Using available fishery, ecological and environmental time series to examine temporal variability in the Southern Benguela ecosystem over the past four decades

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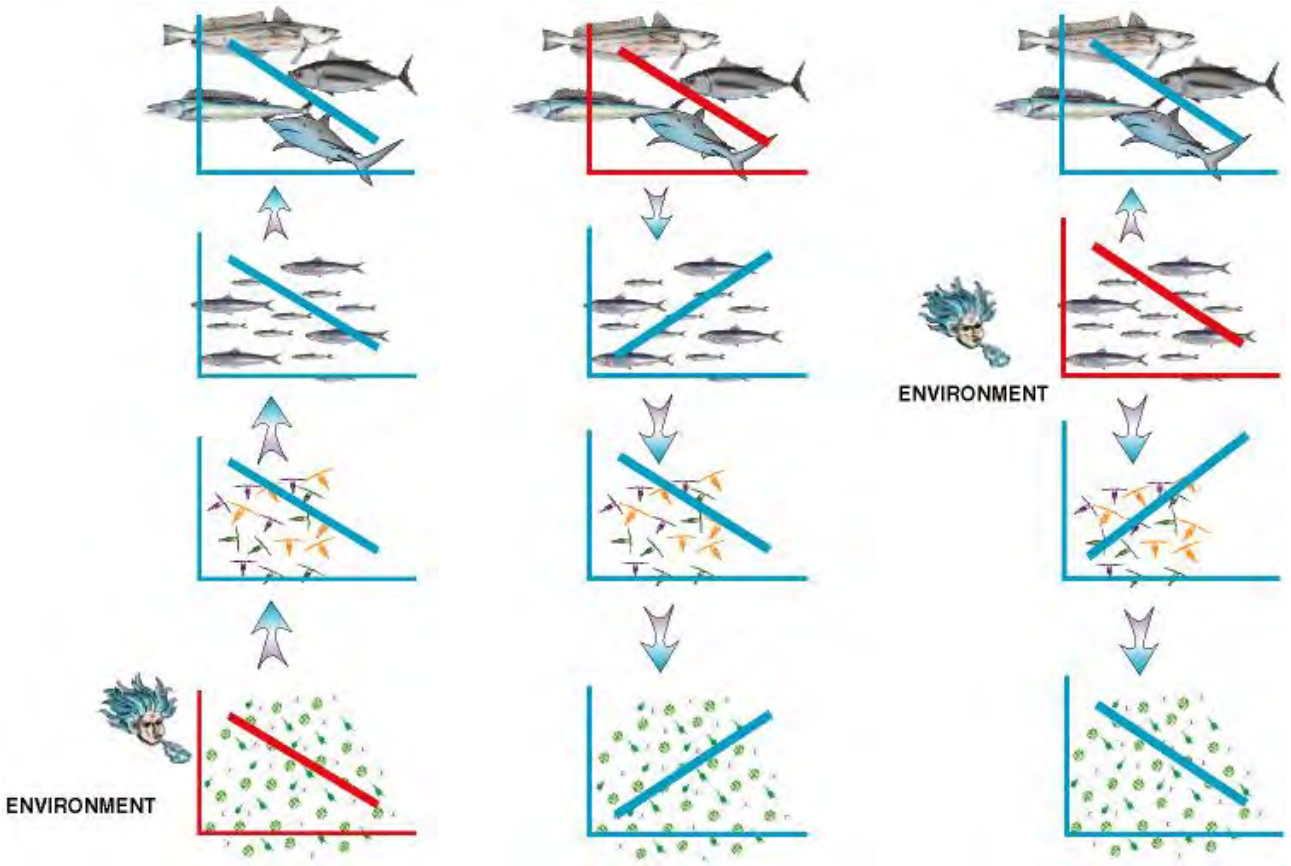
In the context of the foodweb

- **Environmental change may act at several trophic levels**
- **… and in combination with fishing and internal ecosystem dynamics**
- **- causing changes in overall structure (and sometimes functioning) of foodwebs**

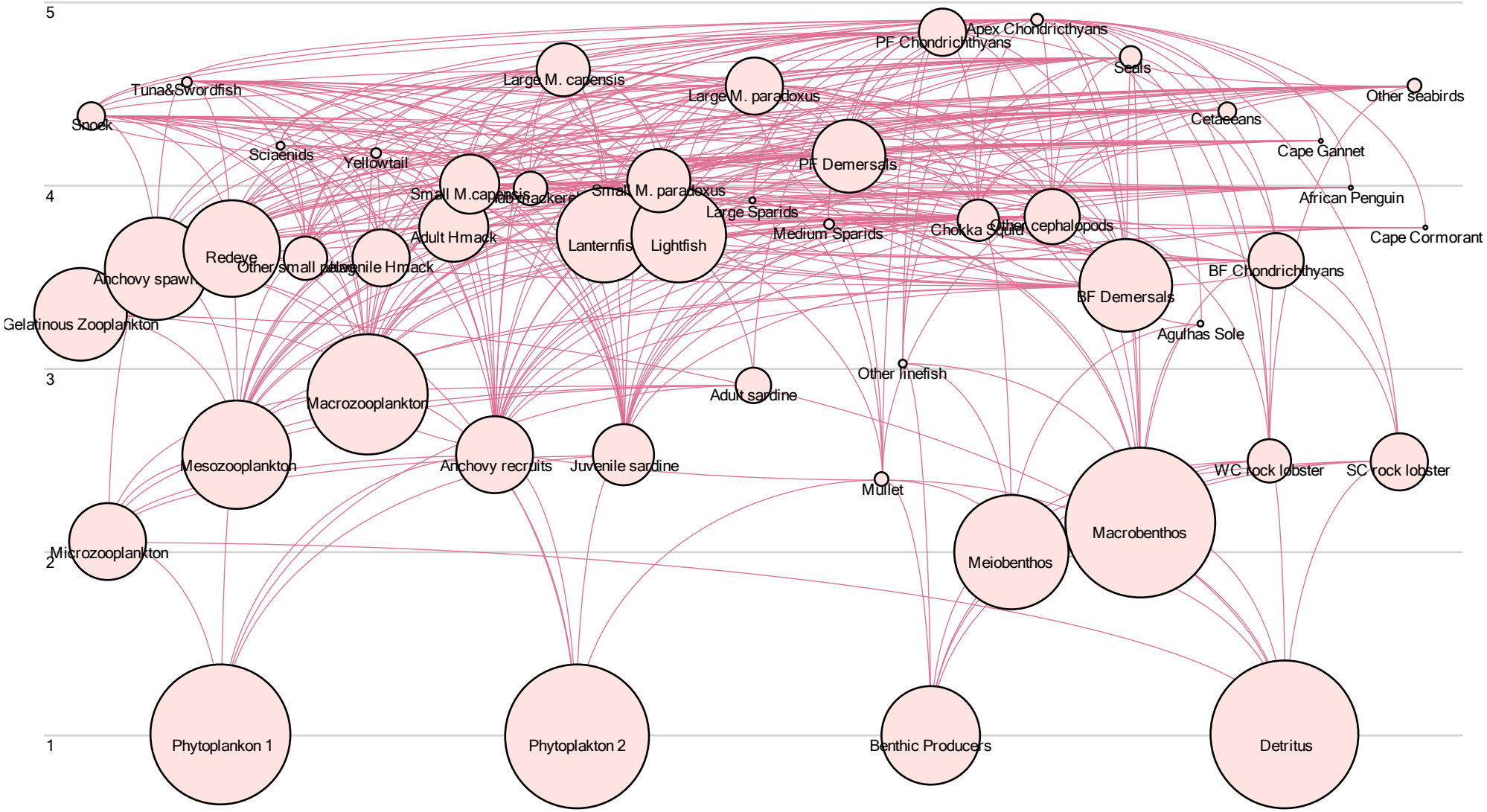


Modelling the Southern Benguela food web: TAMING THE MONSTER

- Ecopath with Ecosim framework (Walters et al. 2000)
- Existing model for 1978-2003 (Shannon et al. 2009) expanded & updated
- 48 living model groups, including 26 fish groups and 7 top predators
- Newly available environmental time series to drive primary production
- Fitting of model consumer groups to 33 time series of abundance, 18 time series of catch and 5 time series of mortality, using 13 time series of fishing effort & 2 time series of fishing mortality

Shannon, L.J., Coll, M. and Neira, S. 2009. Ecological Indicators 9: 1078-1095
Walters, C., Pauly, D., Christensen, V., and Kitchell, J.F. 2000. *Ecosystems, 3*(1), 70-83.

Southern Benguela foodweb modelled using EwE



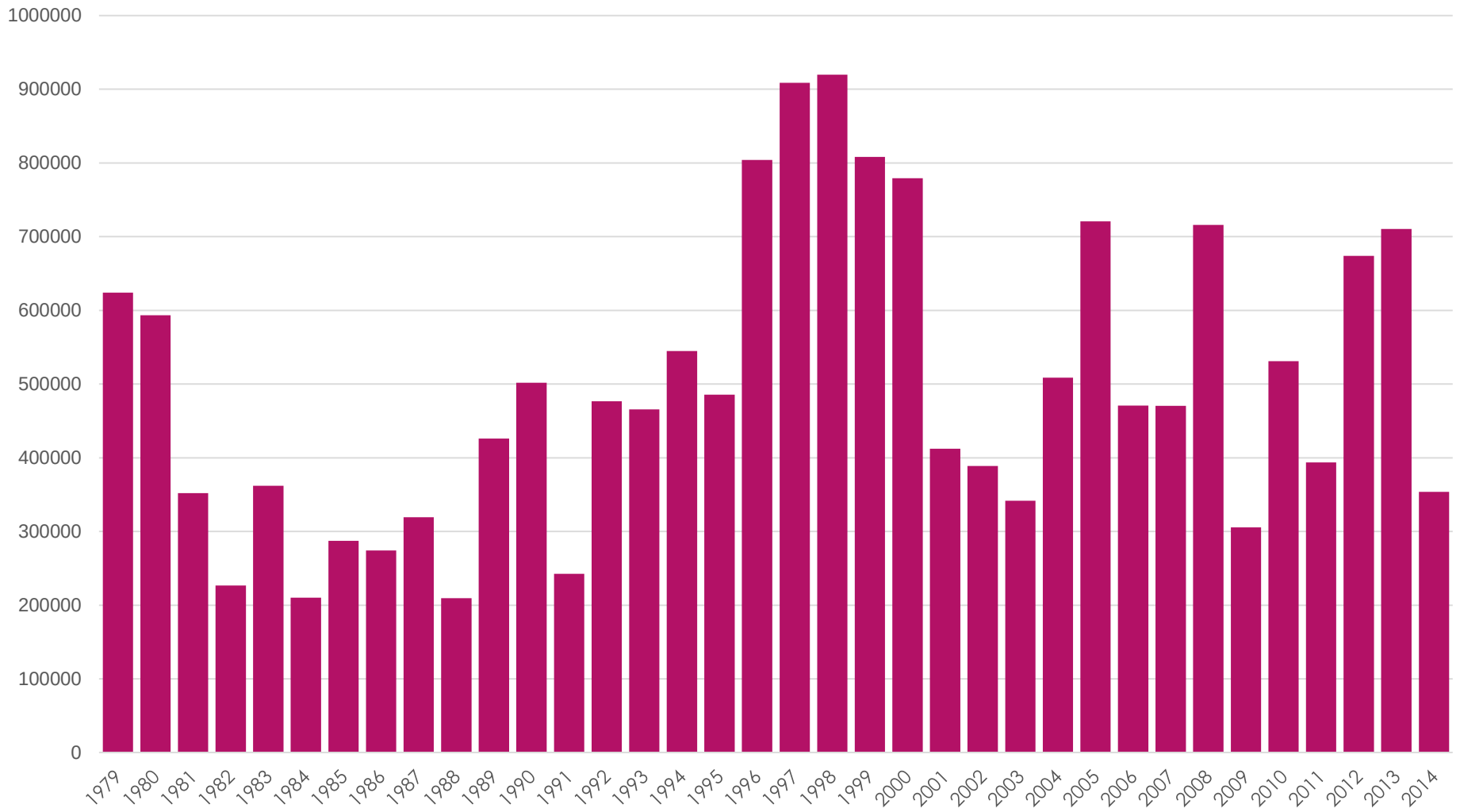
Regime shift: a particular challenge

- 1978: Southern Benguela heavily fished, low biomasses through the 1980s
- Early 1980s: Benguela ecosystem research programme started, more conservative fisheries management since mid-1980s, biomasses recovering
- Late 1990s: Regime shift, increased productivity on the Agulhas Bank, change in spatial distribution of forage fish
- Into the 2000s: massive changes in the Benguela food web
- Question: can such a major spatial event be fitted in a non-spatial framework?

First round of model fitting: 1978-2015

- Model trajectories of biomass and landings outputs for 1978-2015 were compared to 57 catch, abundance and mortality time series
- Total cumulative upwelling was used to directly force large-celled phytoplankton production
- 40 most sensitive predator-prey interactions were identified and vulnerability of prey to predators was estimated to improve model fit to data series of field observations
- A small, additional (hypothetical) environmental anomaly was fitted to small-celled phytoplankton to refine model fits, especially to anchovy biomass data series

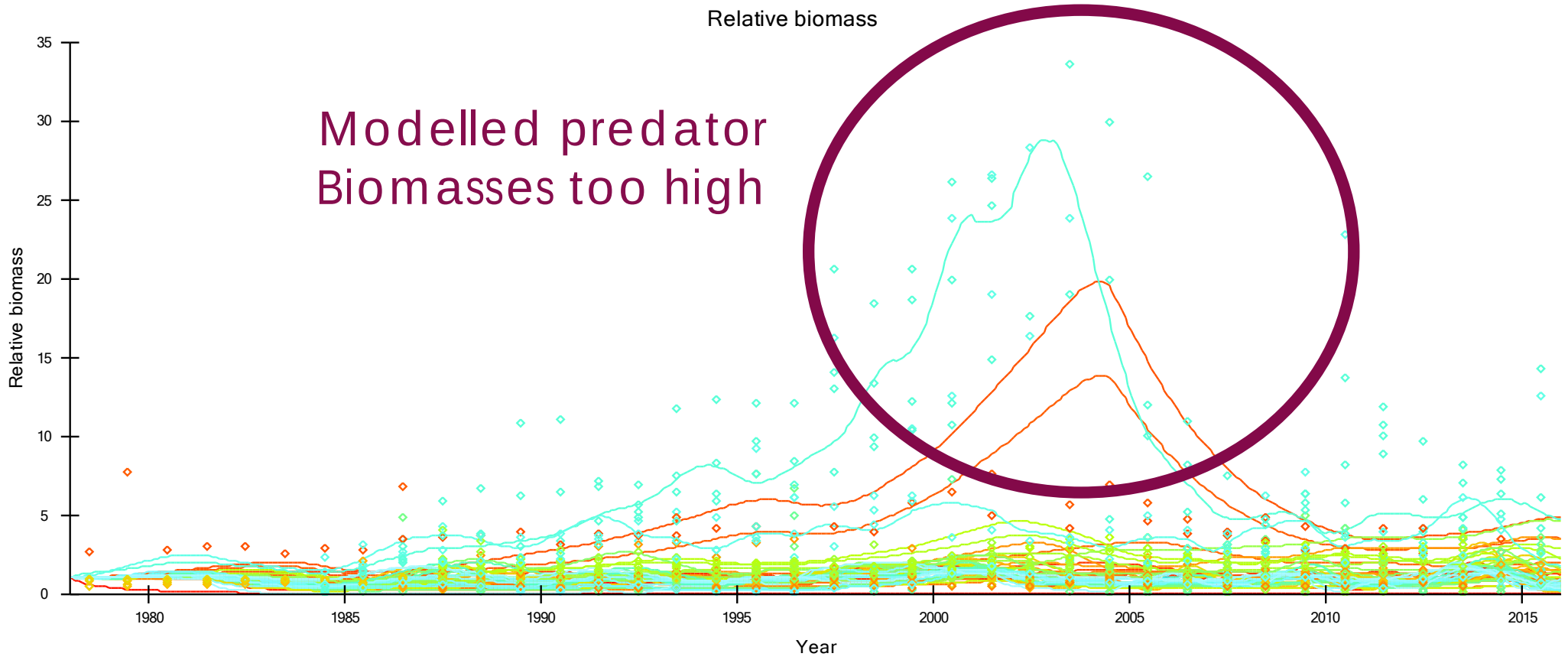
Upwelling in the Southern Benguela - Increased upwelling since 1996



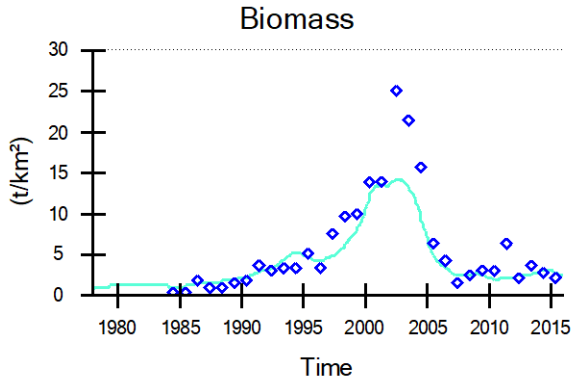
Total cumulative upwelling per year (m^{-3} s^{-1} 100 m^{-1}) in the Southern Benguela (Lamont et al. 2017)

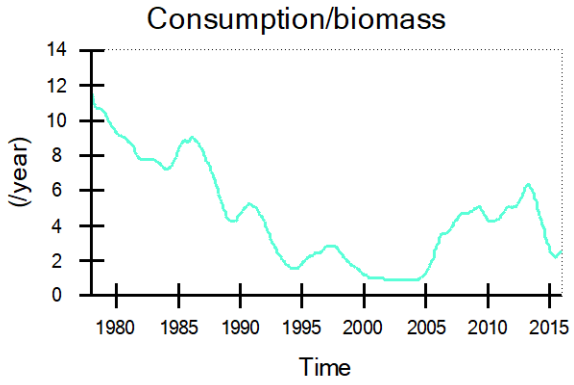
Lamont, T., et al., 2017. J. Mar. Syst. http://dx.doi.org/10.1016/j.jmarsys.

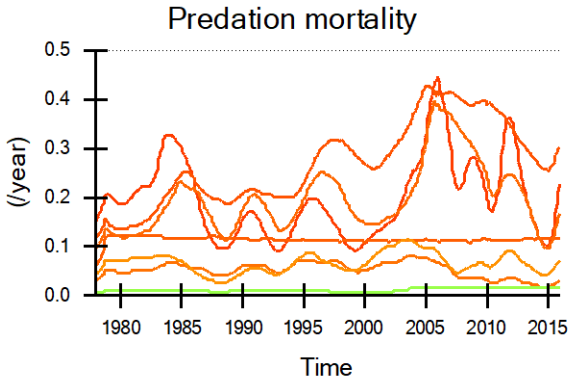
The regime shift – hitting a snag

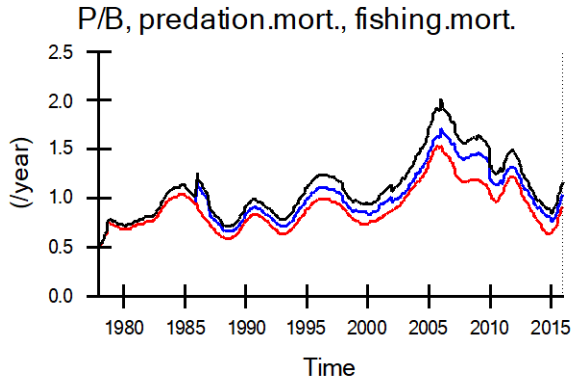


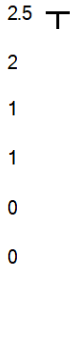
Adult sardine

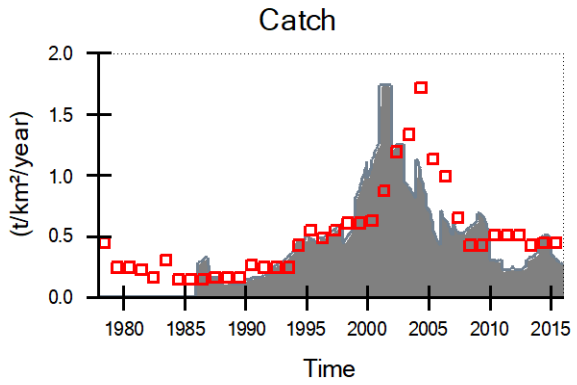








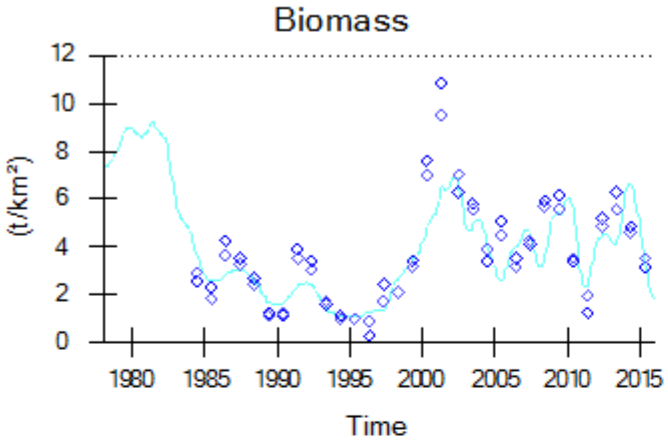




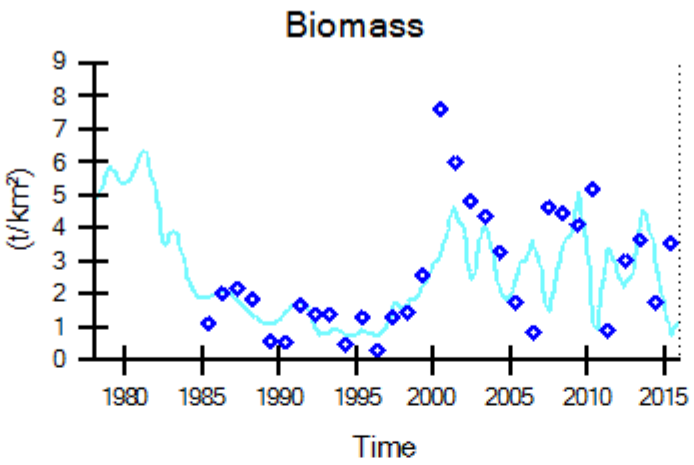
Modelled adult sardine – first fitting

Stock dynamics of other modelled fish: first fitting

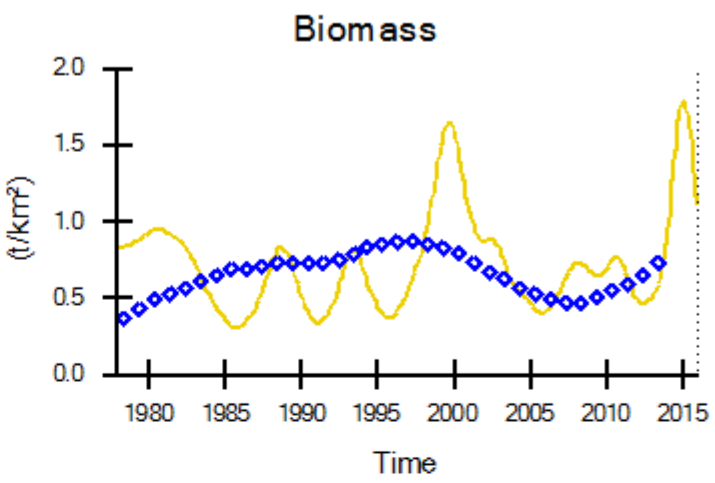
Anchovy Spawners



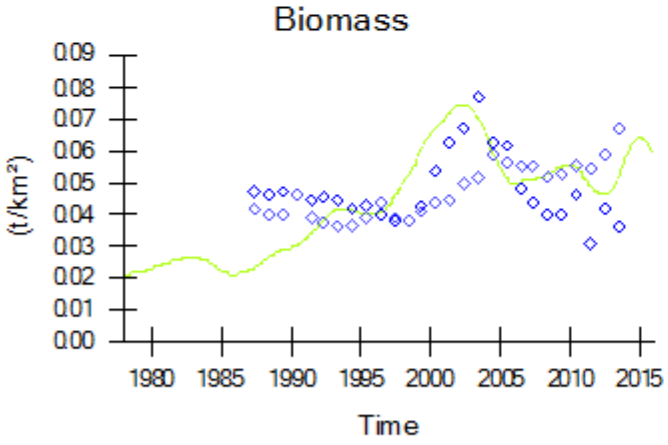
Anchovy recruits



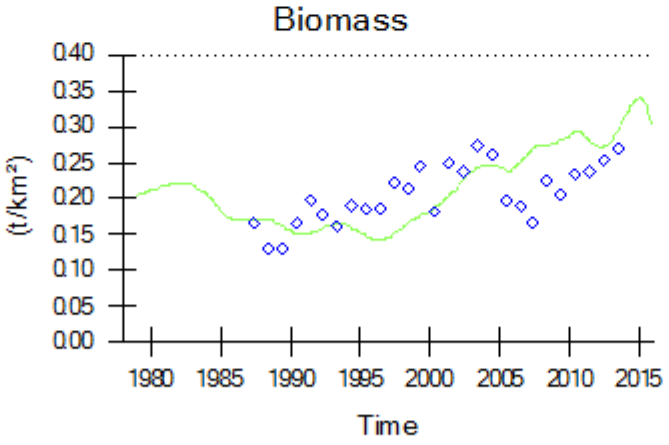
Large Shallow-water Cape Hake



Sciaenids



Snoek



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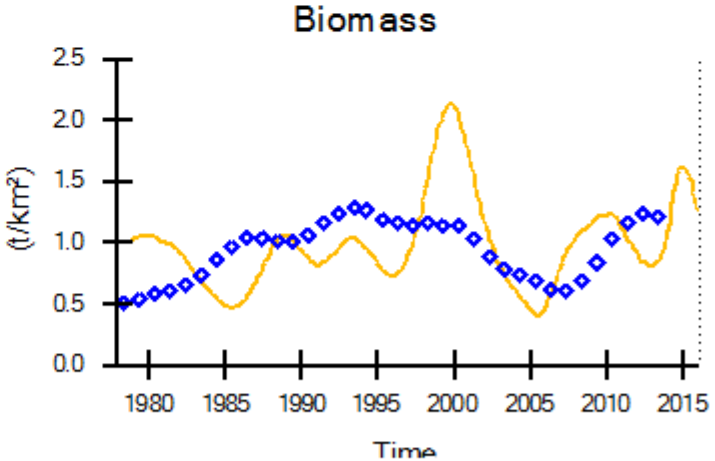
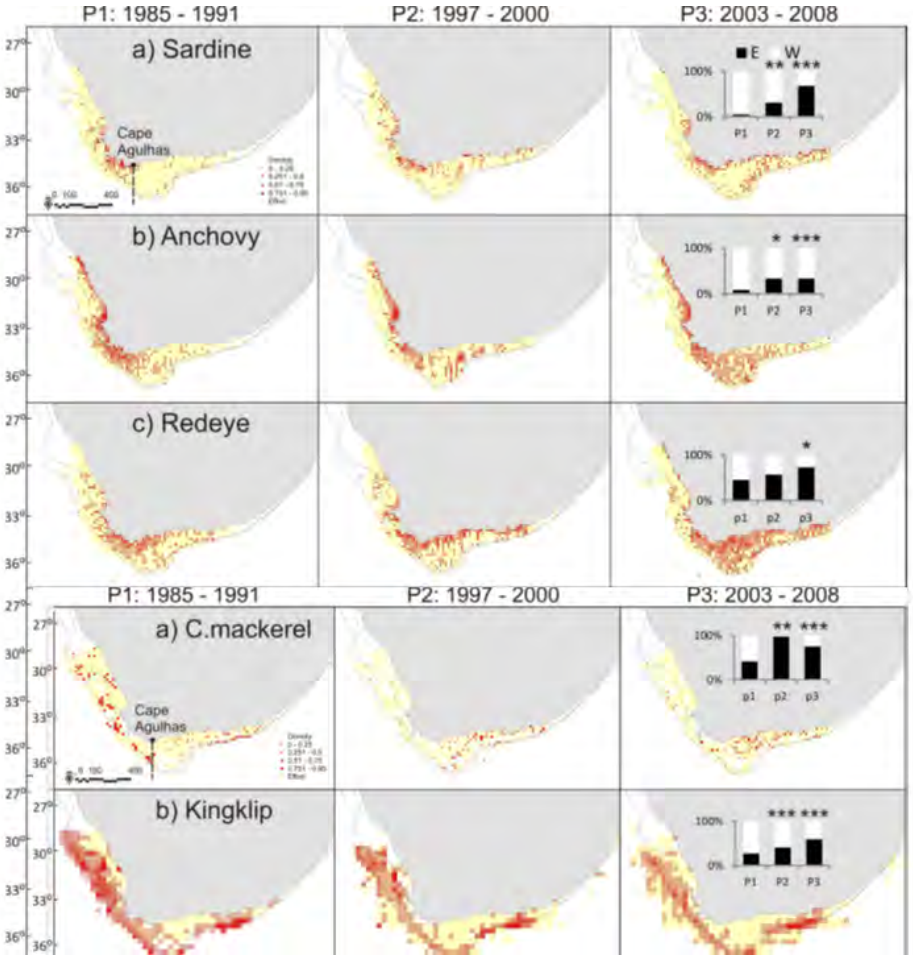


Summary of first model fitting

- When fishing effort series alone drive model groups, the overall model fits are poor for most groups
- Sum of Squares (SS) of model fits to data are reduced by 10% when Total Upwelling is used to force large-celled phytoplankton production
- SS reduced by a further 48% (!!) when vulnerability of prey to predators is fine-tuned under observed fisheries and total upwelling driver series
- SS further reduced by another 20% when an anomaly is applied to small-celled phytoplankton (anchovy fits refined)
- BUT we have a problem in the early 2000s – forage fish-predators…

Second model fit - explore food availability



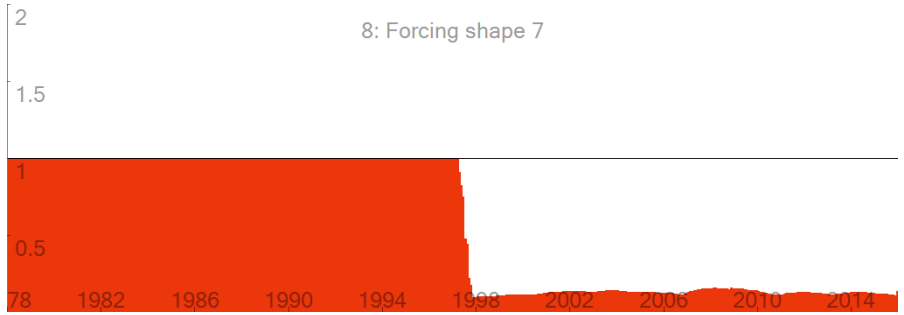
Southward/eastward shift in several resources in the early 2000s

Distribution maps for a selection of fish Species in the Southern Benguela over three time periods 1985-2008

Watermeyer et al. 2016. Plos One 11(7): e0158734

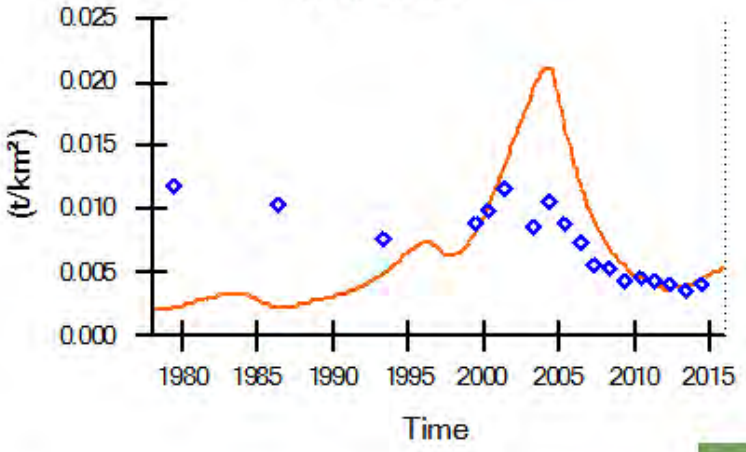
Exploring the “2000s overshoot” in abundance of most predators

Availability function imposed on African Penguins and Cape Gannet eating adult sardine
(20% and 30% of diet composition, respectively)

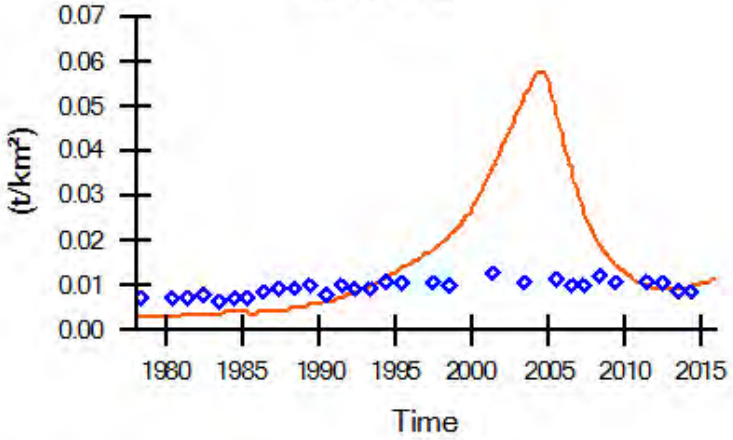


2nd model fit – sardine availabiity is altered for penguins & gannets

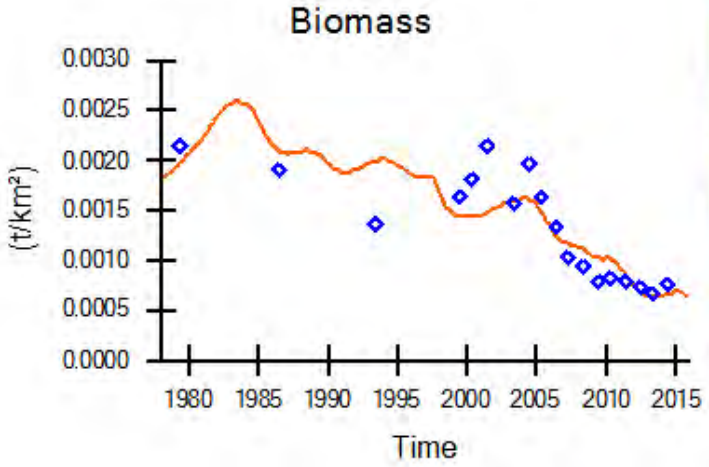
African Penguin – first fit



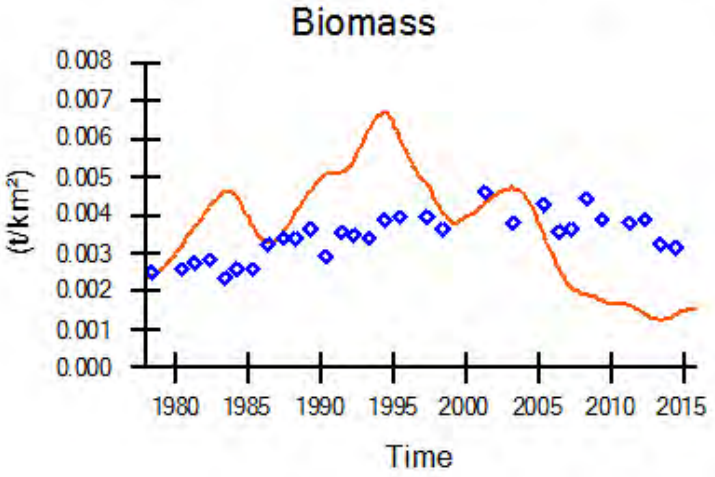
Cape Gannet – first fit



When availability of adult sardine to penguins is reduced after 1998



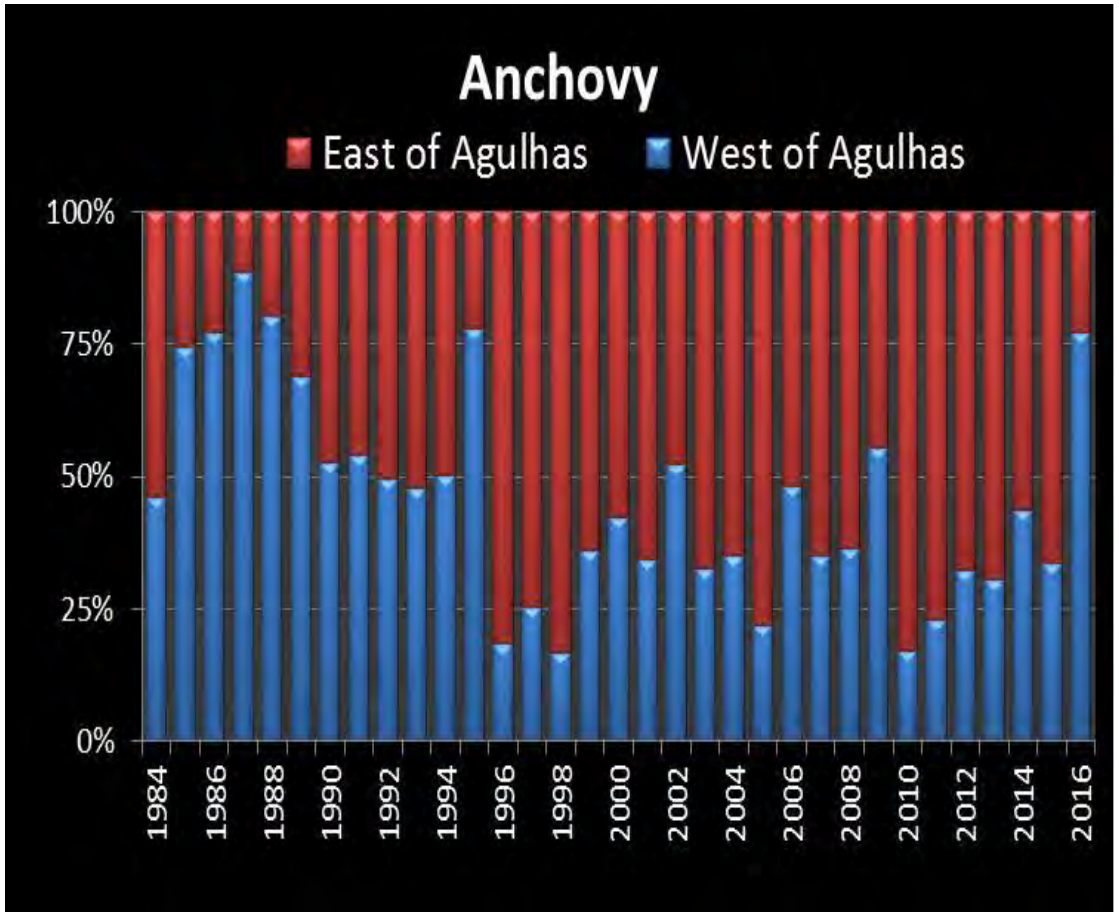
When availability of adult sardine to gannets is also hypothetically reduced after 1998

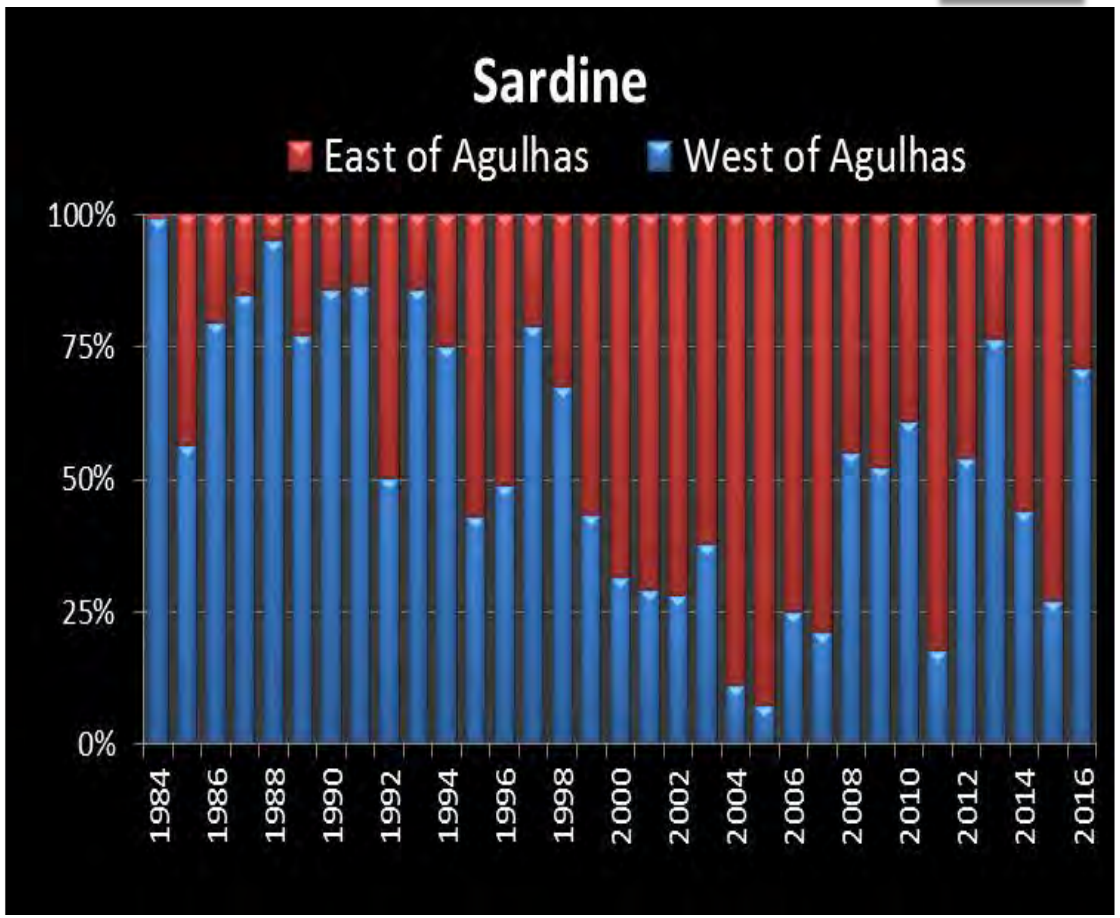


Spatial change modelled as change in prey availability – 3rd model fit

- Total cumulative upwelling (S Benguela) applied to large-celled phytoplankton production ***[real]***
- Relative proportion of sardine spawners on the West Coast, applied to availability of juvenile and adult sardine to all their predators ***[real***]
- Then fit a modelled environmental anomaly to small phytoplankton to fine-tune model fits [mainly anchovy fits improved] ***[hypothetical]***
- SS of fits of model to time series was reduced by 63%

Changes in forage fish on the west & east coast

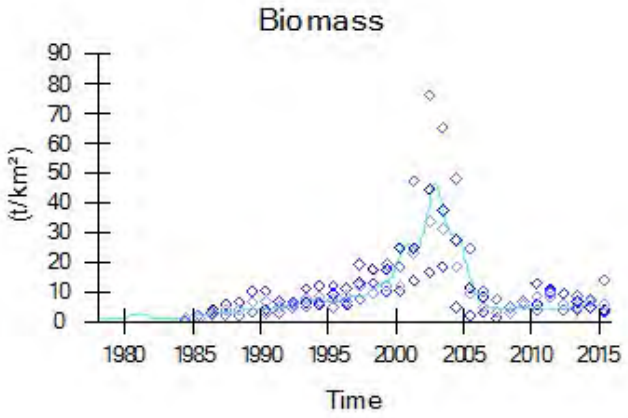




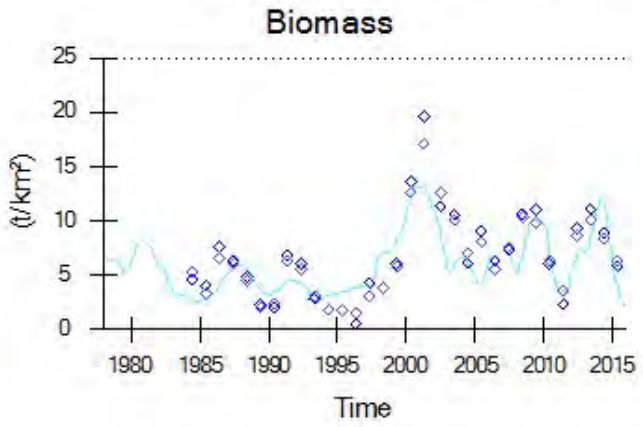
Relative percentage of the biomass found to the west and east of Cape Agulhas. Anchovy (left) and sardine (right). **Coetzee et al 2016** (FISHERIES/2016/DEC/SWG-PEL/79)

3rd model fit – back to "real" forcing

Adult sardine



Anchovy spawners



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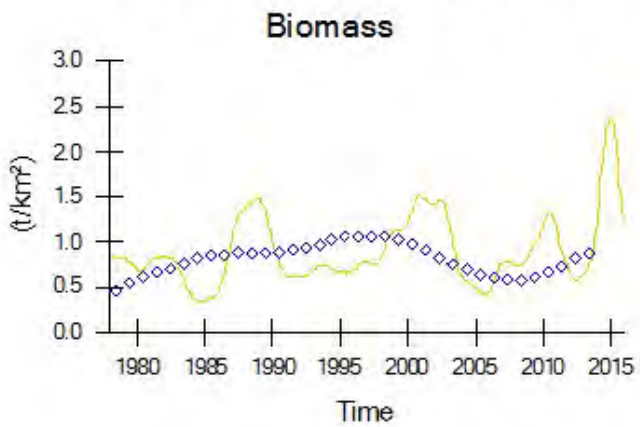

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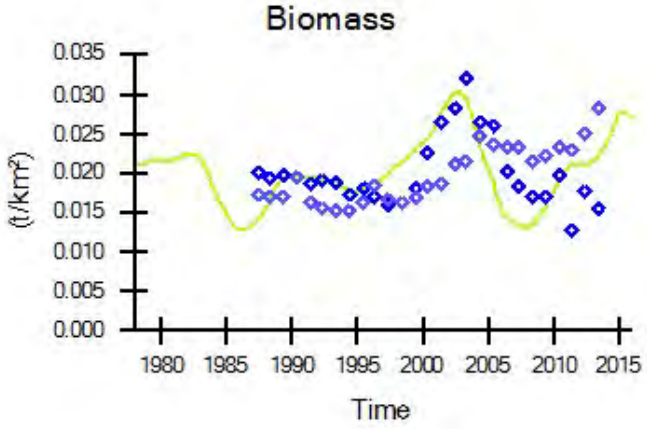

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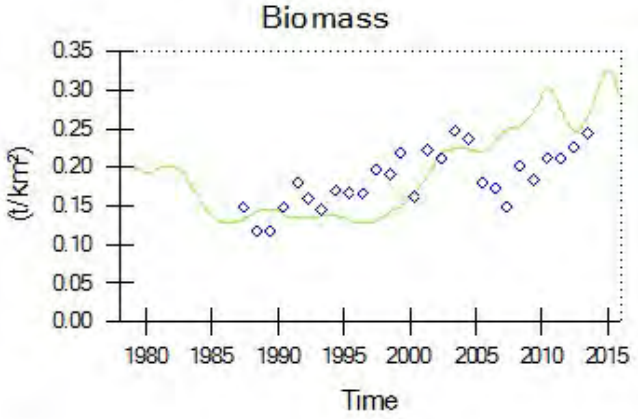

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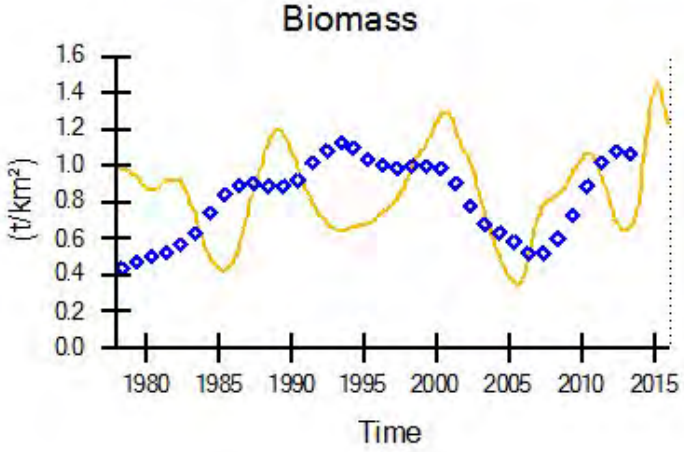

Key findings

- There is no recipe for fitting an ecosystem model – try and try again – test different ways of incorporating process concepts into the model
- Southern Benguela dynamics successfully fitted 1978-2015, through an ecosystem regime shift
- Major spatial change in distribution successfully approximated – through forced changes in prey availability, based on existing time series, as well as biological understanding of the ecosystem dynamics
- Upwelling (intensity) drives productivity in the Benguela, affecting prey abundance of all major fish and top predators- mediated through small pelagic fish especially sardine
- Availability of forage fish to predators needs careful consideration: next step: fully spatialized model for spatially explicit advice on fishing strategies under climate change

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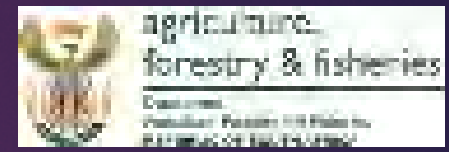
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