $r^2 = 0.9651$
- $n = 2000$

**Redeye**

- $y = 0.0115x^{2.9745}$
- $r^2 = 0.8717$
- $n = 1484$

**Sardine**

- $y = 0.0084x^{3.0911}$
- $r^2 = 0.9844$
- $n = 2713$
2011 Pelagic Spawner Biomass survey – fish (iii)

Sardine CF showed marked spatial pattern, with low CF inshore off the south coast (particularly low off Mossel Bay) and high CF offshore.

No such pattern observed for anchovy or redeye.

What caused the low sardine CF inshore (and of fish from CT sardine run)?
2011 Pelagic Spawner Biomass survey – environment (i)

Normal SST pattern but anomalous SSS pattern with high salinity (>35.5 g.kg\(^{-1}\)) water over WAB and CAB

High salinity water extended down 50-70m

Hypoxic (<1.5 ml.l\(^{-1}\)) conditions at the bottom inshore CAB

Anomalous oceanographic conditions
Satellite data showed high chlorophyll a levels inshore off the west and south coast from mid-October to mid-November.

Peak concentrations between Cape Agulhas and Plettenberg Bay in early-November.
Small (<100µm) dinoflagellates (including mixotrophic *Gonyaulax polygramma* and several colourless, heterotrophic genera e.g. *Protoperidinium* and *Gyrodinium*) completely dominated net (>10µm) phytoplankton community inshore between Cape Columbine and Plettenberg Bay.
2011 Pelagic Spawner Biomass survey – environment (iv)

Dinoflagellates moderately abundant (>25,000 cells.L\(^{-1}\)) between Cape Columbine and Plettenberg Bay; *Gonyaulax polygramma* abundant (>200,000 cells.L\(^{-1}\)) off Cape Peninsula and Mossel Bay (area of lowest sardine CF)

*G. polygramma* blooms observed off SA coast previously (first reported in False Bay in 1962); responsible for fish and invertebrate kills from anoxia following decay

Abundance of all dinoflagellates and of *G. polygramma* at inshore CTD stations
2011 Pelagic Spawner Biomass survey – synthesis

1. Marked spatial pattern in sardine CF: fish inshore in poor condition (cf CT 2011 sardine run) and those offshore in good condition

2. No spatial pattern in CF of either anchovy or redeye

3. Anomalous oceanographic conditions (high salinity water and hypoxic bottom waters off CAB) observed off the south coast

4. High chlorophyll a levels in surface waters inshore the south coast before and during survey; dinoflagellates (particularly *G. ploygramma*) dominated inshore phytoplankton community - also anomalous (cf CT 2011 sardine run)

5. Why did these anomalous conditions negatively impact sardine but not anchovy or redeye?
Why only sardine? (i)

Differences in branchial basket morphology (used to retain plankton prey) - sardine have many more gill rakers giving a smaller gill raker gap (i.e. finer filtering mesh) than either anchovy or redeye.

Effects on dietary composition with sardine feeding on smaller prey (different denticle structure further aids retention of small particles).
Why only sardine? (ii)

Both sardine and anchovy directly observed (in laboratory experiments) to filter-feed (not yet for redeye).

Sardine can retain very small particles (down to 17µm) whereas anchovy can only retain particles > 200µm.
Why only sardine? (iii)

Sardine (but not anchovy nor redevye) able to retain on their gill rakers the small dinoflagellates that bloomed off the west and south coast in spring 2011

We hypothesize that sardine “irritated” in some way by dinoflagellates (via retention when feeding and possibly also when respiring) and so avoided blooms

Sardines inshore of blooms were coastally trapped, where they lost condition because of a cessation of feeding and probable respiratory stress due to crowding in small water volumes, and likely experienced high predation (cf Cape Town 2011 sardine run)

Un-developed gonads of poor condition fish suggested prolonged starvation (either no gonad development or gonad resorption following atresia)

Implications for spawning success and subsequent recruitment strength – likely to reduce productivity of the southern Benguela sardine population
The bigger picture – wind forcing

Daily averaged QuikSCAT wind data for Jan-Dec 2011 from 4 coastal locations (Cape Columbine, Cape Point, Mossel Bay and Cape St Francis) used to calculate Ekman transport

Climatological mean (1984-2010) and monthly Ekman transport (left); monthly anomalies (centre); and daily cumulative Ekman transport Sep-Dec 2011 (right)

Anomalous onshore winds dominated off south coast Sep-Oct 2011
Strong downwelling off the south coast caused by unseasonal westerly winds (Aug-Oct) pushed oceanic South Atlantic Surface Water (SASW) close inshore, bringing with it numerous flagellate and dinoflagellate species.

These unusual hydrographic conditions suppressed normal diatom communities and promoted blooms of the small mixotrophic dinoflagellates; hypoxia on inshore CAB resulted from bloom decay.

Small dinoflagellates hypothesized to have negatively impacted sardine only, due to their finer meshed filtering apparatus compared to anchovy or redeye.

Are dinoflagellate blooms increasing in the southern Benguela?

Synopsis (ii)

Warm water (>20°C) and limited wind- or current-induced upwelling promoted a dinoflagellate bloom off the SA south coast in early 2014.

Dominated by *Lingulodinium polyedrum* (syn. *Gonyaulax polyedra*); small (40-50 µm) dinoflagellate; first record of this spp. off SA.

Bloom moved up the coast from MB to PE and persisted for >3 months (January to March).

Resulted in anoxic conditions and several separate instances of marine organism mortalities in Algoa Bay.
Did the 2014 south coast dinoflagellate bloom negatively impact sardine?

Sardine catches off PE in 2014 markedly reduced (5-10%) of previous recent years.

No reduction in sardine catches off MB in 2014 (but reduced catches in 2012 following 2011 bloom?)

Substantial economic implications as sardine is the high value target of the South African small pelagic fishery.

### Sardine catches off PE in 2014

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<th>Year</th>
<th>Landings (t.week⁻¹)</th>
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<tr>
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<td>2013</td>
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<td>2014</td>
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### Sardine catches off MB in 2014

<table>
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<tr>
<th>Year</th>
<th>Landings (t.week⁻¹)</th>
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<td>2011</td>
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<td>2012</td>
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Synopsis (iv)

Evidence for increasing occurrence of dinoflagellate blooms in the southern Benguela

Significant ecosystem impacts including mass mortalities due to anoxia/hypoxia following bloom decay) and ingestion of toxic species

Hypothesized impact on sardine, but not other small pelagic species, due to their finer meshed branchial basket – reduced productivity of the sardine population?

Substantial economic impacts; further possible indirect ecological impacts since sardine are an important forage fish in the southern Benguela

A taste of the future?
Thanks and acknowledgements

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Photographers (acknowledged and un-acknowledged)
Another anomalous event in November 2011

Unprecedented strandings of buoy barnacles along a 500 km stretch of Western Cape coast (Paternoster to De Hoop) in November 2011 linked to unusually persistent westerly winds.
Sardine wash-ups elsewhere (i)

Redondo Beach, California, USA, 09/03/2011

>1 million dead sardines swept into harbour; initially believed that mortality due to oxygen depletion following crowding but subsequent tests revealed presence of domoic acid
Sardine wash-ups elsewhere (ii)

Isumi City, Japan, 03/06/2012

200 tons dead sardines washed up in fishing harbour; water quality not abnormal
Harmful Algal Blooms elsewhere

Increasing eutrophication seen as a primary driver of increases in HABs

But - climate change and variability play a dominant role in long-term changes in phytoplankton assemblages: ocean warming, changes in salinity and increasing stratification favours the growth and earlier succession of flagellates and dinoflagellates in many systems.

Dinoflagellates increased in the northeast Atlantic from late-1980s (positively correlated with NAO and SST; diatoms negatively correlated); shifts in some populations (e.g. *Prorocentrum* spp.)

*Prorocentrum* spp.  *Ceratium furca*  *Dinophysis* spp.  *Noctiluca* spp.

(Edwards *et al* 2006)