Tracking the spatial dynamic of sardine abundance changes in the California Current large marine ecosystem: An approach to elucidate local and broad scale environmental drivers and their interactions

Rubén Rodríguez-Sánchez

Héctor Villalobos

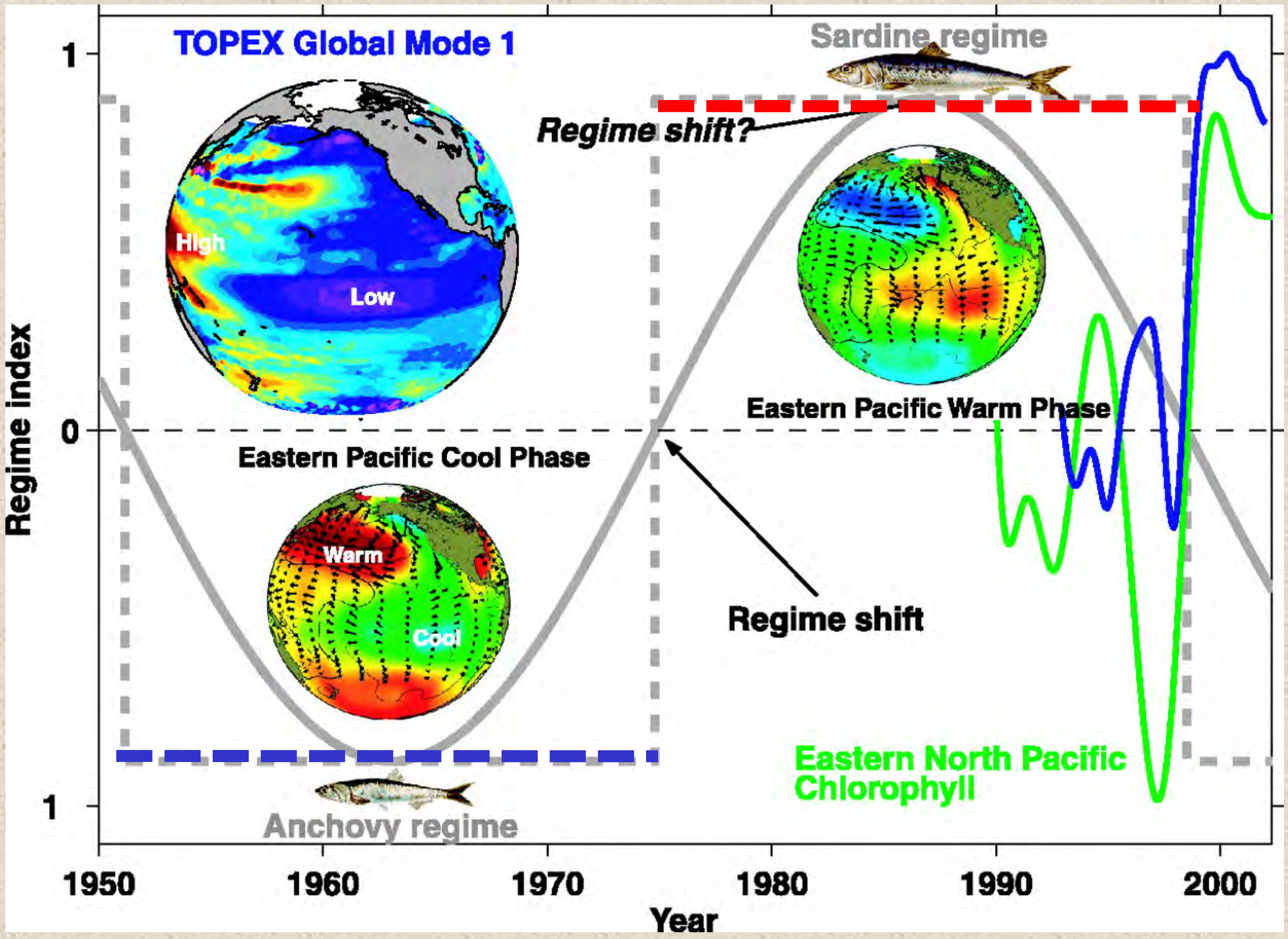
CICIMAR

Apdo. Post. 592, La Paz, B.C.S., México, 23000

rrodrig@ipn.mx

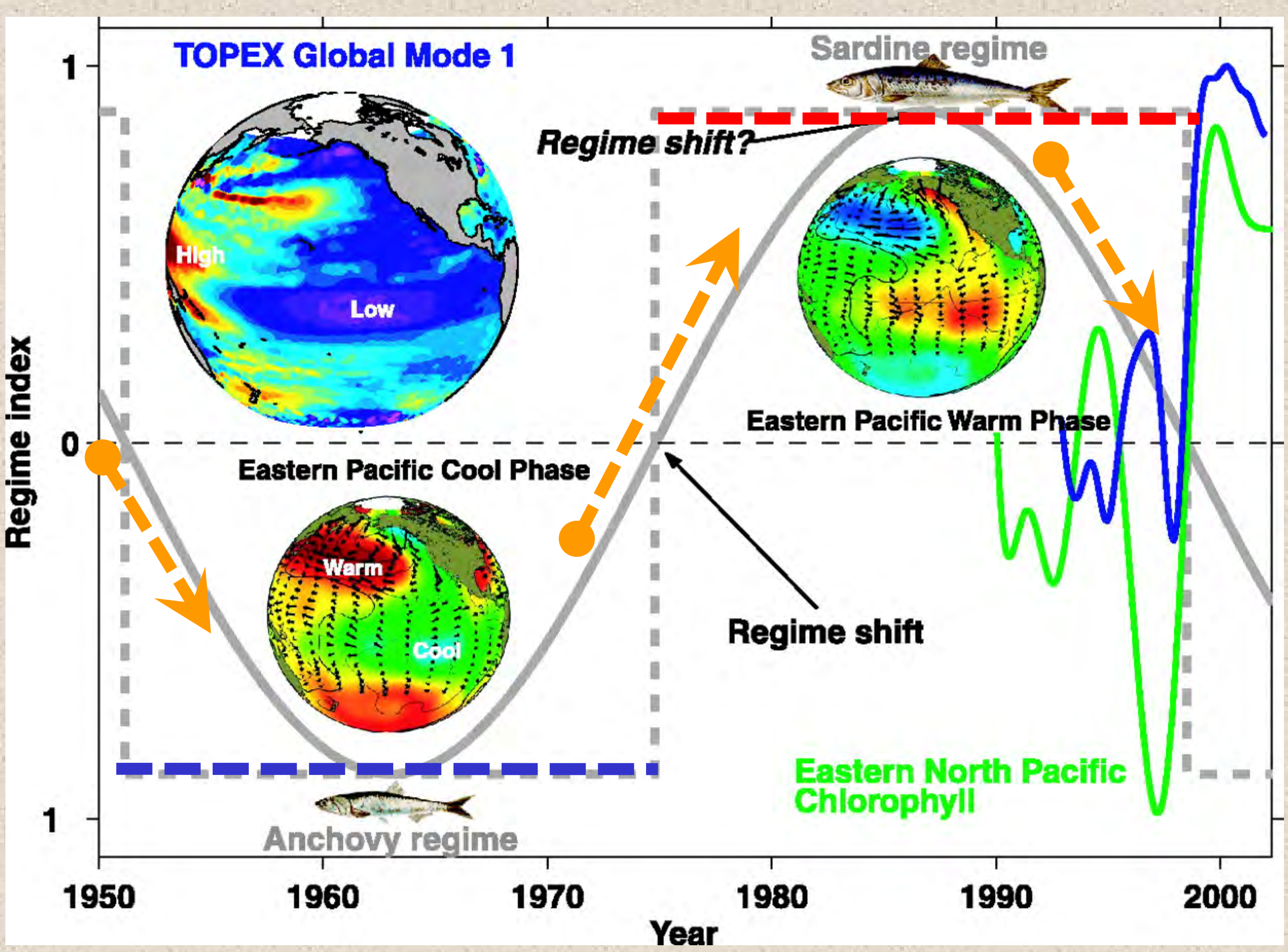
The prevailing paradigm: Hypothetical oscillation of a regime index with a period of 50 years.

Francisco P. Chavez et al. Science 2003;299:217-221



Such hypothesis usually involve the assumption that environmental drivers affect biomass levels in the same way either geographically distant areas within the same time-scale.

Warm-Cold periods vs. Warming-Cooling periods



Such hypothesis usually involve the assumption that environmental drivers affect biomass levels in the same way either geographically distant areas within the same time-scale.

Paradigm: Two low frequency stages (average/stable conditions ??)

15 *Sardine regimes and mesoscale structure (an integrative hypothesis)*
[Alec MacCall]

An Hypothesis Explaining Biological Regimes in Sardine-producing Pacific Boundary Current Systems (South America, North America and Japan): Implications of Alternating Modes of Slow, Meandering Flow and Fast Linear Flow in the Offshore Region

15.3 Physical and biological oceanography

The offshore boundary current tends to exhibit two alternative modes:

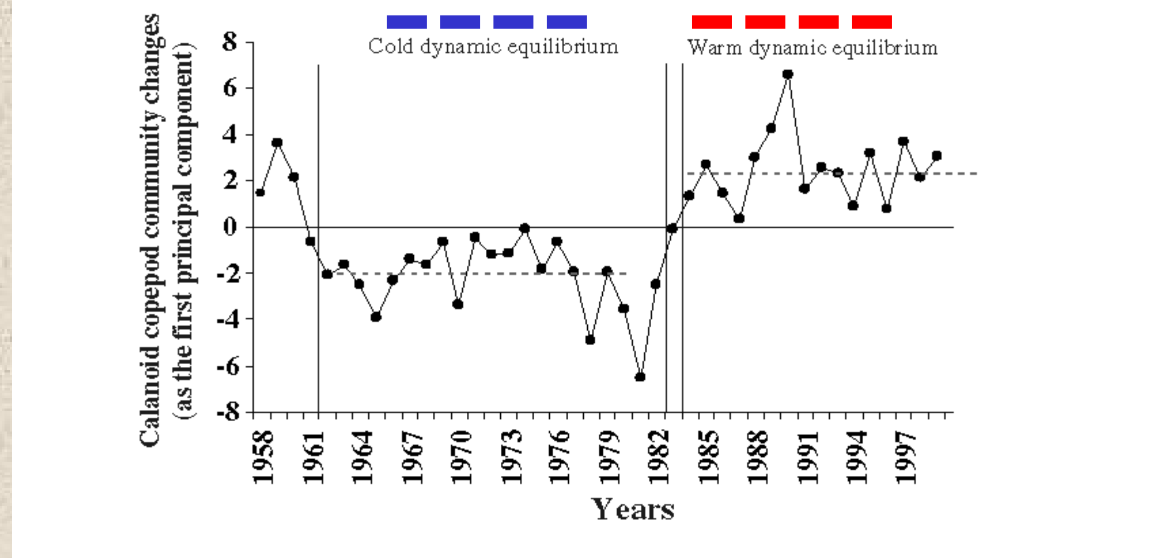
1. A fast transport mode, in which the current is relatively straight (reduced motion perpendicular to the main flow).

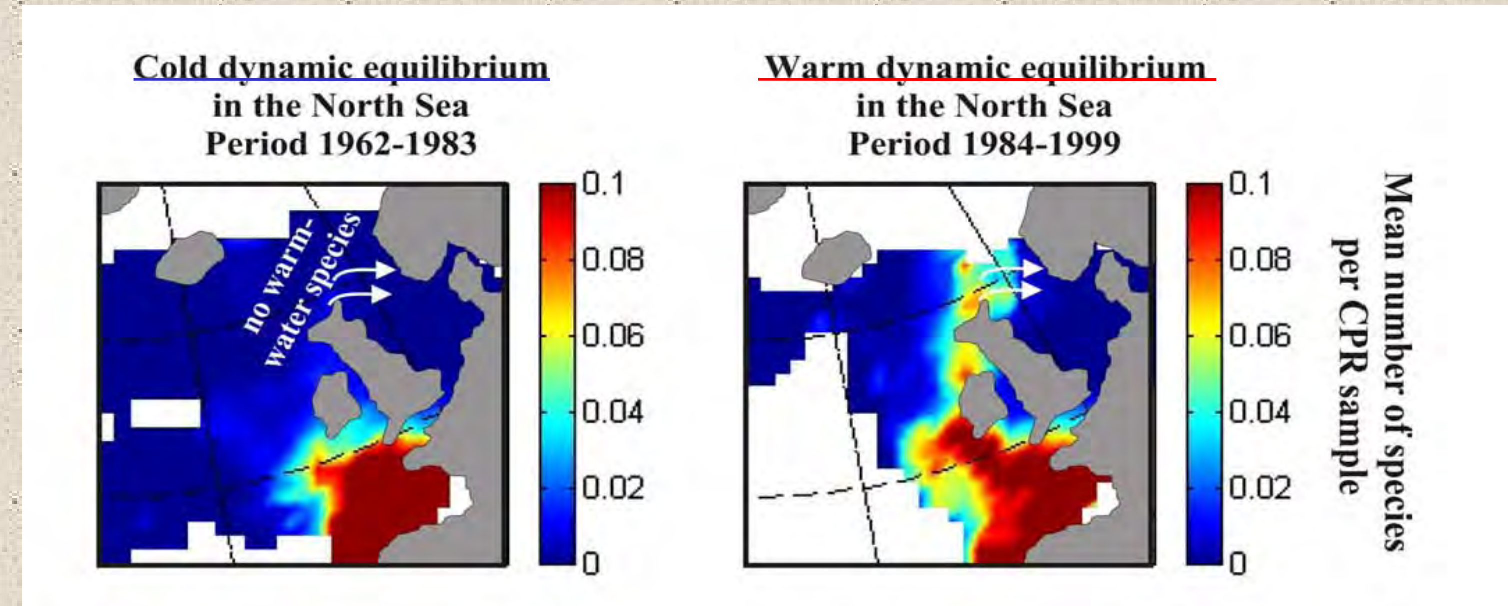
2. A slow transport mode, in which the current meanders (increased motion perpendicular to the main flow) and has complicated structure, a relatively large frontal area, and greater tendency to form persistent mesoscale eddies.

Table 2. Comparison of Pacific Ocean coastal ecosystem properties under weak and strong modes of boundary current flow.

Mode of current flow	Weak, slow flow	Strong, fast flow
Coastal sea level	Higher	Lower
Water motion	Enhanced meandering	Reduced meandering
Frontal area	Increased	Decreased
Offshore larval retention	Favorable	Unfavorable
Temperature anomaly		
Eastern Pacific	Warm	Cool
Japan	Cool	Warm
Nutrient supply		
Eastern Pacific	Reduced (lower lat. source)	Enhanced (higher lat. source)
Japan	Enhanced (Oyashio intrusion)	Reduced
Sardine abundance	Increased	Decreased
Anchovy abundance		
California	Slight decrease	Slight increase
Peru/Chile	Strong decrease	Strong increase
Japan	Slight decrease	Slight increase

Two stages (average/stable conditions ??): A common way to understand and represent regimen shifts in ecology



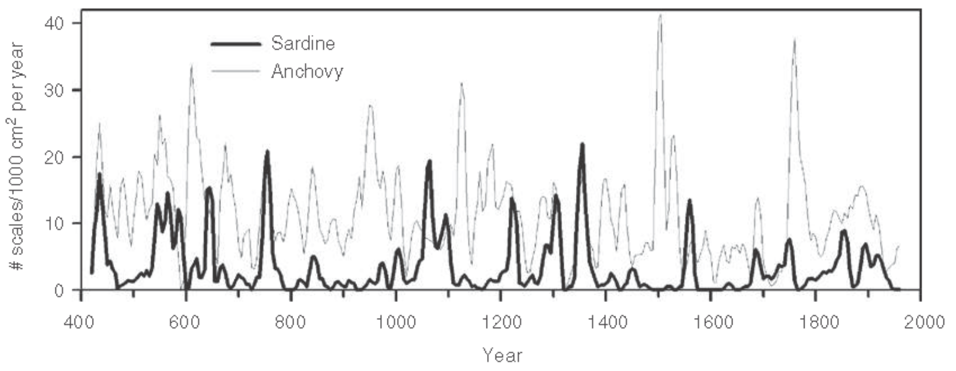


Raw data series : Fish scales and environmental indices

Two alternate modes??

or frequent ups and downs??

Variability from scales in marine sediments and other historical records



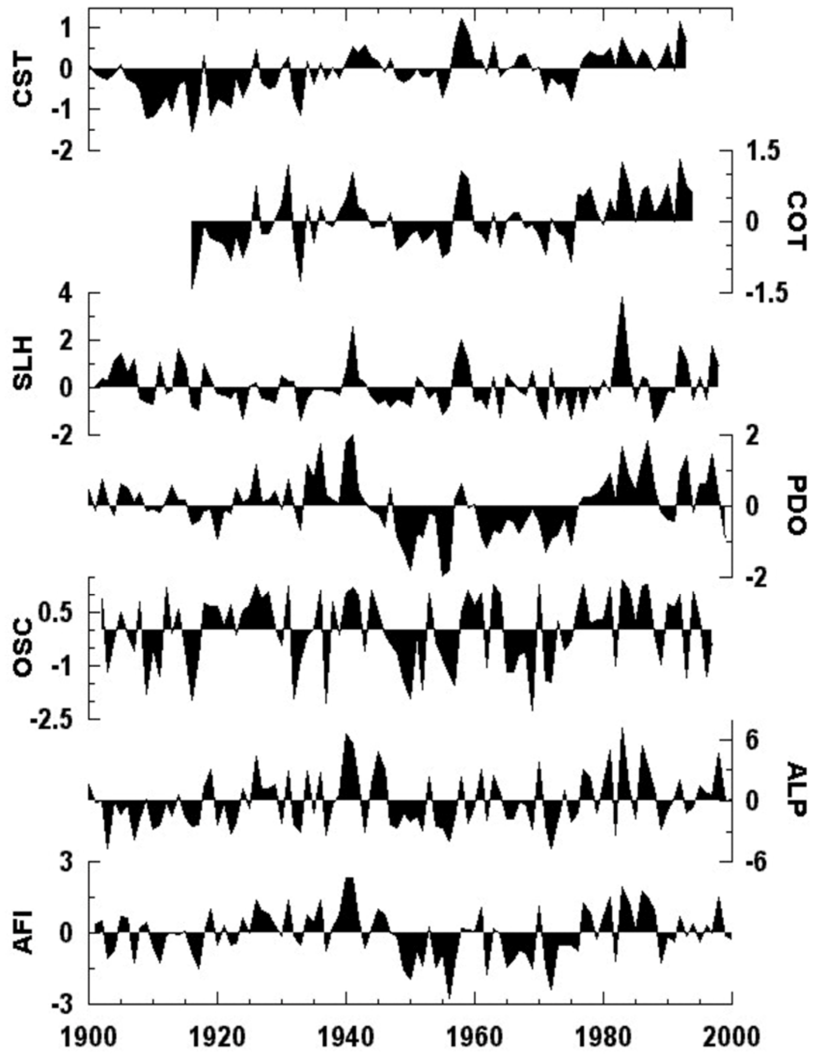


Figure 2. The raw data series. Global index of the California Current system SST anomalies (CST), index of yearly coastal SST anomalies (COT), index of yearly sea-level height anomalies (SLH), Pacific Decadal Oscillation index (PDO), OSCURS index (OSC), Aleutian Low Pressure index (ALP), and Atmospheric Forcing index (AFI).

Nature (and data) seems to be in a state of constant change

Time-series components of the raw data series:

After weighted moving average transformation + filtering process

High-frequency component

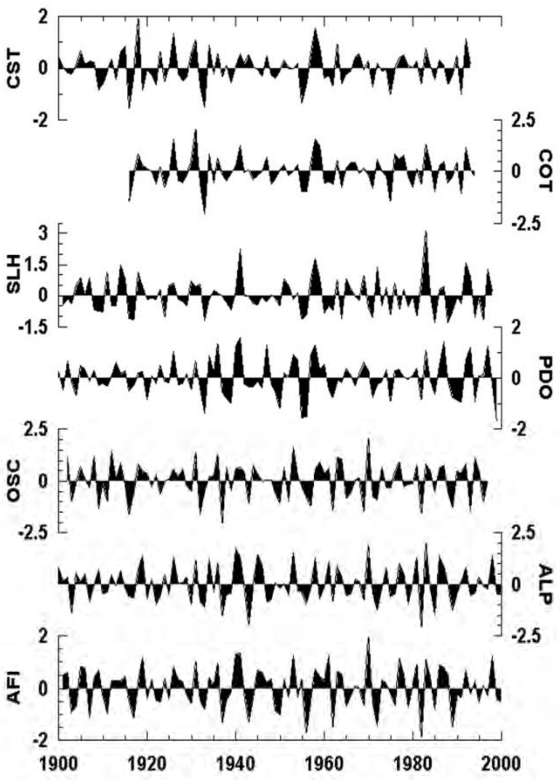


Figure 3. The high-frequency filtered series (residuals of raw data minus 10-year Hamming filter).

Decadal-bidecadal component

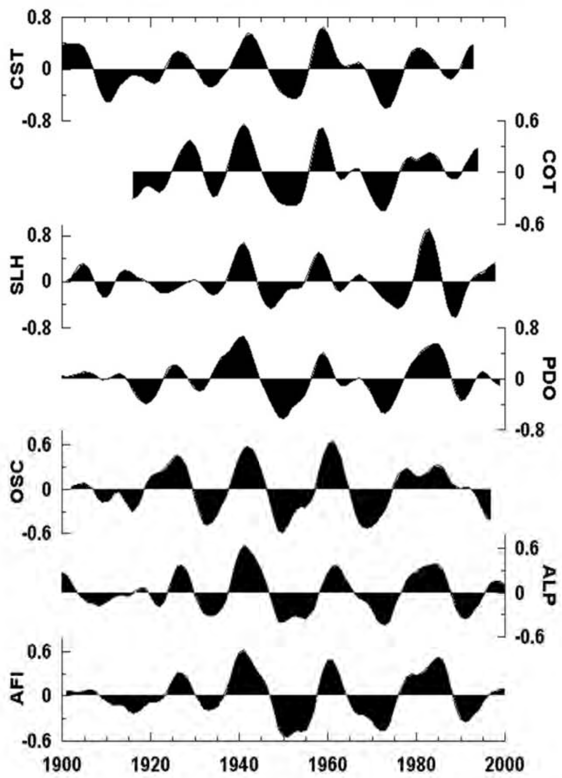


Figure 4. Decadal-bidecadal series (residuals of 10-year Hamming filter minus 30-year Hamming filtered series).

Low-frequency component

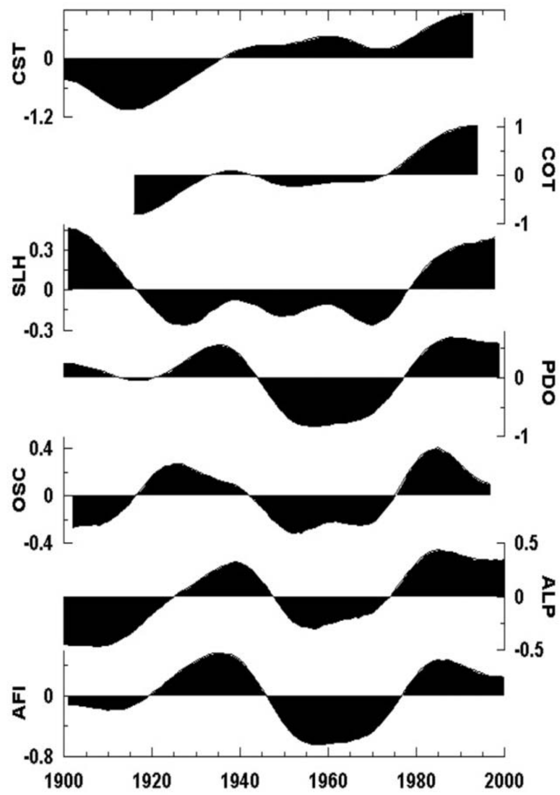
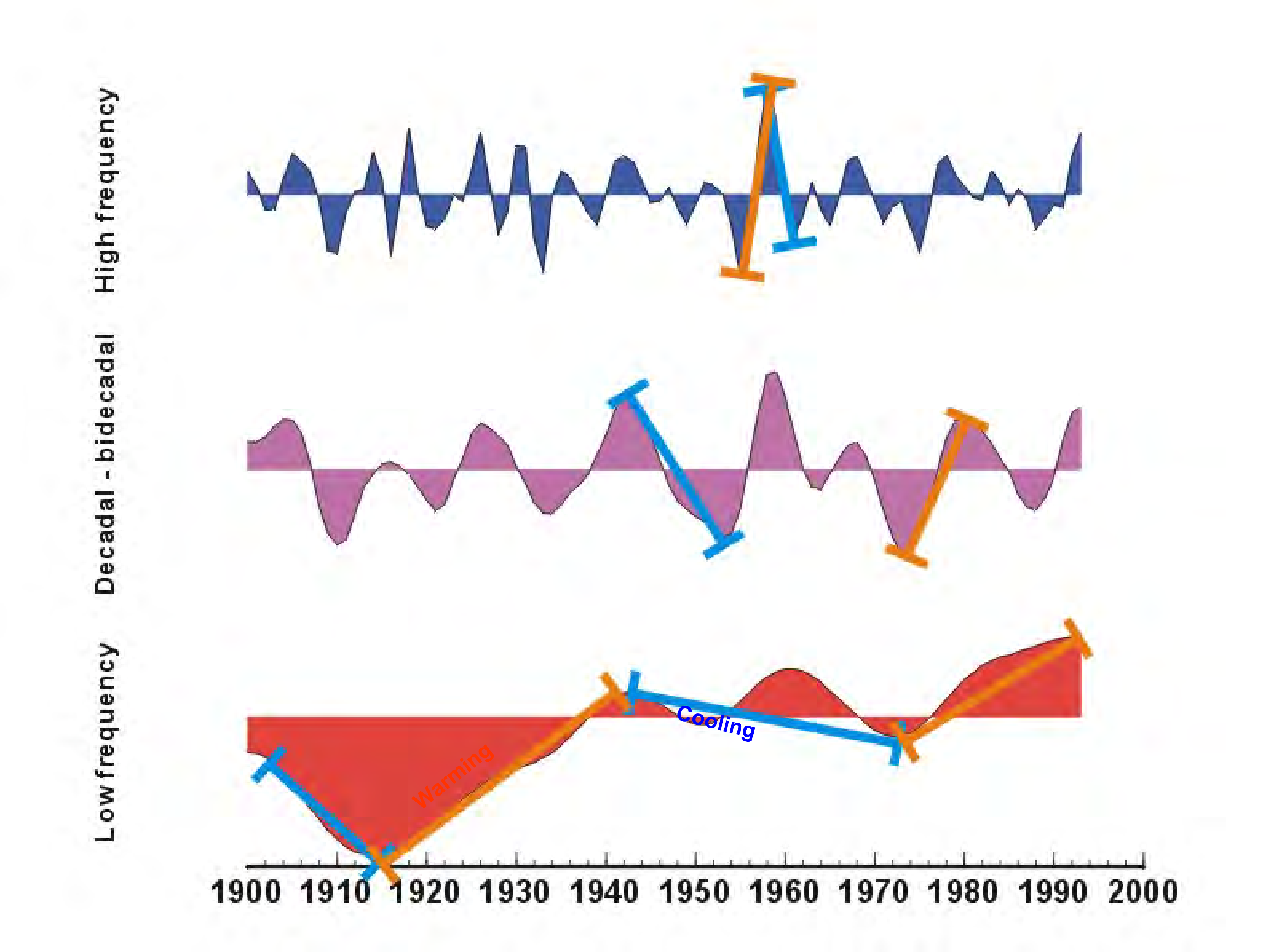


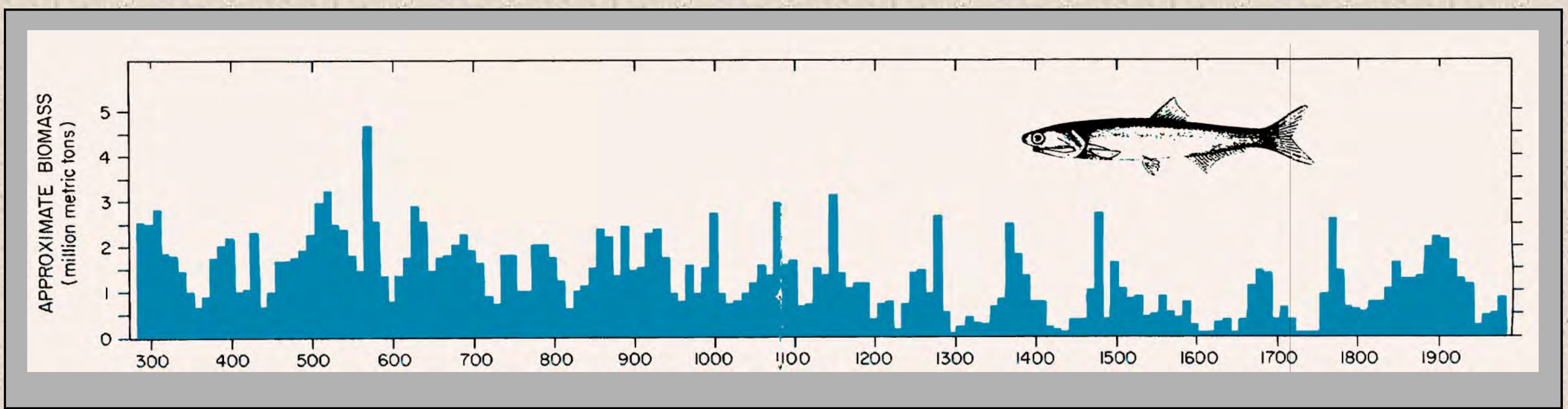
Figure 5. Low-frequency filtered series (Hamming filter of 30 terms).

Components of a data series

two alternate modes?? or frequent ups and downs??



OTHER ABUNDANCE INDEX

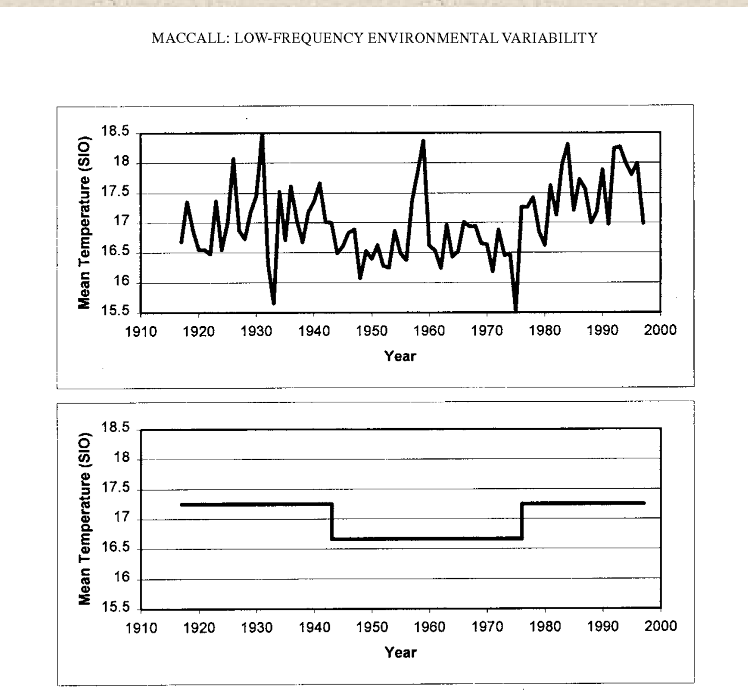


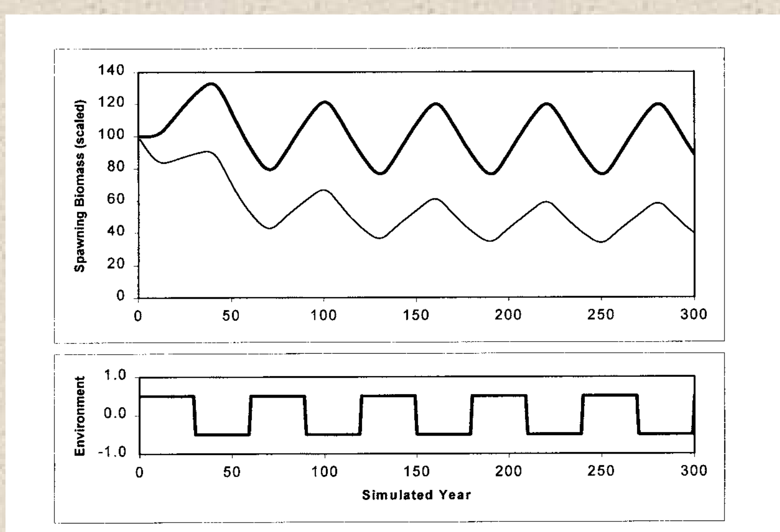
- Long-term variability
- Limited spatial representation

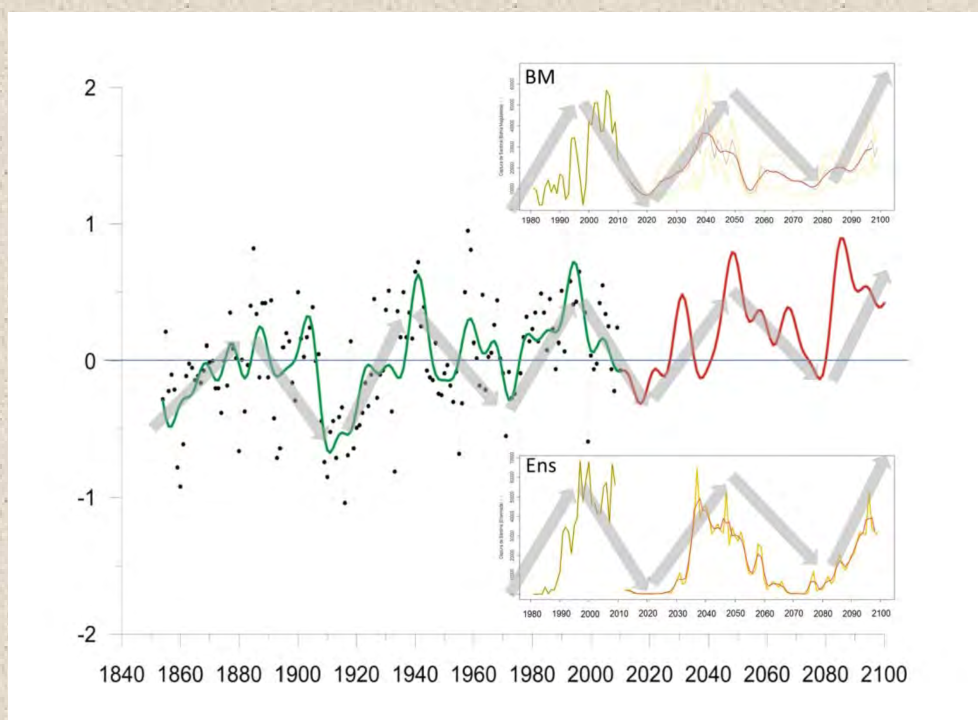
analysis over time-scale only

Modeling and Prognostic:

Warm-Cold vs. Warming-Cooling



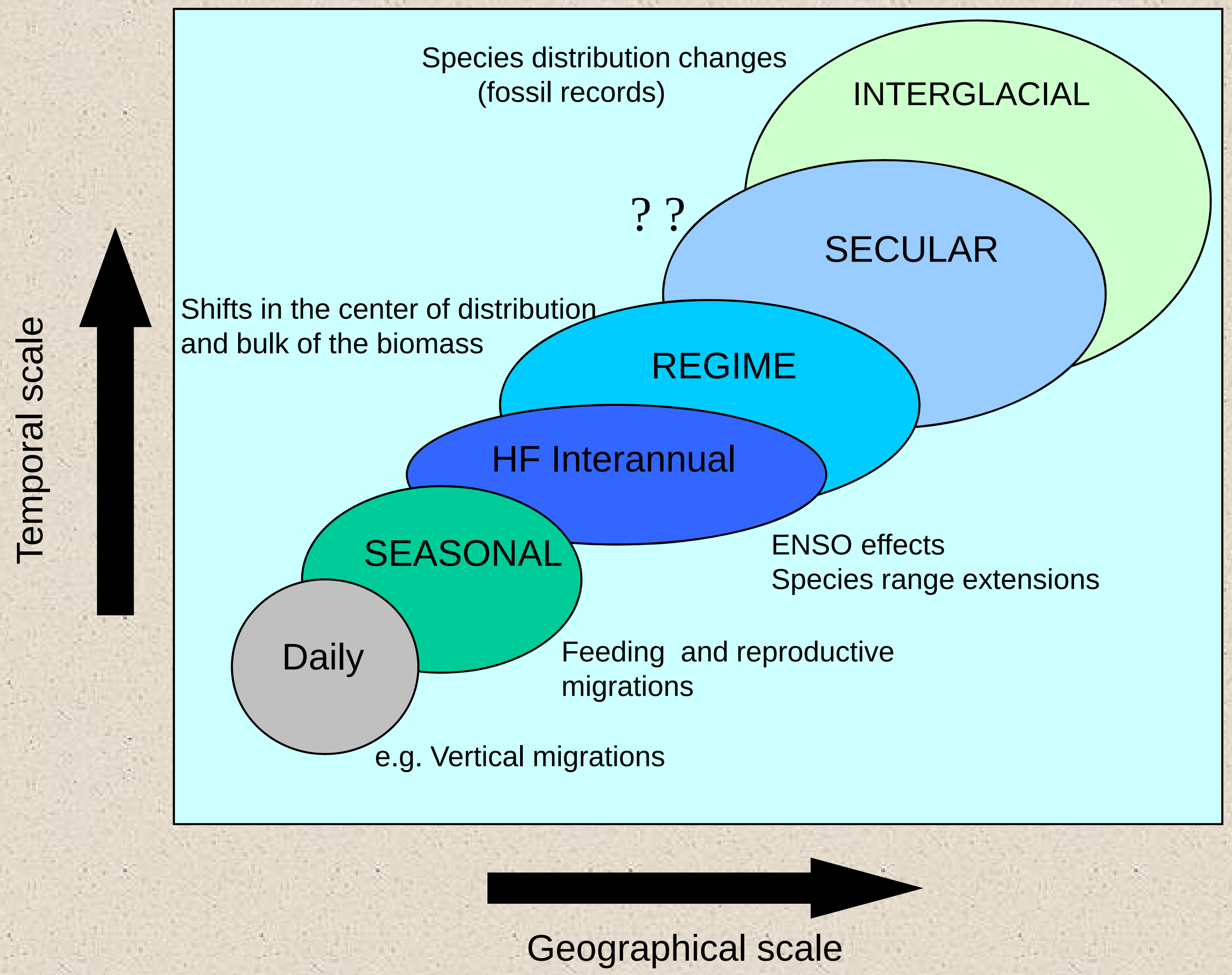


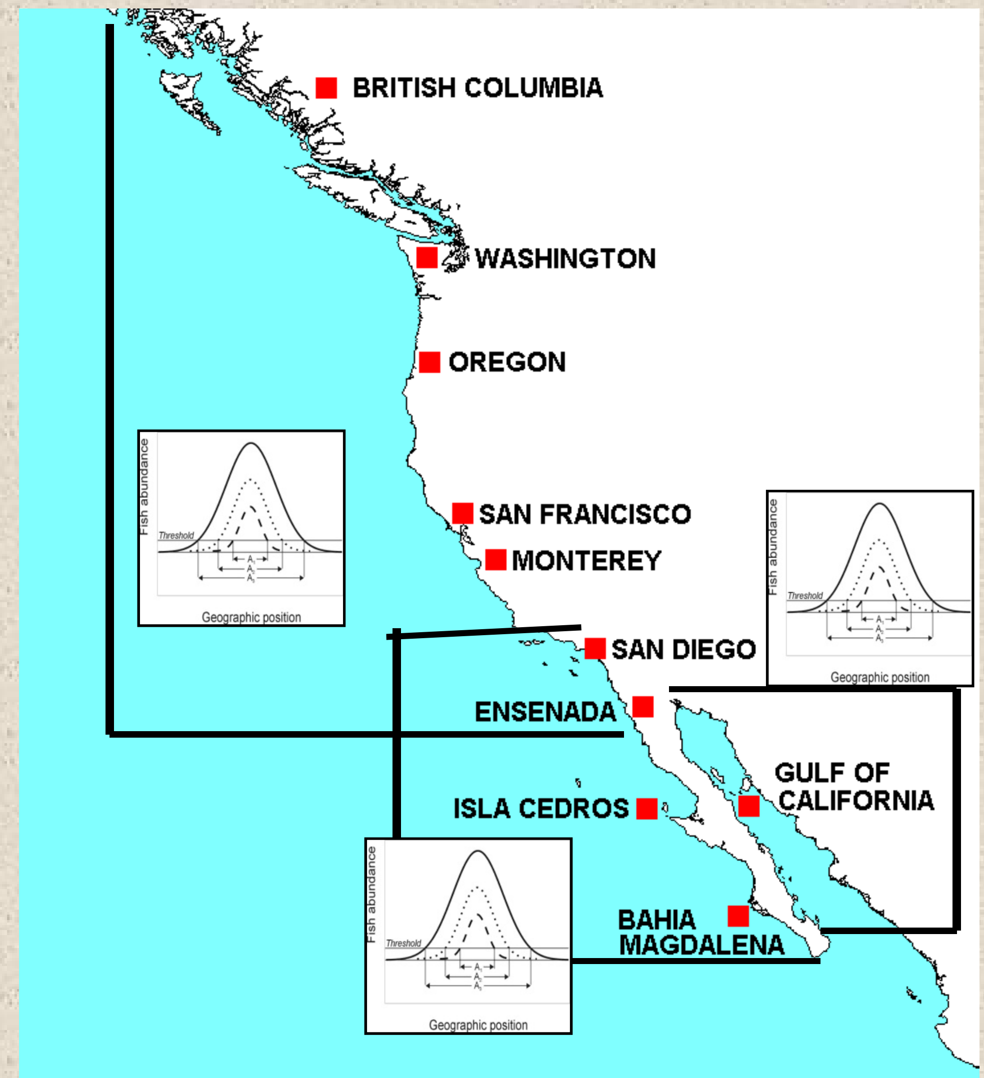


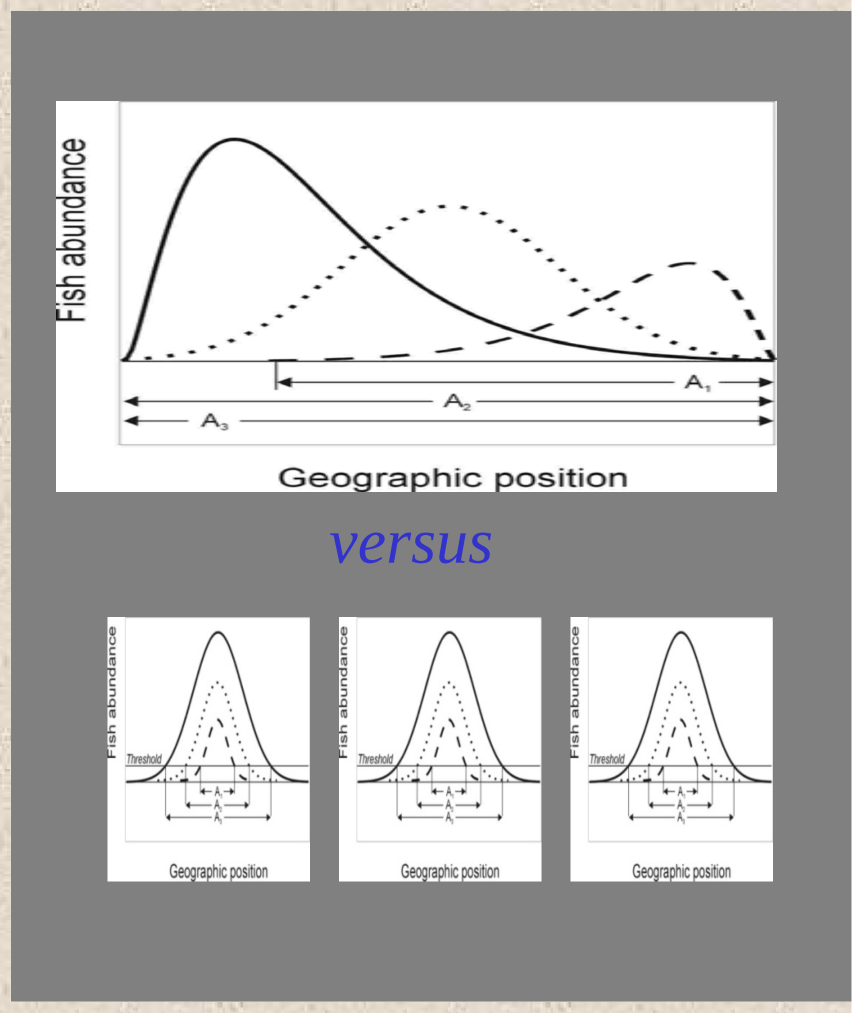
No doubt that the **<u>unidimensional analysis</u>** of time-series of information has been useful to advance in the understanding of population dynamics and their relations with environmental variability.

But …

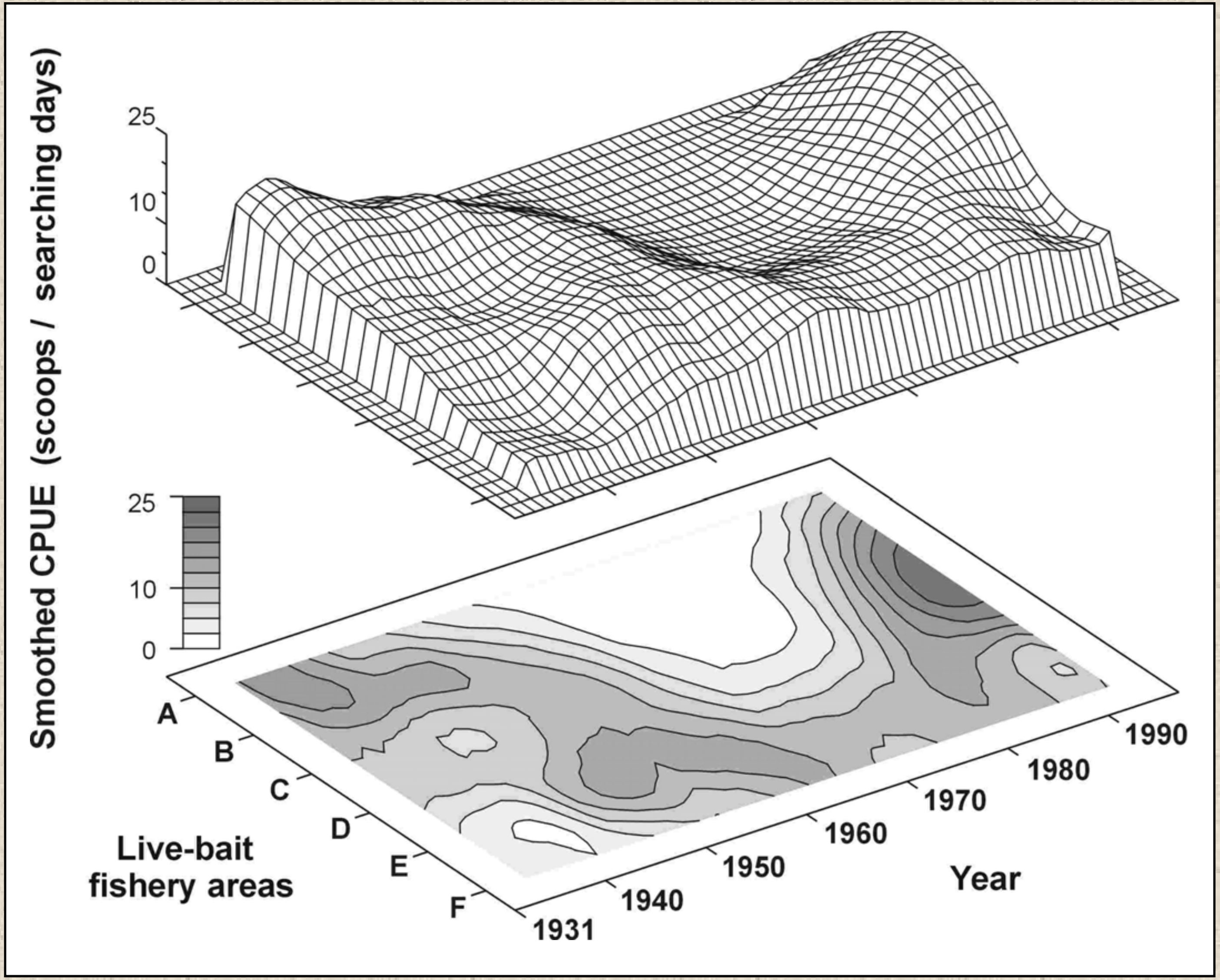
ECOLOGICAL PROCESS (migrations, movements) ON SPATIAL-TEMPORAL SCALES

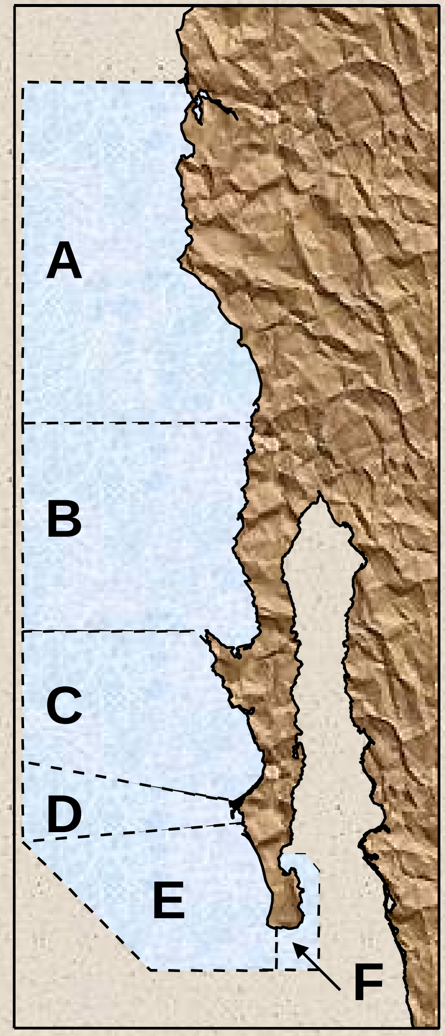



BRITISH COLUMBIA
WASHINGTON
OREGON
SAN FRANCISCO
MONTEREY
SAN DIEGO
ENSENADA
ISLA CEDROS
GULF OF CALIFORNIA
BAHIA MAGDALENA
Fish abundance
Threshold
Geographic position


Fish abundance
A_1
A_2
A_3
Geographic position
versus
Fish abundance
Threshold
Geographic position

Spatial variability of Pacific sardine at regime time-scale (1931-1997)





Rodríguez-Sánchez et al. (2002)

Spatial variability of Pacific sardine at regime time-scale is also supported by other information and different methods

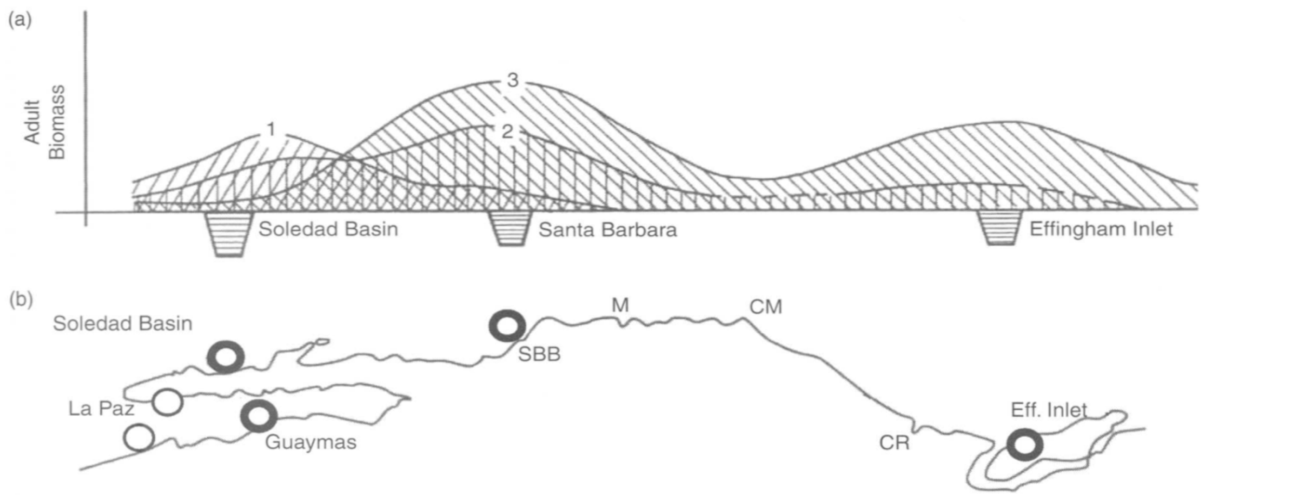
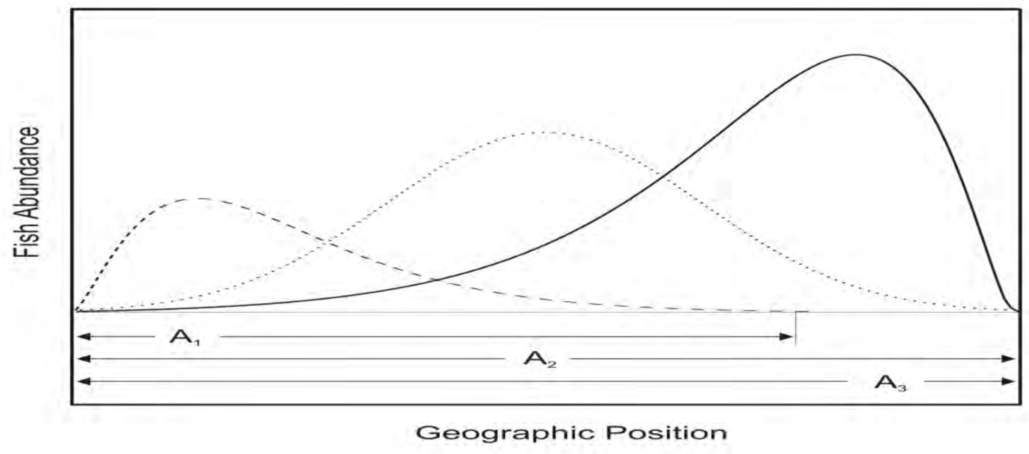
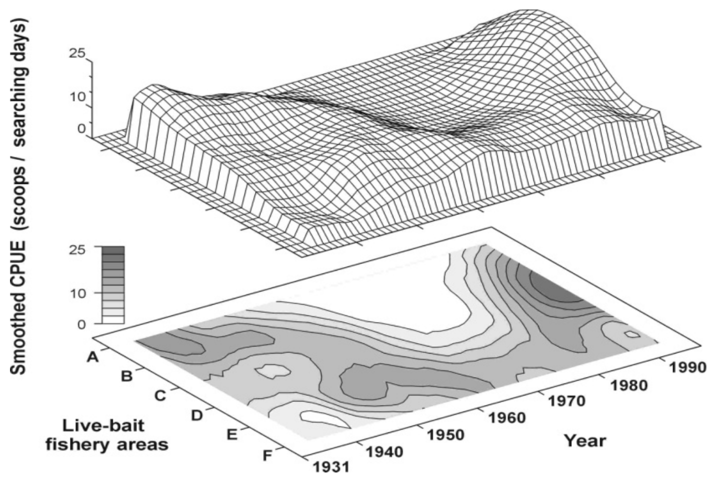


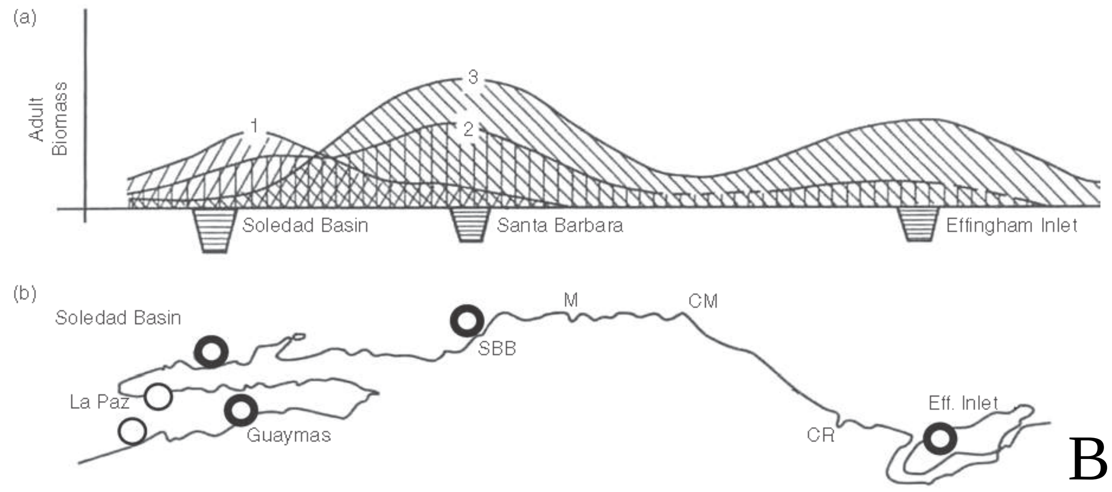
Fig. 4.1. (a) Model of how multiple sedimentary environments from the California Current region (British Columbia to the right and Baja California to the left) could reflect different scenarios for population abundance and distribution of the California sardine: (1) A diminished population contracted to Baja California and the Gulf of California; (2) a moderate population distributed throughout the coast, with highest densities off central California; and (3) an expanded population with a distribution centered off central California and the northern regions of the California Current. (b) Location of known sedimentary sites capable of resolving SDR (bold circles) and potential sites (thin circles). Monterey (M), Cape Mendocino (CM), and the Columbia River (CR) are indicated for reference. Orientation as in (a).

Field, D.F. et al. **2009**. Variability from scales in marine sediments and other historical records, pp. 45-63. **In**: Checkley, D., J. Alheit, Y. Oozeki and C. Roy (eds.). Climate Change and Small Pelagic Fish. Cambridge, UK, Cambridge University Press. 372 pp



A





B

Variability from scales in marine sediments and other historical records

David B. Field, Tim R. Baumgartner, Vicente Ferreira, Dimitri Gutierrez, Hector Lozano-Montes, Renato Salvatteci, and Andy Soutar

Molecular Ecology (2004) 13, 2169–2182 doi: 10.1111/j.1365-294X.2004.02229.x

Living with uncertainty: genetic imprints of climate shifts in East Pacific anchovy (*Engraulis mordax*) and sardine (*Sardinops sagax*)

C

A single range-wide population with a decline in genetic diversity on both sides of a central refuge.

Lecomte et al. (2004)

Spatial and abundance shifts occur in different large marine ecosystems

Decadal-scale variability in populations

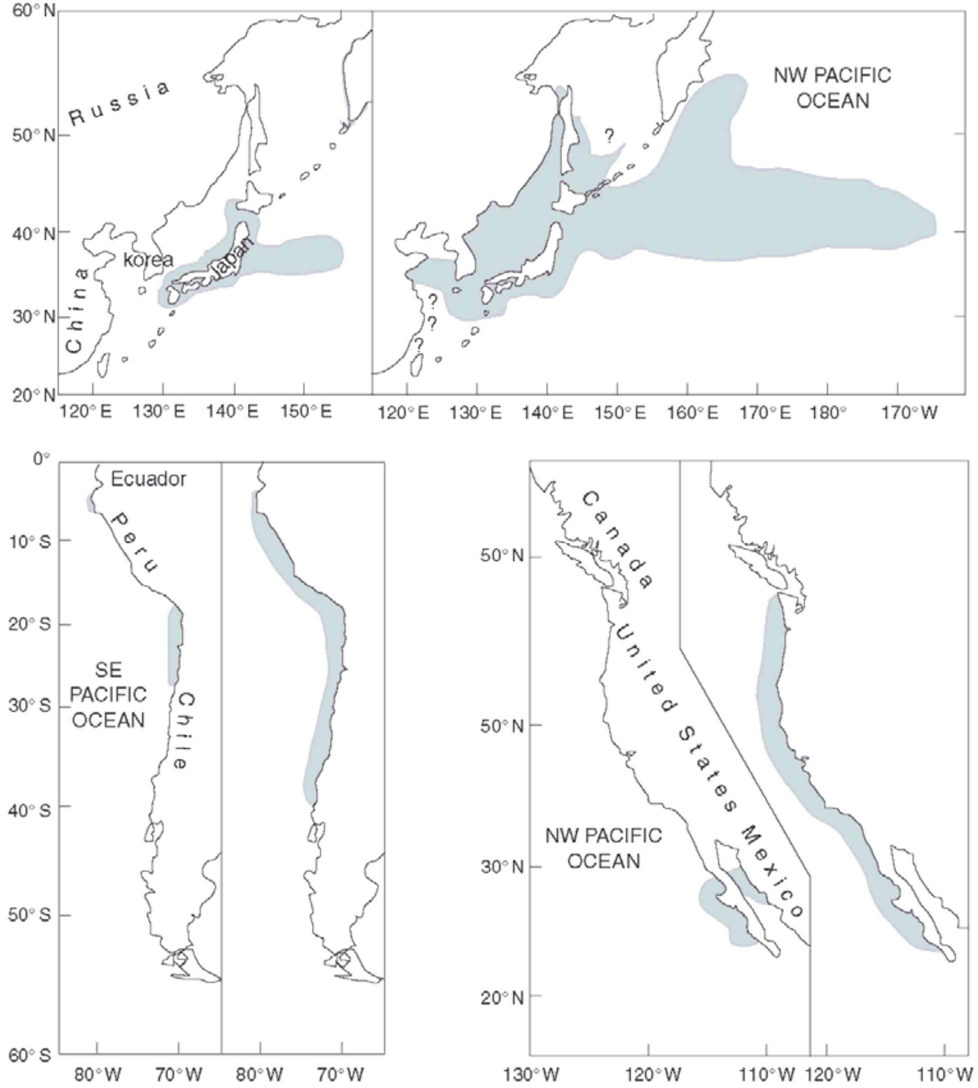
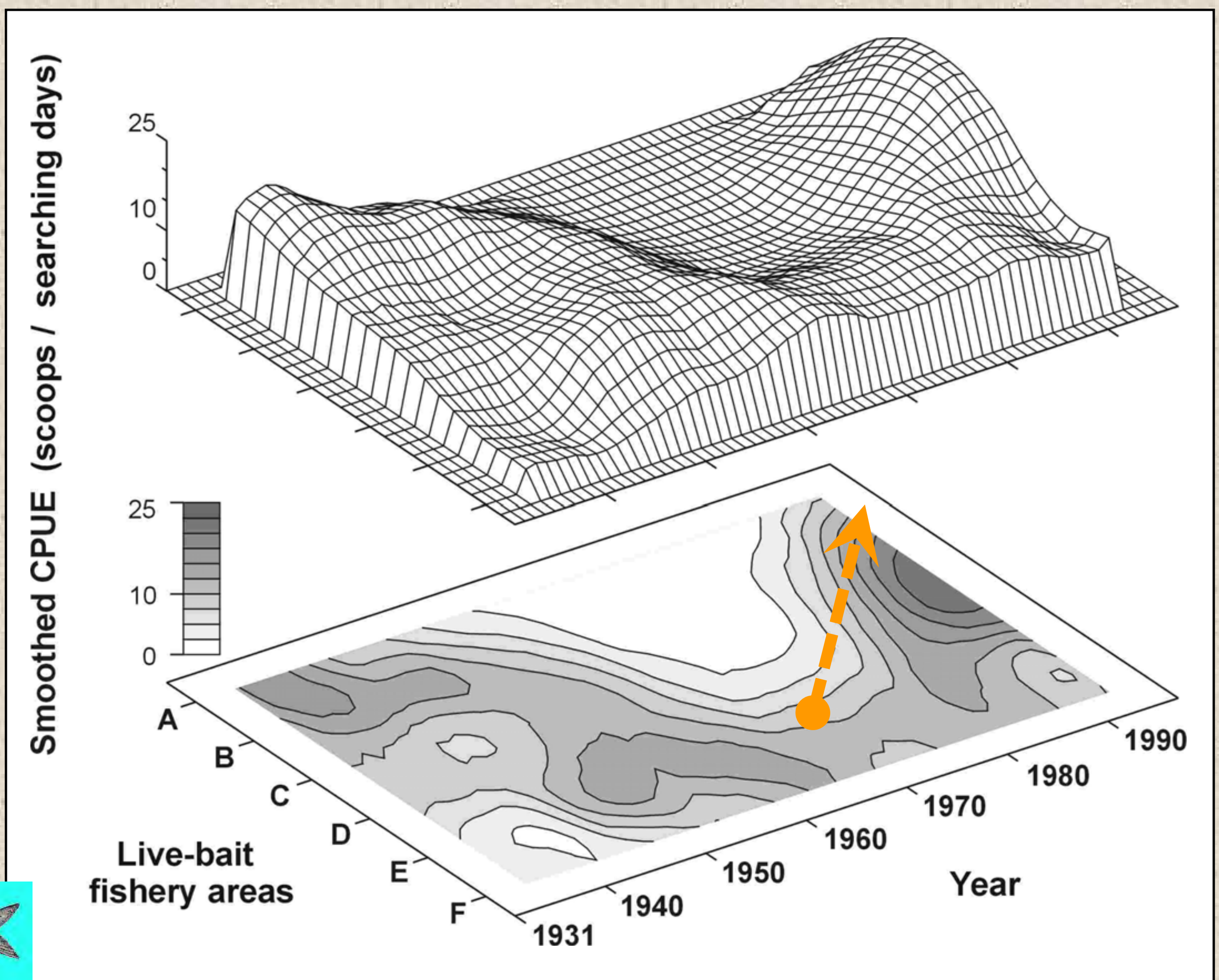


Fig. 5.2. Minimum (left) and maximum (right) areas of distribution of Japanese, Humboldt Current and California Current sardines (redrawn after Hunter and Alheit, 1995).

GEOGRAPHICAL VARIABILITY OF PACIFIC SARDINE ABUNDANCE



Rodriguez-Sanchez et al. (2002)

Canadian J. Fisheries & Aqua. Sci. 59(12):1980-1988

Aims of this work:

- Instead of focusing on long-term equilibriums (sardine in low and high abundance regimes), we pay here attention to show how sardine get from one stage to another stage (from low to hig abundance).
- Understand how biological processes (recruitment and migrations) are integrated at different scales (seasonal and interannual) to produce the macro-scale changes in abundance that we observe at long-term, large-scale.
- To represent by means of a conceptual model how the interannual changes of recruitment zones and of sardine migratory circuits along the California Current may imply changes in space and time of the factors/mechanisms that control the major observed shifts in population size and location.

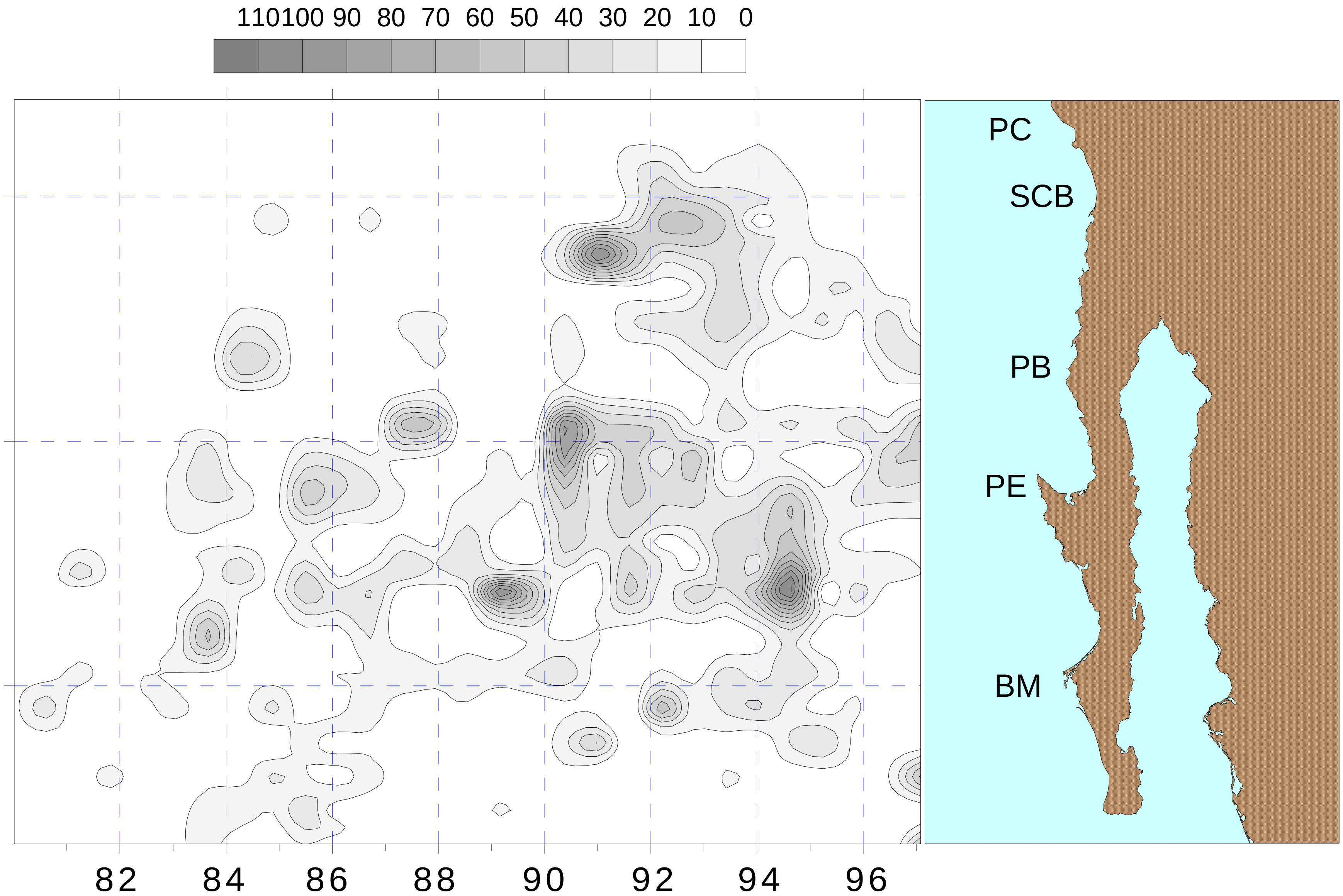
Questions :

- The prediction of the large-scale change may require understanding the interannual variability of intra-annual biological processes?

- Which of the many biological processes that we understand on seasonal scale are critical?

- How to concatenate the deductions concerning different scales ?

Annual abundance indices (CPUE) for Pacific sardine (1980-1997)



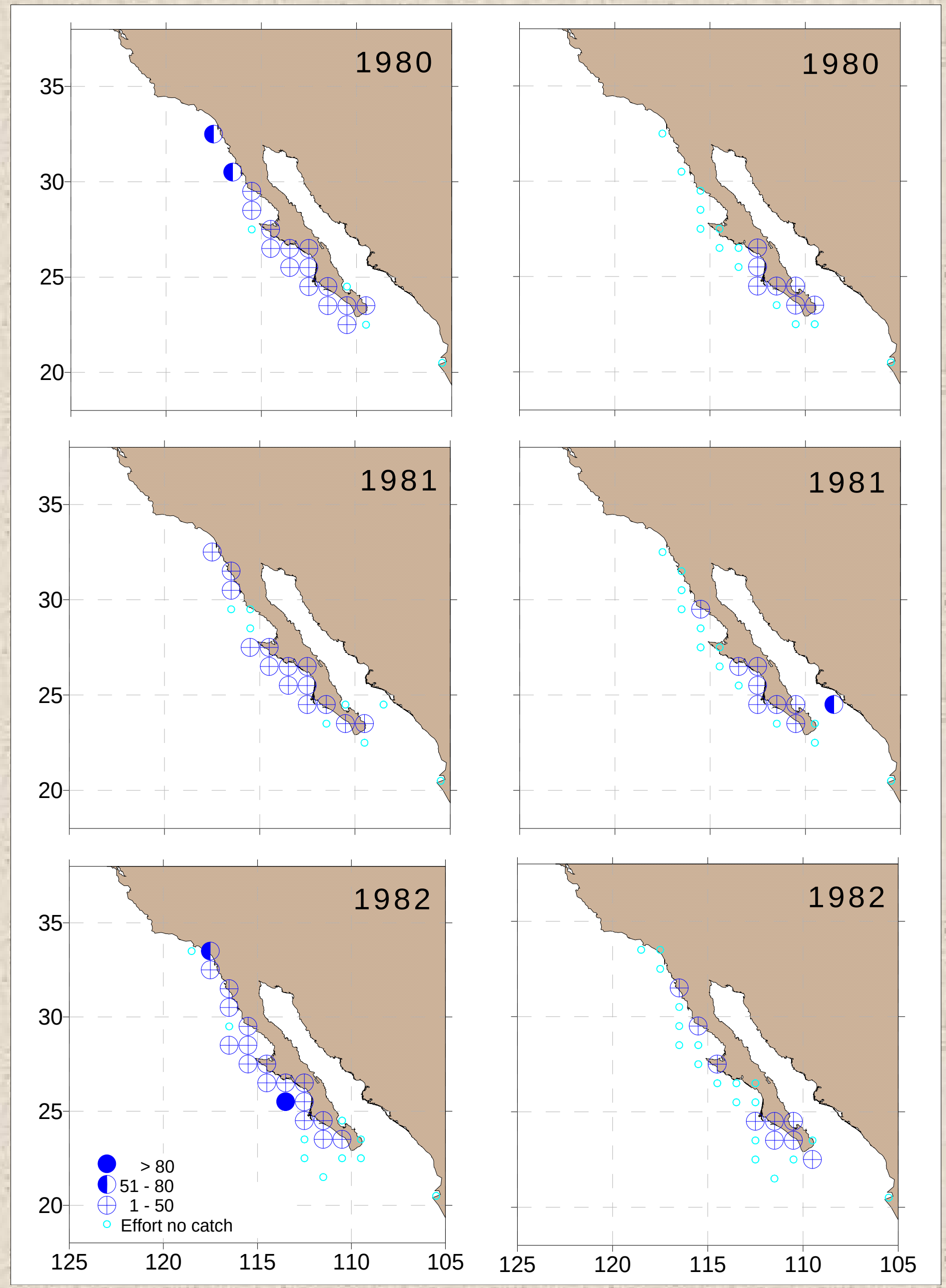
TUNA BAITBOATS

Their small pelagic fish catch data are devoid of bias induced by searching for large schools in high-abundance areas

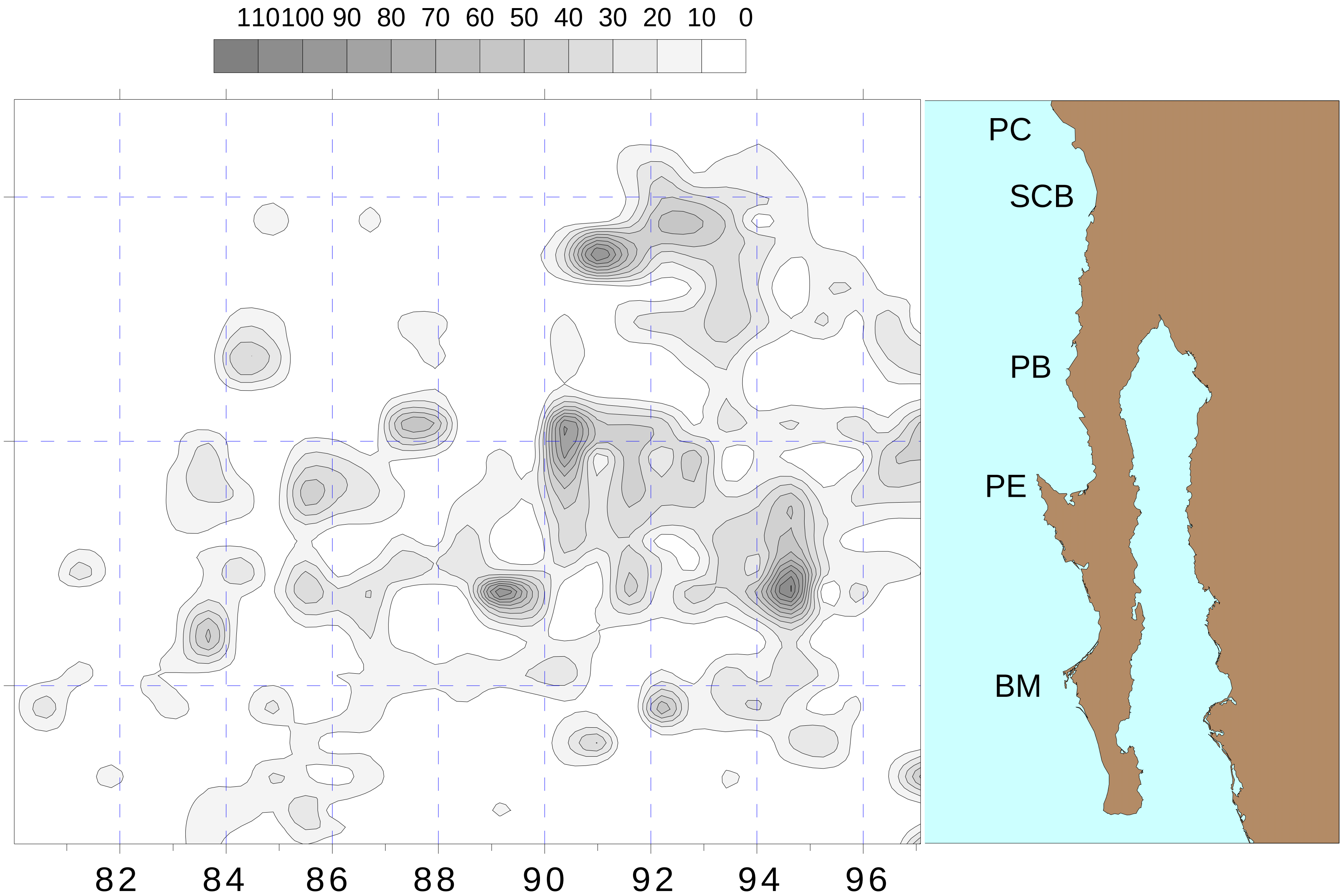
- **TUNAS ARE THE TARGET FISH SPECIES**
- **BOATS DO NOT SEARCH FOR A PARTICULAR KIND OF BAIT NOR IN A PARTICULAR LOCATION**
- **BOATS REPLENISH THEIR FISHPONDS AT THE NEAREST LOCATION**
- **THE AMOUNT OF LIVE BAIT REQUIRED FOR OPERATION IS SMALL**

LIVE-BAIT FISHERY DATA

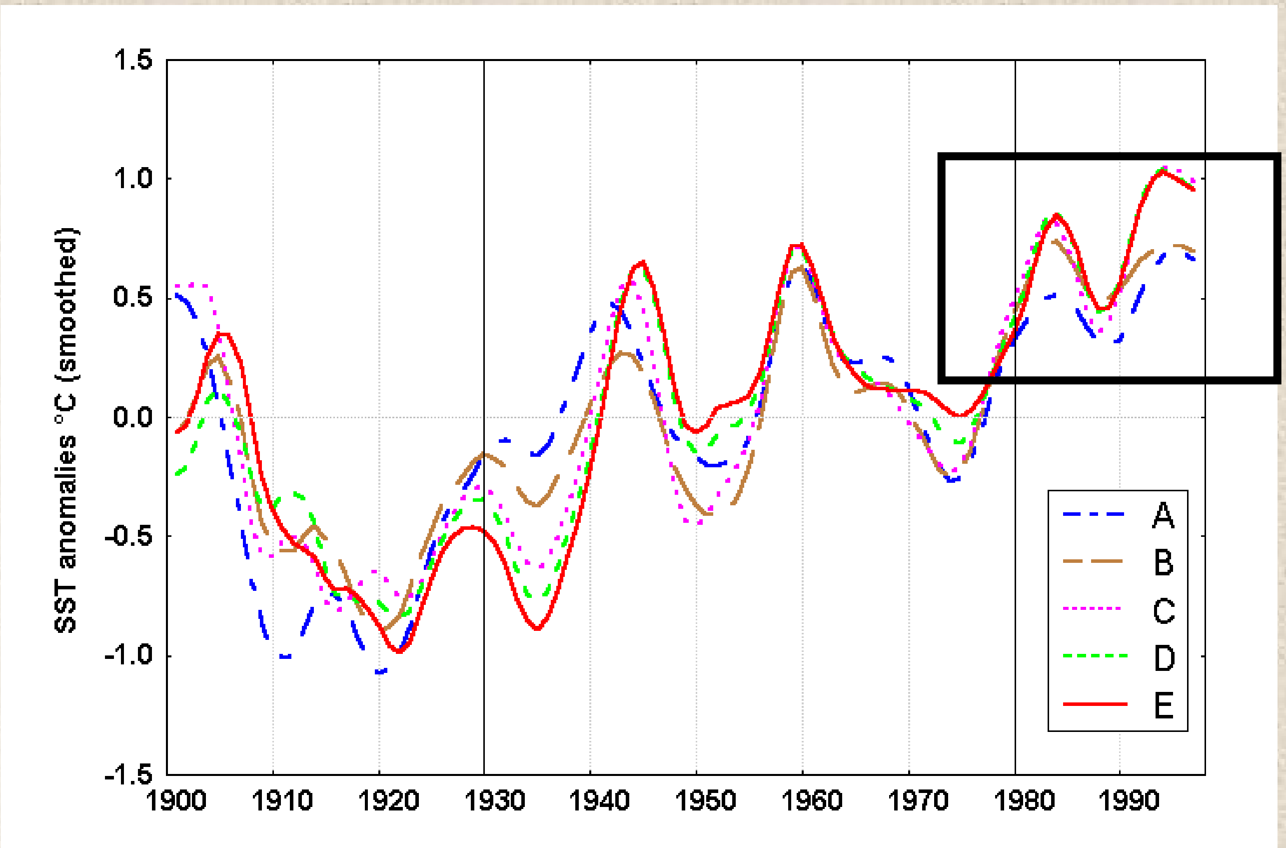
- Data grouped in 1°x1° squares (off California and Baja California)
- Monthly basis for the 1980-1997 period (**during the last warming period**)
- Monthly CPUE by specie referred latitudinally for different average years

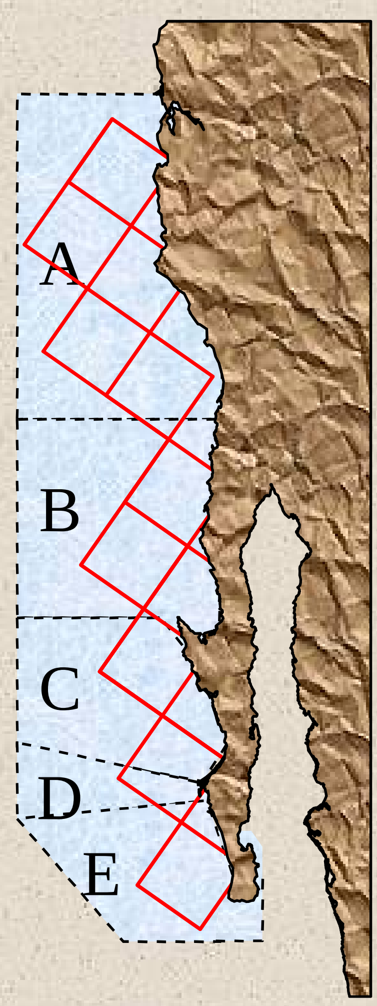


Annual abundance indices (CPUE) for Pacific sardine (1980-1997)

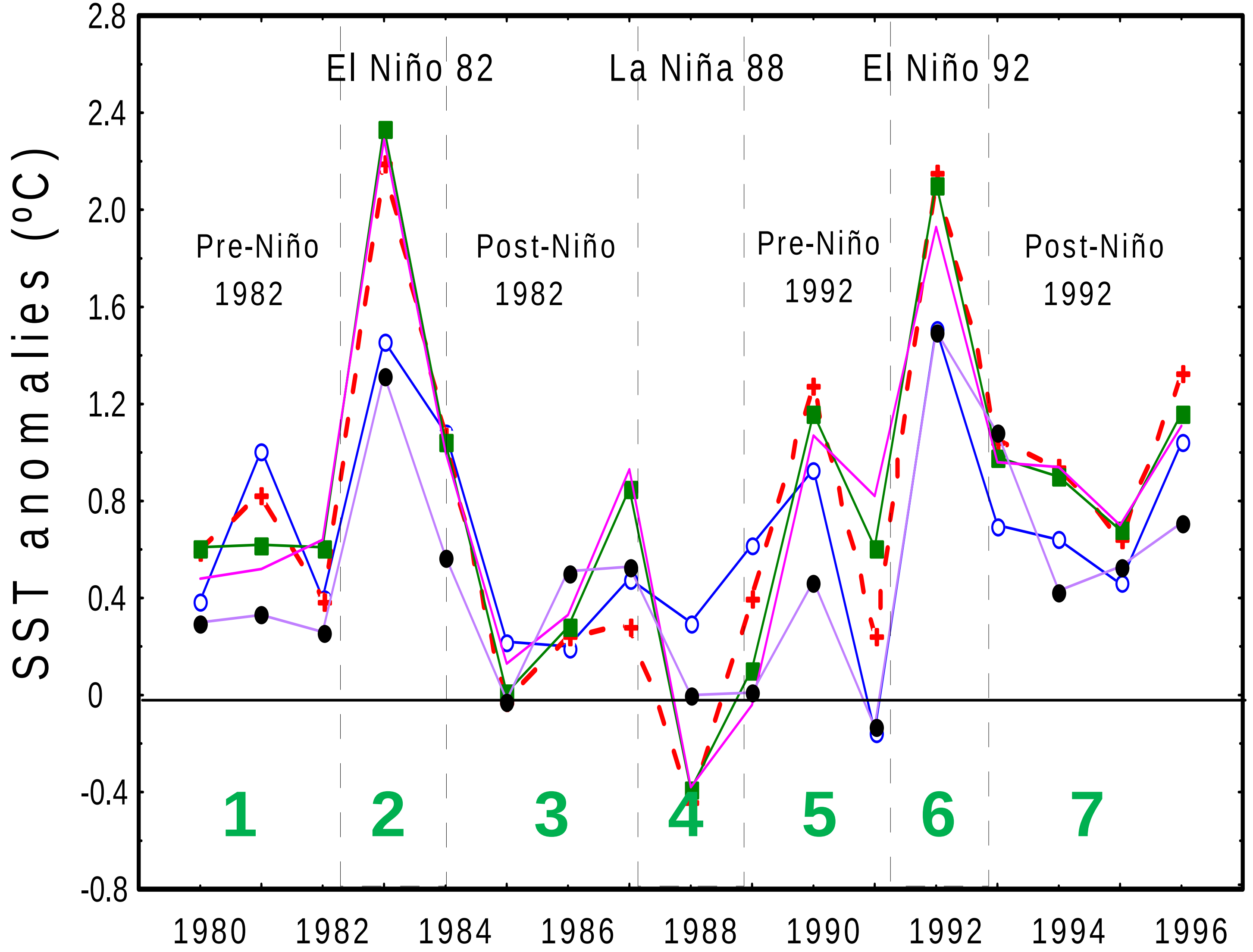


- **Time series of SST anomalies (smoothed) for areas**



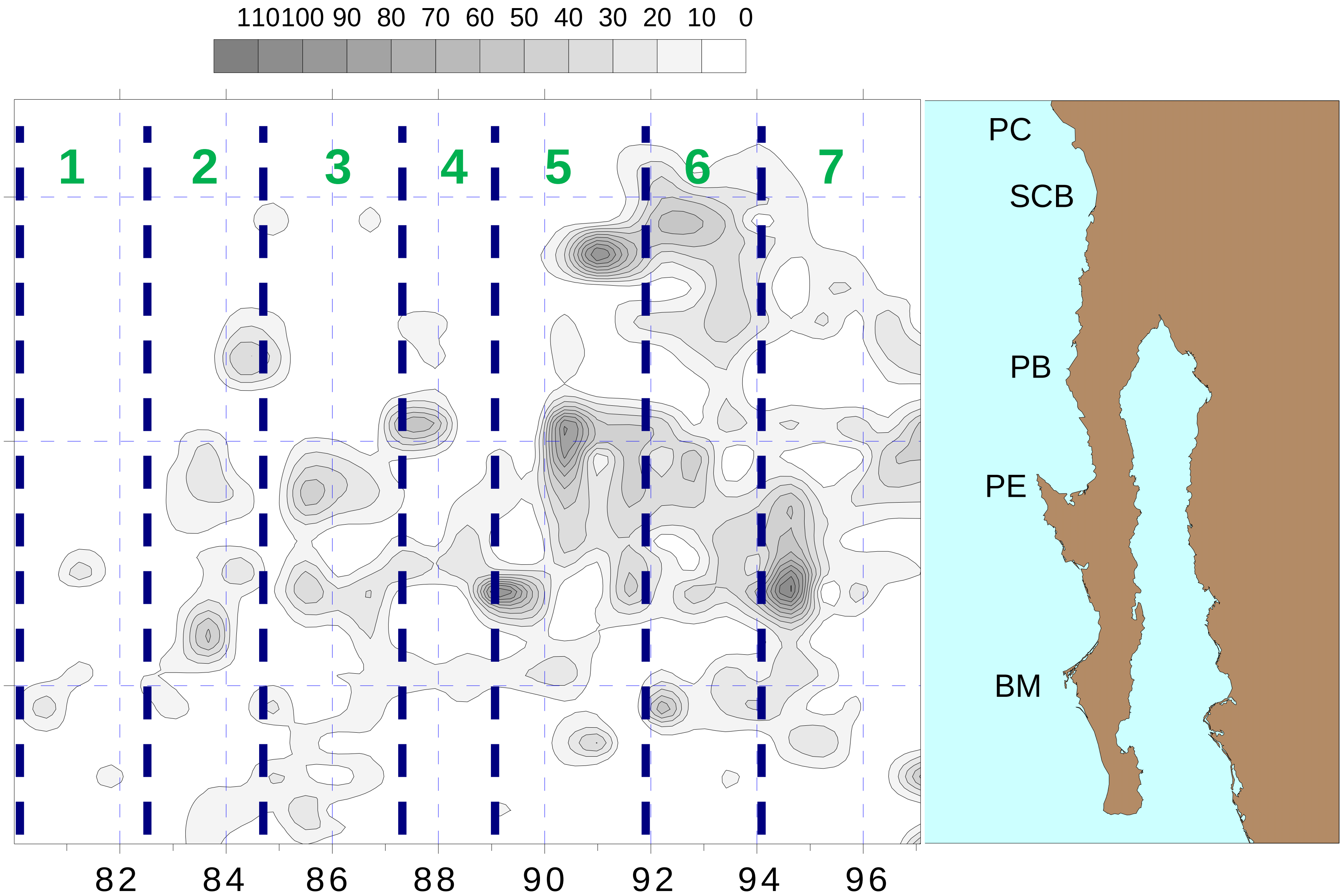


- COADS database (1900-1996)
  squares of 2 X 2 degrees



SST anomalies (ºC)
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
-0.4
-0.8
El Niño 82
La Niña 88
El Niño 92
Pre-Niño 1982
Post-Niño 1982
Pre-Niño 1992
Post-Niño 1992
1
2
3
4
5
6
7
1980
1982
1984
1986
1988
1990
1992
1994
1996

Annual abundance indices (CPUE) for Pacific sardine (1980-1997)



Other prevailing paradigms:

Seasonal migration inferred from the recovery of tagged sardines

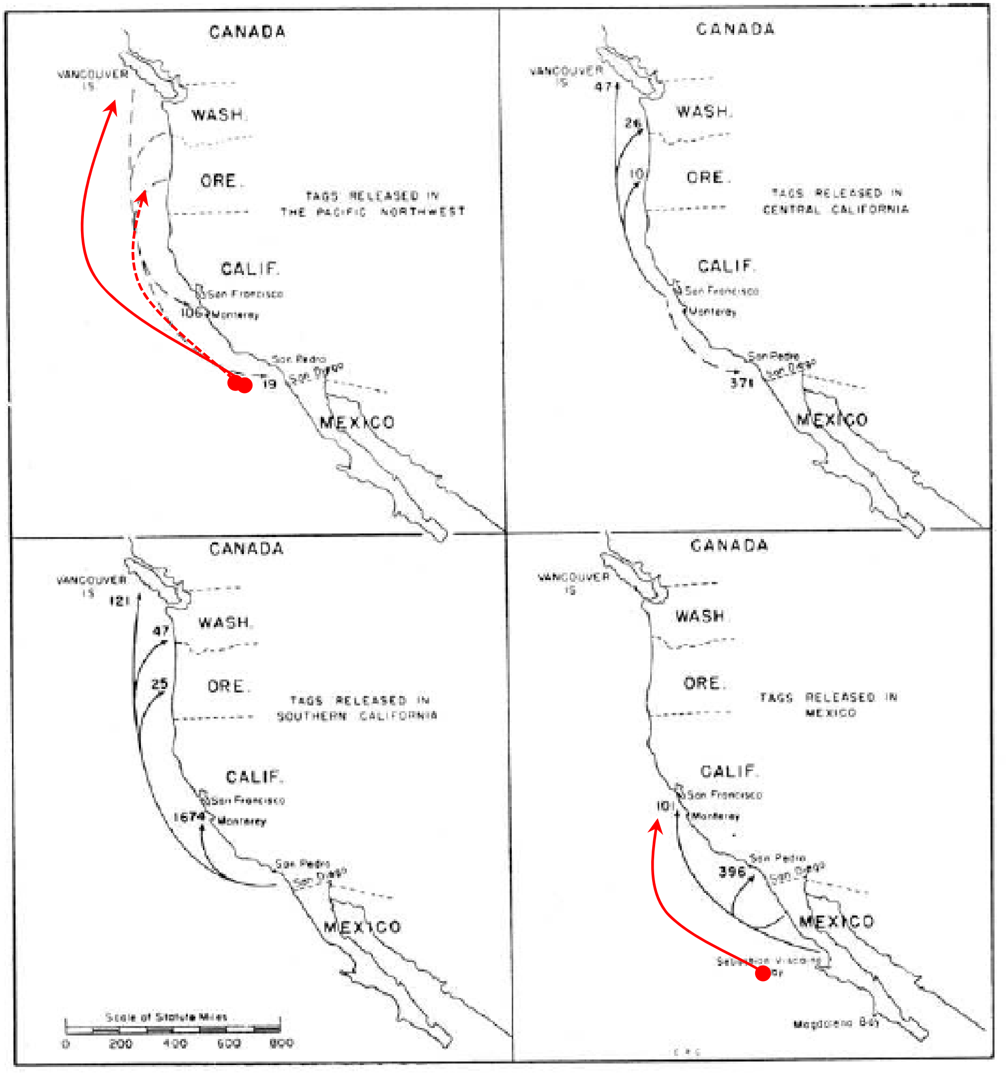


FIG. 1. Sections of the Pacific Coast of North America showing diagrammatically the major movements of tagged sardines as indicated by recoveries from June, 1935 to May, 1944.

Sardine population distribution by stage (a fixed geographical distribution)

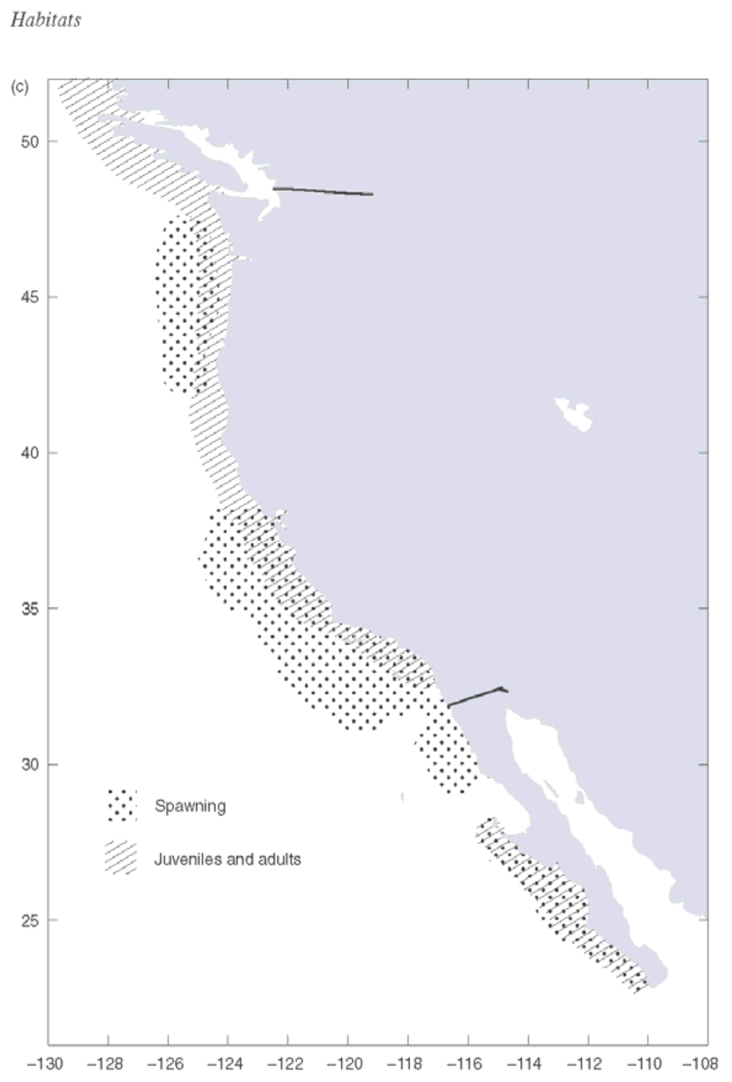
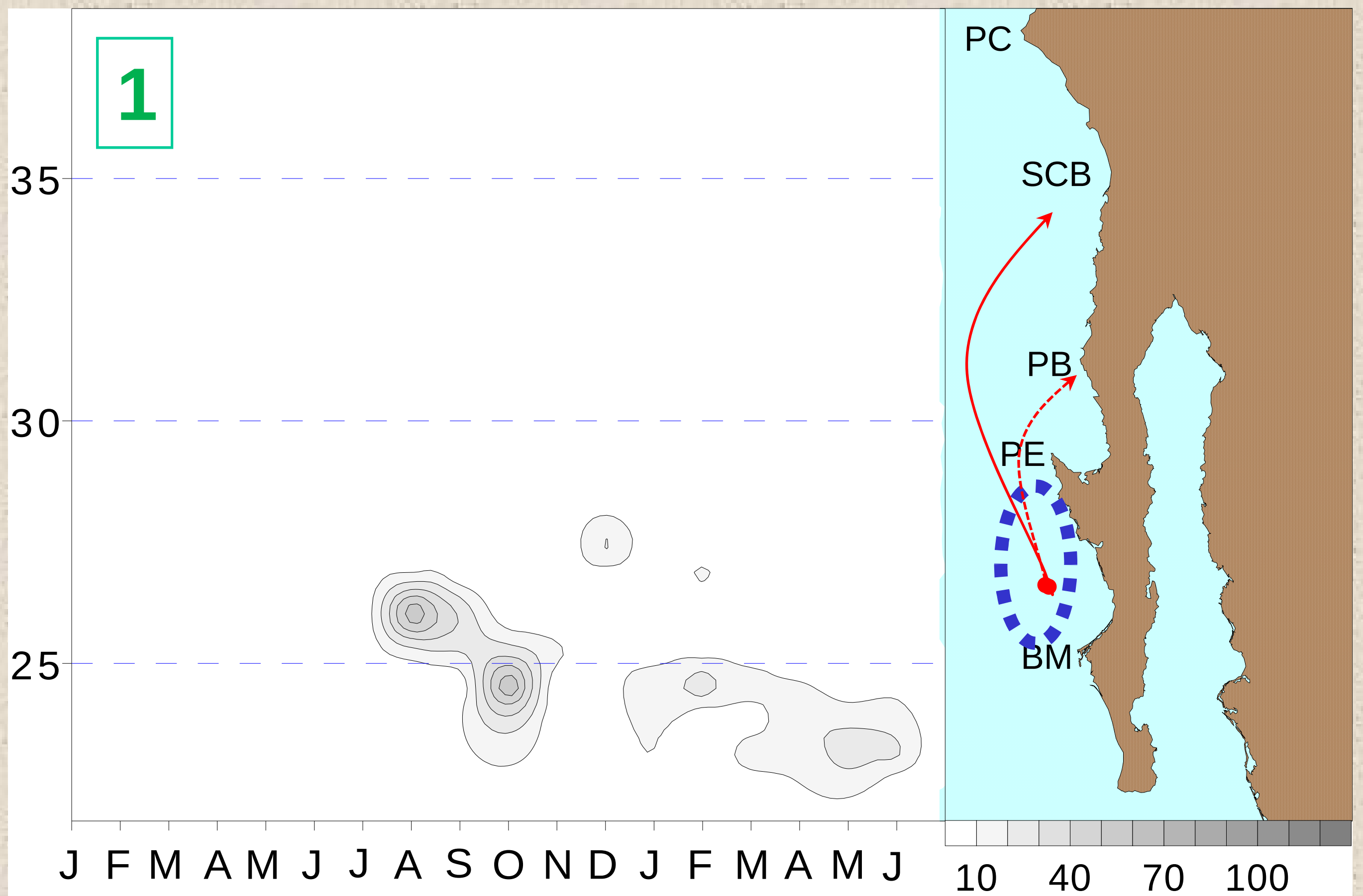
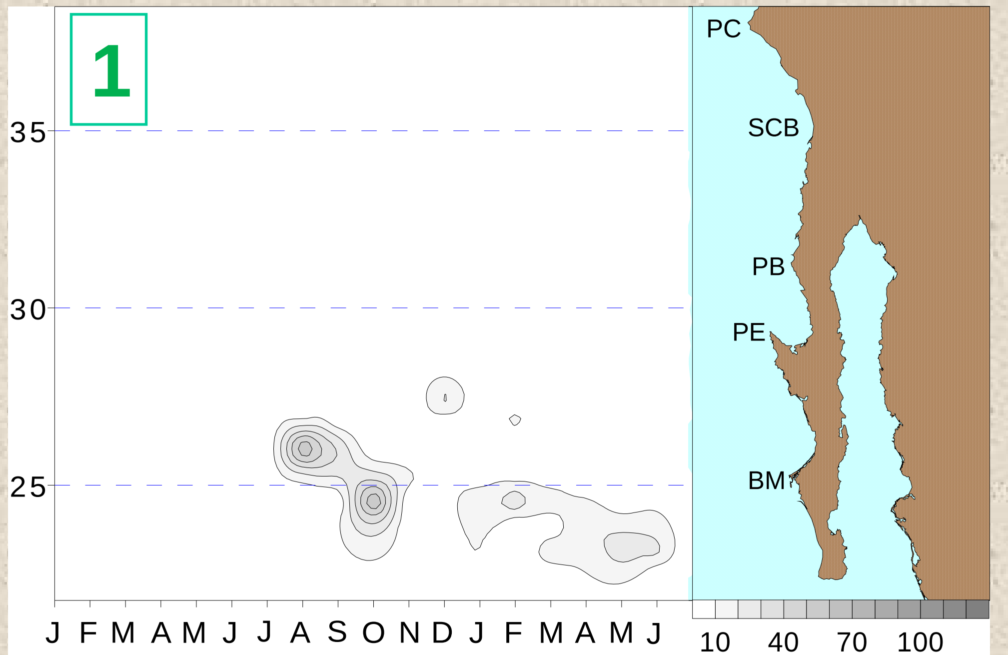


Fig. 3.2 (co

Monthly variability along the coast for the average **Pre-Niño-82 year**

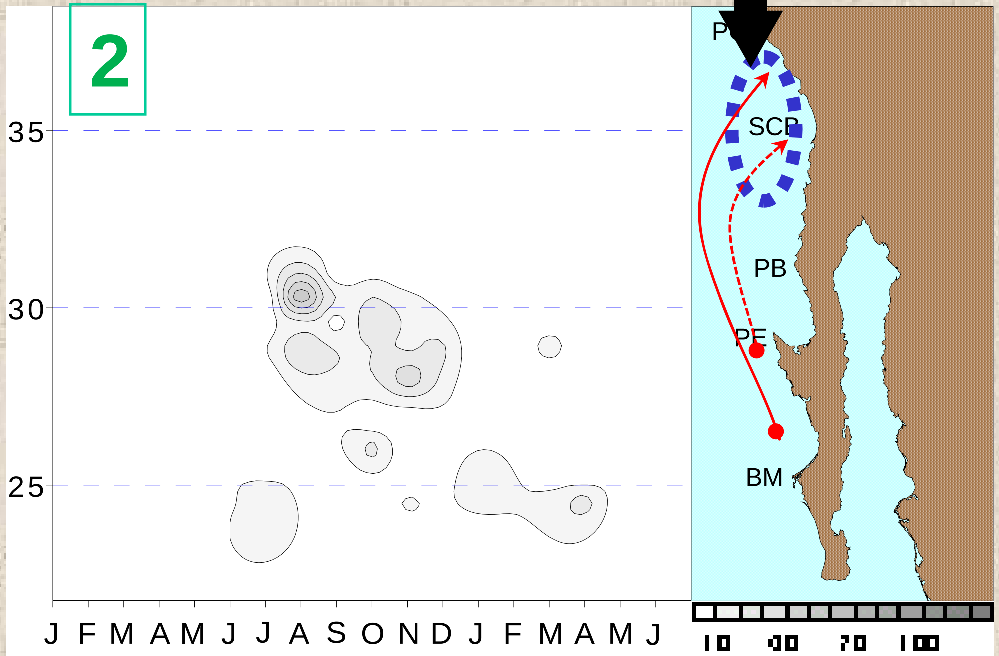


- Spawning season: Summer
- Northward migration of adult sardine (tagging information)

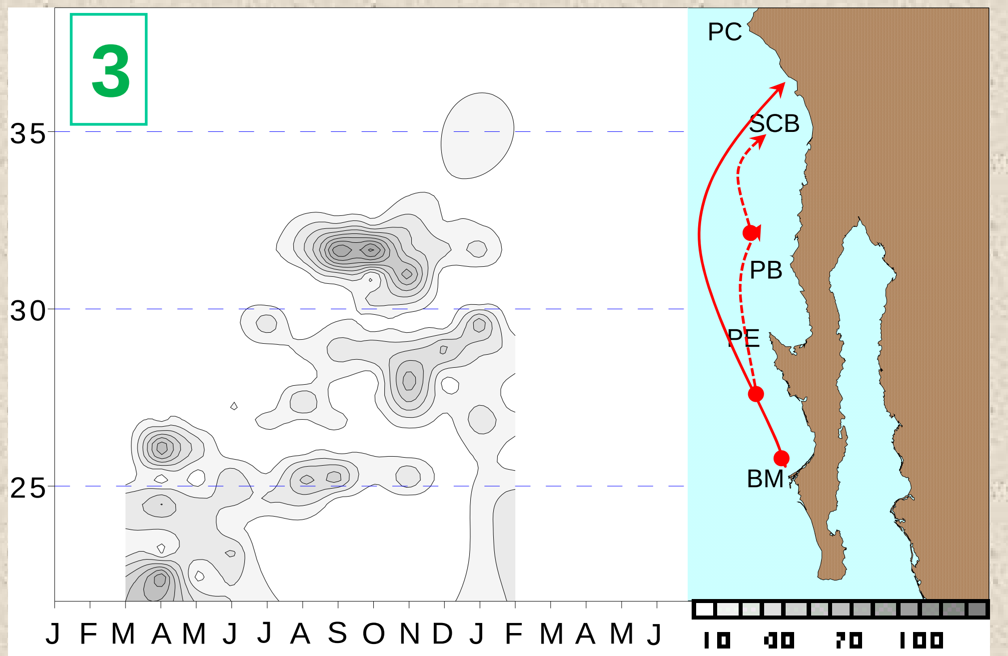


Monthly variability along the coast
for the average **Pre-Niño-82 year**

Sardine eggs and larvae increased (Lavenberg 1986)
but NO RECORDS OF YOUNG SARDINE

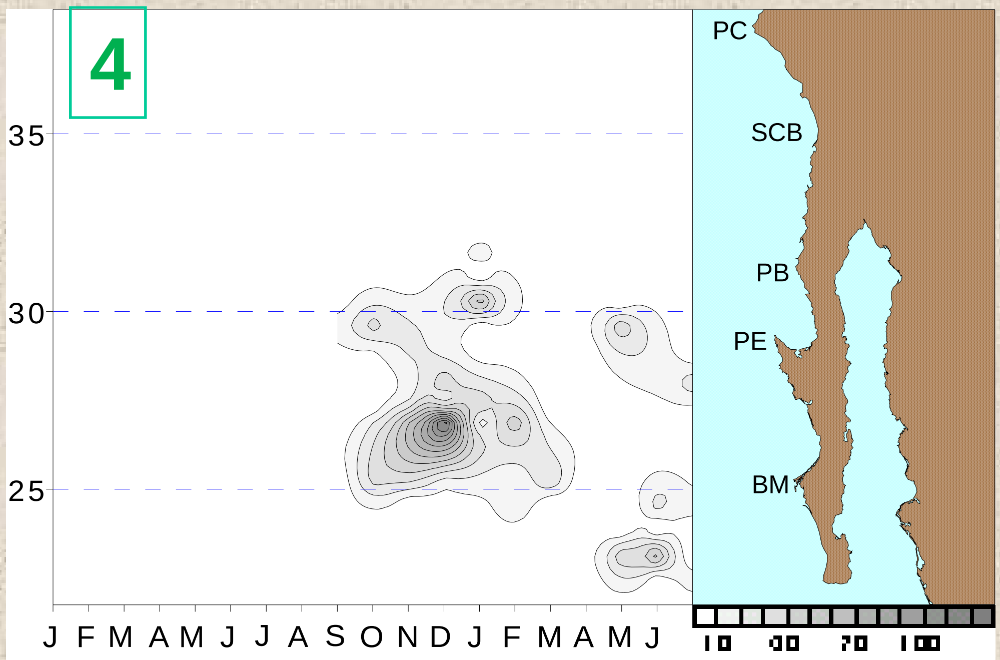


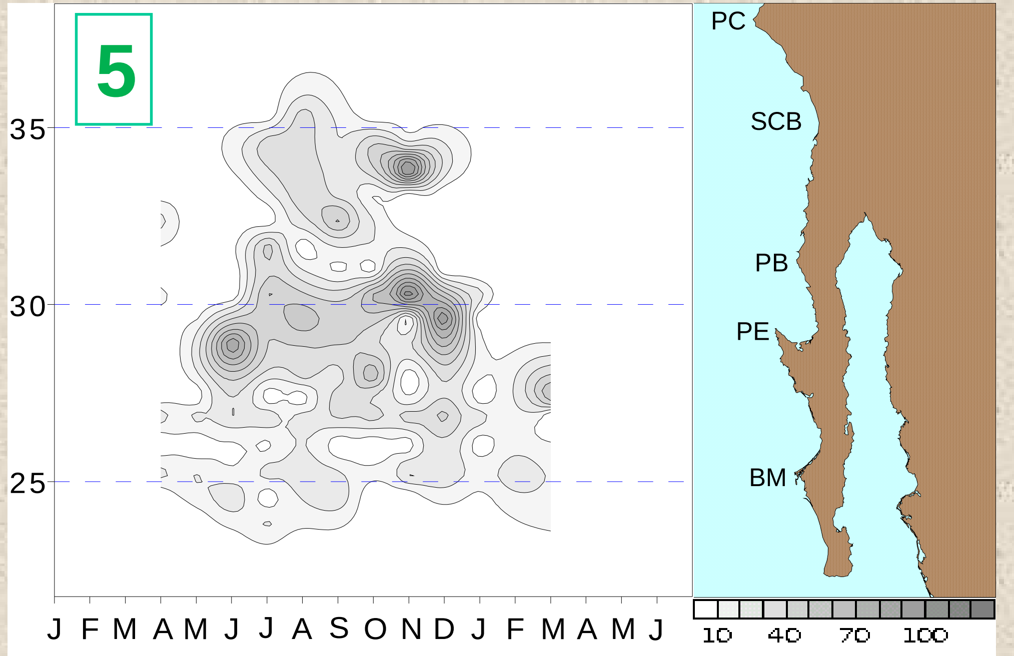
Monthly variability along the coast
for the average **El Niño-82 year**



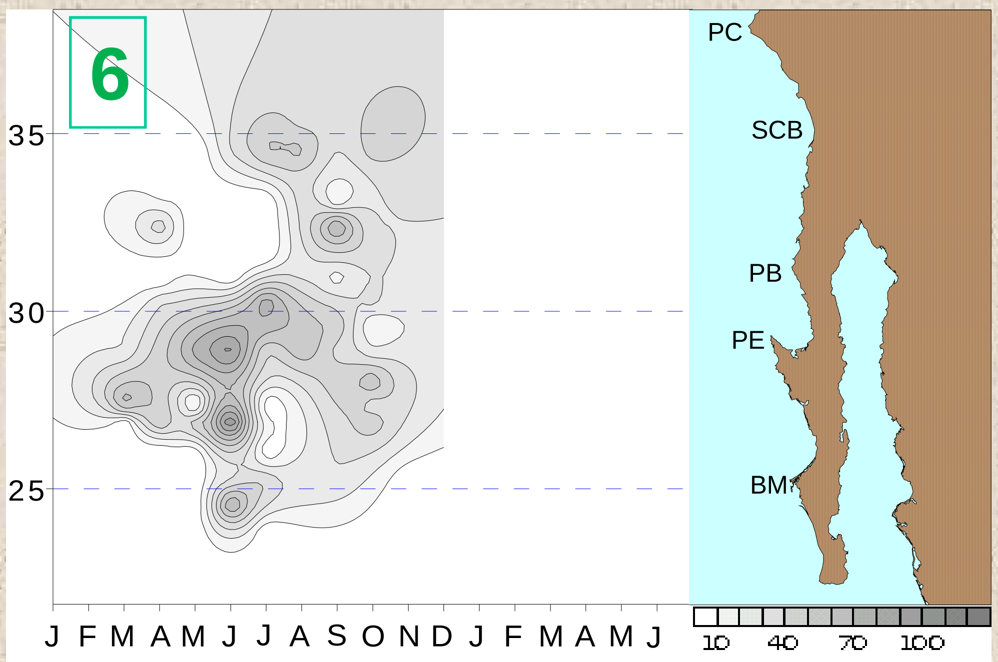
Monthly variability along the coast
for the average **Post-Niño-82 year**

Monthly variability along the coast
for the average **La Niña-88 year**

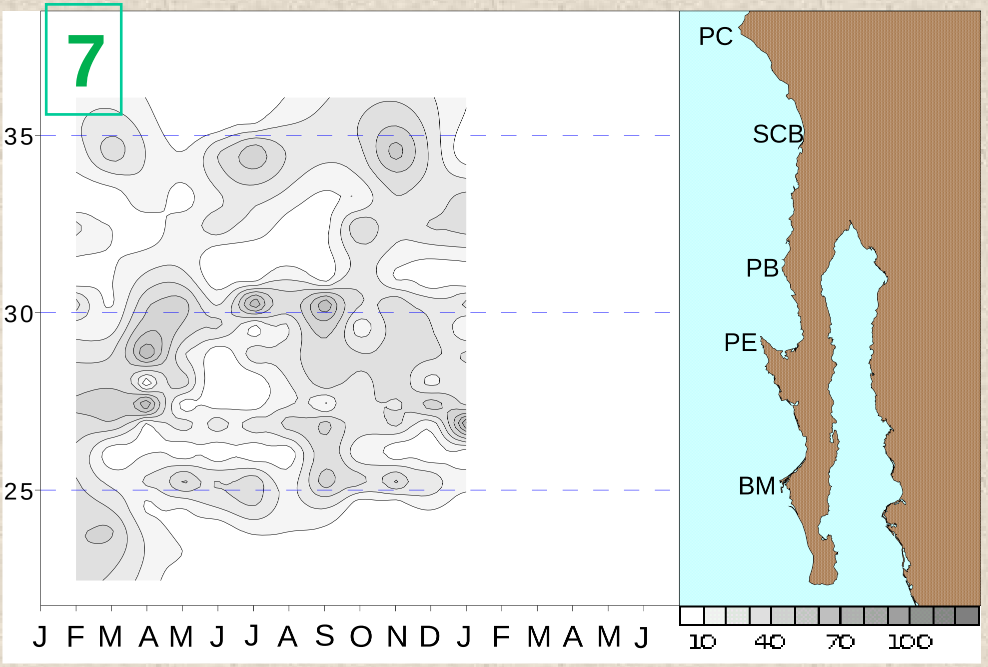




Monthly variability along the coast for the average **Pre-Niño-92 year**



Monthly variability along the coast for the average **El Niño-92 year**



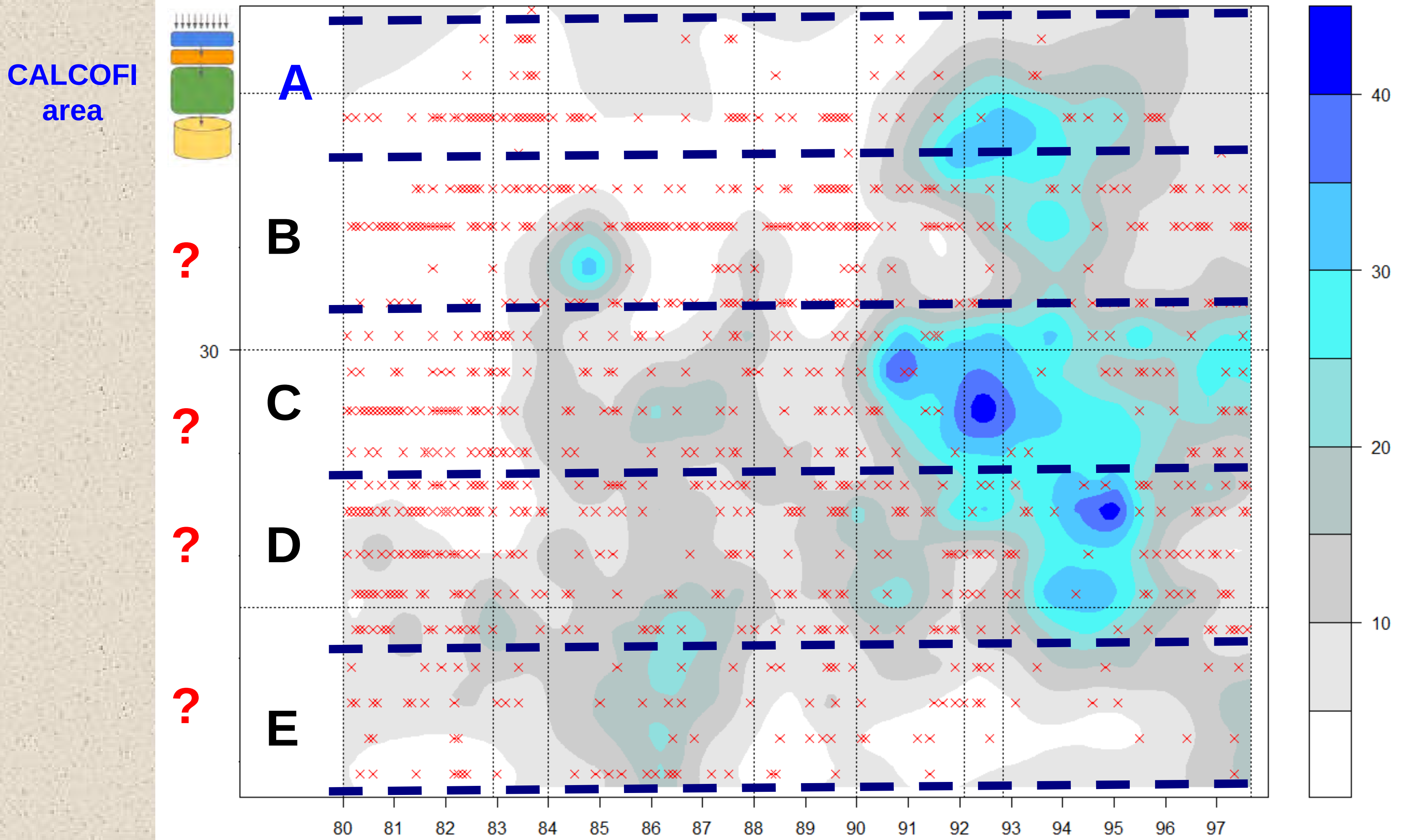
Monthly variability along the coast for the average **Post-Niño-92 year**

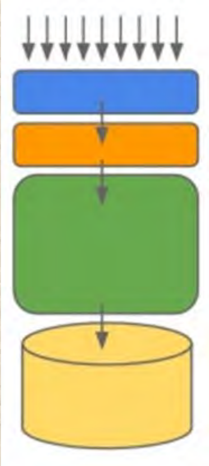
PARCIAL CONCLUSIONS:

Interannual spatial variability of:

- Migration circuits
- Reproduction areas
- Recruitment areas
- The observed shifts suggest that optimal environmental conditions may have to shift over time and space (**S**liding of the **Op**timal **H**abitat-**I**ntegrated **W**indow: **Sophi-W**)

Present way of performing analysis over time-scale of environmental drivers on sardine population

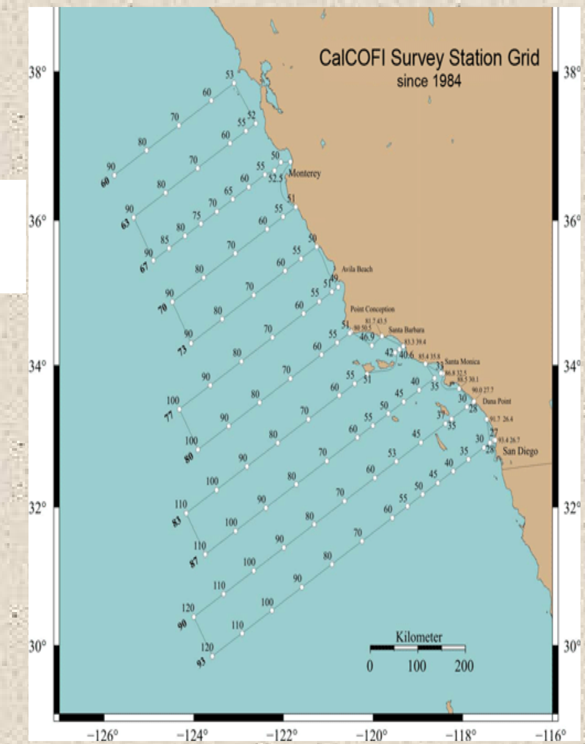




Area A

$$\ln\left(\frac{\hat{p}}{1-\hat{p}}\right) = te(SST, \ln(CHL)) + te(GRAD, \ln(CHL)) + s(CSI),$$

Model for CALCOFI area



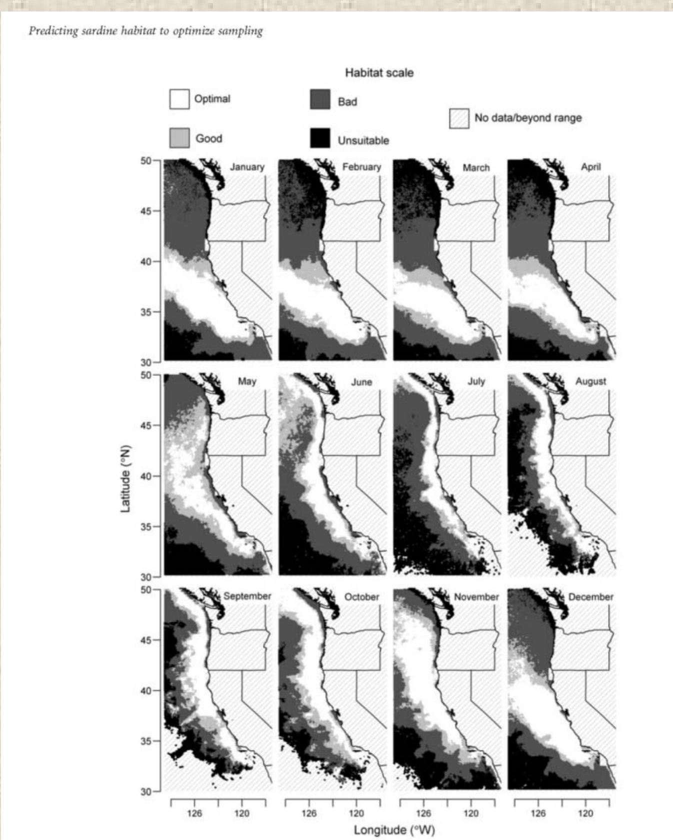
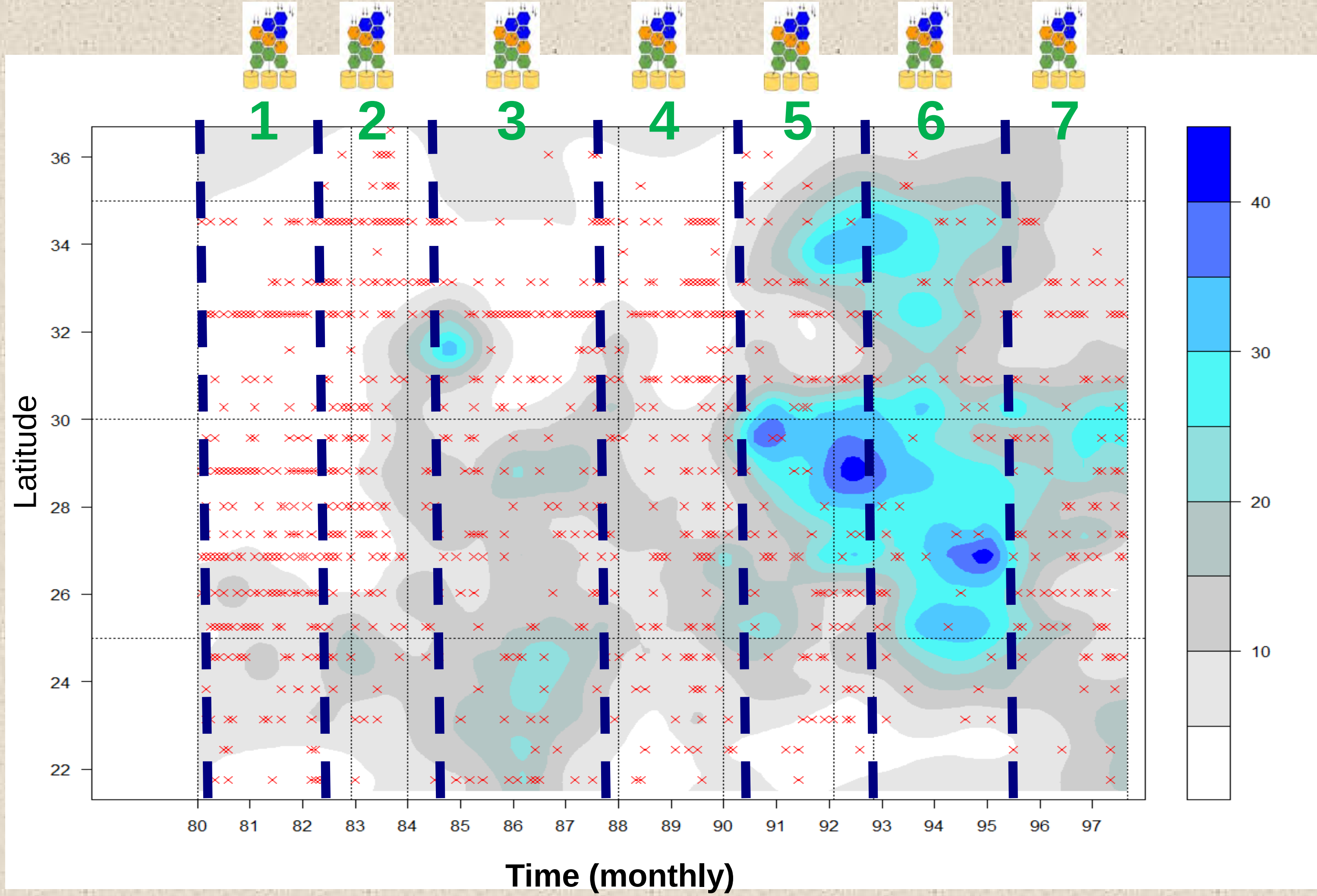


Figure 7. Monthly average sardine habitat, 1998–2009, predicted from the selected GAM [Equation (1)].

Example:
Zwolinski, et al. (2011). Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science **68**(5): 867-879

- **12-year dataset** (presence/absence of sardine eggs)
- concomitant remotely sensed oceanographic
- **A probabilistic generalized additive model is developed to predict spatio-temporal distributions of habitat for the northern stock**
- **The model accurately predicts the habitat and seasonal migration pattern of sardine, irrespective of spawning condition …. FOR A PART OF THE TOTAL SARDINE DISTRIBUTION in the LME**

Proposed analyses to identify and understand the effects of environmental drivers on sardine population over time and space that may result in discrete-time environment-abundance models for *Sardinops* sagax in the California Current - Large Marine Ecosystem.

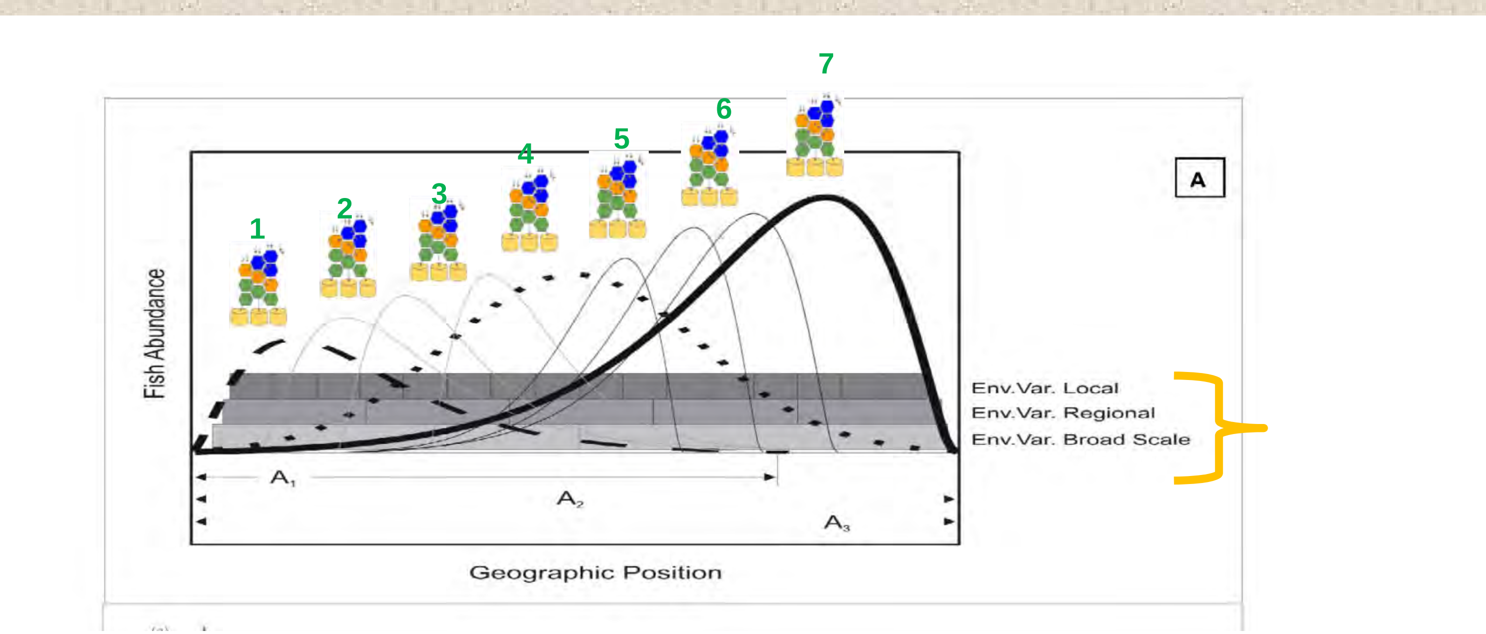


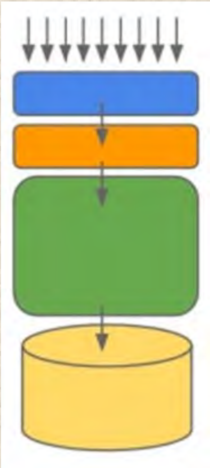
I) Integration of **available climate/ocean variables for construction of models**:

- Local variables
- Regional Indices
- Broad Scale Indices

- McFarlane et al. (2000). **Have there been recent changes in climate? Ask the fish**. Progress in Ocean.47(2-4): 147-169.
- If large scale, ongoing prediction is the goal, the kinds of data that can be used are often restricted to those that are available, since a prediction based on a unique data set (e.g. SST) may not have ongoing utility.

Conceptual model about the Sliding of the Optimal-Habitat Integrative-Window (SOpHI-W) that sardine population follows when is growing and shifting to the North

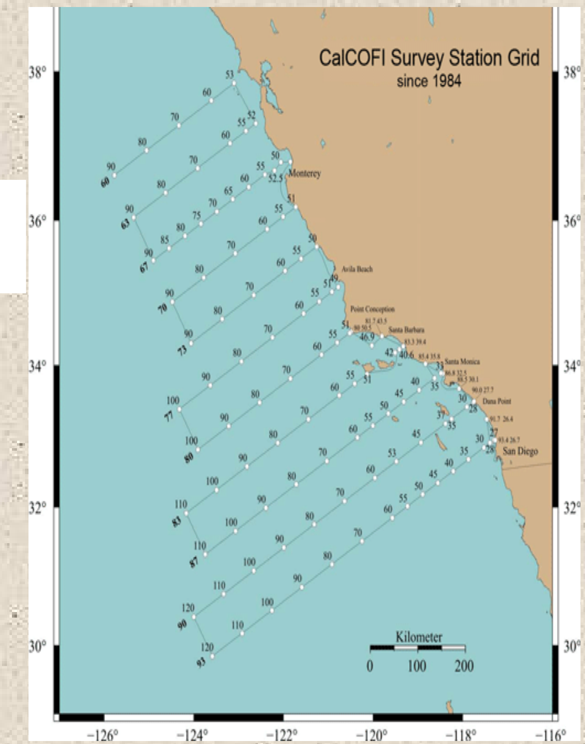




Area A

$$\ln\left(\frac{\hat{p}}{1-\hat{p}}\right) = te(SST, \ln(CHL)) + te(GRAD, \ln(CHL)) + s(CSI),$$

Model for CALCOFI area



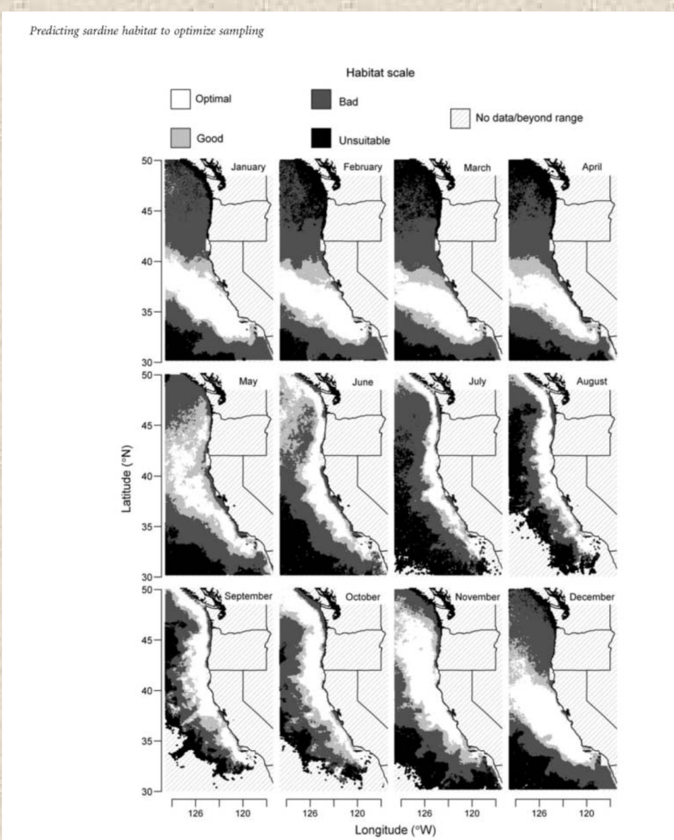
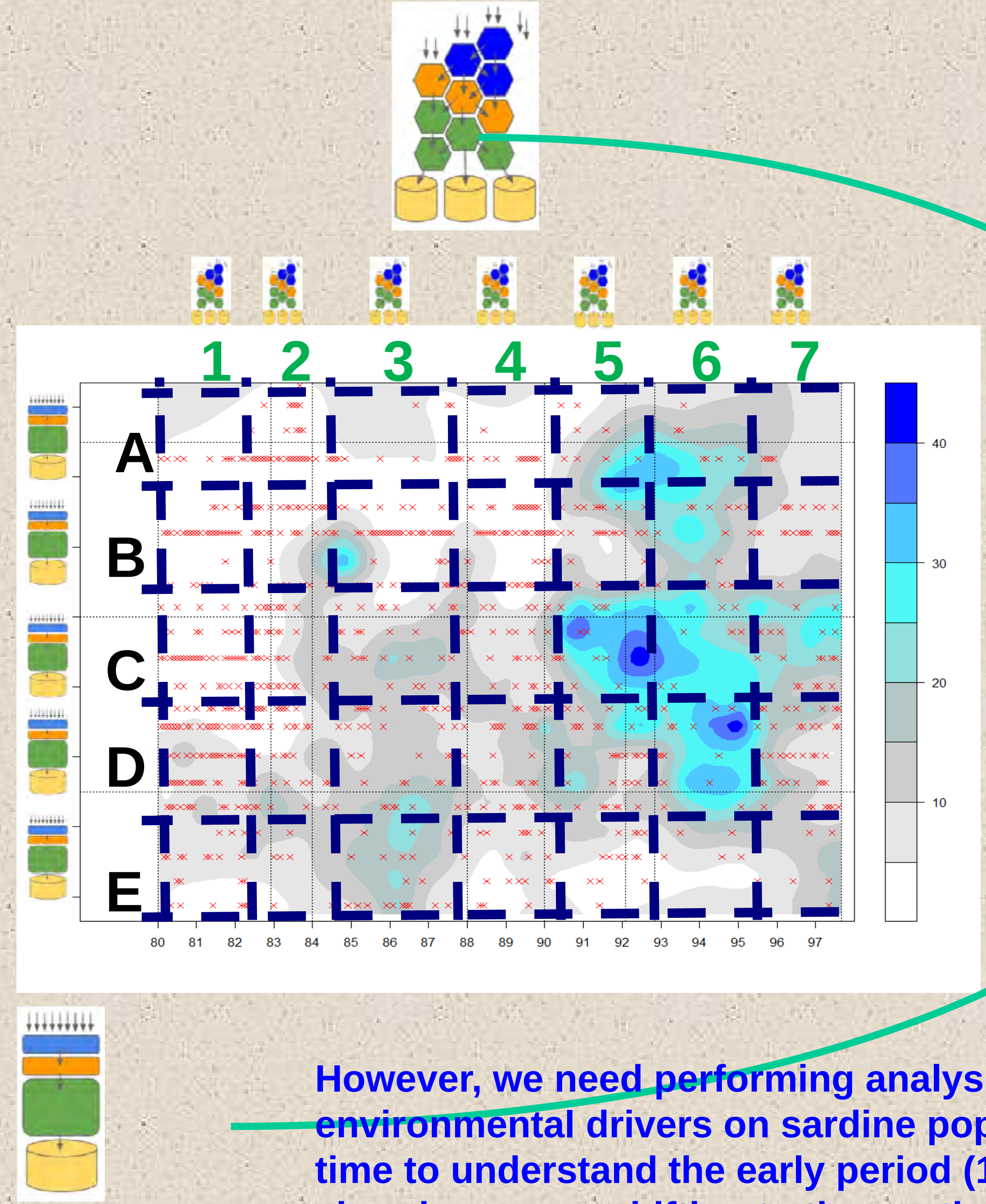


Figure 7. Monthly average sardine habitat, 1998–2009, predicted from the selected GAM [Equation (1)].

Zwolinski, et al. (2011). Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science **68**(5): 867-879

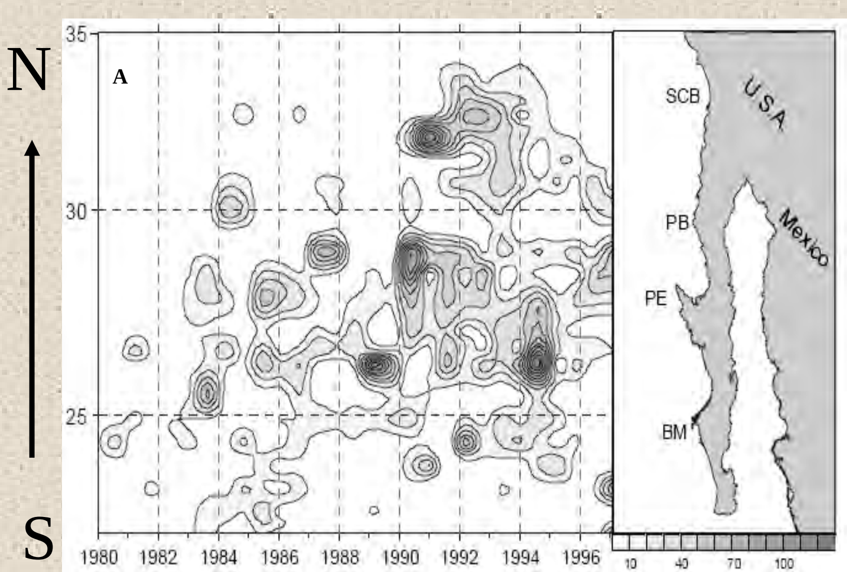
- **12-year dataset** (presence/absence of sardine eggs)
- concomitant remotely sensed oceanographic
- **A probabilistic generalized additive model is developed to predict spatio-temporal distributions of habitat for the northern stock**
- **The model accurately predicts <u>the habitat and seasonal migration pattern of sardine, irrespective of spawning condition</u>**

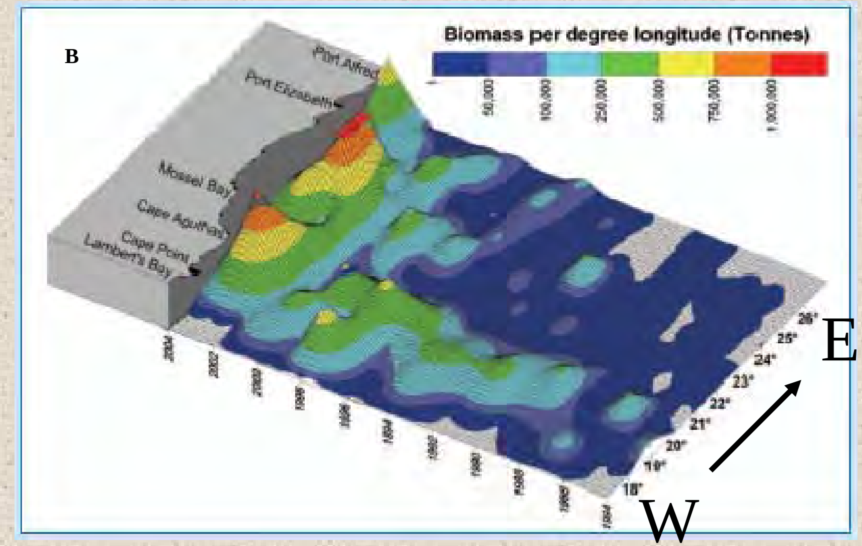


Integrated Spatial Model

However, we need performing analysis over time-scale of environmental drivers on sardine population in order to back in time to understand the early period (1931- 1979) when the sardine abundance was shifting to the south.

An ecologically interesting question is whether such a correlation in data sets taken over one period of time or in one region will be equally satisfactory at future times or in other regions. The relations could well be altered by genetic adaptations of the populations to their many interactions in any ecosystem



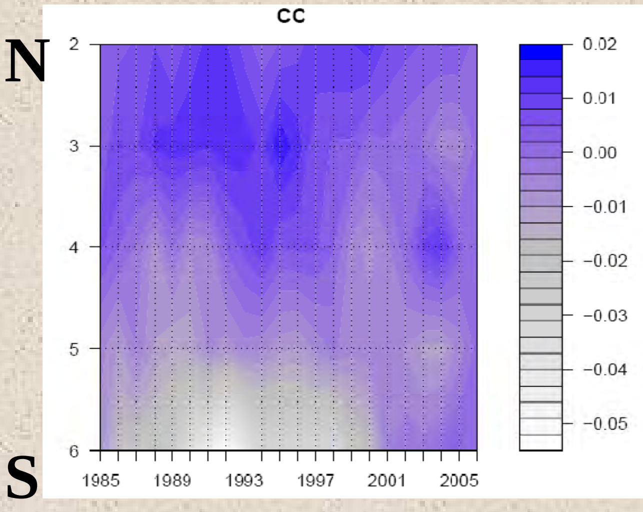


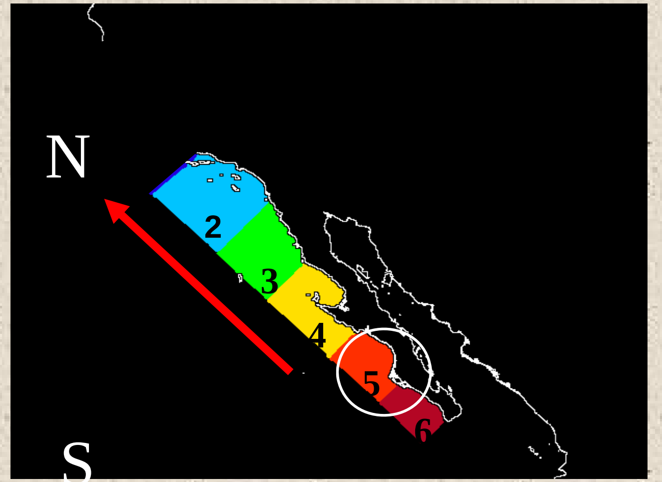
A) California Current system
Northward shift (1984-1997)

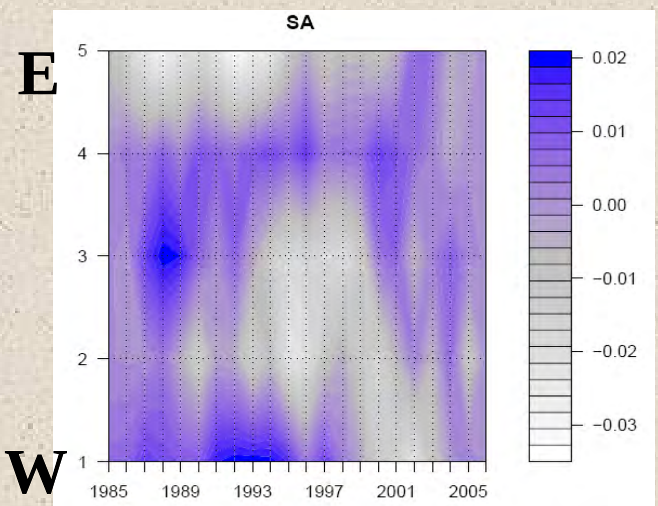
B) Southern Benguela system
Eastward shift (1984-2004)

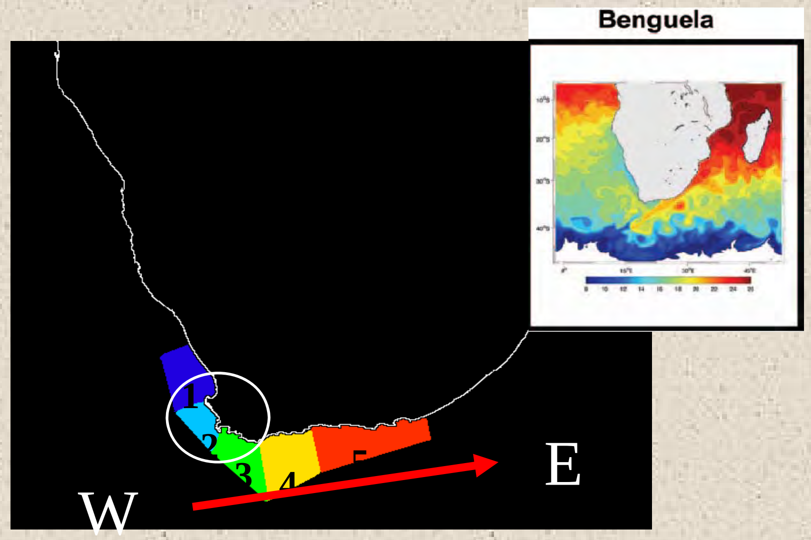
II) Construction of a mechanistic variable that explain changes of abundance in space and time (e.g. FRONTS)

- **Geographical variability of Front Index anomalies over time**









Main conclusions

1) Interannual shifts of seasonal-scale biological processes are integrated to produce the macro-scale changes in abundance that we observe.

Analogy:

- In physical oceanography is well developed the concept of spectrum of scales, and the transfer of variation from one scale to another along this spectrum.
- That is, known hydrodynamic processes cause variance stimulated at one spatial/temporal scale to spread through the spectrum to other scales

Main conclusions

2) The observed interannual changes on recruitment zones and sardine migratory circuits along the California Current may imply shifts in space and time of the optimal factors/mechanisms that control the major observed shifts in population size and location.


GRACIAS !!!