The biological basis for hypothesizing multiple stocks in South African sardine *Sardinops sagax* (cont….)

Carl van der Lingen

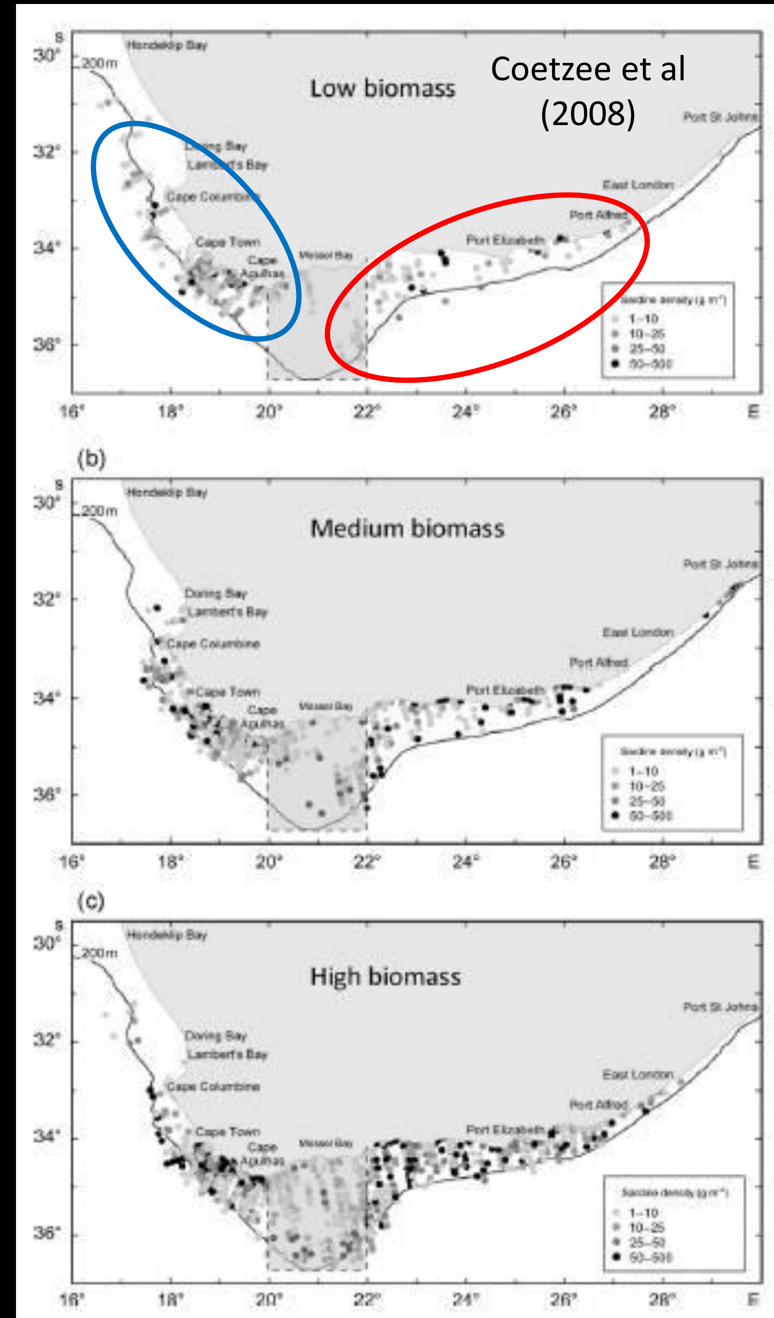
1. Distribution patterns
2. Reproduction (spawning habitats, seasonality, length-at-maturity)
3. Meristics (number of vertebrae and gill rakers) and morphometrics (body shape, otolith shape)
4. Parasites as biotags
5. Stock structure and recently agreed hypothesis

Identifying multiple sardine stocks – Distribution patterns

Analyses of sardine distribution patterns at different biomass levels from acoustic surveys showed that at low and medium biomass sardine distribution is discontinuous, separated by the CAB

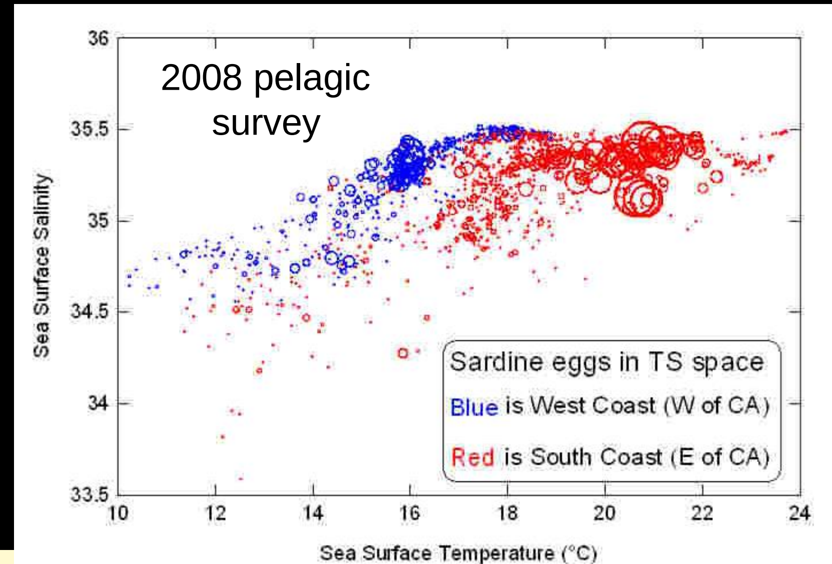
Given that sardine, as observed for other clupeids, retreat into “refugia” at low population size, this analysis suggested the possible existence of two stocks

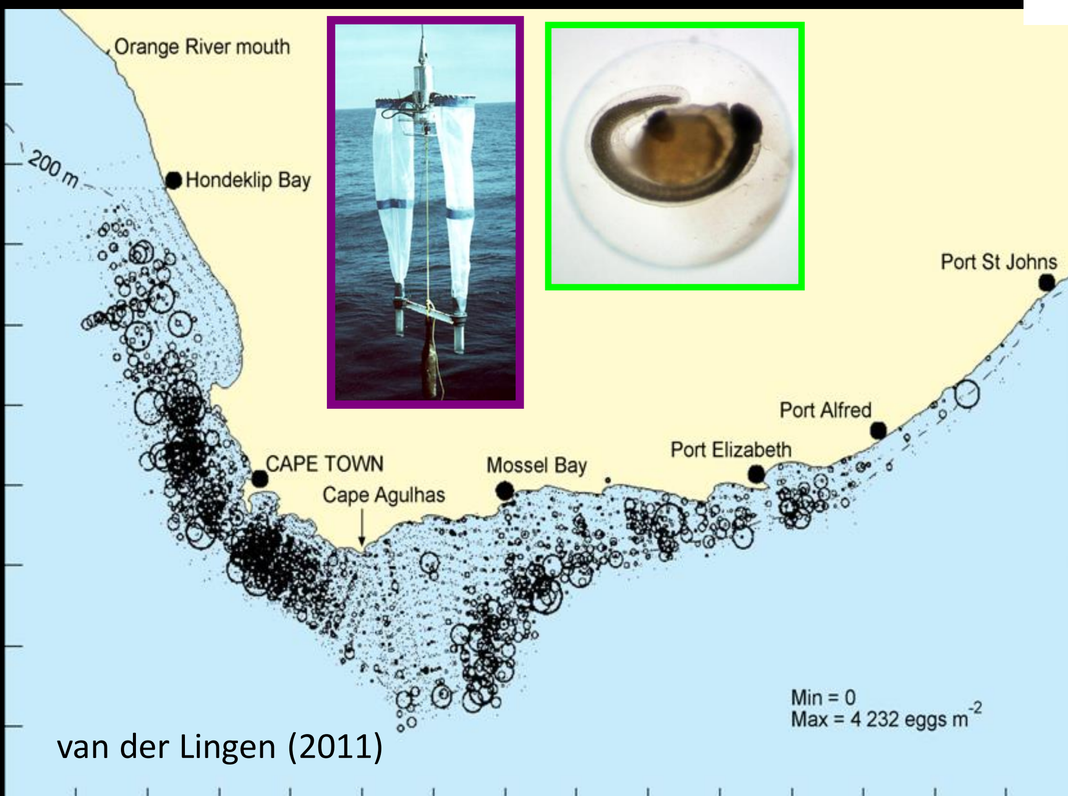
‘Western’ and ‘Southern’ sub-stocks hypothesized



Spawning habitats (i)

Sardine eggs collected during surveys (1986-2009; 7 809 samples) clearly show two discrete spawning areas on the west and south coast, separated by CAB





Different spawning areas have different environmental characteristics (e.g. temperature and salinity)

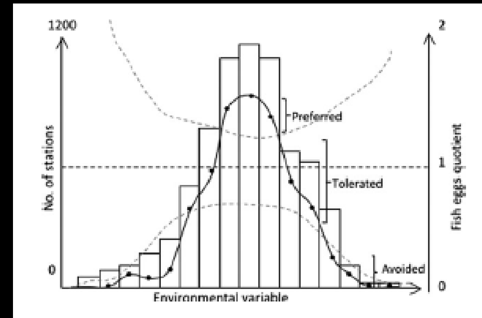
(Also spawning off KZN during winter sardine run)

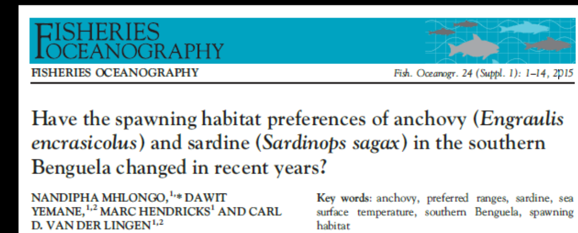
Spawning habitats (ii)

Substantial differences in SST of preferred spawning habitat (PSH; bootstrapped CIs for SPQ) for sardine off the west and south coast

PSH SST off the west coast 1.5-4°C lower than that of sardine off the south coast throughout the time series (1984-2009)

Spawning on west at ± 17.0°C; on south at ± 19.5°





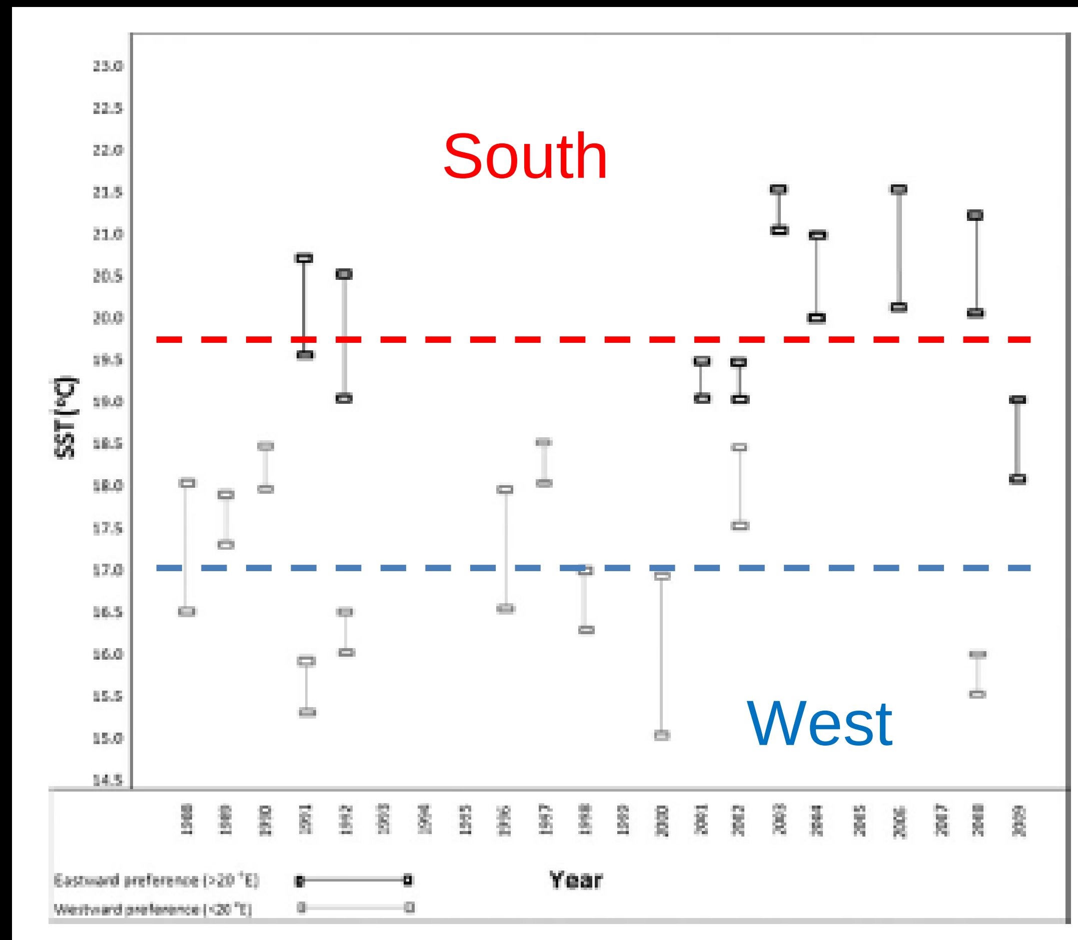
FISHERIES OCEANOGRAPHY

FISHERIES OCEANOGRAPHY Fish. Oceanogr. 24 (Suppl. 1): 1–14, 2015

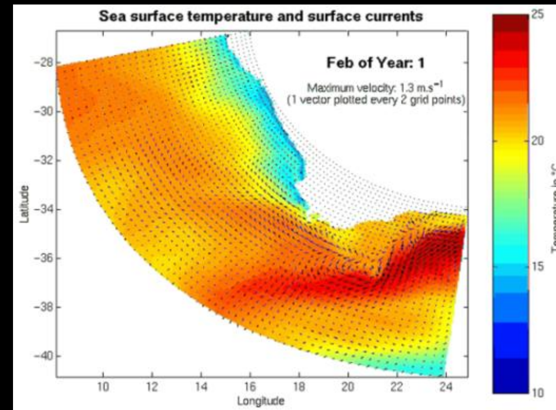
Have the spawning habitat preferences of anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in the southern Benguela changed in recent years?

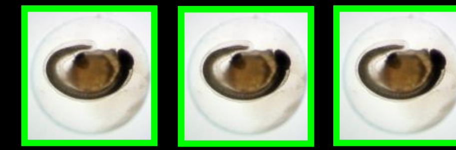
NANDIPHA MHLONGO,[1,*] DAWIT YEMANE,[1,2] MARC HENDRICKS[1] AND CARL D. VAN DER LINGEN[1,2]

Key words: anchovy, preferred ranges, sardine, sea surface temperature, southern Benguela, spawning habitat

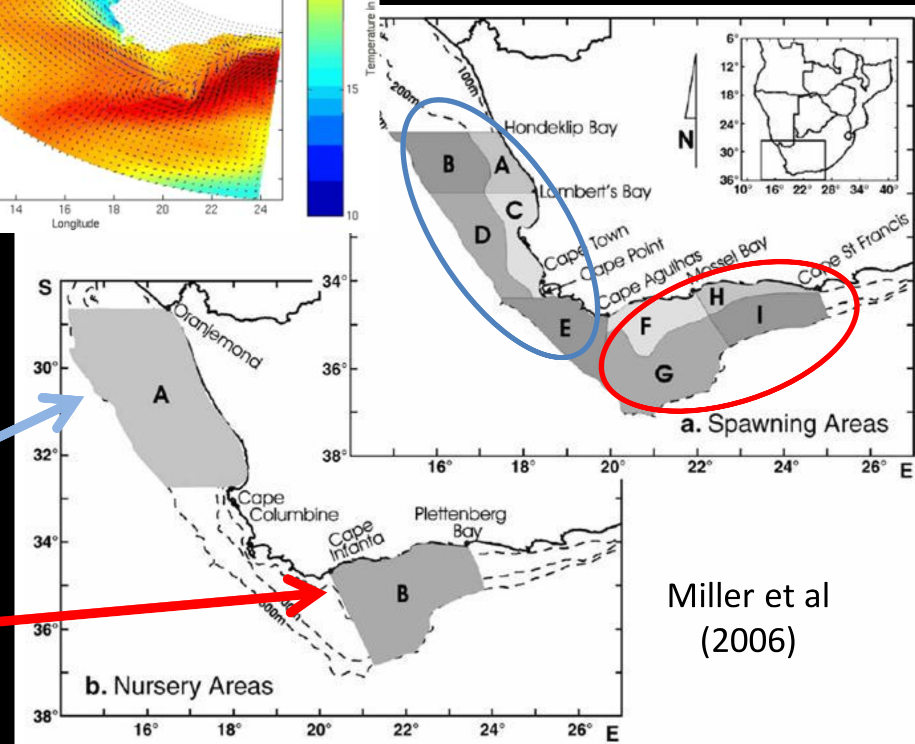


Spawning habitats (iii)

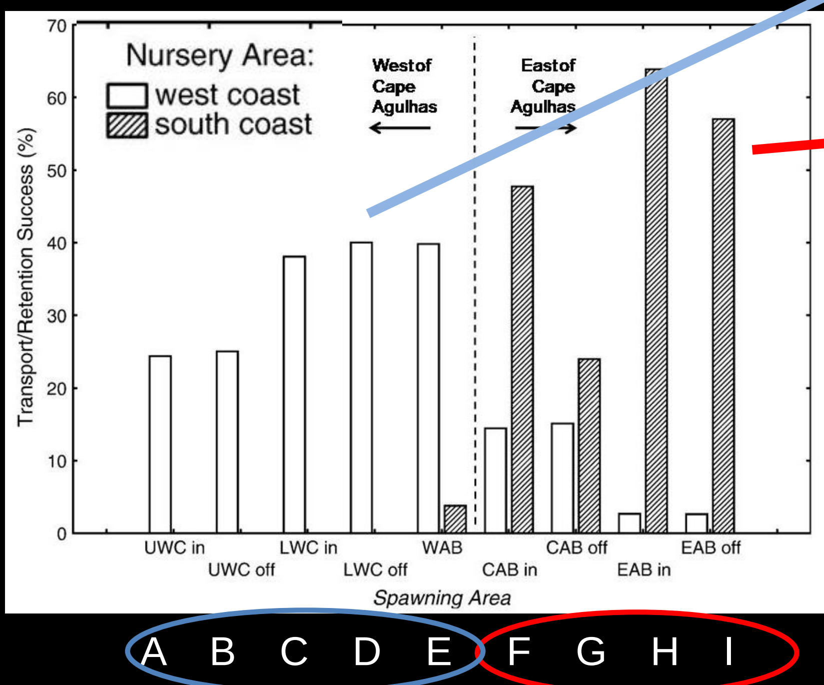




Individual-based model of sardine life history strategies; vary spawning areas and track egg/larval transport to west and south coast recruitment areas



Miller et al (2006)



Results suggest 2 major sardine recruitment systems; spawn east of Cape Agulhas and recruit on south coast, or spawn west of Cape Agulhas and recruit on west coast

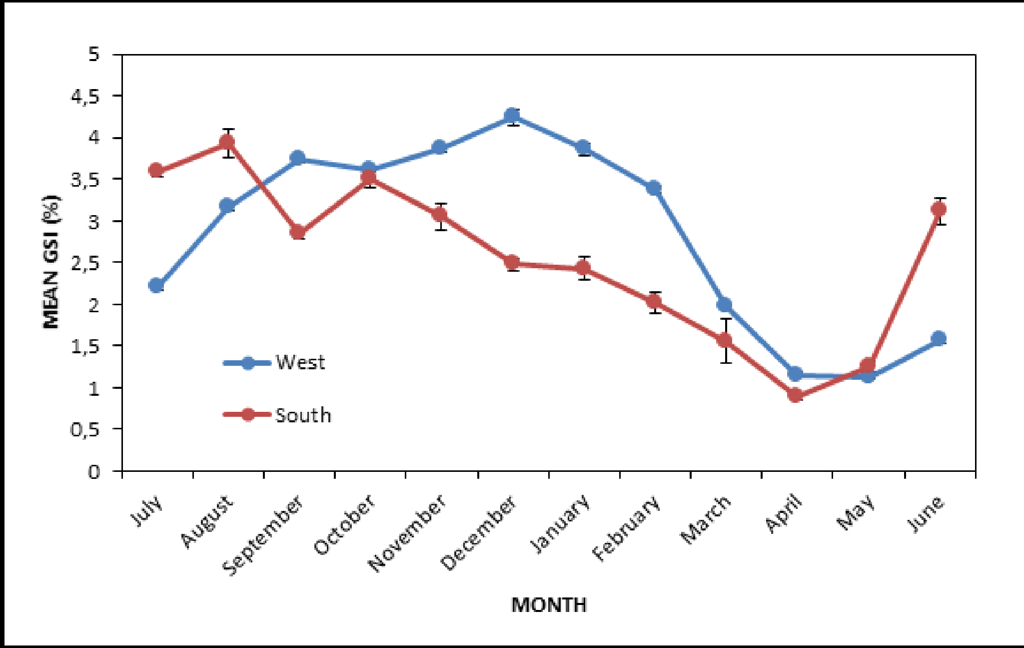
Spawning seasonality and length at maturity

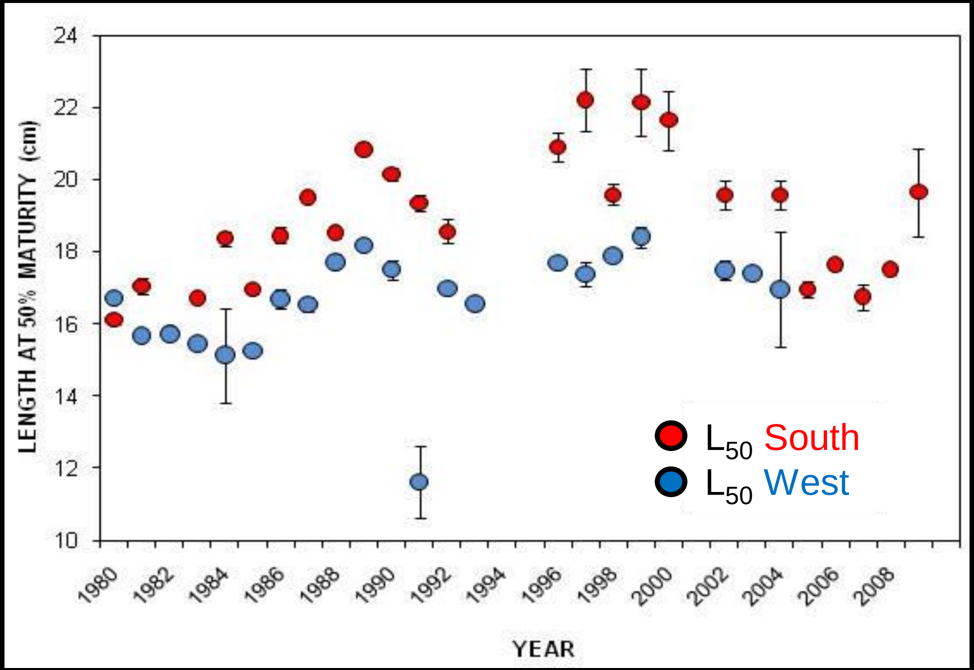
Monthly mean GSI (n = >36 000; 1995-2014)

Western GSI highest from Sep-Feb with peak in Dec; southern GSI highest from Jun-Nov with peak in Aug

L_{50} maturity of females (n = 14 000; 1980-2009)

Fish from west consistently mature at a smaller size than those from south; L_{50} varies synchronously

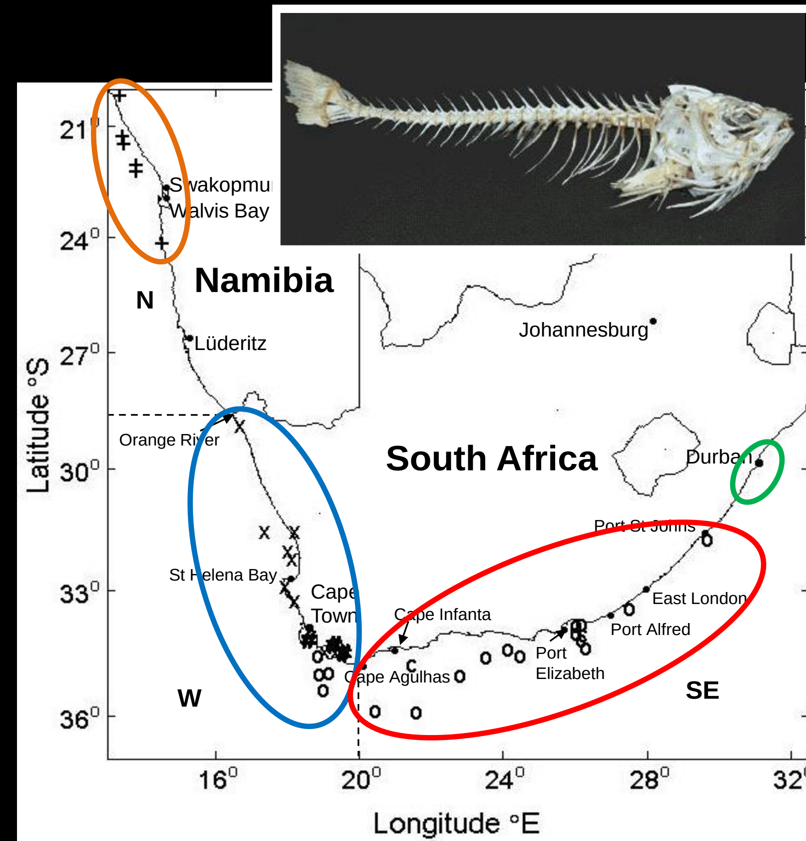


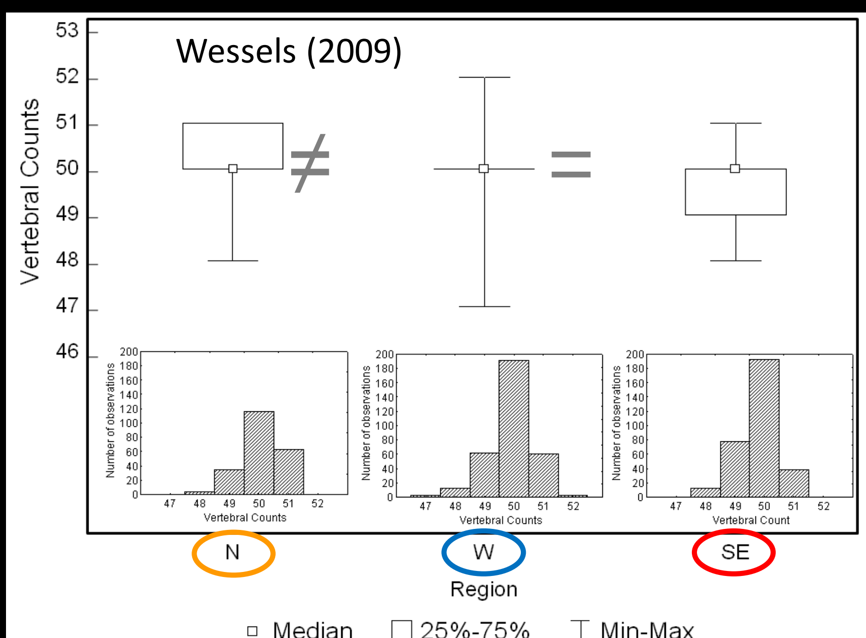


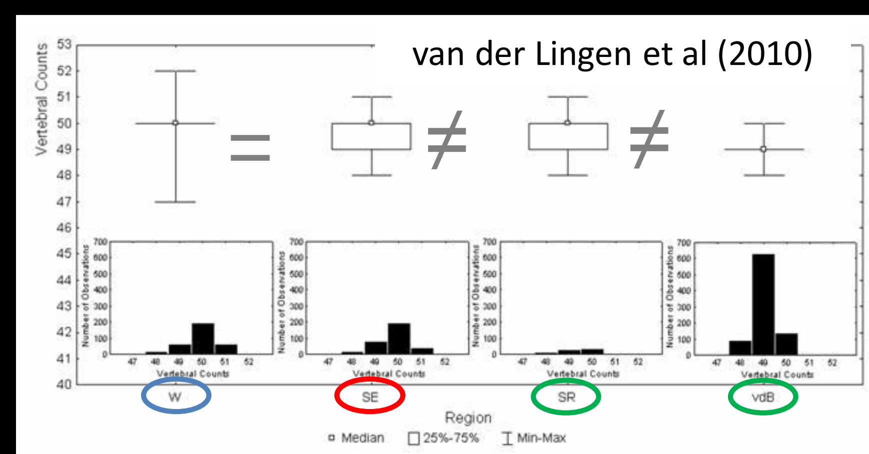
Meristics (i): # of vertebrae

Significant difference in mean number of vertebrae between regions; highest in Namibian sardine, lowest in Eastern sardine, no difference between Western and Southern sardine stocks

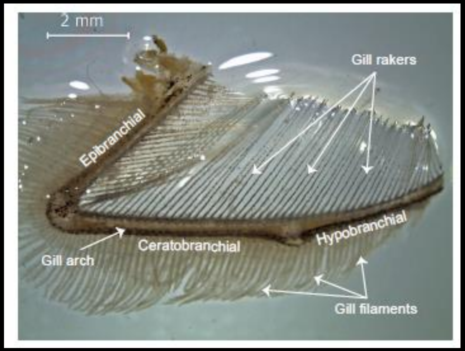
Temperature gradient (Jordan's rule)







Meristics (ii): # of gill rakers



Branchial baskets of 377 sardine from Namibia and West, South and East coast

African Journal of Marine Science 2016, 38(3): 351–362

AFRICAN JOURNAL OF MARINE SCIENCE
ISSN 1814-232X EISSN 1814-2338
http://dx.doi.org/10.2989/1814232X.2016.1204942

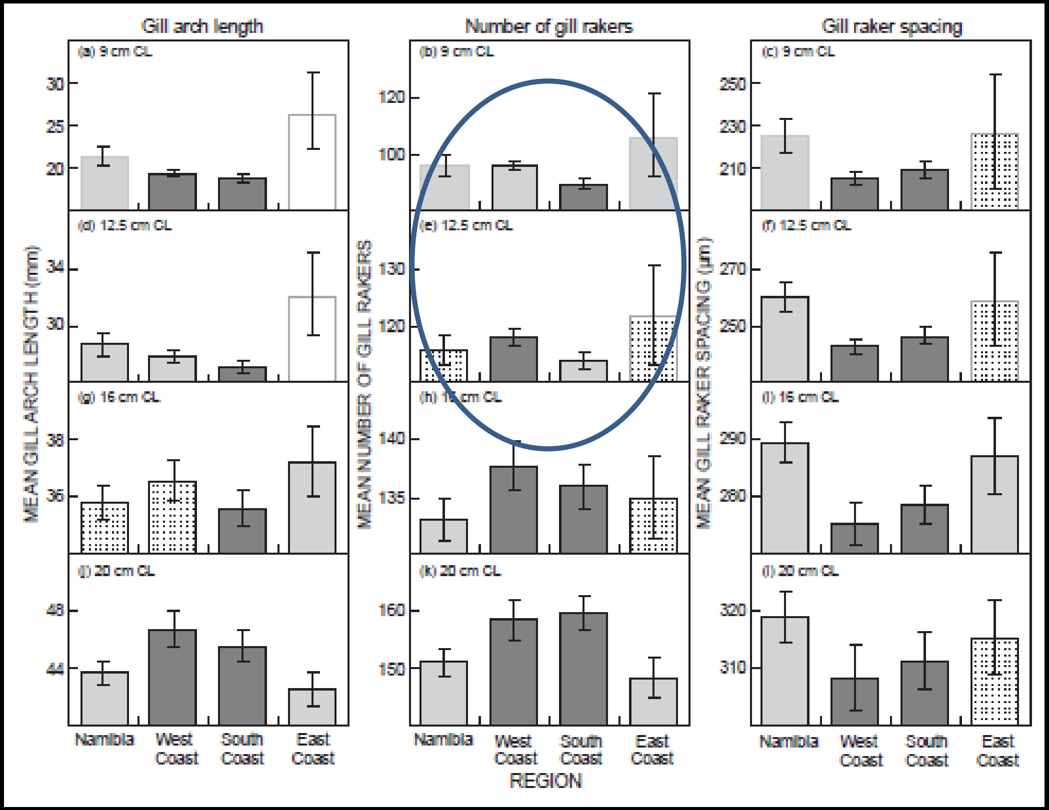
Spatial variability in branchial basket meristics and morphology of southern African sardine *Sardinops sagax*

I Idris[1,2], CL Moloney[1] and CD van der Lingen[1,3*]

Multivariate GLM used to assess regional differences and significant differences observed, although not always consistently across all fish size classes.

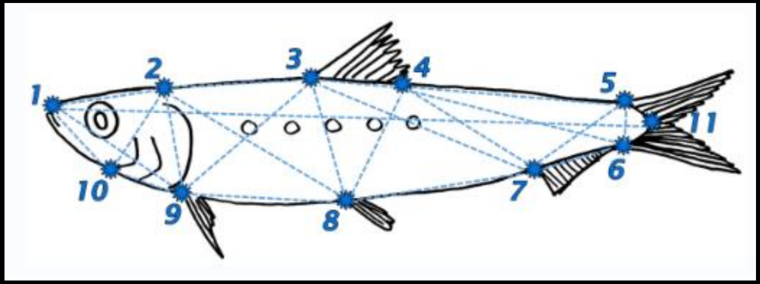
Small SC sardine had fewer gill rakers than small WC sardine, but differences disappeared in larger fish

Namibian and EC sardine coarser branchial baskets



Morphometrics (i): body shape

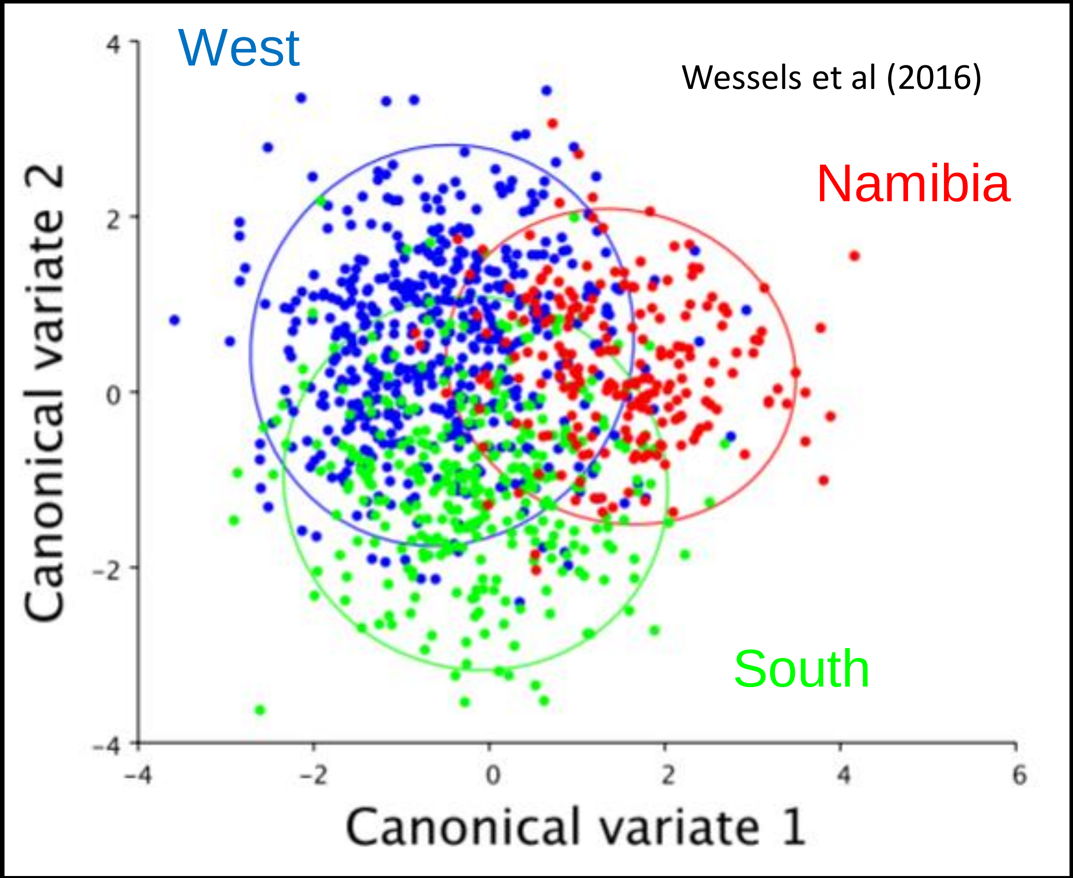
Body shape of sardine from Namibia and West and South coast quantified using 11 landmarks and box-truss network to collect 22 morphometric measurements



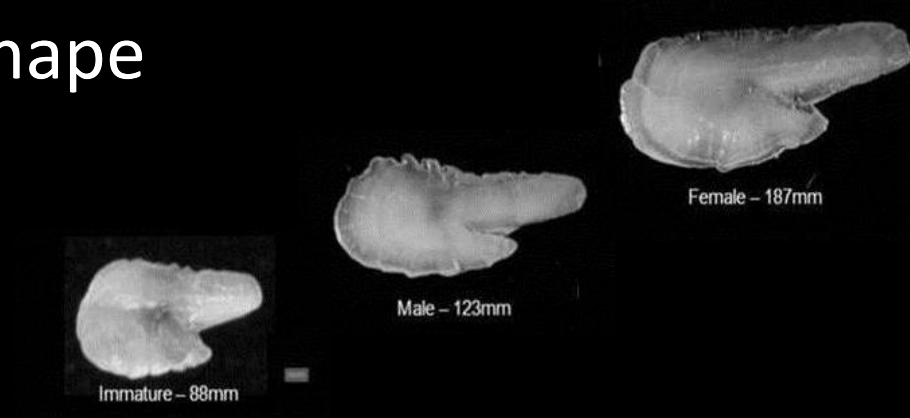
Differences in body shape assessed using geometric morphometrics with canonical variate analysis (CVA)

Significant difference in body shape between all regions

From thicker bodies and larger heads (Namibian) to thinner bodies and smaller heads (Southern)



Morphometrics (ii): otolith shape

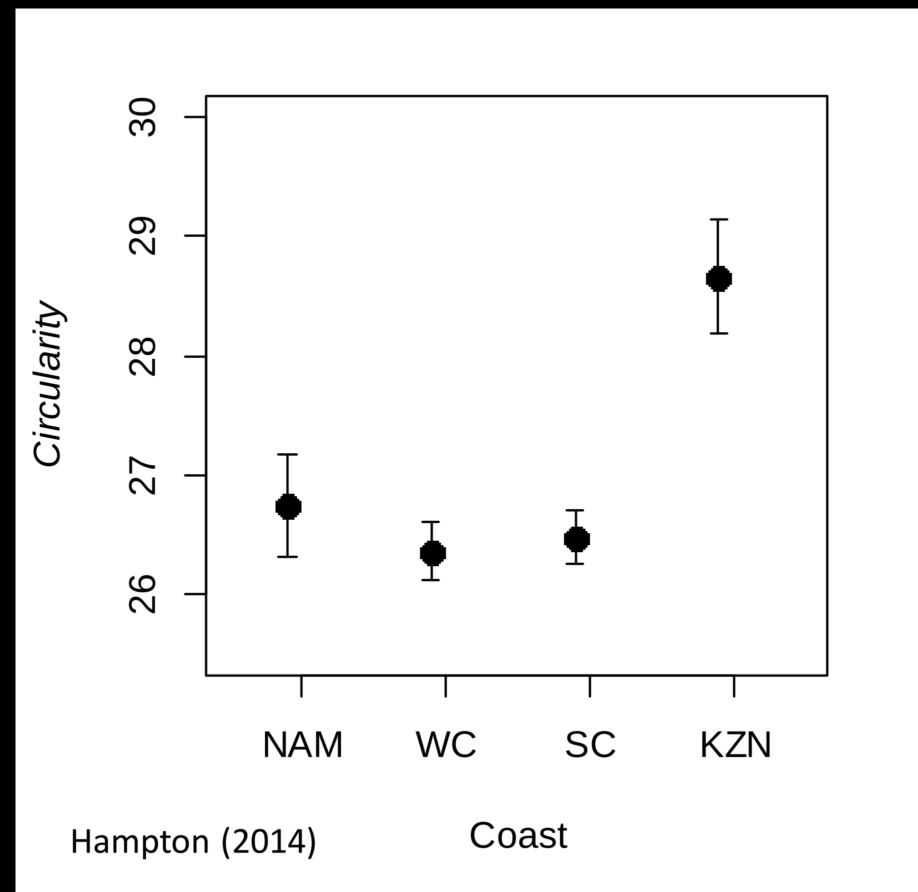


Otolith shape of sardine from Namibia and West, South and East coast quantified using circularity and form factor (regularity of the edge)

GLM to assess the effect of *Coast*, *Length*, *Sex* and *Season* (Circ r^2=0,42 and FF r^2=0,44)

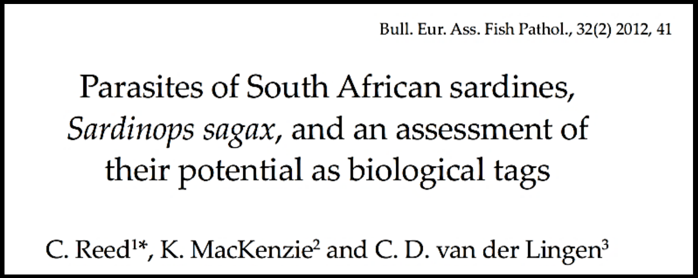
Strong *Length* effect; significant difference in otolith shape of fish from East coast (KZN), and *Season*

East coast otoliths less circular and rougher edge



Parasites as bio-tags (i)

Parasite biotag approach applied to SA sardine



Bull. Eur. Ass. Fish Pathol., 32(2) 2012, 41

Parasites of South African sardines, *Sardinops sagax*, and an assessment of their potential as biological tags

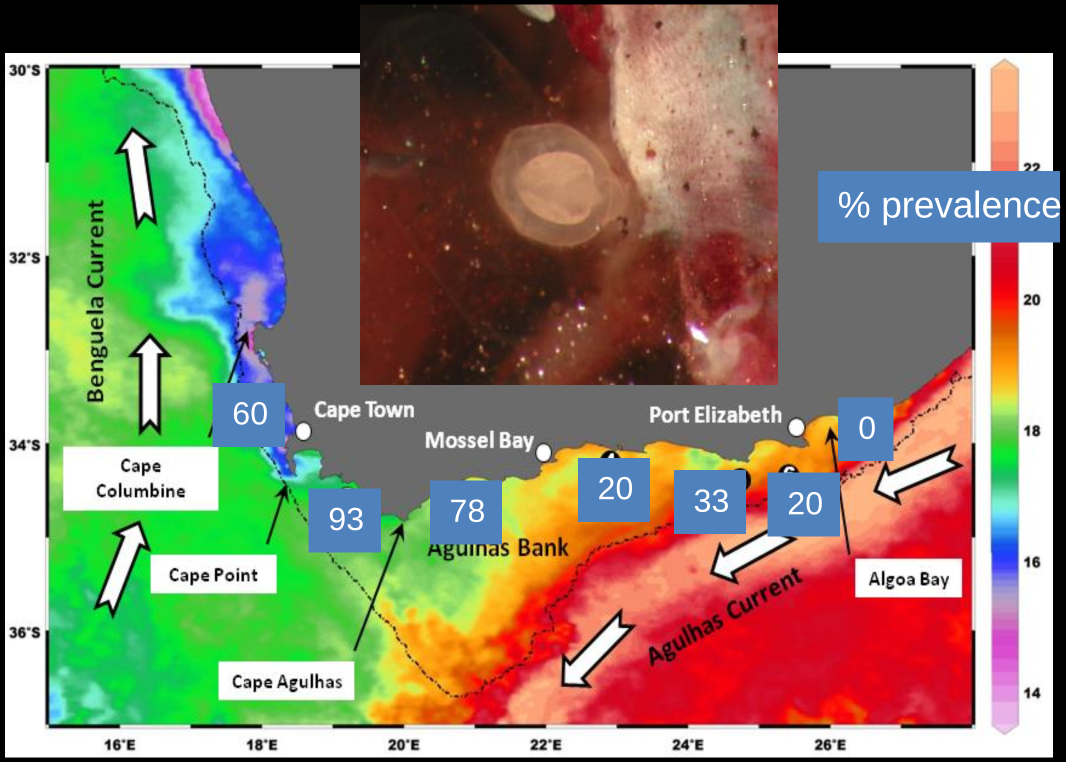
C. Reed[1]*, K. MacKenzie[2] and C. D. van der Lingen[3]

Assess parasite assemblage and identify biotag/s:

102 sardine from 7 sites around SA coast examined

7 parasite taxa, 3 new host records

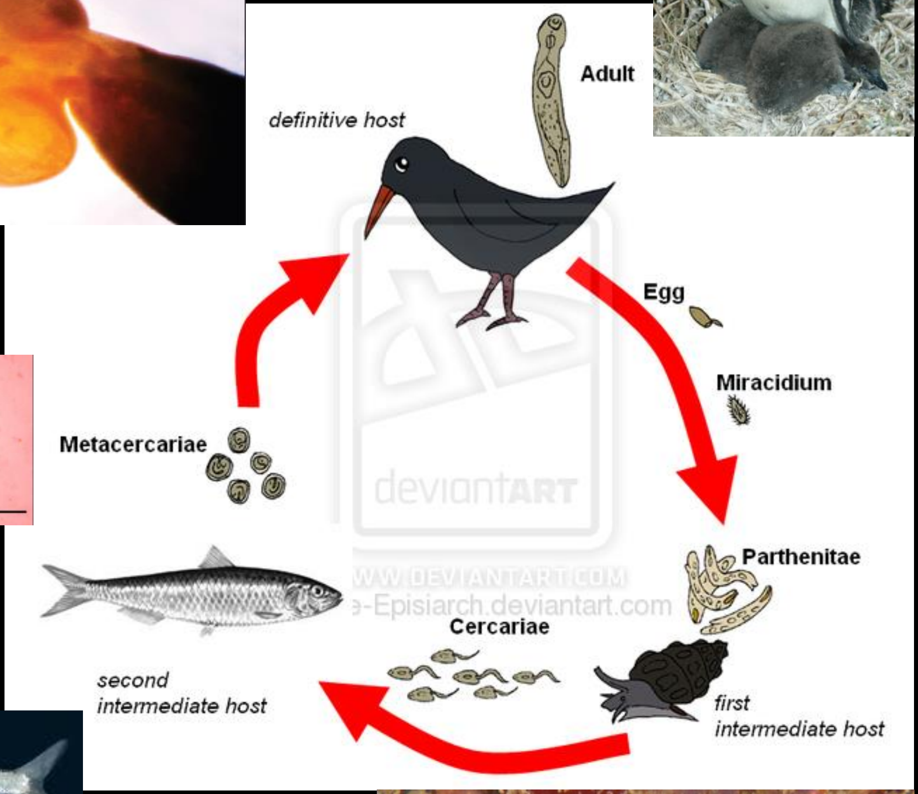
Digenean “tetracotyle” type metacercariae (TTM) found in sardine eyes showed greatest biotag potential (spatial variability in prevalence, endoparasite, other criteria)



Parasites as bio-tags (ii)

TTM considered to be *Cardiocephaloides physalis*

Life-cycle includes a gastropod 1st intermediate host, a fish (sardine) 2nd intermediate host and a seabird definitive host (no fish-to-fish transmission)



African penguin host to adult *C. physalis*

1st intermediate host unknown: hypothesized *Burnapaena papyracea,* abundant subtidal gastropod between Cape Agulhas and Lüderitz

Parasites as bio-tags (iii)

1 318 sardine from commercial catch samples in 2011 and 2012 examined for TTM

GLMs used to assess effects of *Stock*, *Year*, *Season* and *CL* on 3 indices of infection

- Prevalence (pseudo-r^2 0.21): log(*CL*), *Stock, Year*
- Intensity (pseudo-r^2 0.29): *Stock, Season, Year*
- Abundance (pseudo-r^2 0.30): *Stock,* log(*CL*), *Year*

Supports hypothesis of western and southern stocks


Fisheries Research 164 (2015) 120–129

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Stock discrimination of South African sardine (*Sardinops sagax*) using a digenean parasite biological tag

Laura F. Weston[a,*], Cecile C. Reed[a], Marc Hendricks[b], Henning Winker[c,d], Carl D. van der Lingen[b,e]

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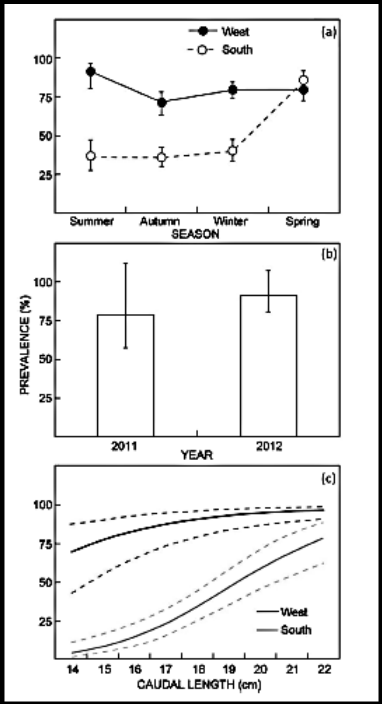
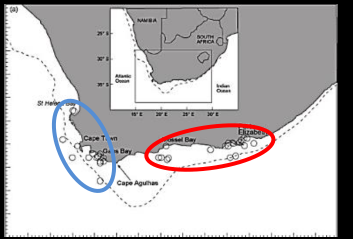
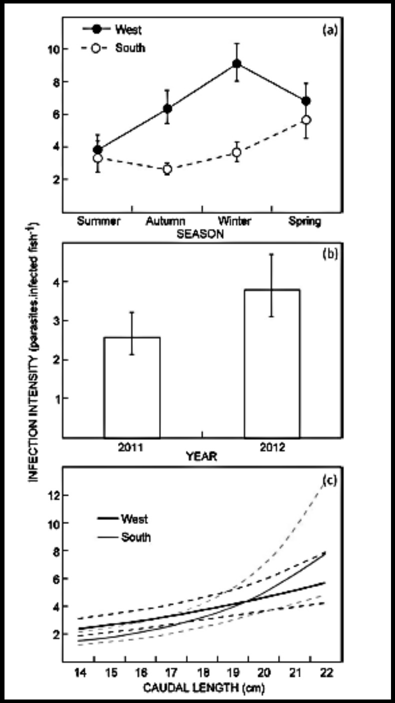
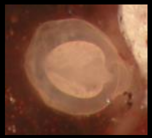
[b] Fisheries Management, Department of Agriculture, Forestry and Fisheries, Private Bag X2, Rogge Bay 8012, South Africa
[c] South African National Biodiversity Institute, Kirstenbosch Research Centre, Claremont 7735, South Africa
[d] Centre for Statistics in Ecology, Environment and Conservation (SEEC), Department of Statistical Sciences, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa
[e] Marine Research Institute, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa

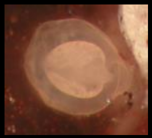


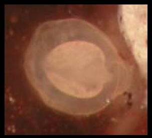




Parasites as bio-tags (iv)





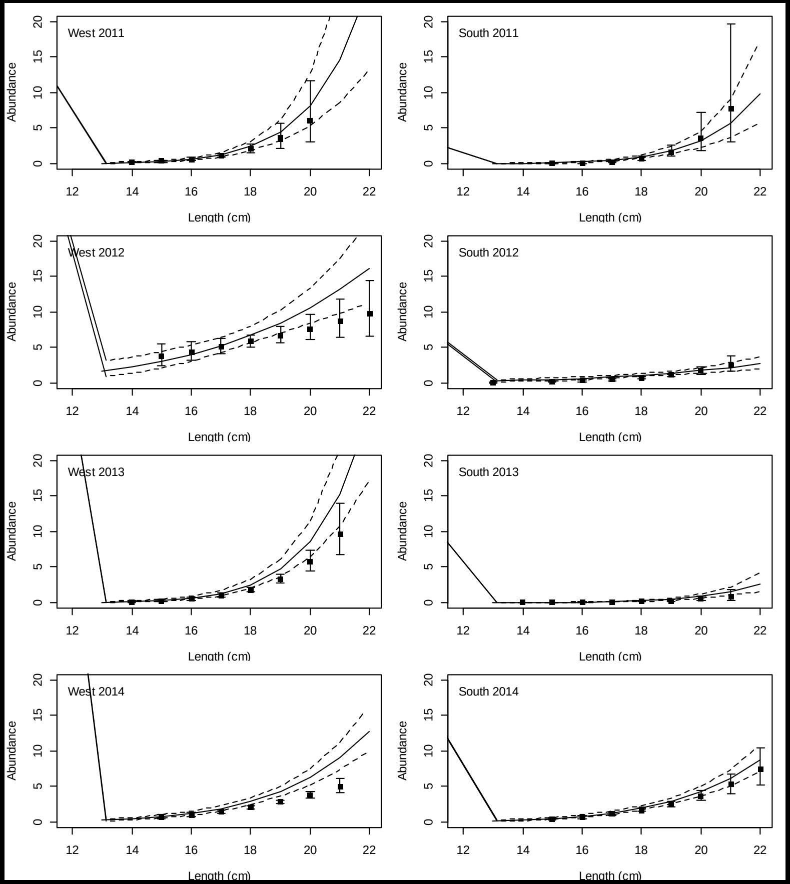


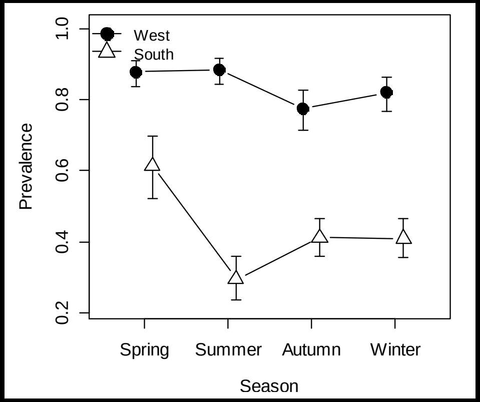
3 000 more sardine from commercial catches in 2013 and 2014 processed for TTM; GLM analyses

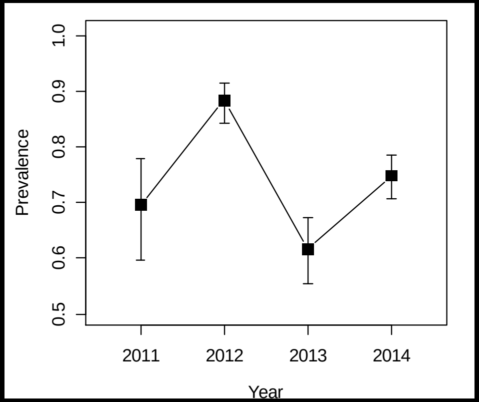
Stock most important for all 3 indices

Increasing infection with *CL* for both western and southern fish suggests W to S movement of larger fish (*i.e.* all ages)

Seasonal and inter-annual variation







Parasites as bio-tags (v)

Sardine from research surveys and beach-seine catches (KZN) of Namibian, W, S and E stocks, 2010-2015, examined

No infection in Namibian sardine (n=200). Mean TTM abundance off SA shows clear spatial pattern, declining from west to south and east (prevalence <3% off KZN)

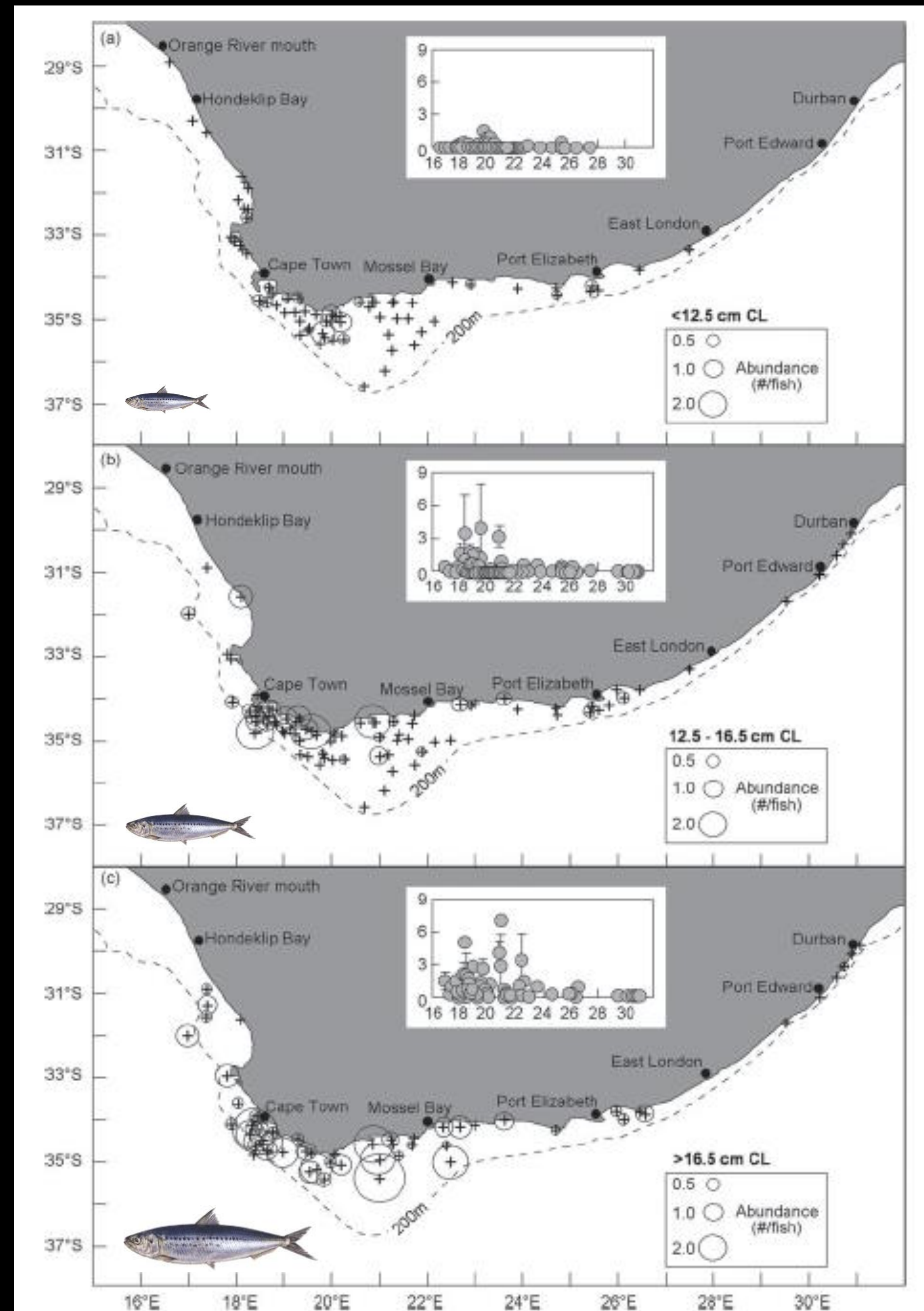
Prevalence-at-length data from PBS used in assessments

Parasitology (2015), **142**, 156–167.
doi:10.1017/S0031182014000018 156

Incorporating parasite data in population structure studies of South African sardine *Sardinops sagax*

CARL DAVID VAN DER LINGEN[1,2]*, LAURA FRANCES WESTON[3]†, NURUDEAN NORMAN SSEMPA[3] *and* CECILE CATHARINE REED[3]

[1] *Fisheries Management, Department of Agriculture, Forestry and Fisheries, Private Bag X2, Rogge Bay 8012, South Africa*
[2] *Marine Research Institute, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa*
[3] *Department of Biological Sciences, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa*

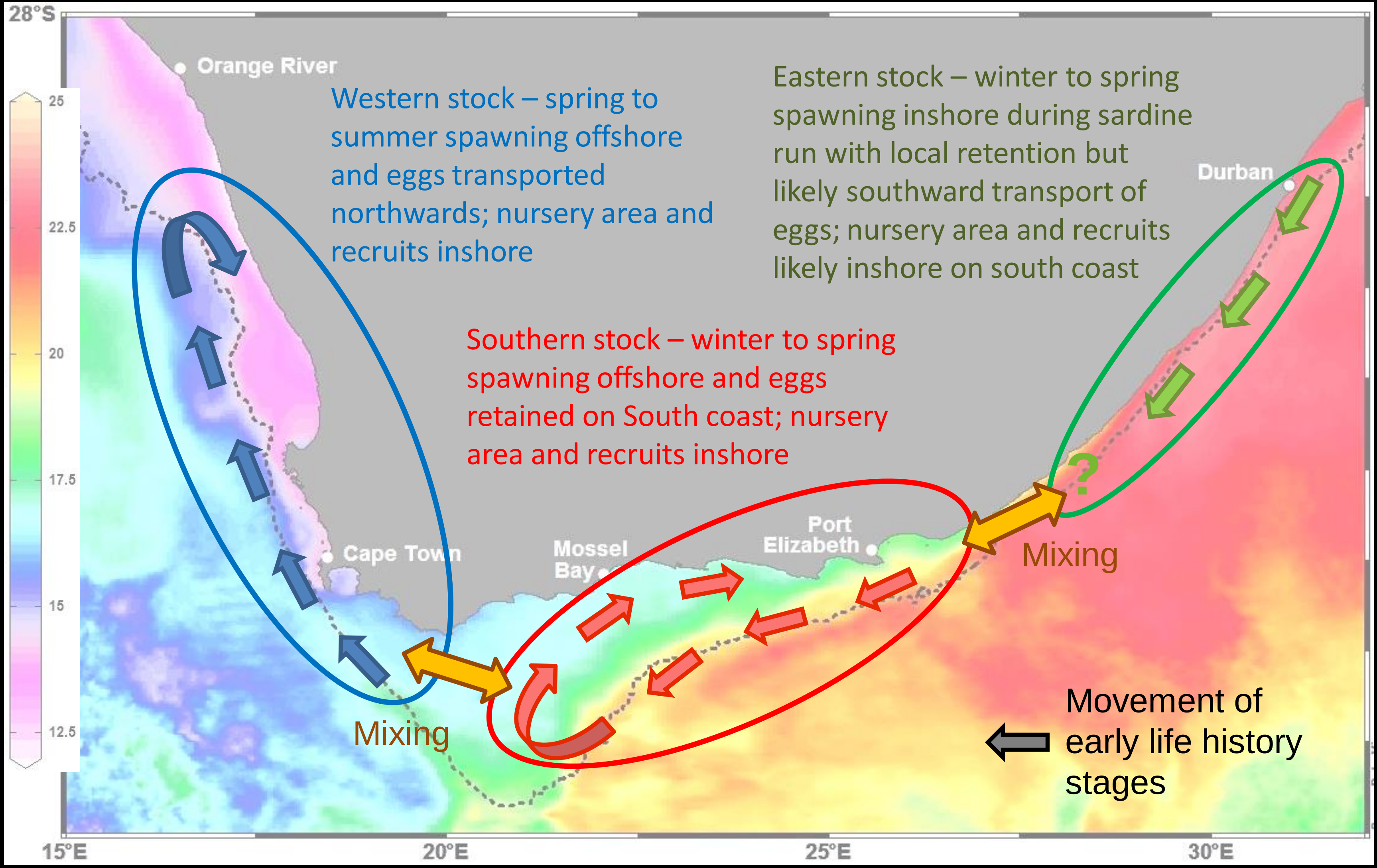


Stock structure?

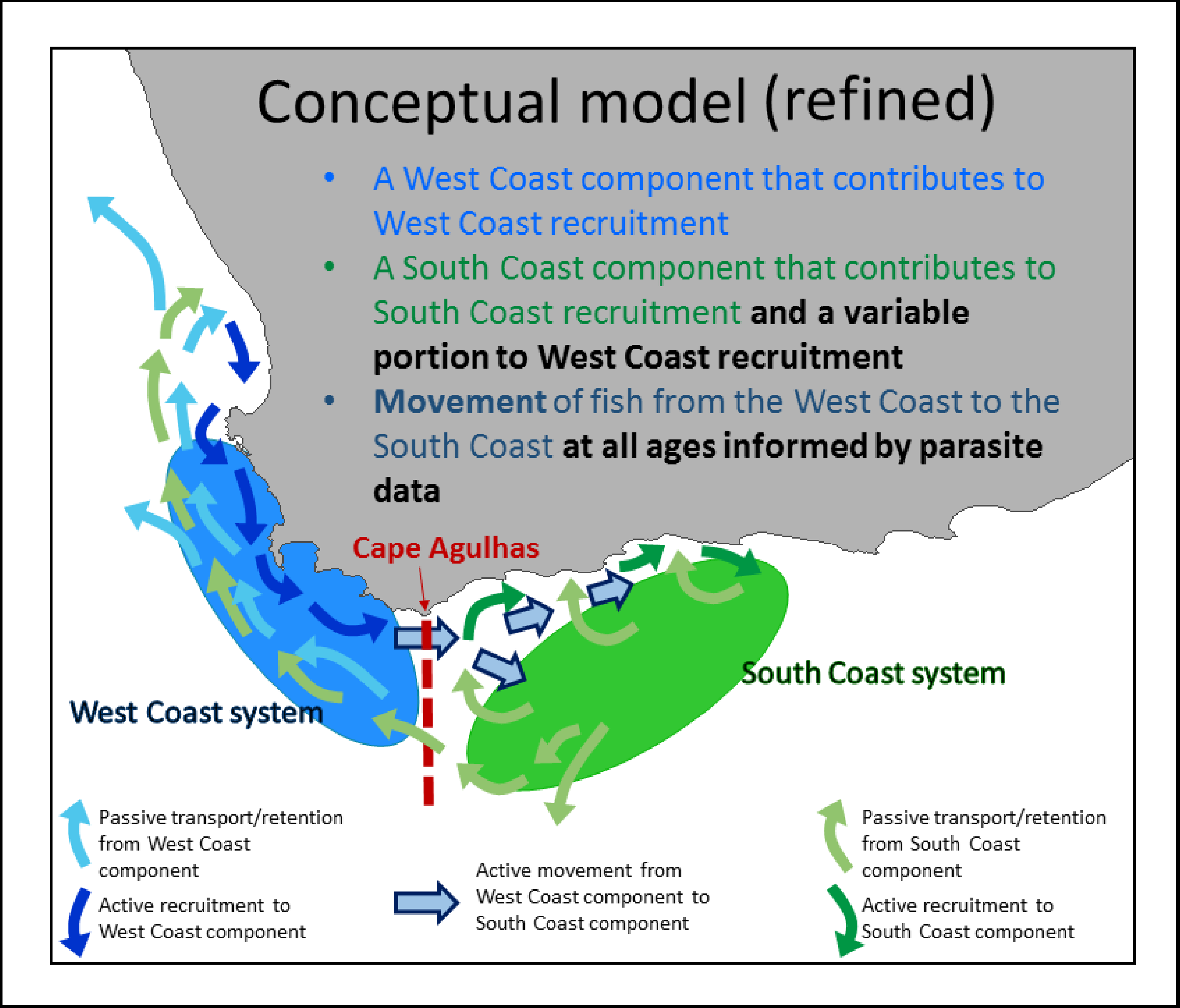
Significant spatial difference in several phenotypic characteristics; different life history strategies

Characteristic	Different between sardine from west and south coasts? (east coast in brackets)
Spawning habitat/season	Yes (Yes)
# of vertebrae	No (Yes)
Body shape	Yes (Yes)
Gill arch length	Yes; not shown (Yes)
# of gill rakers	Yes for small but not large fish (Yes)
Length-at-maturity	Yes (Undetermined)
Length-at-age	No; but poor age data; not shown (Undetermined)
TTM parasite	Yes (Yes)
Otolith shape	No (Yes)
Genetics	No; not shown (No)

Hypothesized stock-specific life histories (3 sub-stocks)

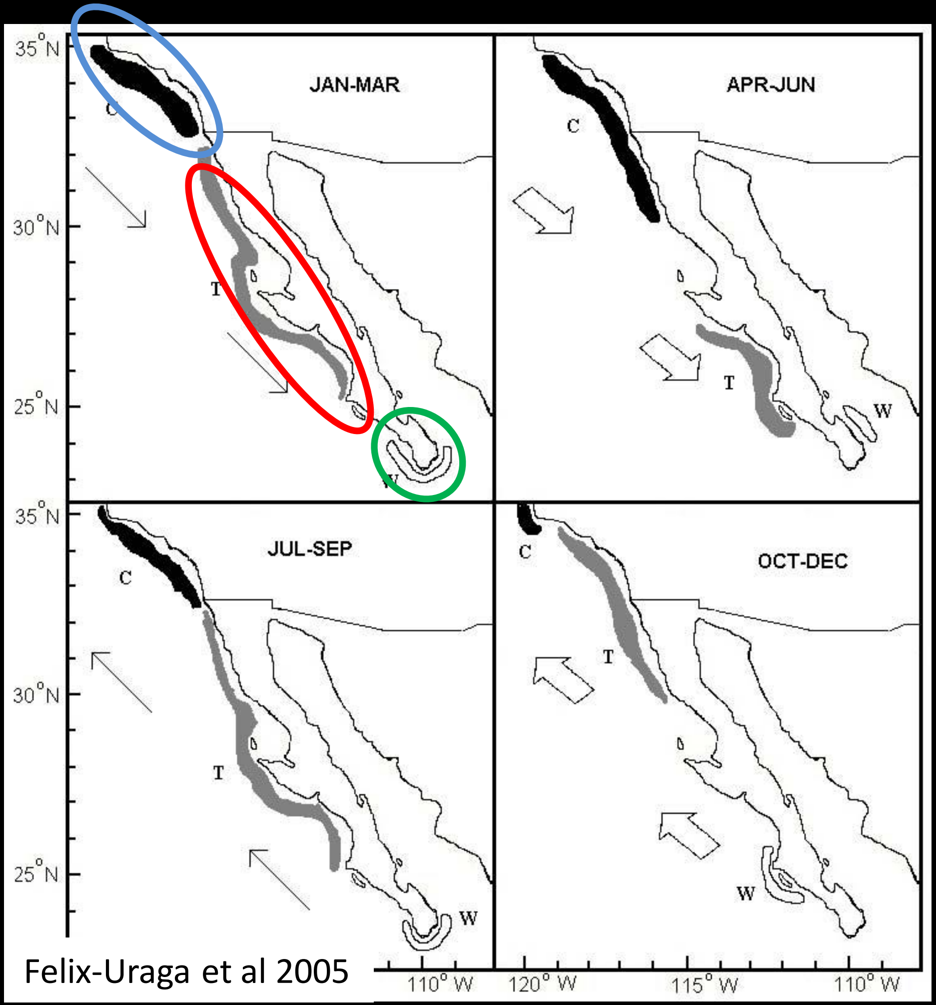


Agreed hypothesis for W and S sub-stocks (components)



Multiple sardine stocks elsewhere (i)

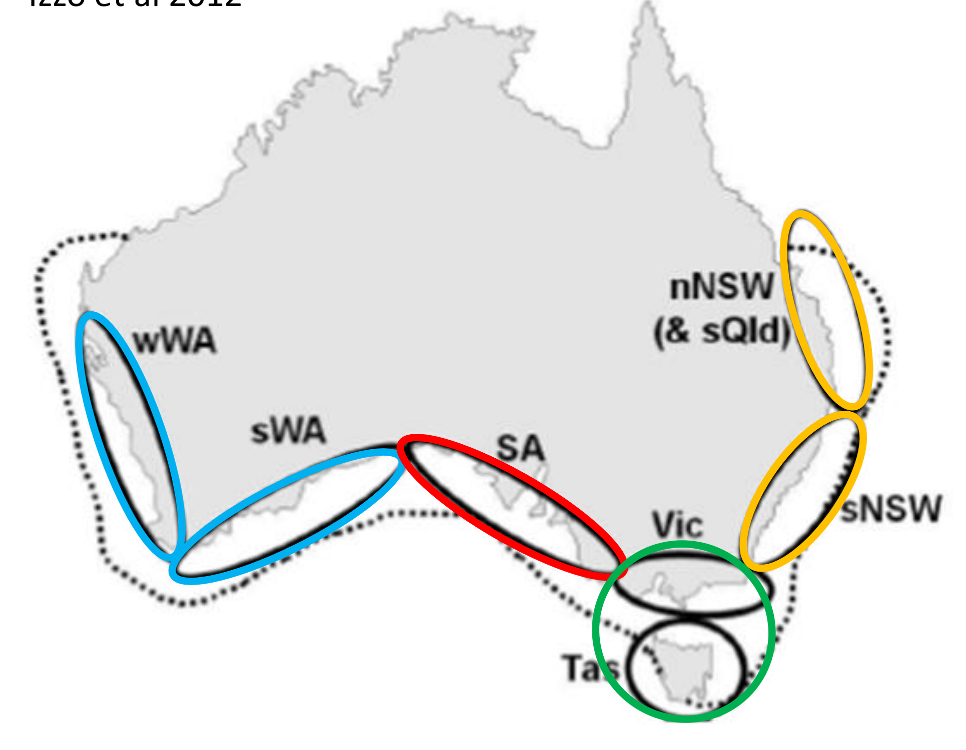
- Three Pacific sardine (*Sardinops sagax*) stocks hypothesized off southern California and Baja California - identified by otolith shape and temperature-at-catch
- Cold (expands to Canada at high biomass), temperate and warm stocks; show seasonal movement patterns
- Model separately for stock assessment and management purposes



Felix-Uraga et al 2005

Multiple sardine stocks elsewhere (ii)

- Three or four semi-independent regional groups, across seven regions, proposed for Australian sardine (*Sardinops sagax*)
- Identified by wide variety of approaches (tagging, genetics, morphology, meristics, otolith chemistry, parasites, commercial catch patterns, life history parameters)
- Explore options for finer scale spatial management



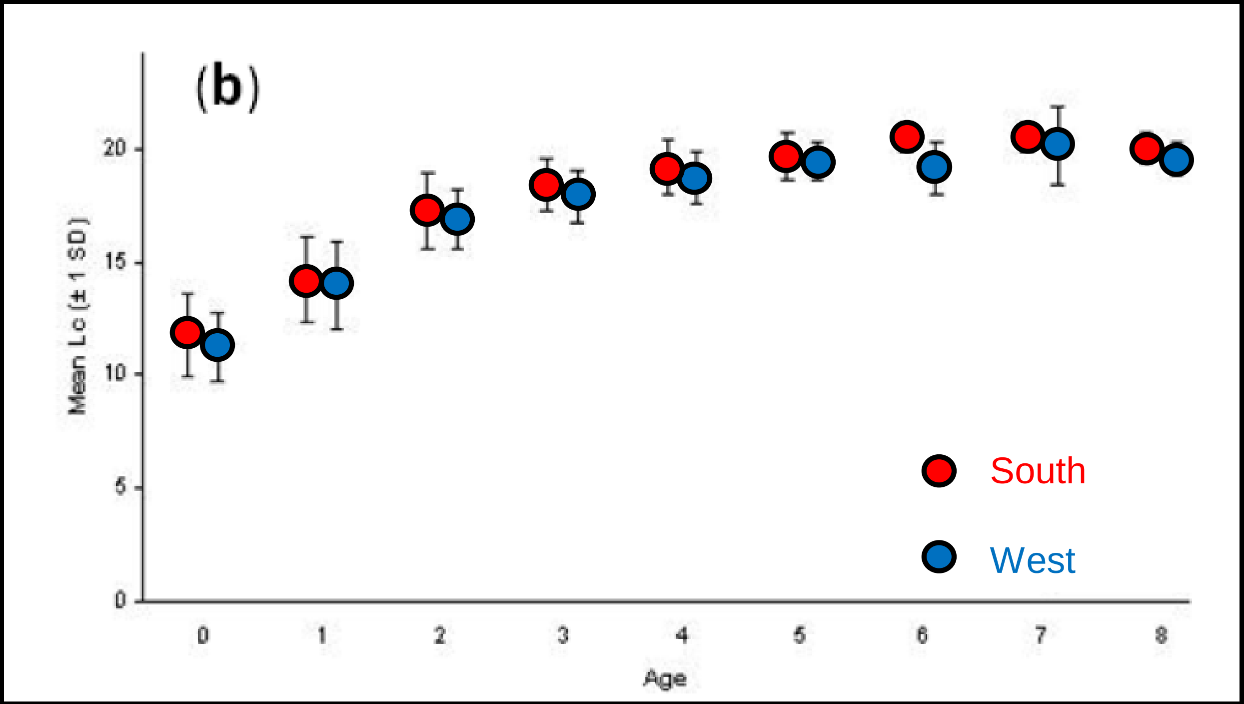
Izzo et al 2012

Additional things about SA sardine stock structure……………………..………..

(but not all of them)

Length-at-age

- Length at age of sardine from research survey samples 1993, 1994, 1996, 2001-04, and 2006-07 (D. Durholtz, DAFF)
- No spatial difference in length-at-age, tendency for fish from the west to be slightly smaller than those from the same age group in the south (but sardine ageing data considered poor)



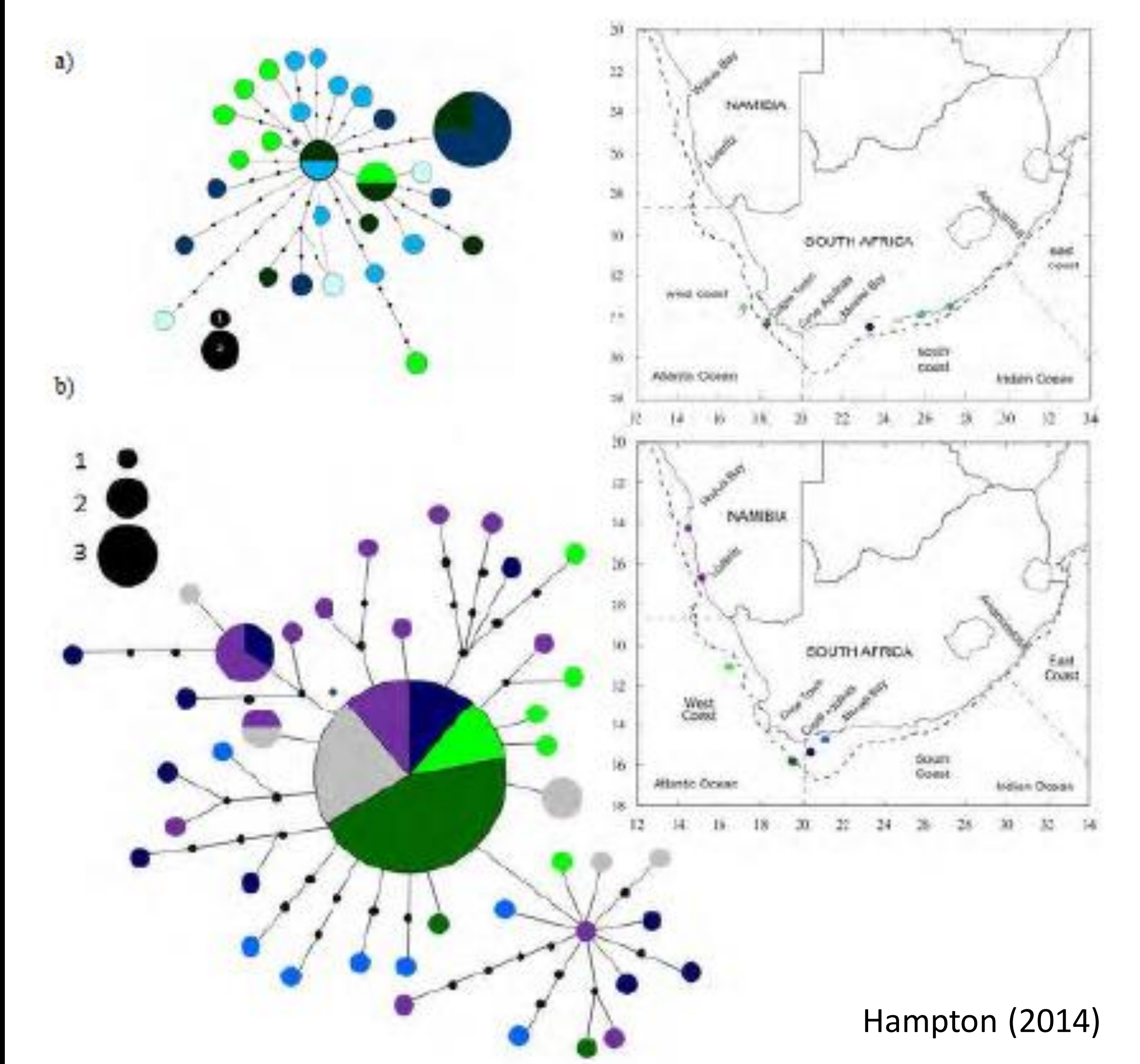
Genetics

Analysis of mitochondrial DNA marker (ND2) shows a large number (52) of haplotypes for South African sardine

Analysis of 7 microsatellite loci

No spatial structuring or genotypically-differentiated stocks; sweepstake hypothesis supported

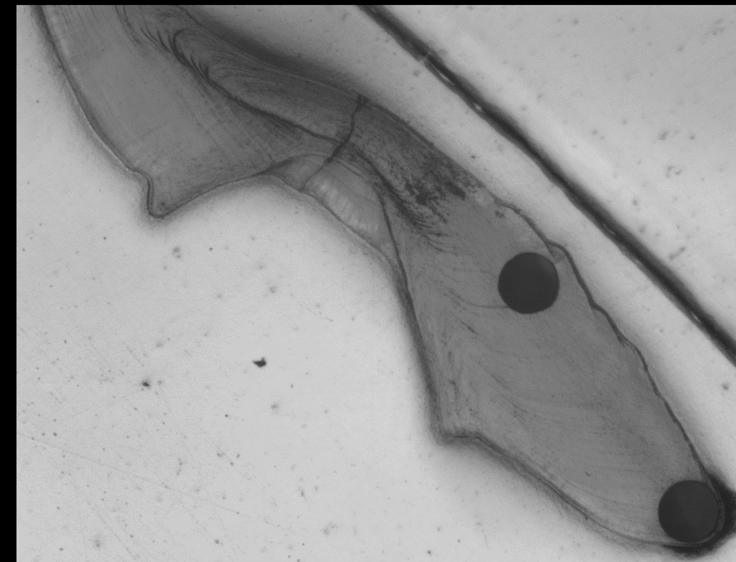
Genomics project….



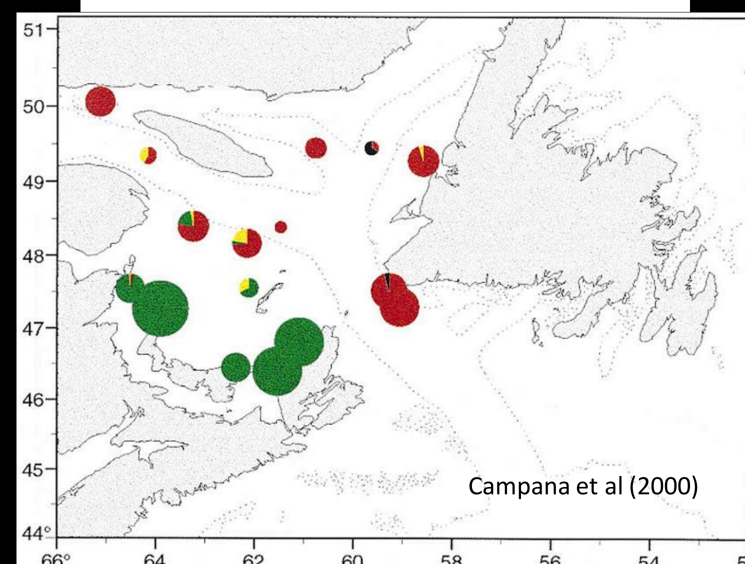
Hampton (2014)

Otolith microchemistry (i)

- Otolith elemental composition reflects chemical composition of ambient seawater at the time of (incremental) deposition
- Spatial differences in otolith elemental composition used to examine stock structure, and fish movement patterns, elsewhere
- Otoliths laser-burnt at selected sites (edge = present conditions, core = conditions at early development) and chemical concentrations determined
- Spatial heterogeneity in OC a requirement for utility in SDS

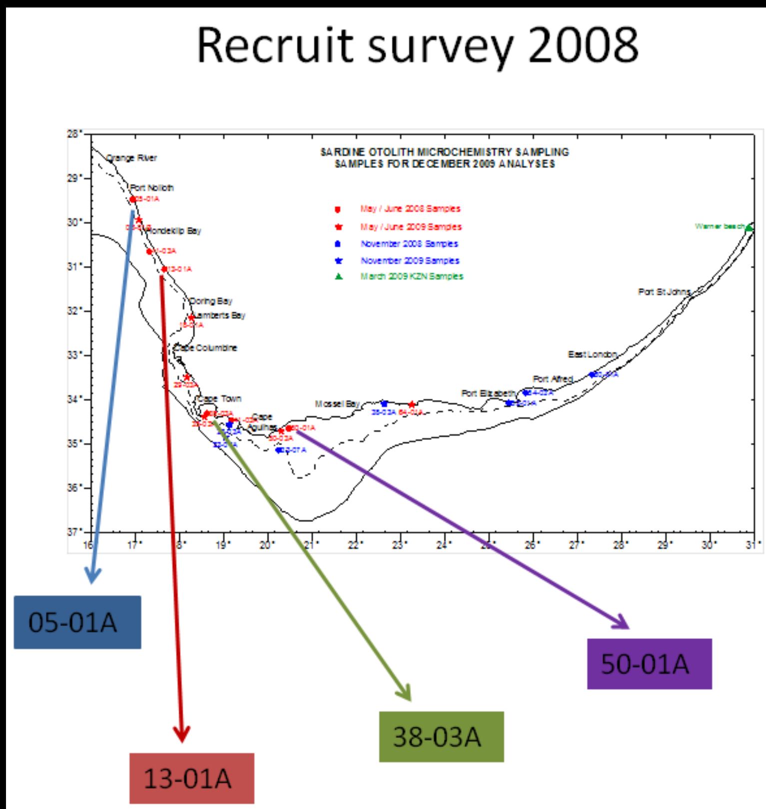


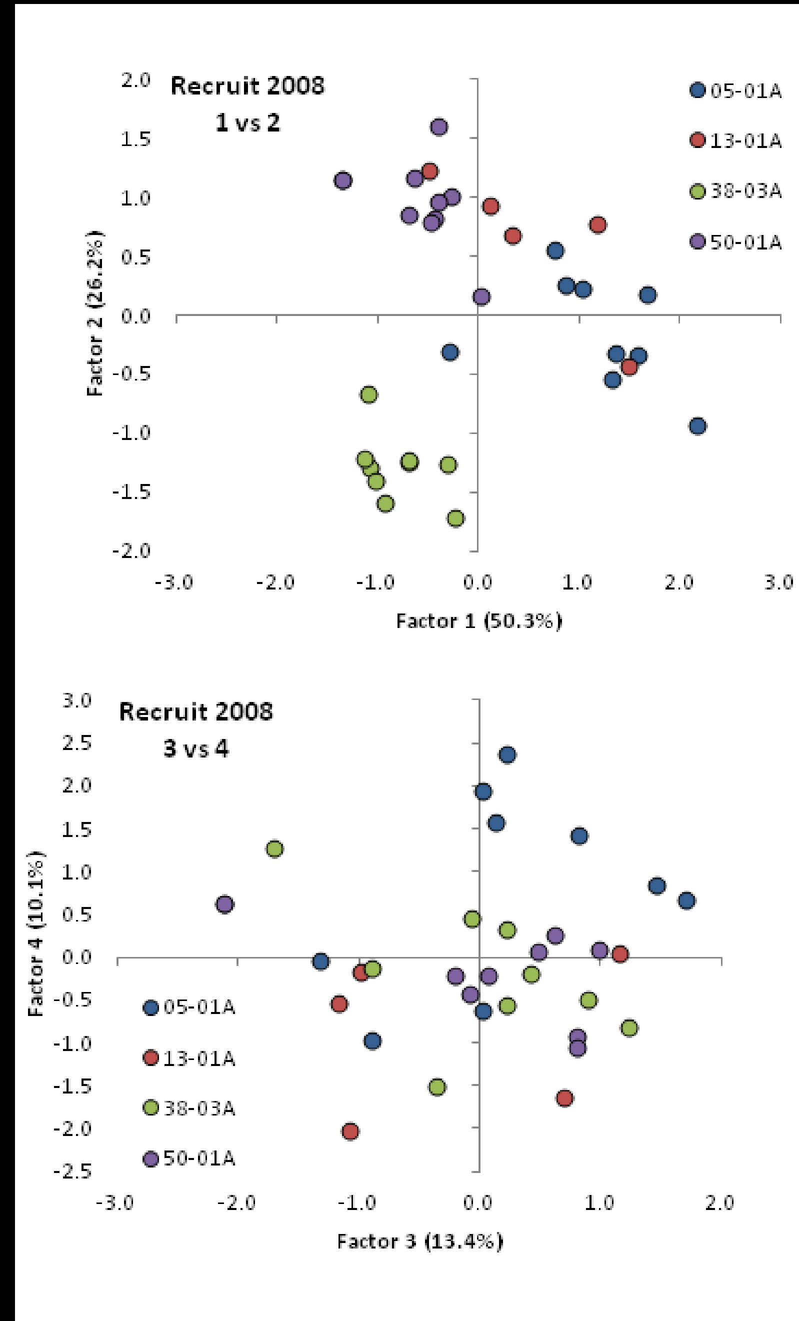
Stock composition of Gulf of St Lawrence cod



Otolith microchemistry (ii)

- Otolith composition of juvenile sardine collected during 2008 measured (IRD's CHRONOS RU); PCA on B, Mg, Sr, Ba

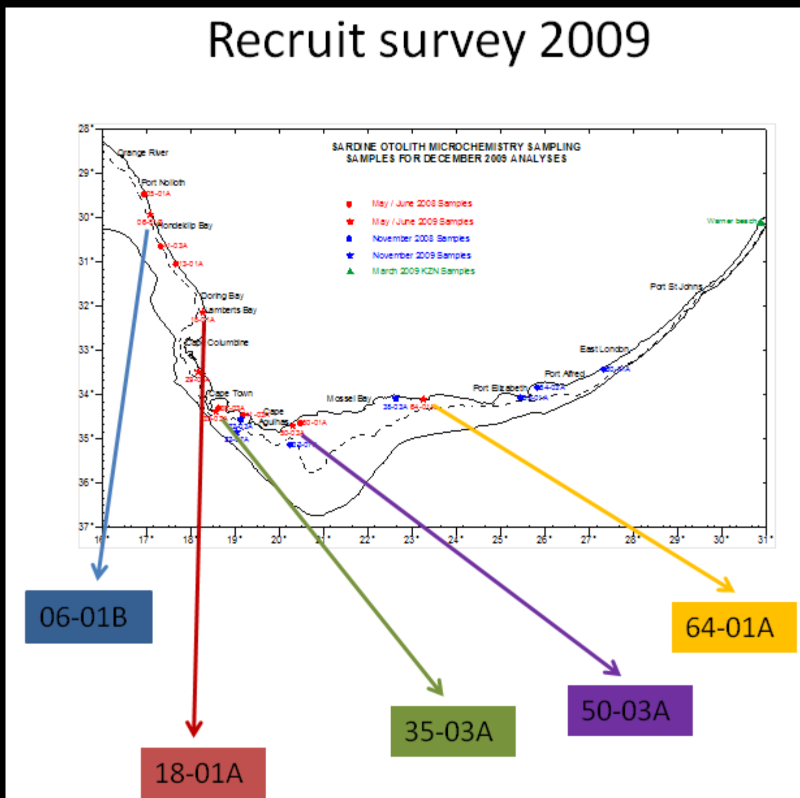


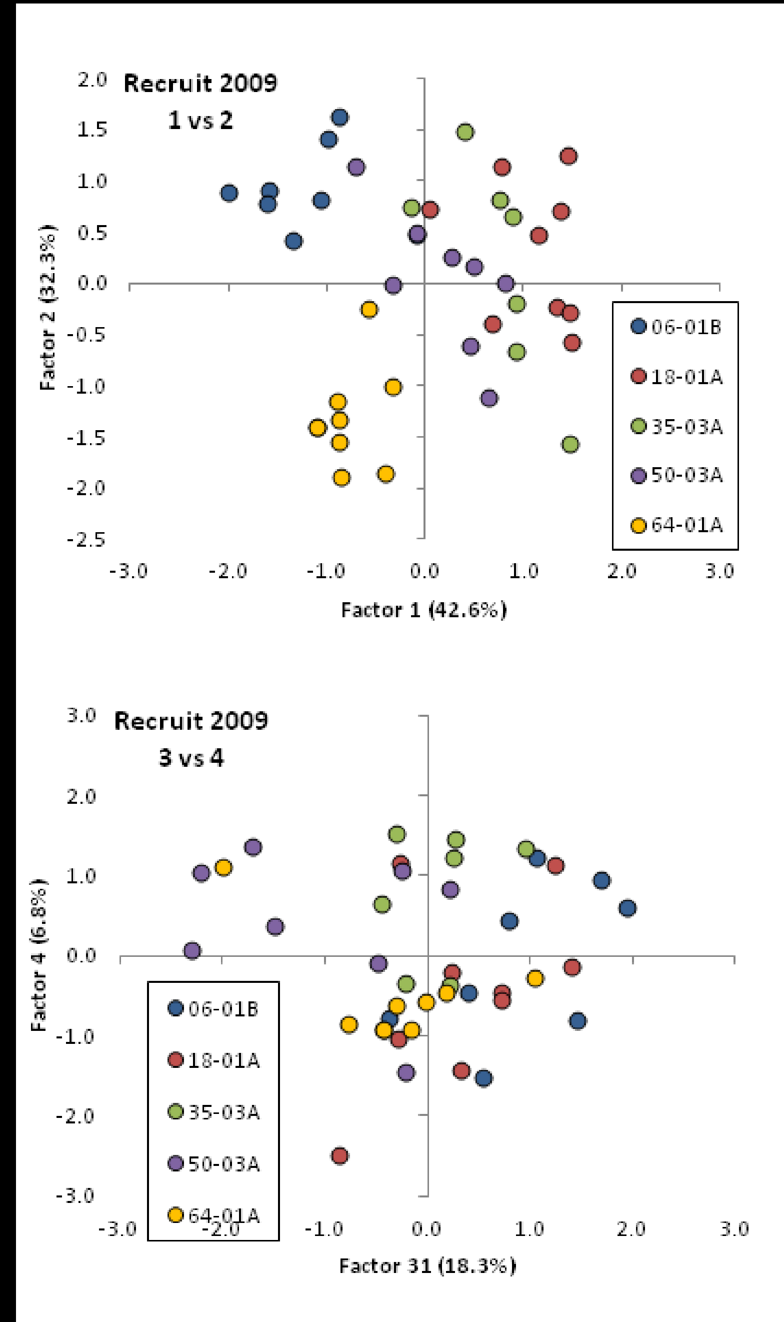


- Spatial effects apparent

Otolith microchemistry (iii)

- Otolith composition of juvenile sardine collected during 2009 measured

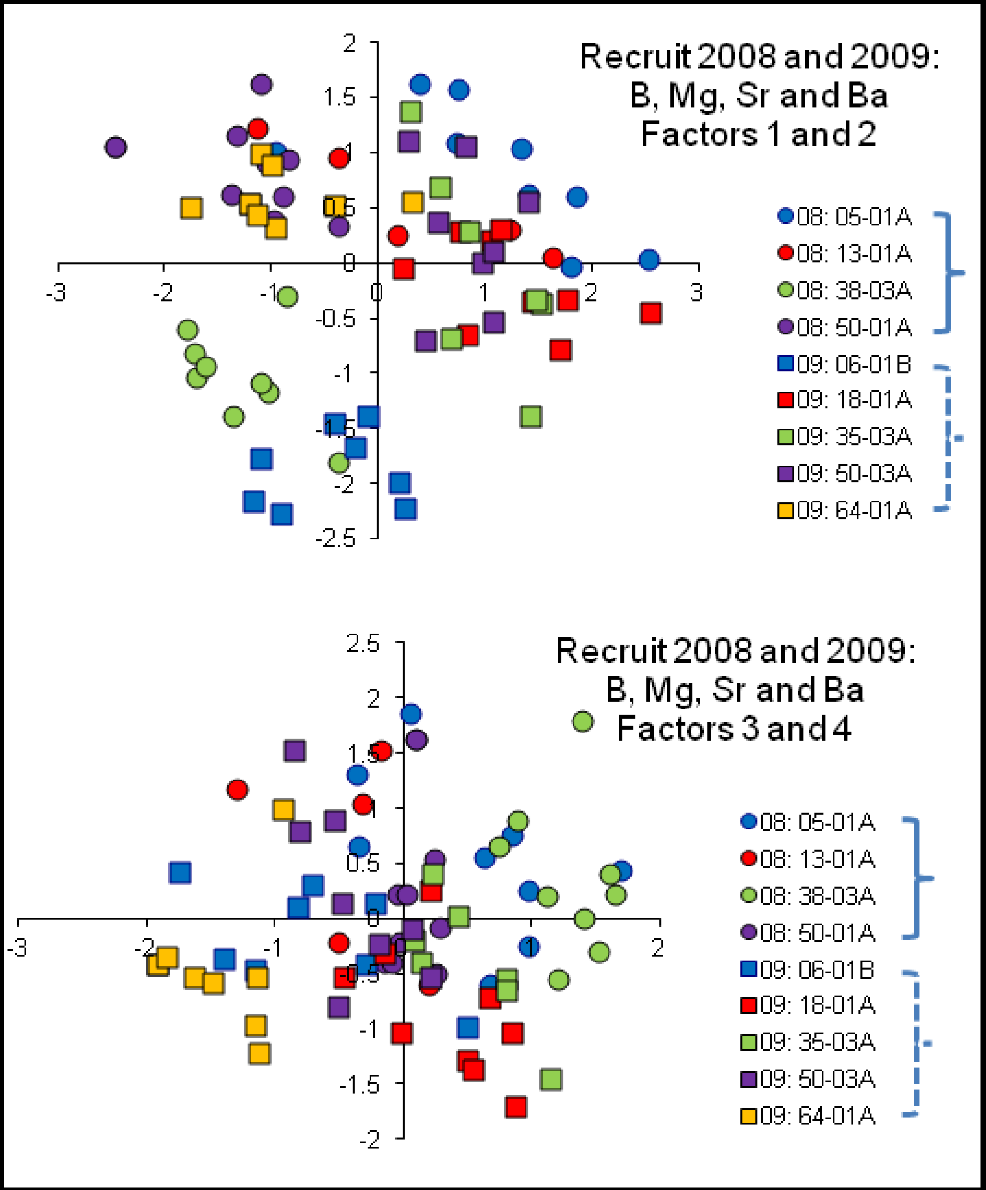




- Spatial effects apparent

Otolith microchemistry (iv)

- Otolith composition of juvenile sardine collected in both years shows spatial variability (required if this is to be used for stock structure studies)
- But samples from nearby locations can be similar (red squares and circles on upper plot) or different (blue squares and circles on upper plot) in successive years
- More interannual than spatial variability?



How might multiple stocks have come about?

- Estimated sardine habitat (shelf waters of 12-22°C) at Last Glacial Maximum (LGM; 18 000 BP) possibly divided into two regions (west and east) of proto-Cape Agulhas due to a more-southward extent of the continental shelf as a result of lower sea levels then

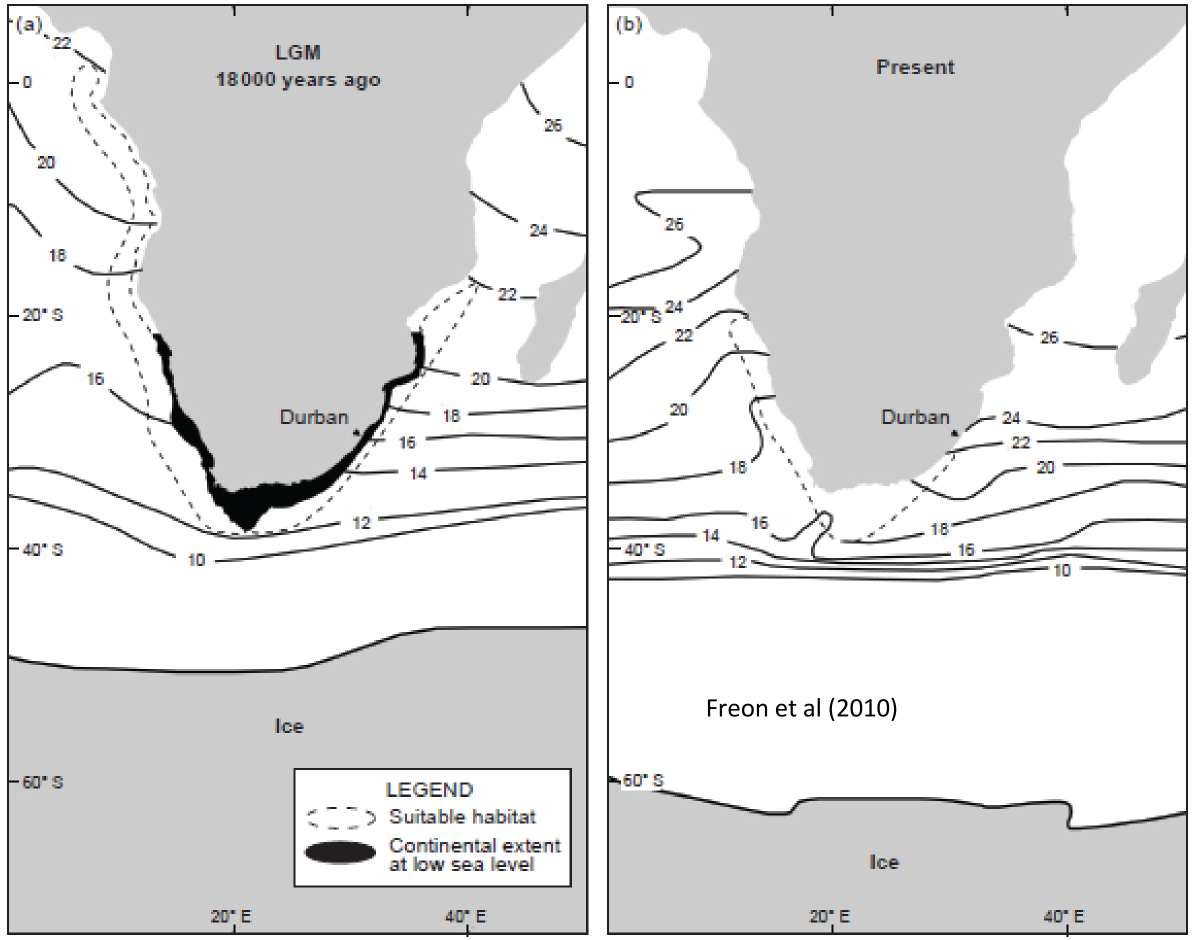


Figure 13: Sea surface temperature (°C) and estimated sardine habitat (see text for details) during (a) the Last Glacial Maximum (LGM) (18 000 years before present, redrawn from Stanley 1989), and (b) at present (winter). Also shown is the expansion of the southern part of the African continent as a result of much lower sea level during the last ice age. The continental expansion southward is redrawn from Parkington (2006) and the temperatures in (b) were drawn from a global SST map (100 km resolution) downloaded from a NOAA website (www.osdpd.noaa.gov/data/sst/contour/global100.fc.gif) at the beginning of June 2010