Progress in small pelagic fish research in the 3½ decades since '*Costa Rica*'

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Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, Florida
USA

"… without speculation there is no good and original observation"

Charles Darwin, Letter to A. R. Wallace (22 Dec 1857)

In the decade following the Second World War, a burst of creative activity by expert applied mathematicians (Beverton, Holt, Ricker and others), without very much knowledge of the actual processes and mechanisms involved in the dynamics of marine ecosystems, produced a beautifully ingenious framework for making fishery management decisions largely based on terrestrial analogies (i.e., perhaps equally applicable to deer in patch of forest, or to fish in a lake or garden pond)

Corten, A. 2013. Recruitment depressions in North Sea herring. – ICES Journal of Marine Science, 70: 1–15.

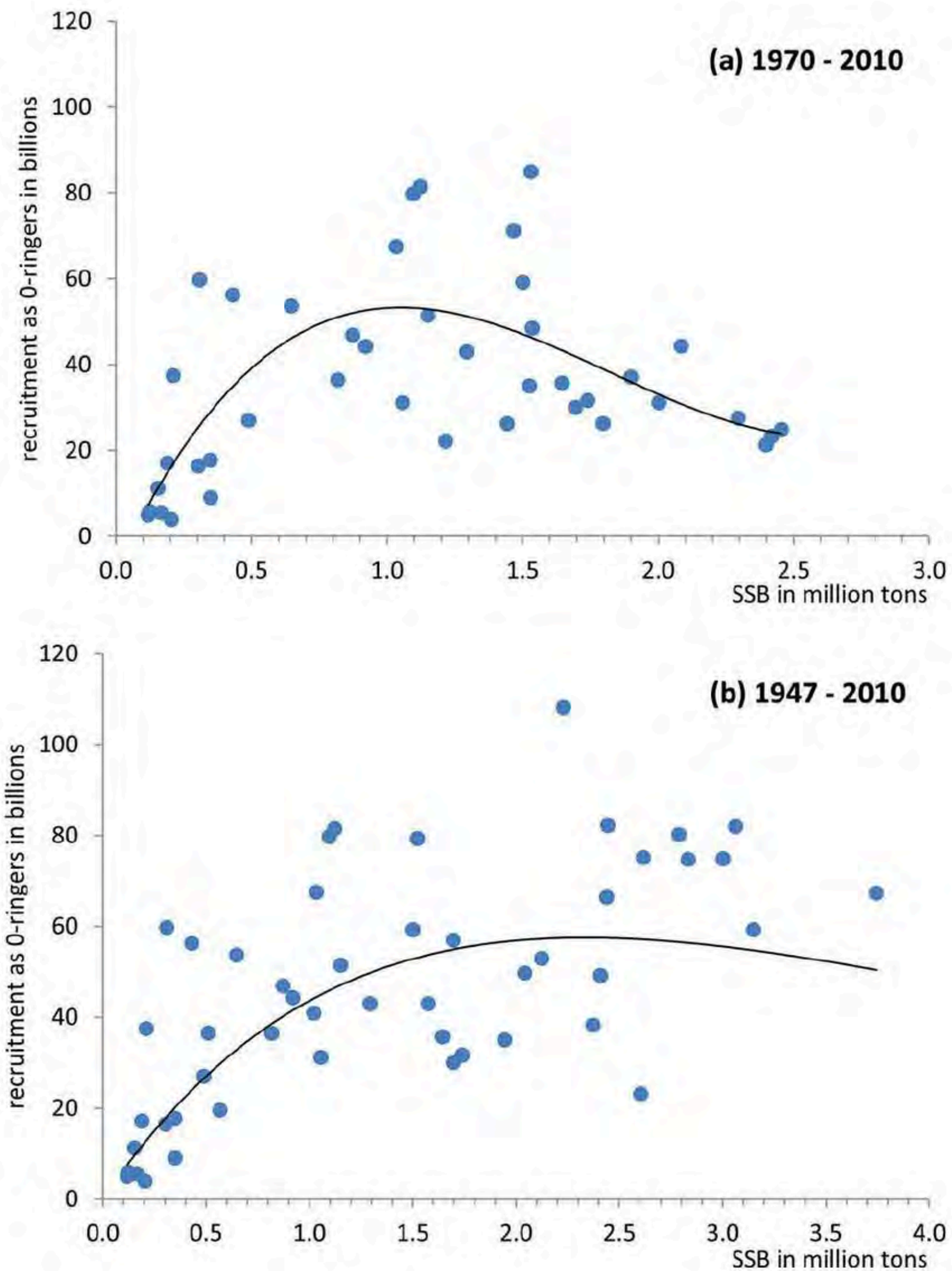

Figure 9. Ricker curves describing the stock–recruitment relationship for North Sea herring for the most recent years (1970 – 2010) and for the entire period for which data are available (1947 – 2010). Data from ICES (2012).

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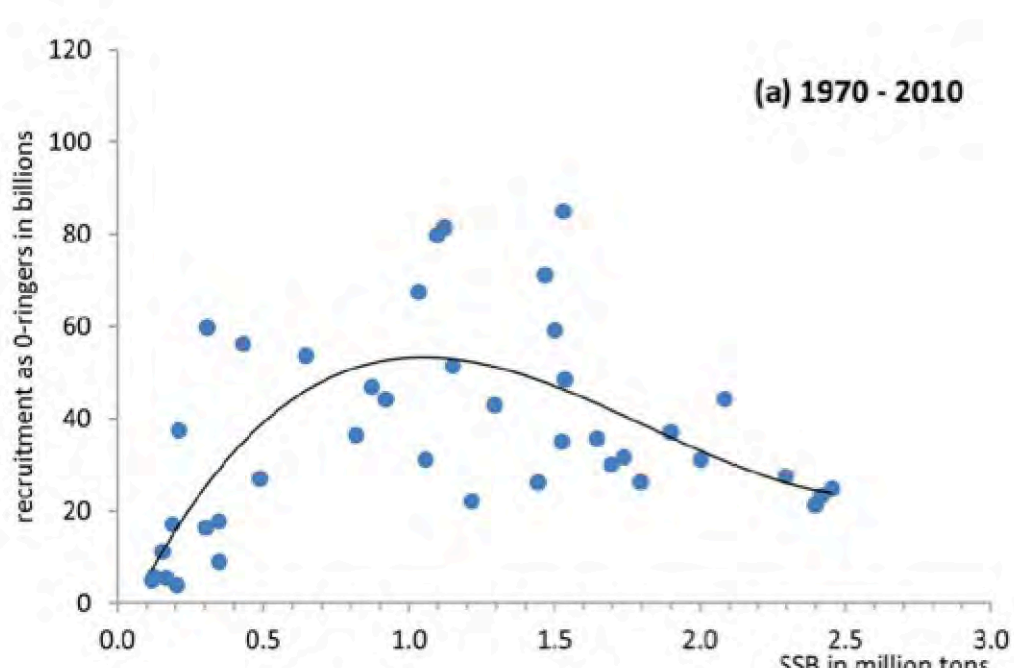
But this framework has been far from uniformly successful. Reliable prediction continues to elude us and unexpected "surprises" continue to decimate our fishing industries and the coastal communities that rely on them.



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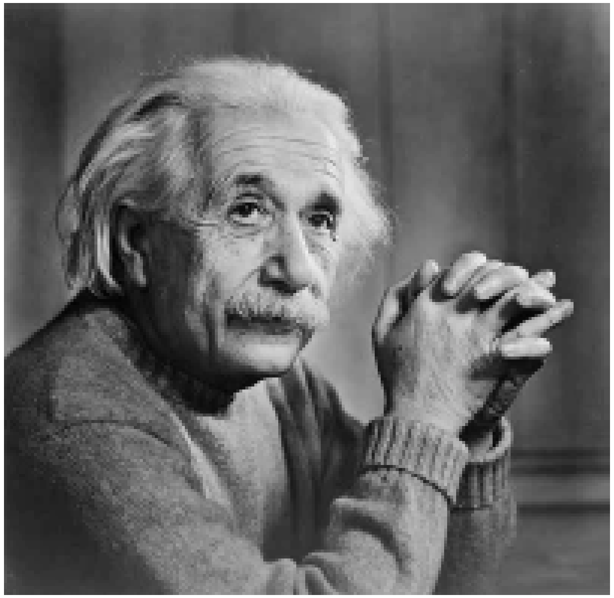
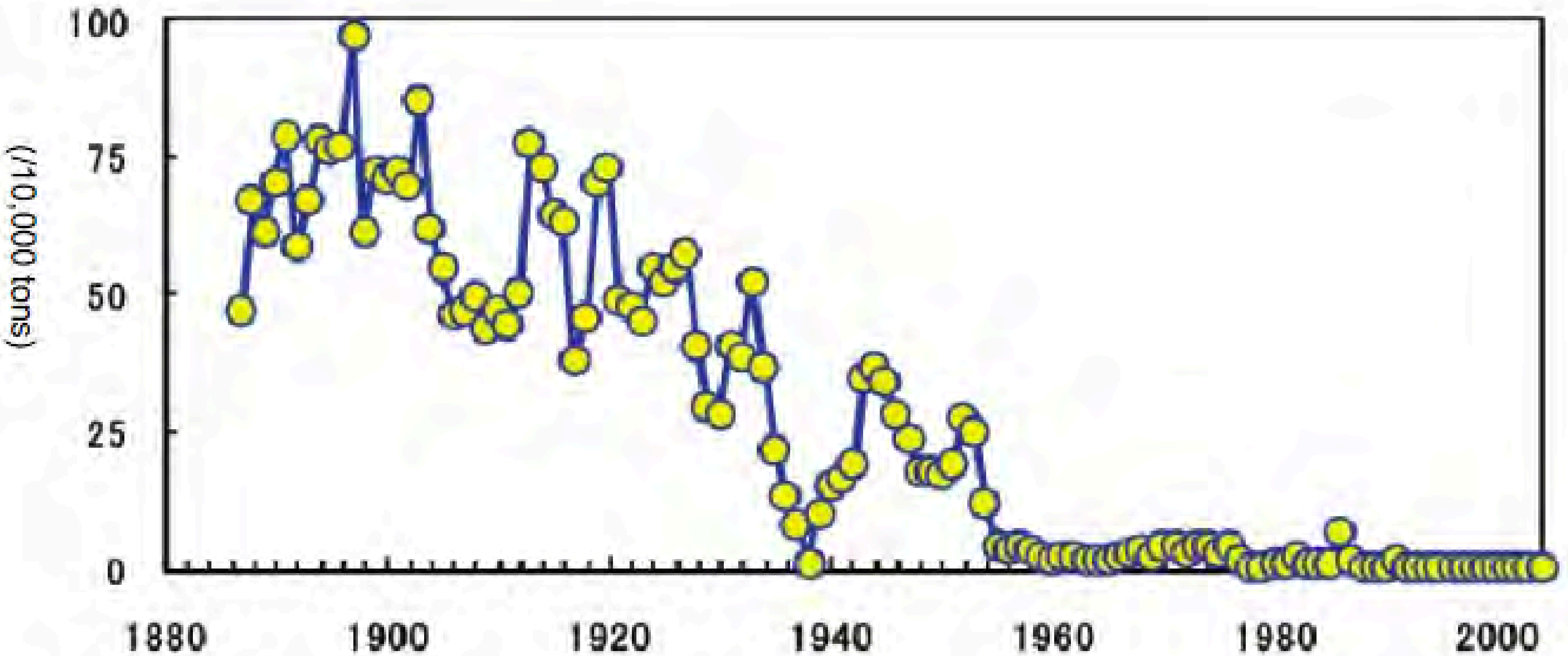


"Everything should be made as simple as possible, but not simpler."

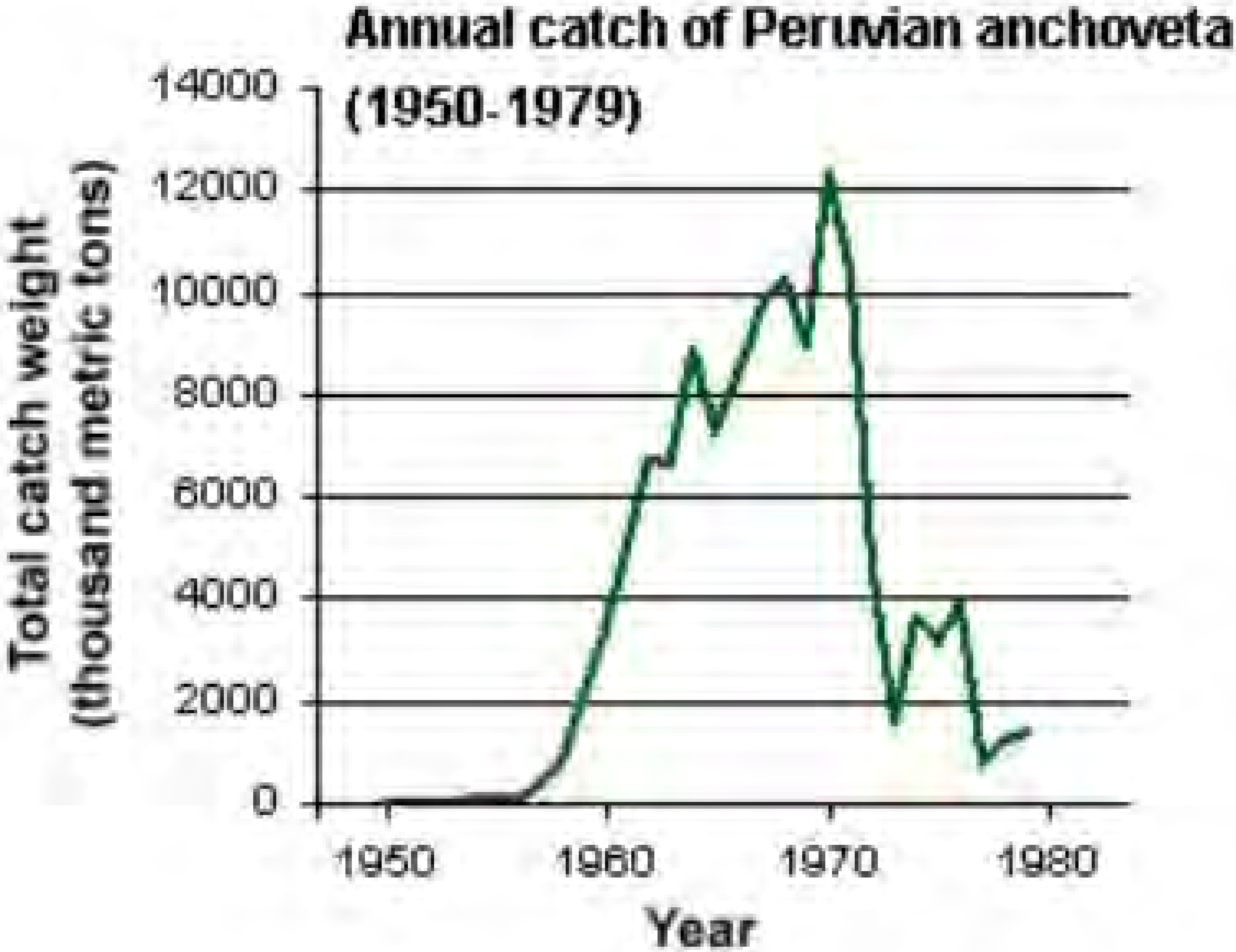
Albert Einstein

Major Jomon and Epi-Jomon Sites
(5500BP~700 AD) (Nishimoto 1984)

Major Okhotsk, Satsumon, Epi-Satsumon
(Ainu) Sites (700AD~) (Nishimoto 1985)



Fluctuation of herring catch in Northern Hokkaido (Okhotsk and Japan Seas)



Annual catch of Peruvian anchoveta
(1950-1979)
Total catch weight
(thousand metric tons)
14000
12000
10000
8000
6000
4000
2000
0
1950
1960
1970
1980
Year

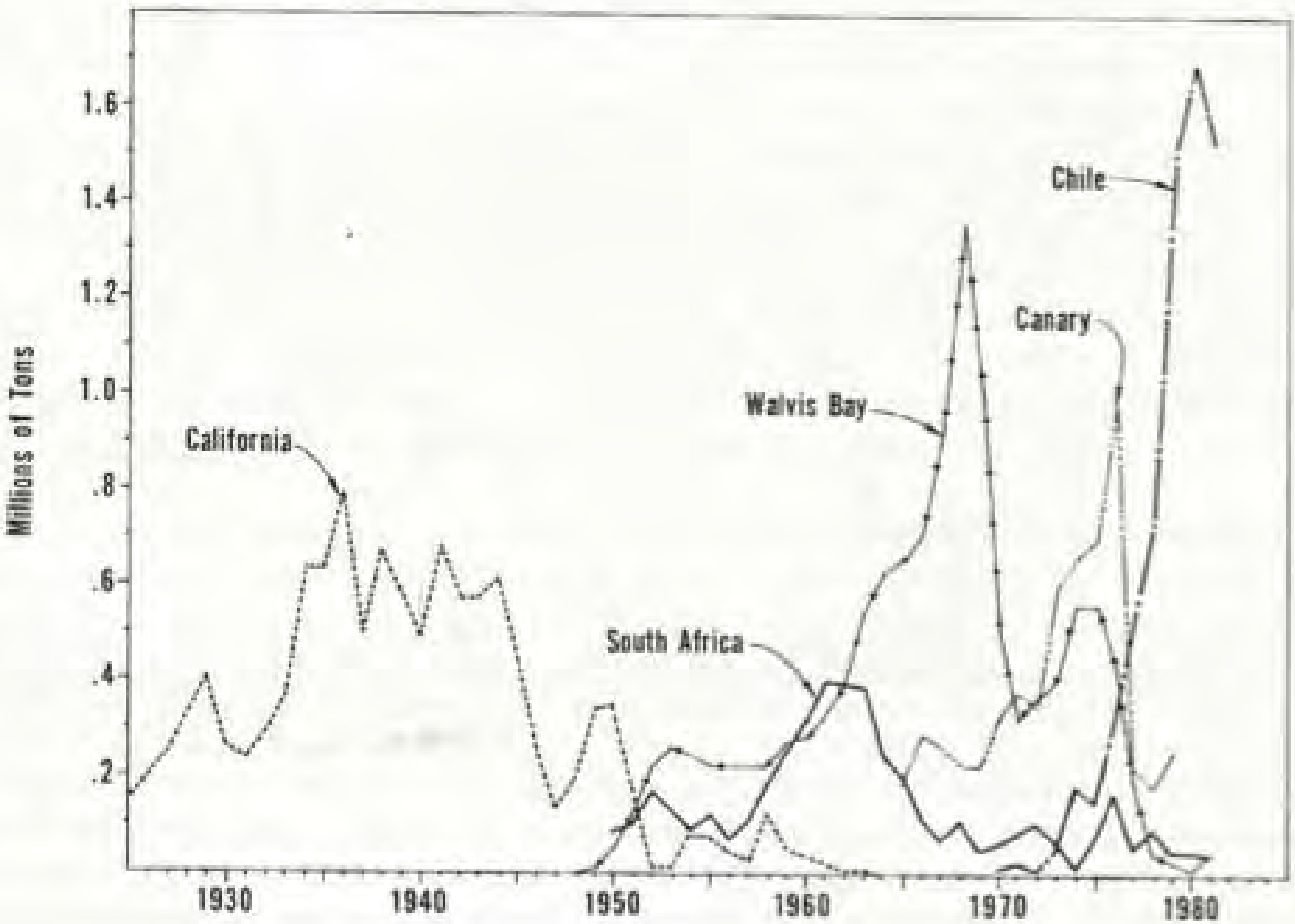


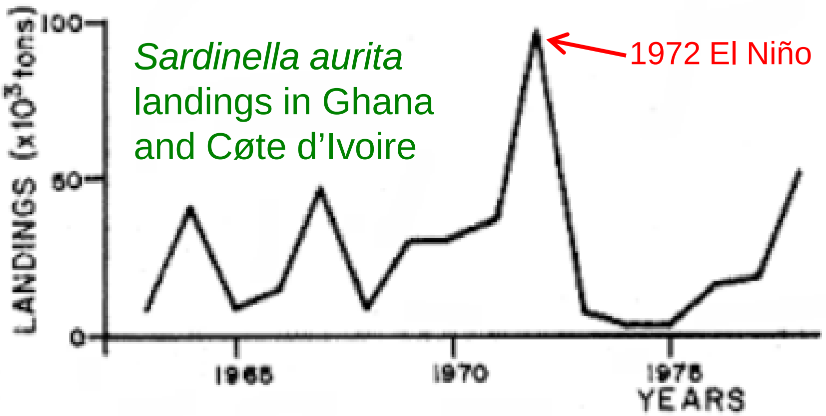
Figure 2. Yearly pilchard (sardine) landings from several eastern boundary current stocks.

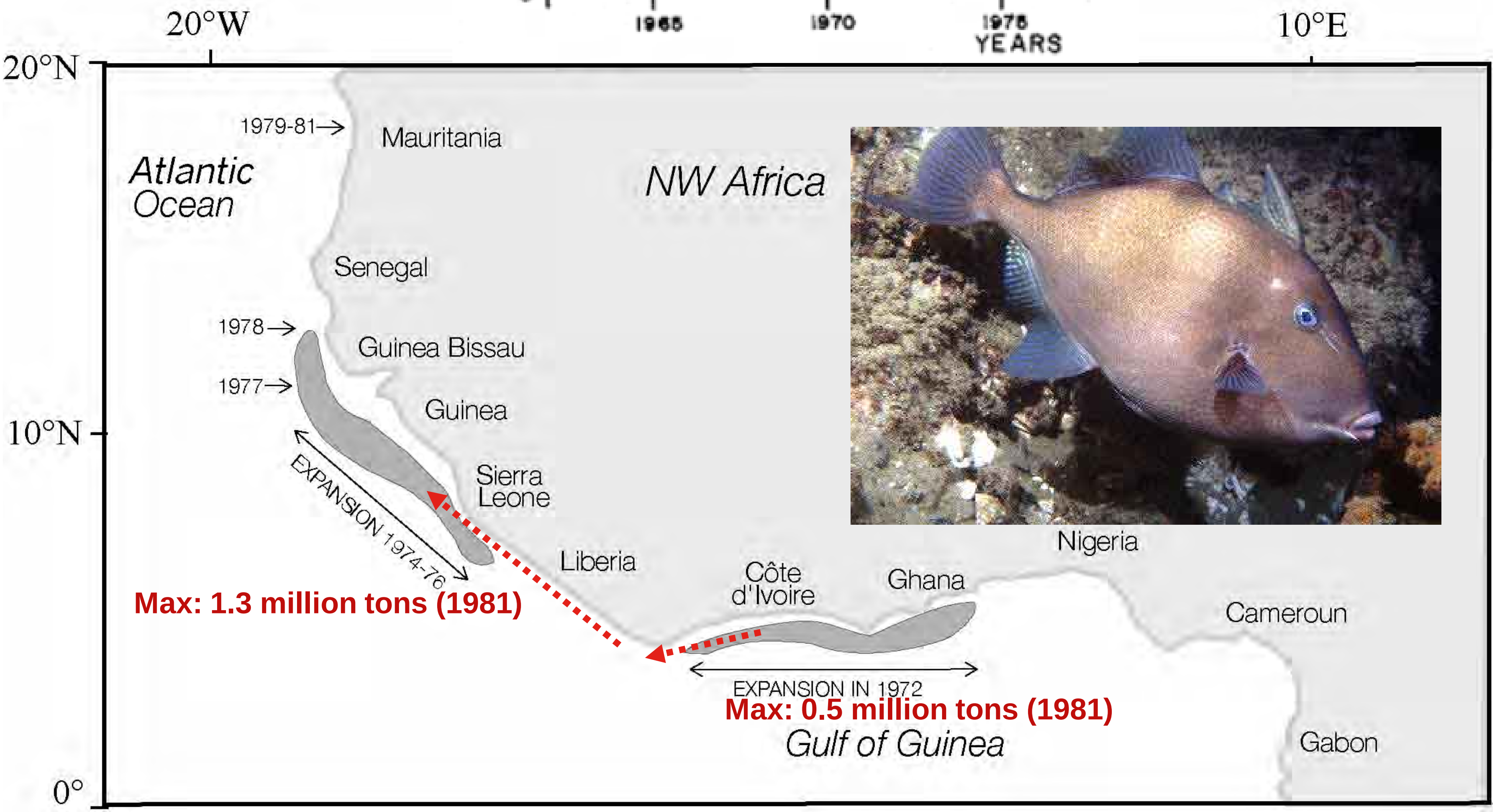
Meanwhile (early 1970s), a million tons* of snipefish suddenly appeared off Morocco

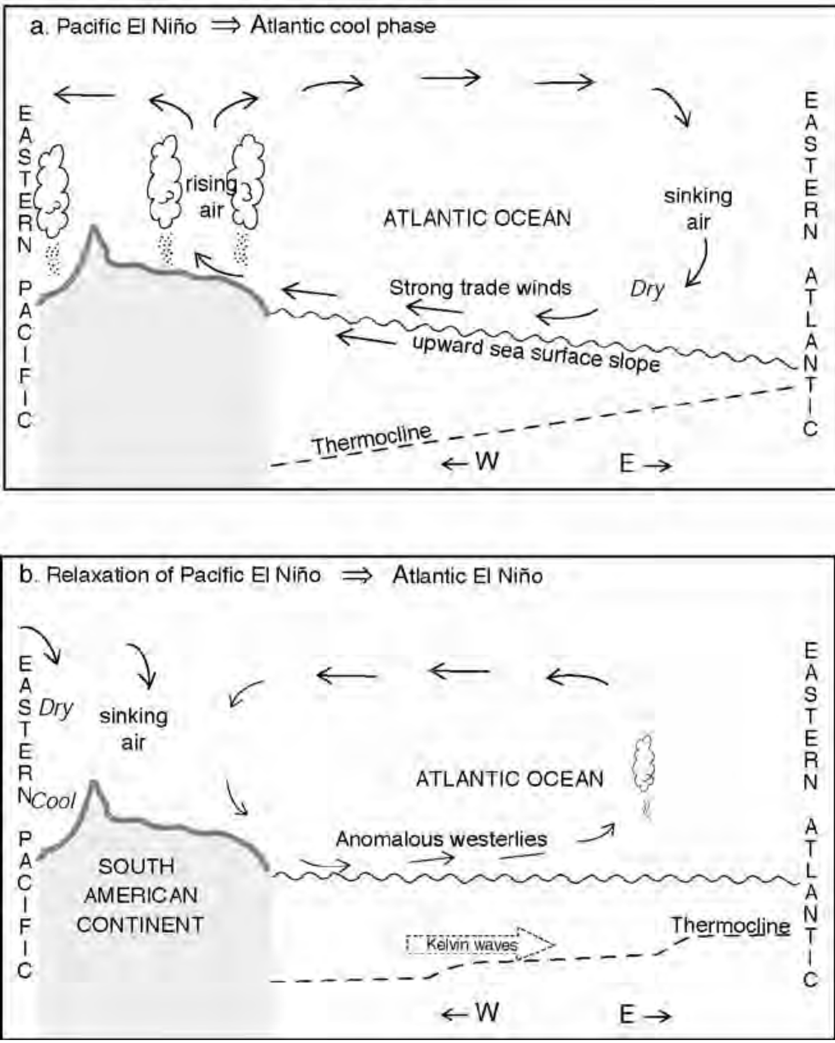
-- then disappeared

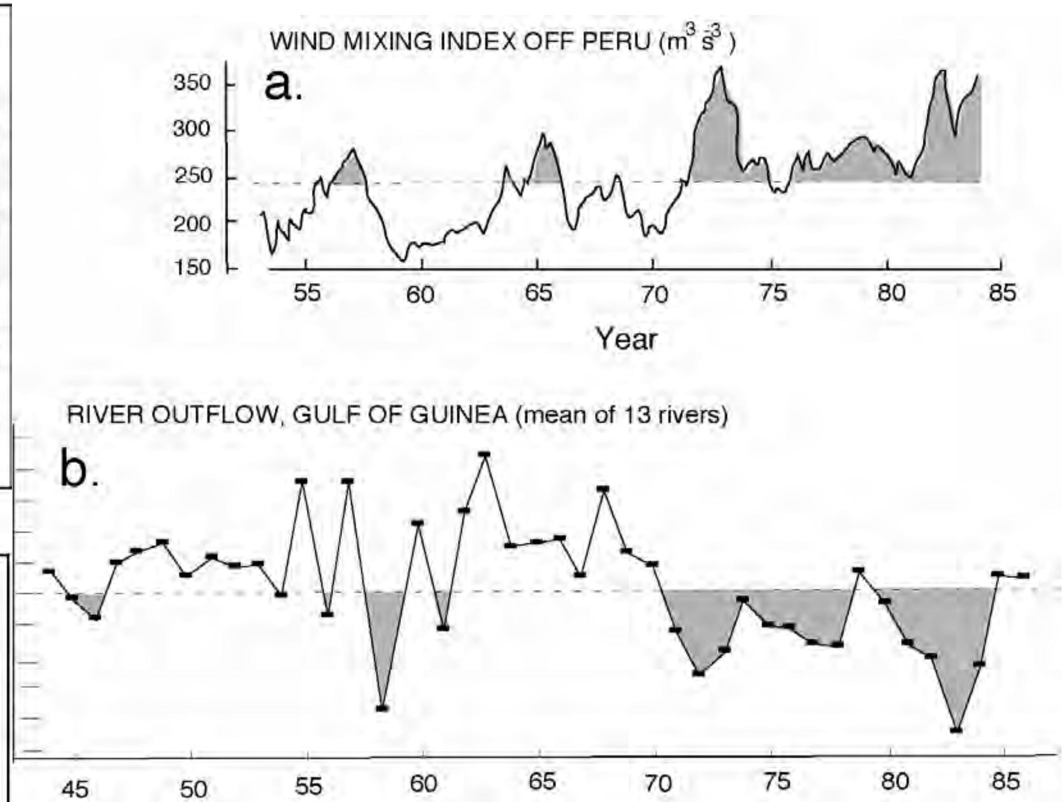
*** representing about a hundred billion (10^{11}) individual fish**

1970s: Triggerfish explosion in the Gulf of Guinea









<u>From:</u>

Bakun, 1996

Csirke, J. & G.D. Sharp (eds). 1984. Reports of the Expert Consultation to examine changes in abundance and species composition of neritic fish resources. San José, Costa Rica, 18– 29 April 1983. A preparatory meeting for the FAO World Conference on fisheries management and development. FAO Fish.Rep., (291) Vol.1: 102 p.

3 volumes,
1224 pages

REPORTS OF THE EXPERT CONSULTATION TO EXAMINE CHANGES IN ABUNDANCE AND SPECIES COMPOSITION OF NERITIC FISH RESOURCES

San José, Costa Rica, 18–29 April 1983

Edited by

J. Csirke[1] and G.D. Sharp[2]
[1]FAO Fisheries Department
[2]P.O. Box 12294, Gainesville, Florida, 32604, USA

A preparatory meeting for the FAO World Conference on Fisheries Management and Development

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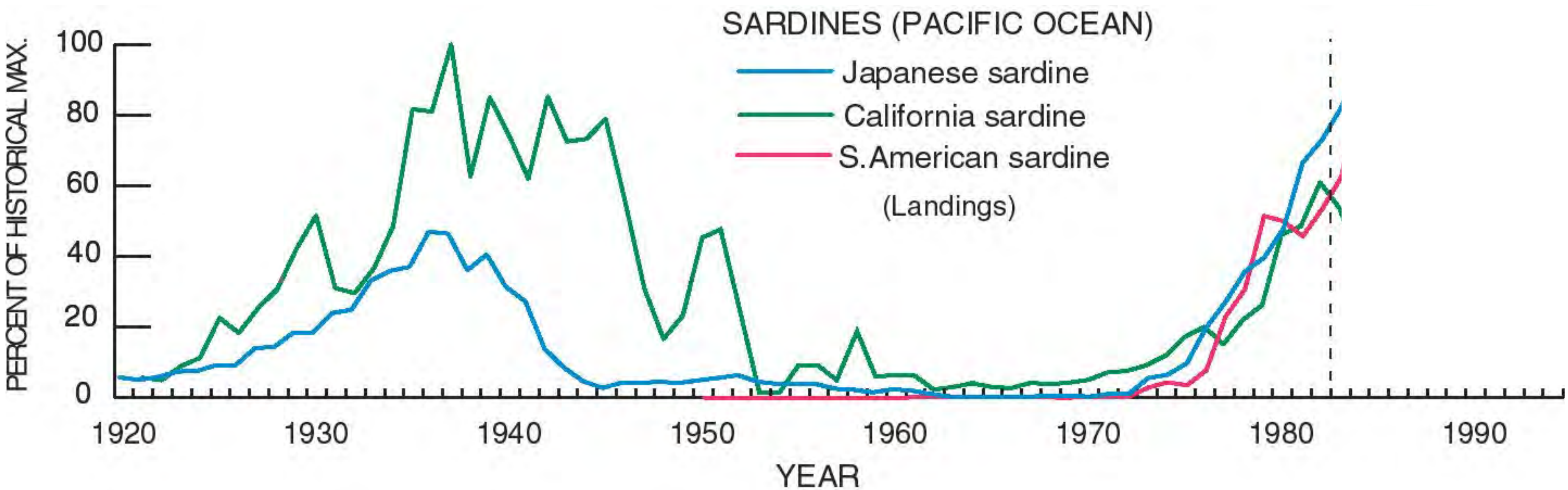
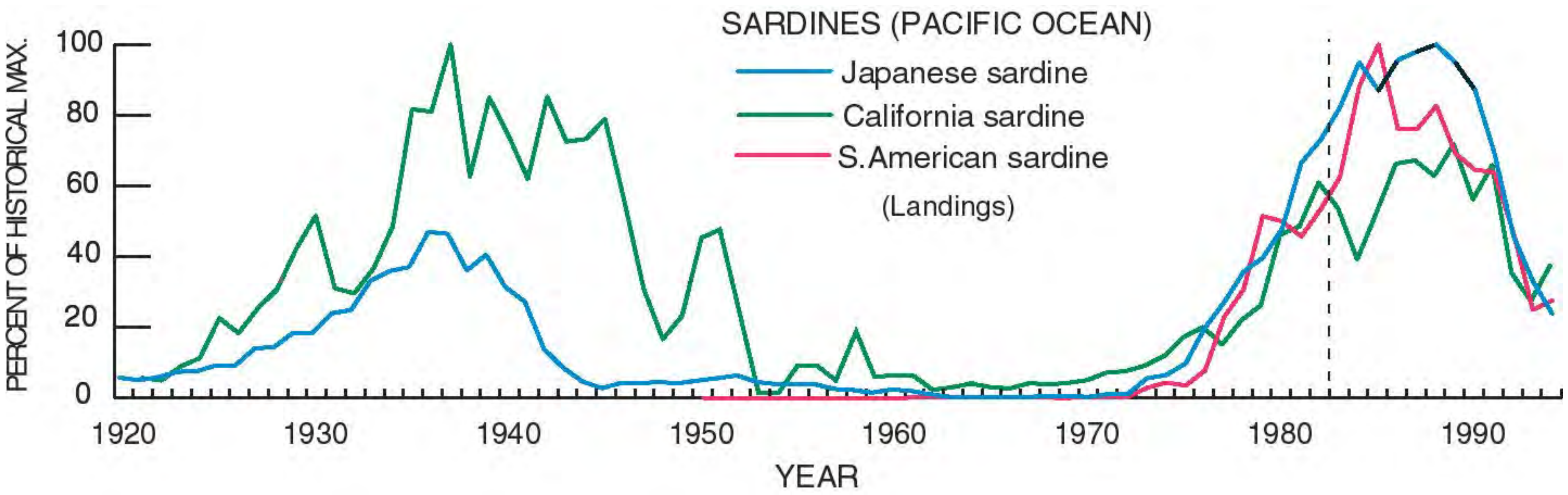
M-43
ISBN 92-5-102097-3

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome 1984


SARDINES (PACIFIC OCEAN)
Japanese sardine
California sardine
S.American sardine
(Landings)
PERCENT OF HISTORICAL MAX.
100
80
60
40
20
0
1920
1930
1940
1950
1960
1970
1980
1990
YEAR



Lluch-Belda, D., R.J.M. Crawford, T. Kawasaki, A.D. MacCall, R.H. Parrish, R.A. Schwartzlose and P.E. Smith (1989) World-wide fluctuations of sardine and anchovy stocks: the regime problem. *South African Journal of Marine Science* **8**, 195-205.

First OSLR-GGE Session
Paris, 16-20 July 1985

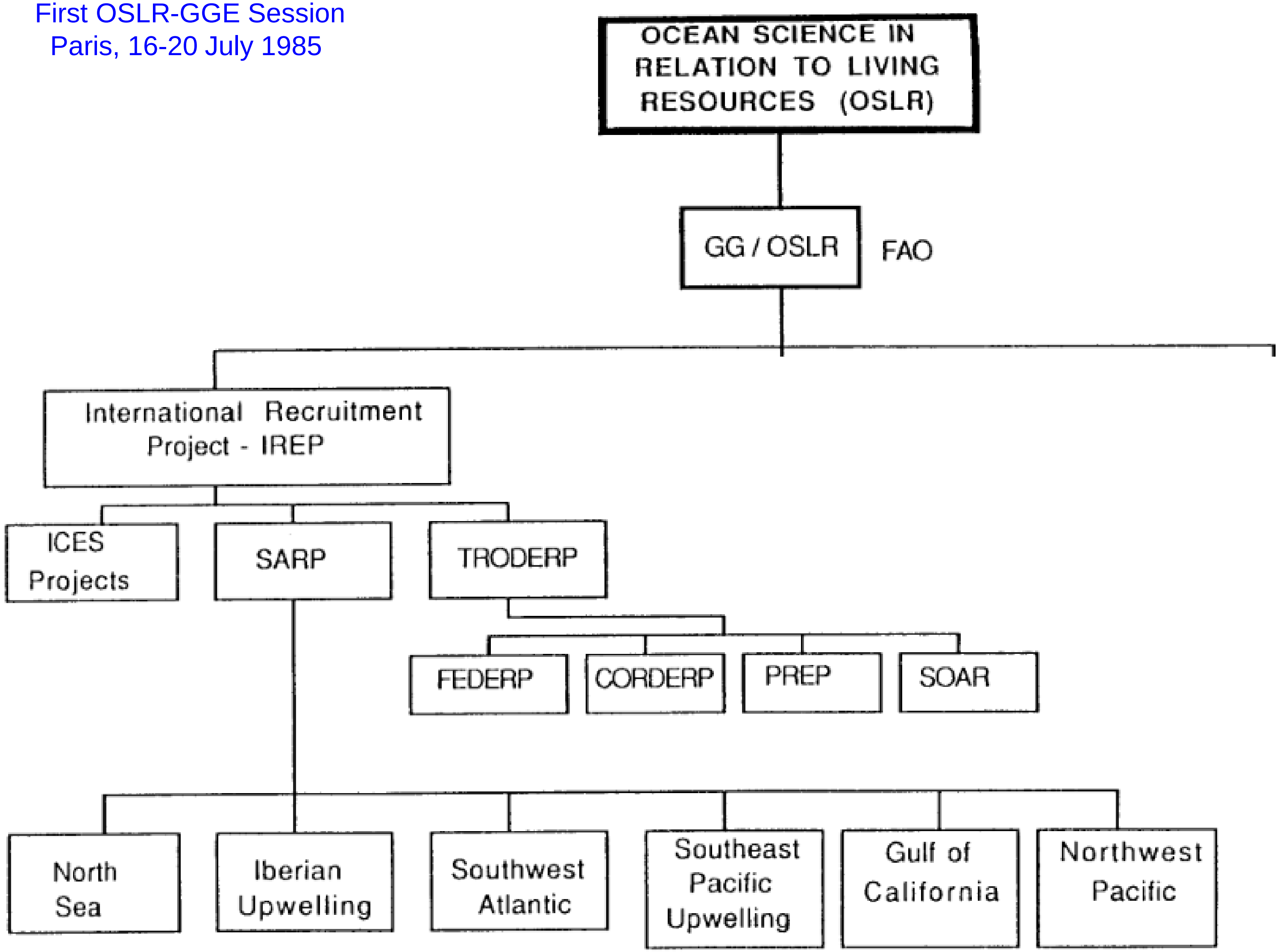


Fig. 1 OSLR and its components

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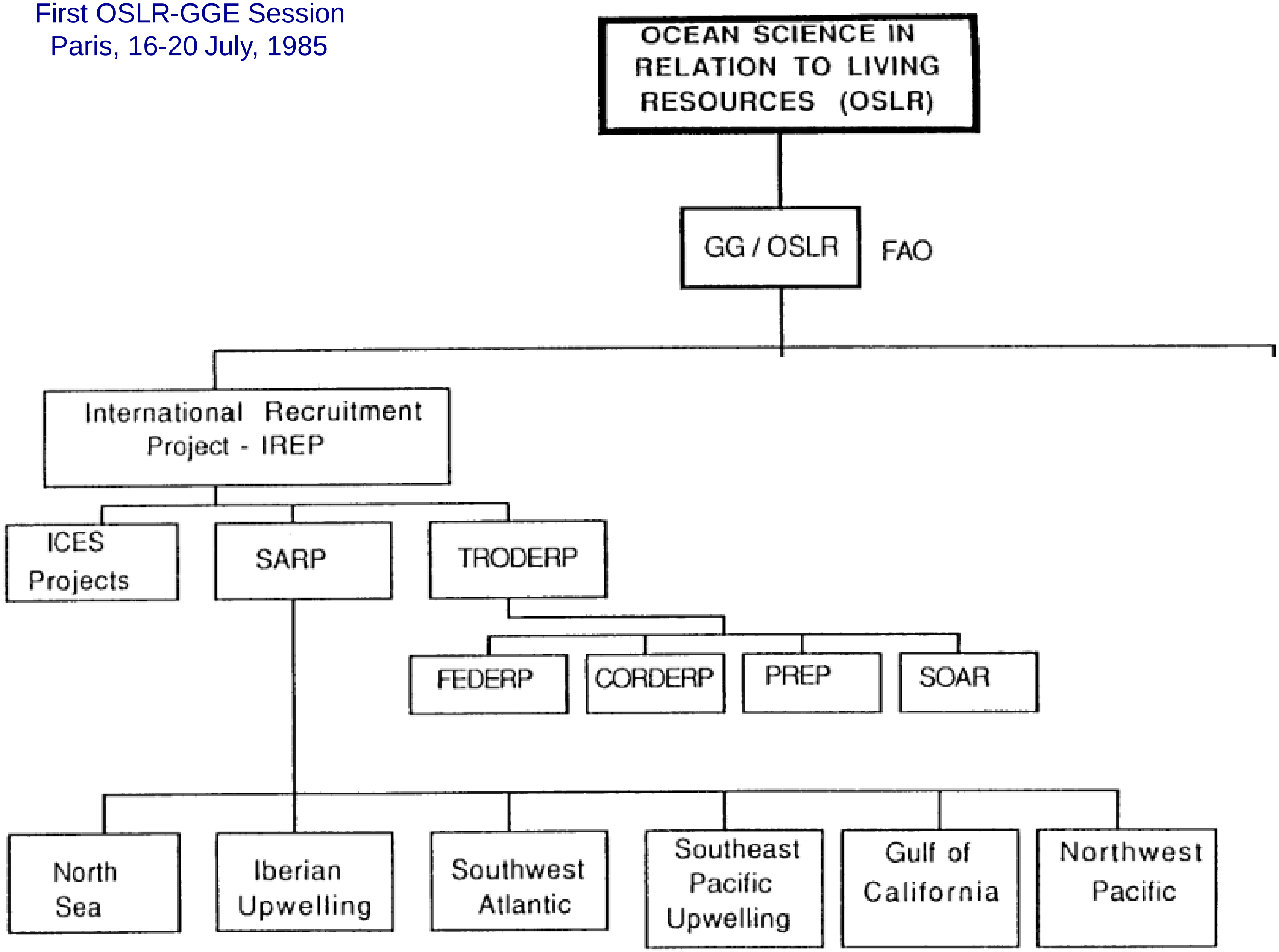


Fig. 1 OSLR and its components

Second OSLR-GGE Session
Rome, 8-12 June, 1987

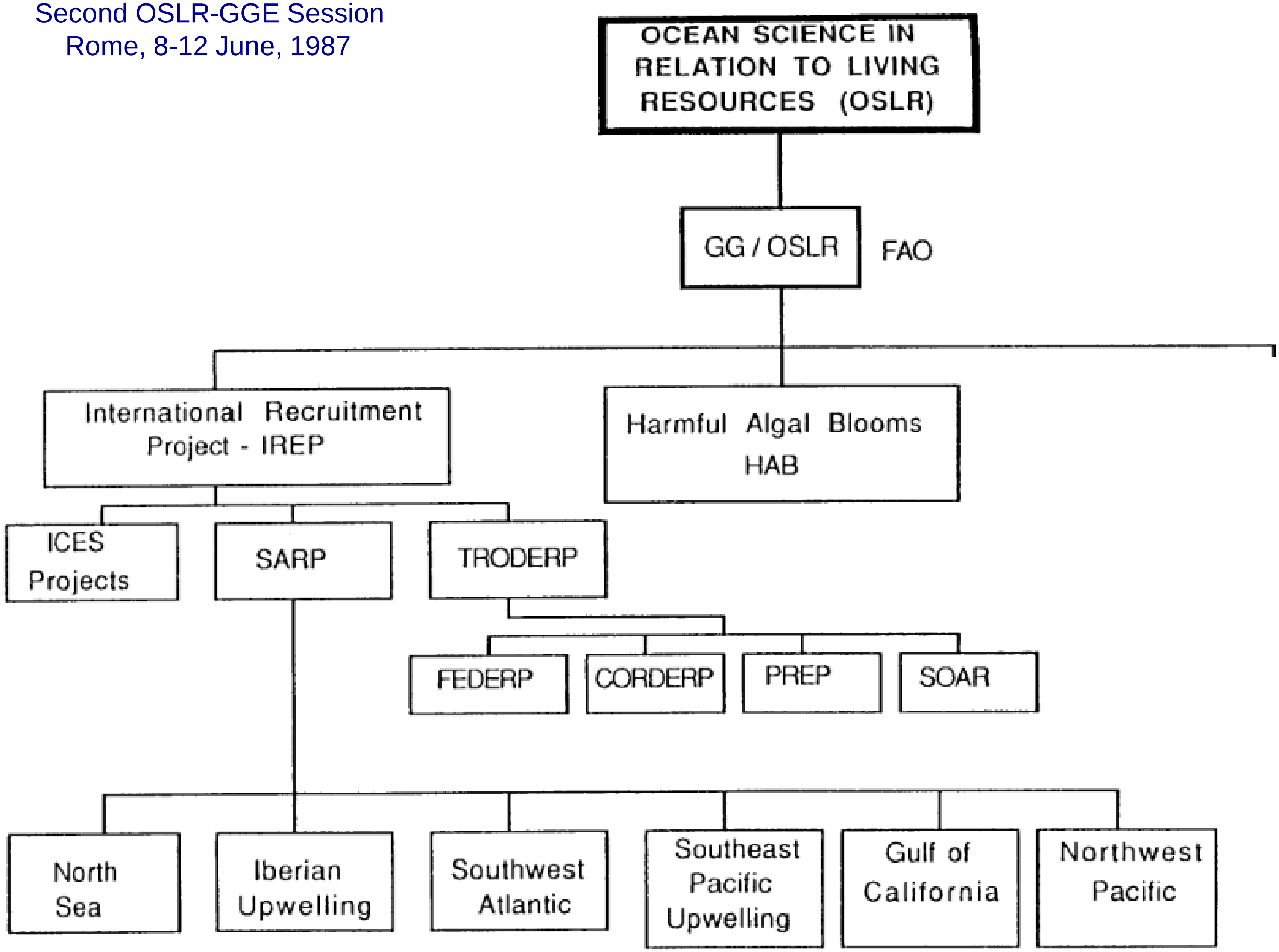
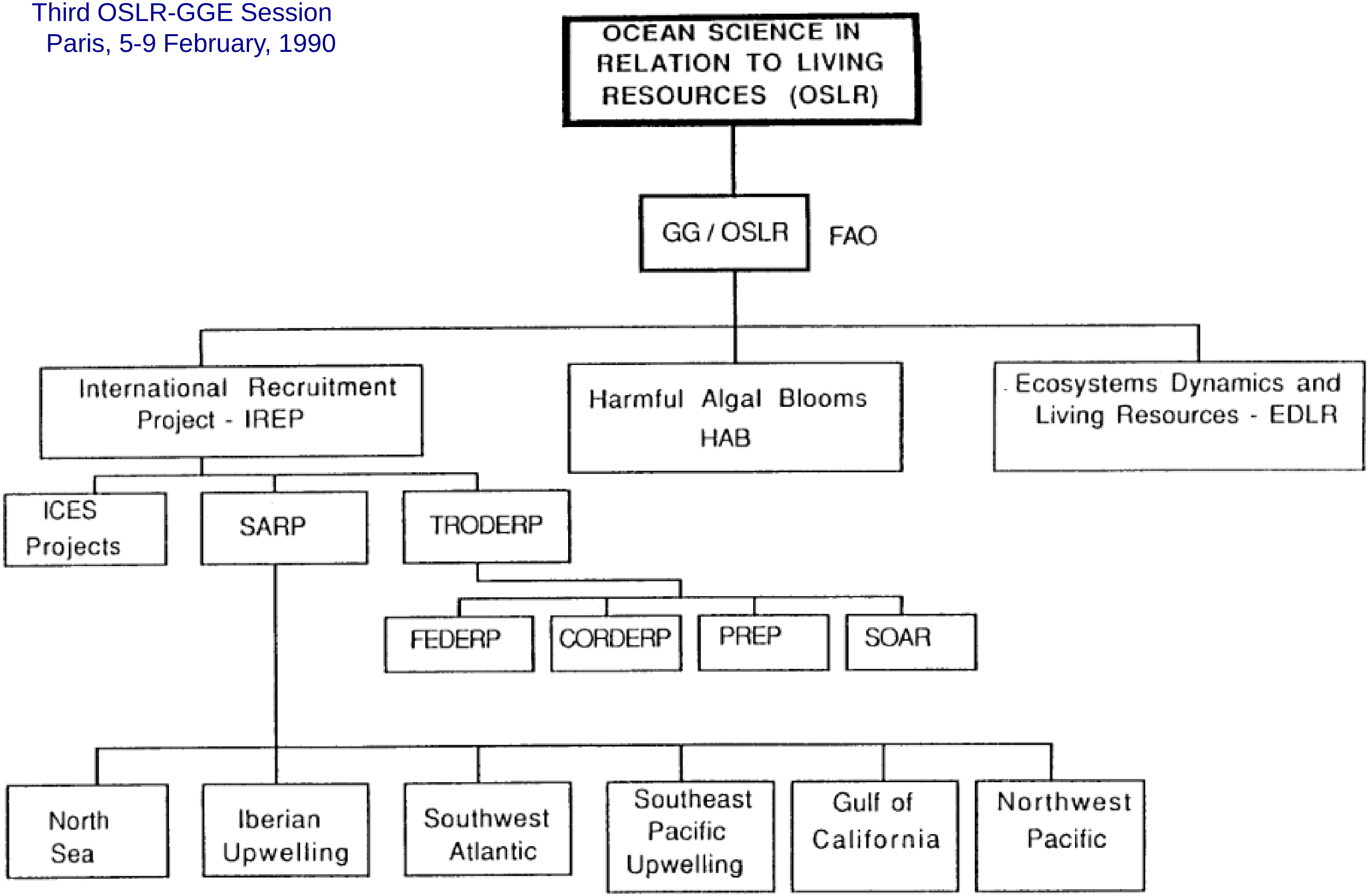


Fig. I OSLR and its components

Third OSLR-GGE Session
Paris, 5-9 February, 1990



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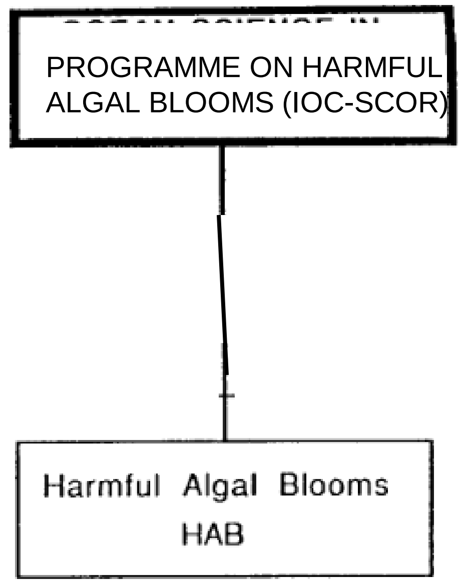
Newport, Rhode Island, USA
2-3 November , 1991



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Turbulence-enhanced larval food particle encounter rates (Rothschild and Osborn)

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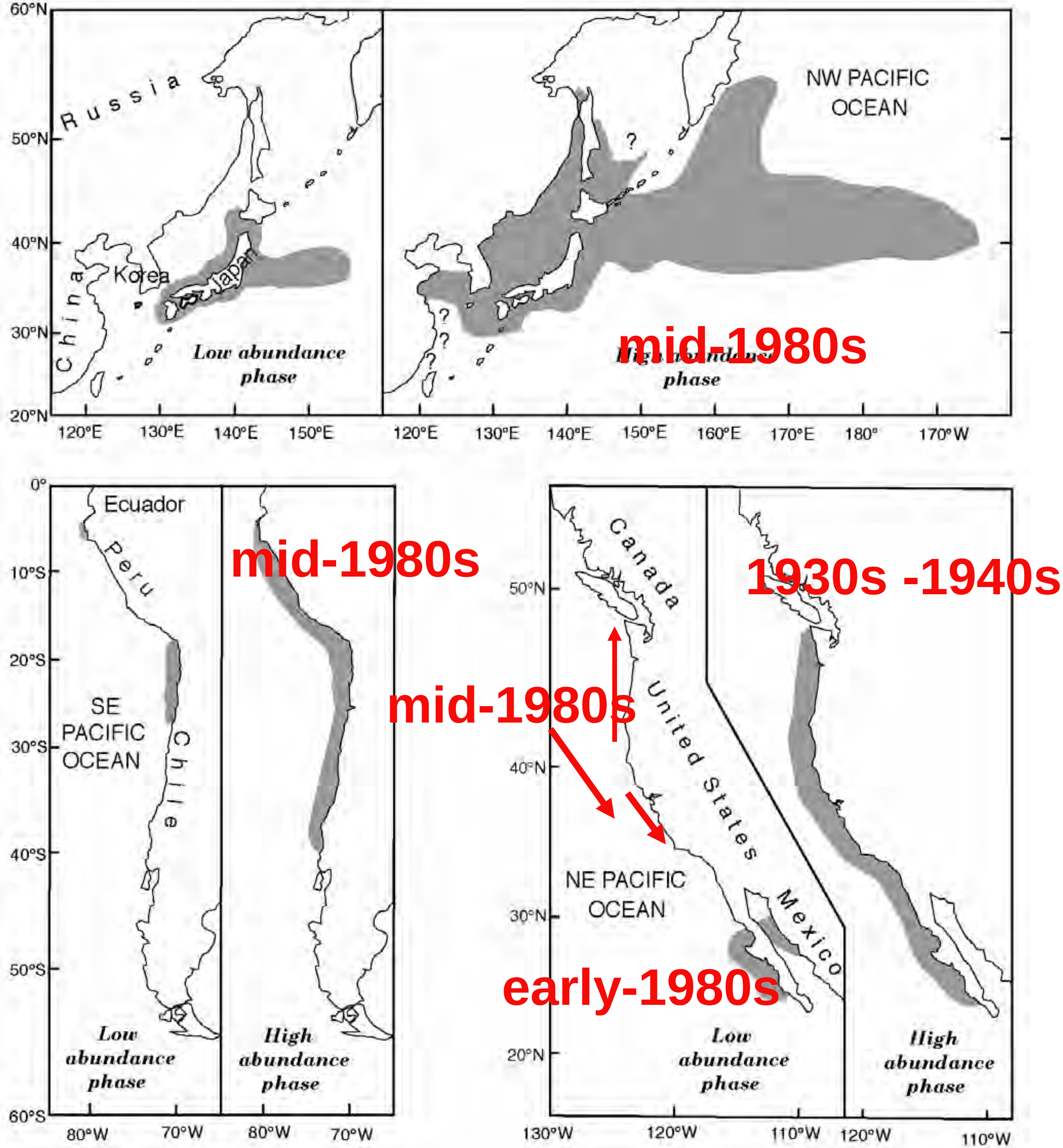
Pacific sardine expansions



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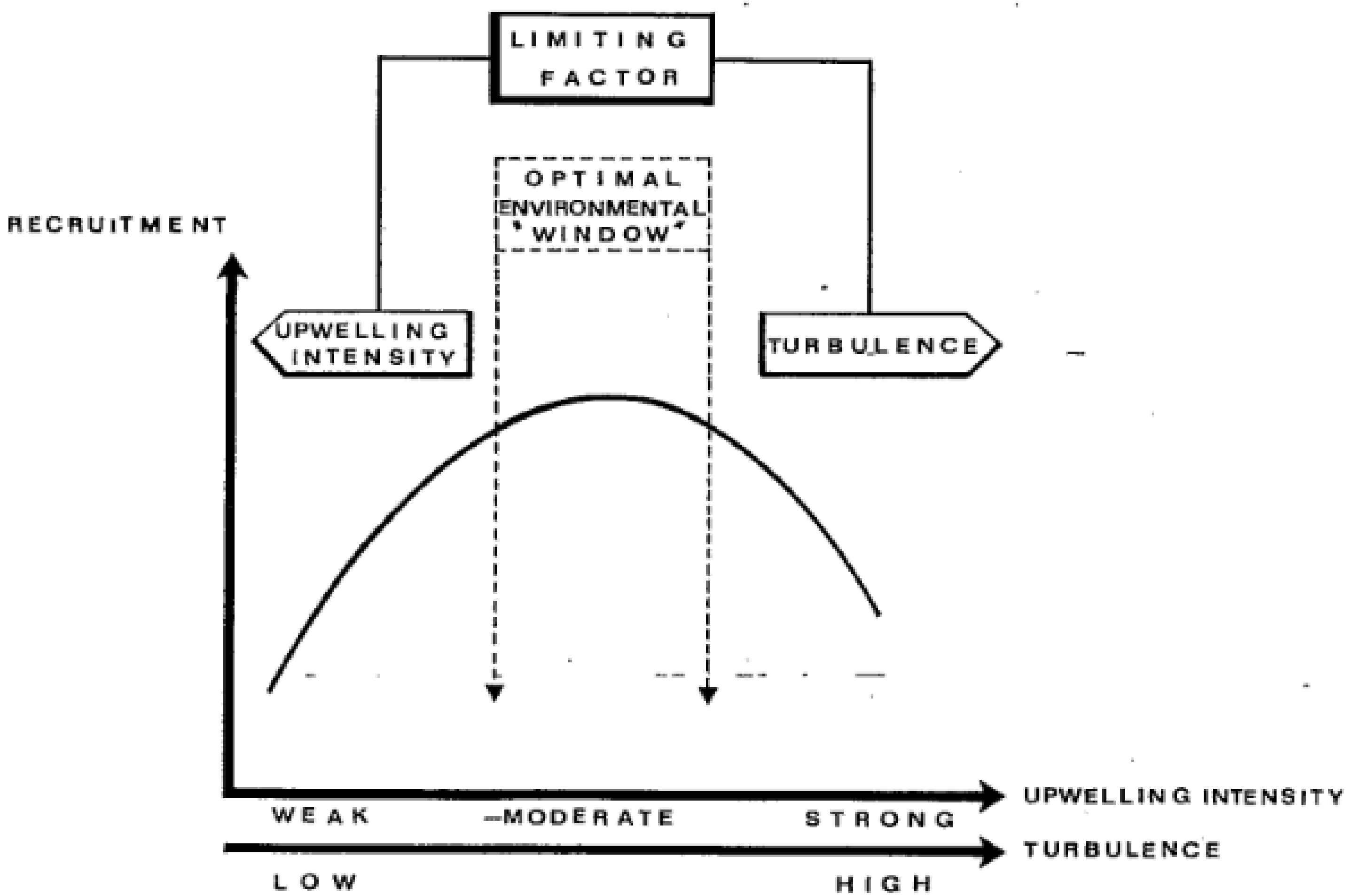

FIG. 3. Theoretical relationship between recruitment and environmental factors in upwelling areas.

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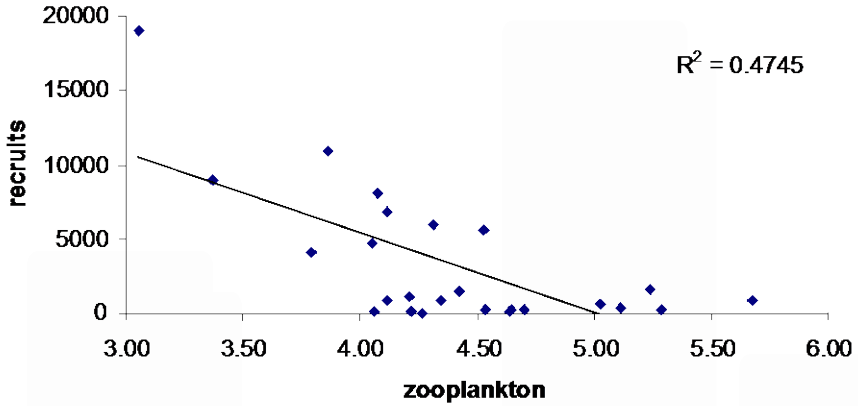
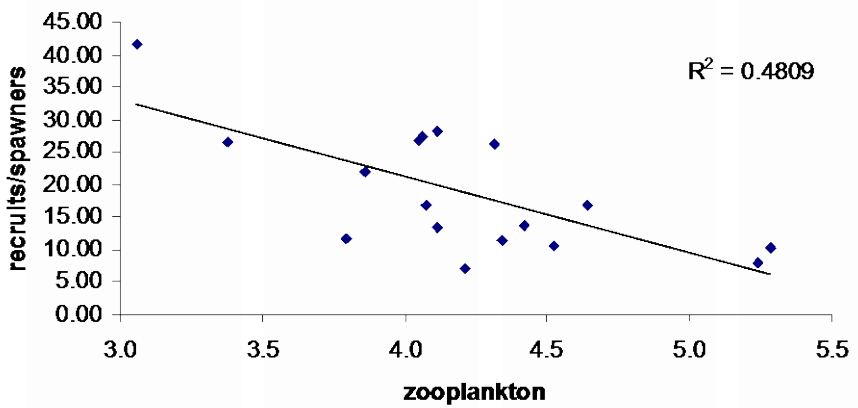
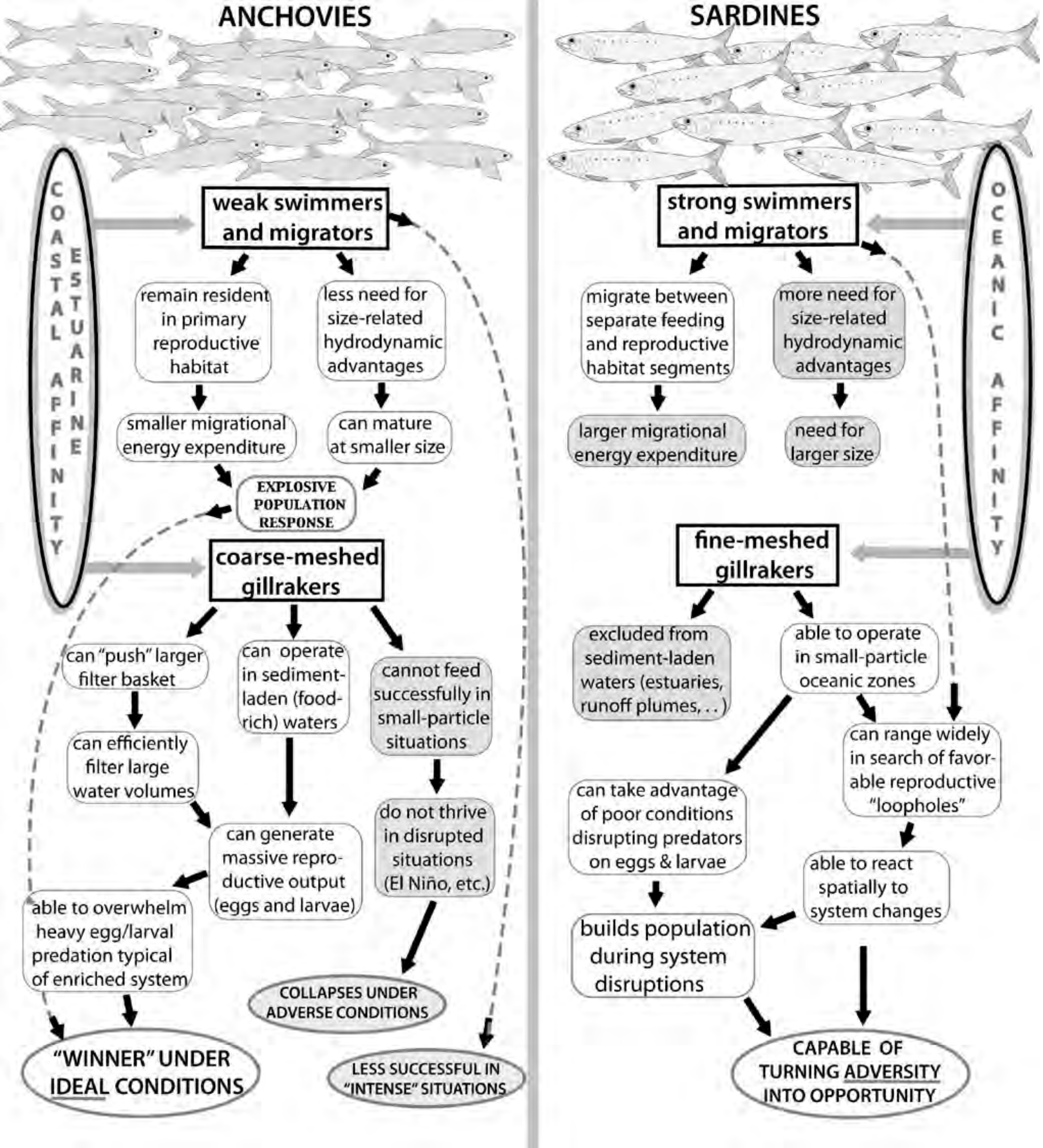


a



b

Figure 3: Log-linear relationship between **a)** recruits (# age 0 fish x 10^6) and zooplankton abundance (ml/m^3) in preferred sardine spawning habitat (see methods section for definition); **b)** recruits/spawners and zooplankton abundance (ml/m^3) in preferred sardine spawning habitat (see methods section for definition).



Sardines do well in El Niño while anchovies collapse

Sardines do well in El Niño-dominated groups of years; anchovies do poorly

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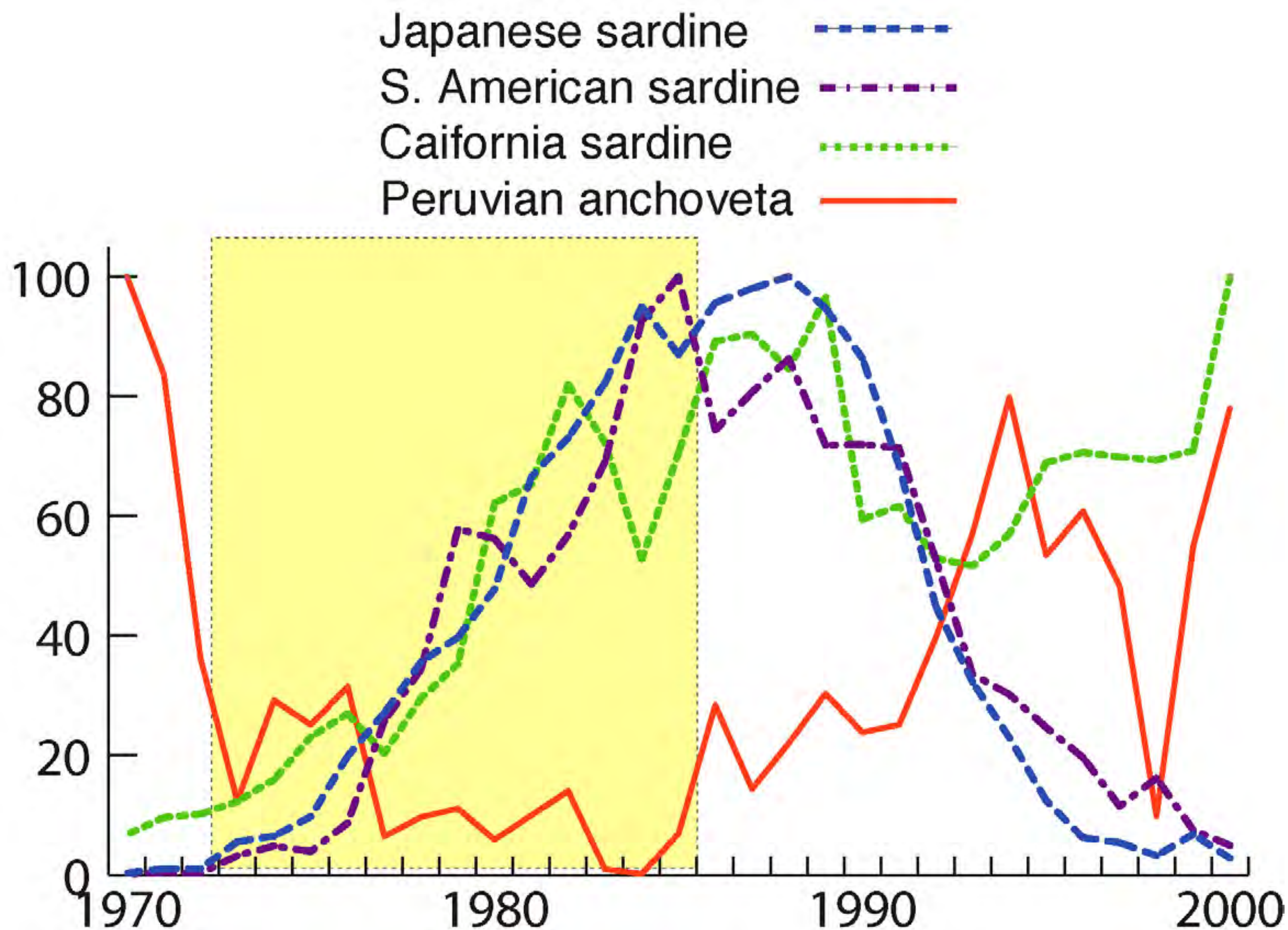
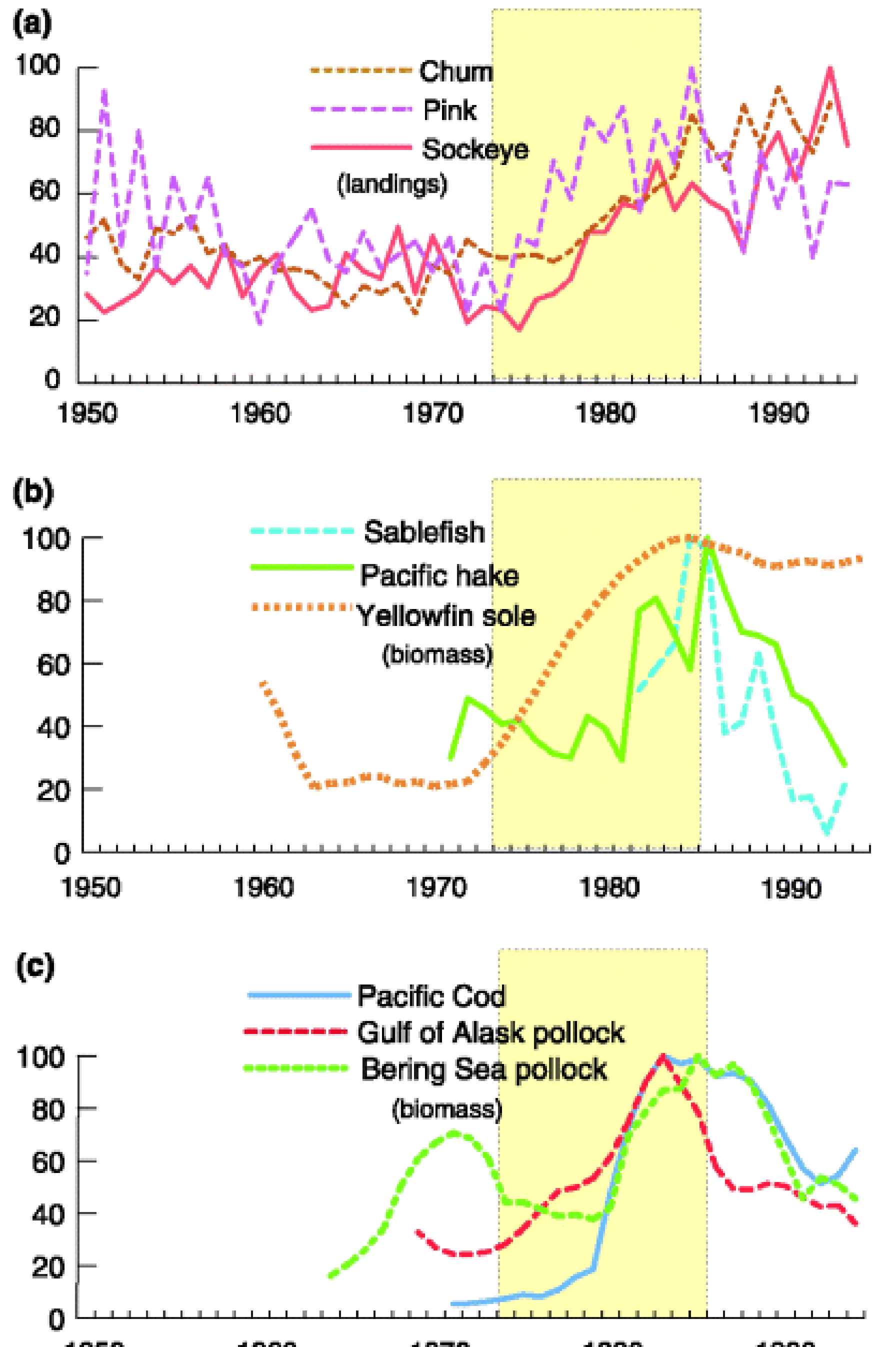
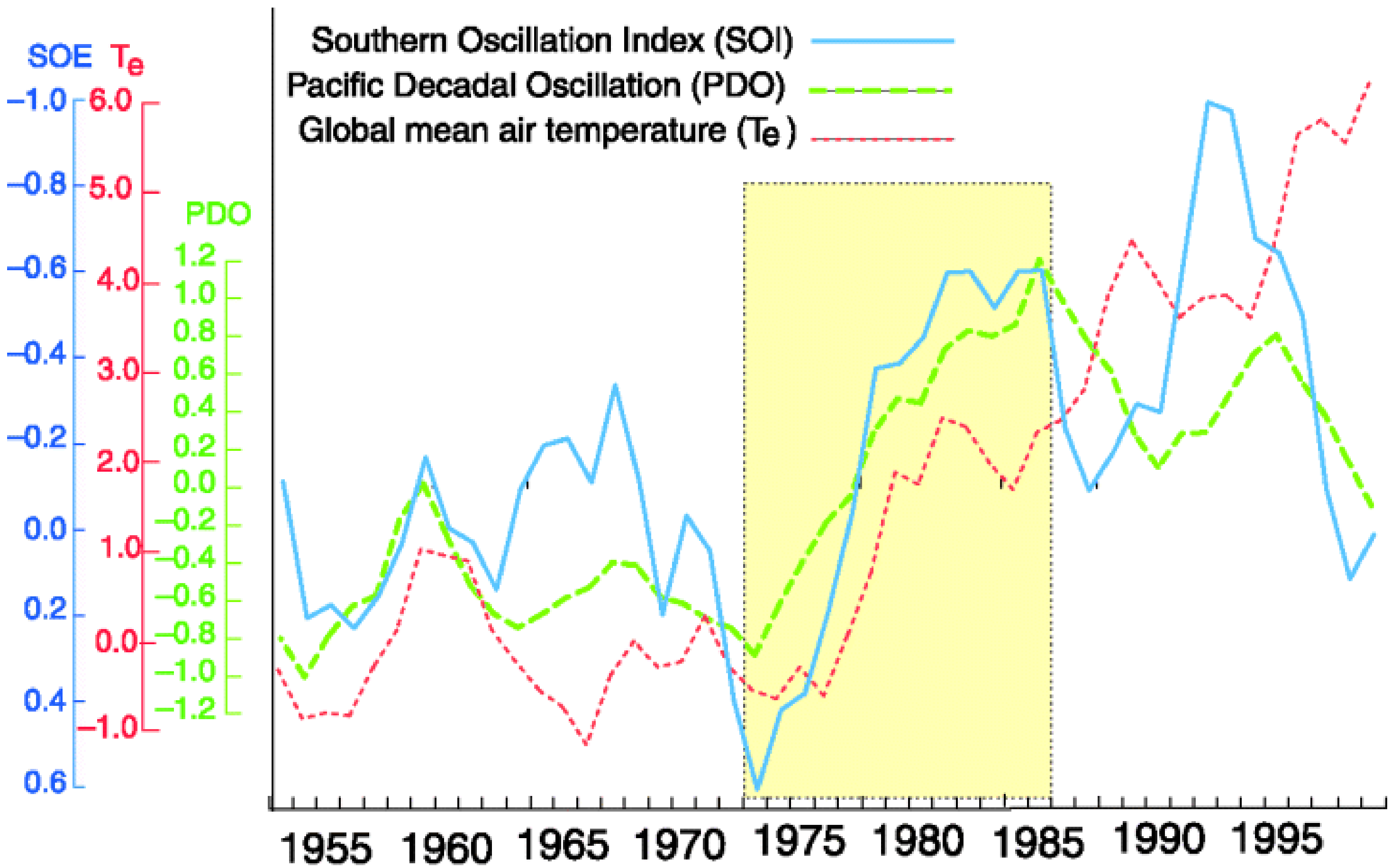


Japanese sardine
S. American sardine
Caifornia sardine
Peruvian anchoveta
100
80
60
40
20
0
1970
1980
1990
2000



(a)
Chum
Pink
Sockeye
(landings)
(b)
Sablefish
Pacific hake
Yellowfin sole
(biomass)
(c)
Pacific Cod
Gulf of Alask pollock
Bering Sea pollock
(biomass)
100
80
60
40
20
0
1950
1960
1970
1980
1990



SOE
T_e
PDO
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
6.0
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
Southern Oscillation Index (SOI)
Pacific Decadal Oscillation (PDO)
Global mean air temperature (T_e)
1955
1960
1965
1970
1975
1980
1985
1990
1995

"DOME-SHAPED" POPULATION CURVE: RISING FROM *EARLY OR MID-70S TO MID-80S*
PEAKING IN MID-1980S, FALLING THEREAFTER.

SARDINES (JAPAN, PERU-CHILE, CALIFORNIA)

BENGUELA **ANCHOVY**

NORTH PACIFIC GROUNDFISH (ALASKAN POLLOCK AND OTHER STOCKS)

LOBSTERS, **SEA BIRDS**, **SEALS**, **REEF FISHES** IN TROPICAL NORTH PACIFIC

NEWFOUNDLAND-SPAWNING NORTHERN **COD** STOCK

BALISTES (W. AFRICA)

IN OPPOSITE PHASE:

ANCHOVIES (JAPAN, PERU-CHILE, CALIFORNIA)

BENGUELA **SARDINE**

NORTH PACIFIC **ALBACORE**

JAPANESE COMMON SQUID

POPULATION EXPANSION BEGINNING IN MID-1970S

SARDINELLA AURITA (GULF OF GUINEA)

N. PACIFIC YELLOWFIN & SKIPJACK TUNA

"CRASHING" FOLLOWING MID-1980s

BRAZILIAN **SARDINE** (*SARDINELLA*)

NORTHERN **COD** STOCKS

BALISTES (W. AFRICA)

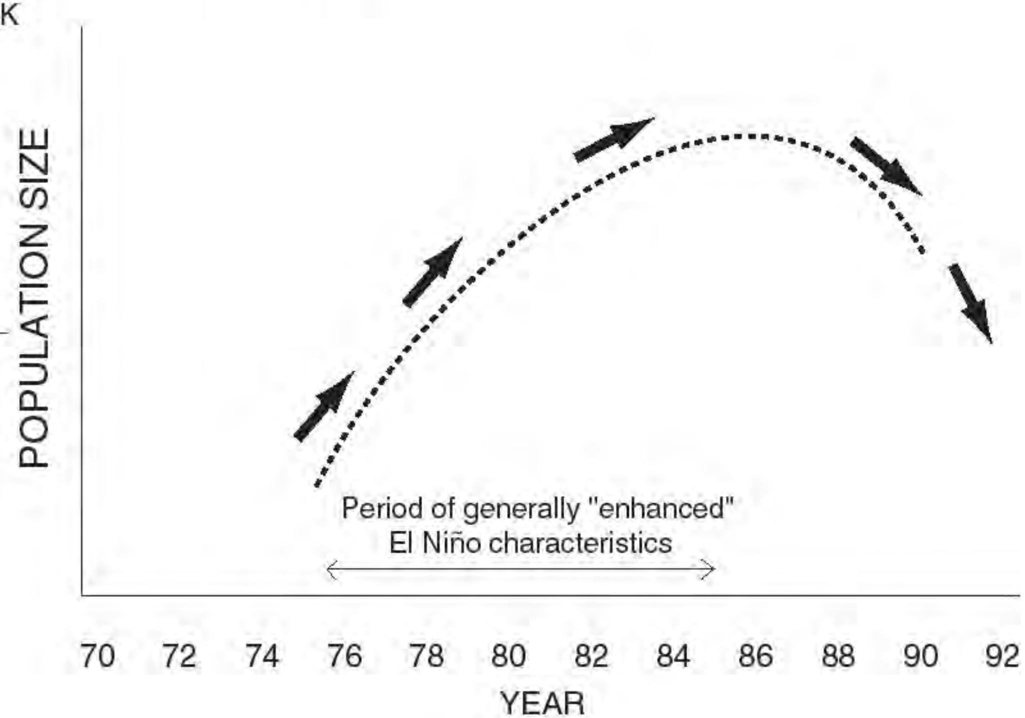


Fig. 2.3, *Patterns in the Ocean* (Bakun, 1996)

Climatic teleconnections do have the required basin-scale (or even global) reach

But the effects tend to play out distinctly differently in the different regional systems

e.g., the SE Pacific sardine operates in an eastern ocean wind-induced upwelling ecosystem)

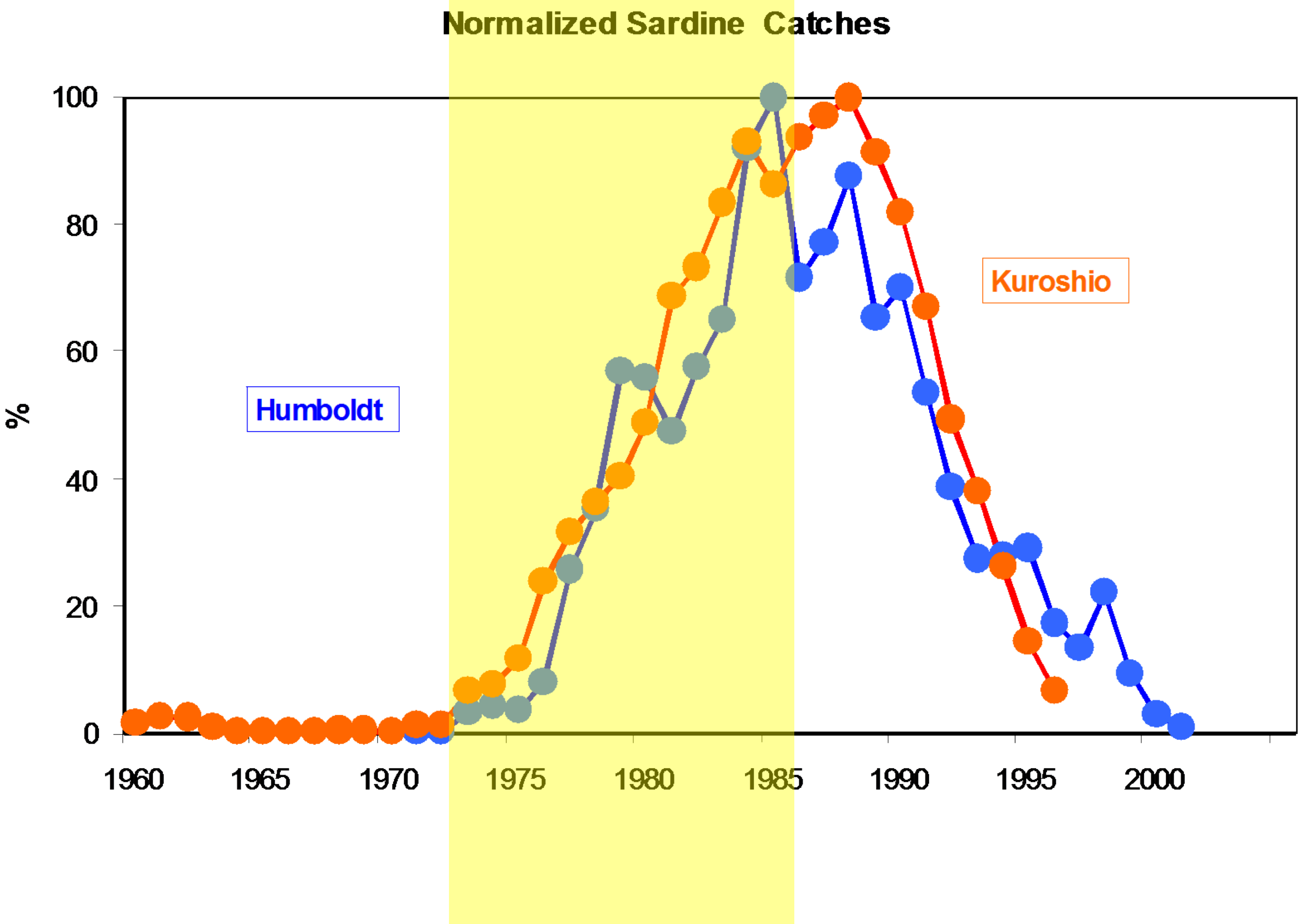
while the NW Pacific sardine operates in an energetic western boundary current situation

Not only must the sardines in each system have adopted behaviors and habits to solve distinctly different ecological challenges

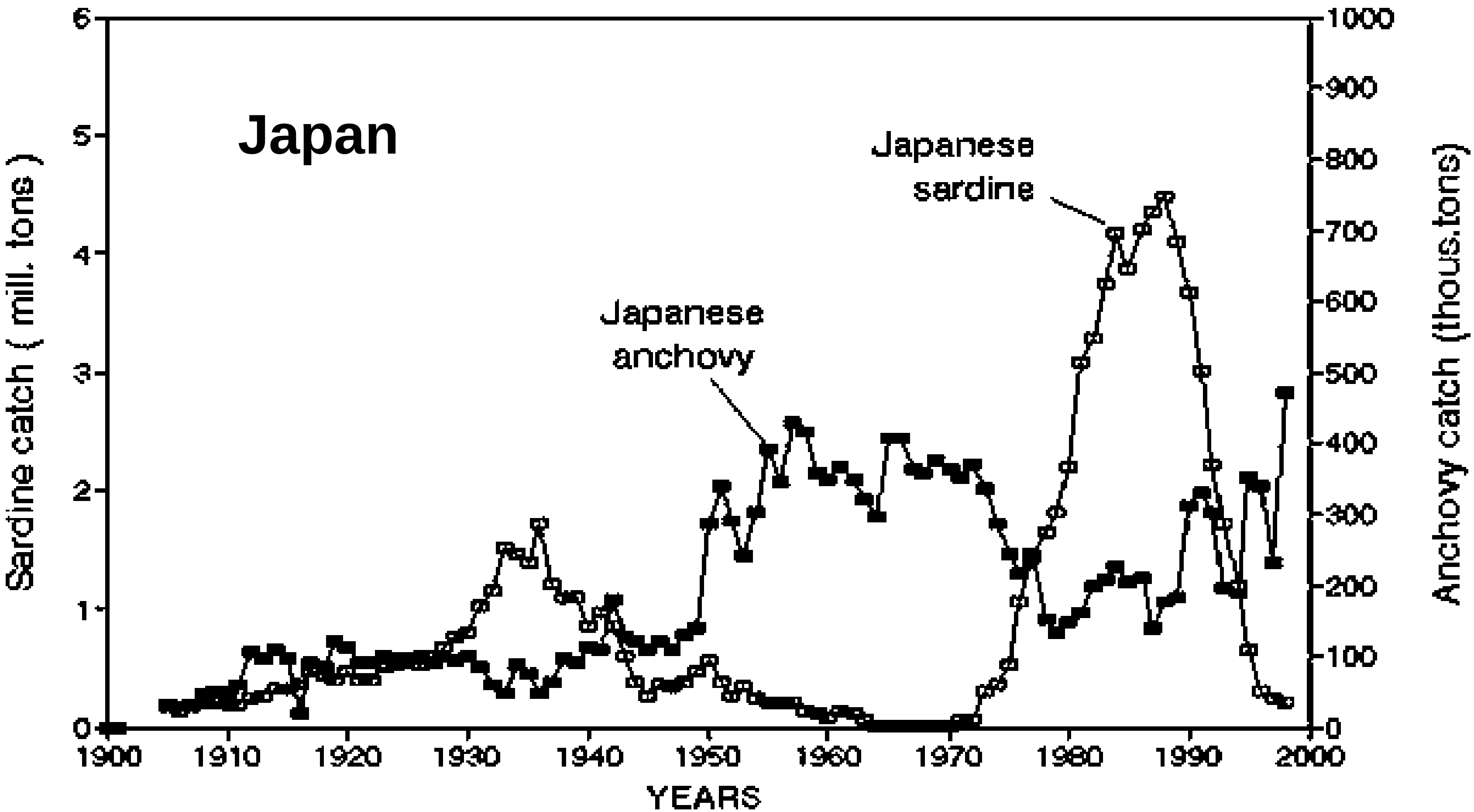
But variability exerted by large-scale climatic effects acts to alter the different systems in distinctly different ways

e.g., when the eastern Pacific is warm, the western Pacific is generally cool – and vice-versa . . . etc.

And yet


Normalized Sardine Catches
100
80
60
40
20
0
%
Humboldt
Kuroshio
1960
1965
1970
1975
1980
1985
1990
1995
2000

http://www.fao.org/DOCREP/005/Y2787E/y2787e3d.gif



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There appear to be abundant possibilities for self-amplifying **nonlinear** feedback loops (Bakun & Weeks, 2006)

To the extent that such **nonlinear** feedbacks are realized, system trajectories may not converge toward unique solutions

Yikes!

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Moreover, as the record of available experiences lengthens, it is becoming apparent that marine ecosystems in many ways operate as **complex adaptive systems** (Levin, 1998, 1999) meaning that the systems may be continually altering their structure and operation as they react to a suite of external stresses (climatic variations, fishing, habitat alteration, etc.)

Bakun, A. and S.J. Weeks (2006) Adverse feedback sequences in exploited marine ecosystems: Are deliberate interruptive actions warranted? Fish and Fisheries 7, 316–333

Hsieh, C., Glaser, S.M., Lucas, A.J. and Sugihara, G. (2005) Distinguishing random environmental fluctuations from ecological catastrophes for the North Pacific Ocean. Nature 435, 336–340.

Levin, S.A. (1998) Ecosystems and the biosphere ascomplex adaptive systems. Ecosystems 1, 431–436.

Levin, S.A. (1999) Fragile Dominion: Complexity and the Commons. Perseus Books, Reading, MA.

O’Dor’s Law of Biology

There is no law

Chemistry and physics have “real” laws (i.e., immutable, eternal)

To the extent biology has real laws, they act at the molecular level where they merely embody the laws of chemistry and physics

According to O’Dor’s Law, chemistry and physics are the ‘legislators’.

Organisms are the ‘lawyers’

Chemistry and physics **make** the laws

Organisms seek out and exploit the **loopholes** in the laws

Result: marine ecosystems continually evolve their dynamics in response to a variety of stresses:

- climatic trends and variability
- fishery exploitation
- habitat alteration
- nonlinear predator-prey feedback dynamics

Time scales of system evolution are generally comparable to (or longer than) available data series

Accordingly conventional assumptions of stationarity are rendered invalid to:

establish empirical relationships and models to identify relevant dynamics

or even to parameterize prognostic (or diagnostic) models based on some <u>assumed</u> dynamics

PROBLEM!!!

The more we know, the more complex everything seems to become

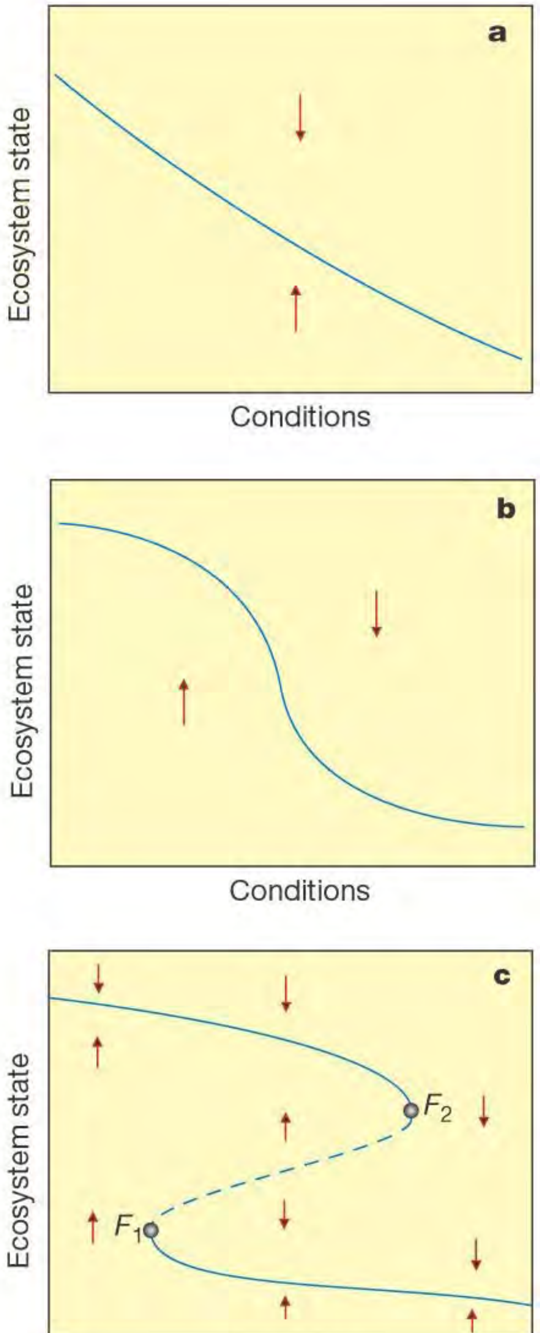

Figure 1 Possible ways in which ecosystem equilibrium states can vary with conditions such as nutrient loading, exploitation or temperature rise. In **a** and **b**, only one equilibrium exists for each condition. However, if the equilibrium curve is folded backwards (**c**), three equilibria can exist for a given condition. It can be seen from the arrows indicating the direction of change that in this case equilibria on the dashed middle section are unstable and represent the border between the basins of attraction of the two alternative stable states on the upper and lower branches.

Scheffer, M., S. Carpenter, J.A. Foley, C. Folke and B. Walker, 2001. Catastrophic shifts in ecosystems. Nature **413**, 591-596.

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Emerging from Hjort's Shadow

published August 18, 2008 11:27

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HOUDE, E. D. 2008. Emerging from Hjort's Shadow. *J. Northw. Atl. Fish. Sci.*, **41**: 53–70. doi:10.2960/J.v41.m634

Abstract

Is There a Recruitment Problem?

Solving the "Recruitment Problem" was the Holy Grail of fishery science in the late 20th century. In retrospect, casting recruitment

Understanding causes of recruitment variability is a desirable goal; "solving the problem" may be an unrealistic goal.

bility in recruit abundances.

listic goal.

Why Isn't Recruitment Even More Variable Than Observed?

Recruitment typically varies 10-fold inter-annually and 100-fold variability is observed. But, given the extraordinary abundances of eggs and larvae and the high and variable mortality they experience, many of us are surprised that variability isn't higher yet. More than 100-fold variability is in fact observed rather commonly in some fishes, *e.g.*, haddock (*Melanogrammus aeglefinus*), and on occasion in many species. Regulation is an expression of compensatory ability (density dependence) that generally reduces variability and tends to stabilize or dampen recruitment variability. Much of the compensation may occur in the juvenile stage. Even a small amount of compensation during early life can have a substantial stabilizing effect.

However . . . .

THE BLACK SEA

INVASION


0 mi
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Dnieper
MOLDOVA
UKRAINE
Prut
ROMANIA
CRIMEA
Sea of Azov
RUSSIA
Don
Kuban'
Danube
Varna
BULGARIA
BLACK SEA
GEORGIA
Sinop
GREECE
Bosporus
Sea of Marmara
Dardanelles
Sakarya
Kizilirmak
AEGEAN SEA
TURKEY
EUROPE
Black Sea
ASIA
Mediterranean Sea
AFRICA

Mnemiopsis is an exotic species that had previously been absent from the eastern side of the Atlantic. It is believed to have been introduced into the Black Sea ecosystem in discharges of ballast water from ships coming from the American side of the ocean.

But it evidently remained at low abundance for a number of years (it was first identified in the Black Sea in 1982).

In the late 1980s fishery landings of anchovy in the Black Sea increased to levels approaching 900,000 T per year

At their maximum, in 1988, the catch of anchovy represented more than 60% of the total fishery catches taken from the Black Sea

The following year, the anchovy spawning biomass had collapsed to less than 15% of its former size

In 1989, the year following the drastic reduction in anchovy biomass by the fishery, zooplankton biomass increased sharply, assumedly in response to the resulting reduction in grazing pressure

After collapse of anchovy, reduction of anchovy predation may have shallowed the “predator pit” for *Mnemiopis* (early stages?)

And reduction of competition from anchovies for zooplankton prey would have increased production rate of *Mnemiopis*

Mnemiopsis explosively increased to a level approaching a billion tons

Mnemiopsis is a very efficient predator on fish eggs and larvae

The outbreak quickly led to near total collapse of all fisheries in the Black Sea


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Sinop
GREECE
Bosporus
Sea of Marmara
Dardanelles
Sakarya
Kizilirmak
AEGEAN SEA
TURKEY
EUROPE
Black Sea
ASIA
Mediterranean Sea
AFRICA

Gotcha!!

A BILLION TONS OF EFFICIENT PREDATOR!

(the area of the Black Sea is only about one six-hundredth of the total area of the worlds oceans; a billion tons represents more than ten times the total annual fish production of the entire world)

Gotcha!!!

(early stages)

Most recently, the situation is again impacted by the outbreak of a new alien ctenophore.

Beroe ovata, is an obligate predator on other ctenophores such as *Mnemiopsis*.

Beroe appears to have reduced *Mnemiopsis* to low abundance levels.

Beroe is a "hyperspecialist" with no alternative prey to *Mnemiopsis*. There is thus a possibility of a cyclically oscillating predator pit for *Mnemiopsis* caused by alternating episodes of breakouts and starvation-caused collapses of *Beroe*, leading to alternating linked cycles of explosion and collapse of the two species into the indefinite future

Gotcha!!!


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GREECE
Bosporus
Sea of Marmara
Dardanelles
Sakarya
Kizilirmak
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EUROPE
Black Sea
ASIA
Mediterranean Sea
AFRICA

It could have been nice if we could have known that adequate efforts toward preserving the role of the anchovy in the Black Sea ecosystem, might have avoided disruption of the system as a whole.

As climate change proceeds, ocean deoxygenation seems to be becoming a more and more worrisome problem. Some anecdotal information suggests that keeping sardines as major system components may help. (I want to subtitle my contributed paper in Wednesday's "Food Web Dynamics" session as "***Silvery 'first responders' of neritic ecosystems – Can sardines save our skins?***")

JK Llopiz, RK Cowan (2008) Marine Ecology Progress Series 358, 231-244 Precocious, selective and successful feeding of larval billfishes in the oceanic Straits of Florida

"Diets of larval billfishes were notably narrow, with *Farranula* copepods and *Evadne* cladocerans numerically dominating throughout early ontogeny. Such a narrow diet, as indicated by the selectivity analyses, was not a reflection of what was available since calanoid copepods usually occurred in higher concentrations than *Farranula* and *Evadne*."