Effects of ENSO phases on Peruvian anchovy spatial aggregation patterns

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International Symposium: Drivers of dynamics of small pelagic fish resources

Background

- Humboldt ecosystem: one of the major Eastern Boundary Upwelling Ecosystems
- Environmental variability at interdecadal and inter-annual scales
- The highest fish catch productivity (Chávez *et al.*, 2008), sustaining the world's largest monospecific fishery: Peruvian anchovy (*Engraulis ringens*)
- Most important stock (in catch): North-Central off Peru

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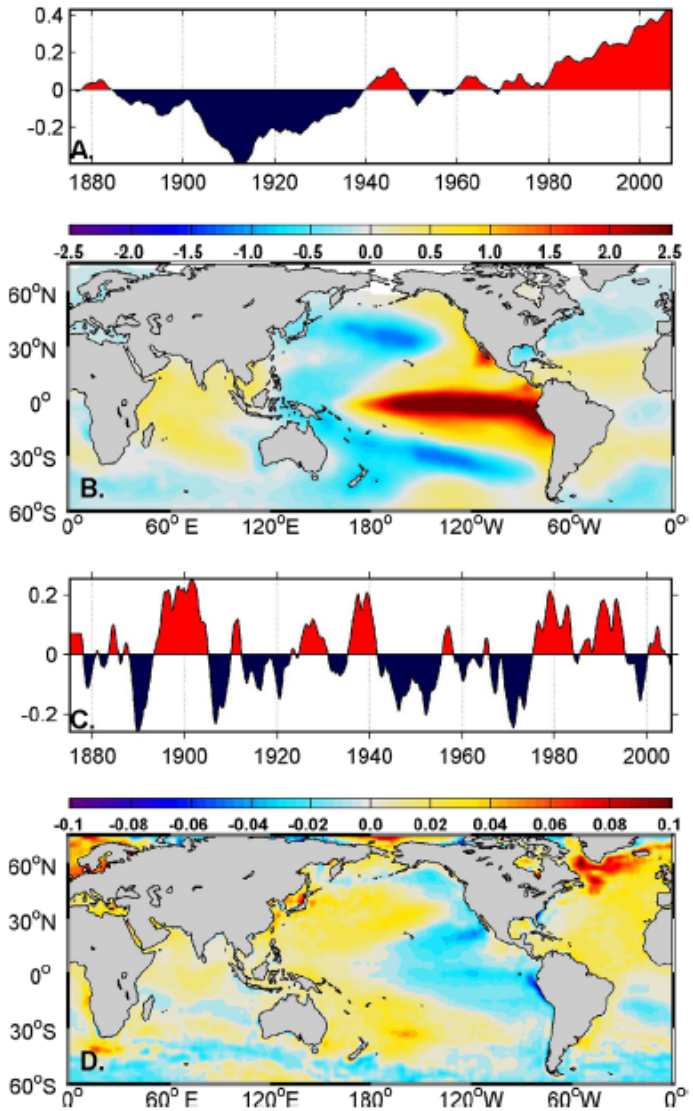

Chávez *et al.*, 2008

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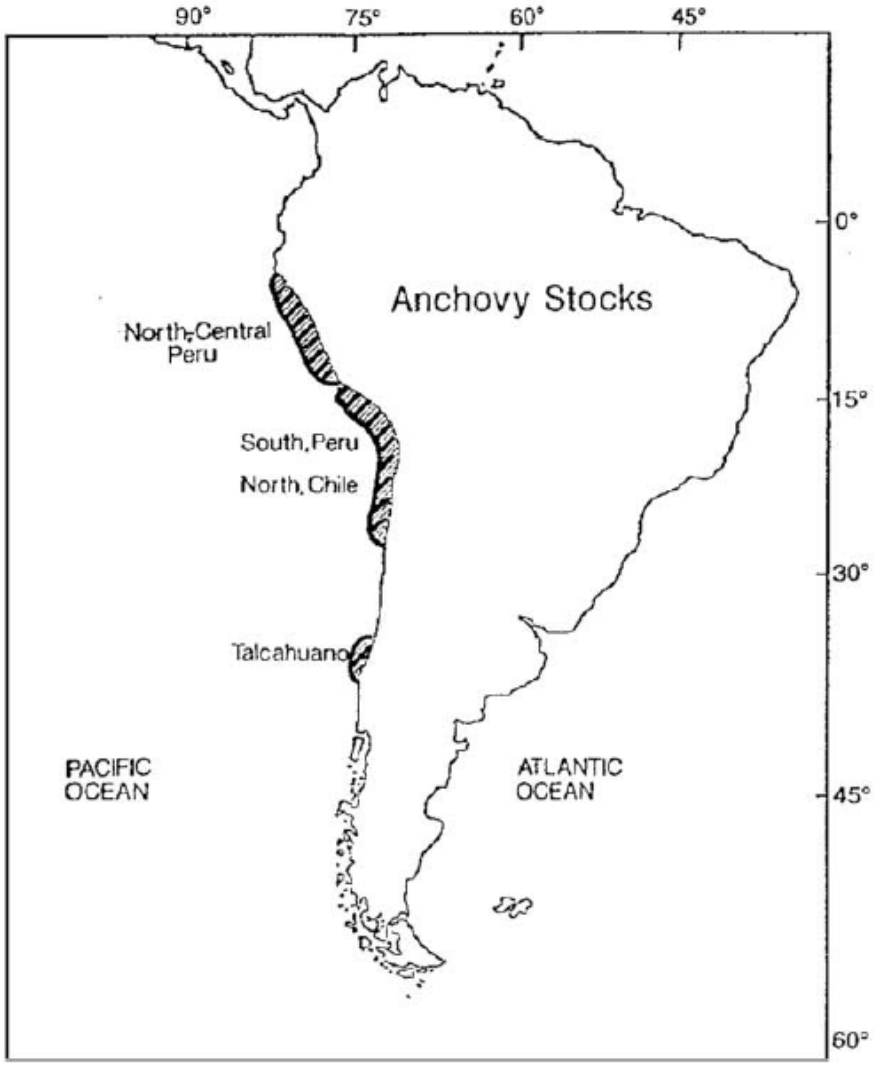

Alheit and Niquen, 2004

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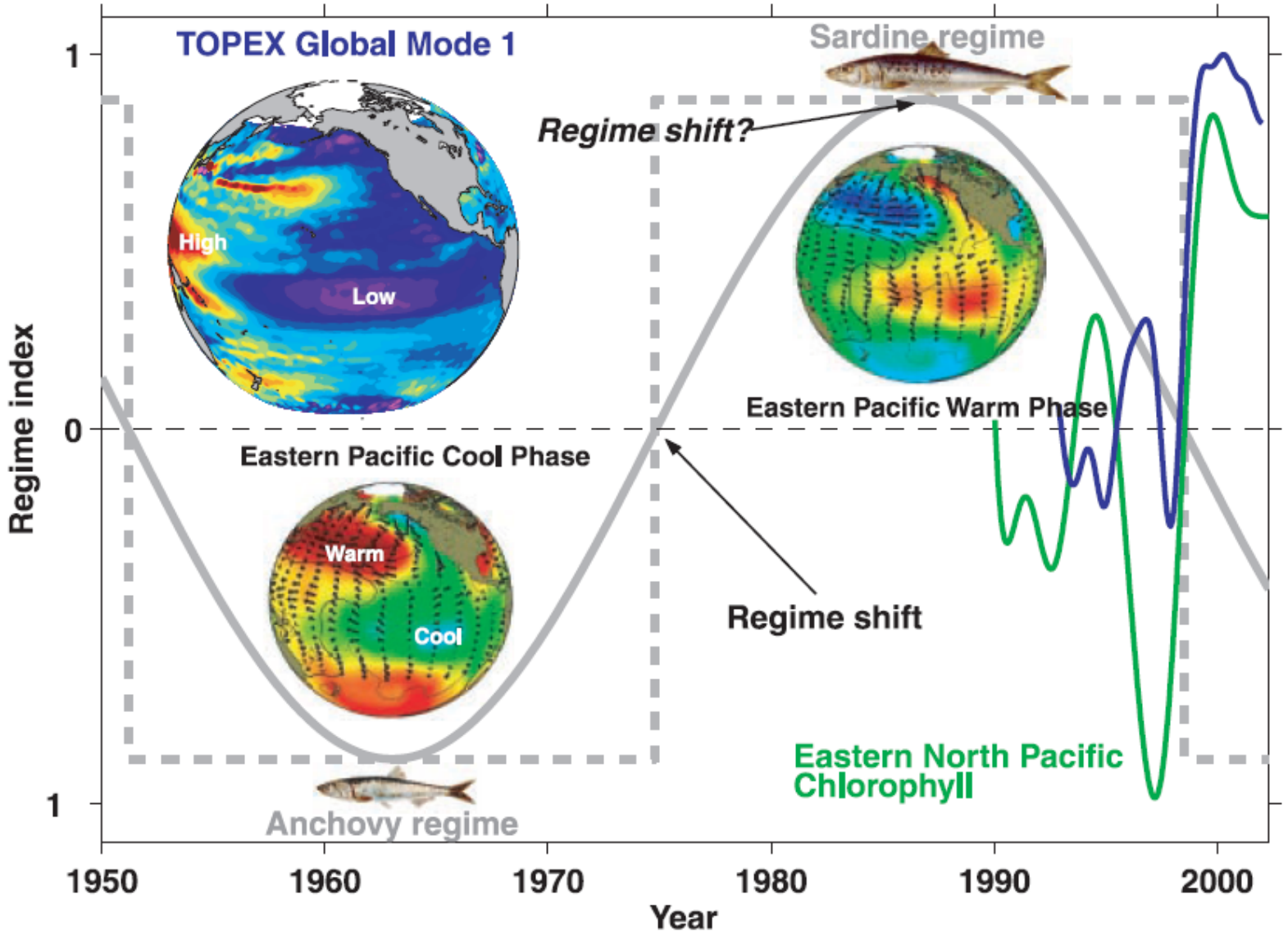

Shifts in abundance of Peruvian anchovy and sardine (Chávez *et al.*, 2003)

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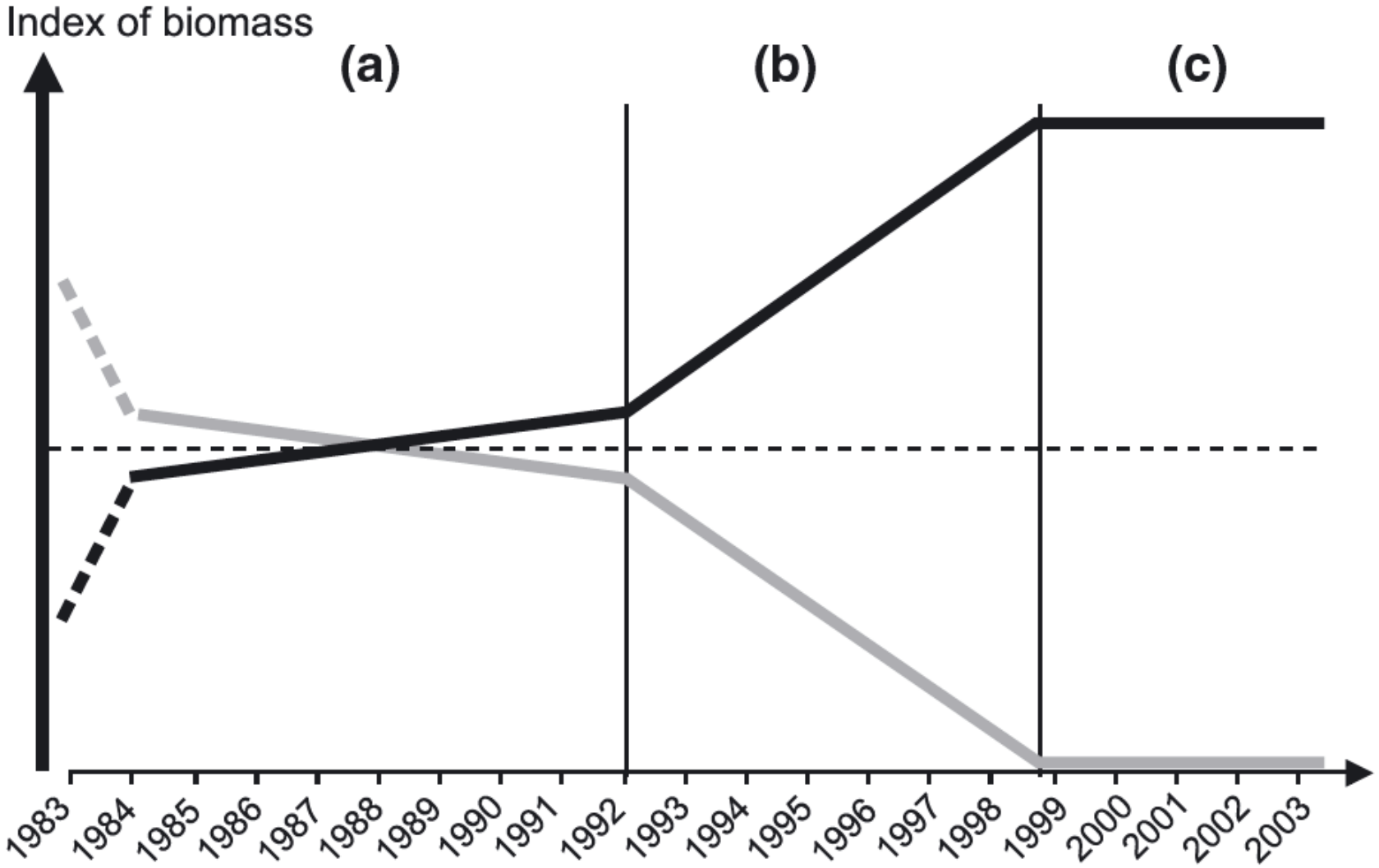

Mixed sardine-anchovy dominance (a), anchovy dominance and sardine collapse (b) and full anchovy era (c) (Gutierrez *et al.*, 2007)

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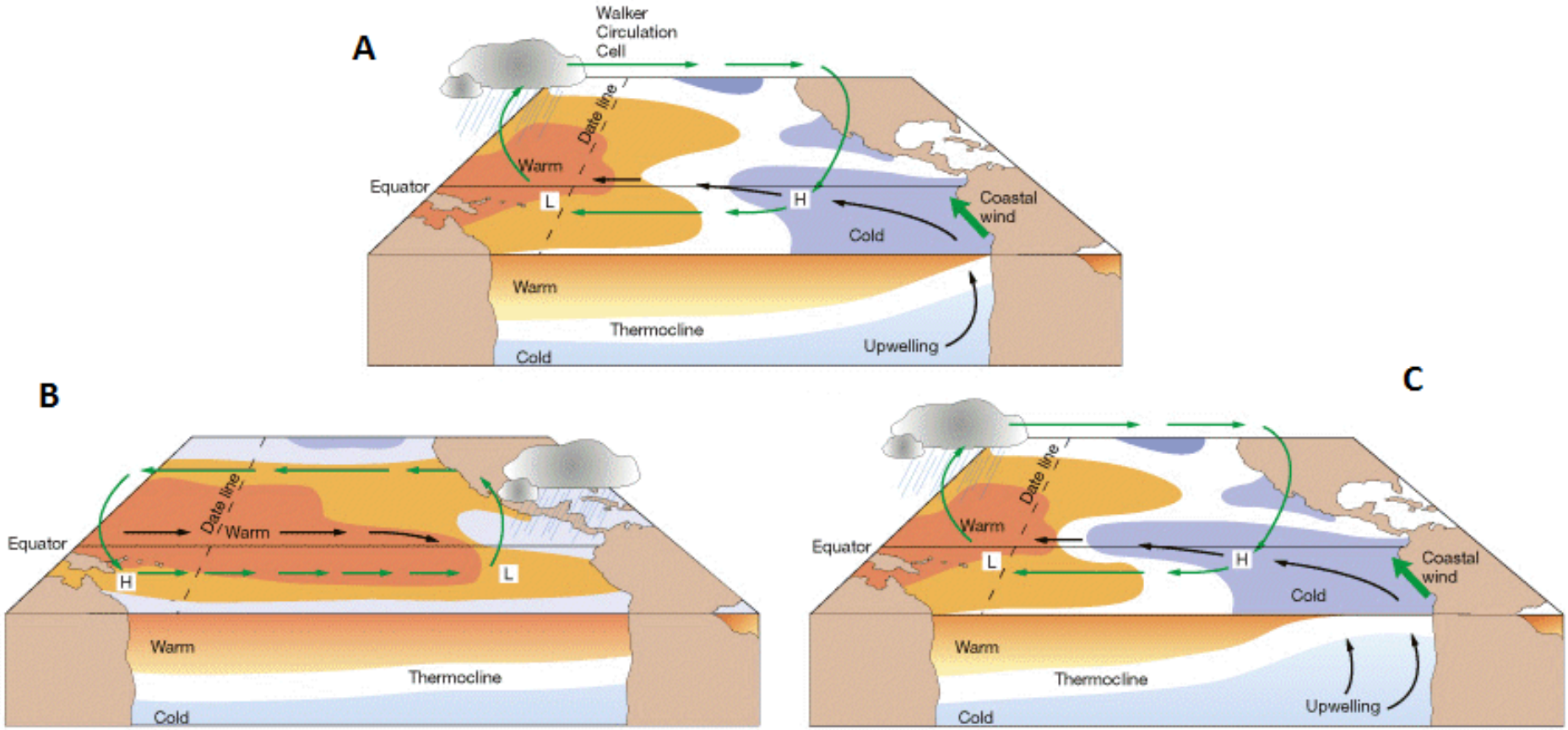

ENSO phases: Neutral (A), El Niño (B, warming scenario) and La Niña (C, cooling scenario) (Fiedler, 2002)

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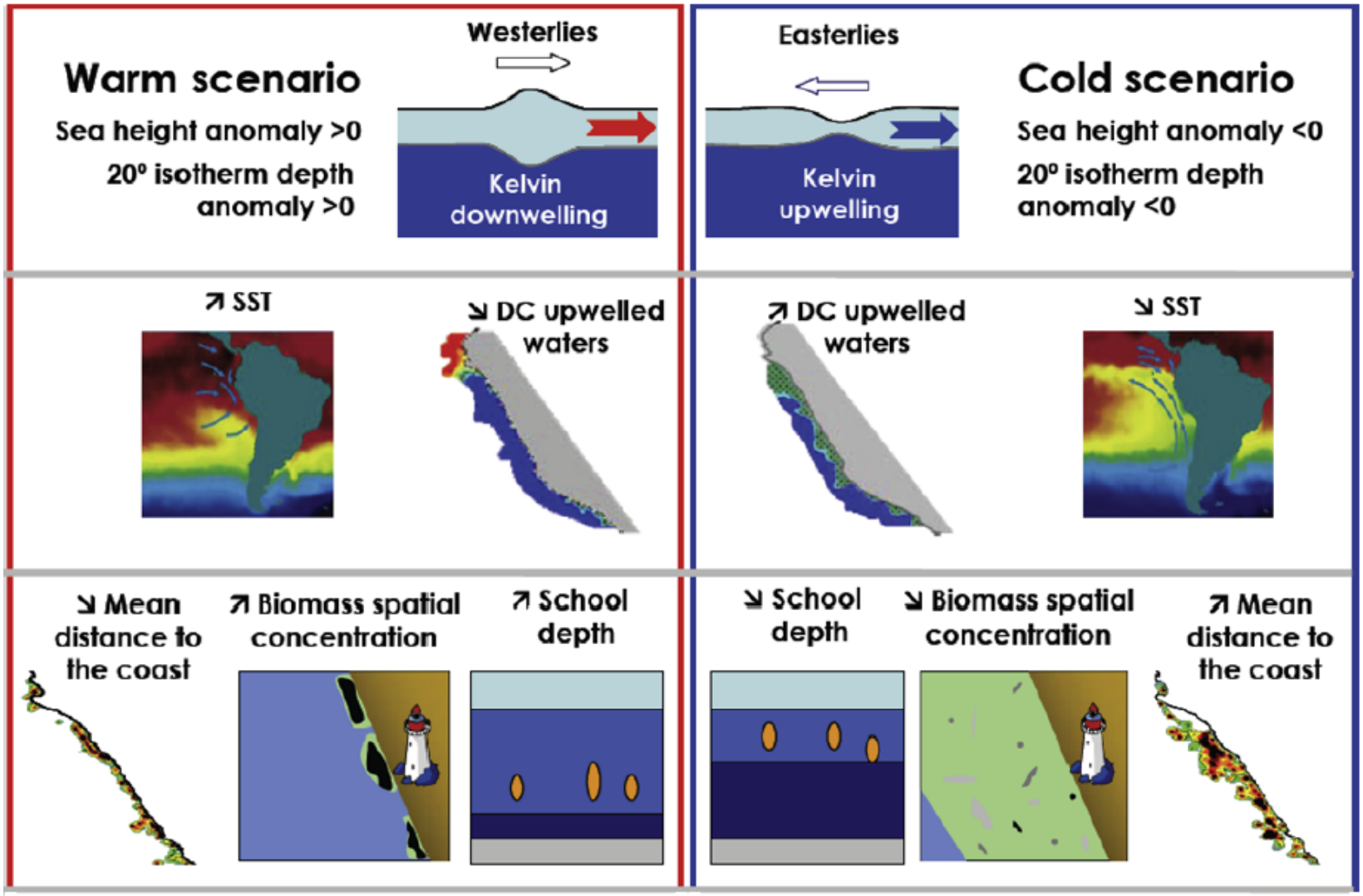
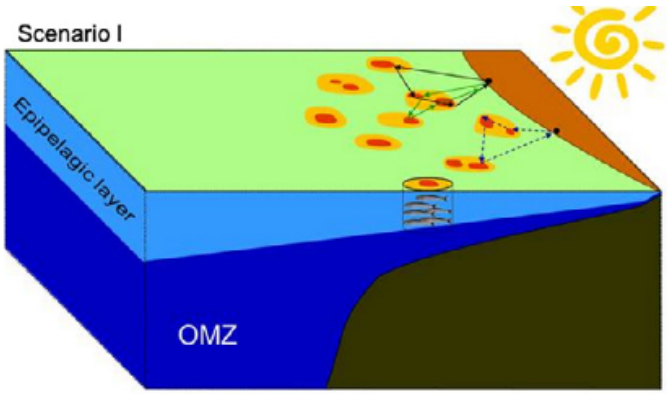
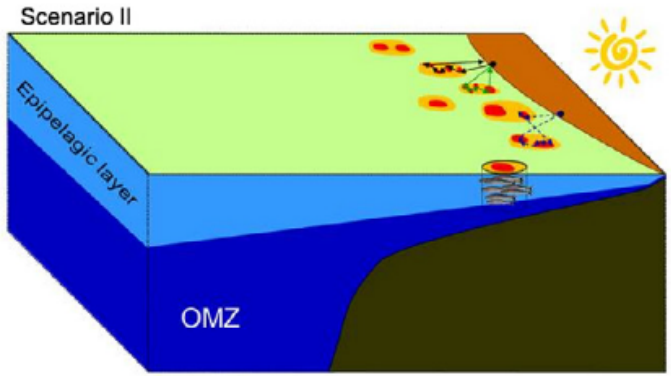


Impacts of ENSO phases on anchovy spatial distribution (Bertrand *et al.*, 2008)

Background



Variable	Level
SST	++
CHL	++
OXY	-
s_A	++
s_A+	+
ISO	++
DC	-
I	--
Max.DC	-
Fishing	+
Cruising	-
k	-
sigma	-



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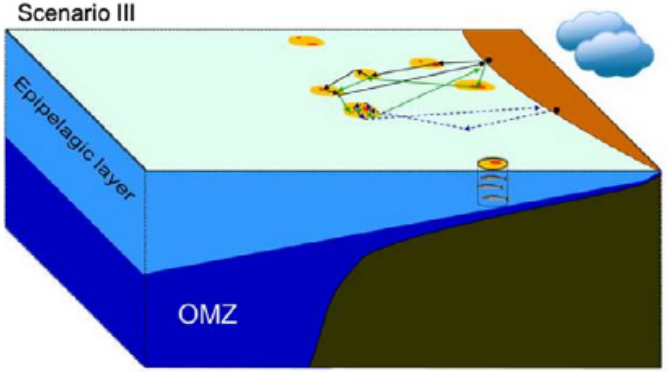

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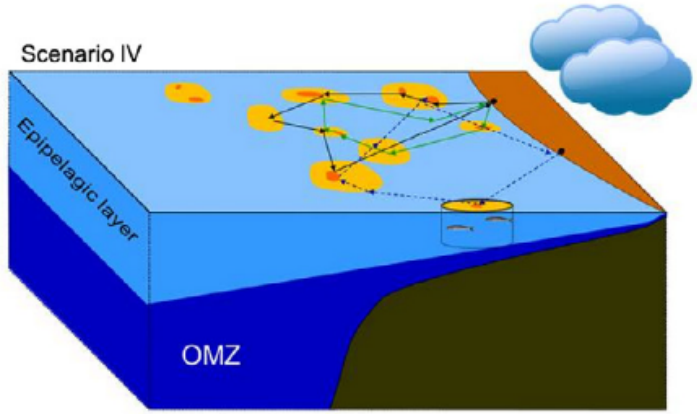

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Interactions environment-resource-fishermen. Define scenarios related with spatial behavior and abundance (Joo *et al.*, 2014)

Goals

- Analyze changes in spatial aggregation patterns of the North-Central stock of Peruvian anchovy, focusing on the last El Niño/La Niña events
  - Get the spatial distribution
  - Define spatial and biological indicators describing the resource behavior
  - Find temporal trends in spatial indicators
  - Identify recurrent areas during cooling and warming events (Levievre *et al.*, 2014)

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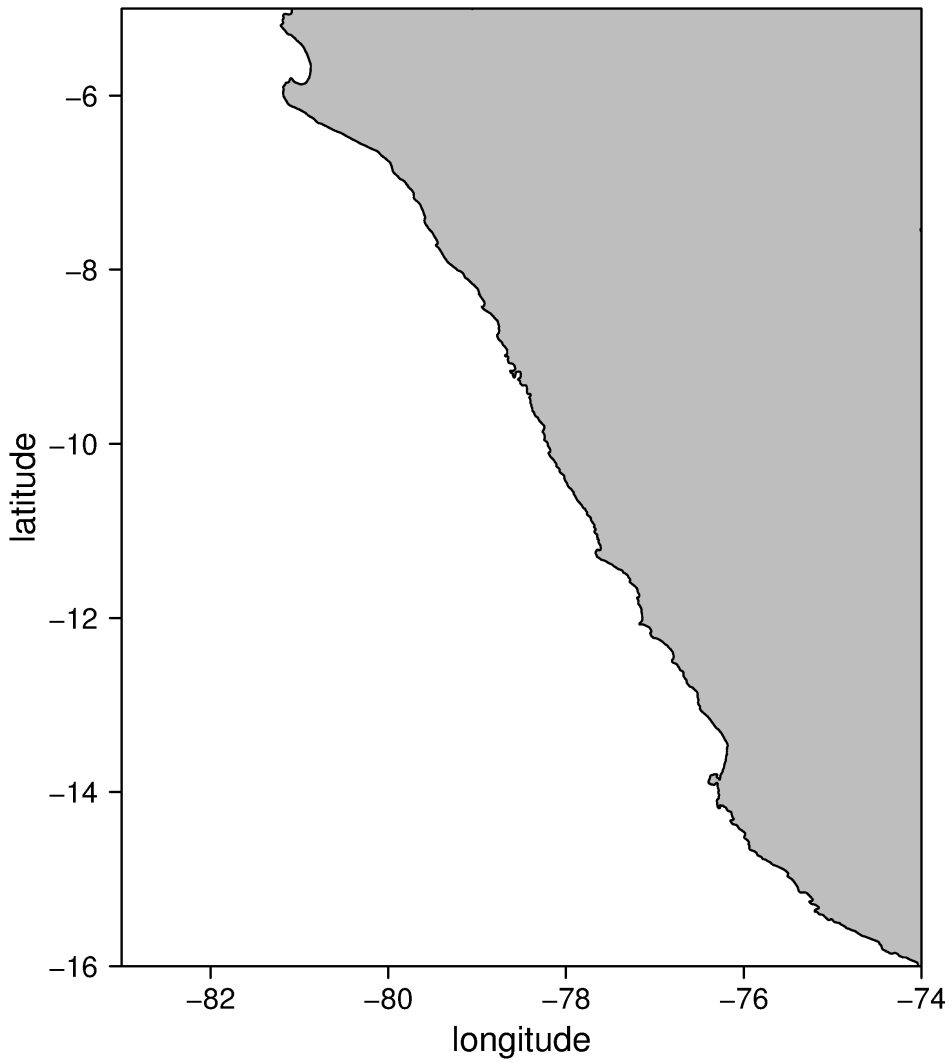
Data

- Acoustic data coming from 41 scientific surveys carried out by IMARPE during 1994 - 2016
- parallel cross-shore transects of ∼100 nm long, with a ∼15 nm inter-transect spacing
- record nautical area scattering coefficient (NASC, $m^2.nm^{-2}$), a proxy of fish abundance (Simmonds and MacLennan, 2005), each ESDU (1 nm)
- other samplings: oceanography (SST, SSS, OXY, CHL) and length composition
- Survey name: Cr(year)(starting month)(ending month)



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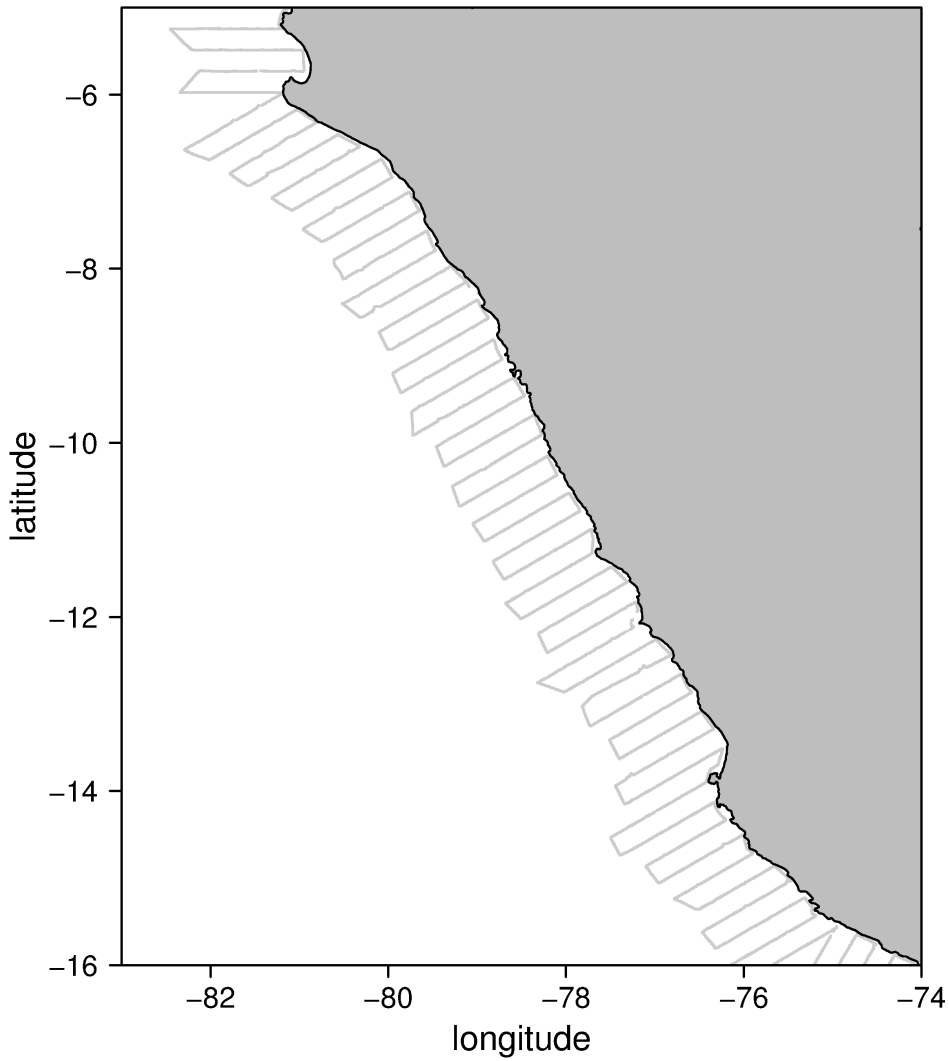

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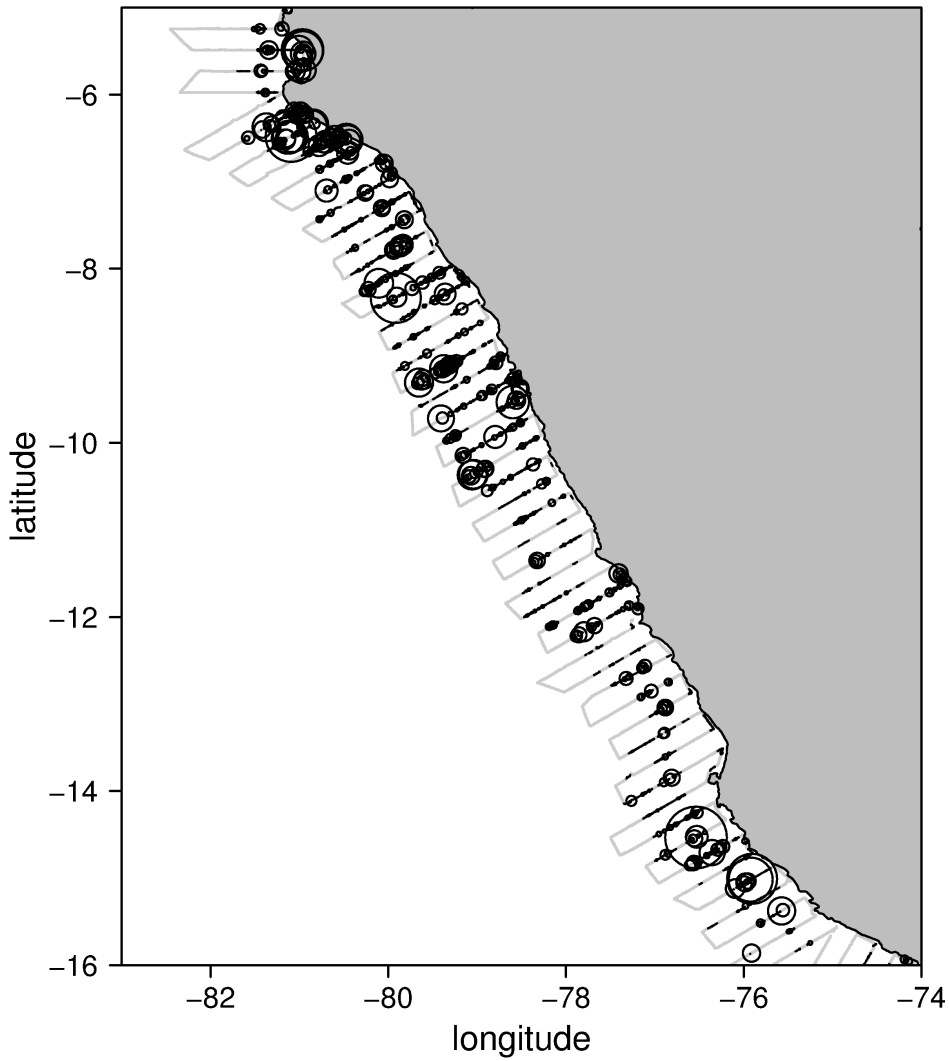

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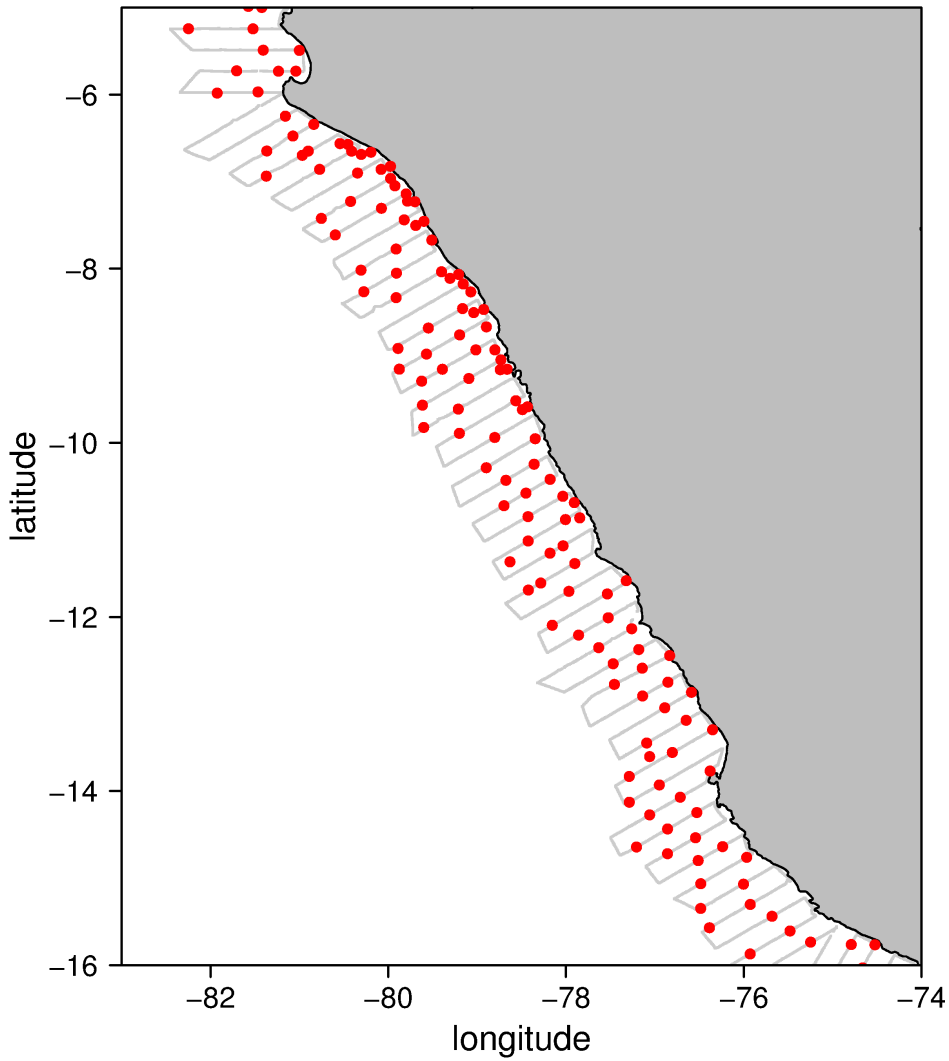

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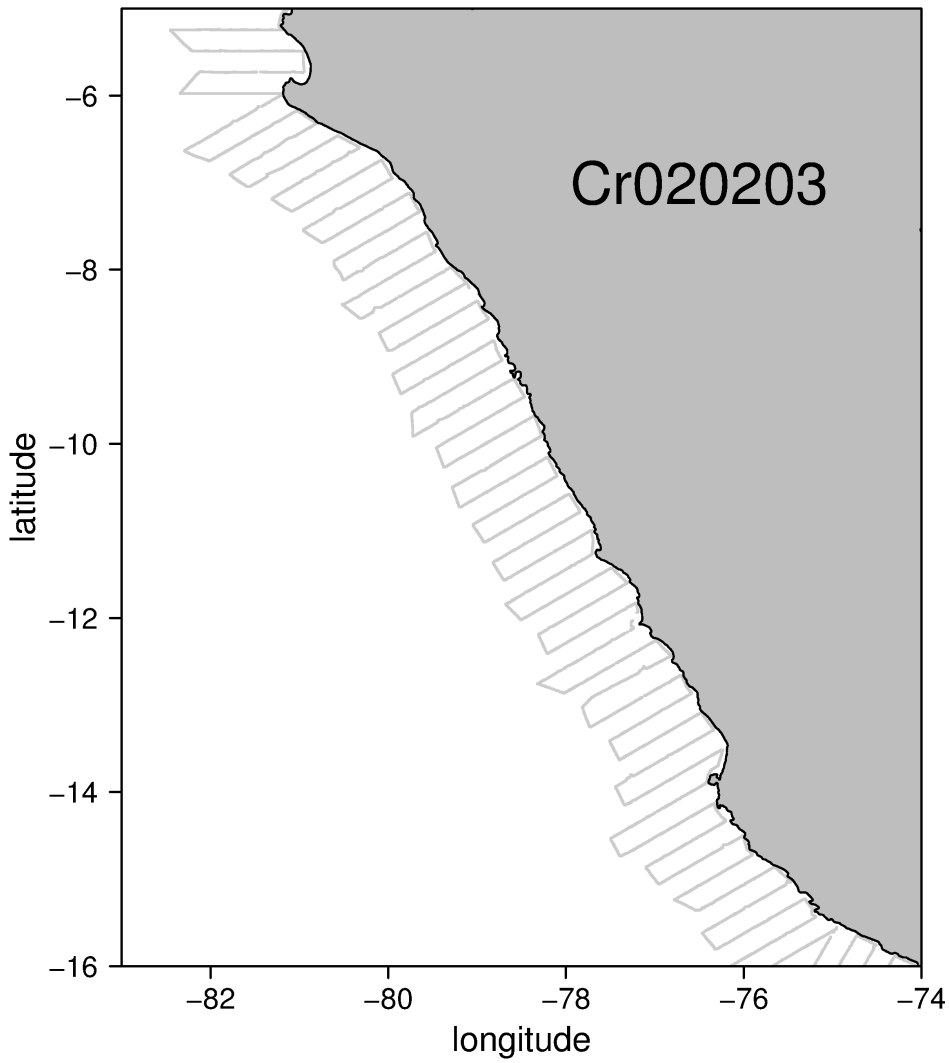

Spatial model

- Bayesian hierarchical spatial model using the Integrated Nested Laplace Approximation (INLA) method (Rue *et al.*, 2009)

$$y_i \sim lognormal(\mu_i, \sigma_i^2)$$
$$log(\mu_i) = \beta_0 + W_i$$
$$W_i \sim GF(0, \Sigma)$$
$$\mu_i = NASC_i + 1$$

  - Stochastic partial differential equation (SPDE) approach (Lindgren *et al.*, 2011)
  - Numerical solutions: Triangulation and finite element method
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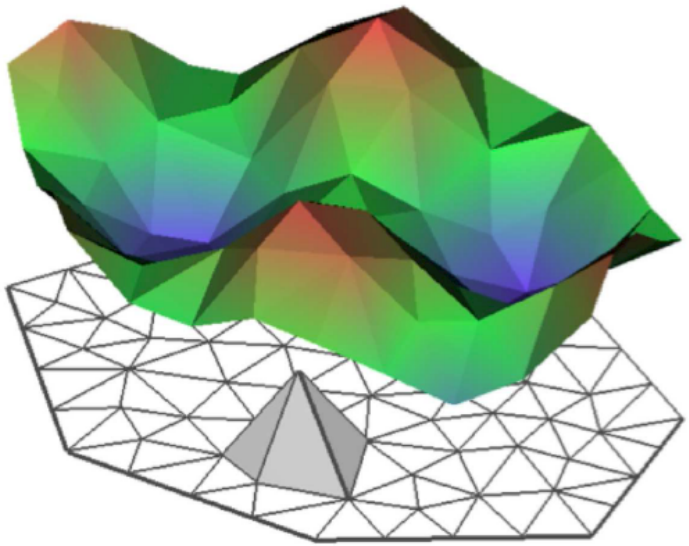

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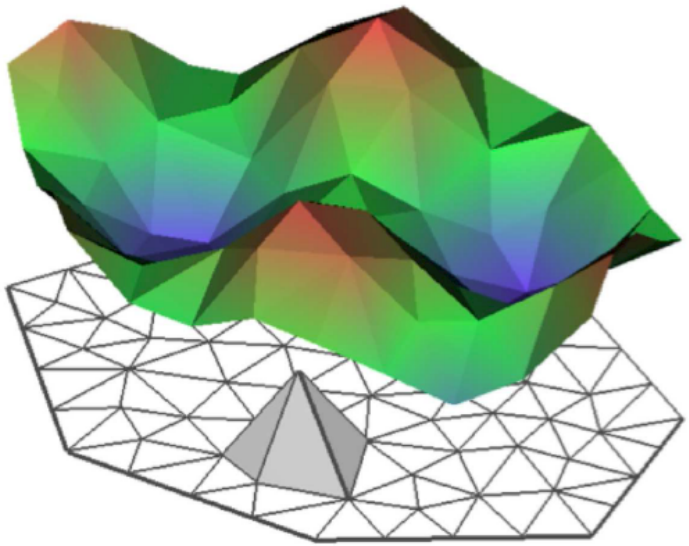

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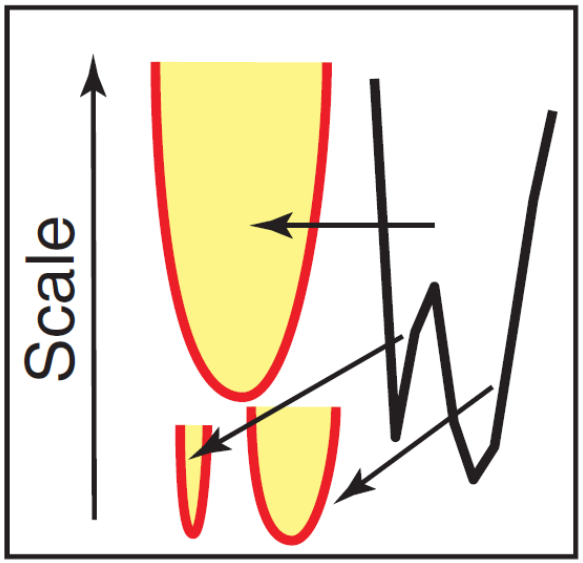
Hotspot identification



- Anchovy tends to aggregate at different scales (Bertrand *et al.*, 2014)
- Focus on:
  - large scale structures (A, >100 km)
  - submesoscale structures (B, ∼1-20 km)
- Consider here submesoscale structures as hotspots of abundance
- Identification criteria: grids with a level of abundance greater than 95th percentil of positive NASC (Williams *et al.*, 1996).

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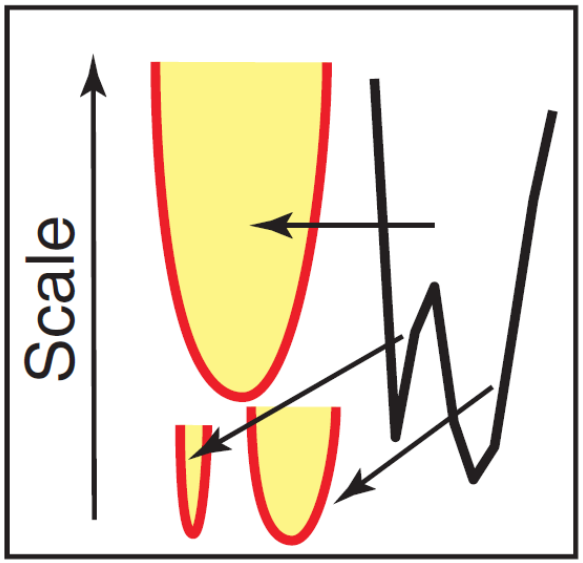

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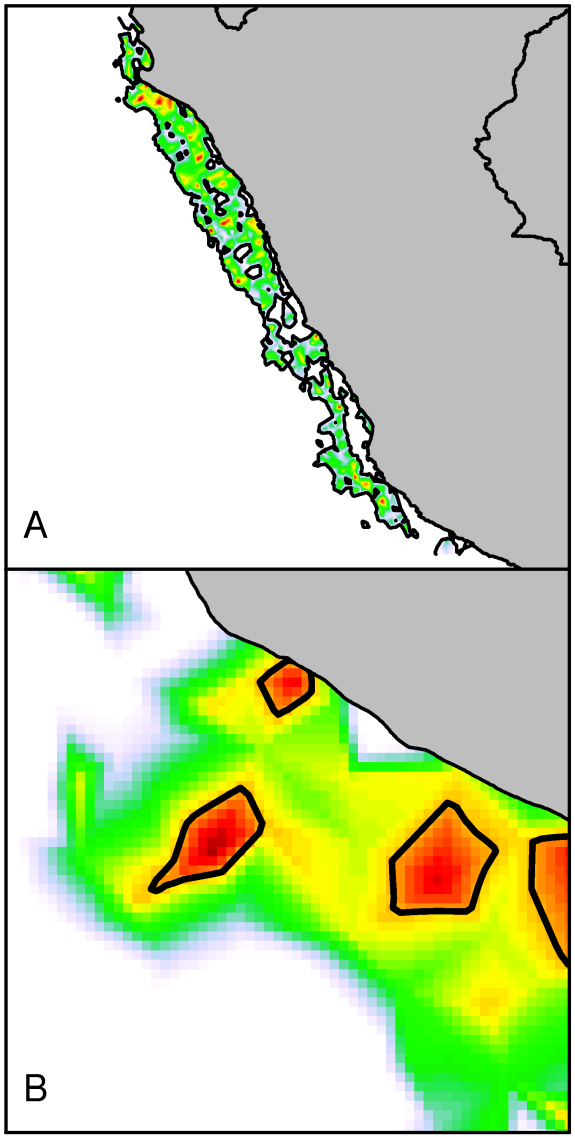

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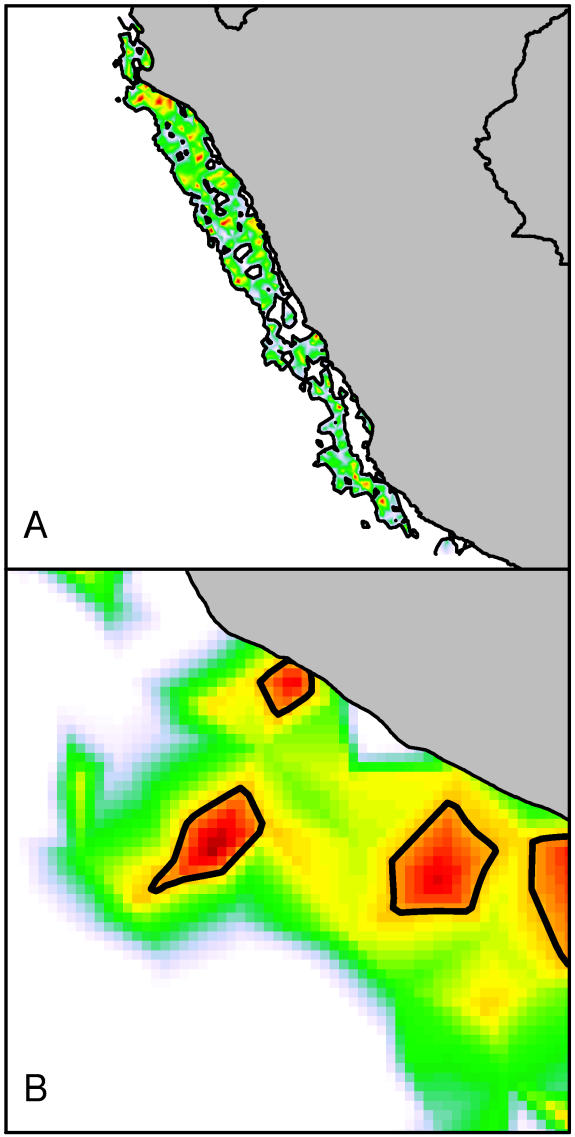

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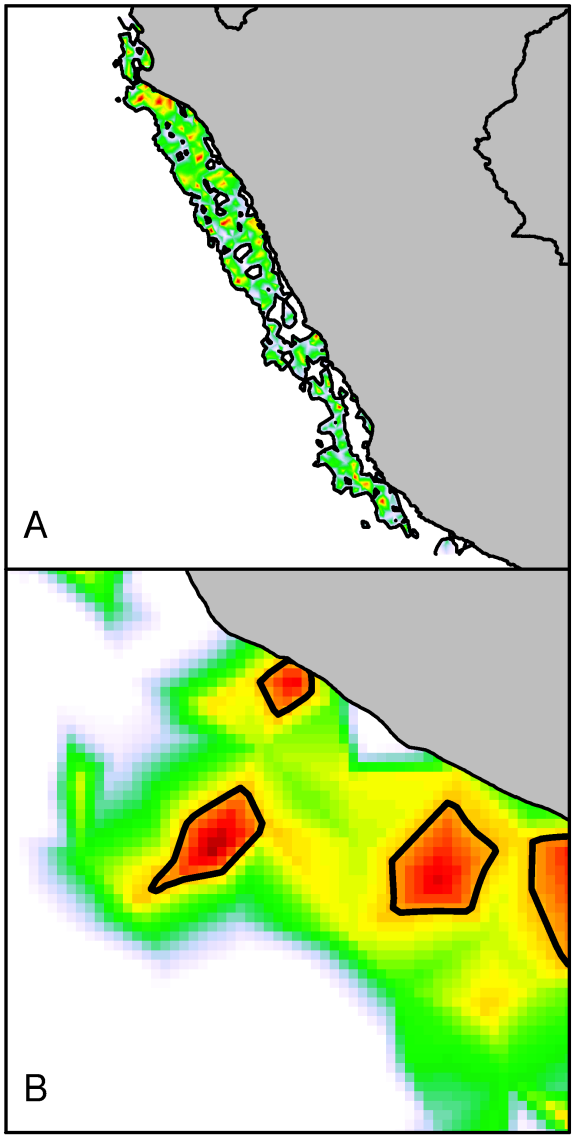

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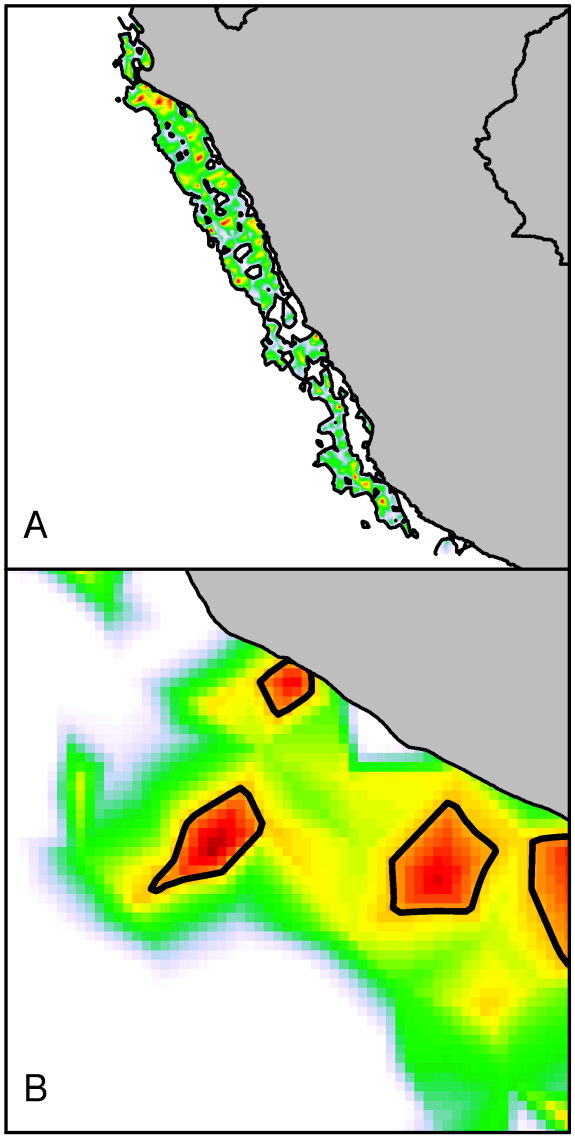

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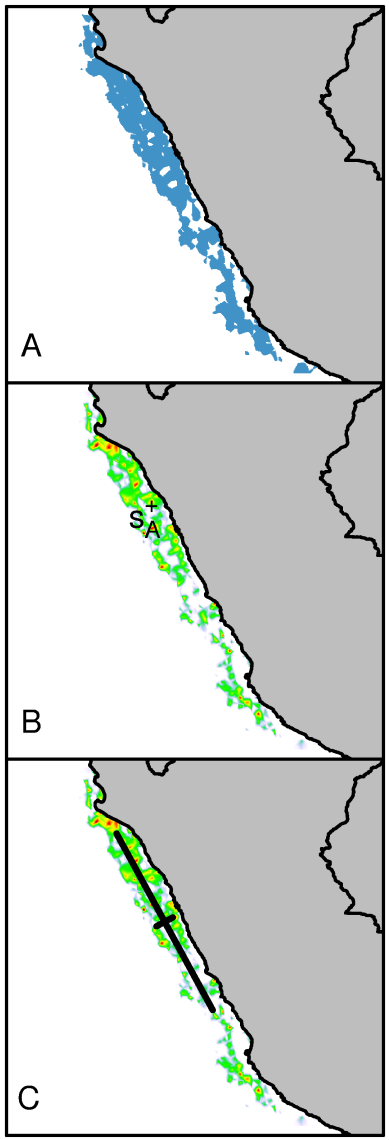
Global indicators

- Presence area (PA, mn^2). Total area where the stock have been found, not considering its level of abundance (A).
- Index of local fish biomass (s_A^+, $m^2.mn^{-2}$, Gutierrez *et al.*, 2007). Indicator of level of abundance. Equal to $\sum_{i=1}^{n} \log(NASC_i + 1)/n$, $\forall NASC > 0$ (B).
- Isotropy (I, Woillez *et al.*, 2007). Degree of equality in inertia between two directions. Equal to $\sqrt{\frac{I_{min}}{I_{max}}}$ (C).



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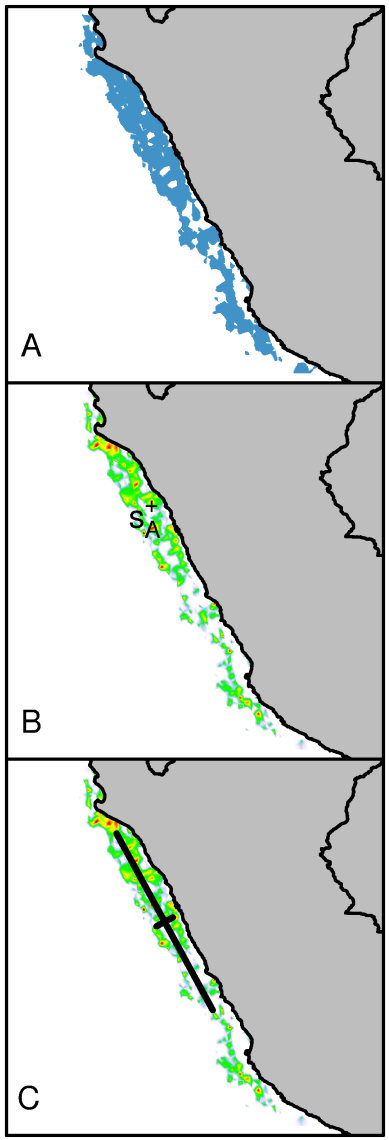

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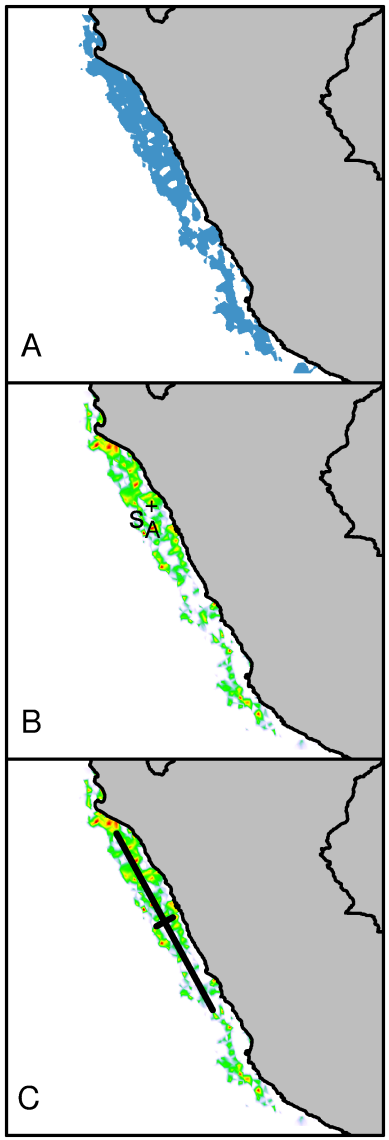
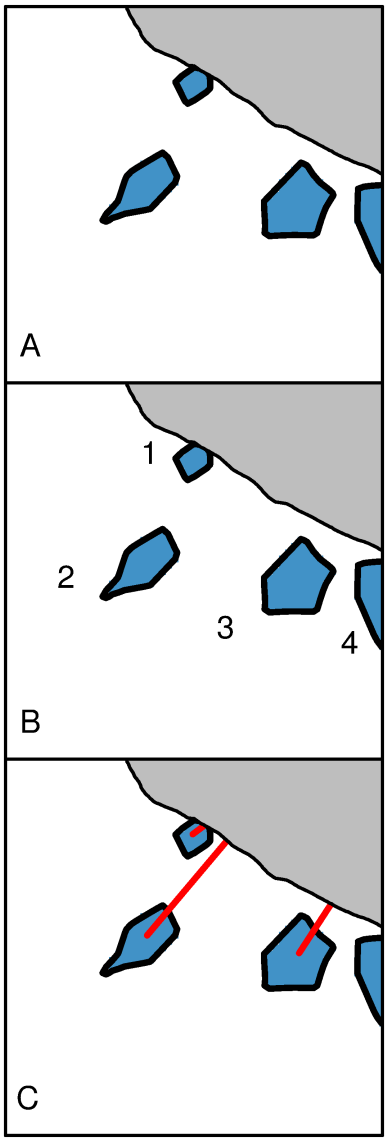


Aggregation indicators



- Aggregation area (HA, mn^2). Total hotspot area of the stock (A).
- Number of aggregation areas (N). Number of hotspots detected (B).
- Center of aggregation (DC). Mean distance to the coast of hotspots weighted to their areas. Equal to $\frac{\sum_{i=1}^{N} dc_i A_i}{\sum_{i=1}^{N} A_i}$ (C).

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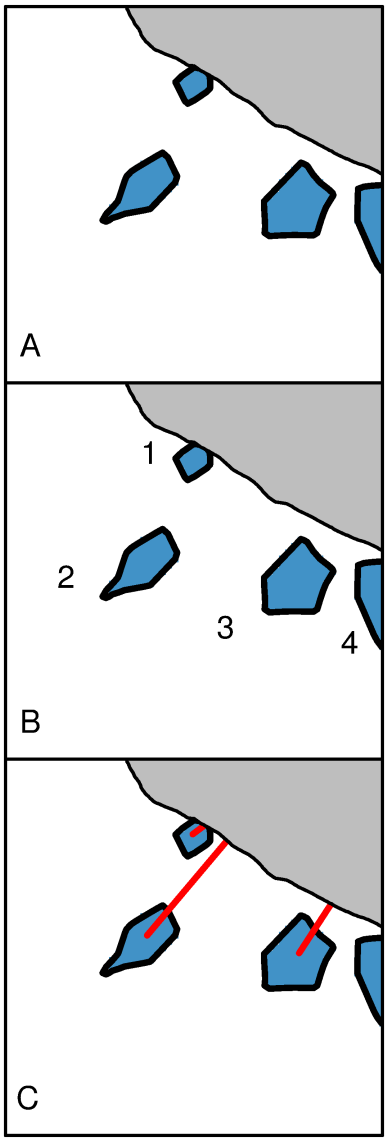

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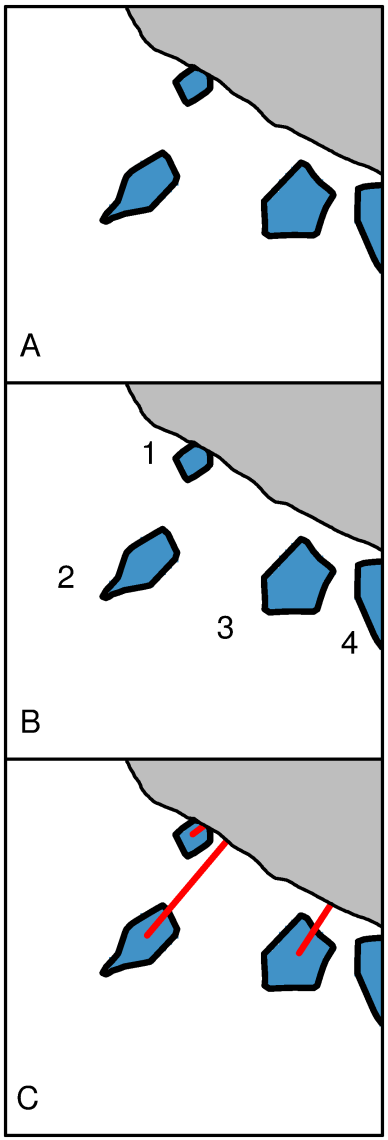

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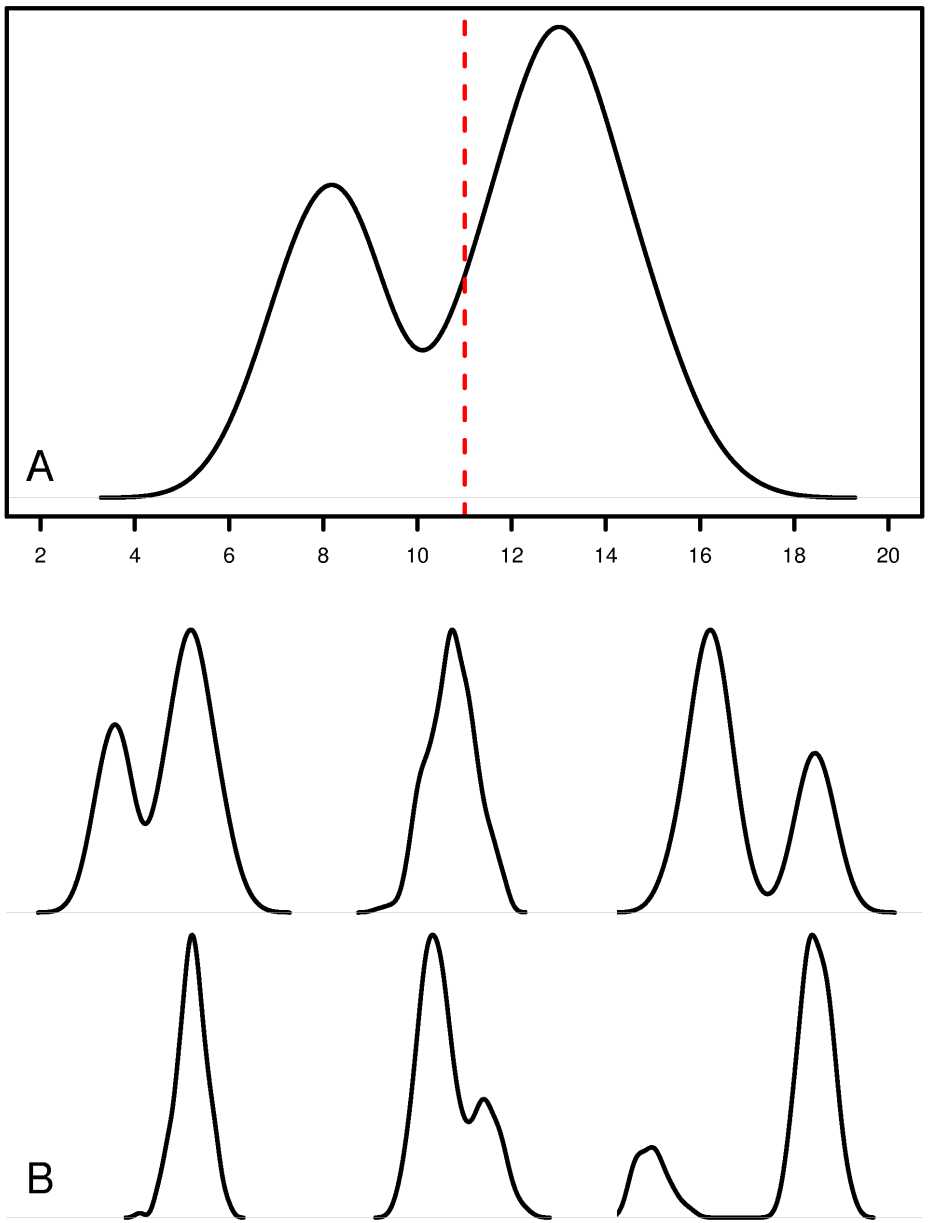
Length composition indicators

- Mean length (MLEN, cm). Mean length of all mid-water trawl samples (A).
- Percentage of one mode (PMOD). Percentage of mid-water trawl samples with only one mode detected (B).



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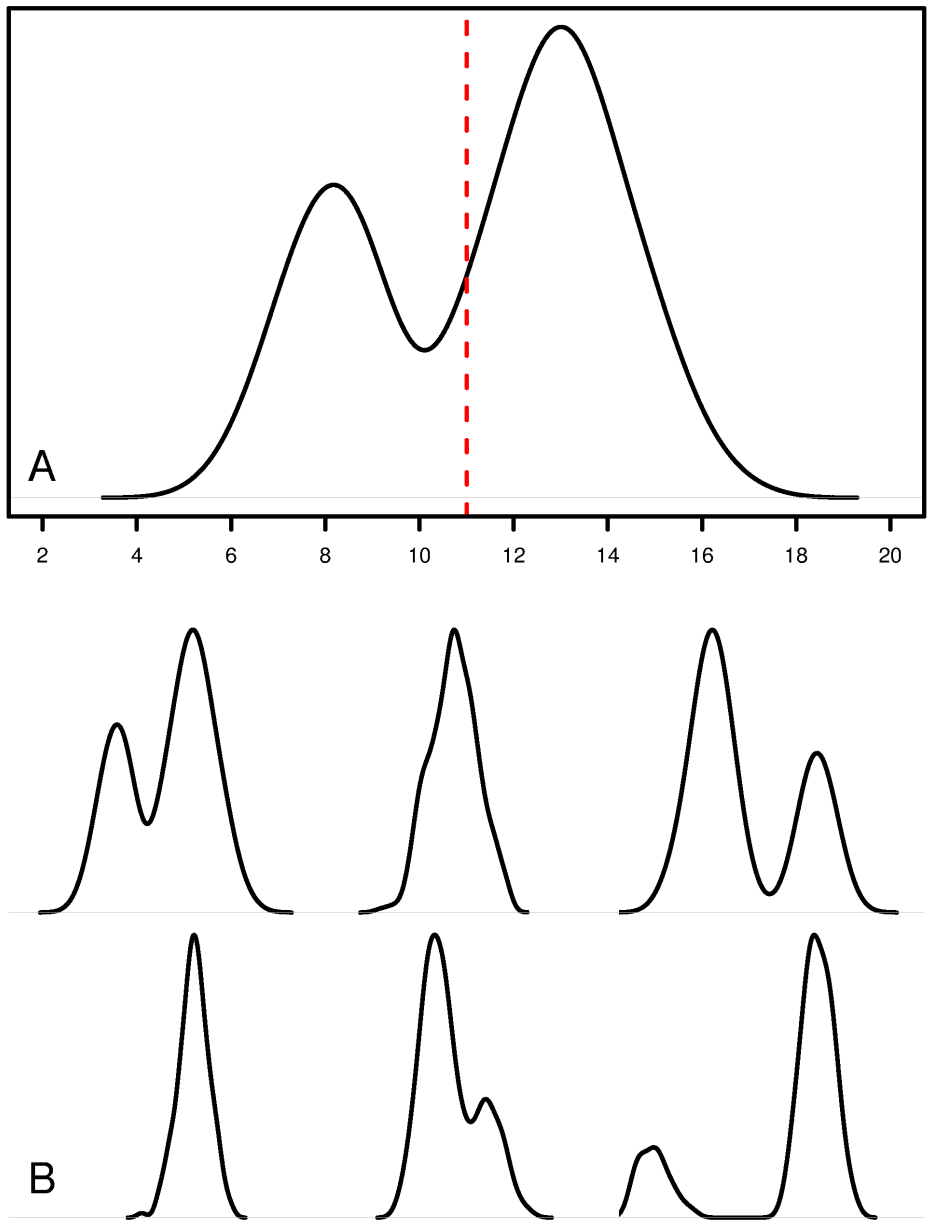

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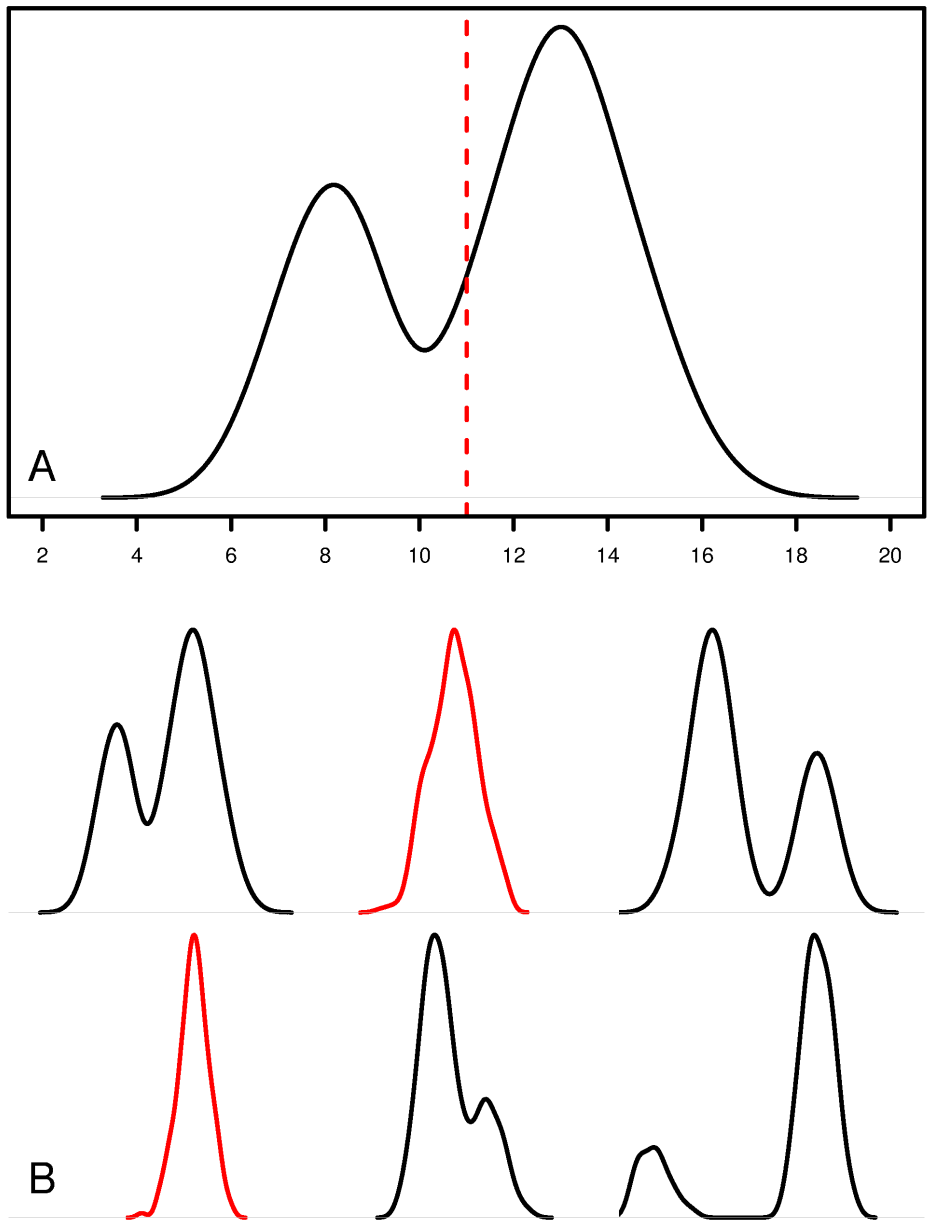
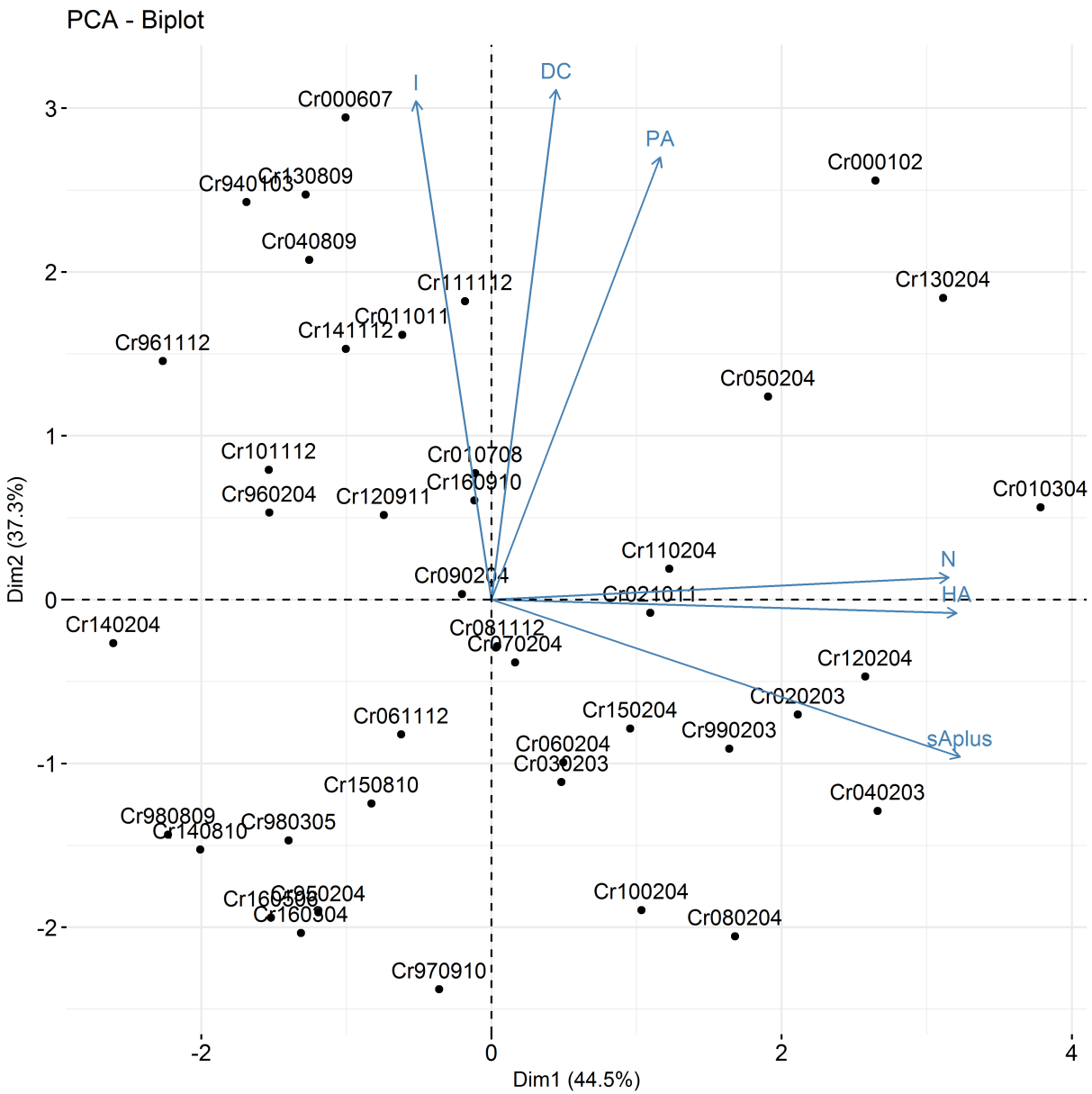
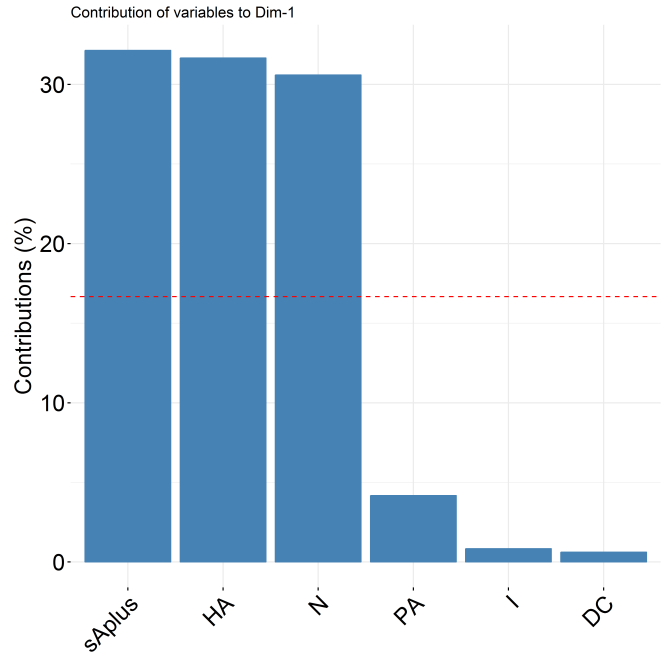
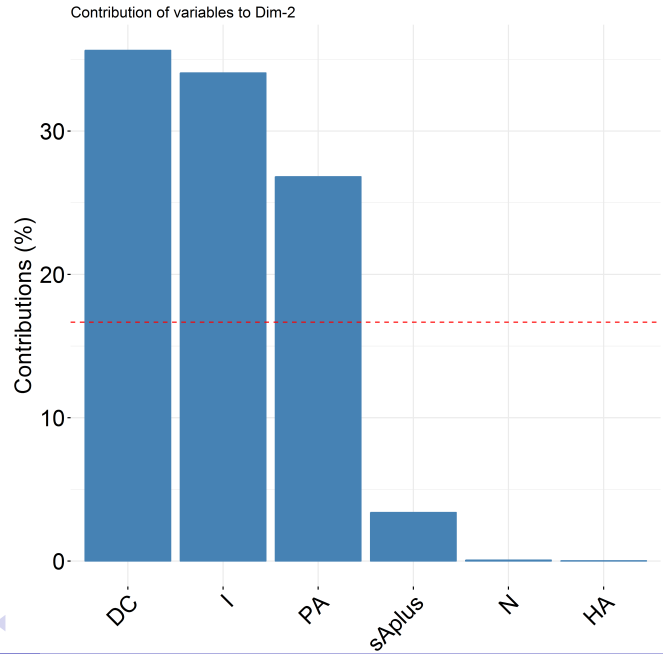


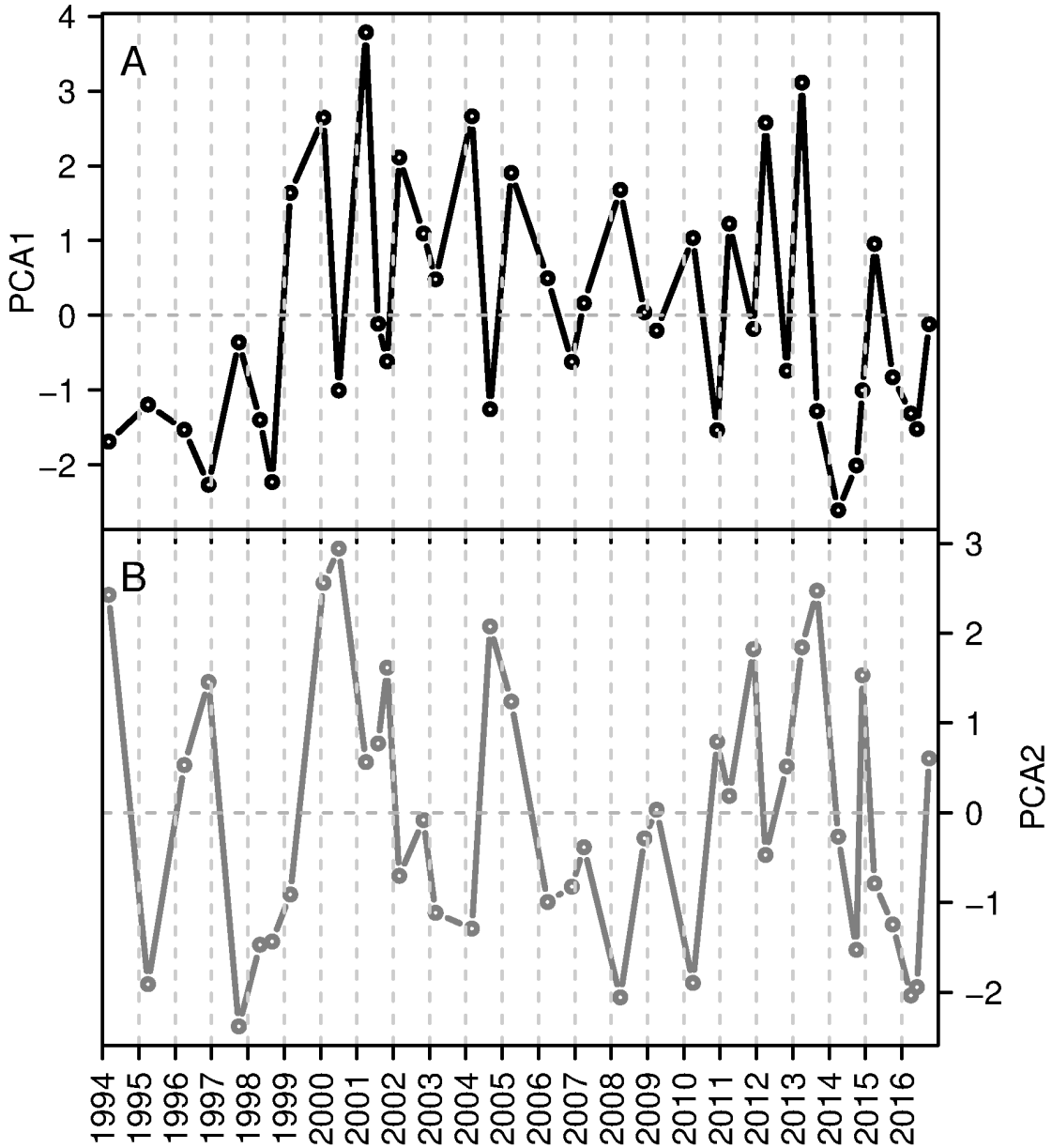
Multivariate analysis - Spatial indicators







Temporal trends - Spatial variables



- PC1: 'Agreggation and abundance' (A)
- Two breakpoints identified (Bai, 1994) (∼1998 and 2013)
- PC2: 'Global occupancy' (B)
- Low values during warming events and the opposite during cooling events

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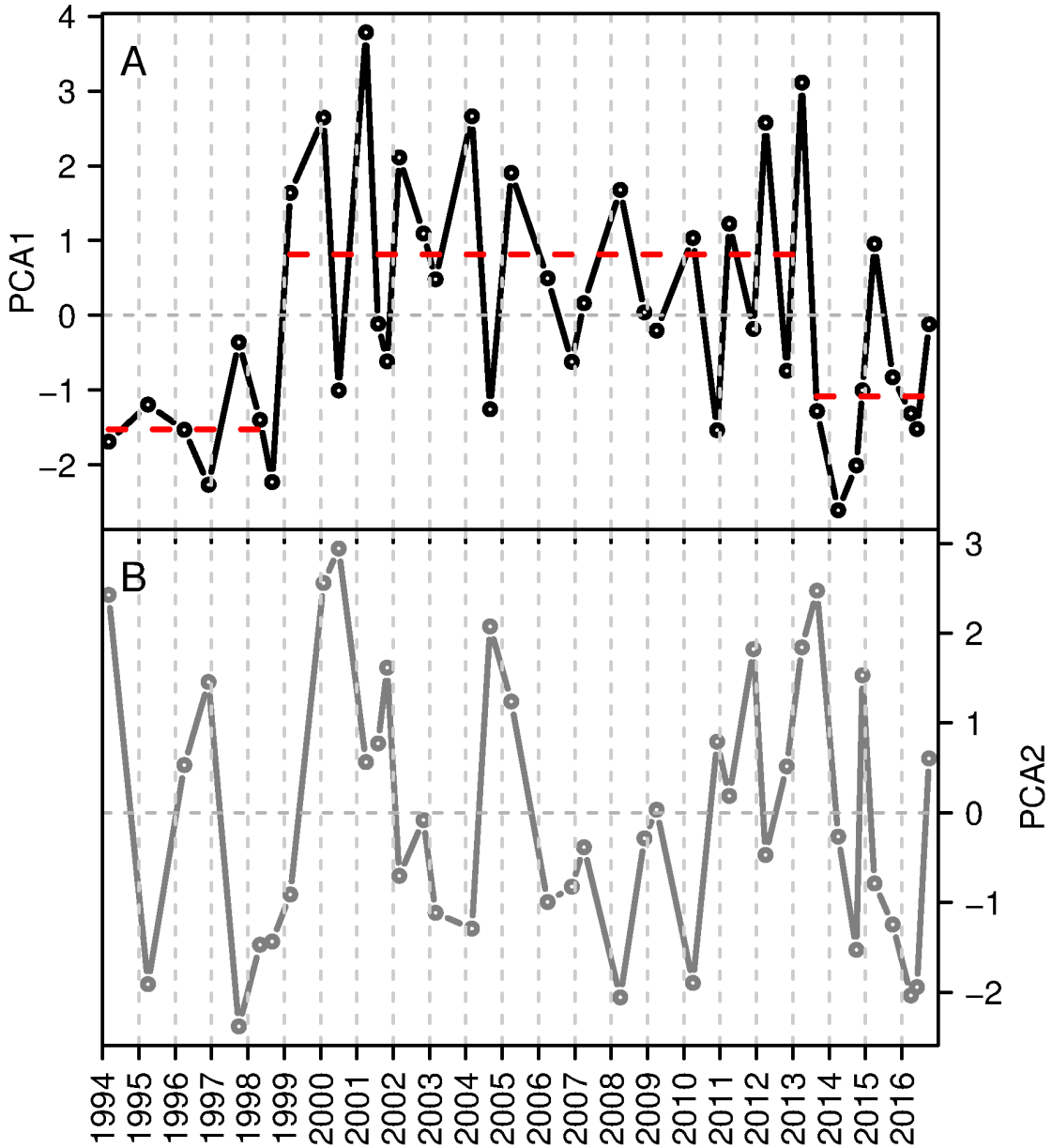

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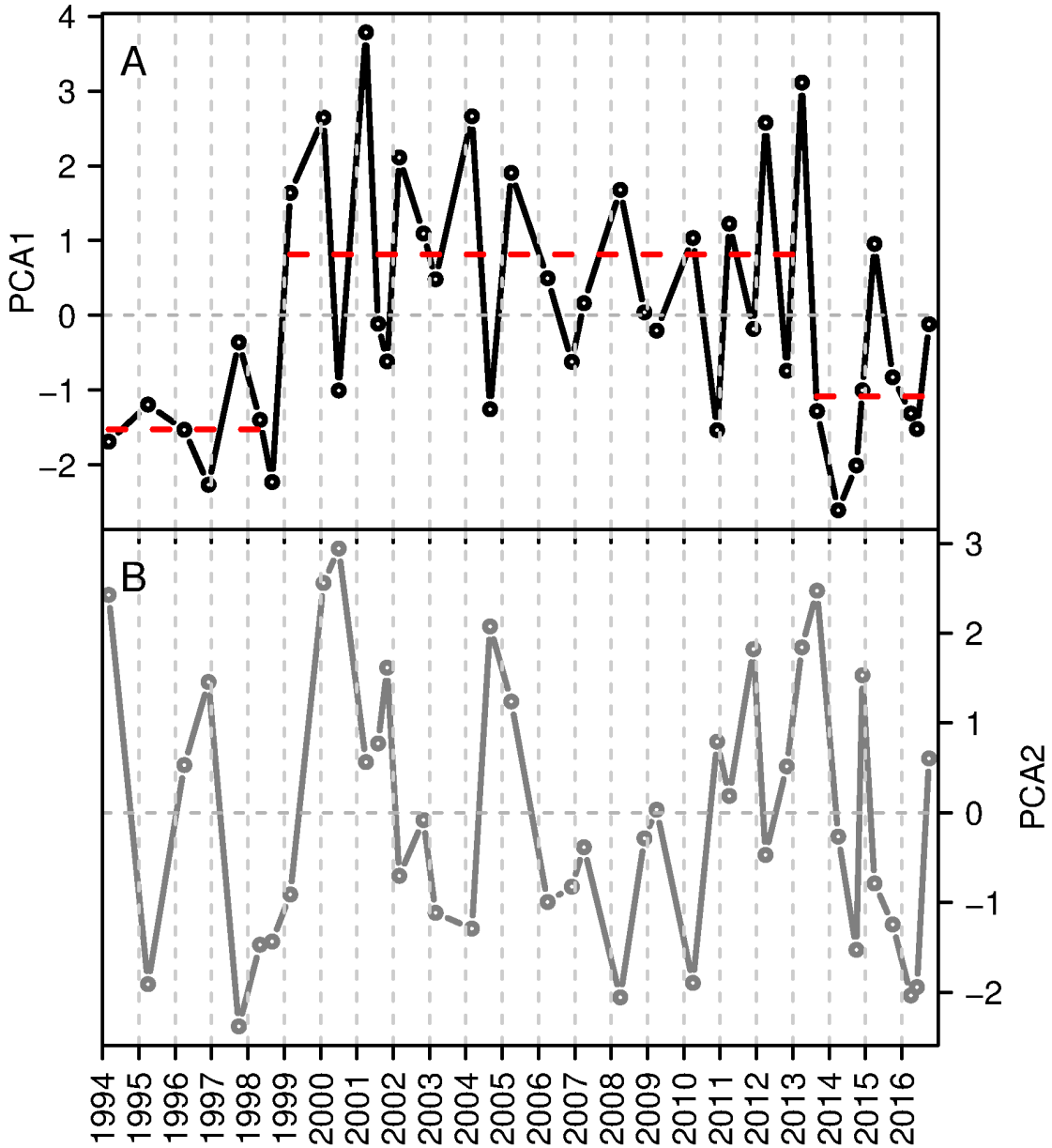

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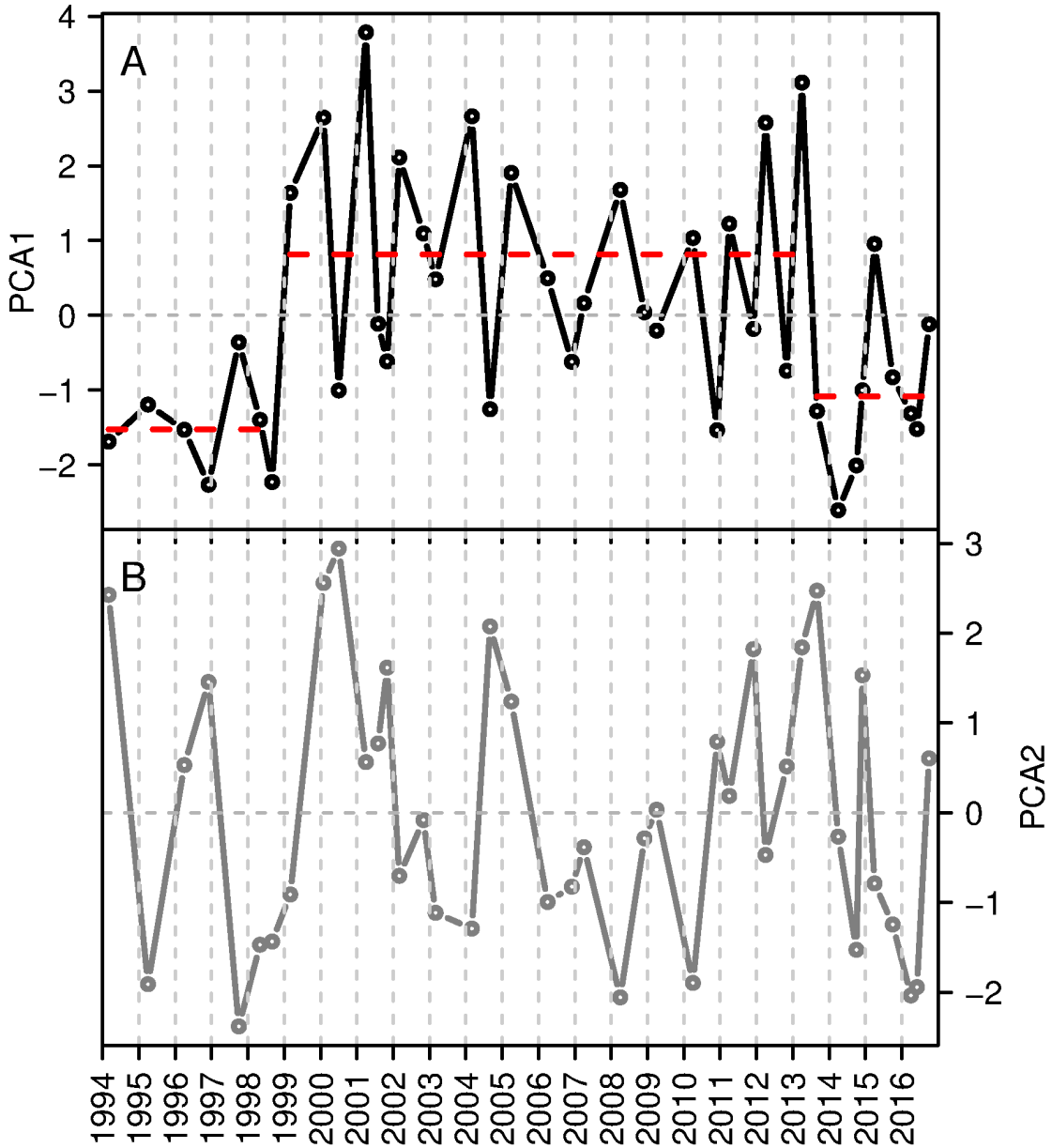

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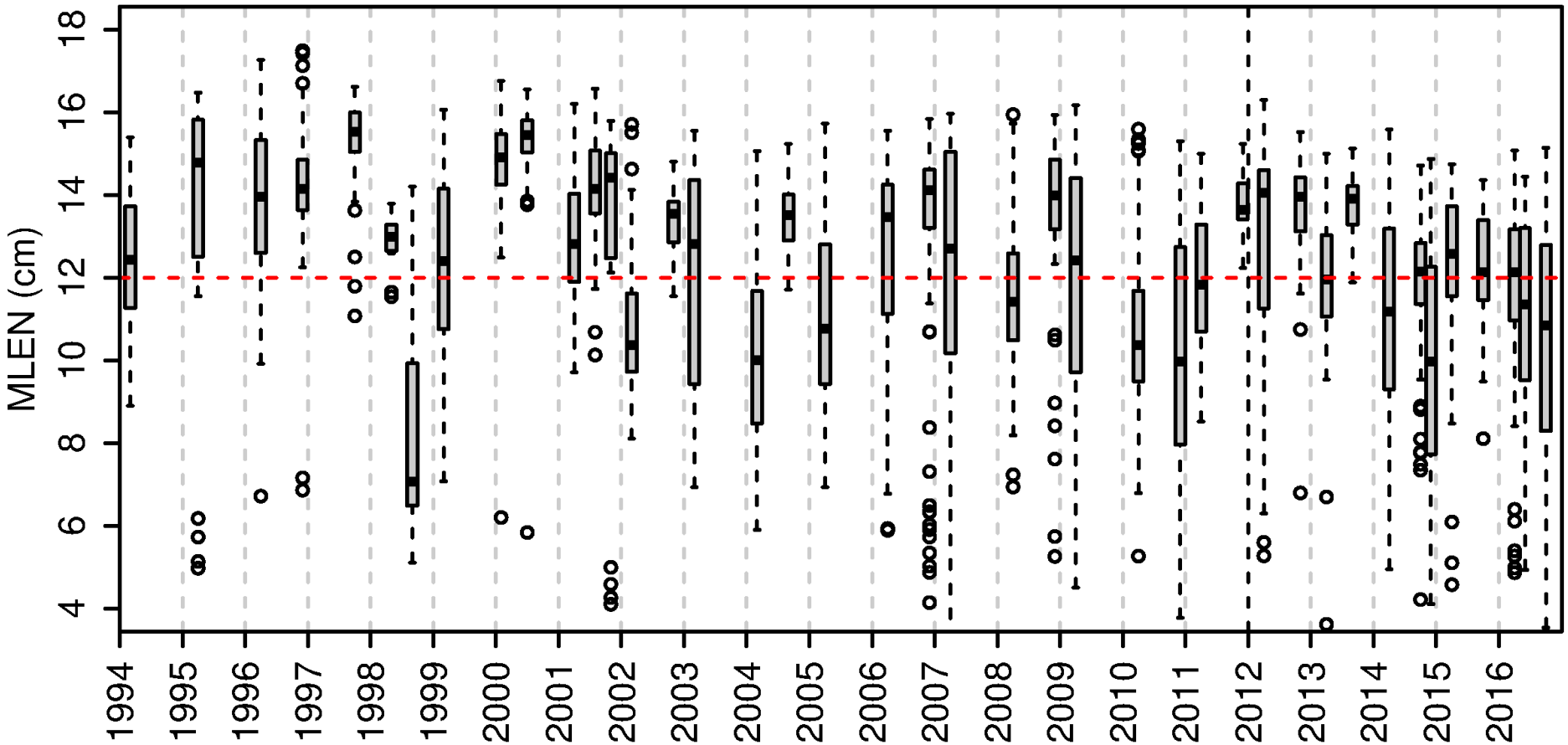

- Continuous decrease since 2012
- Significant correlation ($p<0.001$) between PMOD and PA ($r = 0.52$)
- Significant correlation ($p<0.001$) between PMOD and MLEN ($r = 0.46$)

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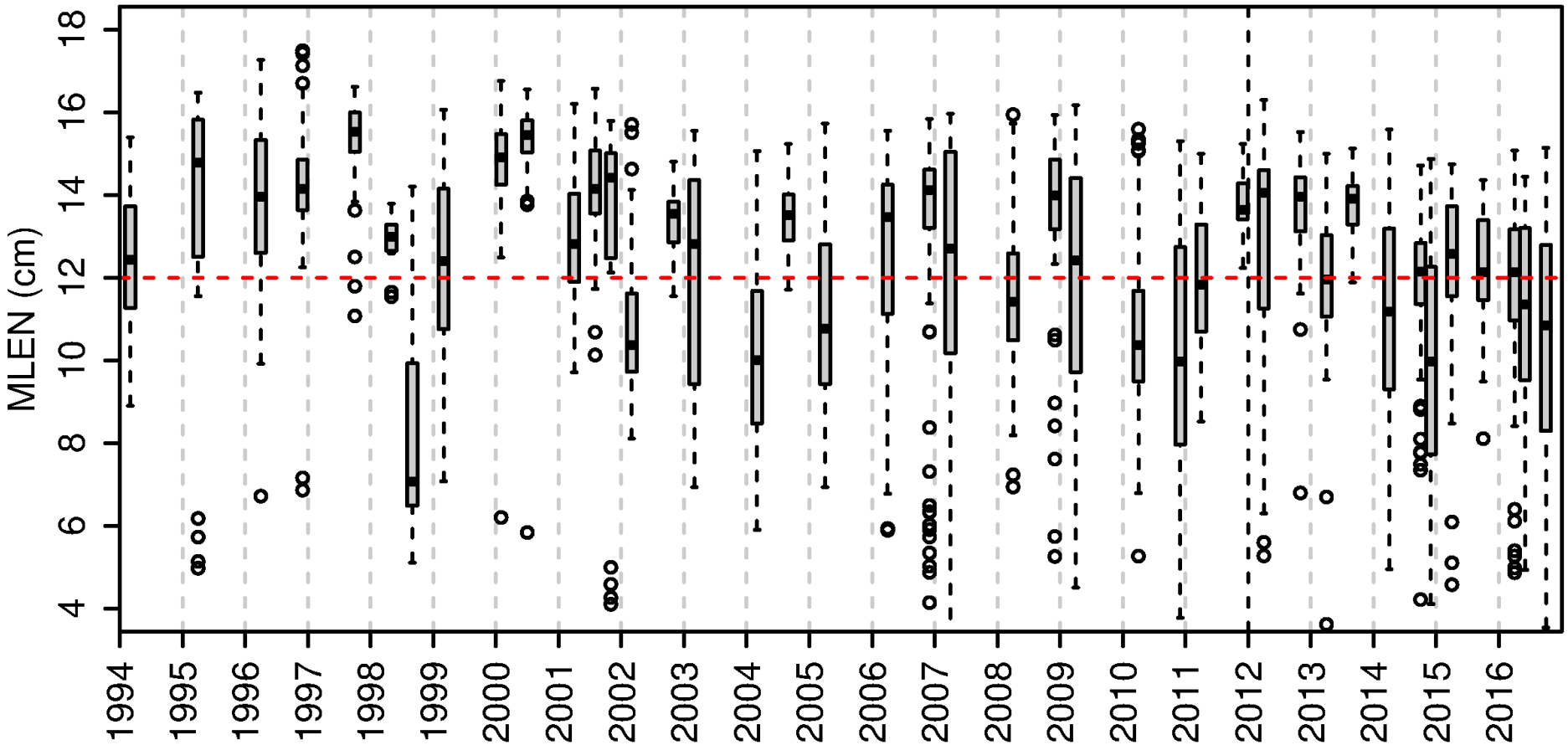

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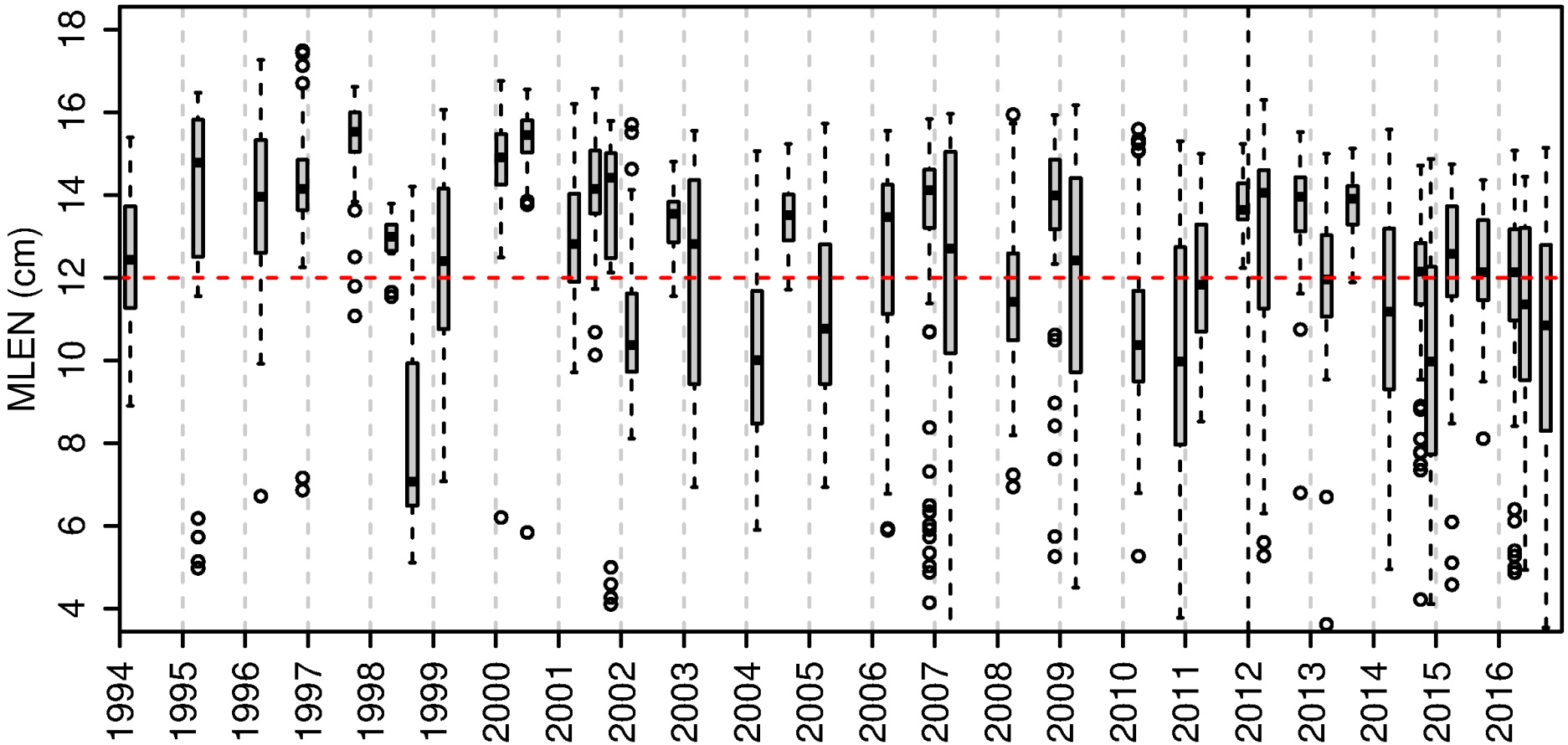

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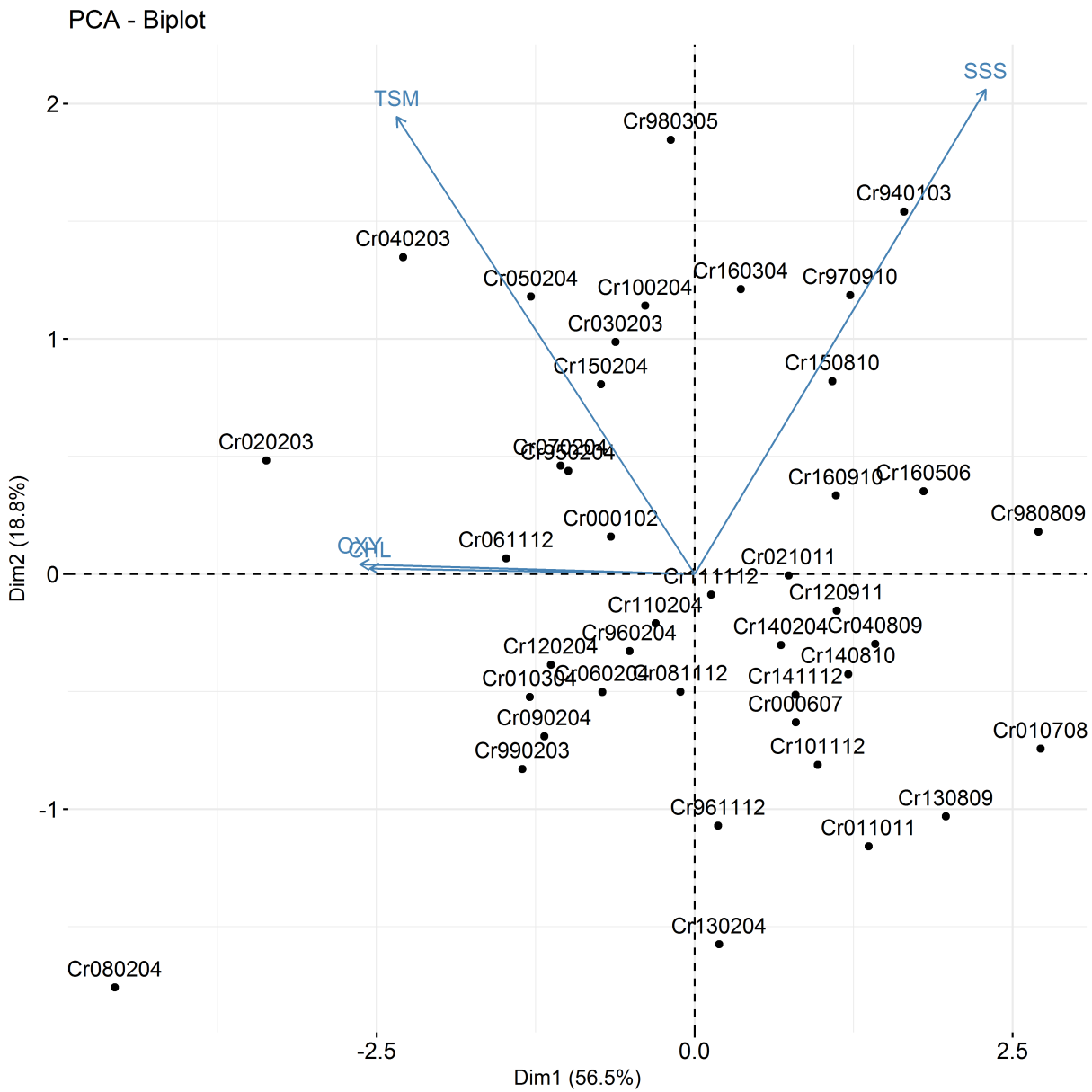

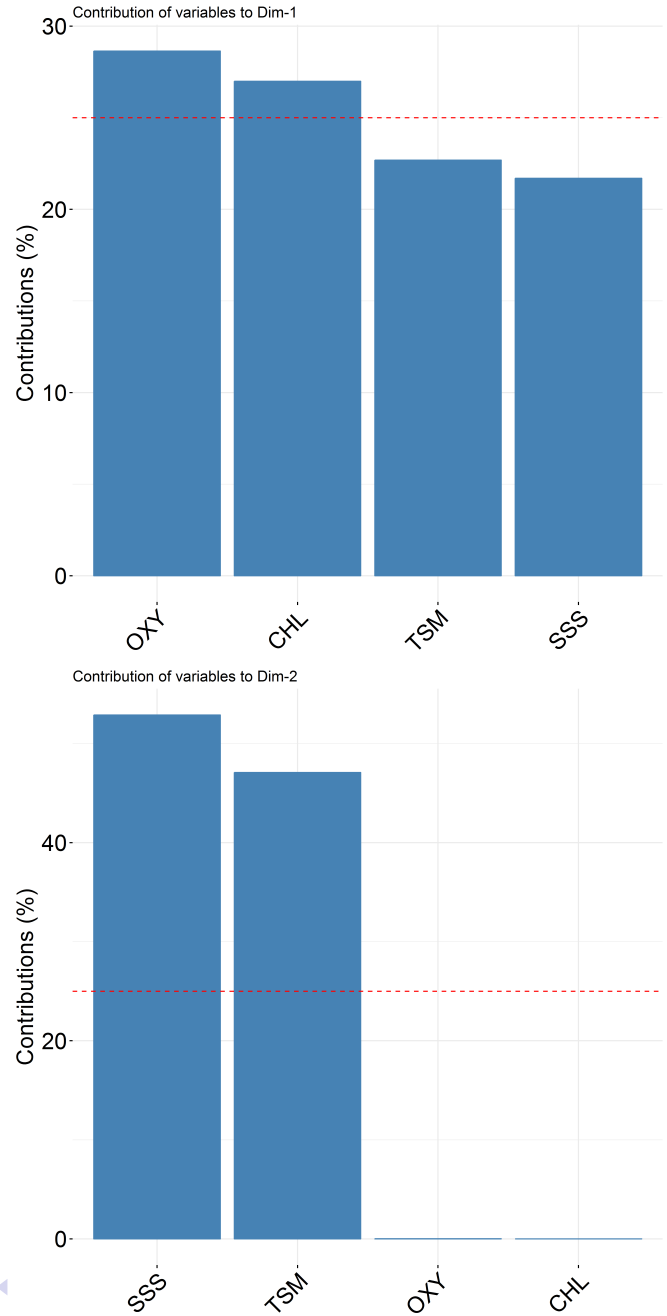

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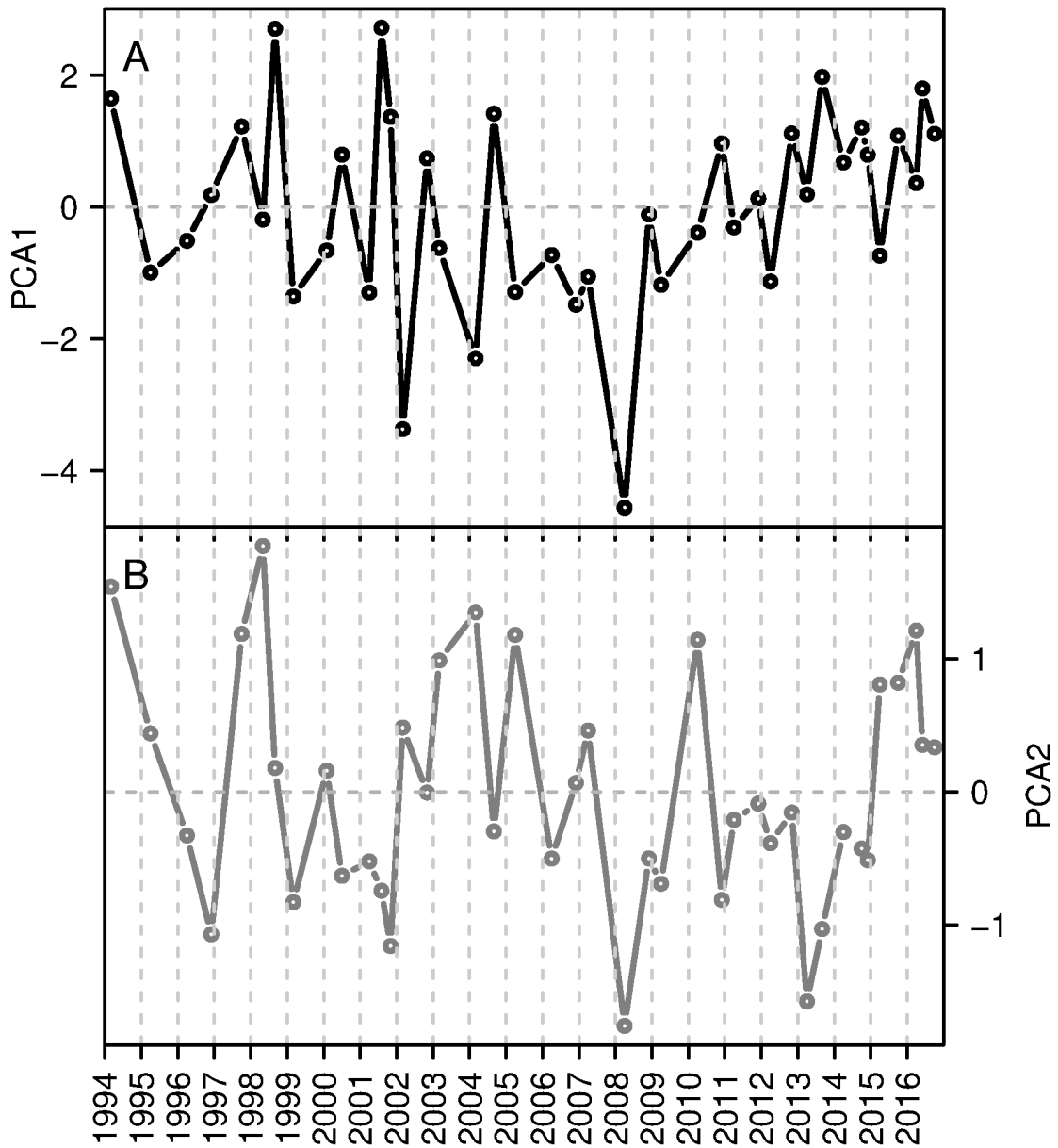

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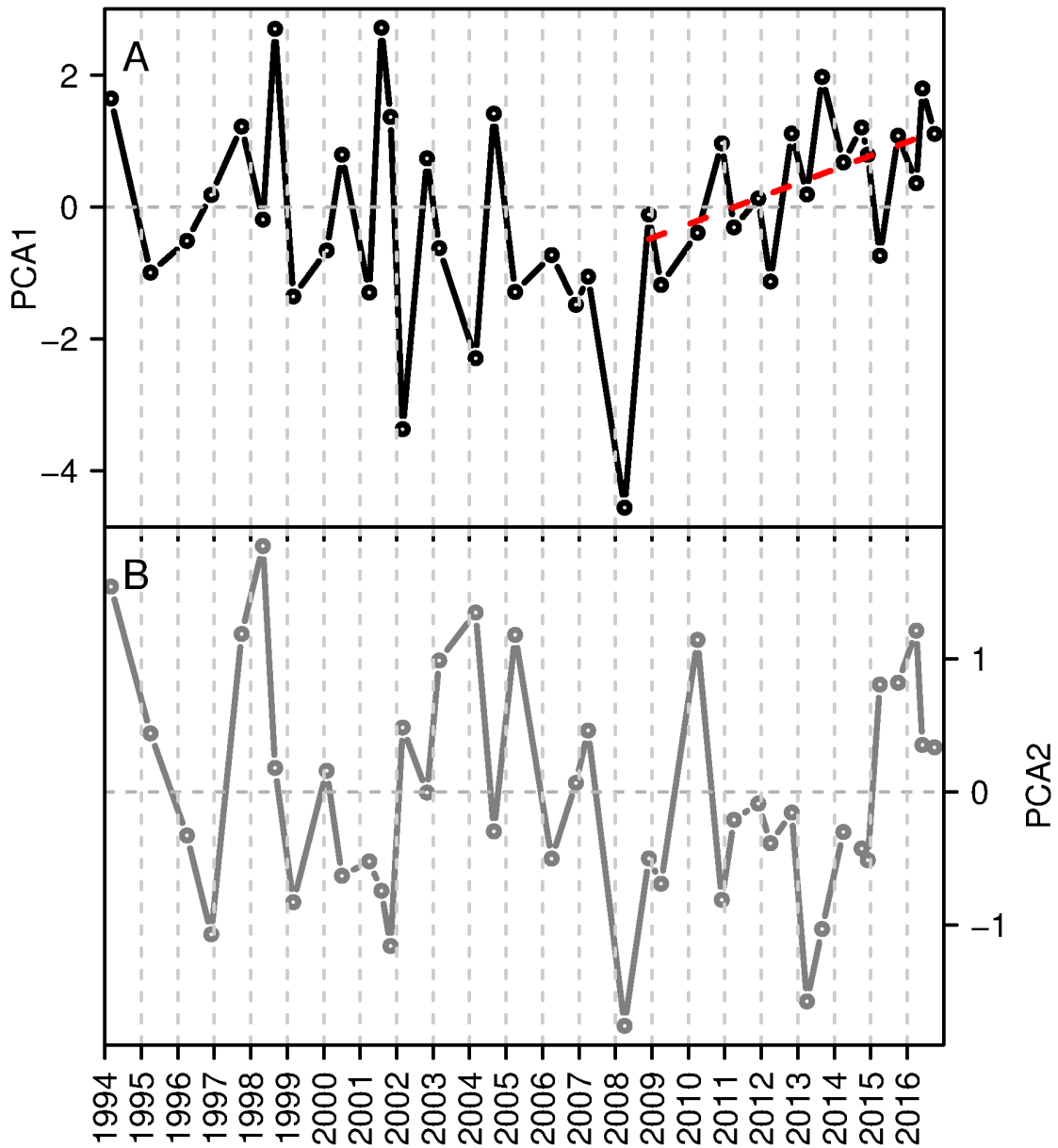

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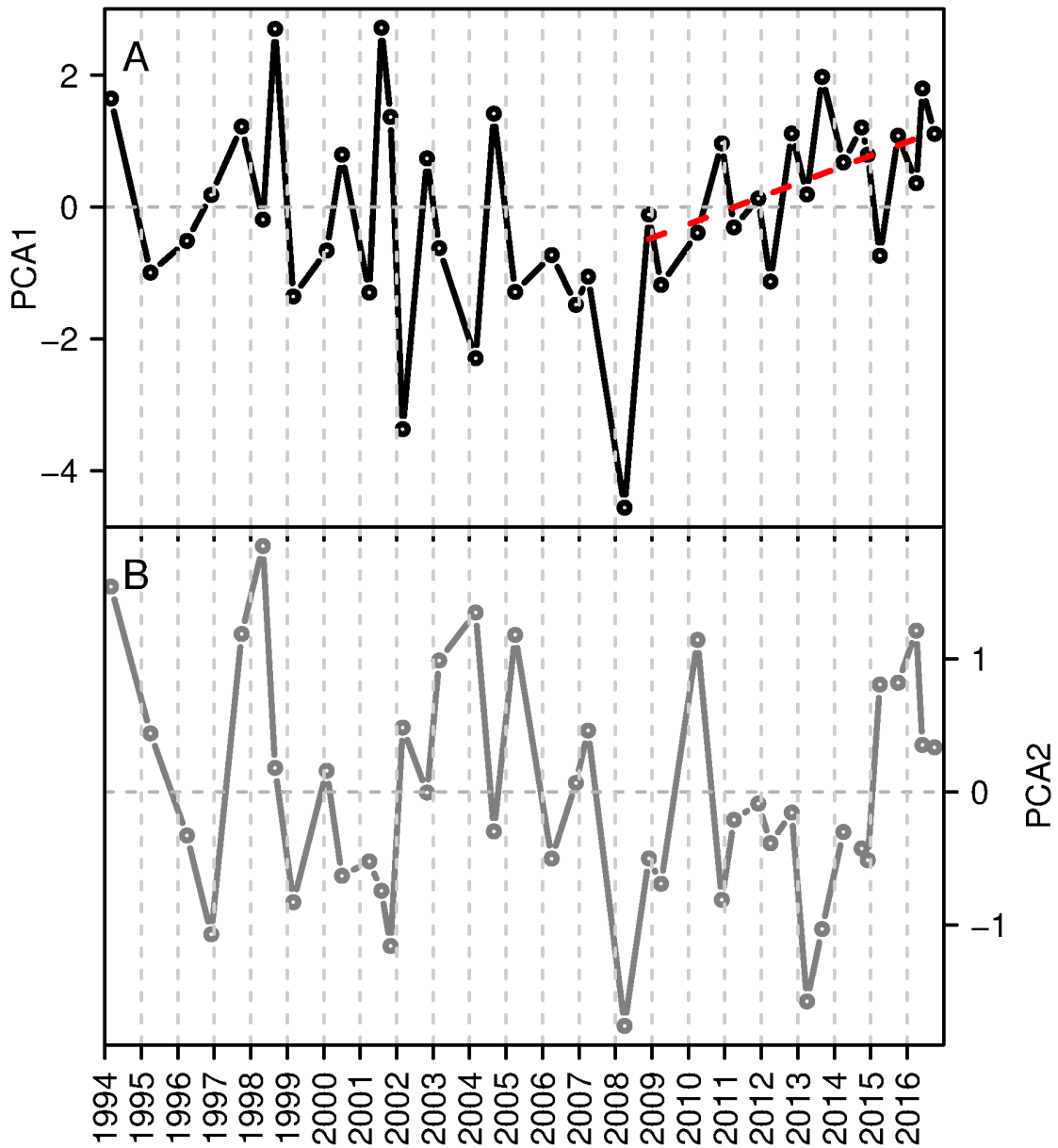

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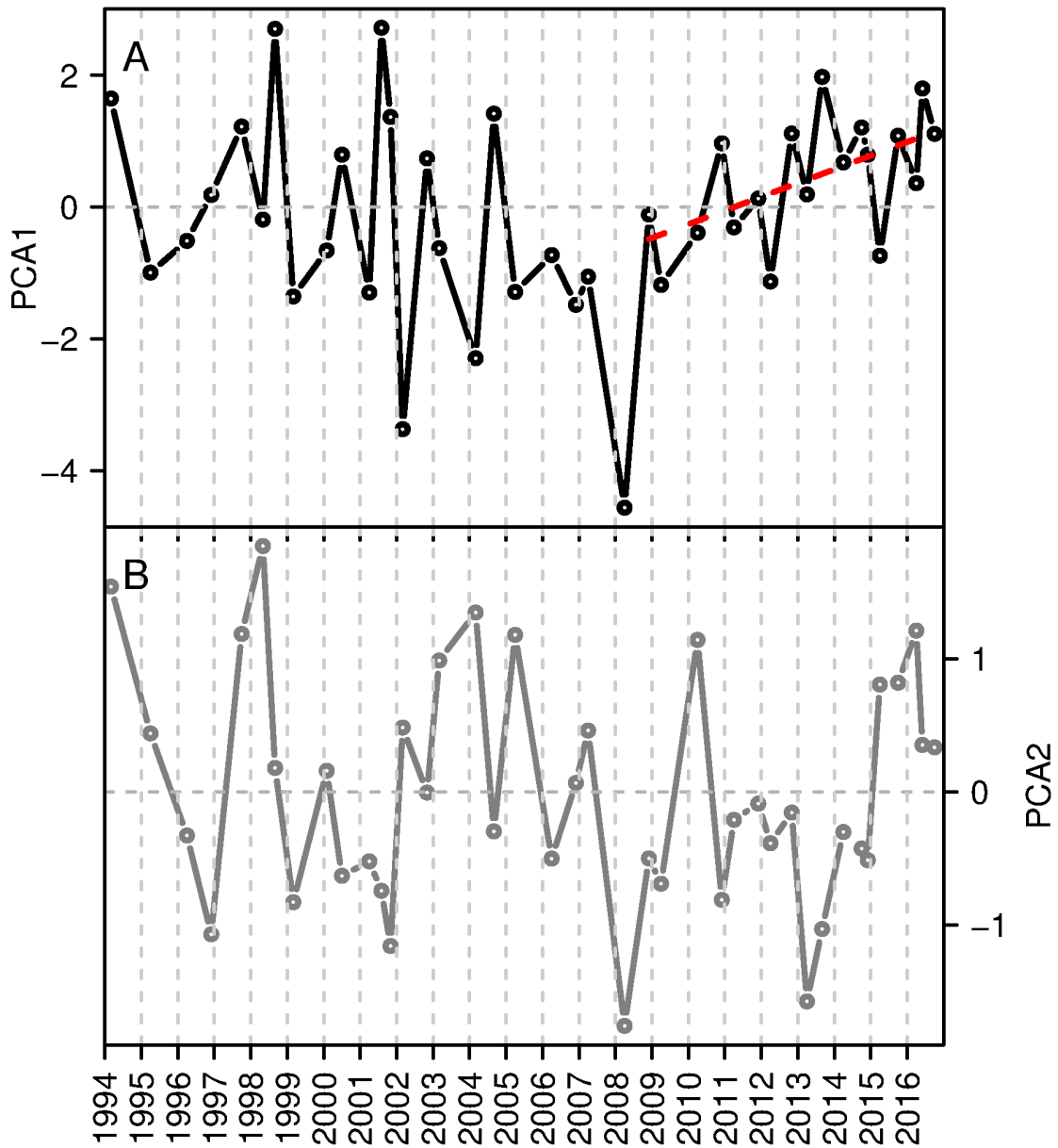

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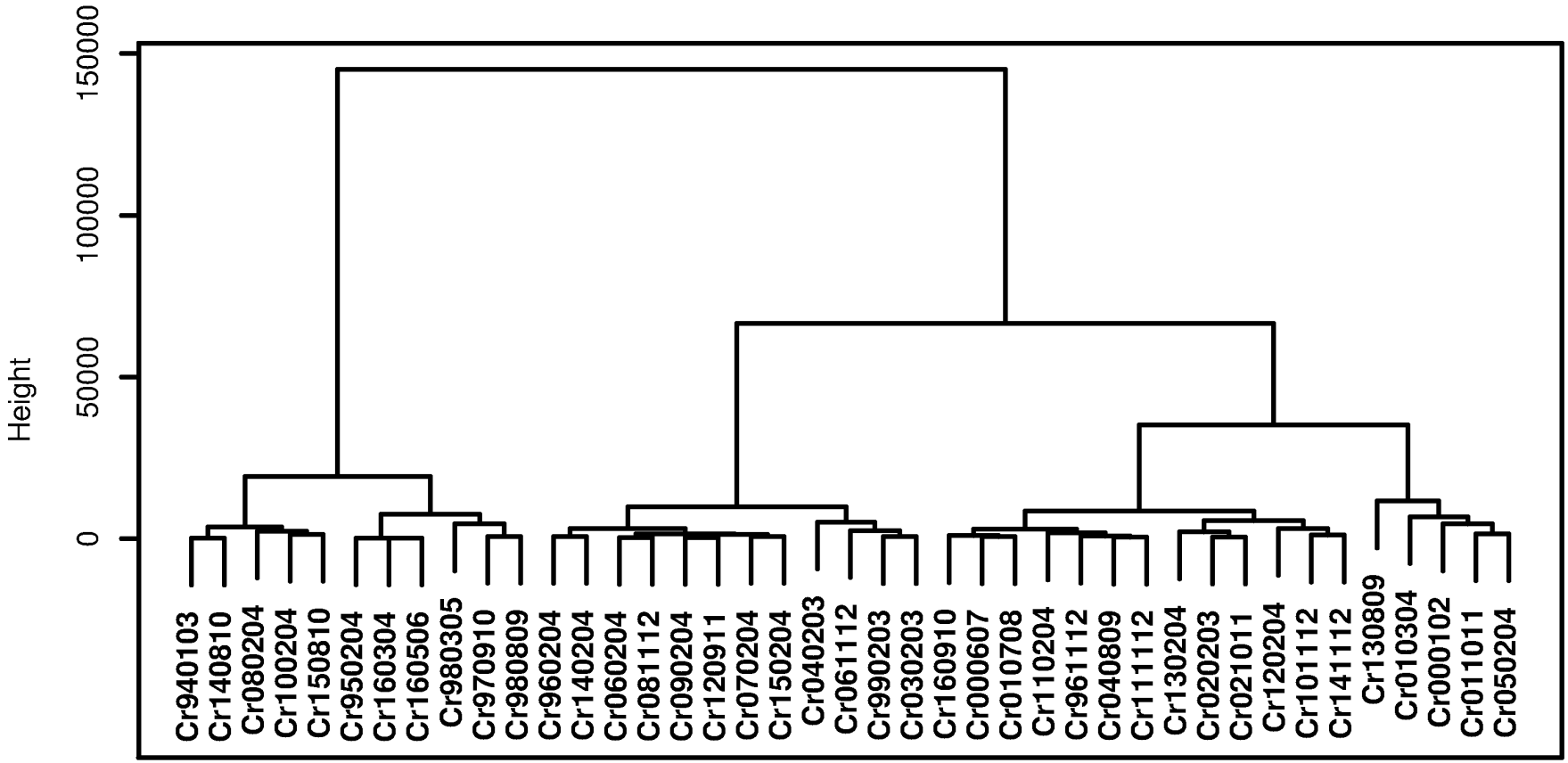
Hierarchical clustering - Spatial variables



- Three Mantel-optimal number of cluster (Borcard *et al.*, 2011)
- Only for areas classification, we consider two groups: cooling- (blue) and warming-type (red) periods

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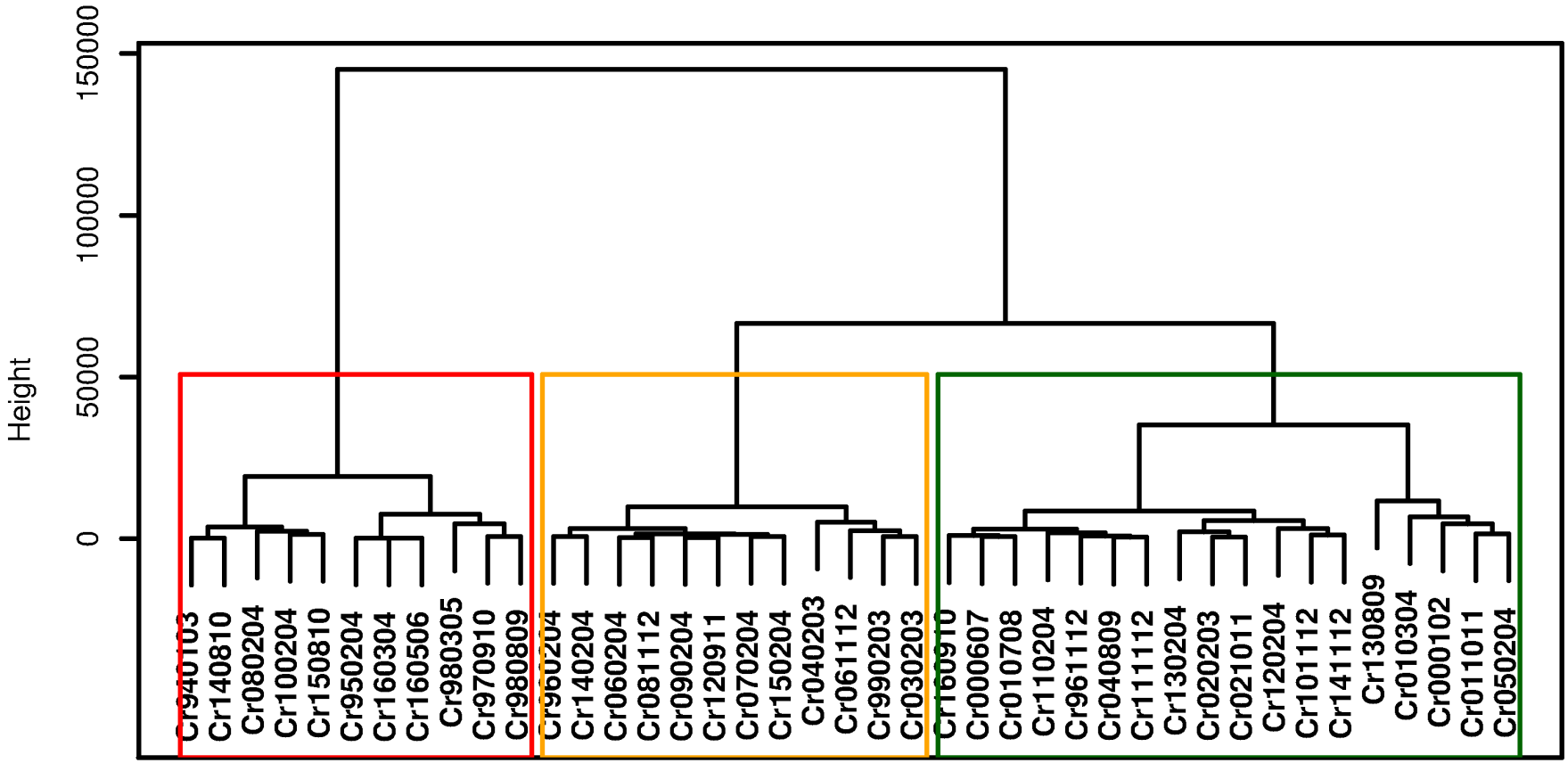

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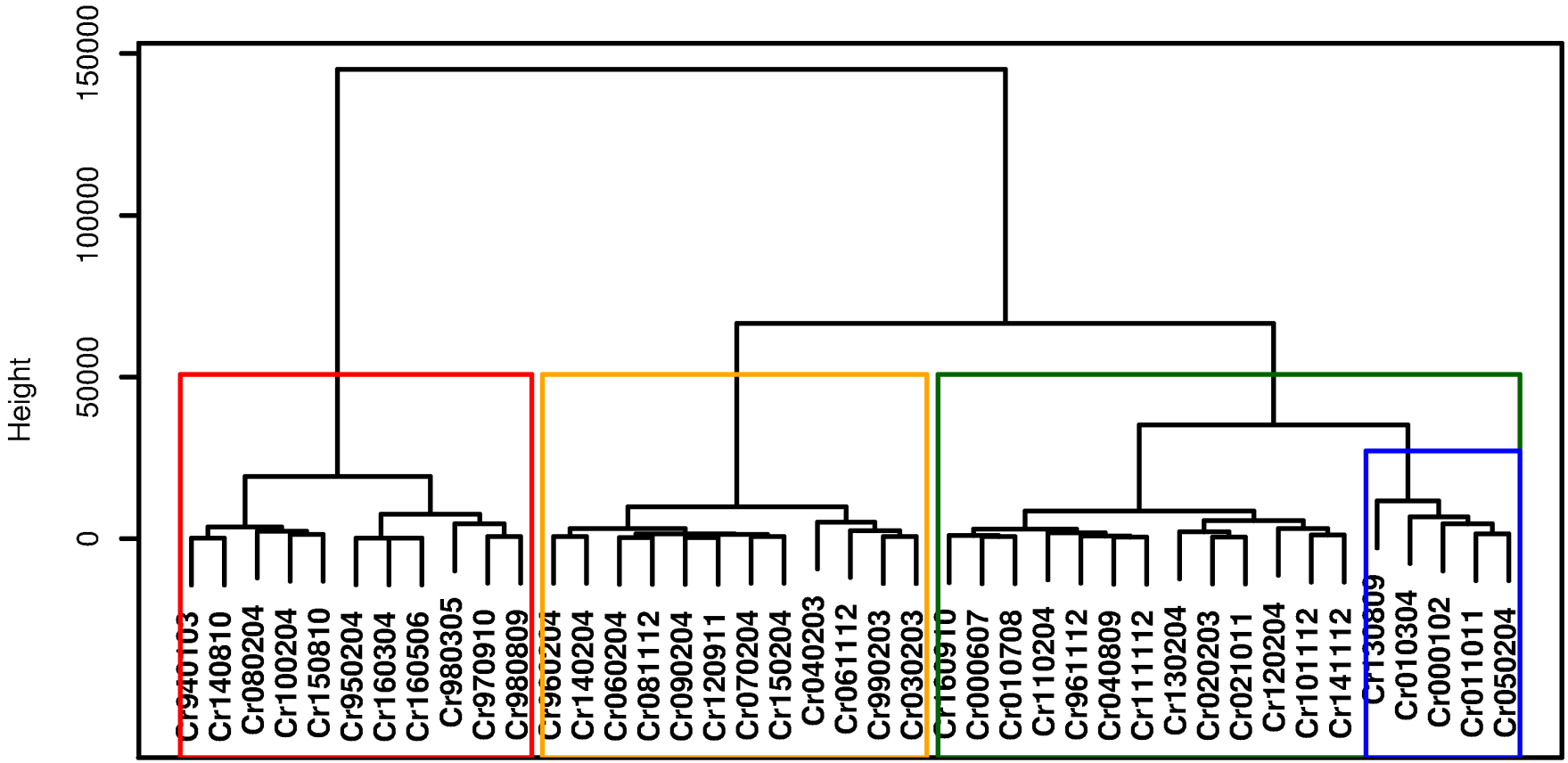

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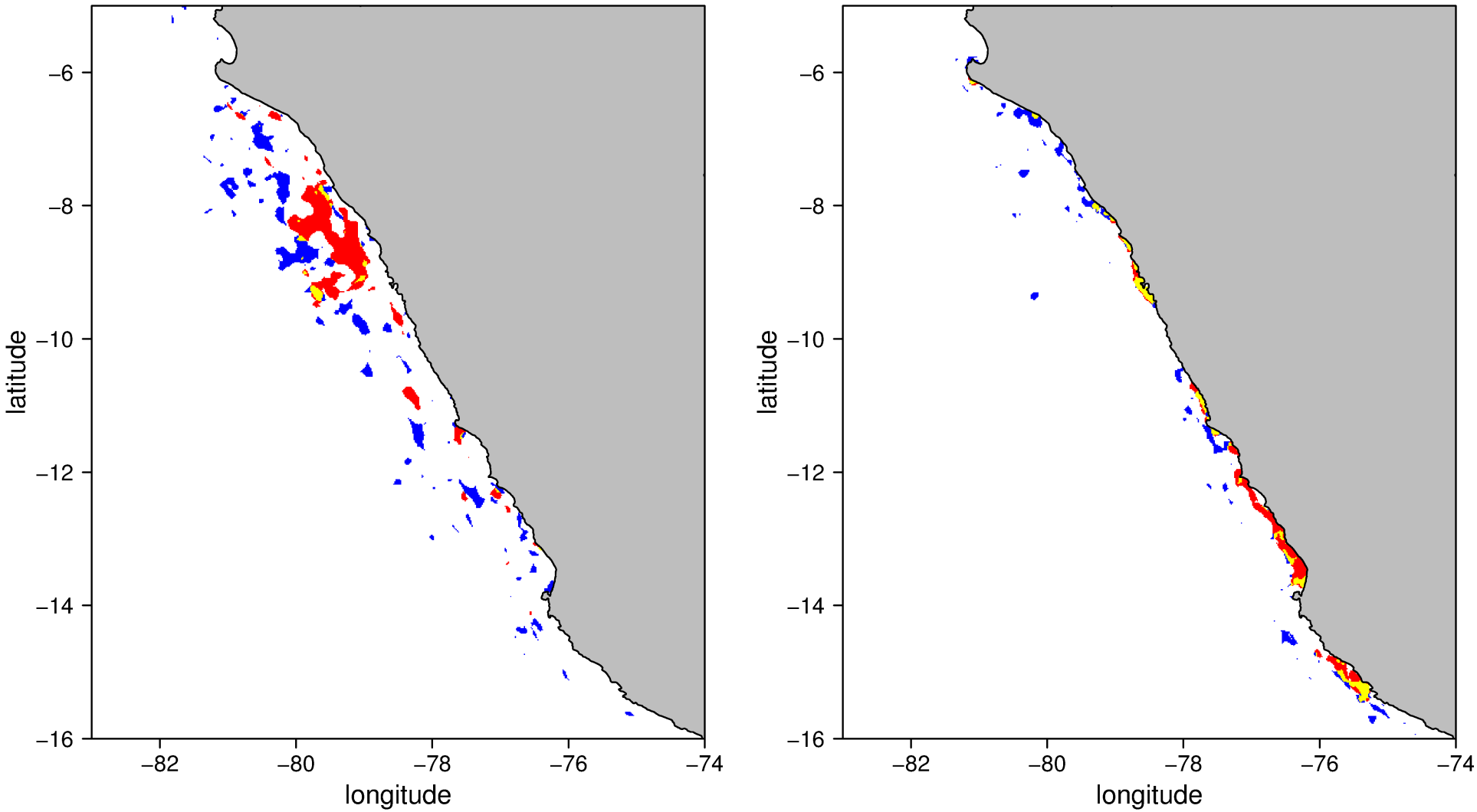
Classifying areas



Recurrent ($\uparrow \mu$ and $\downarrow \sigma$, red), occasional ($\uparrow \mu$ and σ, yellow) and rare ($\downarrow \mu$ and $\uparrow \sigma$, blue) areas during cooling (left) and warming (right) events

Conclusions

- Reduction since 2014 mainly in number of hotspots, aggregation area and abundance
  - Adapt scientific surveys and management strategies
  - Higher fishing effort (Diaz *pers comm.*)
  - Only effect of El Niño? Several El Niño events since 2012 off Peru
- Reduction in mean length since 2012
  - Reduction in age at first maturity (Perea, *pers comm.*)
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- A more robust statistical approach to find hotspots
- Use 3D oceanographic variables
- Oceanographic features of aggregation and recurrent areas

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Thank you!

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Picture from ellaquaint