From Physical Mechanisms to Natural Fluctuations of Small Pelagic Fishes: The Angolan Upwelling Scenario

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with contributions from Pedro Tchipalanga, Robert Kopte, Marcus Dengler, Peter Brandt, Rodrigue A. I. Kounque and Volker Mohrholz
1) What type of upwelling dominates in the tropical sector off Angola 6°-12°30’S?

2) The annual cycle of oceanography and SPF habitats inferred from satellite and in situ data

3) Warming of the coastal climate and interannual events 1982-2014 inferred from satellite data

4) The changes in the distribution pattern and length structure of *sardinella* spp. from acoustic surveys 1991-2014

5) Strength of the interannual warm events, the Benguela Niños vs. changes to the southern range of the sardinella stock. Is there a correspondence?
Towards understanding the role of Tropical Atlantic Variability (TAV) and Coastally Trapped Waves (CTW) in controlling the coastal upwelling in the ATUR.

Picaut (1983): the first observational evidence of remotely forced propagations as the source of the Angolan upwelling (pressure sensors and bucket temperature at coastal stations).

Schouten et al. (2005): description of the semi-annual cycle of upwelling and downwelling propagations along the Angolan coast from altimetry.

Florenchie et al. (2004): connecting the subsurface temperature fluctuations along the Angolan coast to the Benguela Niños – the remotely forced interannual events that outcrop to the surface at the ABF.

Hutchings et al. (2009): identifying the remotely forced Angolan upwelling area as a distinct component within the Benguela Ecosystem.
The satellite derived variability nearest the Angolan coast, averaged over the latitude range 6°30’-12°30’S:
The mean seasonal cycle and its interannual variability: SST (blue), UI (violet), SSH(blue), meridional wind (green)

Highlights from the results of the recent mooring observations and long-term spatial averages of the EAF NOD.

Transport estimate at 11°S, across the shelf from a combined mooring result (2013-2015) and a repeated ADCP section data
- Southward transport dominates
- Intraseasonal and semiannual variability
- D1, D2 southward Angola current (AC) accelerates
- U1, U2 AC subsides or reverses

Kopte et al. 2017

Cross-shelf structure of the current (average of 2005-2014 ADCP):
- D1 Surface intensified “El Niño-like” current extends inshore
  Northward undercurrent along the cont. slope.
  Vertical shear very strong
- U1 The core of the AC above the shelf break.
  Weak southward or reversed (northward) current inshore
  Vertical shear weak

Interannual variability (IV – RMS of 1985-2014, CTD data):
- D1: the strongest IV the thermocline – due to the IV the first mode baroclinic CTW: the cause of the Benguela Niños; the lowest IV is below the 70 m depth of SACW during that season.
- U1: low IV near the bottom expands to a 30 m depth range due to the upwelling CTW induced uplift of SACW. This results in low oxygen and high nutrient concentrations near the bottom without the wind action.
An enrichment mechanism observed on the inner shelf: persistence of internal waves (IW) during U1, enrichment in regions of their IW breaking.

An acoustic record (in the background) showing an internal wave train breaking with a trace of an undulated CTD showing oxygen concentration. At the IW breaking front a larger portion of the column is occupied with low in oxygen (and rich in nutrients) SACW.

Kinetic energy dissipation rates averaged over several microstructure casts increase to $10^{-5}$ W kg$^{-1}$ suggest an intense mixing at the region of IW breaking.

The nonlinear internal waves are a ubiquitous physical feature in the ATUR during U1: Ostrowski et al. 2009.
Concentration of small pelagic fishes at the front associated to a collapsing internal bore as visualized by multi-frequency acoustics

Feb 2014. Internal bore absent. Fish do not concentrate inshore

Sardinella schools

31 Jul 2012. Internal bore arriving; nighttime fish dispersed in the water column inshore of the front

Fish scattered in the water column

31 Jul 2012. the same region; next day. Fish near the bottom
Macro-zooplankton, micronecton and fish responses to the ISWs driven regime during U1

Thin scattering layers are entrapped within the strongly fluctuating thermocline and entrained in ISWs propagations.

Sardinella tends to be confined within the inshore productivity areas where ISWs break
Macro-zooplankton, micronecton and fish responses to the vertically sheared regime during D1

Thin zooplankton layers associated with the shear of the current

Sardinella tends to be widely distributed across the shelf

Stacey et al. 2007

Ambriz on 3 Feb 2014
The offshore ranges of the acoustically derived distributions of *Sardinella spp.* respond to the D1 and U1 regimes.

February-March

June-August
SUMMARY 1: The annual scenario of the SPF habitat in the CTW controlled Angolan Tropical Upwelling Region

**D1, D2:**
Favors transport habitat; offshore foraging, larval transport and adult fish migration with the persistent current to the south.

**U1, U2:**
Favors spawning habitat; Inshore foraging, retention of spawning products within The inshore areas. Weak southward to northward currents, particularly inshore, are favorable to natal homing migration of the adults towards the north.

Adapted from Boley and Freon 1980, after Ghéno and de Campos Rosario, 1972
Evolution of the weekly SST anomaly nearest to the Angolan coast (8-16 km), 6°-12°30’S and periods of largest disturbances

Trend: 0.35 °C/decade (removed)

- D1: the 1984 Benguela Niño
- D1: the 1995 Benguela Niño
- D1: the 1997 “Benguela Niña”
- D1: the 2007 Benguela Niño
- D1: the 2011 Benguela Niño

The method: Torrence and Compo (1998)
The synchrony between the strength of remotely forced circulation and intensity of the seasonal migration of sardine along the Angolan coast was observed in 1970s to 1990s.

The percentage of sardine biomass to the north (top) and south of Luanda (bottom) regions during D1 and U1 surveys, with Dr. Fridtjof Nansen 1994-1998.
Following 1998, the Dr. Fridtjof Nansen trawls started to record juvenile sardinella species in Angolan waters, suggesting a decrease in the spawning migration to the Gabon-Congo region and development of local spawning areas off Angola, particularly for flat sardinella to the south of Luanda.

Comparing the length structure between fish caught off the Gabon Congo region with those caught of Angola between the 1990s and more recent surveys indicate that following the late 1990s warming the Angolan upwelling region has become a new spawning/nursery area for the southeastern Atlantic stock of flat and round sardinella.

Changes in relative biomass between the north and southern region of the ATUR, 1985-2014, winter surveys only.
Patterns of correspondence between SSTA 8-16 km from the Angolan coast and evolution of *sardinella spp.* biomass index by acoustic surveys with RV Dr. Fridtjof Nansen 1992-2014

**Biomass index by acoustics vs. landings by the Angolan industrial fleet**

**Benguela Niños**
- drop in the estimated biomass
- For 1995 BN the estimate returned to the previous level the half year later
- For 2011 BN it took it one year to rebound.
- A huge increase in the estimated biomass in the wake of the 2011 BN. It coincided with a prolonged cooling 2012-2014.
- Long term effect: Juvenile sardinella started appearing in the Nansen trawls after 1999, coincident to a strengthening of the annual cycle in SST.

![Graph showing biomass index and normalized abundance over time](image)
Passage of coastally trapped propagations (CTW) along the Angolan coasts induces the similar warm and cold water column scenarios to those known from the passage of El Niño/La Niña scenarios along the Pacific Coasts, e.g. Huyer et al. (2002), Kosro (2002) but the difference is that off Angola these scenarios are locked to the seasonal time-scales.

The largest interannual variability falls on the austral summer and autumn. Warm events, the Benguela Niños, affect the SPF habitat of Angola by inducing particularly strong downwelling and southward current episodes that shut down productivity from the inshore fish habitats, enforce the alongshore poleward transport.

Benguela Niños episodes are found to affect biomass estimates of sardinella by acoustic surveys. Southward shifts of its distributional range and drop in the estimated biomass were observed. However, these changes were transient, rebound to the previous state within one season or year. The population structure was not affected.

Both flat and round sardinella did well in connection to the warming observed in the Angolan waters during the last two decades. Its biomass increased, while spawning and nursery grounds were expanded to the south of the Congo River.
THANK YOU