Interannual spatial dynamic of frontal activity along the southern part of the California Current (1985-2015)

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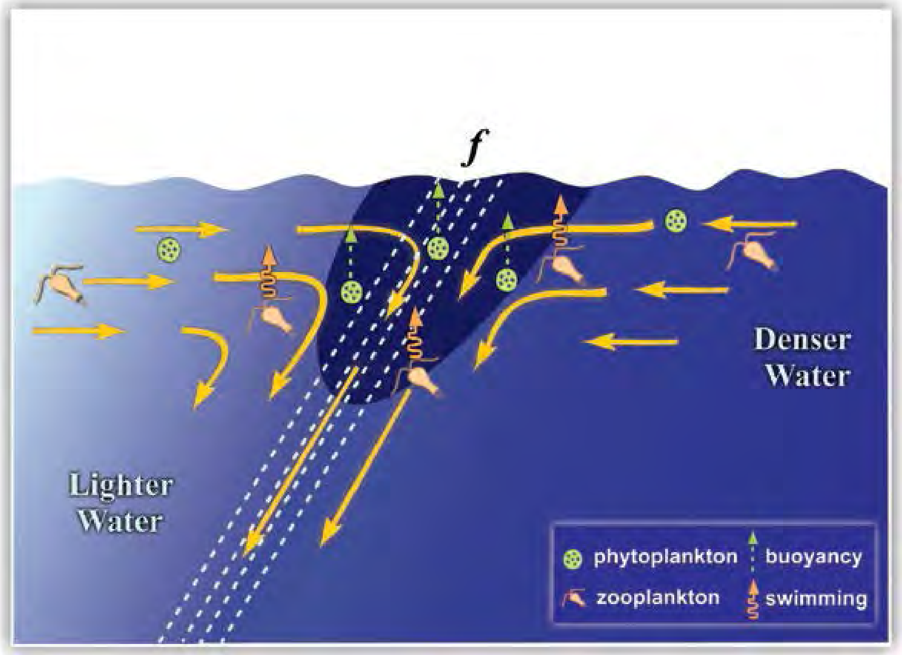
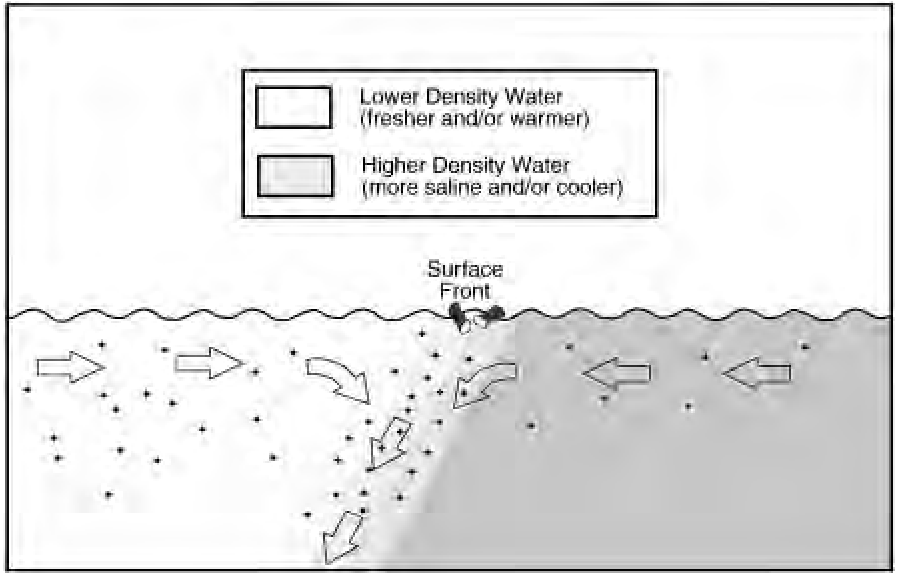
- **Fronts are a dynamic process separating water masses of different properties.**

- **They are narrow three-dimensional structures caused by diverse forcing mechanisms; and are characterized by distinct physical, chemical, and biological properties.**

- **Fronts occur throughout the world ocean at several spatial and temporal scales.**

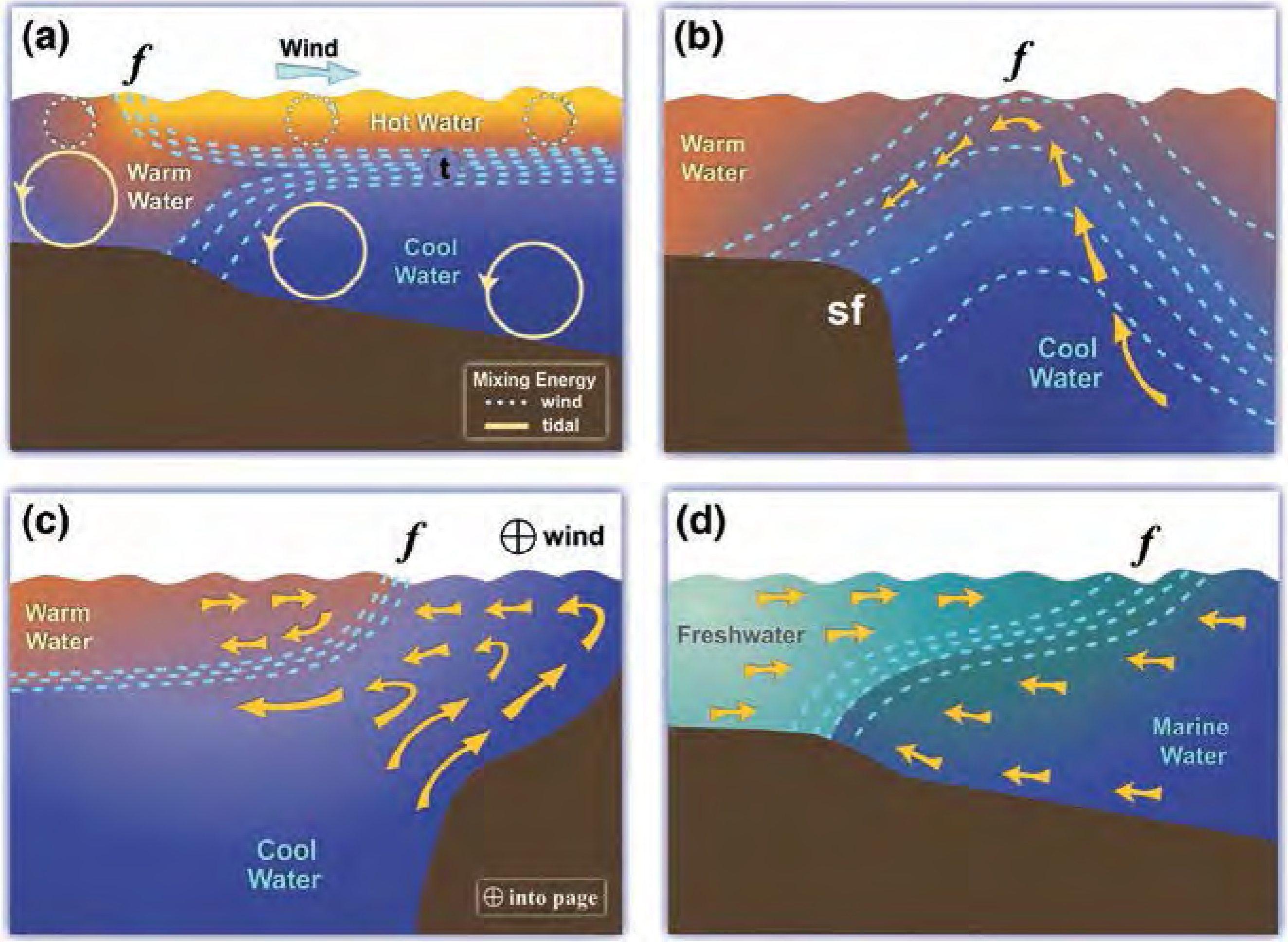




Bakun, A. (2010)

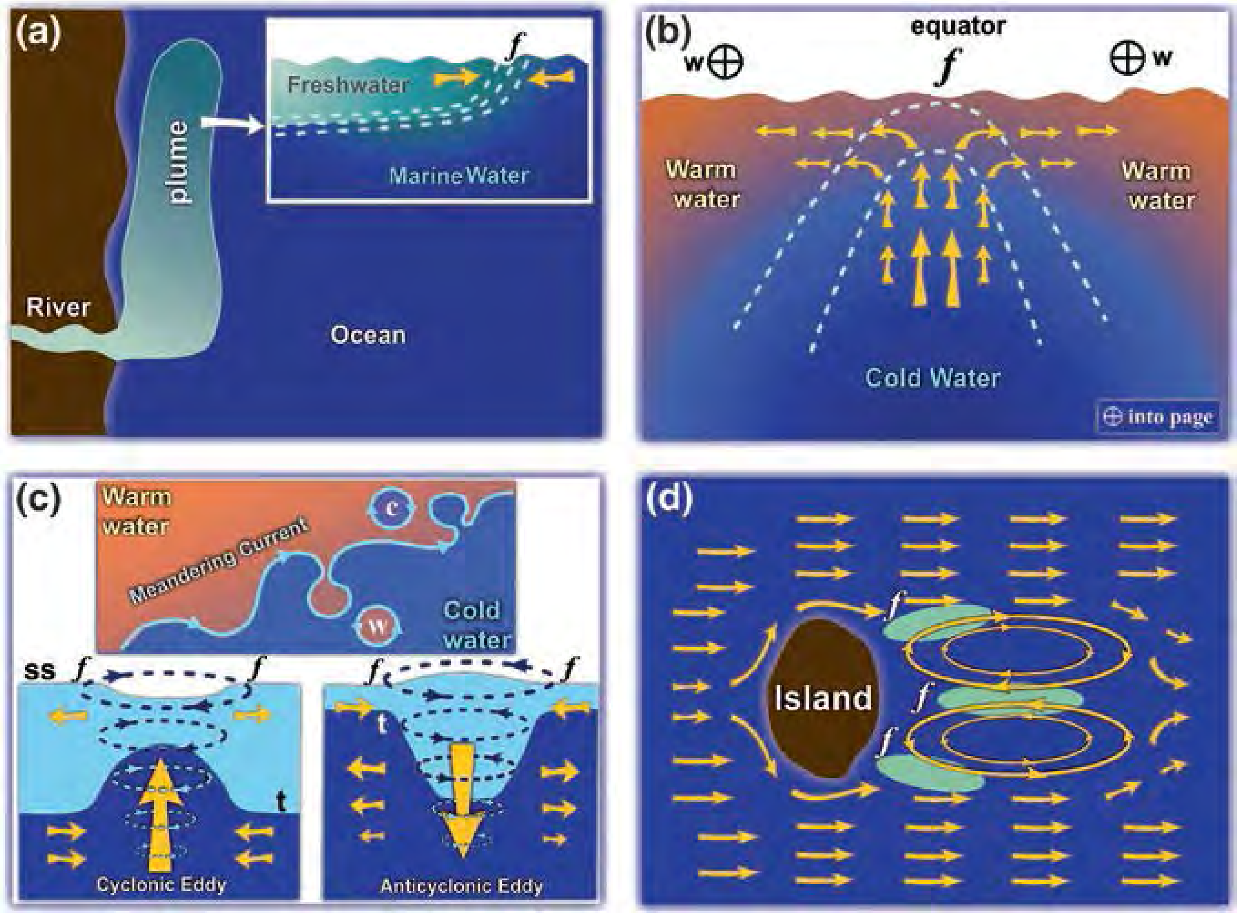
In theory, the convergence between adjacent water masses develops favorable mixing conditions resulting in enhanced biological production along the front (Bakun, 1996).

Fronts are regions of higher biological productivity that the rest of the ocean (Owen, 1981).



Frontal types are:

- tidal fronts
- shelf-break fronts
- upwelling fronts
- estuarine fronts
- plume fronts
- fronts generated by convergence or divergence of water masses
- frontal eddies
- fronts associated with abrupt topographic features.



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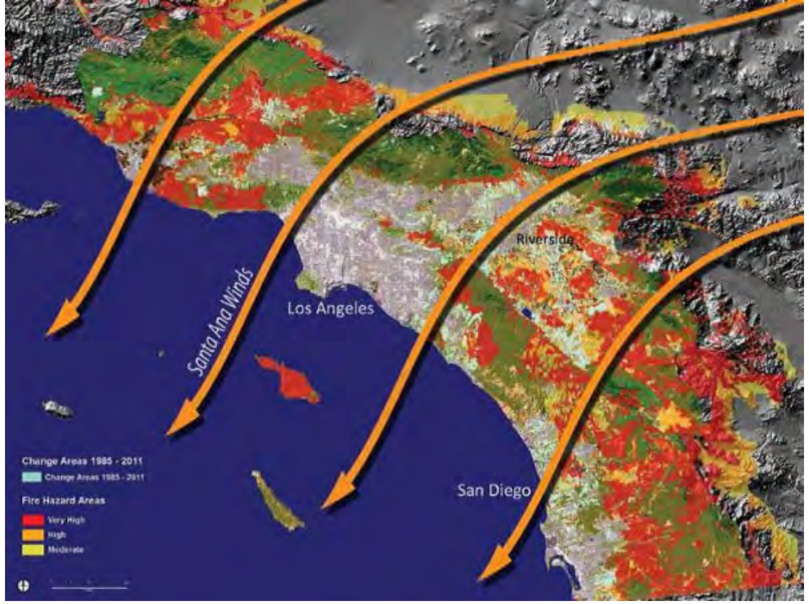
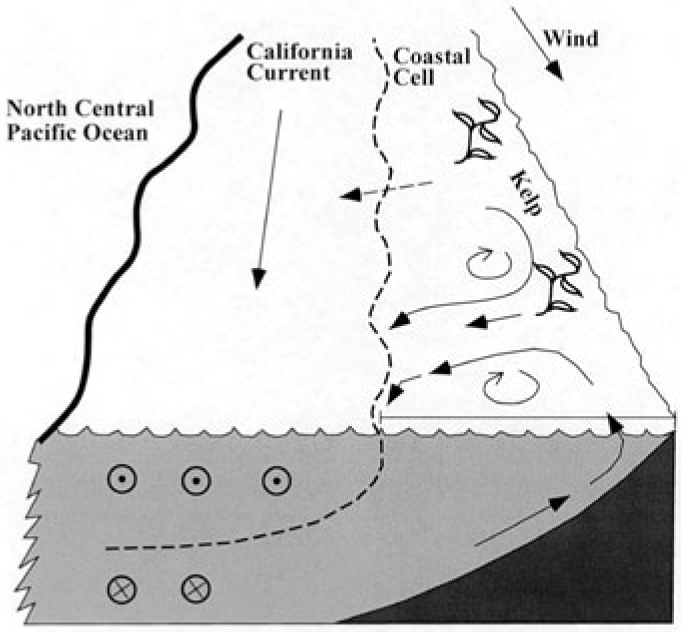
Seattle
Boise
Crescent City
Denver
Monterey
Las Vegas
Santa Maria
Albuquerque
Los Angeles
San Diego
Dallas-Fort Worth
San Antonio
Pacific High
Steady NW Winds
bing



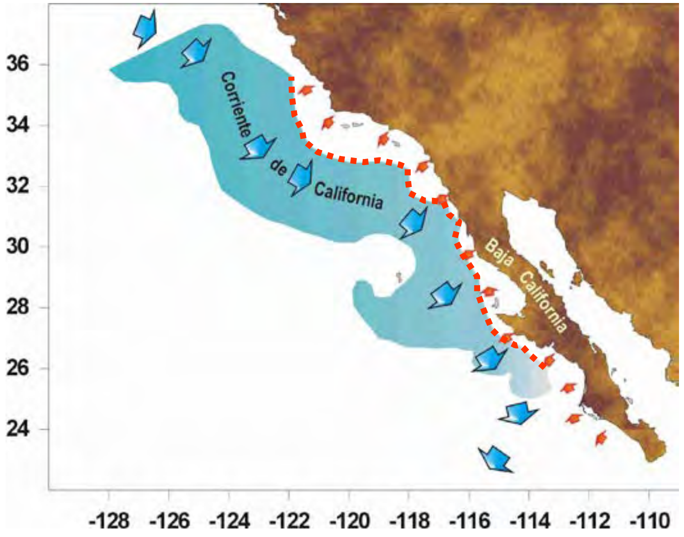
Santa Ana Winds
Los Angeles
Riverside
San Diego
Change Areas 1985 - 2011
Change Areas 1985 - 2011
Fire Hazard Areas
Very High
High
Moderate

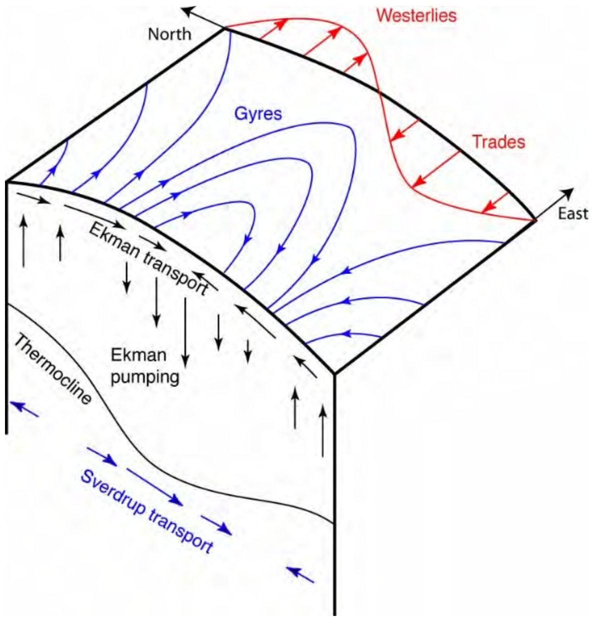
Las Vegas
Santa Maria
Point Conception
Los Angeles
Swirling EDDY Circulation
San Diego
bing

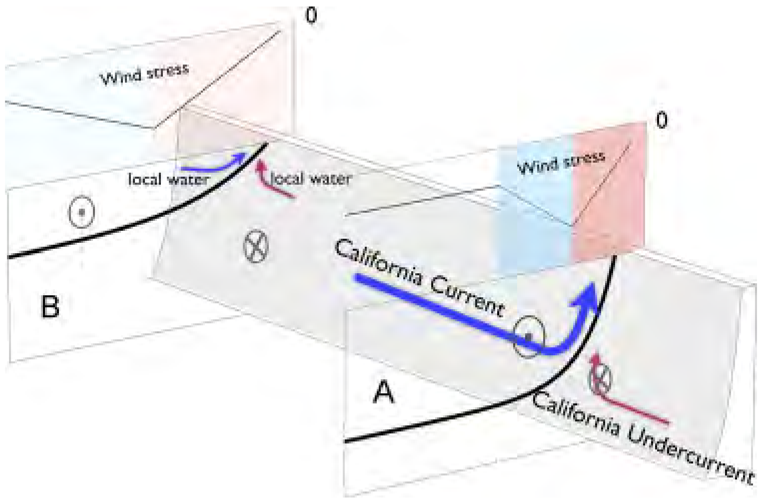


California Current
Coastal Cell
Wind
North Central Pacific Ocean
Kelp

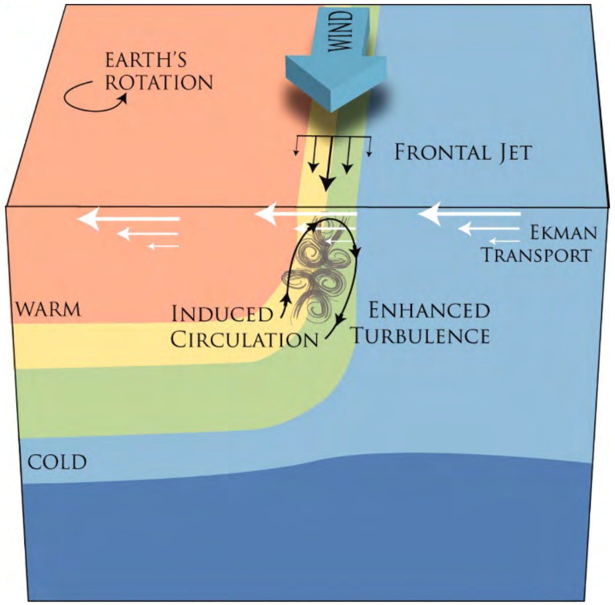
Cartoons to illustrate the relation between the wind stress curl and upwelling and its water sources



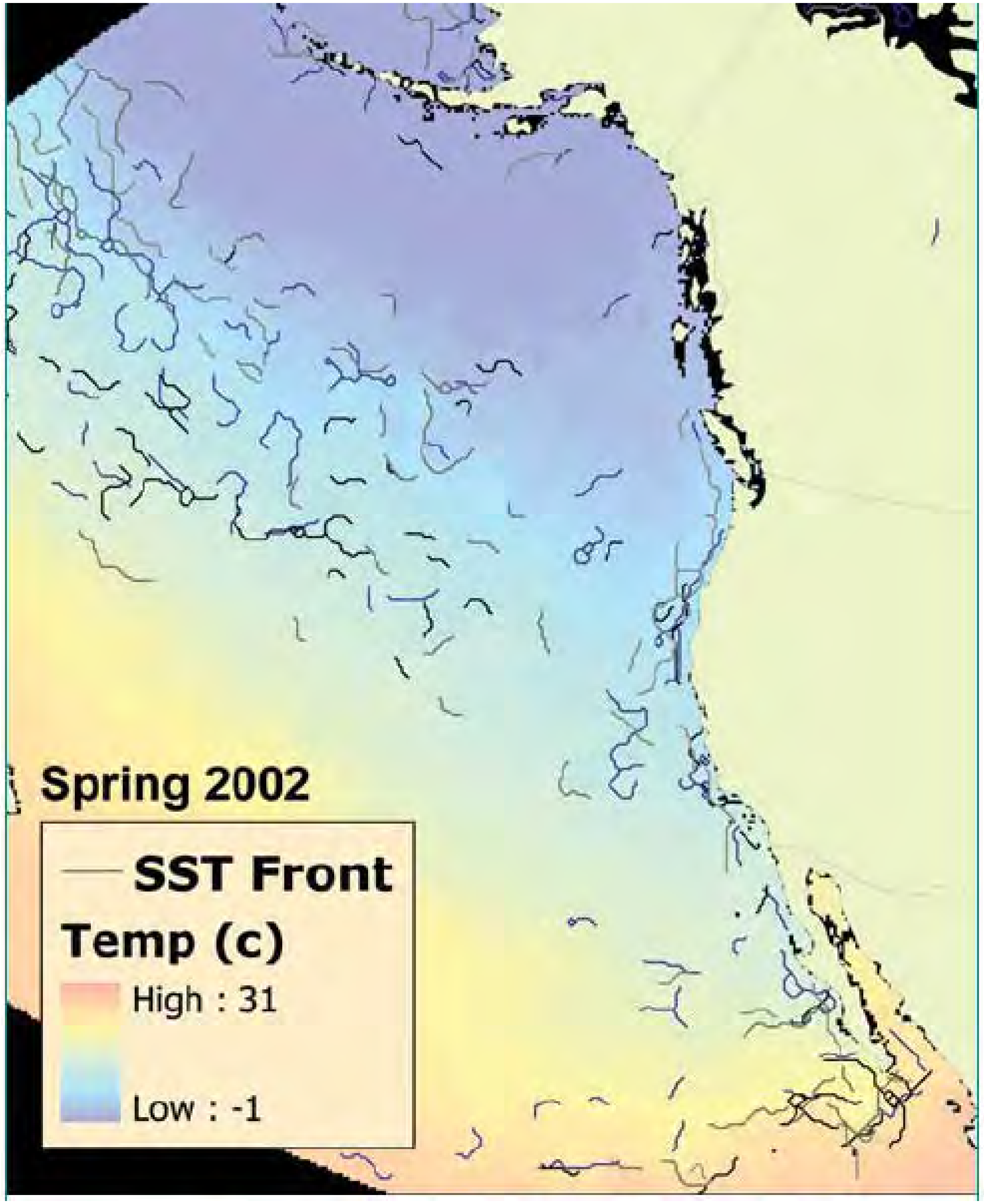




Song, H., et al. (2011)



D'Asaro, E., et al. (2011)



Etnoyer et al. (2004)

Not a single persistent front, but as a dynamic region characterized by a persistent high concentration of frontal features generated by the confluence of the cool southbound California Current and warmer northbound California Counter- Current as it intersects the Baja California Peninsula.

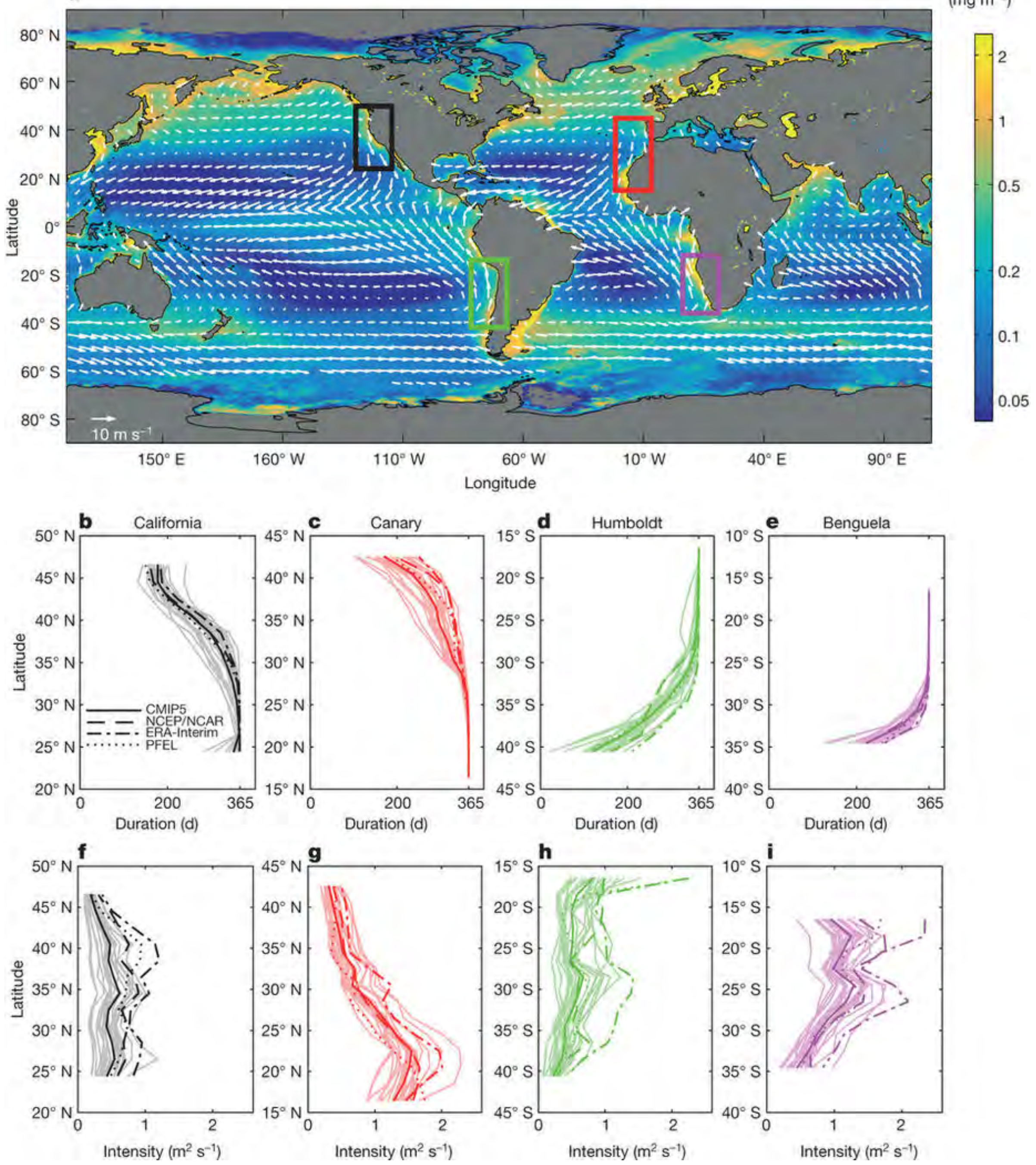
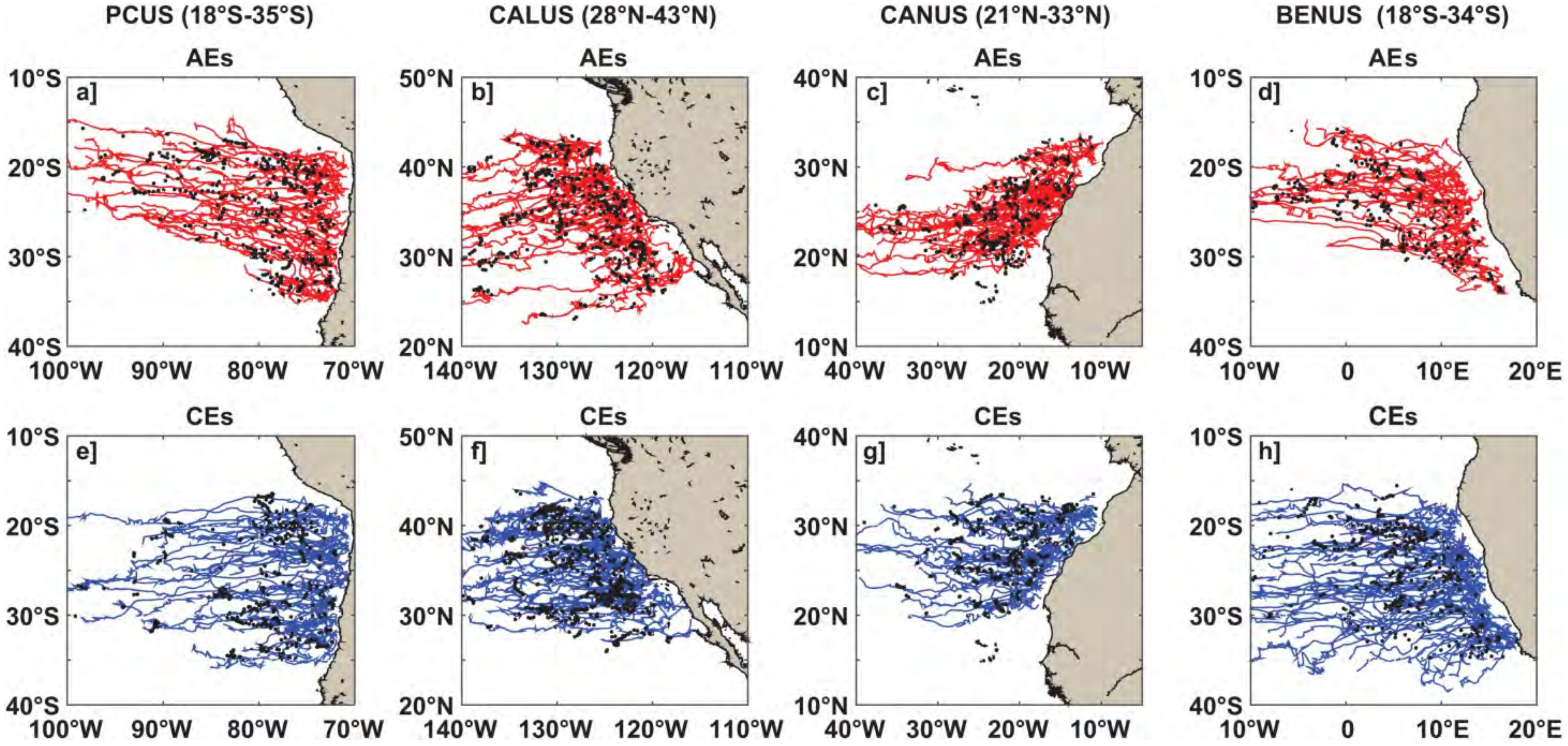


Figure 1: Geographic locations of four EBUSs and latitudinal variations in coastal upwelling in each system.

a, Aqua MODIS mean ocean chlorophyll *a* concentrations for 2002–2013 (colour scale; EBUS regions outlined with rectangular boxes) and mean QuikSCAT ocean surface vector winds for 1999–2009 (white arrows). **b**–**i**, Mean durations of the upwelling season **(b**–**e)** and upwelling intensity **(f**–**i)** for individual CMIP5 models (thin lines). Also shown are the multimodel mean (thick solid lines), the NCEP/NCAR reanalysis (thick dashed lines), the ERA-Interim reanalysis (thick dash–dot lines) and the PFEL upwelling index analysis (thick dotted lines) for 1981–2005 in each EBUS.

Main eddy vertical structures observed in the four major Eastern Boundary Upwelling Systems

Peru-Chile Upw. Syst | Calif. Upw. Syst | Canarias Upw. Syst | Benguela Upw. Syst

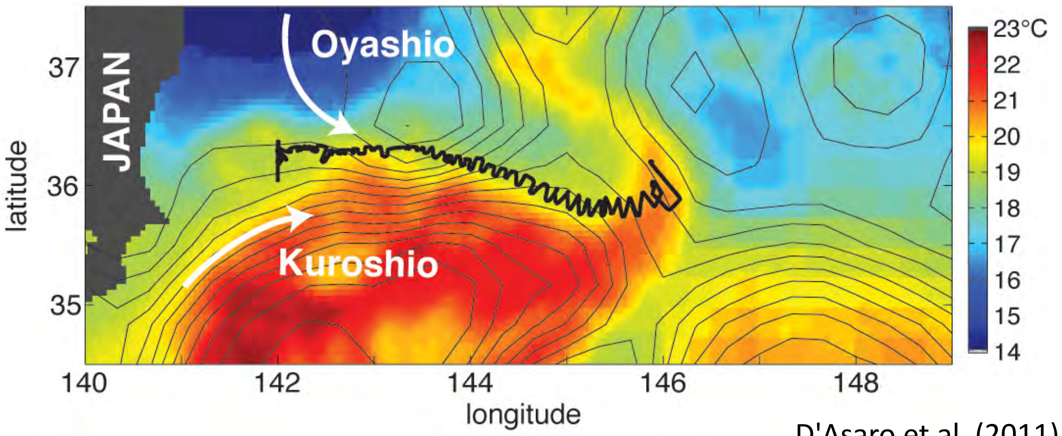


Trajectories of the long-lived anticyclonic (in red)

Trajectories of the long-lived cyclonic eddies (in blue)

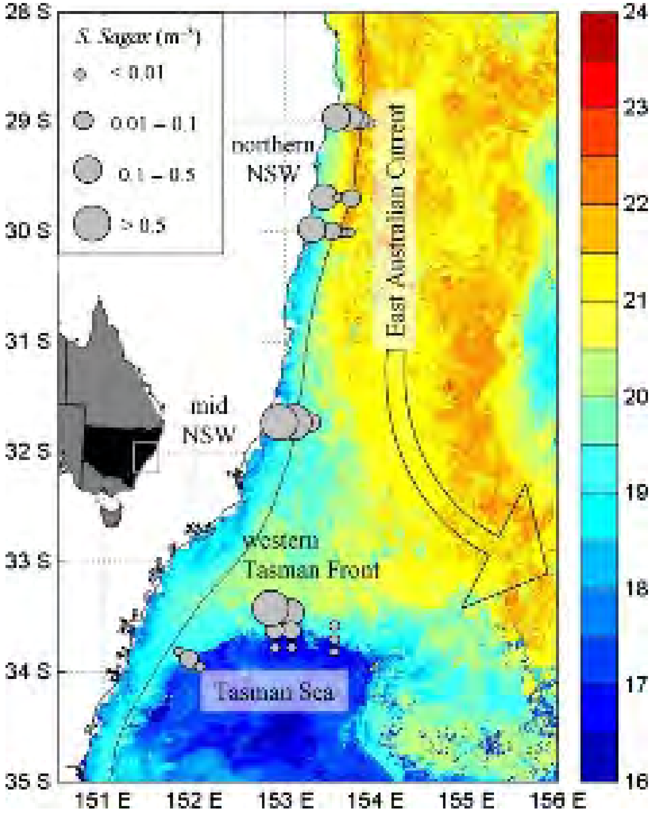
Pegliasco et al. (2015)

Turbulence and Energy Dissipation at Ocean Fronts



D'Asaro et al. (2011).

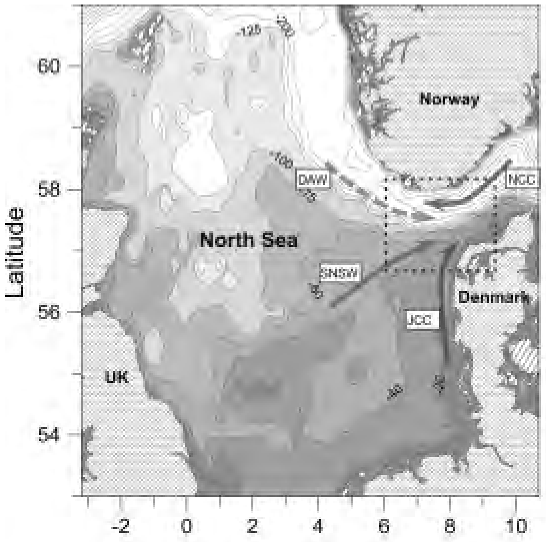
Entrainment and advection of larval sardine by the East Australian Current and retention in the western Tasman Front

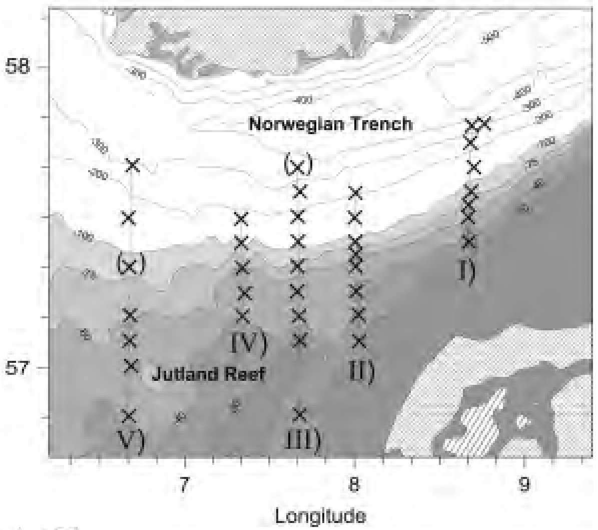


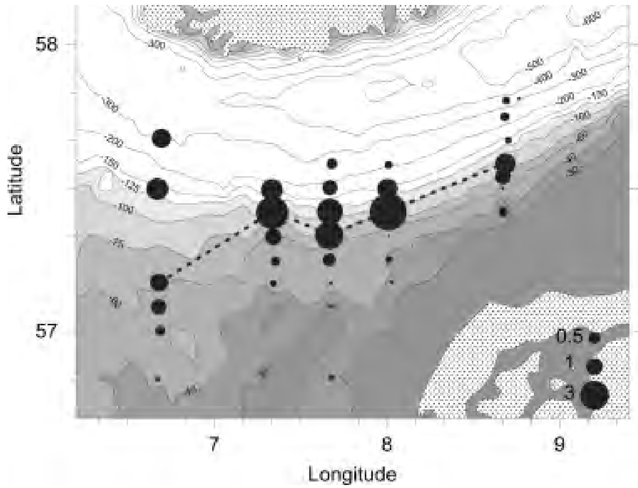
Mullaney et al (2014)

Fish larvae at fronts

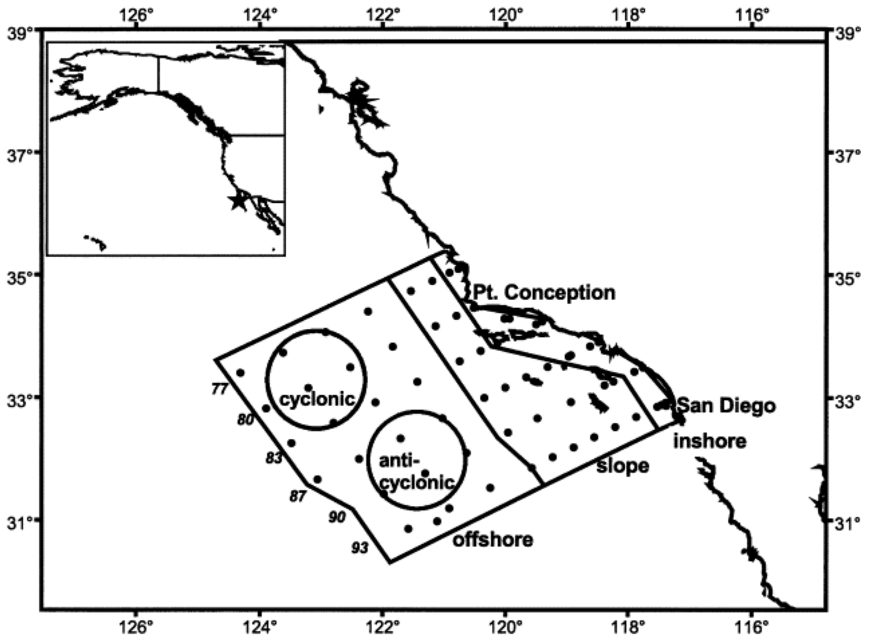
Horizontal and vertical distributions of gadoid fish larvae across a frontal zone at the Norwegian Trench





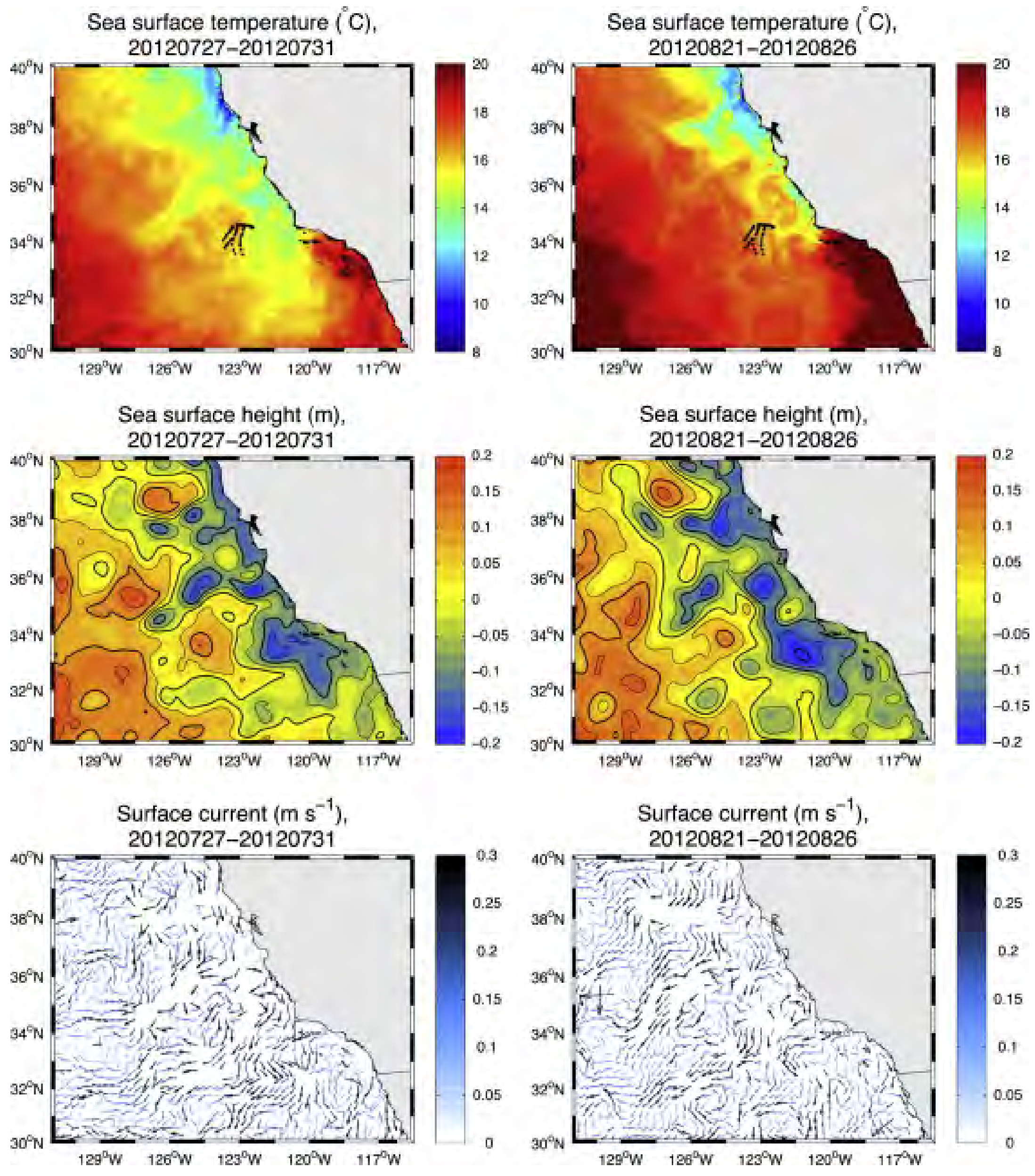


Munk (2014)



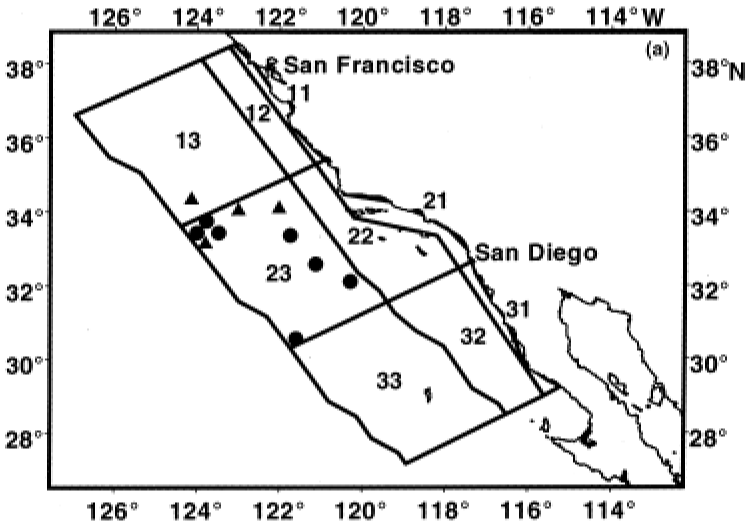
Stations by California Cooperative Oceanic Fisheries Investigations (CalCOFI) in the Southern California Bight.

Processes during cruise time interval



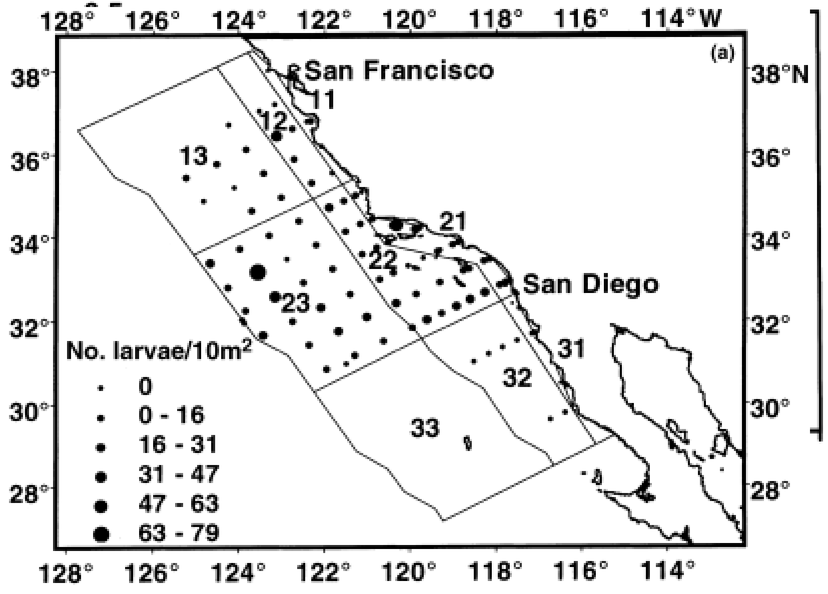
Miller et al. (2015)

Mesoscale eddies and survival of late stage Pacific sardine (*Sardinops sagax*) larvae

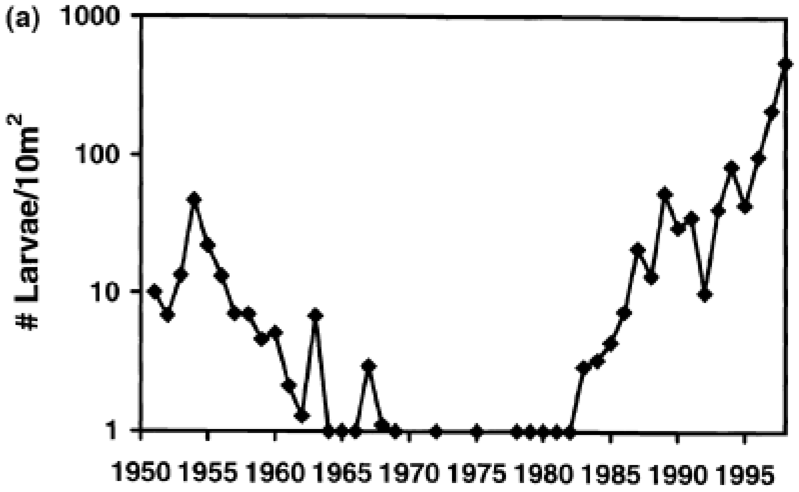


Distribution of eddies observed in satellite AVHRR sea surface temperature imagery, 1987–1998.

- Solid circles, anticyclonic eddies
- Solid triangles, cyclonic eddies

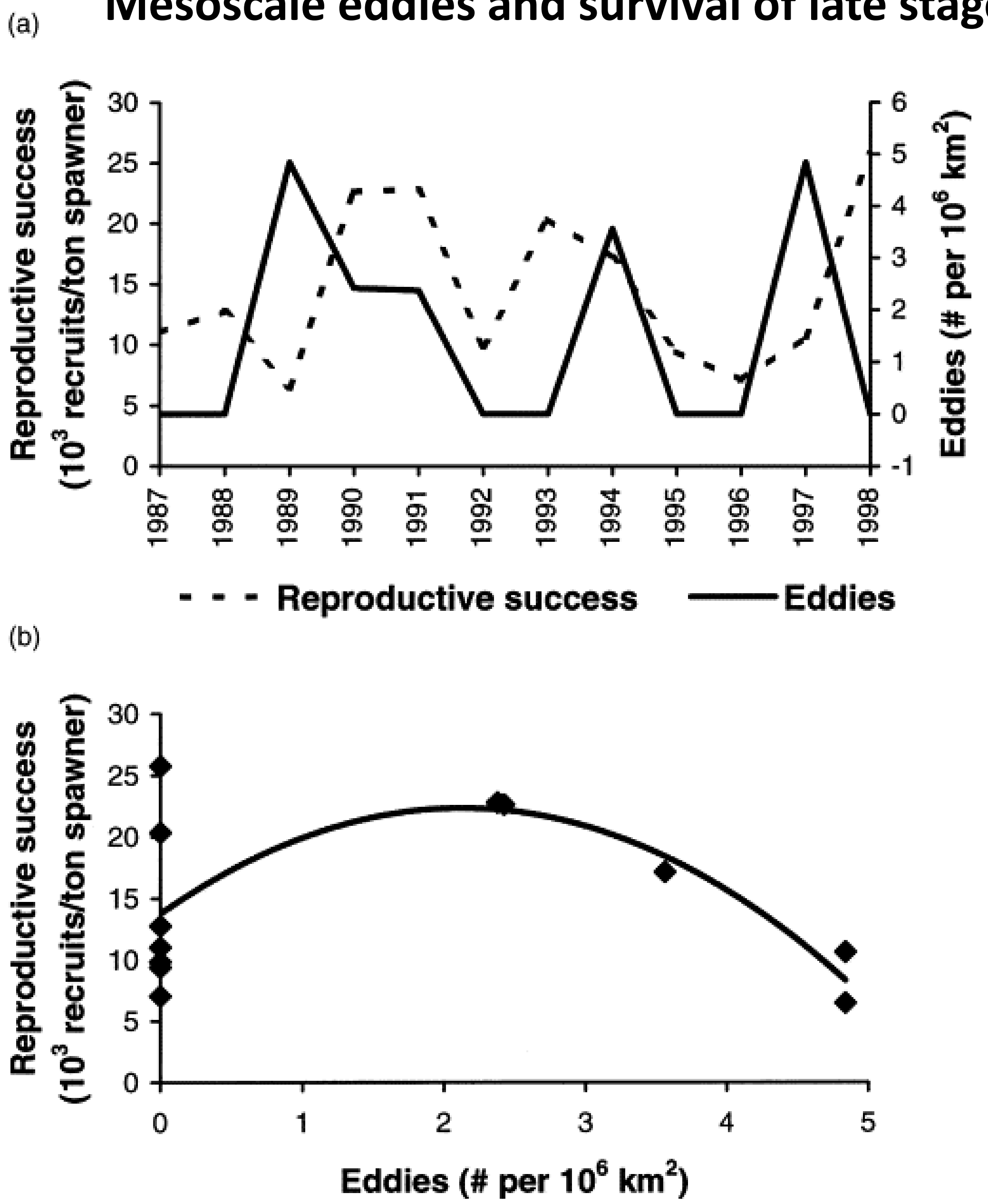


Long-term average distribution of sardine larvae, 1983–1998. Diameters of filled circles are proportional to larval density.



Logerwellet al. (2001).

Mesoscale eddies and survival of late stage Pacific sardine (*Sardinops sagax*) larvae

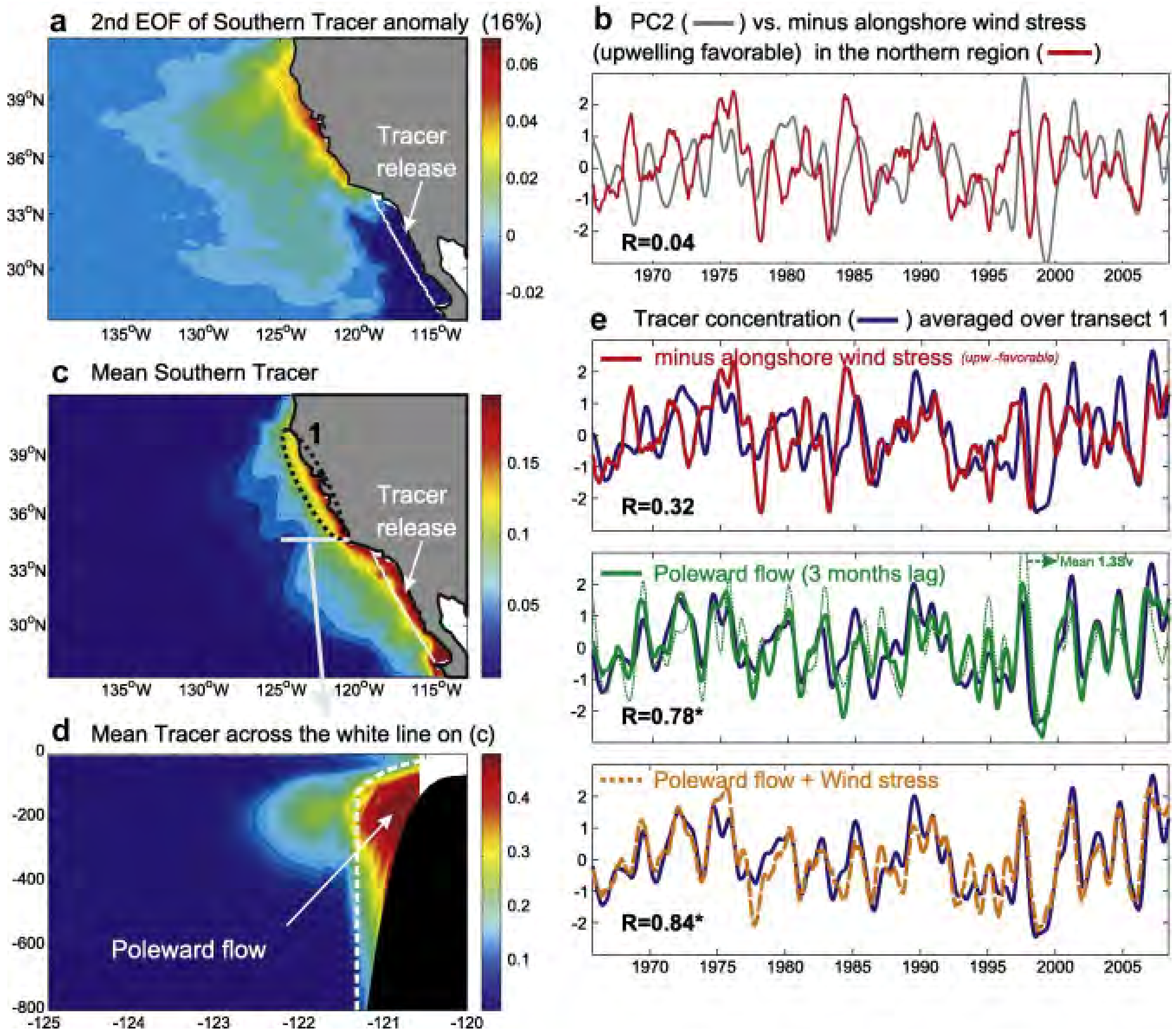


Relationship between eddy density and sardine reproductive success.

The fact that high eddy density does not necessarily lead to strong recruitment suggests that there is no single mechanism that is responsible for year–class variability in sardines, but that a suite of interacting processes are likely to be important.

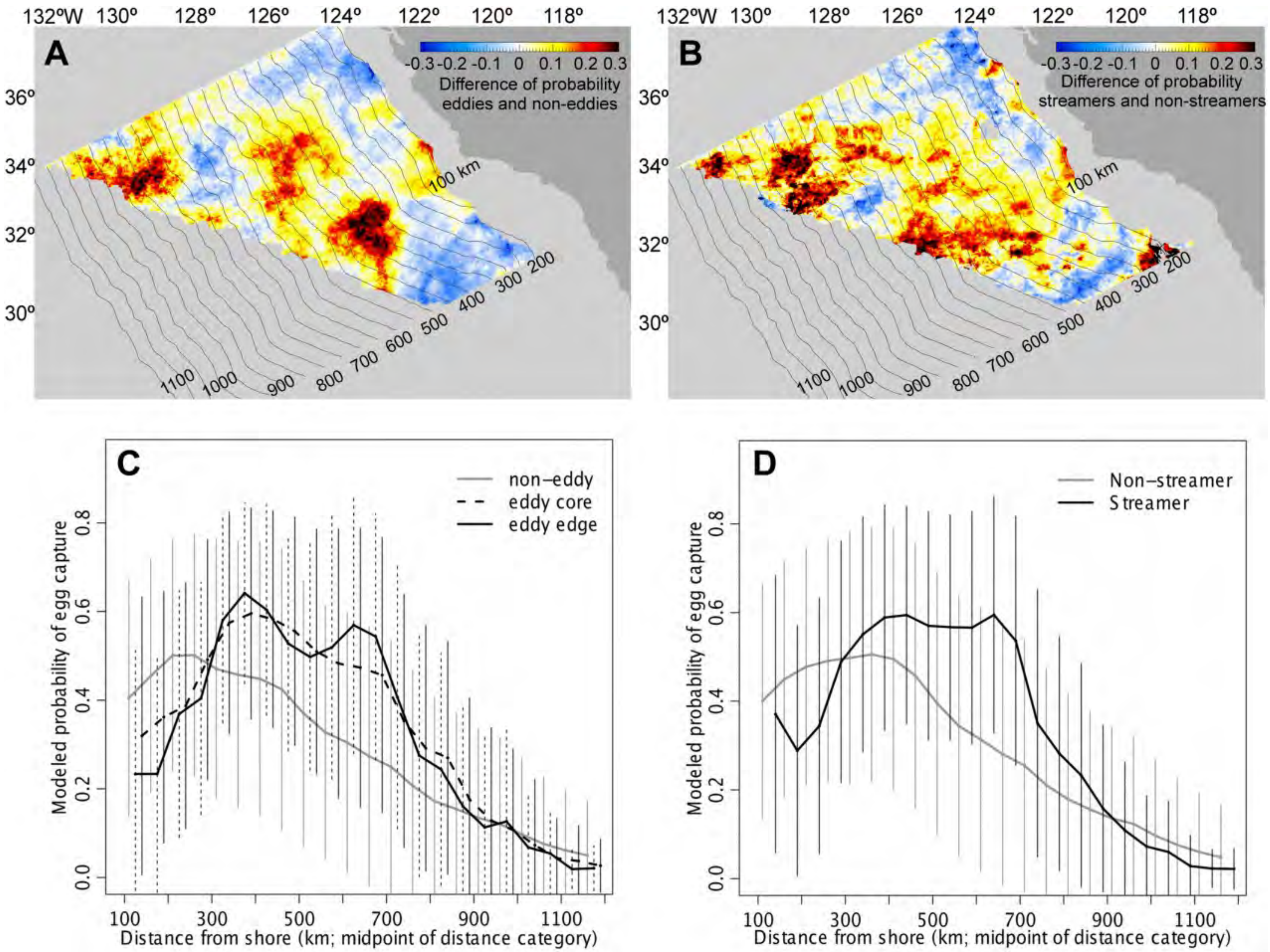
Logerwellet al. (2001).

Cross-shore transport variability in the California Current: Ekman upwelling vs. eddy dynamics



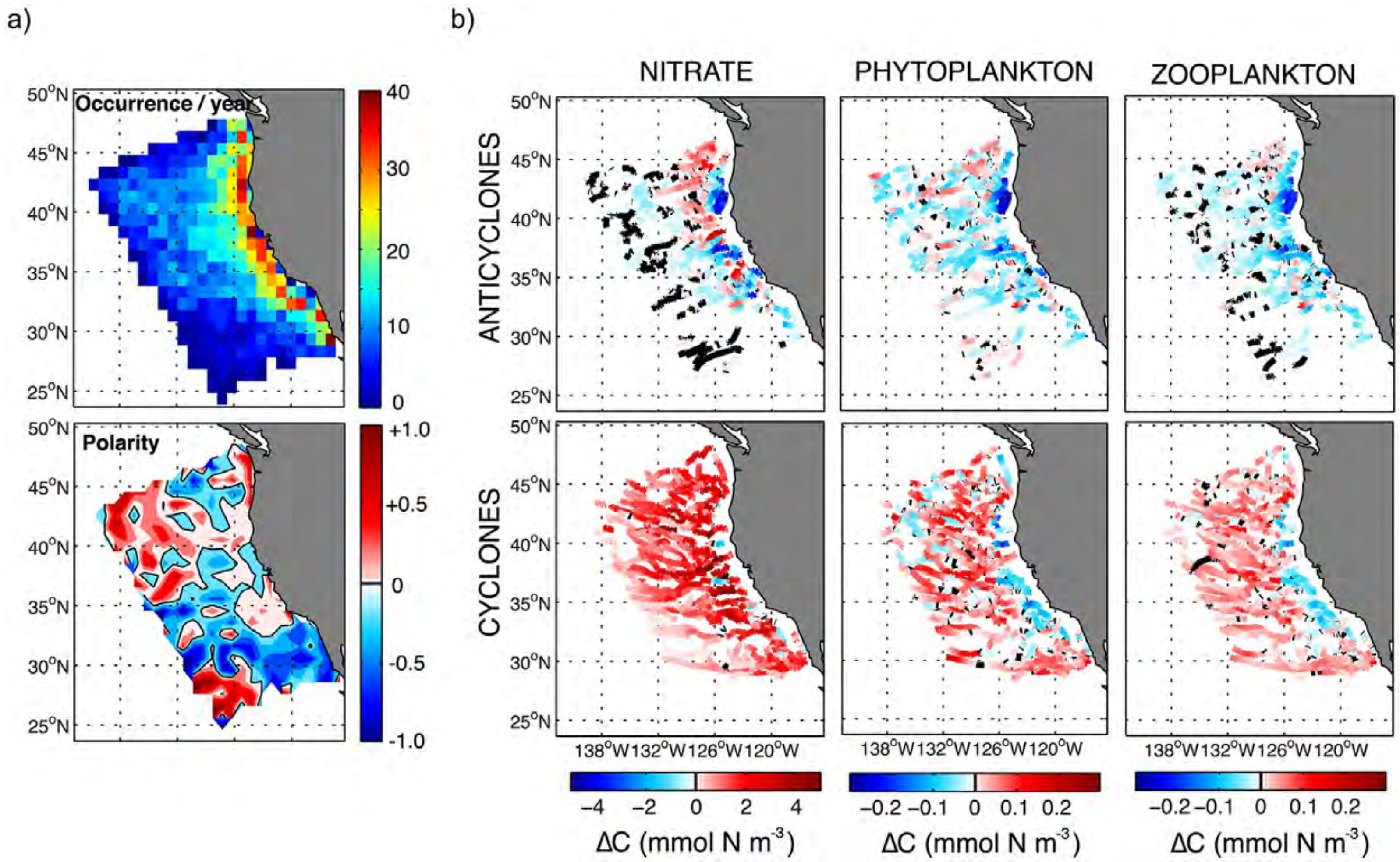
Combes, V., et al. (2013)

Effect of mesoscale eddies and streamers on sardine spawning habitat and recruitment success



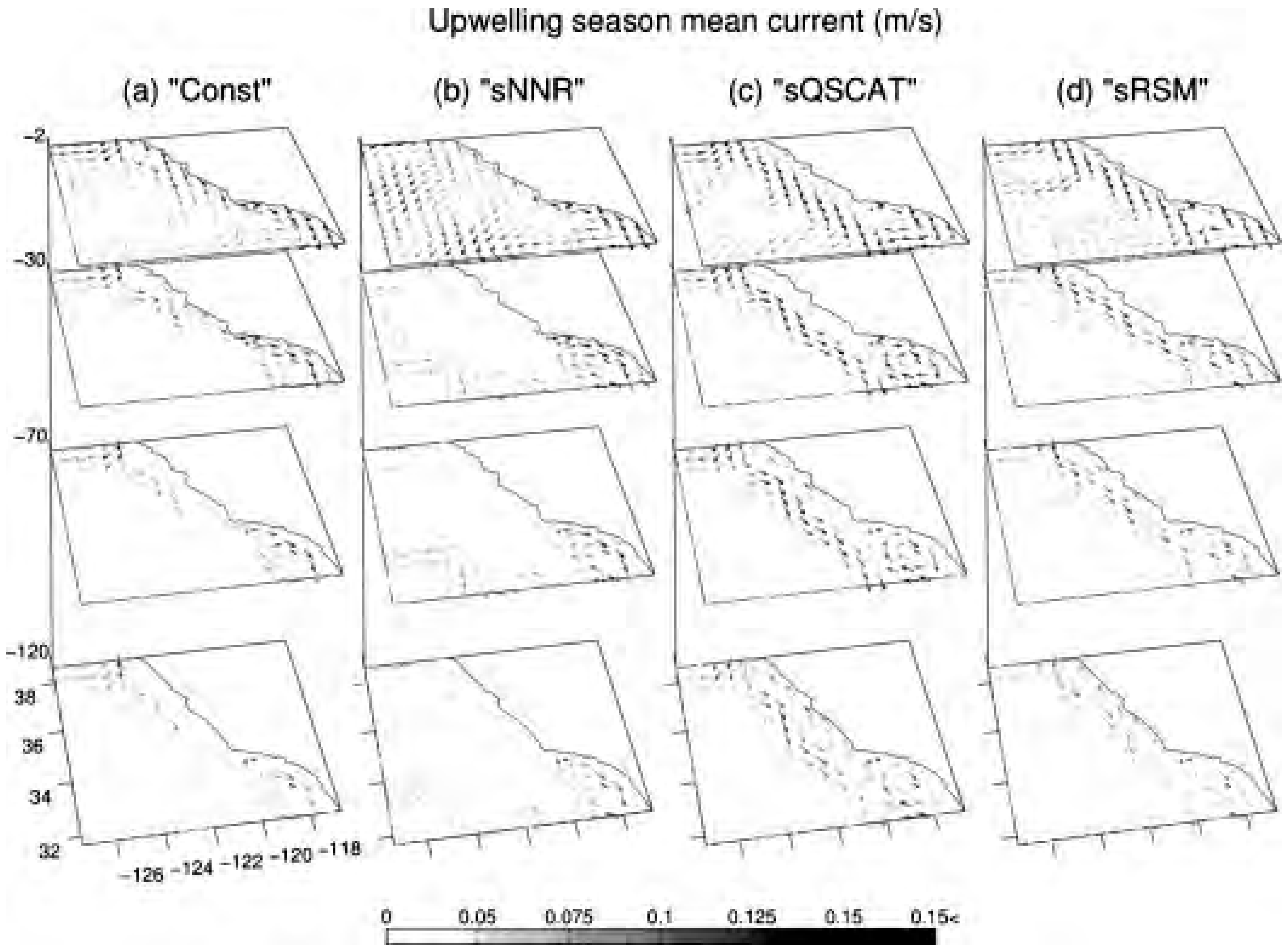
Nieto et al. (2014).

Biogeochemical properties of eddies in the California Current System



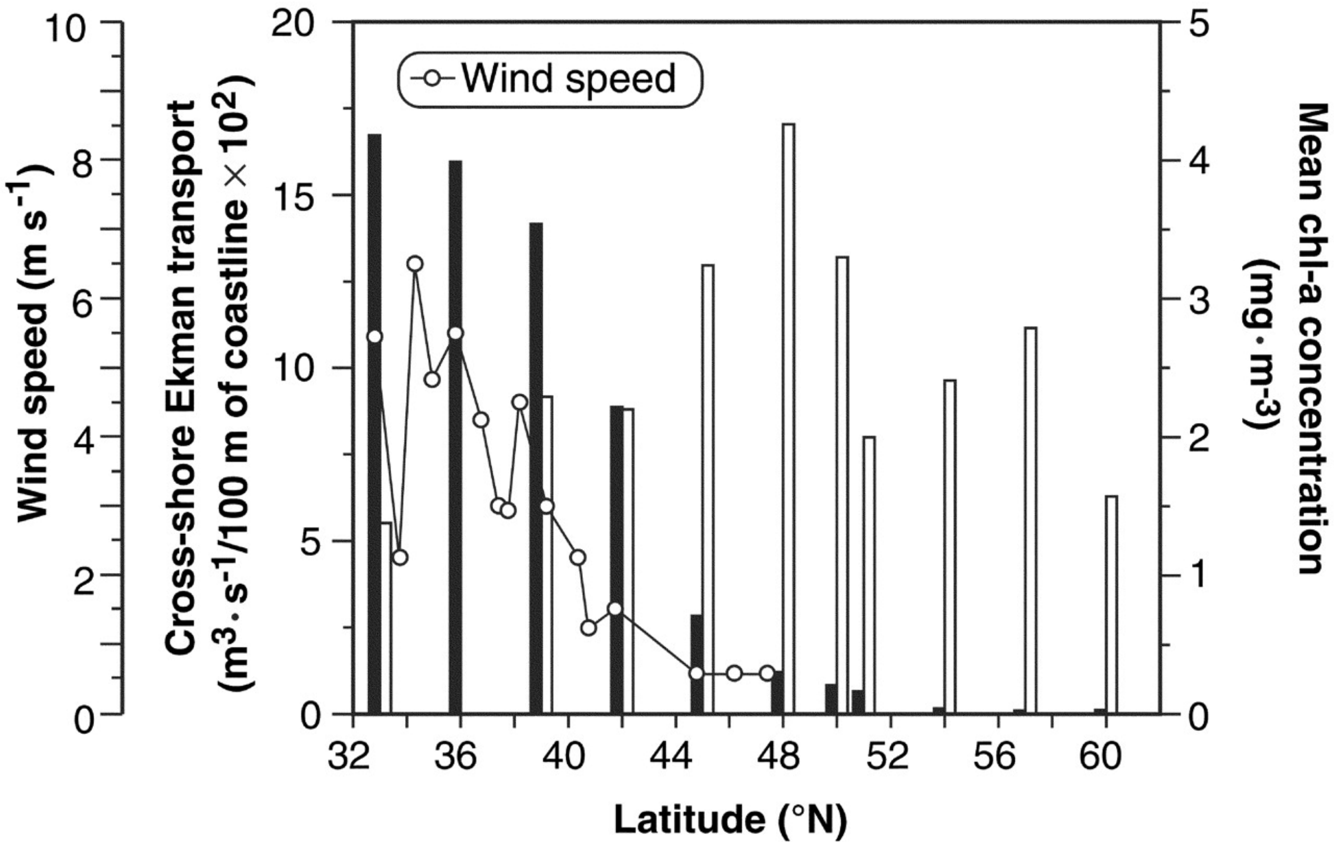
Chenillat, F., et al. (2016).

Changes in upwelling and its water sources in the California Current System driven by different wind forcing

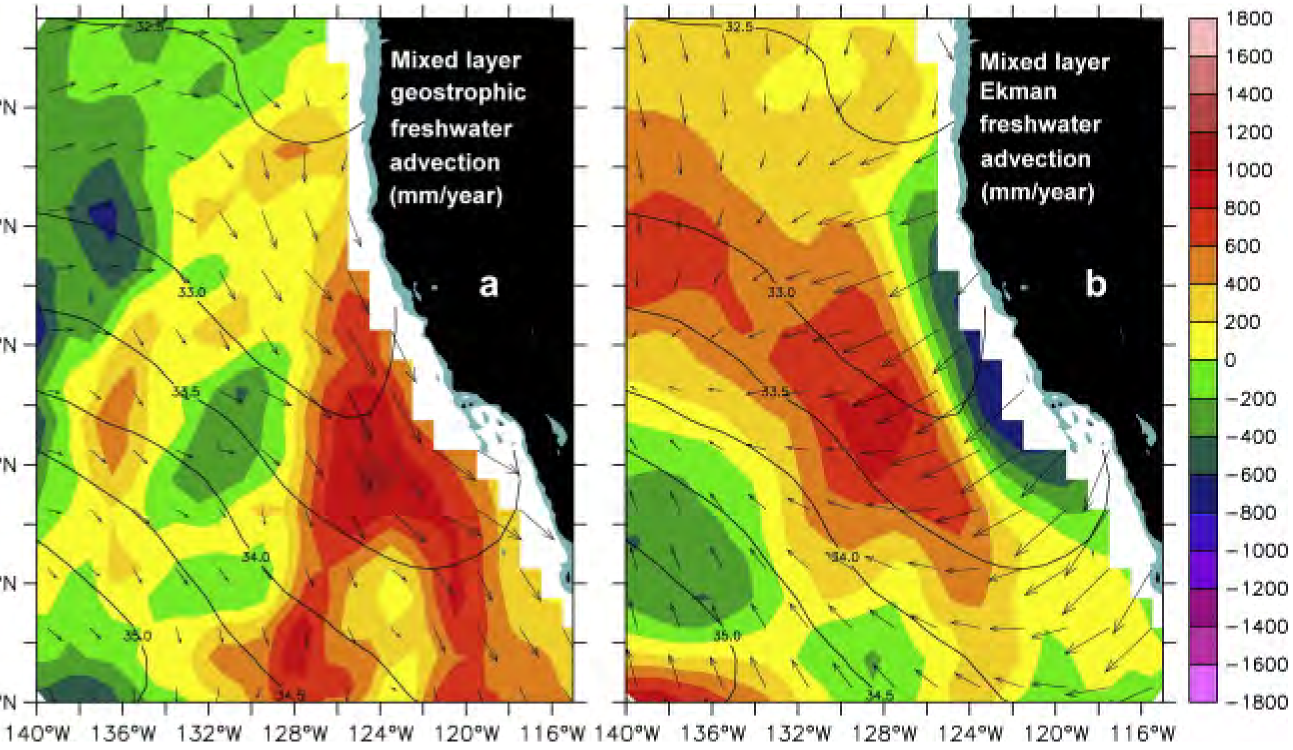


Song et al. (2011)

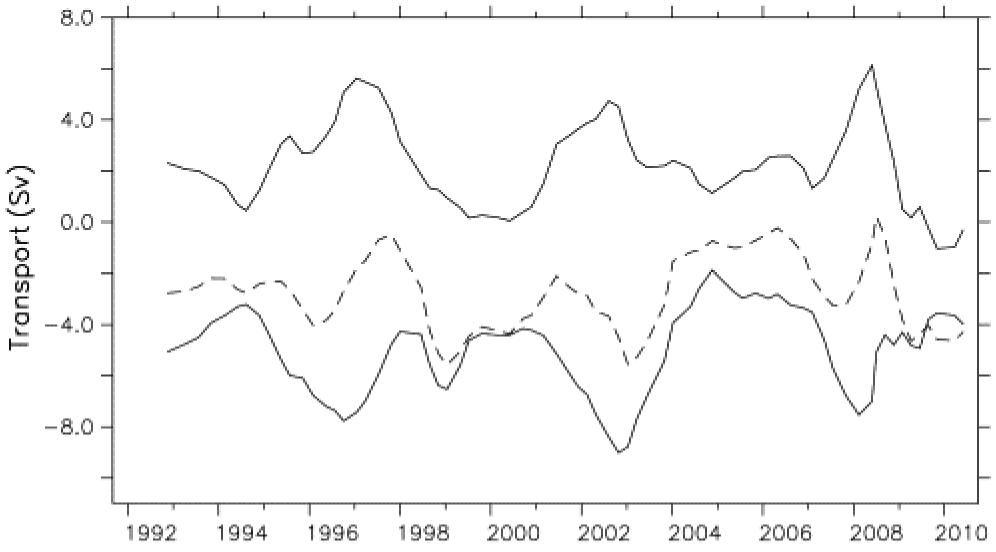
Latitudinal variation in the mean annual seaward component of accumulative Ekman transport given positive (upwelling) values only (black bars) and the mean annual chl-a concentration from SeaWiFS (white bars), averaged (1998-2003) over the scale of the Northeast Pacific regions



Ware and Thomson (2005).



Mixed layer geostrophic (a) and Ekman (b) freshwater advection in mm/year displayed as colors.

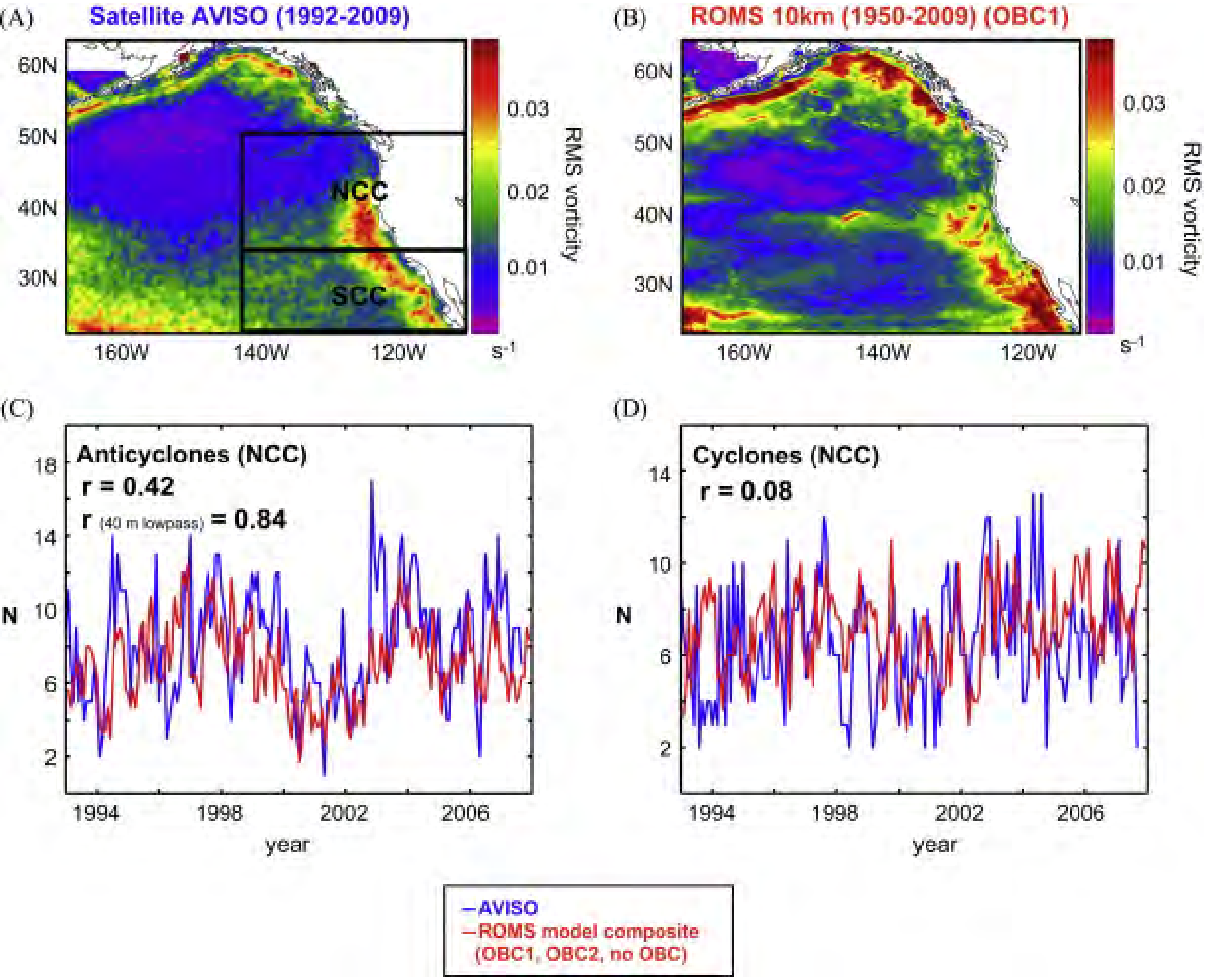


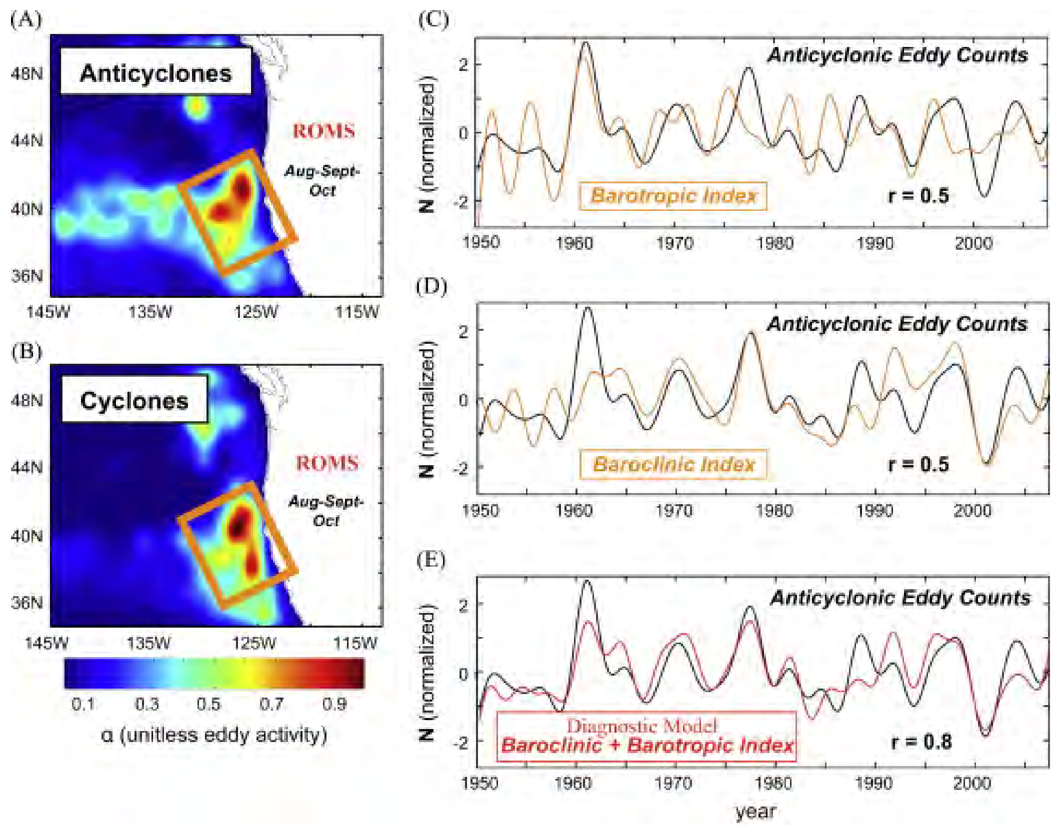
Transport time-series off San Francisco

- The upper solid line - northward California Undercurrent.
- The lower solid line - southward California Current.
- The dashed line is the sum of the two

Auad et al. (2011)

Interannual forcing mechanisms of California Current transports: Mesoscale eddies

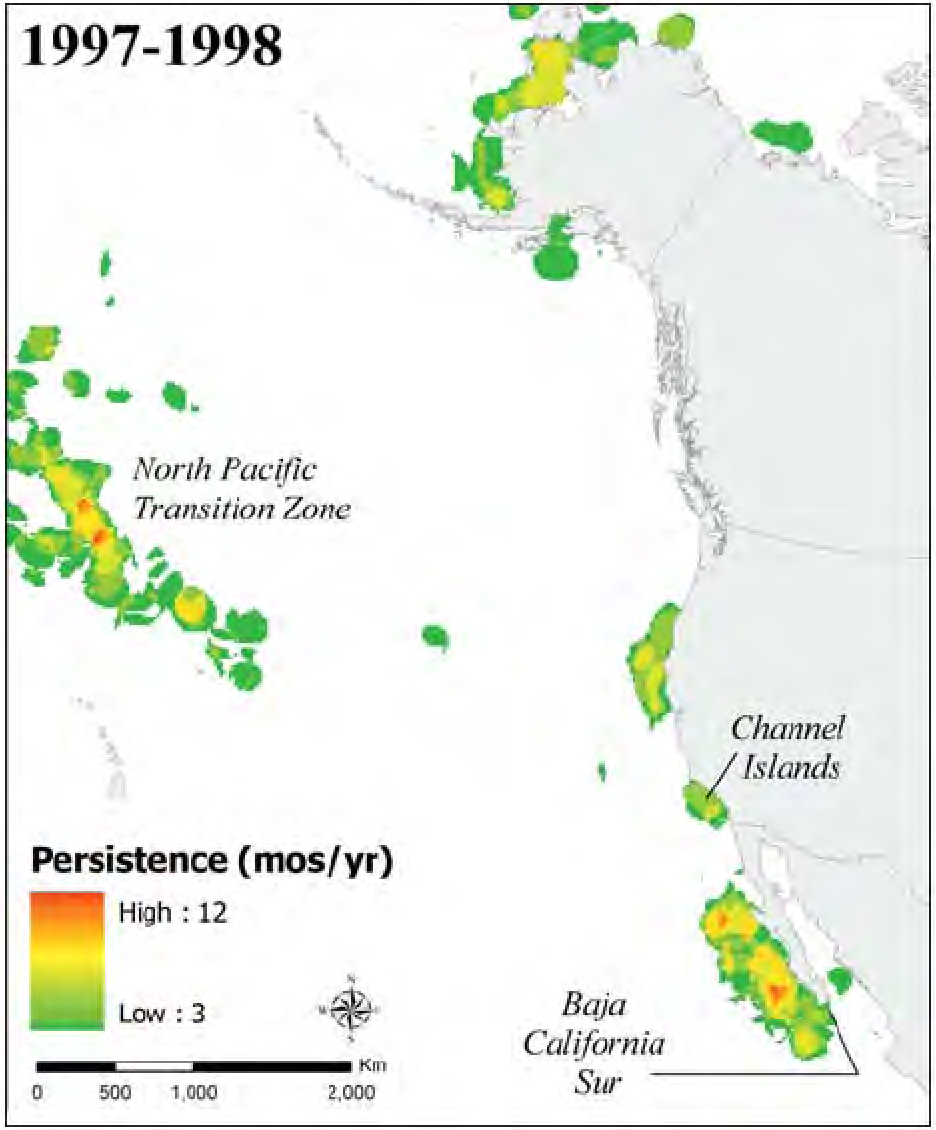


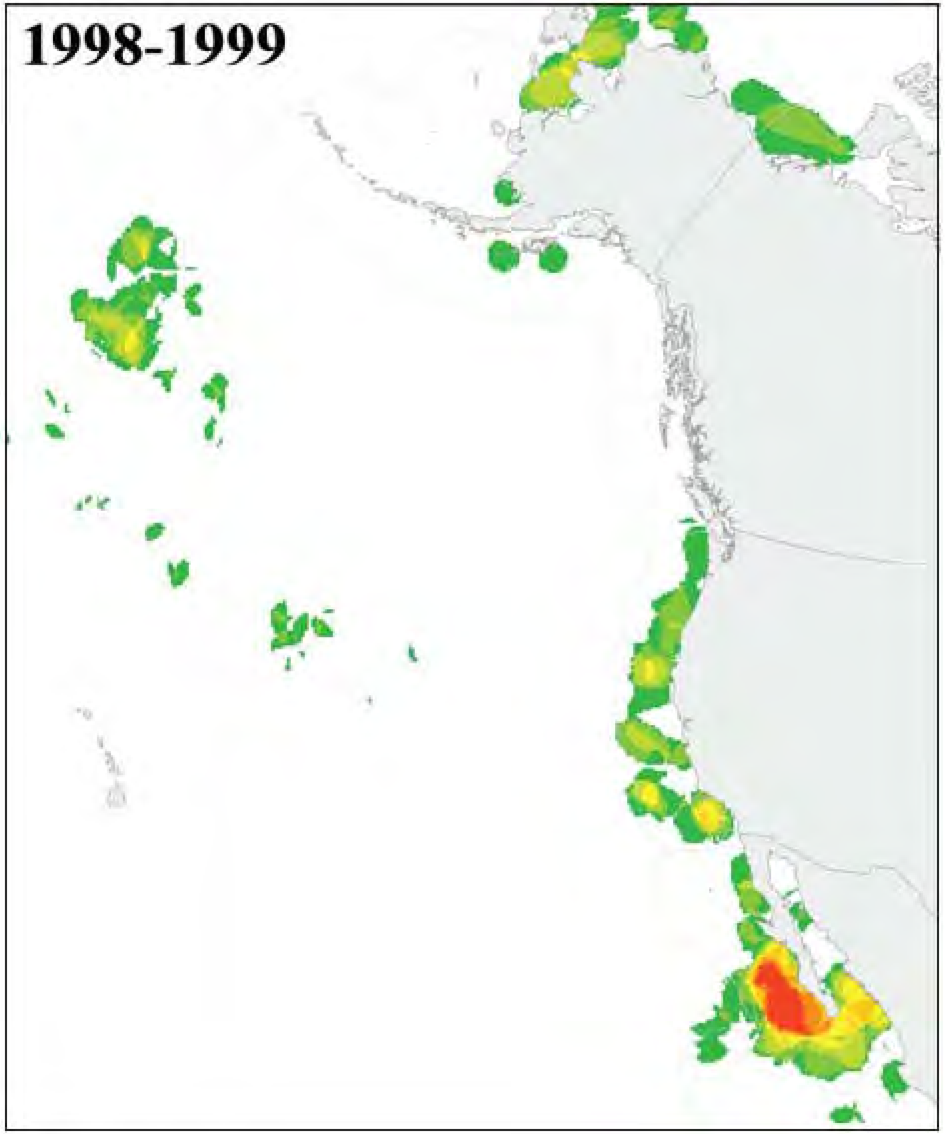


Davis and Di Lorenzo (2015)

Intra- and Interannual variability in California Current - Counter Current Front

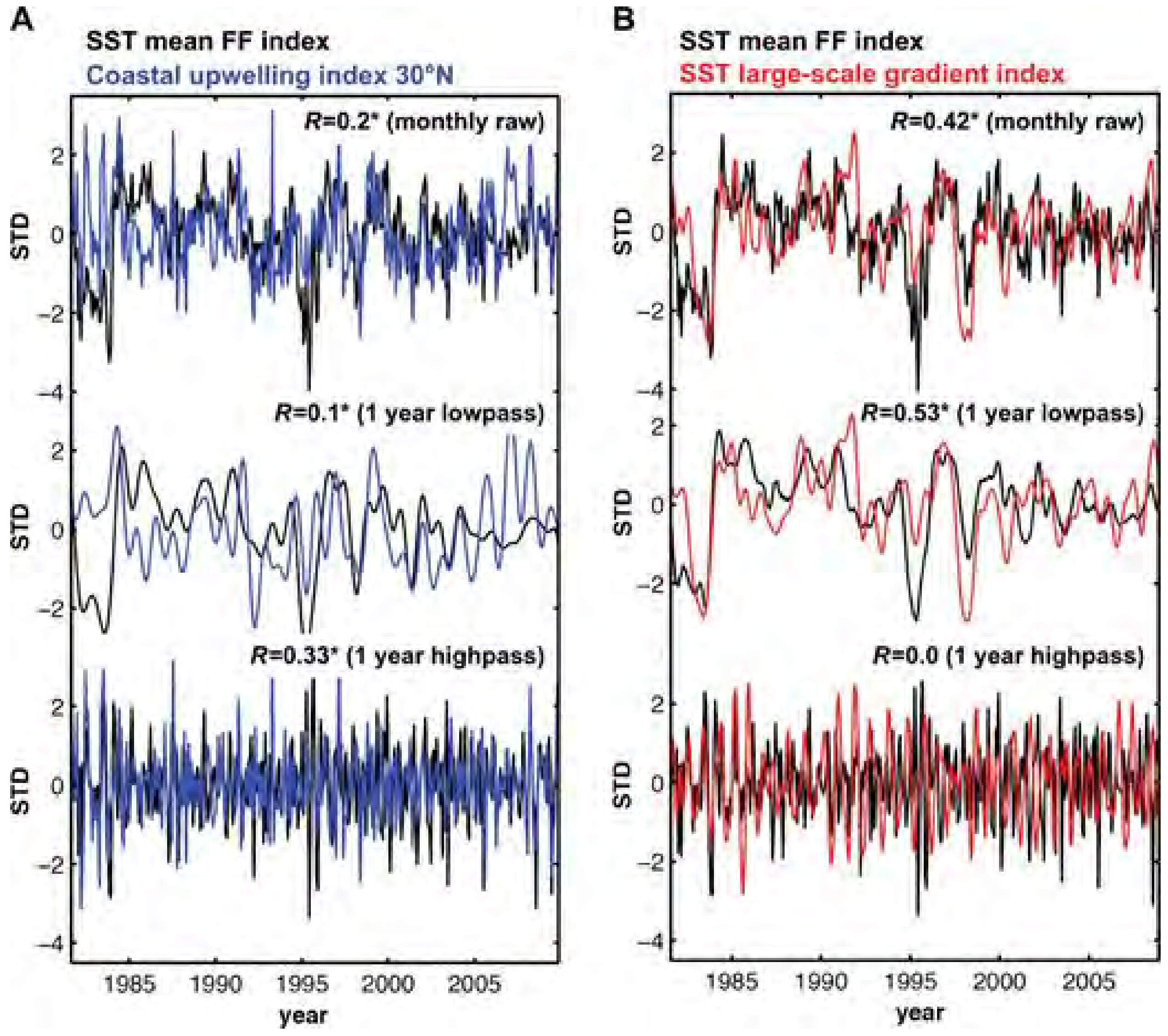
(Satellite image analysis)





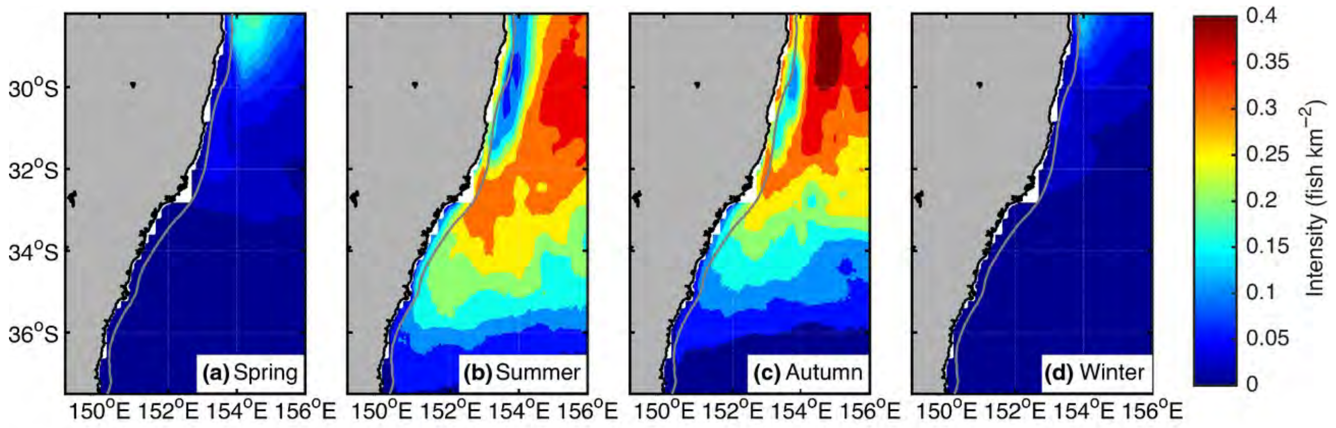
Etnoyer et al. (2004)

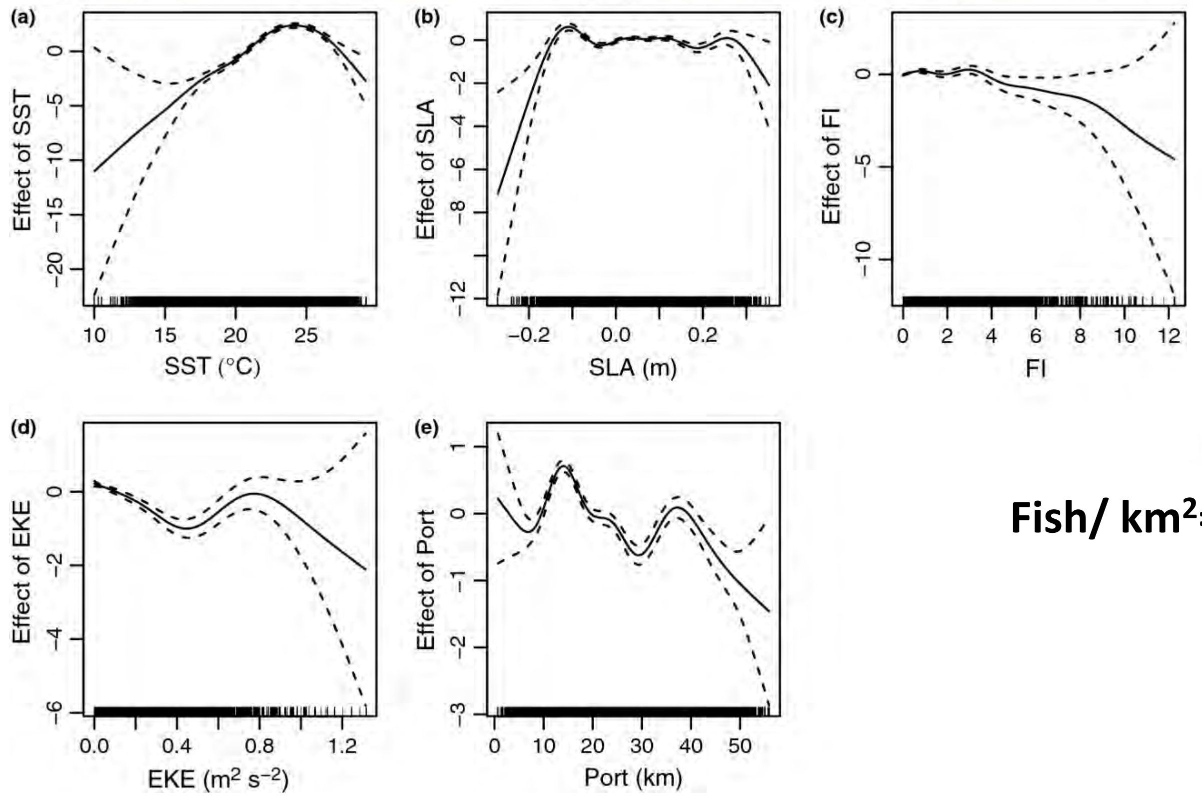
Sea surface temperature and chlorophyll fronts in the California Current



Kahru et al. (2012)

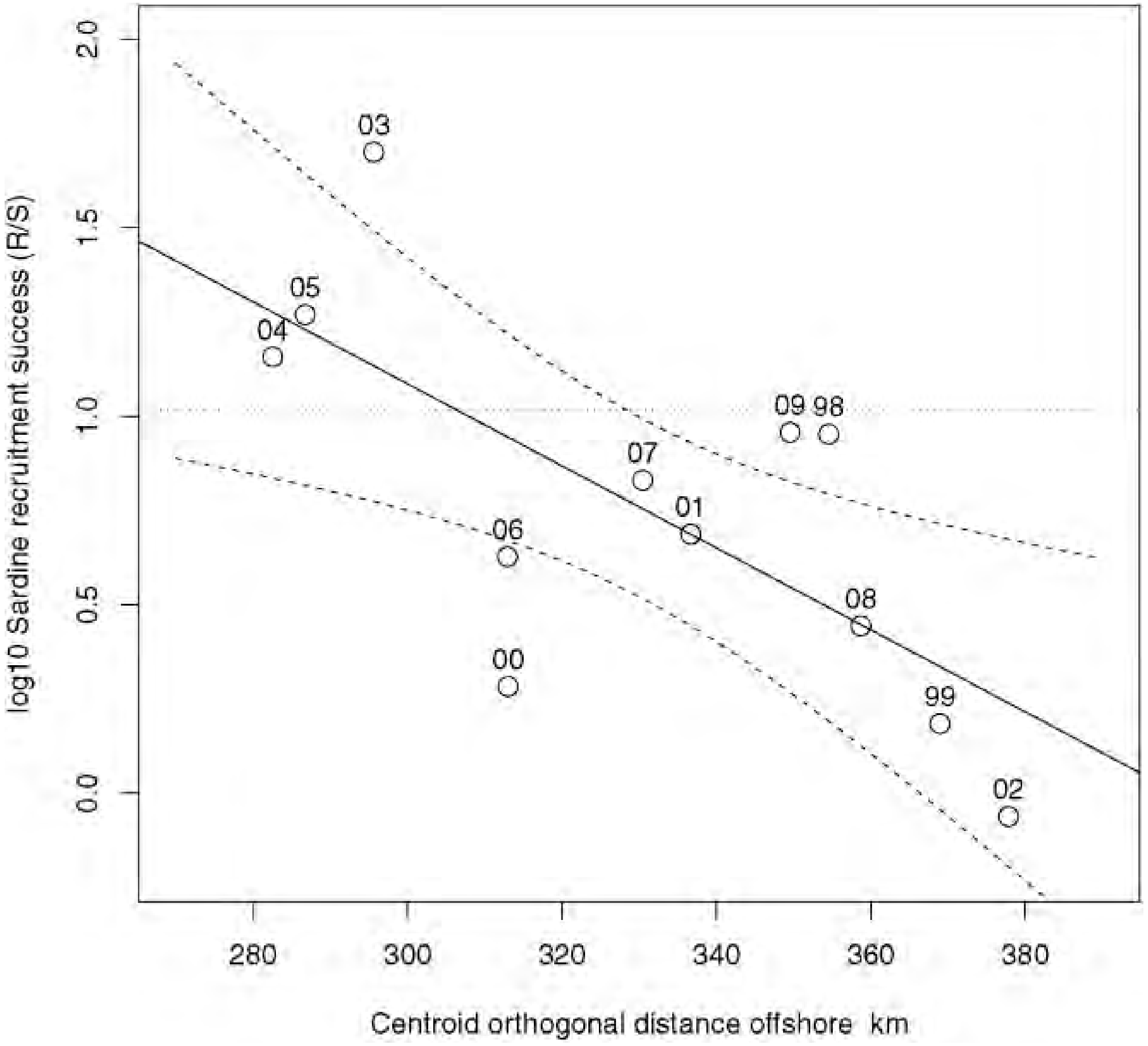
Modelling the oceanic habitats of pelagic species using fisheries data





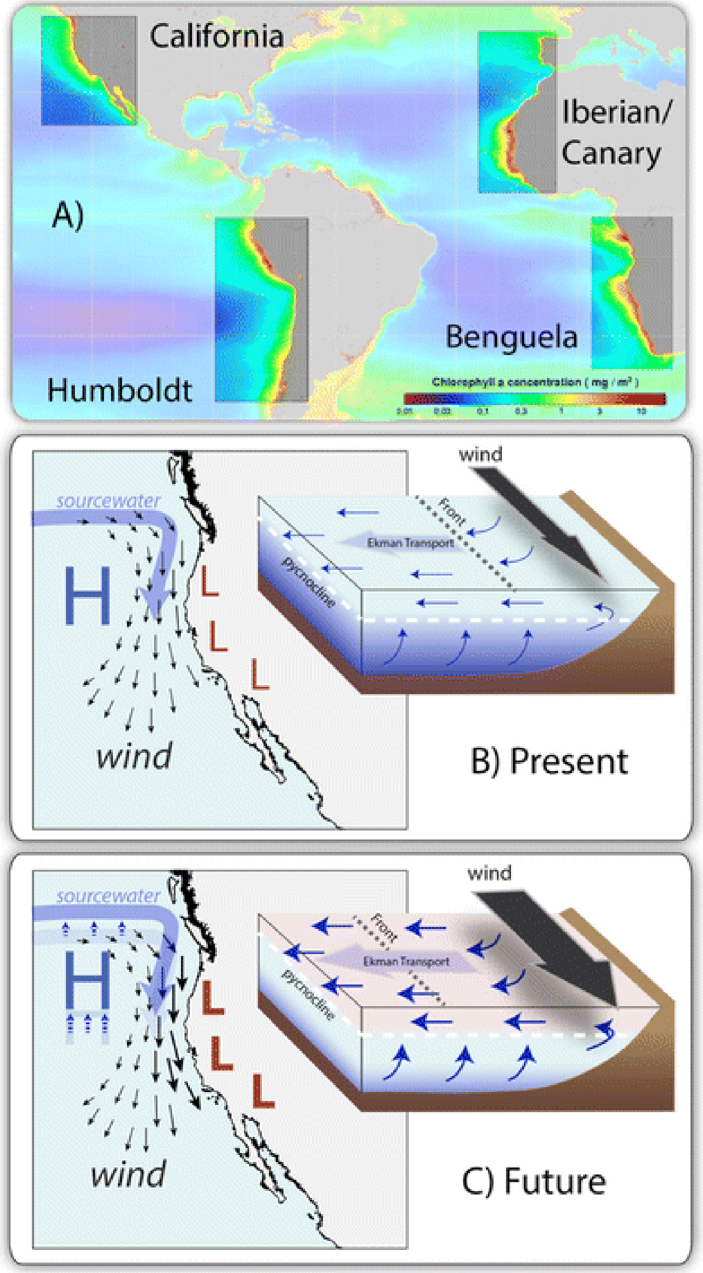
Fish/ km^2= s(SST) + s(SLA) + s(EKE) + s(FI) + s(Port) + Year random

Effect of mesoscale eddies and streamers on sardine spawning habitat and recruitment success off Southern and central California



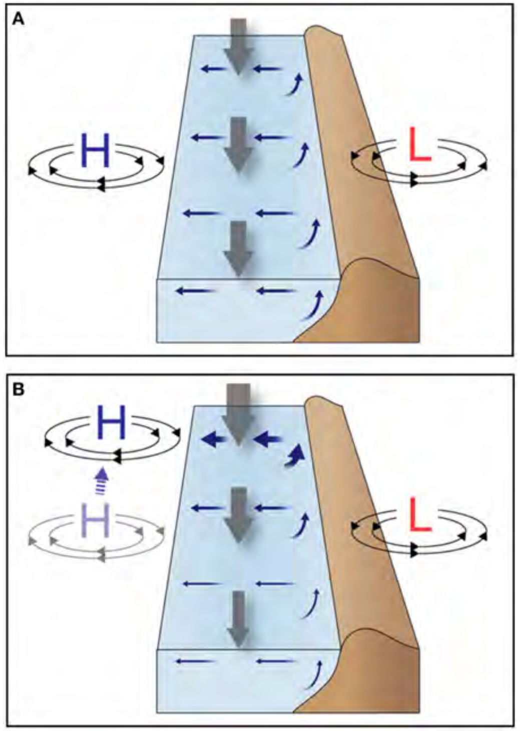
Nieto et al. (2014).

Anticipated Effects of Climate Change on Coastal Upwelling Ecosystems.



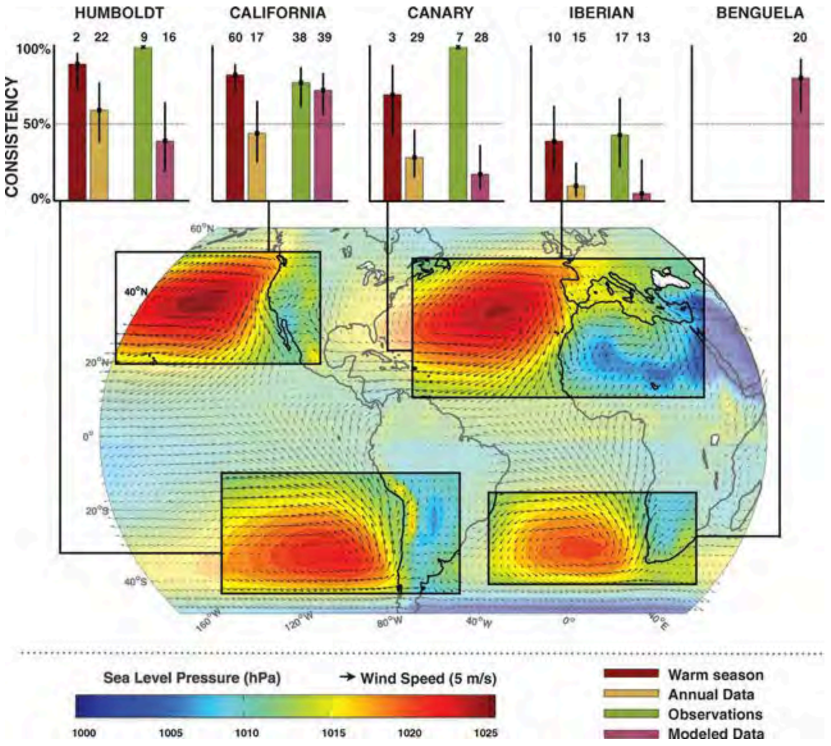
Bakun et al. (2015)

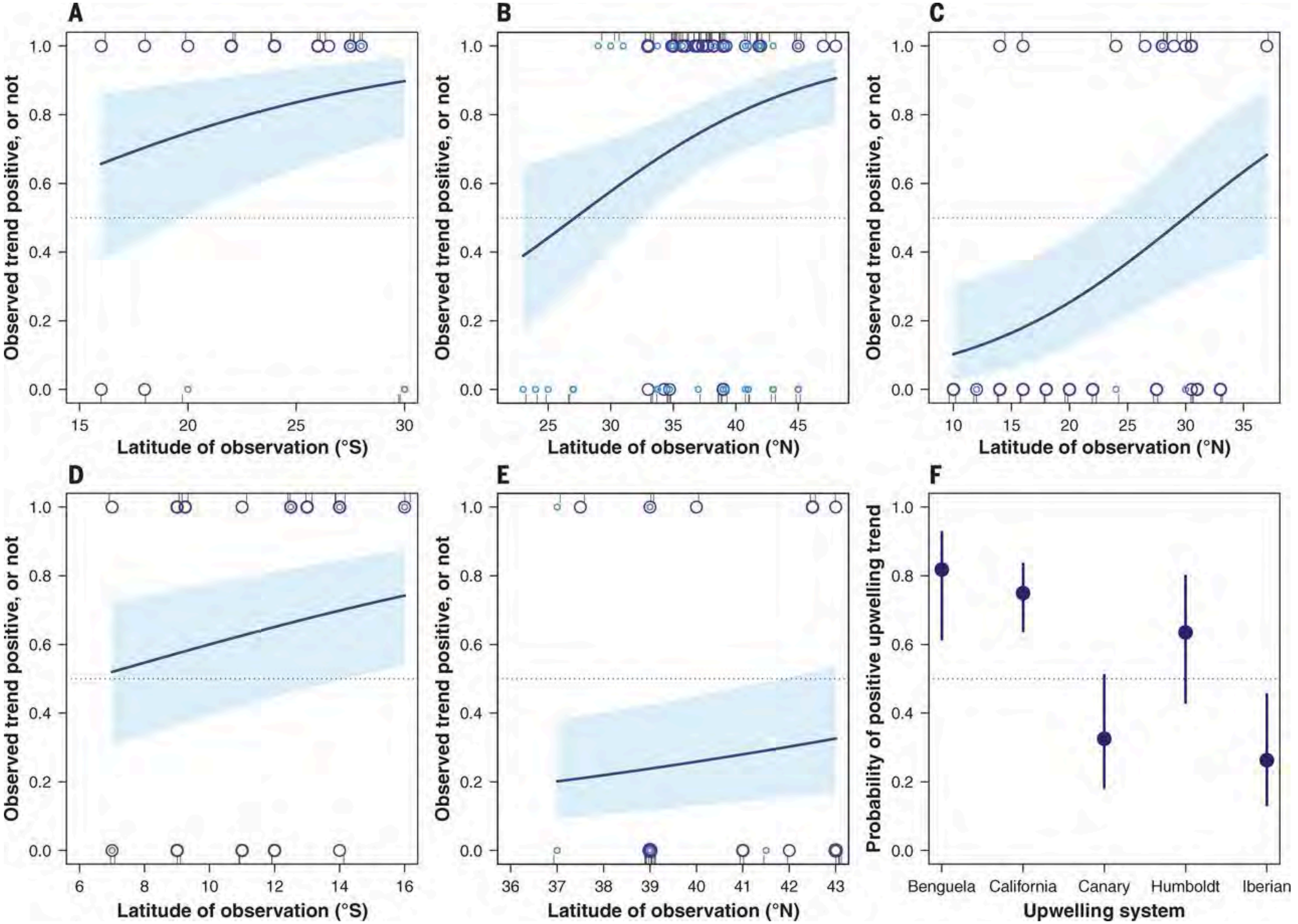
Anticipated changes include the poleward migration of the Oceanic High and source waters. Continental thermal lows are anticipated to deepen, which will intensify upwelling-favorable (equatorward) winds. Changes in the water column include greater stratification, greater rates of upwelling, and greater offshore transport as well as the offshore migration of the upwelling front.



García-Reyes et al. (2015)

Climate change and wind intensification in coastal upwelling ecosystems





Sydeman et al. (2014).

- **Defining the oceanic habitats of marine species is important for both single species and ecosystem- based fisheries management, particularly when the distribution of these habitats vary on several spatial-temporal scales.**

- **Besides climate change associated with anthropogenic activity, there is growing evidence of a natural global multi-decadal climate signal in the ocean–atmosphere–biosphere climate system.**

- **Different hypothesis suggests that fronts engender significant pattern in the habitats of marine pelagic species.**

- **Fronts may offer opportunities for foraging and breeding aggregations**

- **The spatio-temporal evolution of mesoscale fronts is thus analyzed during a 30-year period (1985-2015) along the southern part of the California Current and compared to the variability of small-pelagic fish data.**

- SST fronts were derived from edge detection algorithms, essentially slope functions that identify the highest rate of change in temperature across a surface, and discern this boundary between adjacent water masses.

- This method was applied to monthly satellite-derived data from AVHRR Pathfinder v5

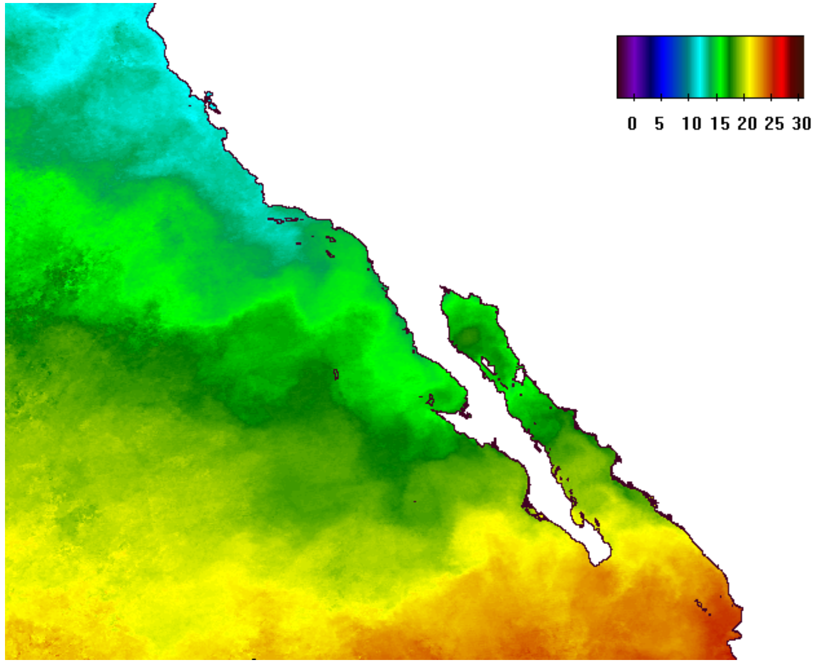
- As a proxy, we build time-series of frequency of SST fronts for different strata sizes along the California-Baja California coast (1985 – 2015)

FRONT DETECTION

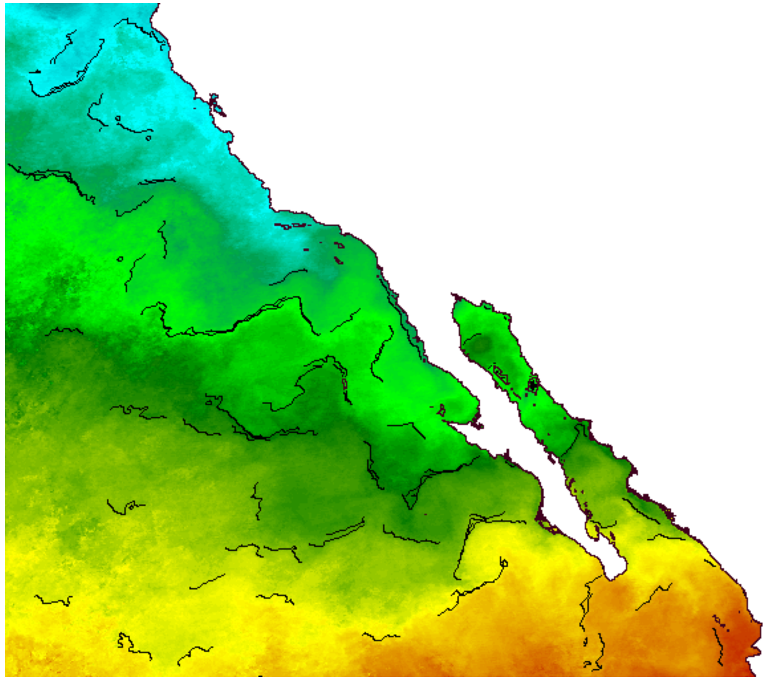
Single-image Edge Detection (SIED) algorithm

(Cayula and Cornillon, 2002)

Monthly SST images (AVHRR v5.0)

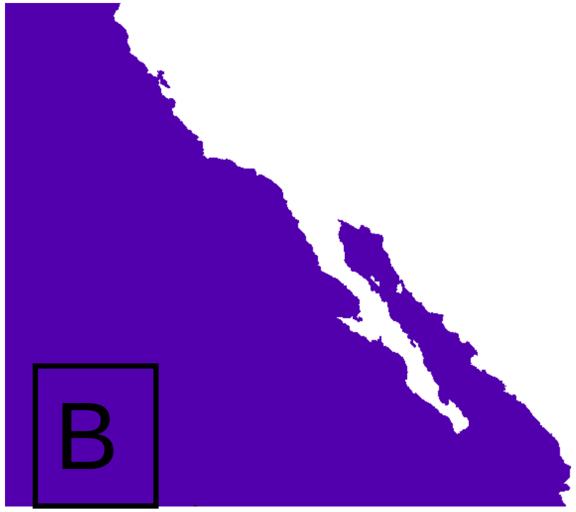


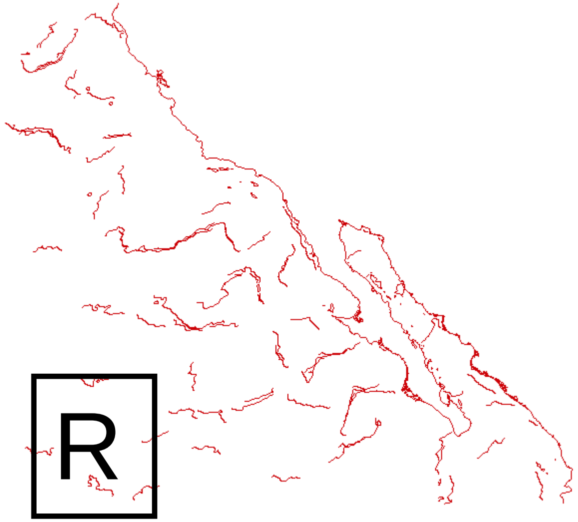
SST image of January 2006



Fronts detected by the SIED algorithm

FRONT FREQUENCY INDEX





Valid SST count image
(Blue = valid pixel values)

R/B =

Front frequency index
(ranging from 0-1)
It's the ratio of the edge count to the valid SST count showing the frequency of that a front was detected for a pixel

Edge count image
(Red spaghettis = front pixel values)

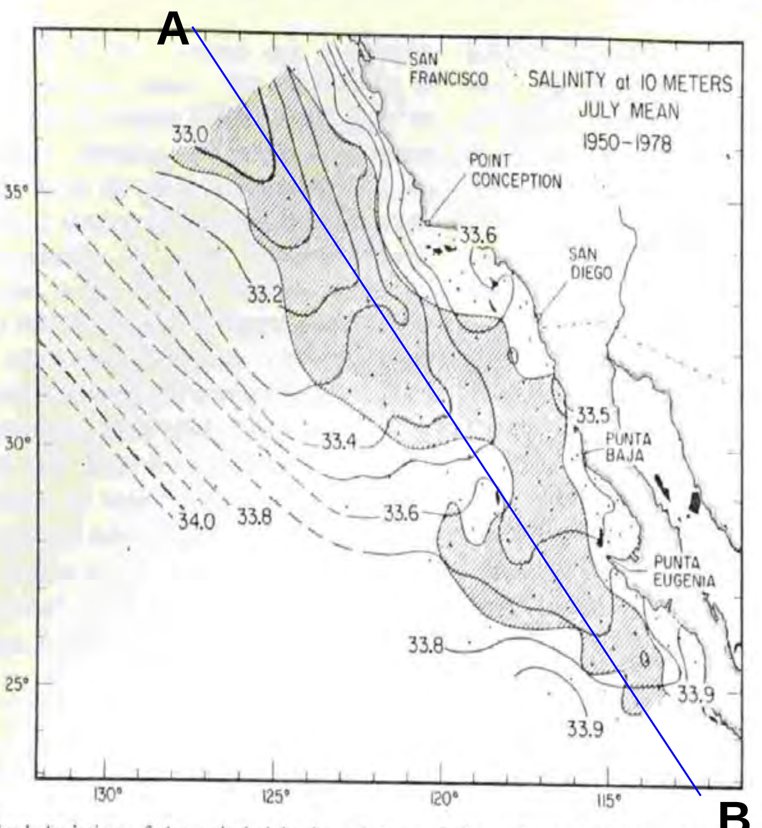
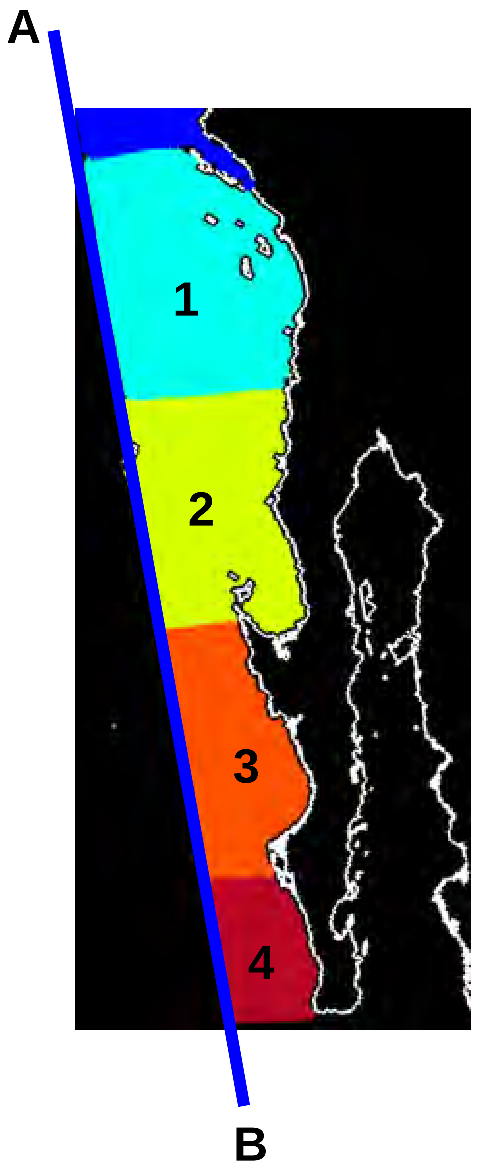
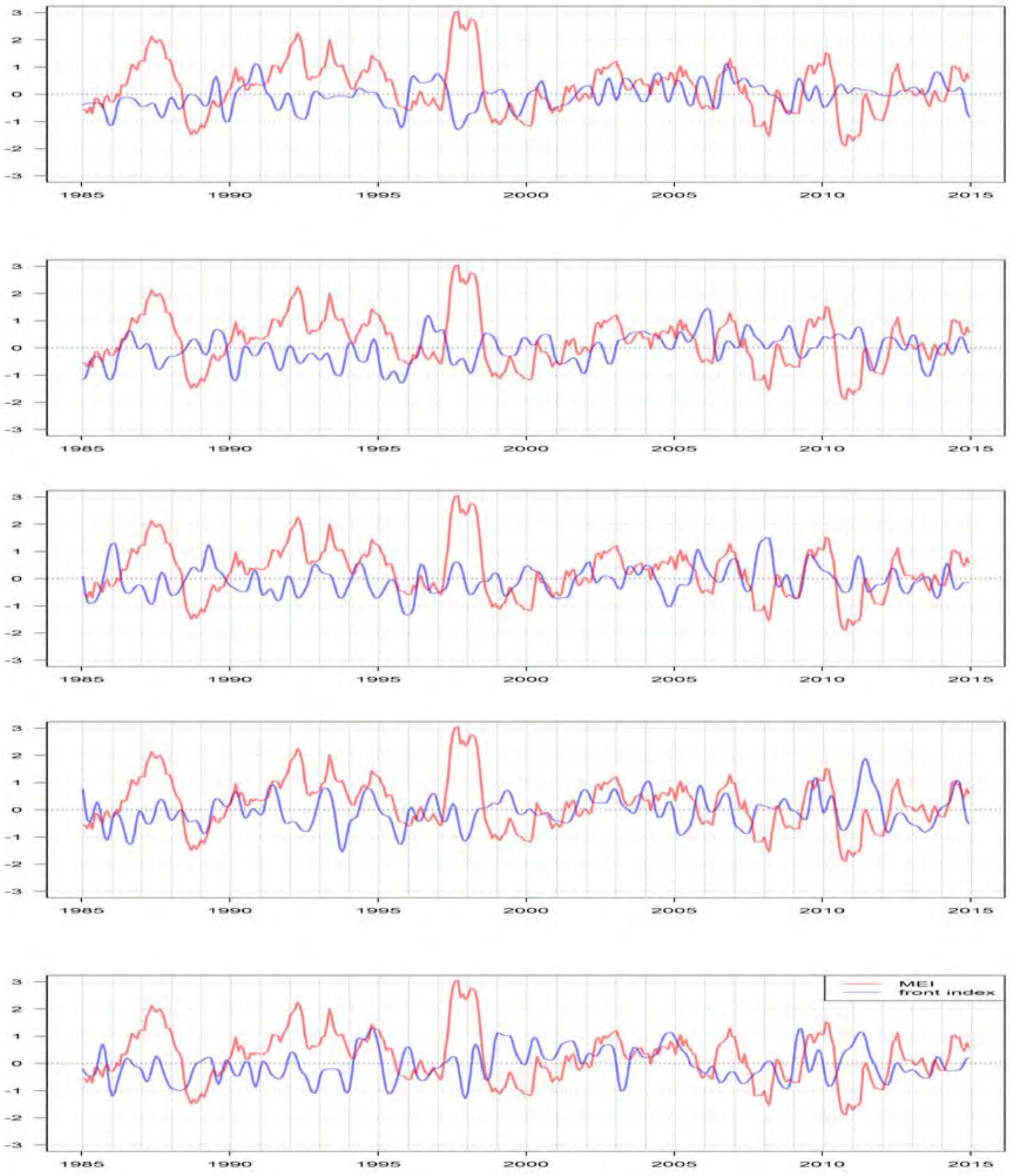
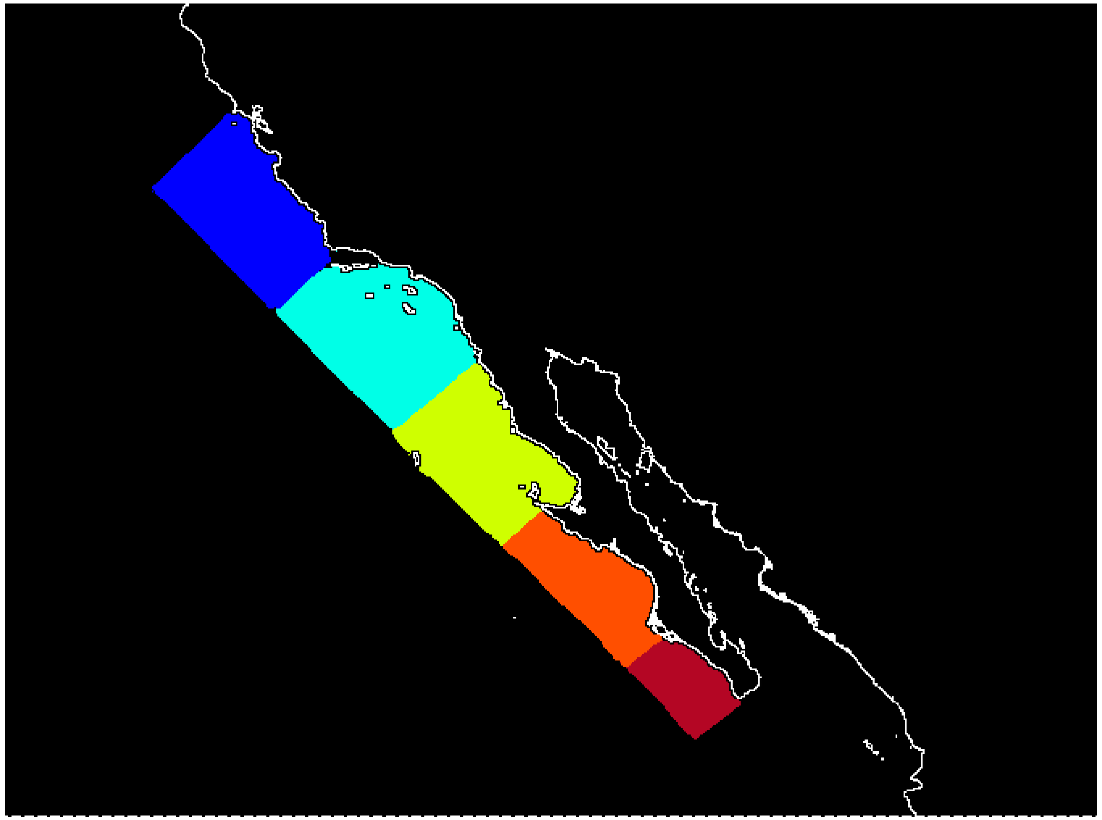


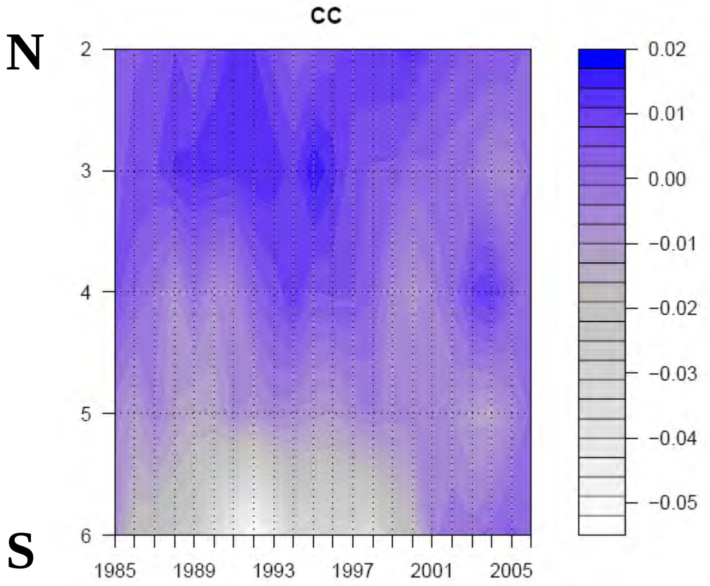
Fig. 15. Standard deviation of dynamic height (> ± 4 dyn cm) from Figure 4*d* (shown hatched) plotted over on the long-term mean 10-m salinity for July [from *Lynn et al.*, 1982].

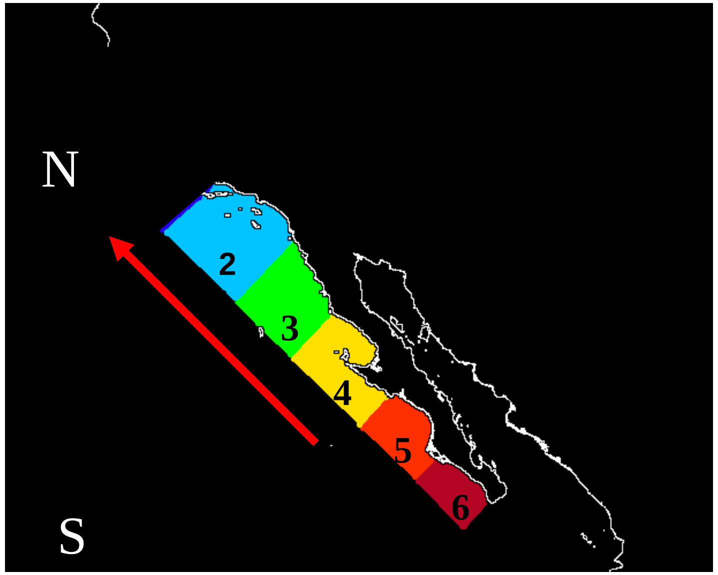



MEI
front index

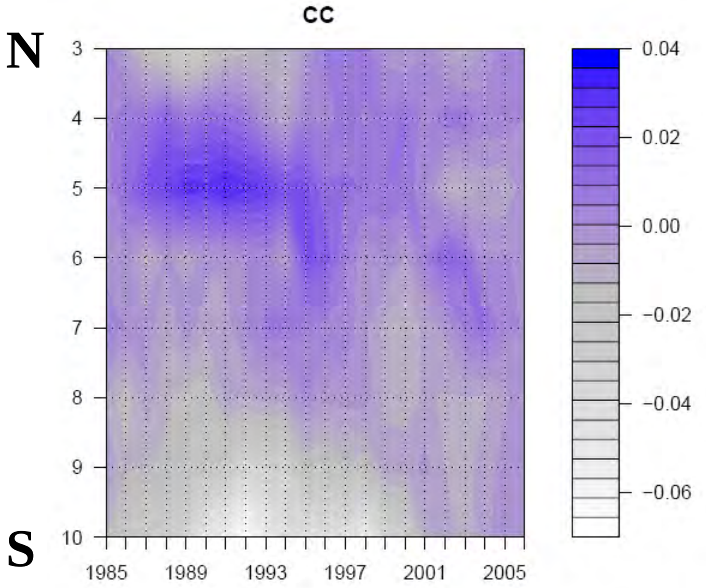


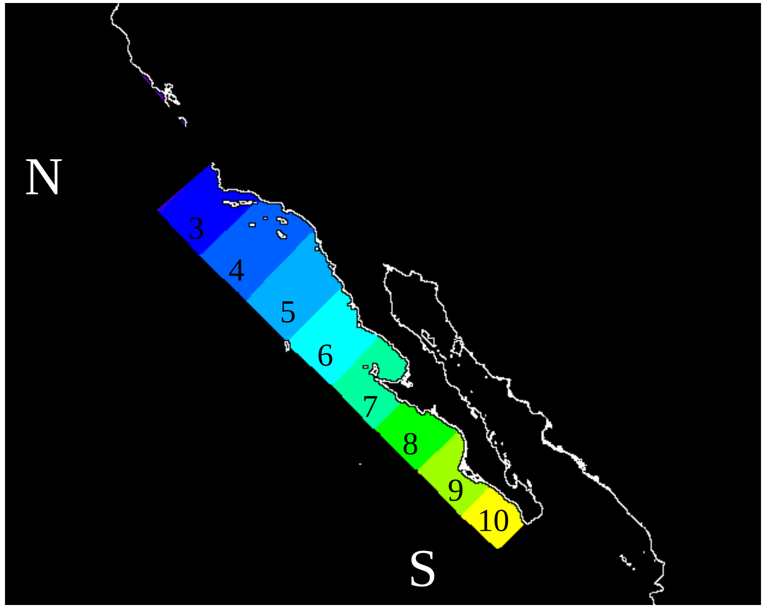
Geographical variability of Front Index anomalies (large strata)



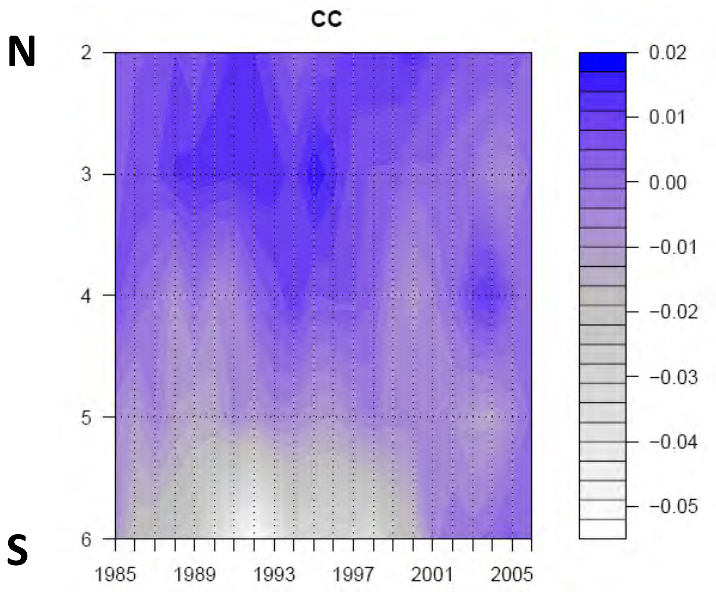


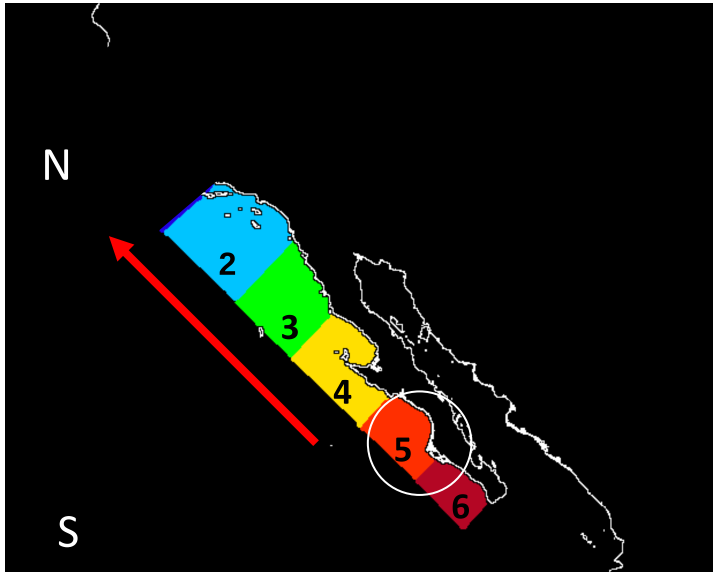
Geographical variability of Front Index anomalies (smaller strata)

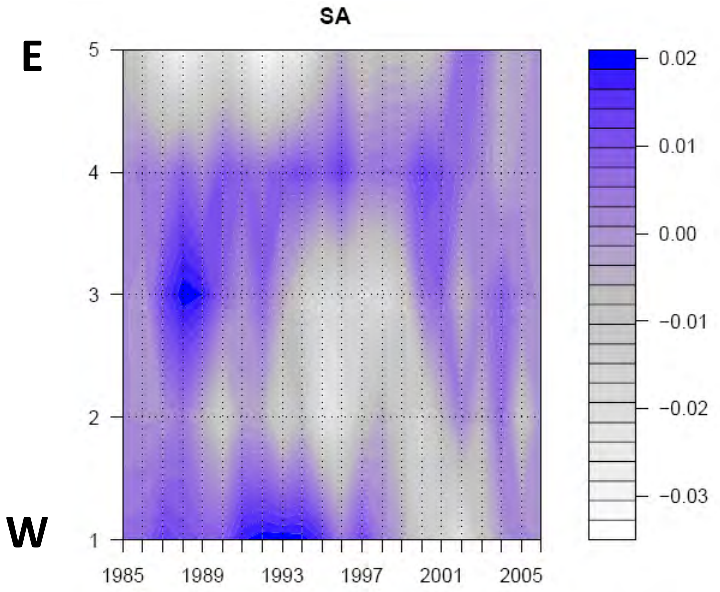


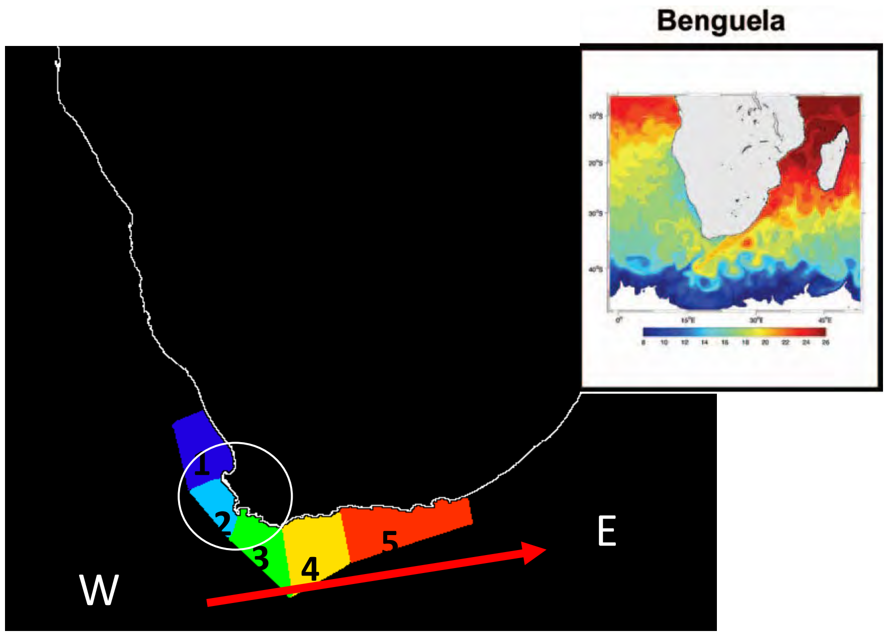


Geographical variability of Front Index anomalies

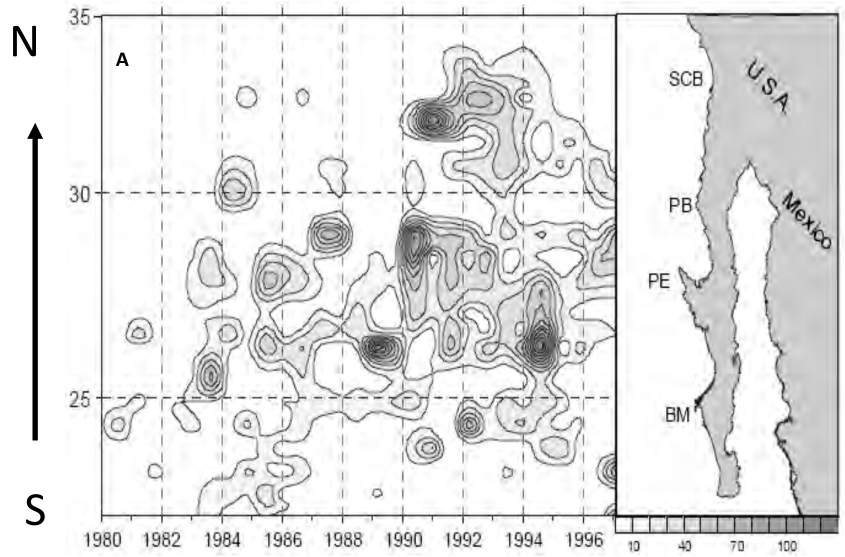


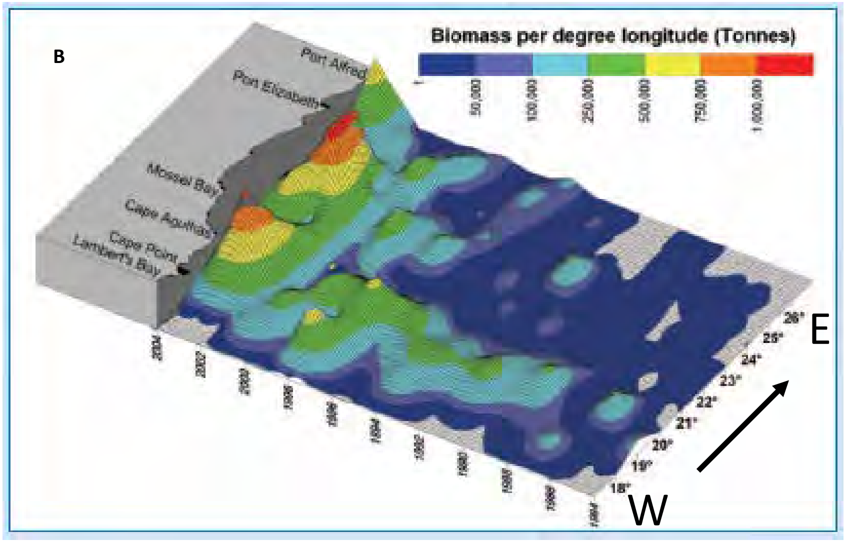






Evaluate the influence of oceanographic fronts on interannual changes in the distribution and relative abundance of sardine in the California and Southern Benguela Current system



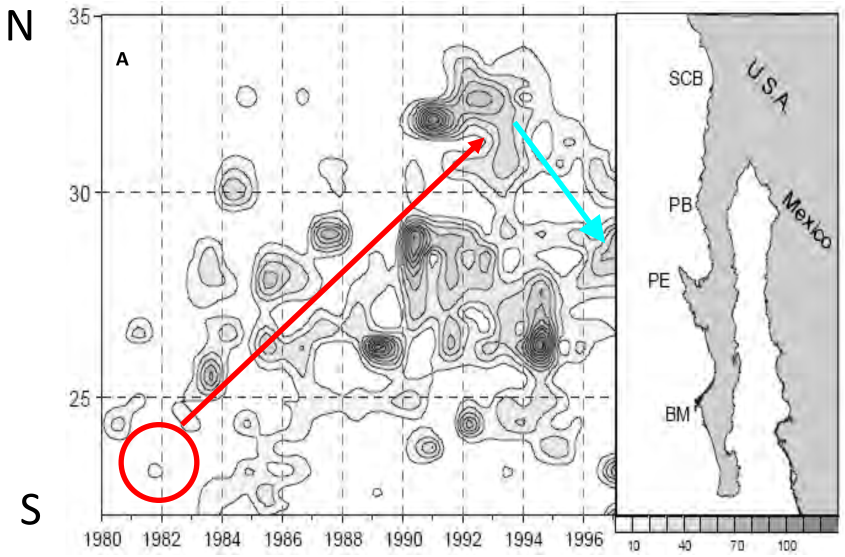


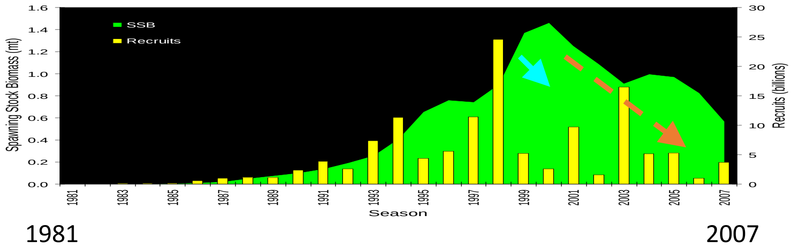
A) California Current system
Northward shift (1984-1997)

B) Southern Benguela system
Eastward shift (1984-2004)

SSB and Recruitment

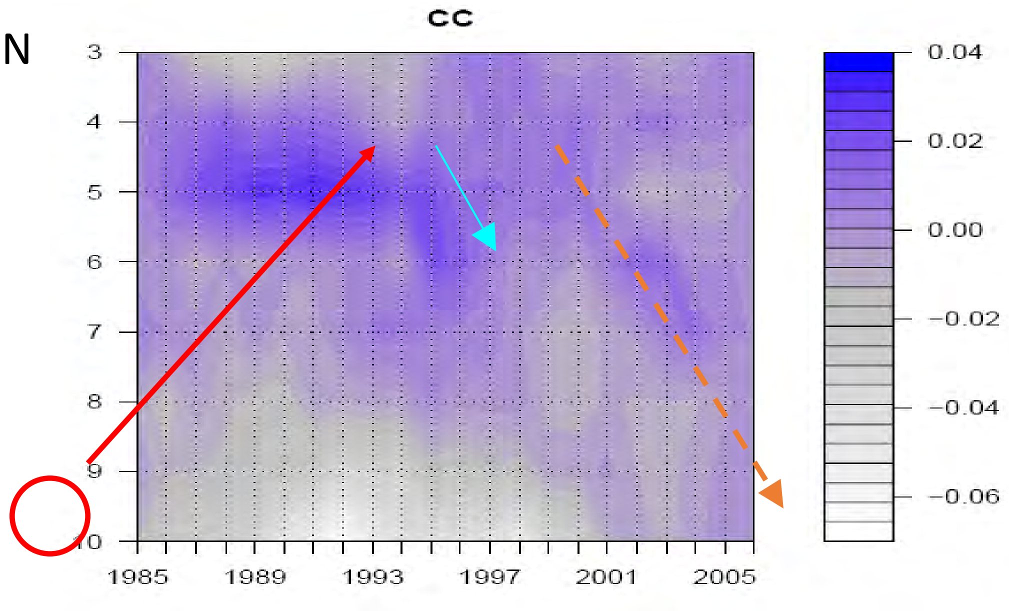
From Hill et al. 2007

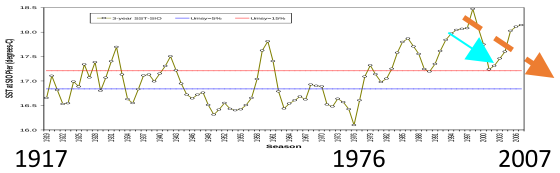




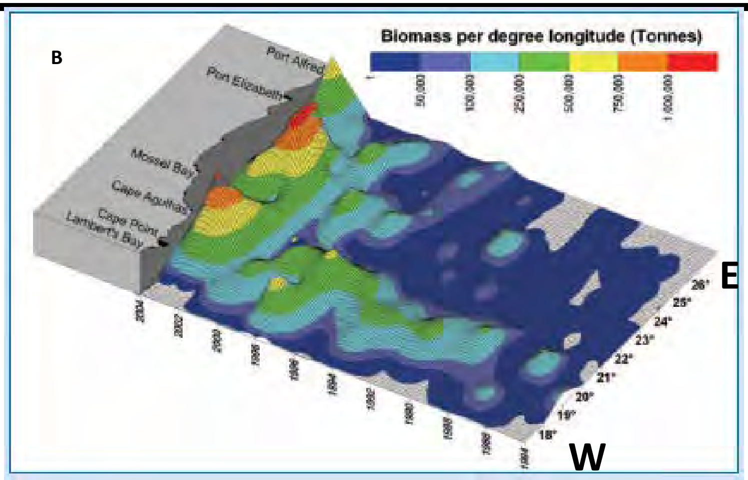
SST at SIO Pier

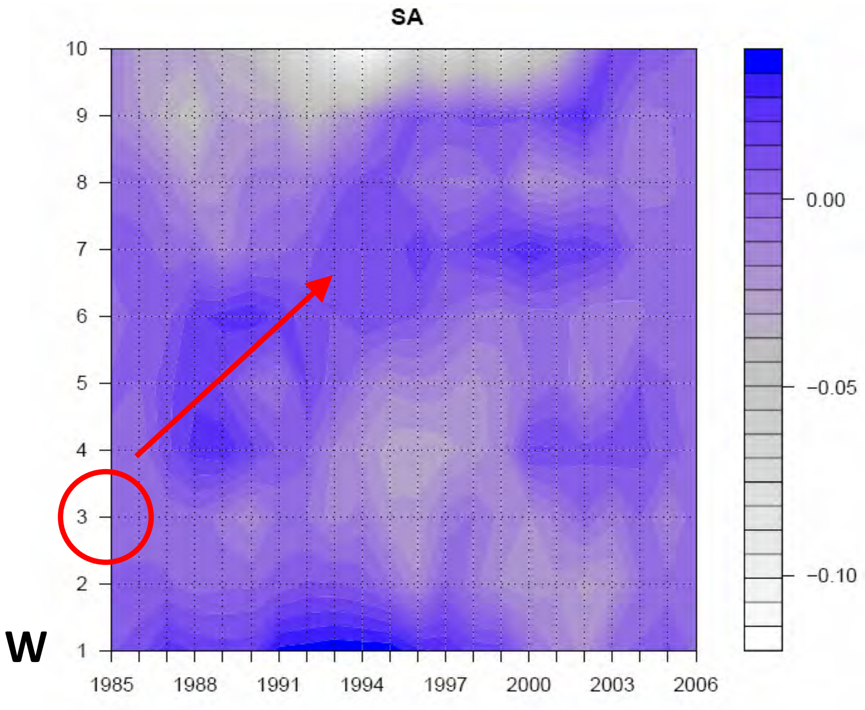
From Hill et al. 2007





SARDINE BIOMASS





SARDINE EGGS