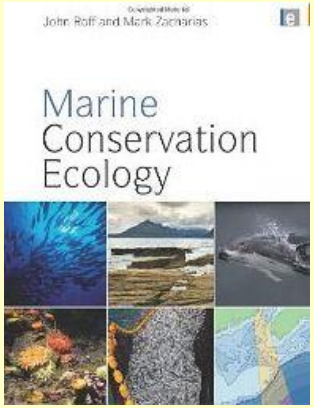
Life in the Sea: Physical Forcing

Differences between Terrestrial and Marine Systems



Larger spatial scales:
(Distributions, habitats, movements)

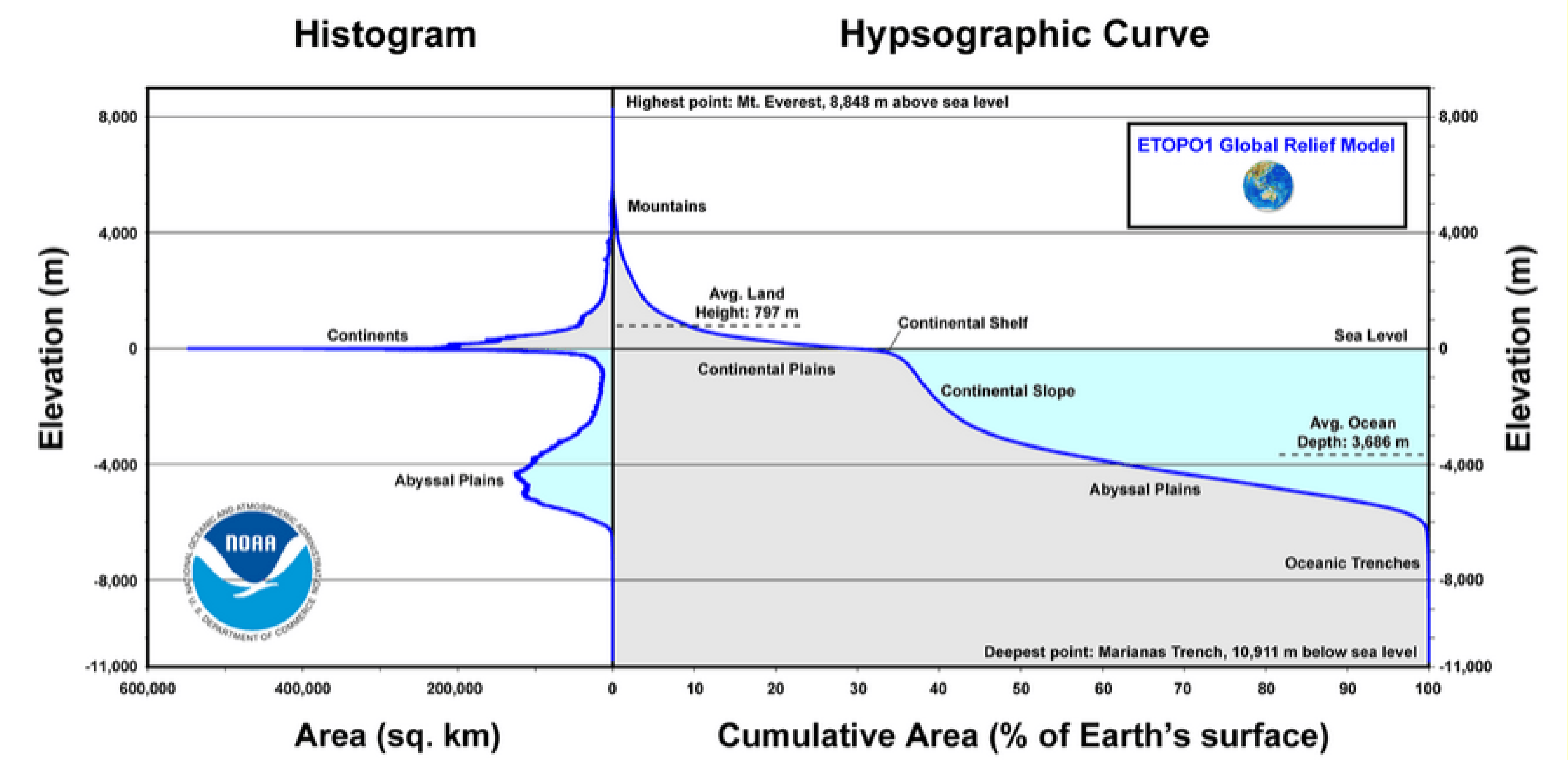
More interconnected marine systems:
(Physical forces have larger influence, physical structures are longer-lasting, larger dispersal scales)

Different Organisms: Taxonomy and Ecology
(More phyla found in the sea; unicellular vs multicellular plants; drifters / filter-feeders)

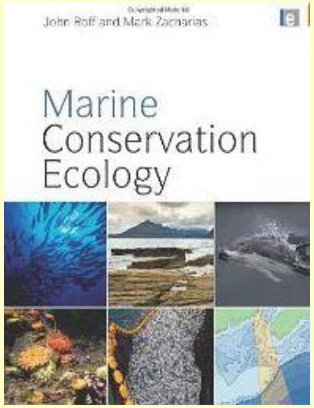
Human Dimensions: Awareness and Ownership
("Out of sight, out of mind", Property rights)

Vast Three-Dimensional Habitat

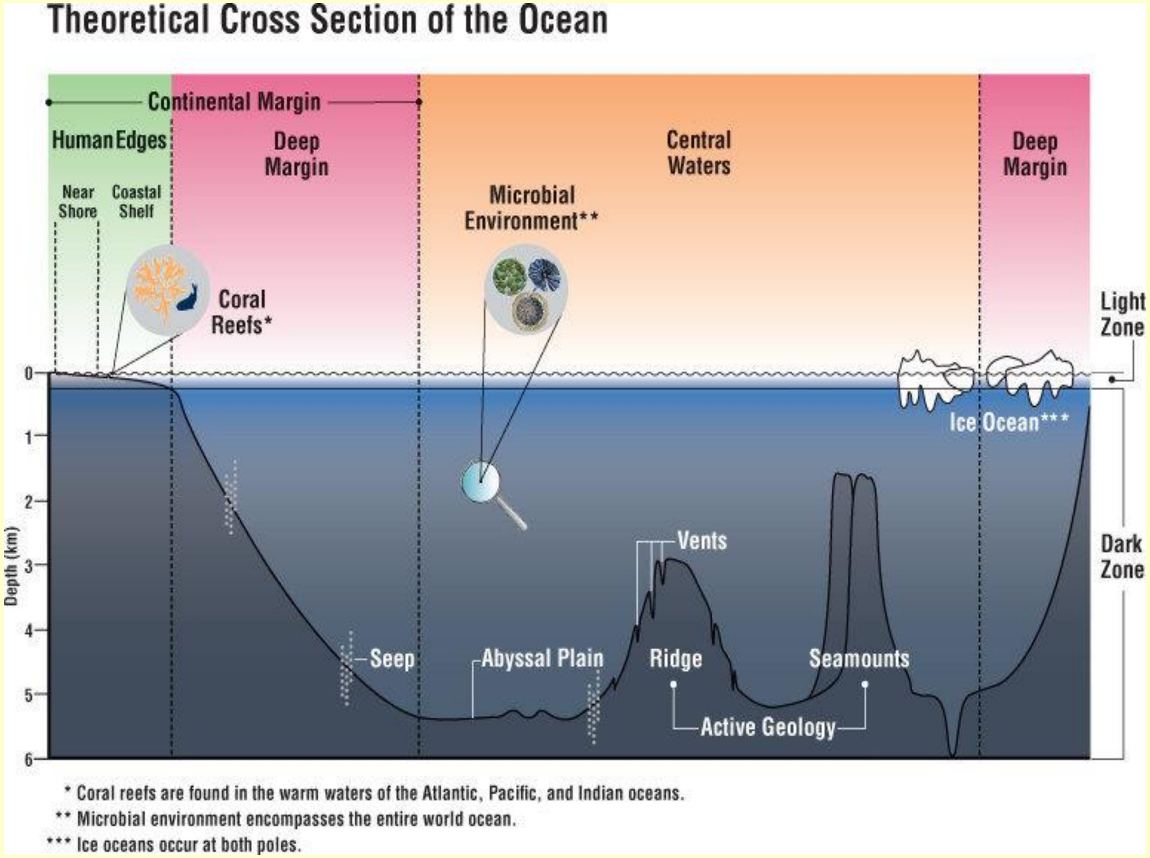
Ocean surface = 70.6% of the Earth's surface
Ocean depth = 3800 m (on average)



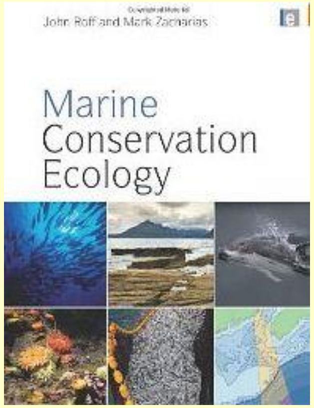
Habitat Structure and Complexity



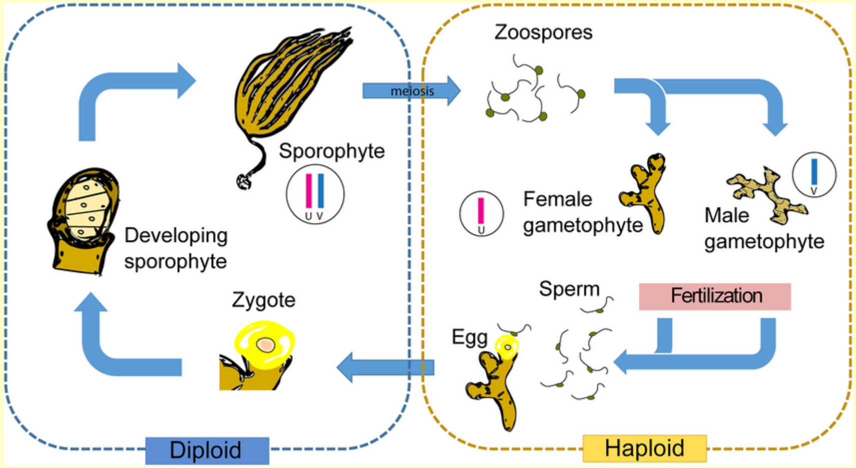
- Physical Properties: density
- Vertical gradients: light, productivity
- Different realms:
  - Surface
  - Water column
  - Bottom
  - Substrate

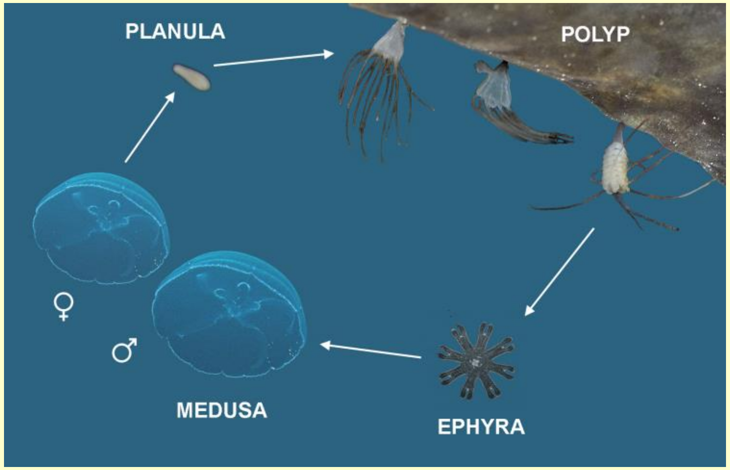


Habitat Structure and Complexity



- Complex Life-histories:
  - Alternation of generations





  - Larval dispersal

Vast Distributions – Wandering Albatross

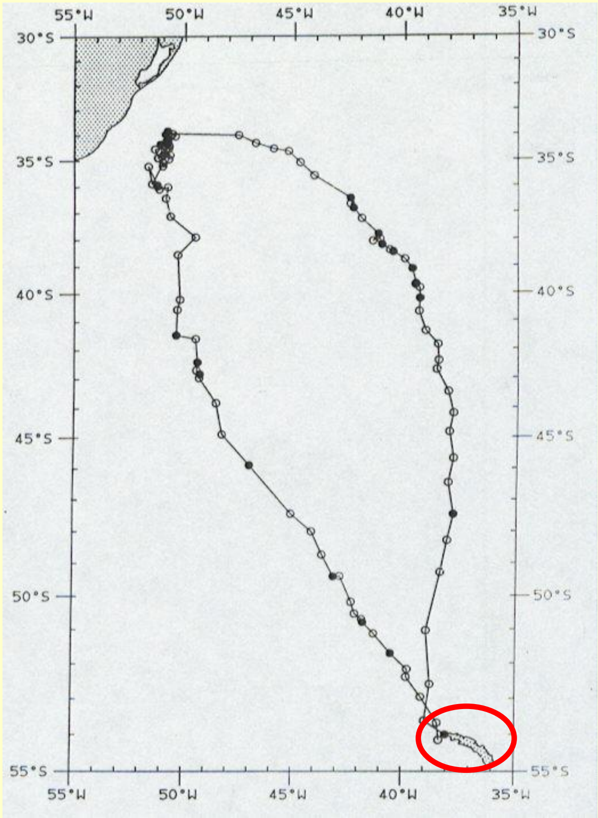
Breeding

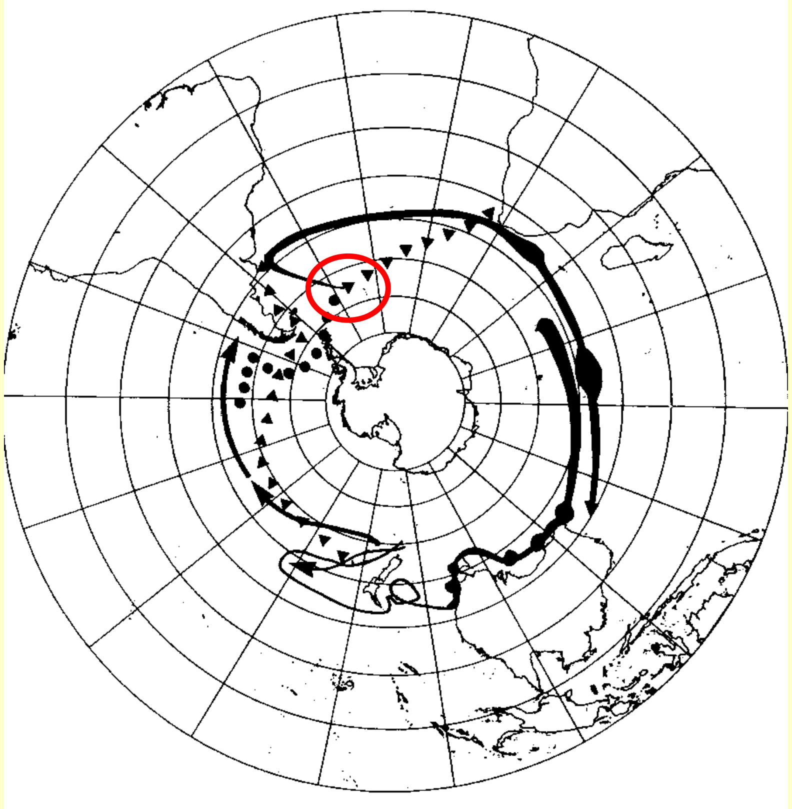
- 6,479 kms
- 8 days

Post-Breeding

- 20,619 kms
- 40 days

Wandering Albatross

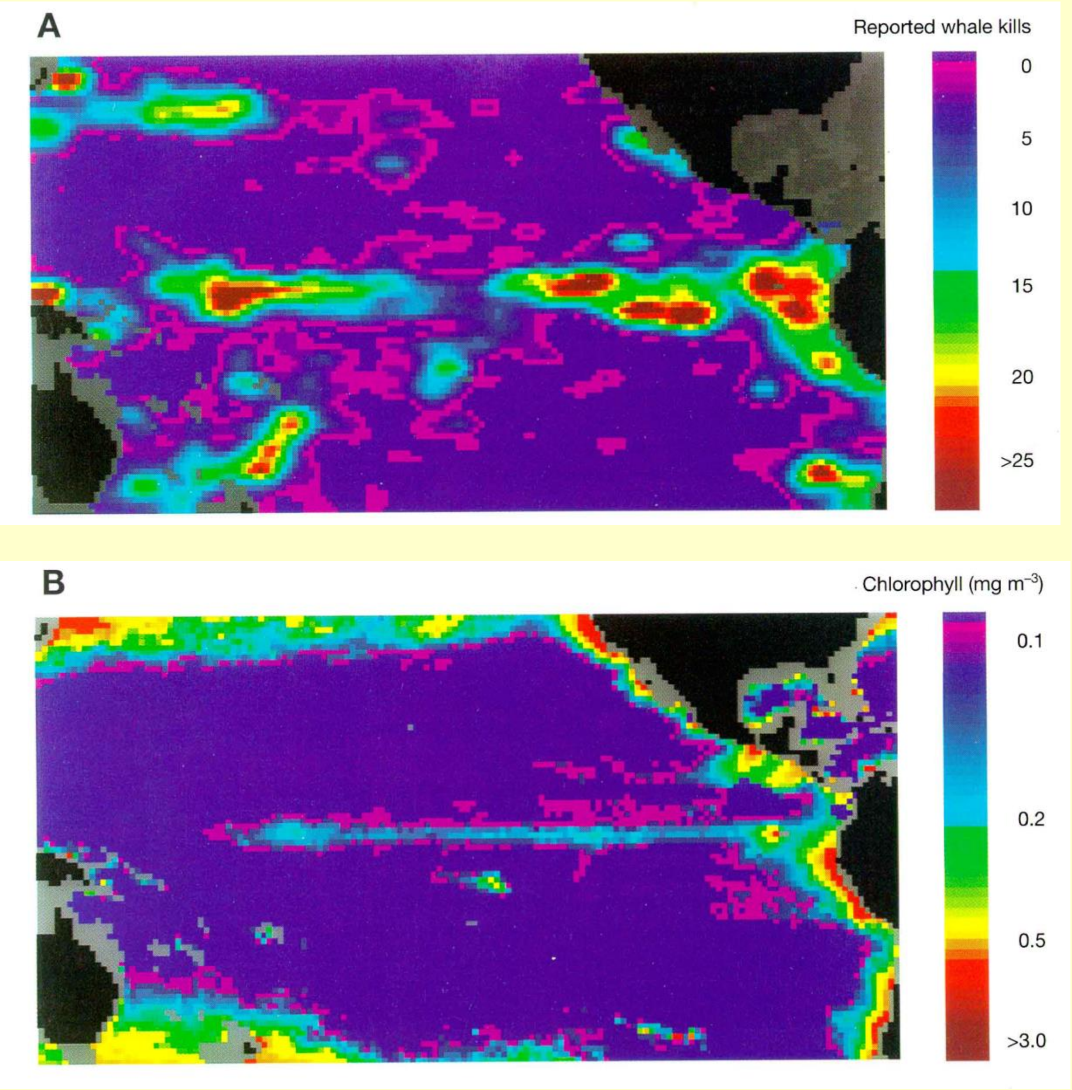




(Prince et al. 1992)

(Phillips et al. 2004, Prince et al. 1997)

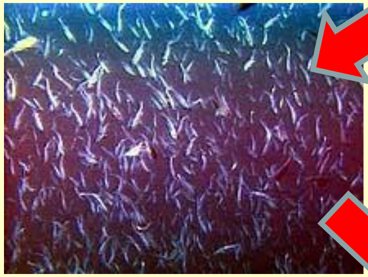
Pelagic Systems – Foraging Habitats

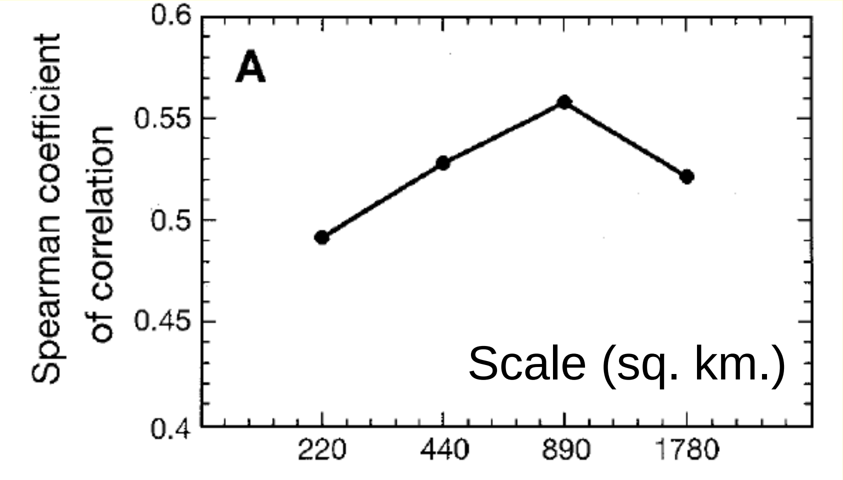


(Jacquet et al. 1996)

Pelagic Systems – Trophic Links

Very large spatial scales of association with high primary production (mediated by squid / myctophids / plankton)





(Jacquet et al. 1996)

Benthic Systems – Population Structure

Comparing species population structure across seascapes provides insights into forcing.

Comparative approach identifies key geographic barriers and processes causing genetic connectivity.

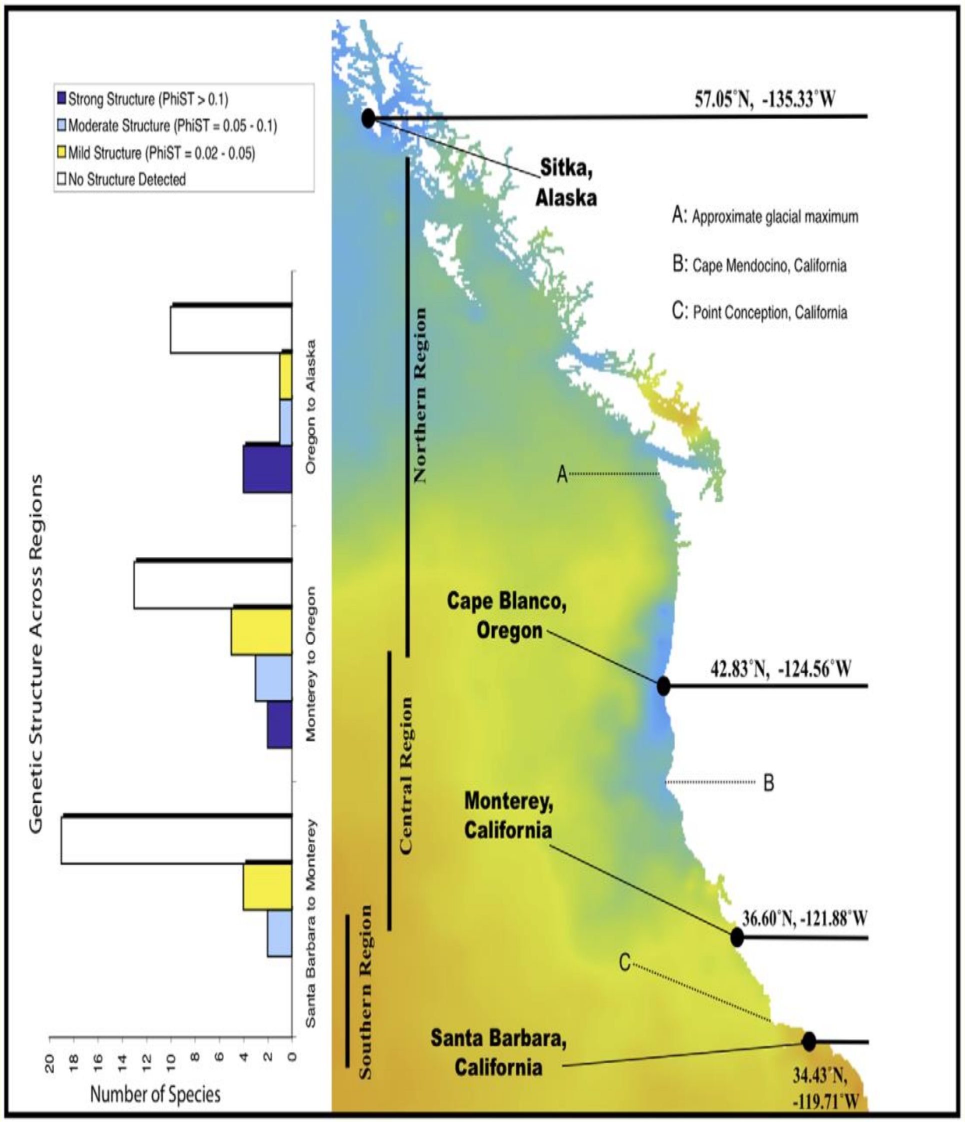
Understanding critical to devise large-scale management.

Collection locations, geographic regions, and major boundaries. Structure classes (Phi ST) are:

mild: 0.02 - 0.05,

moderate: 0.05 - 0.1

strong > 0.1

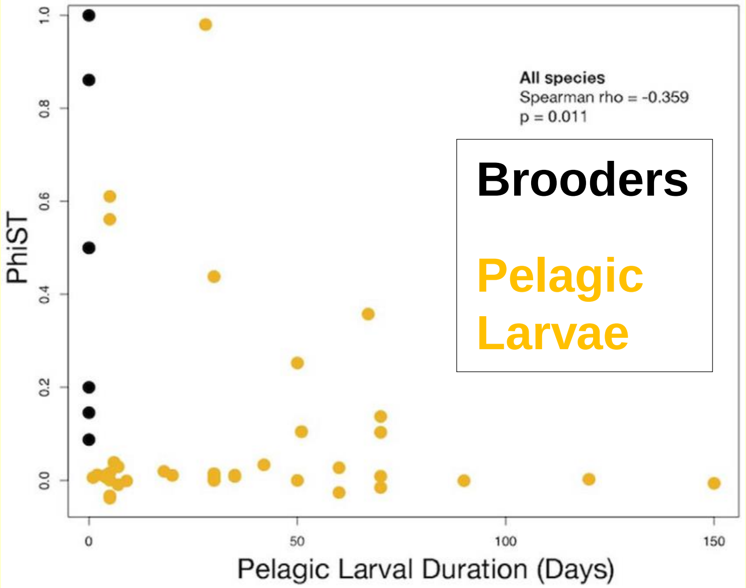


(Kelly and Palumbi 2010)

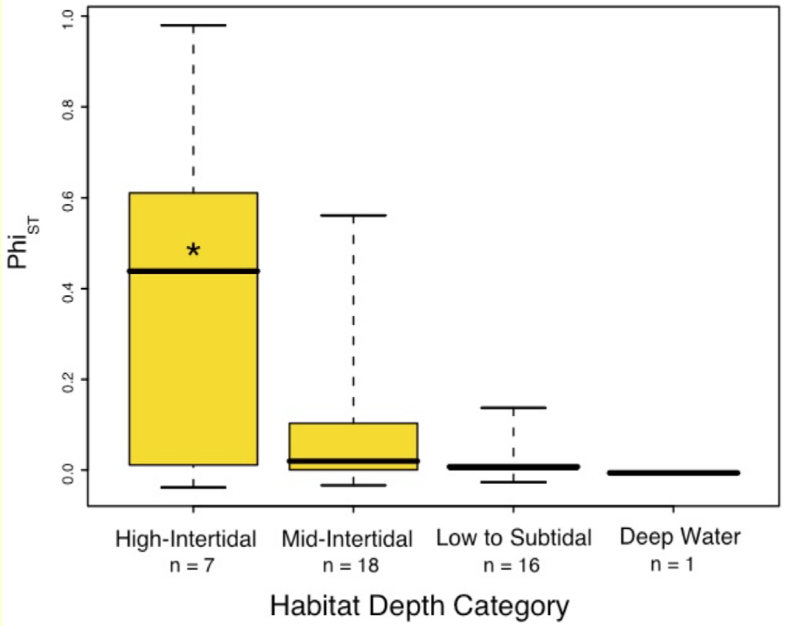
Benthic Systems – Life-history & Habitat

- Across 50 species studied:

- Dispersal ability matters:
  Those without a pelagic period have highest population structure, (in accord with previous studies)



- Significant habitat differences:
  More structure in species from high intertidal and mid-intertidal habitats

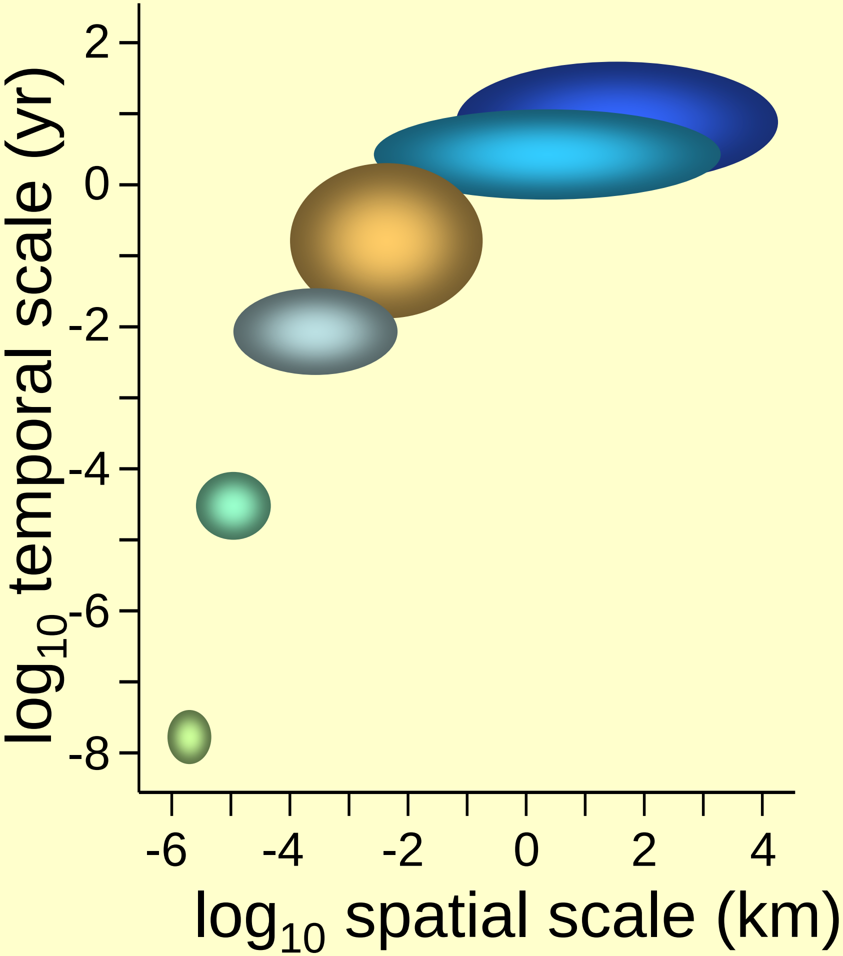


(Kelly and Palumbi 2010)

Implications: Vast Spatial Scales

Dynamic habitat
(Water flow)

Time – Space Links
(Temporal separation influences spatial separation)



Levin, S.A. 1992.
The problem of pattern and scale in ecology.
Ecology 73:1943-1967.

Is the Ocean Unique ?

NATURE VOL. 313 31 JANUARY 1985 REVIEW ARTICLE 355

A comparison of terrestrial and marine ecological systems

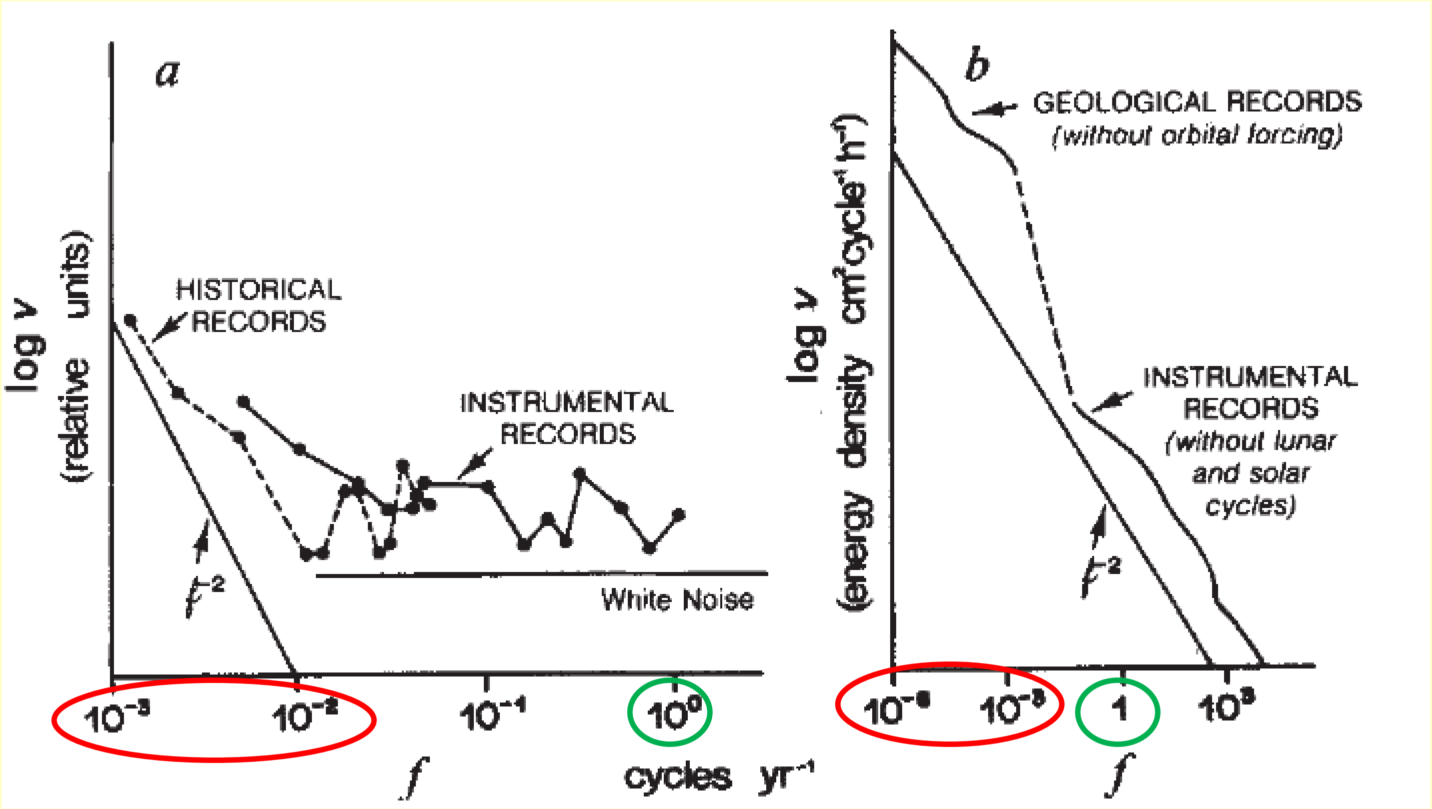
John H. Steele

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

I review here the differences between temporal variability in terrestrial and marine environments and consider how this external forcing may affect population fluctuations in the two systems. The internal dynamics and community responses are expected to differ significantly with marine populations more likely to show longer term changes between alternative community structures.

(Steele 1985)

Why is the Ocean "Red"?



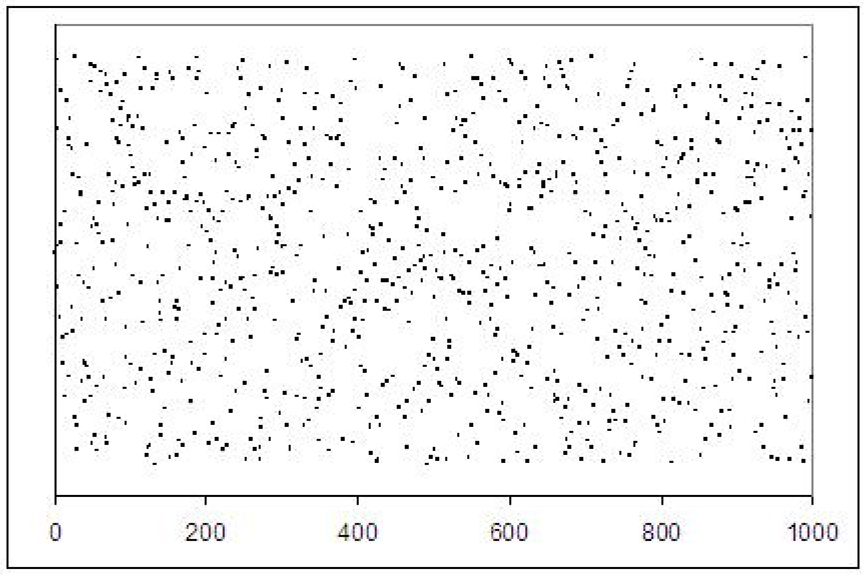
(a) Atmospheric temperature records

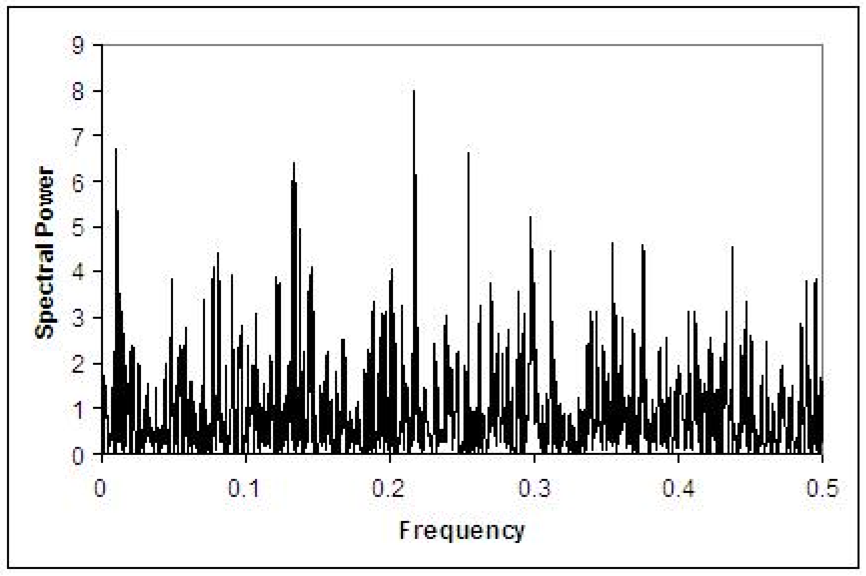
(b) Sea-level records

Equal variance in 1-50 year range. More variation (energy) in frequencies of > 50 years

Variance increases with decreasing frequency

➢ White noise: equal energy in all frequencies





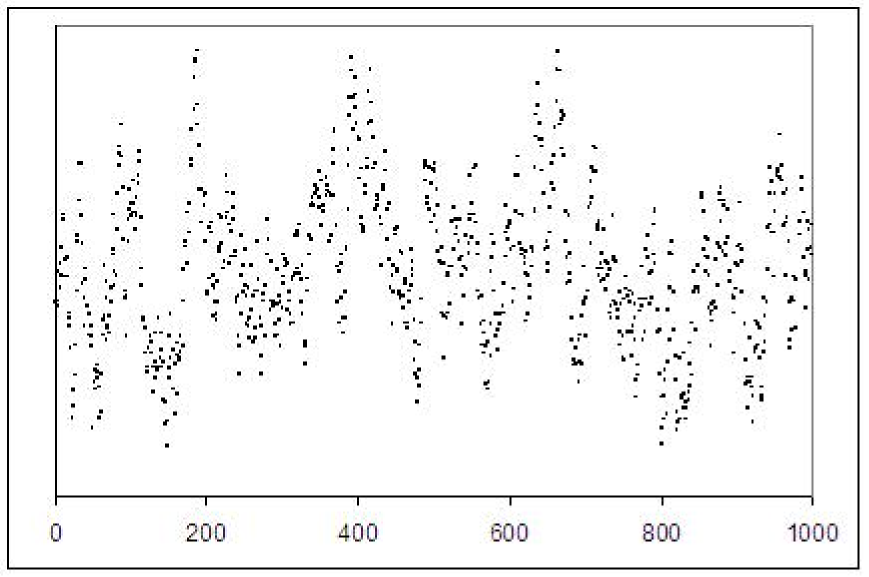
Years

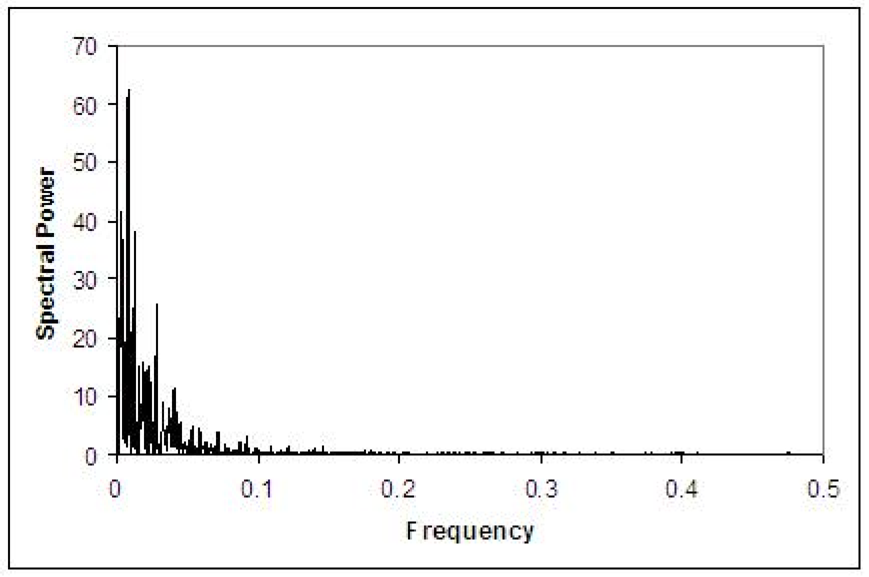
10 yrs

2 yrs

- Each individual observation is independent
- There are no cycles

➤ Red noise: higher variance in low frequency (long time)

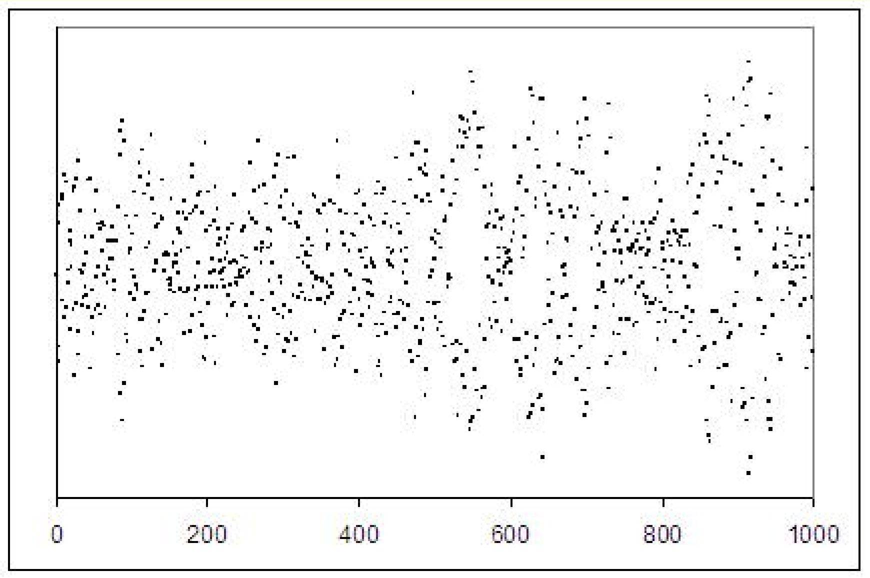


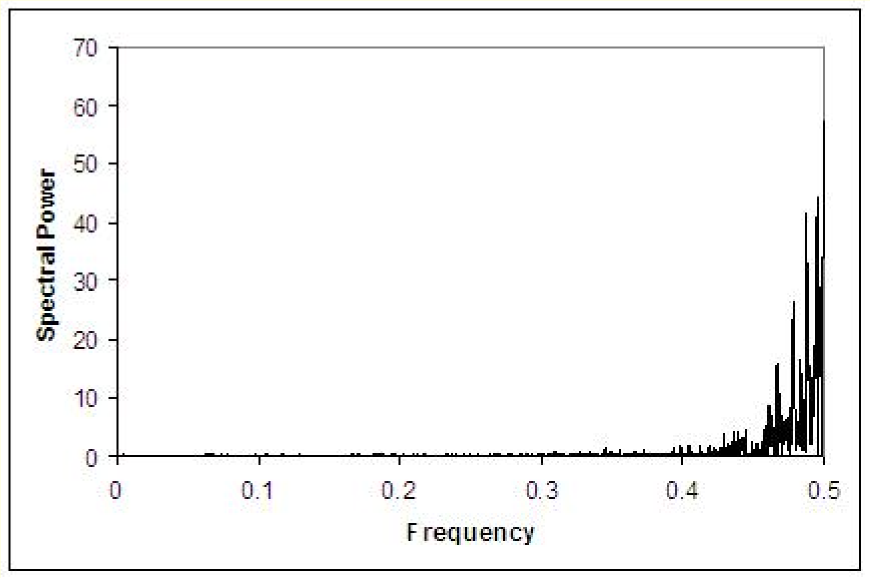


Years **10 yrs** **2 yrs**

- Adjacent values are *not* independent of each other
- Consecutive values are positively correlated (similar to each other)

- Blue noise: higher variance in high frequency (short time)



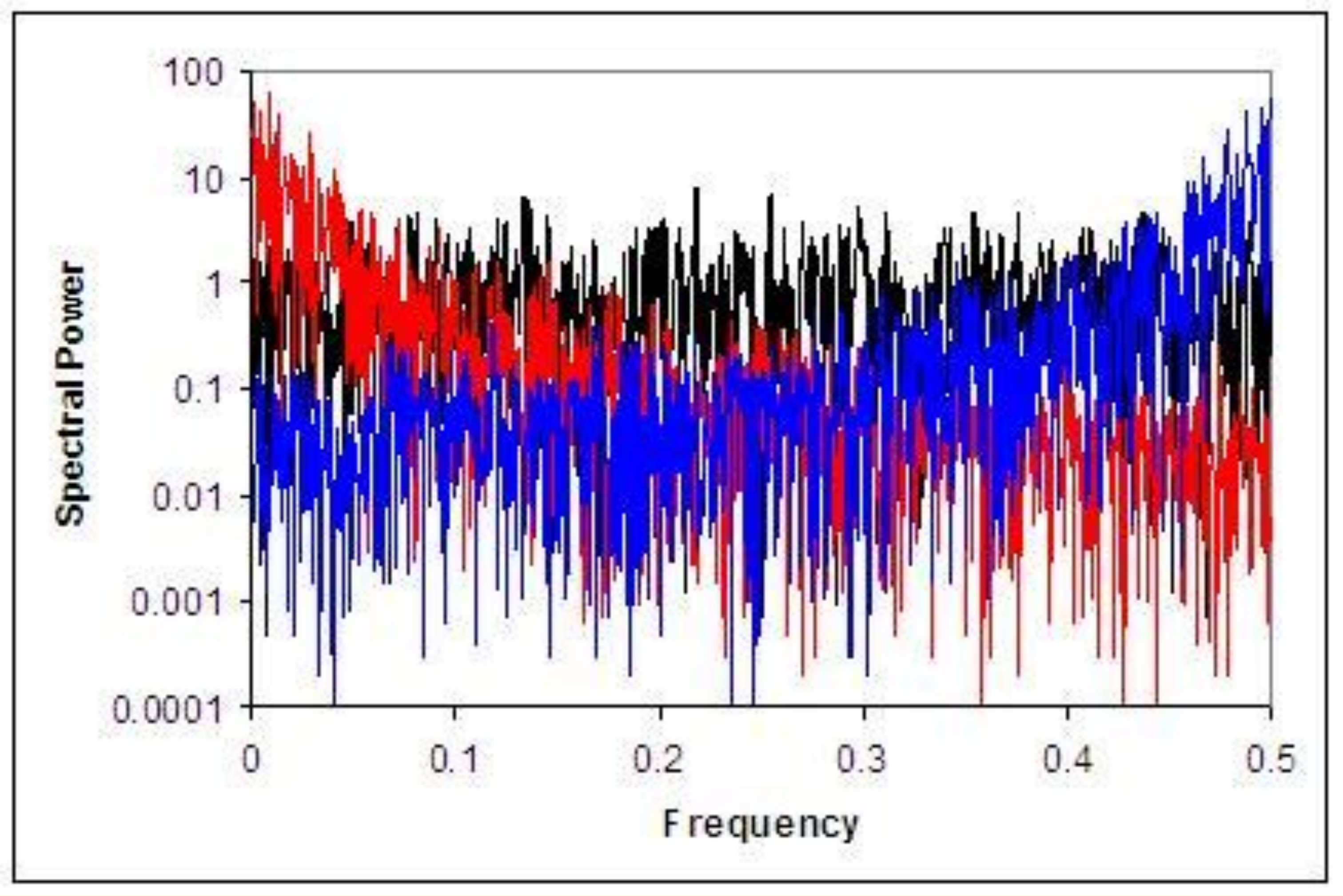


Years **10 yrs** **2 yrs**

- Adjacent values are *not* independent of each other
- Consecutive values are negatively correlated (different from each other)

Main take-home Message

- Ocean time series are red: Long-term variance dominates

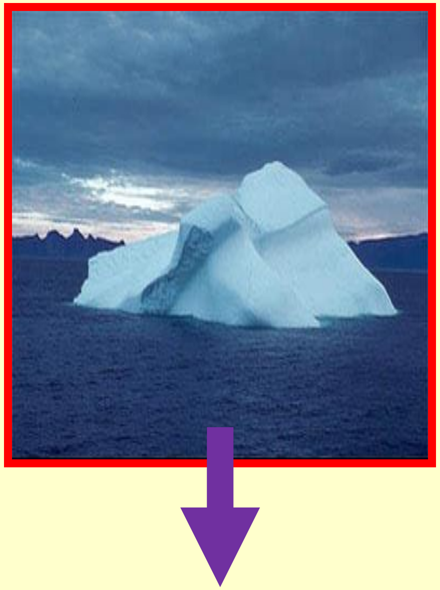


Reason: Long-term "Memory"

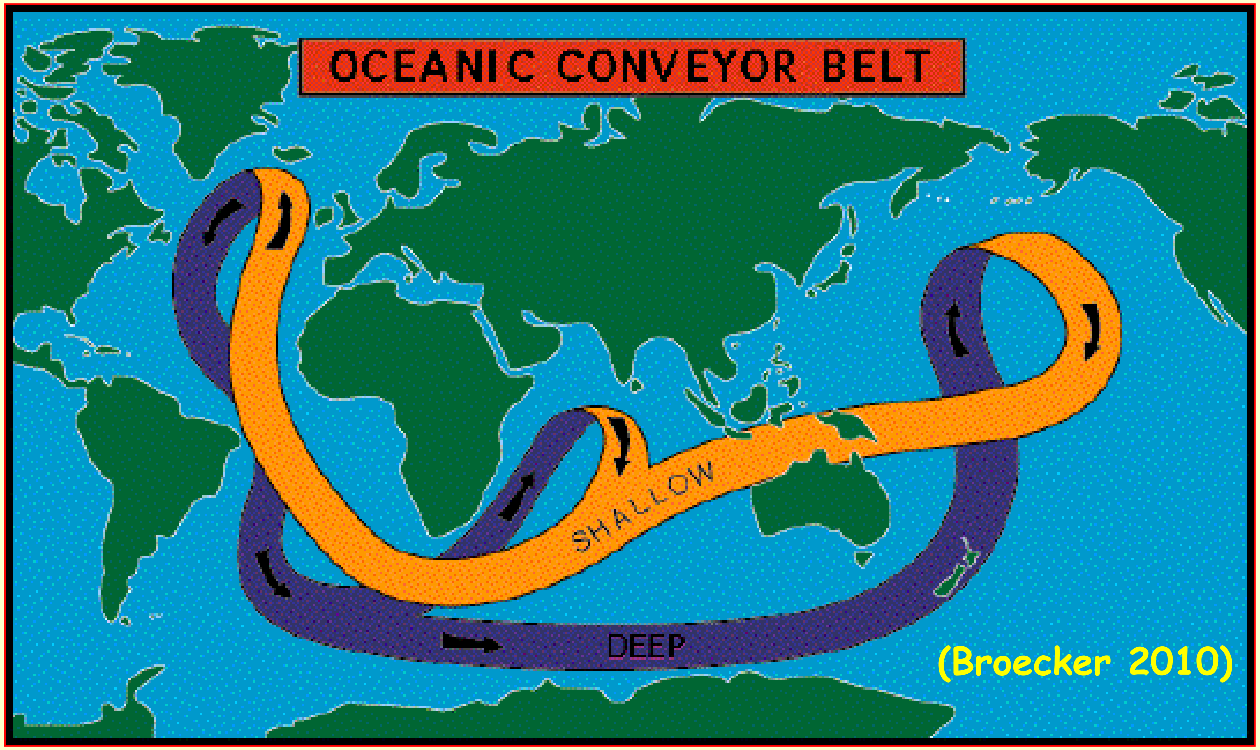
The ocean has "inertia":

Sea water has high heat capacity (season / year scales)

Turn-over is very slow (residence time ~ 1000 years)



Deep Water Formation



Managing a Red Ocean

Implications of a “Red” Ocean

At long time scales, the system is inherently unpredictable.

Many species undergo periodic oscillations (with large wavelengths), even in the absence of harvesting.

These behaviors can be recreated with simple models, when the forcing frequency is less than the response rate of the system.

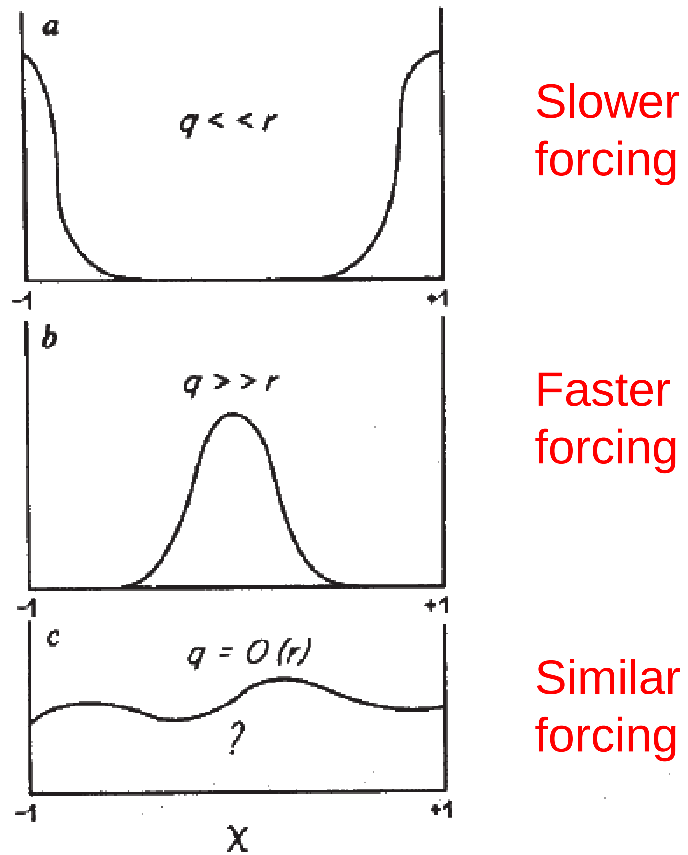


Fig. 4 Response of a two-equilibria system to stochastic forcing at frequencies: *a*, much less than and *b*, much greater than the intrinsic response rate of the system. *c*, Indeterminacy of the system when the rates are comparable.

(Steele 1985)

Implications of a "Red" Ocean

Simulated population oscillations over long periods in response to "red" forcing

Observed fish oscillations – without fishing

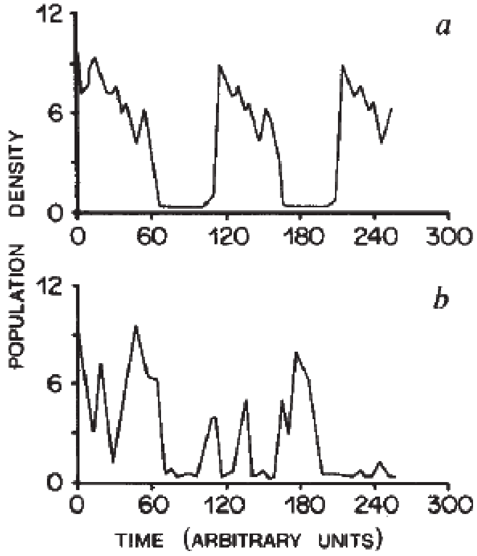
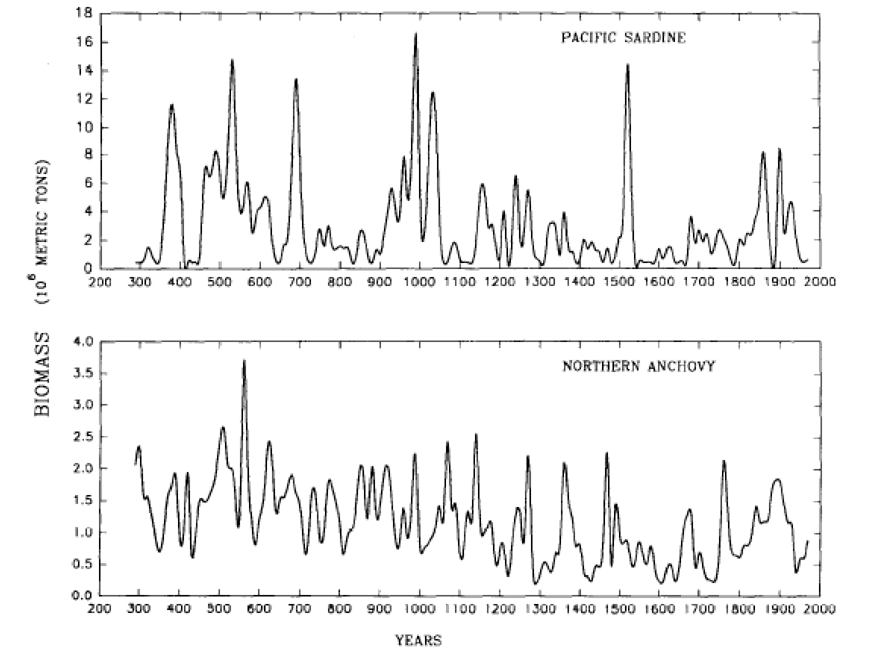


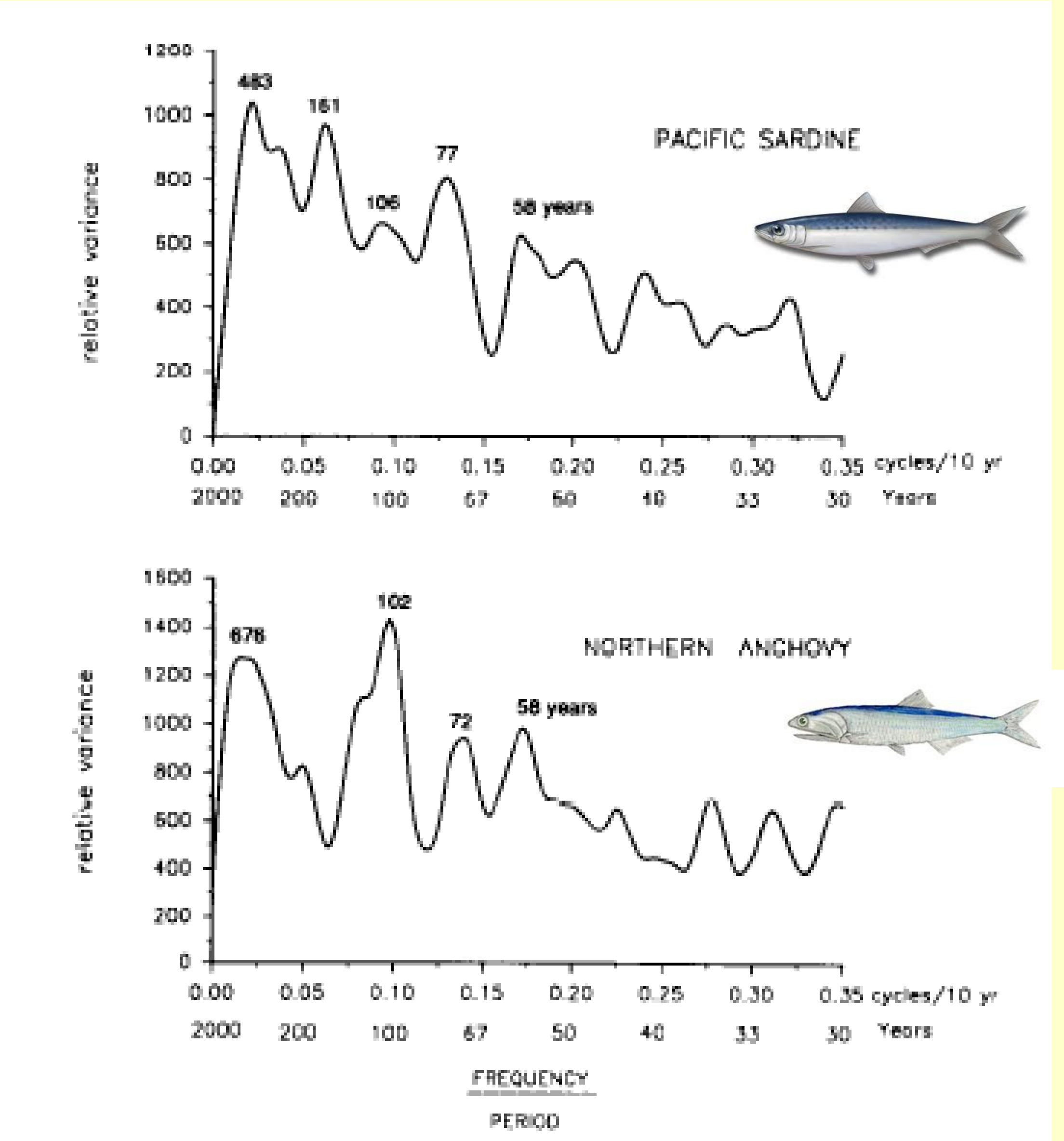
Fig. 5 Response of *P* to stochastic forcing by red noise (*a*) and white noise (*b*) (see text for details).

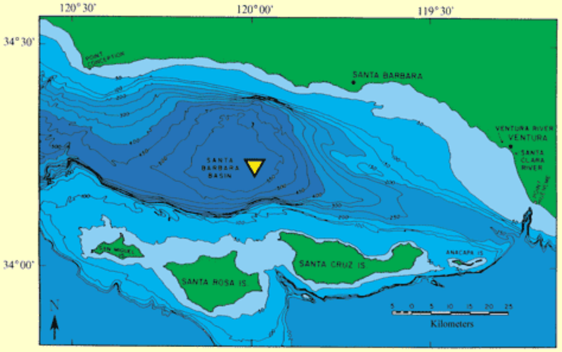


(Steele 1985)

(Baumgartner et al. 1992)

Implications: Population Oscillations



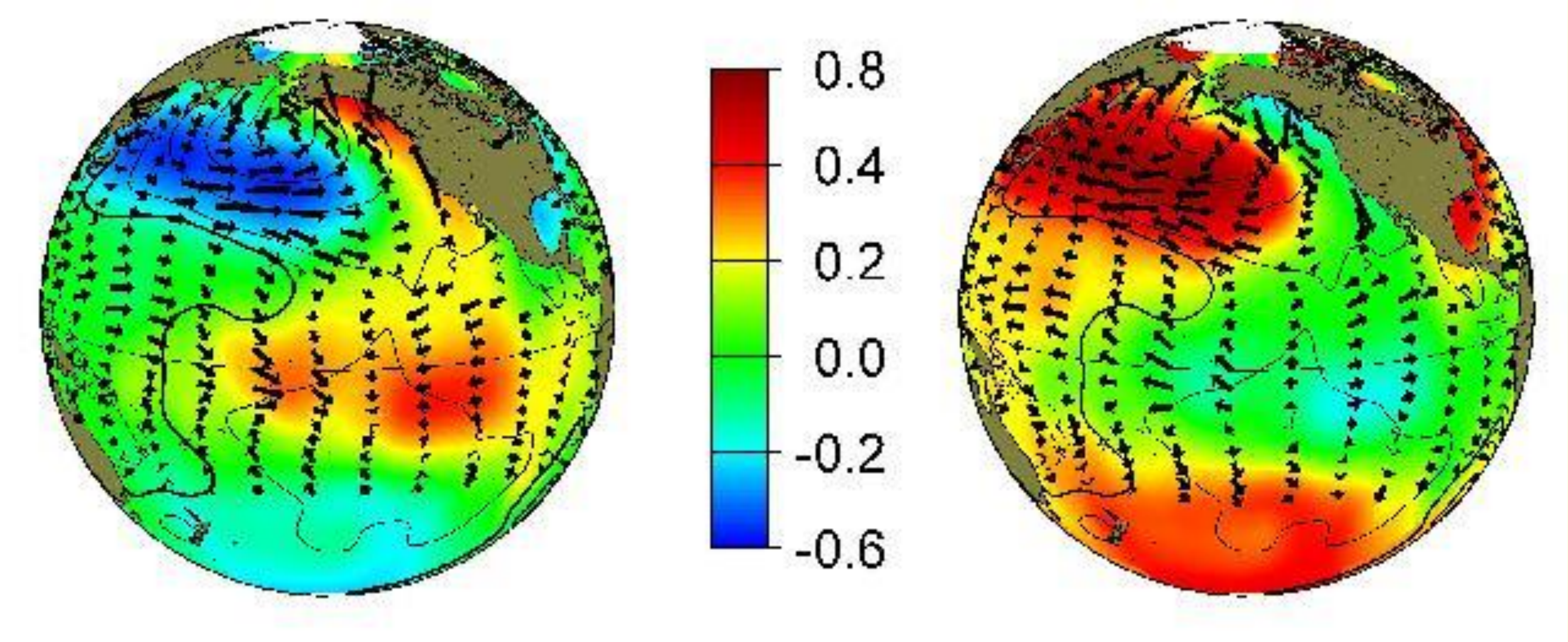


Long time scales of "natural" variability in anchovies and sardines, without fishing

(Baumgartner et al. 1992)

Example: Decadal Oscillations

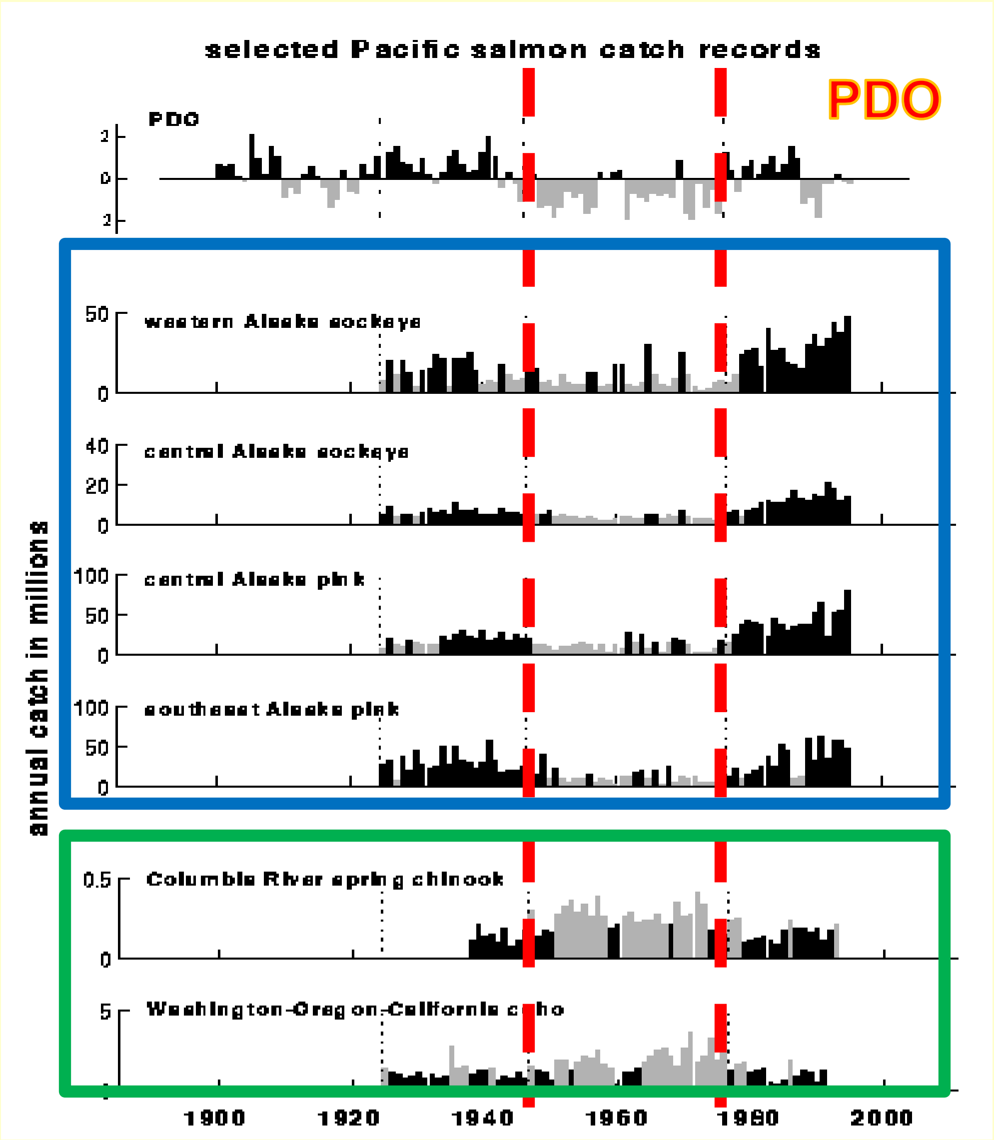
"Positive State" "Negative State"



Correlations between PDO and SST

(Mantua et al. 1997)

PDO Driven Step-like Changes



Out of phase salmon catches in Alaska and California Current

Related to SST variability (PDO)

(Beamish et al. 1999)

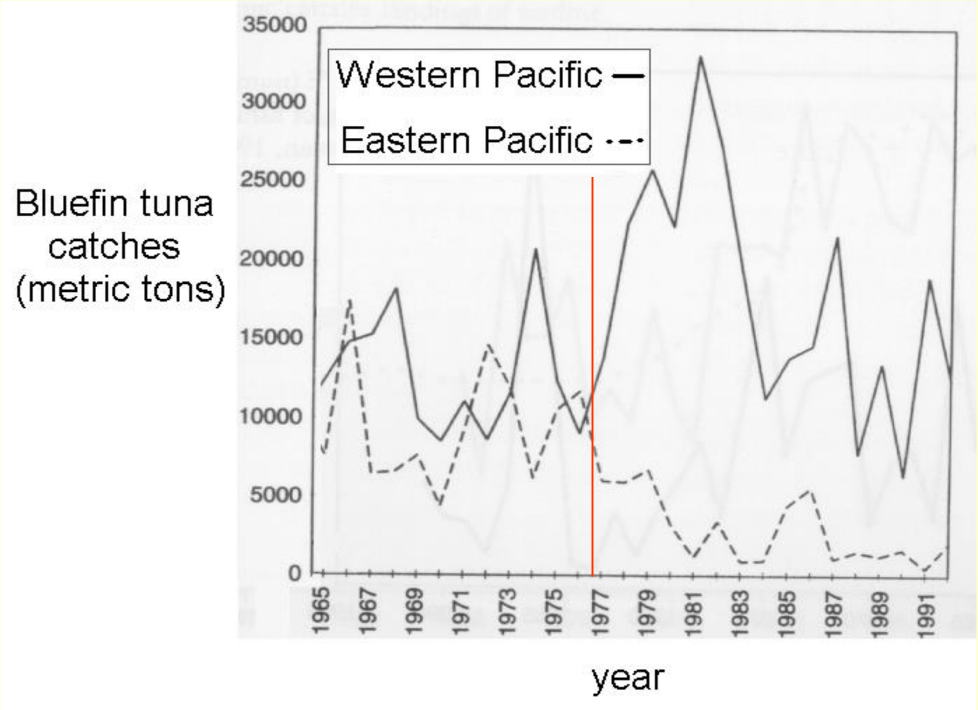
PDO-driven Distribution Changes

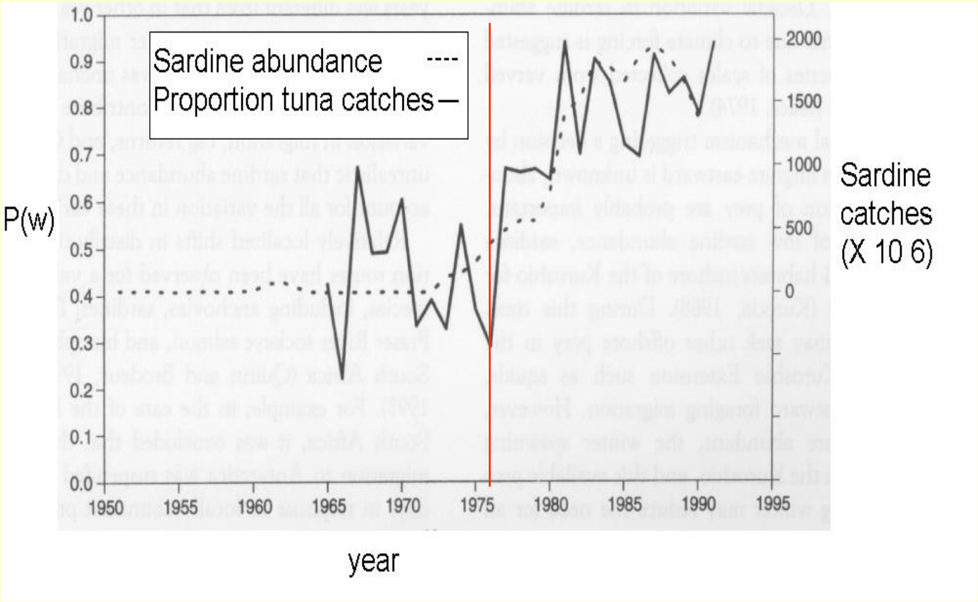
- Shift in the distribution of bluefin tuna catches

- Ascribed to changes in prey abundance

(Japanese sardine)

(Polovina 1996)

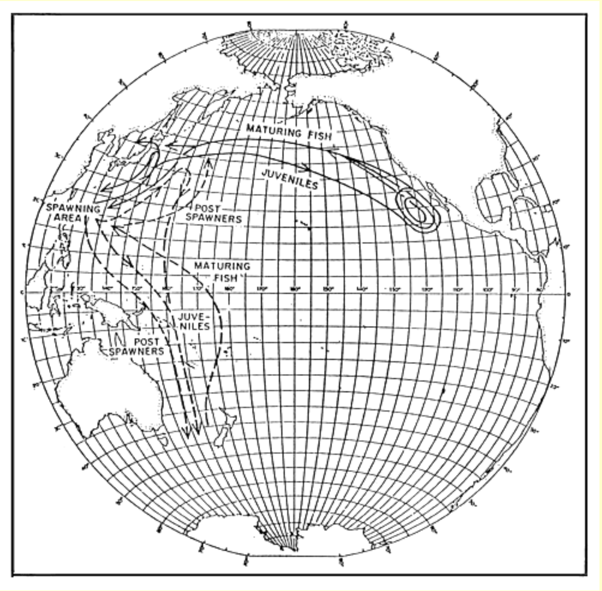




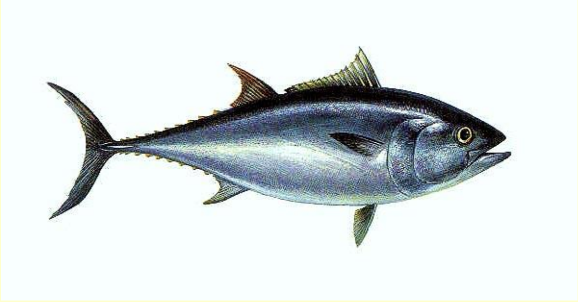
Bluefin Tuna Transpacific Range

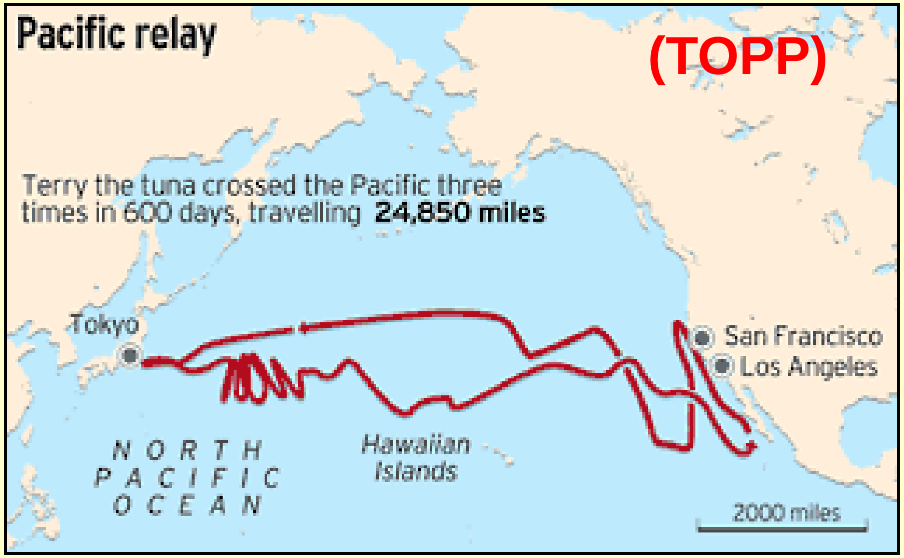
Range widely, from warm tropical (~ 28 ^{o} C. SST) to cool temperate (~ 10 ^{o} C. SST) waters

(Bayliff 1980)



Migrate 8,000 km
in just 50 days





Implications: Constraints to Conservation

- **Disconnect** between spatial / temporal scales of the management and ocean variability
- **Time lags** between climate perturbation and the eventual ecosystem-wide responses make it difficult to anticipate effects on a given stock / fishery
- **Incomplete understanding** of the ecology of the species (distributions, predator / prey interactions) and the impacts (e.g., high-seas fisheries)
- **Lack of awareness / political will** to change practices is perhaps the biggest constraint

Uncertainty, Resource Exploitation, and Conservation: Lessons from History (Ludwig et al. 1993)

Although there is considerable variation in detail, there is remarkable consistency in the history of resource exploitation.

We suggest that such consistency is in part due to the following:

Large levels of natural variability mask effects of overexploitation

Thus, initial overexploitation is not detectable until it is severe

Furthermore…
Perception influences our attitude towards changing nature

Uncertainty, Resource Exploitation, and Conservation: Lessons from History (Ludwig et al. 1993)

Five Principles of Effective Management:

Lack of understanding and inability to predict require a cautious approach to resource exploitation. Here are some suggestions:

1) Study human motivation and responses as part of the system
2) Act before scientific consensus is achieved
3) Rely on scientists to recognize problems, but not to remedy them (interdisciplinary problems / external pressures)
4) Distrust claims of sustainability. Be always ready to act
5) Confront uncertainty. Effective policies are possible under conditions of uncertainty, but they must take uncertainty into account

“The future's uncertain and the end is always near”
- J. Morrison (Roadhouse Blues)

“Those who cannot remember the past are condemned to repeat it”

- J. Santayana

We are not in Kansas any more

- Wizad of Oz

Intro to Modelling

"All models are wrong. Some models are useful"

Deming

Modelling – What is it Good For?

NATURE VOL. 313 31 JANUARY 1985 REVIEW ARTICLE 355

A comparison of terrestrial and marine ecological systems

John H. Steele

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

Simplified models provide insights behavior of the system

Models facilitate experiments (hind-casting and forecasting)

Models allow us to build and evaluate uncertainty in predictions

Modelling – What is it Good For?

A PRAGMATIC APPROACH TO MODELING FOR WILDLIFE MANAGEMENT

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Abstract: I contrast 2 views of modeling: the model as a representation of "truth" and the model as a problem-solving tool. Examples are given of how, in the latter case, the objective drives the design of small, simple models that focus relentlessly on the problem to be solved. A number of applications for small, focused models are offered. I stress the need for wildlife professionals to develop the skills for constructing and using such models on a regular basis; I end with ideas about how to create a modeling culture in conservation and resource management organizations.

J. WILDL. MANAGE. 61(2):261–270

Two Views of Modelling: "The Truth" vs. "A Tool"

Modelling – What is it Good For?

Seven common misconceptions about Modelling in Wildlife Management:

(Starfield 1997)

1. A model cannot be built with incomplete understanding of the behavior of a system or population.
2. It is not useful to build a model if there are gaps in the data it is likely to need (so the priority is to collect data).
3. A model cannot be used in any way or form until it has been validated or been proven to be accurate.
4. A model must be as realistic as possible, accounting for all the detailed intricacies of a biological system.
5. Modeling is a process akin to mathematics; as such it cannot be used or understood by most managers and many field biologists.
6. The primary purpose of building models is to make predictions.
7. Modeling is time-consuming and expensive; it follows that models must be designed to answer all the questions that have been thought of, or questions that may arise in the future. The more multipurpose the model, the better the value one is getting for one's investment.

Population Growth Models

Discrete time:

$N(t+1) = N(t) * R$

$N(t+2) = N(t) * R * R$

. . .

$\boxed{Nt = No * R^t}$

What is R ?

R = N(t+1) / N(t)

R = Lambda = λ

$\boxed{R = e^r}$

Continuous time:

$N(t+1) = N(t) * e^r$

$N(t+2) = N(t) * e^r * e^r$

. . .

$\boxed{Nt = No * e^{r\,t}}$

What is r ?

r = intrinsic rate of growth

r = birth rate – death rate

Population Growth Models

Non-structured population models help answer simple questions:

1. What is the population rate of growth ?

For example: $N_o = 100$, $N(5) = 87$ Lambda = ?

$0.87 = \lambda^5$ Lambda = 0.972

2. What will be the population size after n years (or generations)?

For example: Lambda = 0.972, $N_o = 100$ N(5) = ?

$100 * (0.972)^5 = N(5) = 87$

3. How long will it take for a population to grow to a specific size?

For example: $N_t = 87$, $N_o = 100$ time required = ?

$0.87 = (0.972)^t$ $\log(0.870) / \log(0.972) = t = 5$

Population Growth Models

We can also incorporate probabilistic outcomes into predictions:

For example: The population growth rate (Lambda) varies.
There are good and bad years. Time is discrete.

Lamba (good years) = 2.0
Lambda (bad years) = 0.5

probability (good years) = 0.5
probability (bad years) = 0.5

<u>Question</u>:

We start with N = 4. How large will be the population after 2 years?

Four possible outcomes: 1 (b,b), 4 (g,b), 4 (b,g), 16 (g,g)

NOTE: "Average" Outcome, given p (good year) = p (bad year) is N =4

Outcome 1 (b,b) = 4 to 2 to 1
Outcome 2 (g,b) = 4 to 8 to 4
Outcome 3 (b,g) = 4 to 2 to 4
Outcome 4 (g,g) = 4 to 8 to 16

Observed outcome varies: Mean population size: 6.25 +/- 6.65 (S.D.)

Variability: CV = (6.65) * 100 / (6.25) = 106%

Final Thoughts on Modelling

"By operating the model the computer faithfully and faultlessly demonstrates the implications of our assumptions and information. It forces us to see the implications, true or false, wise or foolish, of the assumptions we have made. It is not so much that we want to believe everything that the computer tells us, but that we want a tool to confront us with the implications of what we think we know"

Botkin

"The best explanation is as simple as possible, but no simpler"

Einstein