Fishing effects enhanced variability and sensitivity of exploited fish populations

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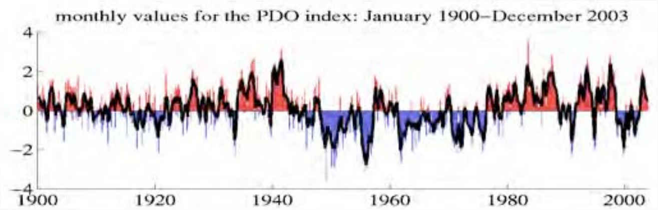
One big issue in fisheries

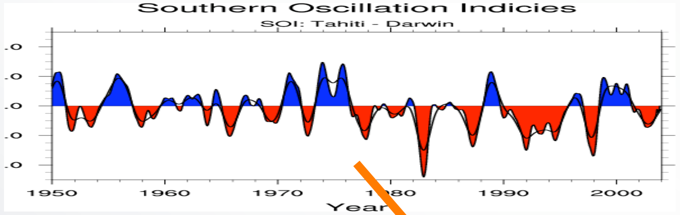
Try to understand climatic and fishing effects on fish populations.

Climate

PDO



ENSO



Fisheries

How to examine fishing effects in the context of a changing climate?

Difficulty

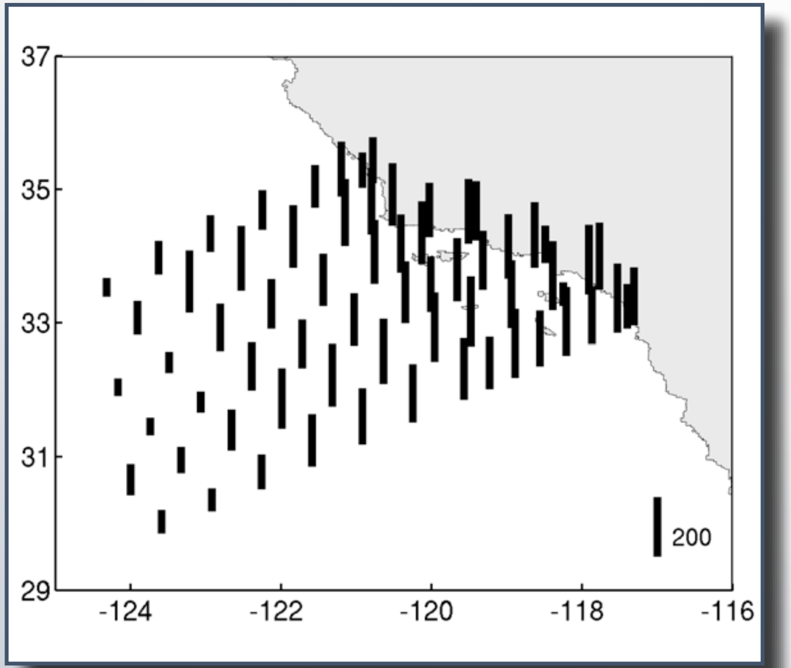
What’s the baseline?

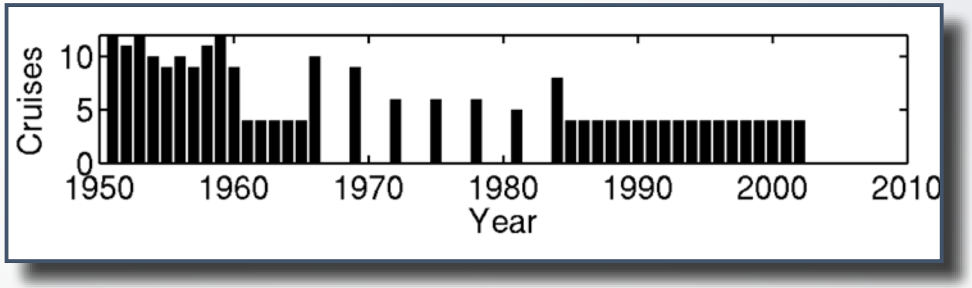
One possible solution

Compare exploited to unexploited species **(although no perfect comparison can be made).**

CalCOFI
(California Cooperative Fisheries Investigation)

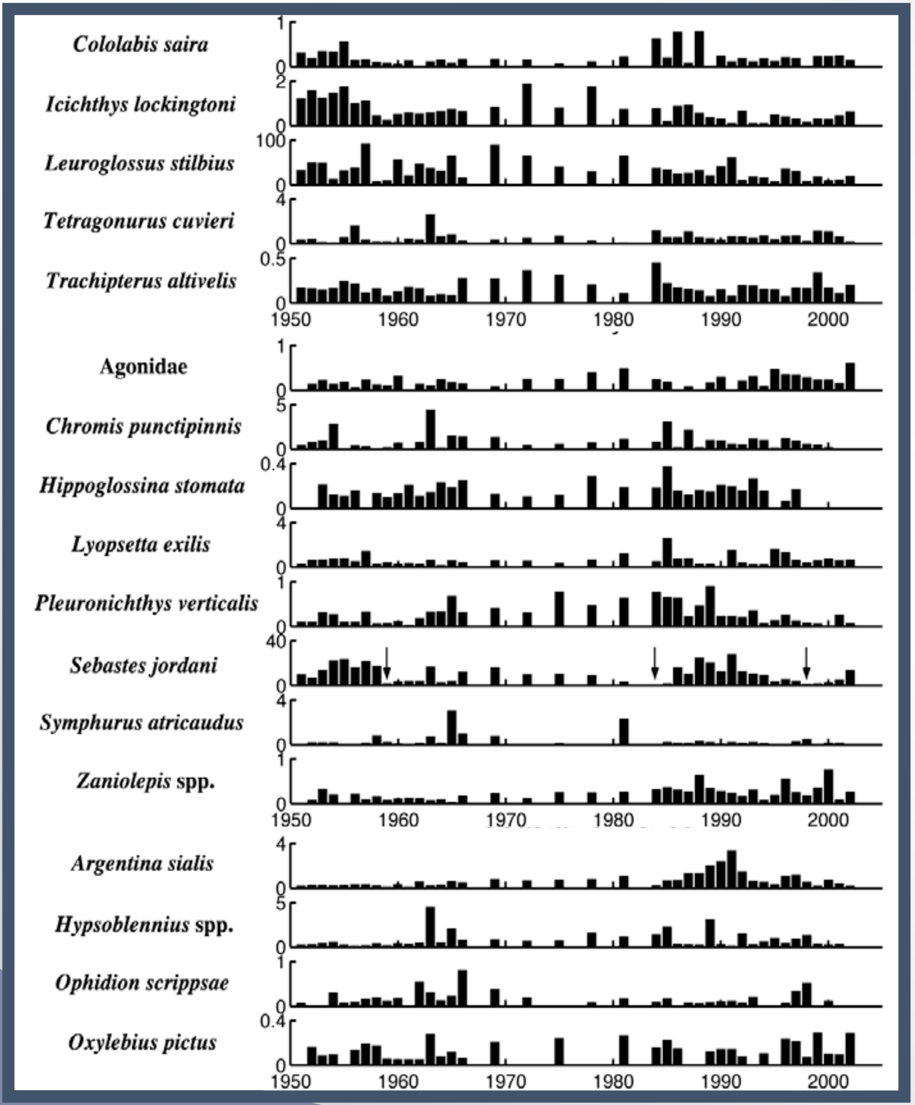
- **Standardized sampling methods**
- **Both exploited and unexploited species**
- **Long-term (1951-now)**



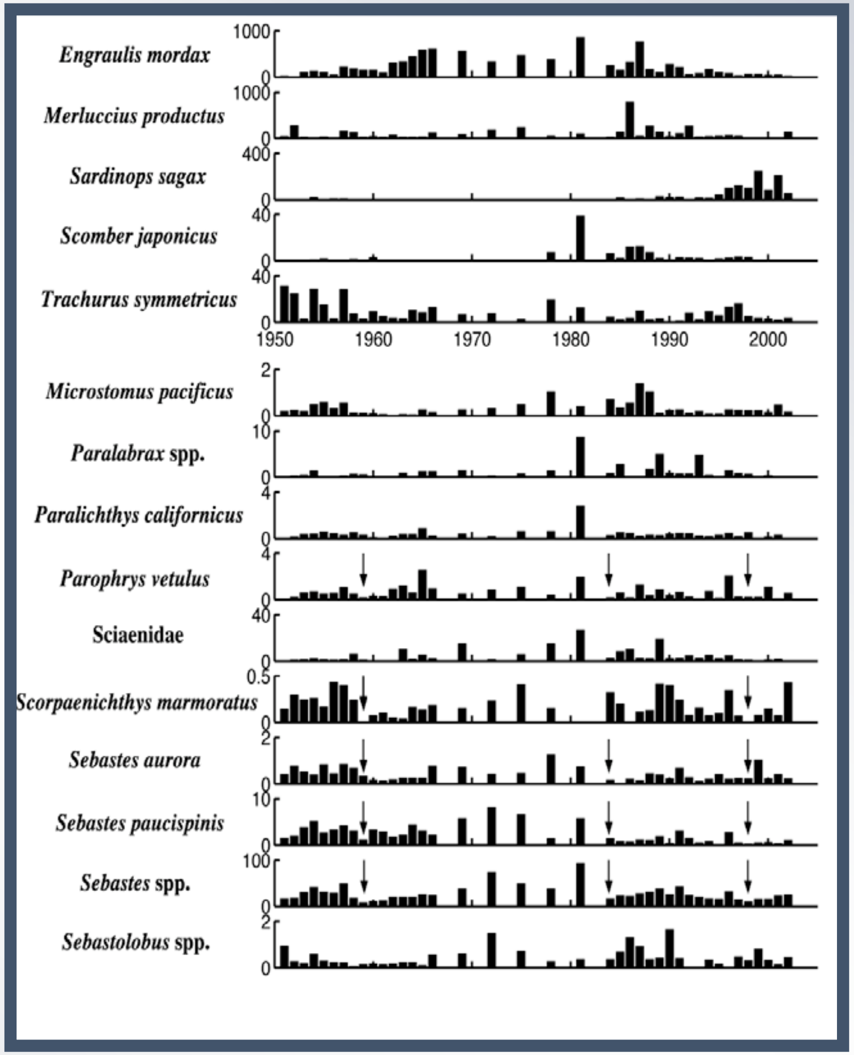


Data

Unexploited



Exploited



(Hsieh et al., 2005. Prog. Oceanogr. 67: 160-185)

No clear declining trend

	Species	Correlation coefficient	p-value
Exploited	*Engraulis mordax*	-0.126	0.439
	Merluccius productus	0.072	0.659
	Sardinops sagax	0.583	< 0.001
	Scomber japonicus	0.159	0.327
	Trachurus symmetricus	-0.451	0.004*
	Microstomus pacificus	0.105	0.521
	Paralabrax clathratus	0.179	0.270
	Paralichthys californicus	-0.010	0.950
	Parophrys vetulus	-0.050	0.758
	Scorpaenichthys marmoratus	-0.097	0.550
	Sebastes aurora	-0.243	0.131
	Sebastes paucispinis	-0.505	0.001*
	Sphyraena argentea	0.230	0.154
Unexploited	*Cololabis saira*	0.037	0.822
	Icichthys lockingtoni	-0.569	< 0.001*
	Leuroglossus stilbius	-0.359	0.023*
	Tetragonurus cuvieri	0.100	0.539
	Trachipterus altivelis	0.040	0.809
	Chromis punctipinnis	-0.099	0.544
	Lyopsetta exilis	0.172	0.289
	Hippoglossina stomata	-0.097	0.554
	Pleuronichthys verticalis	0.069	0.673
	Sebastes jordani	-0.206	0.203
	Symphurus atricaudus	-0.123	0.448
	Zaniolepis frenata	0.541	< 0.001
	Argentina sialis	0.437	0.005
	Hypsoblennius jenkins	0.042	0.799
	Ophidion scrippsae	-0.167	0.303
	Oxylebius pictus	0.189	0.244

Understanding temporal Variability is important

- In determining reference points, decision making and risk assessment in precautionary fisheries management.
- In evaluating the extinction risk of a population.

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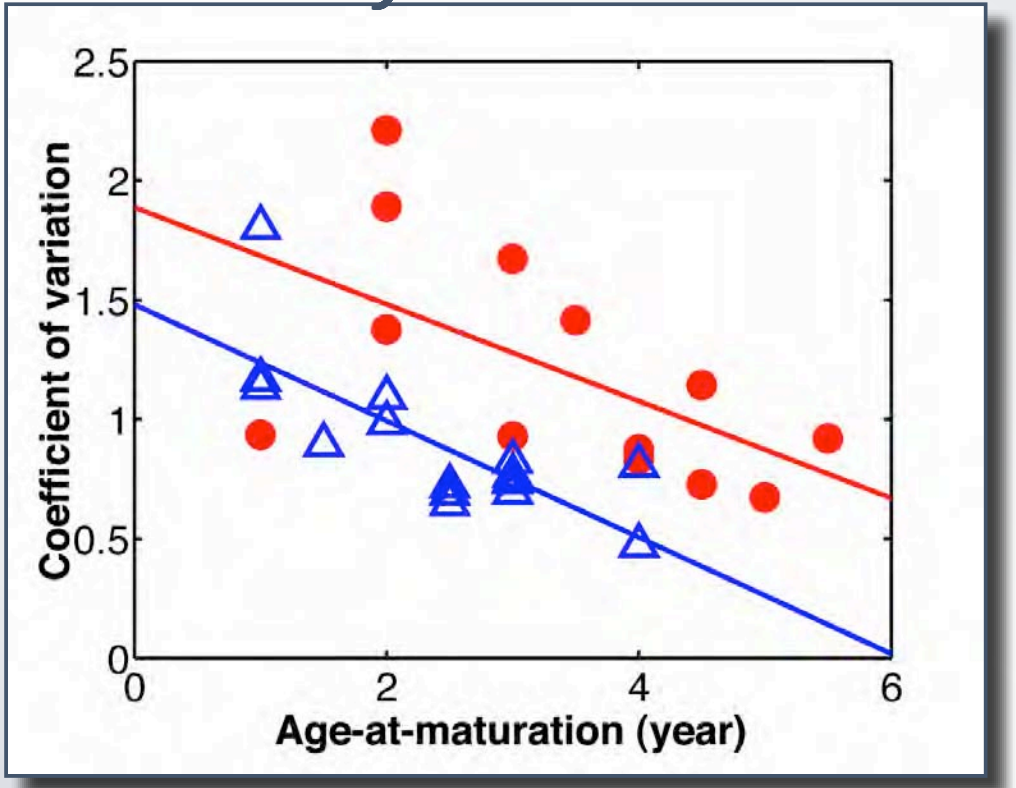
Concepts

- **“Controlled experiment.”**
- **All species experienced much the similar large-scale environmental forcings.**
- **Differential responses to the similar environmental forcing are likely due to their life history, ecological characteristics and phylogenetic constraints.**

$$\text{CV} = \underbrace{\text{fishing}}_{\text{main effect}} + \underbrace{\boxed{\text{life history, abundance, ecological traits, phylogeny}}}_{\text{covariates}}$$

Use the coefficient of variation (CV) as the measure of long-term variability

Summary

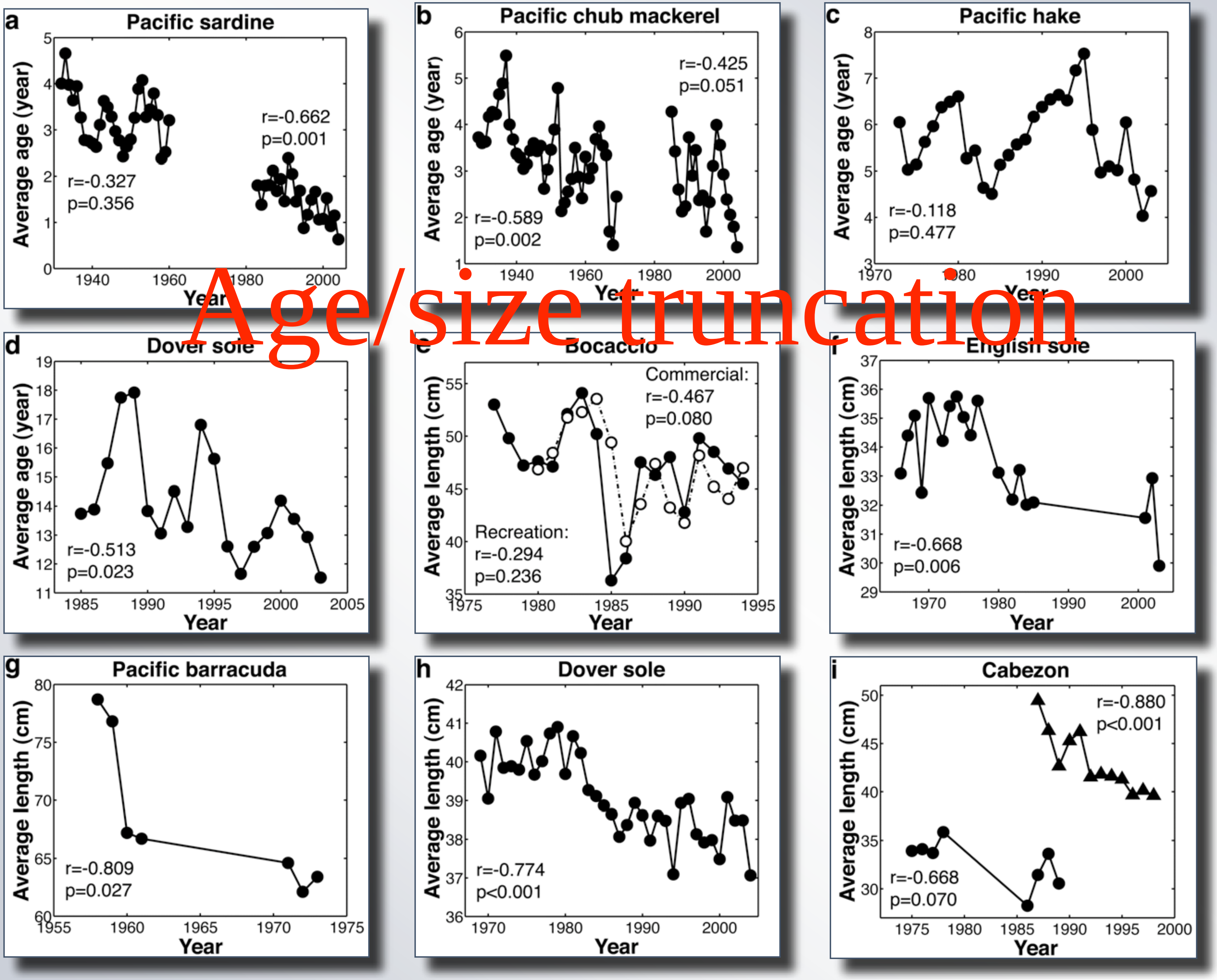


Red: exploited
Blue: unexploited

Exploited populations are more variable than unexploited populations. Fishing magnifies uncertainty in a changing environment.

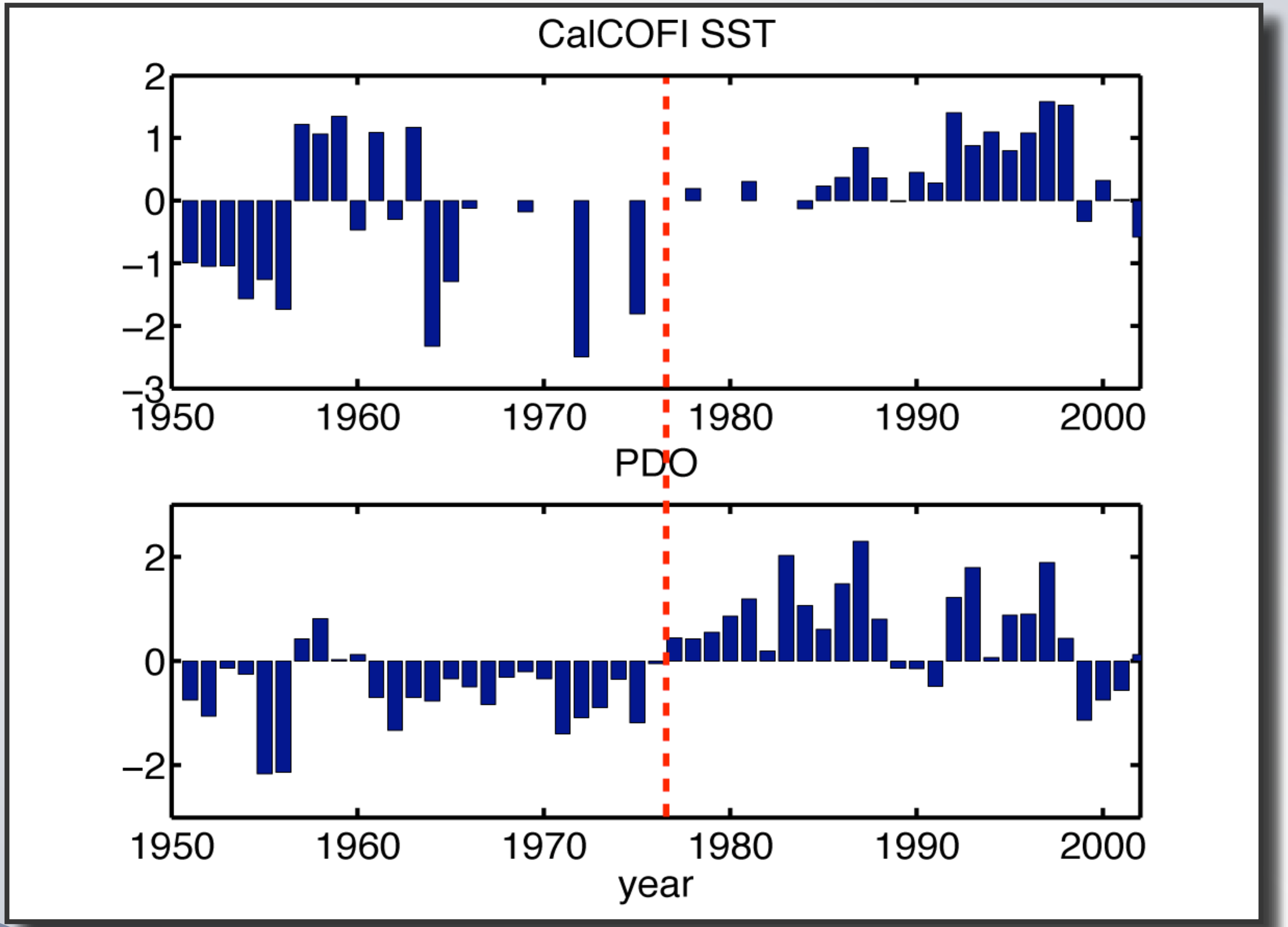
(Hsieh et al., 2006. Nature. 443: 859-862)

Age/size truncation



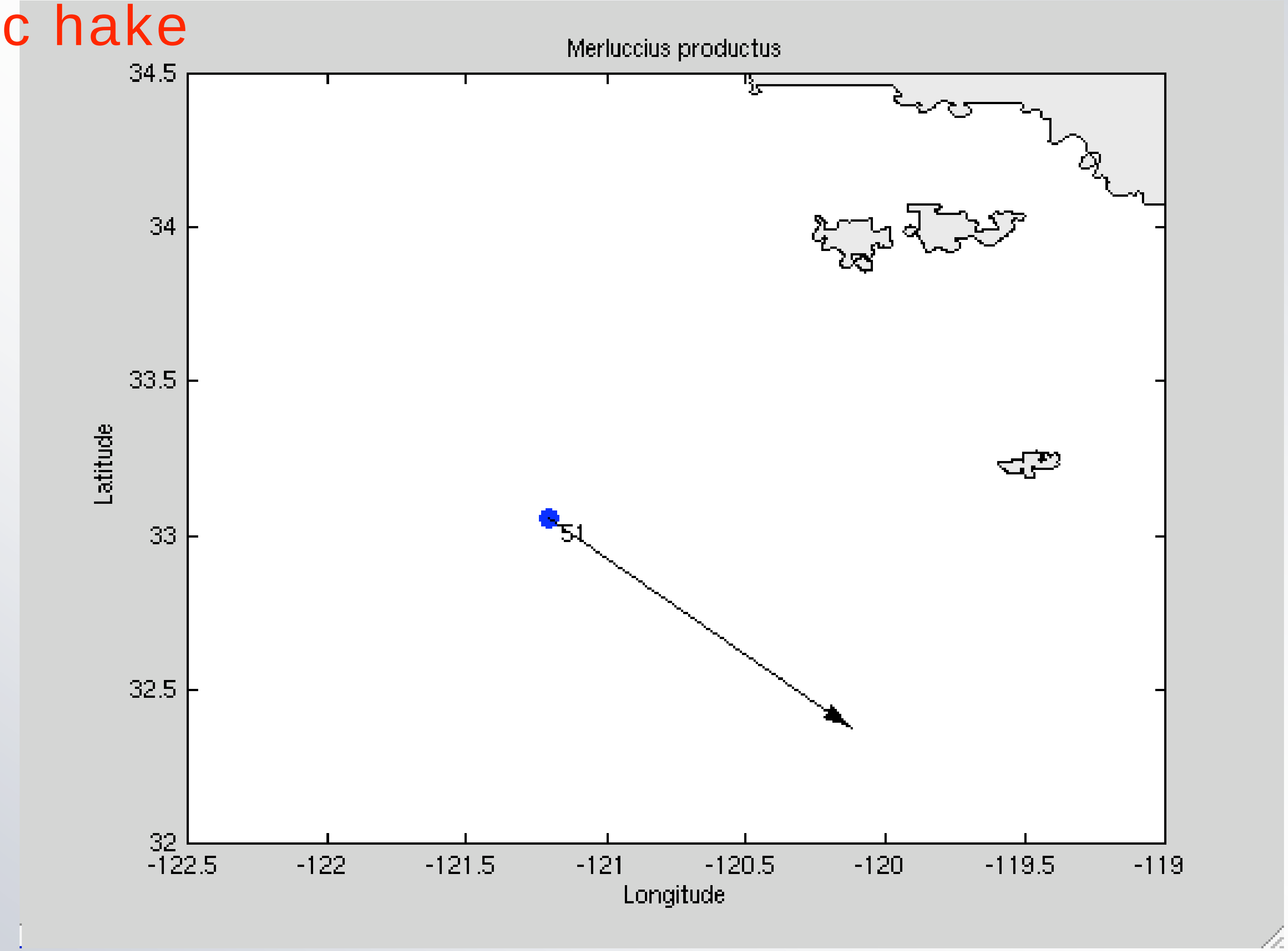
How well do fish track environmental changes in the spatial distribution? Does fishing play a role?

Interannual and bi-decadal variations



The density-weighted centroid for each sampling year

Pacific hake

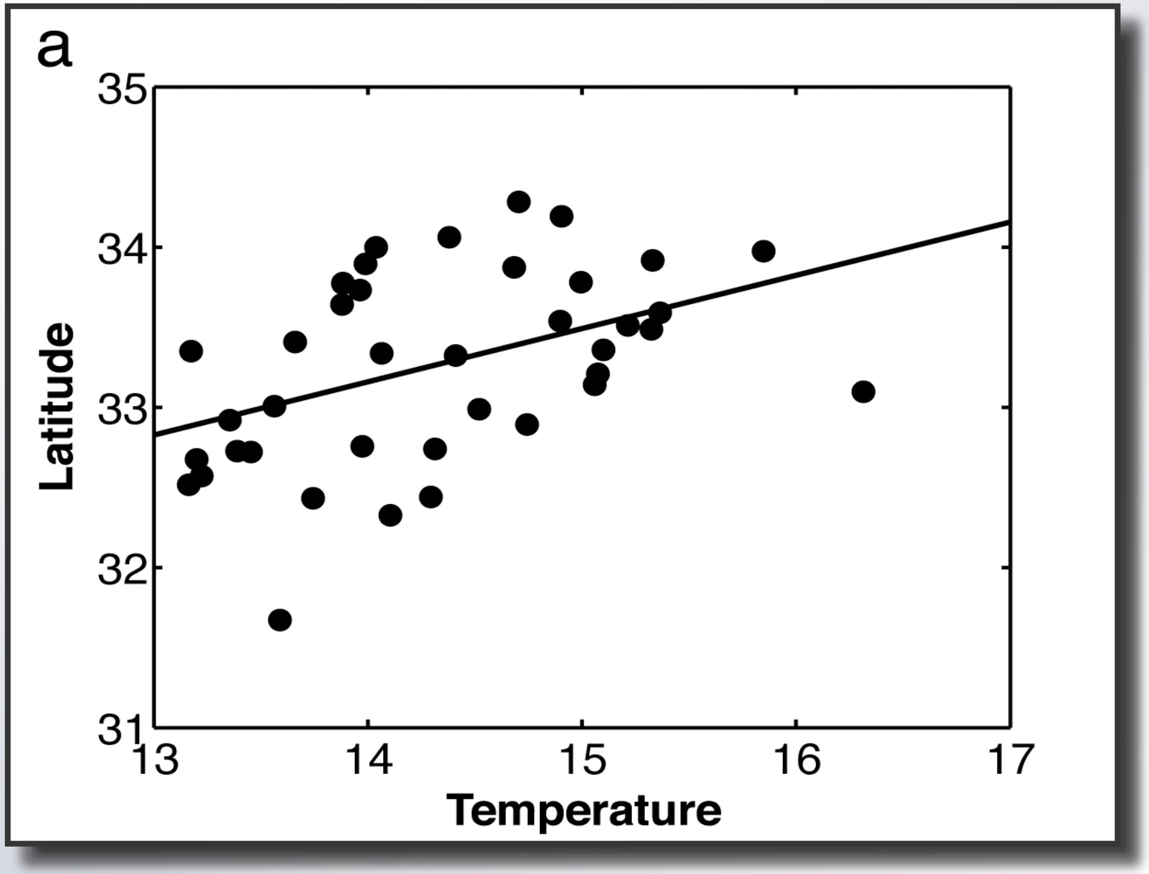


● : 1951-1976 ● : 1977-1998 ● : 1999-2002

Interannual variability

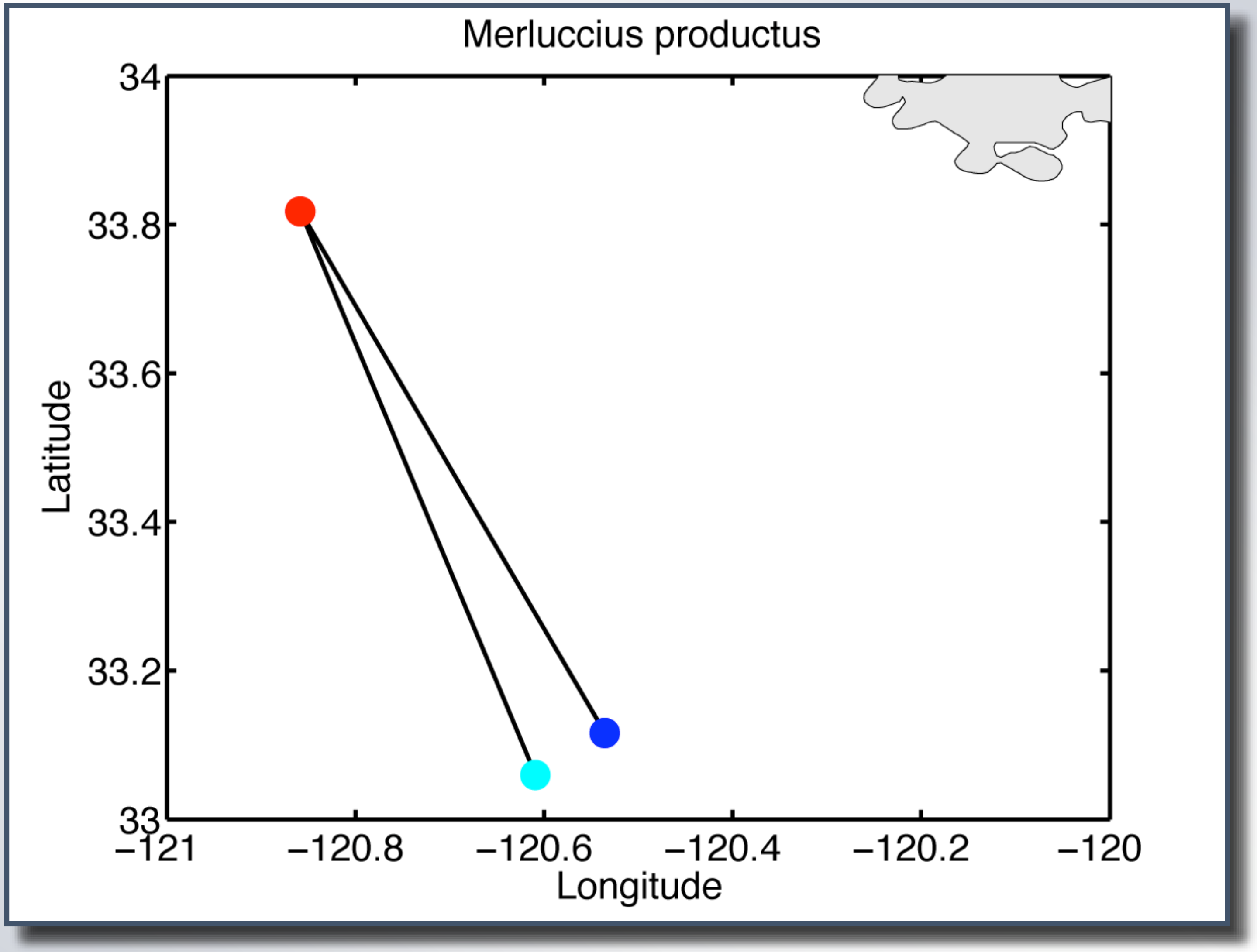
- Use CalCOFI SST as a proxy to the climate
- Correlate mean latitude and boundaries to SST
- Climate indices (SOI, NPI, PDO) are also checked.

Pacific hake



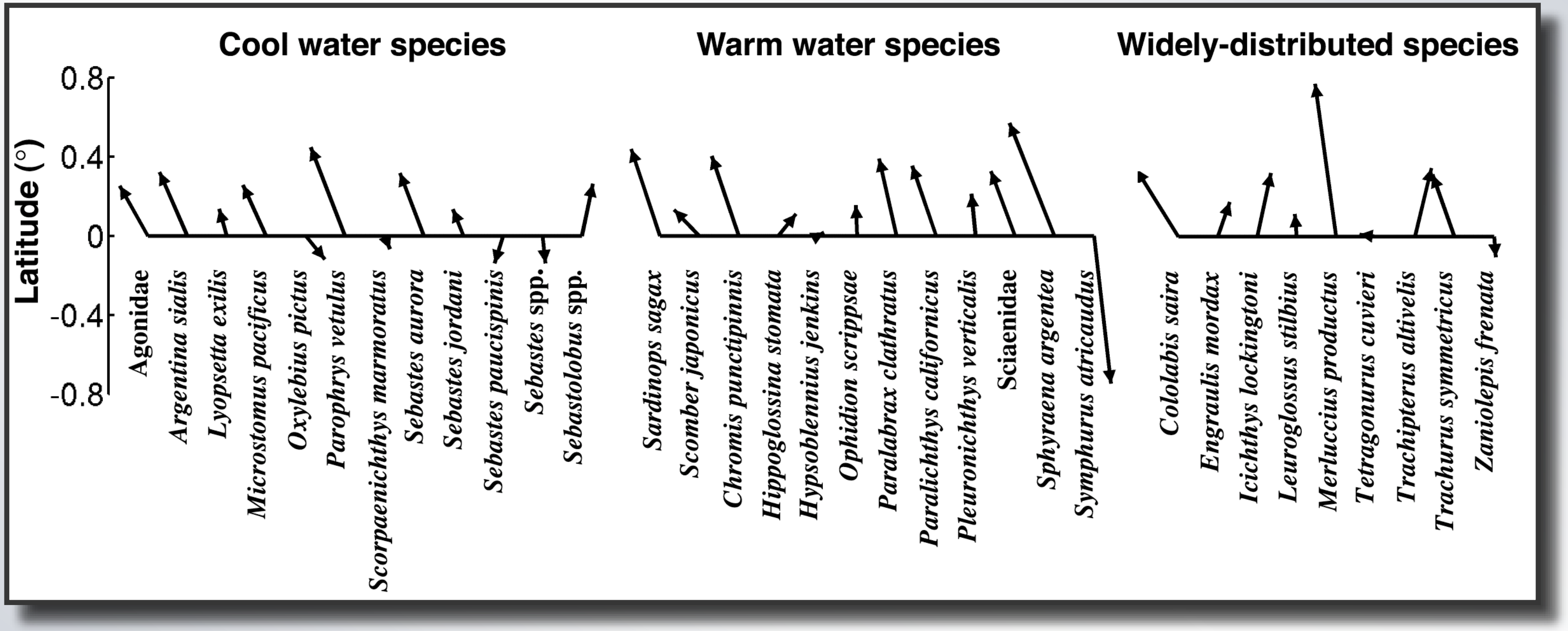
Bi-decadal variability

Pacific hake

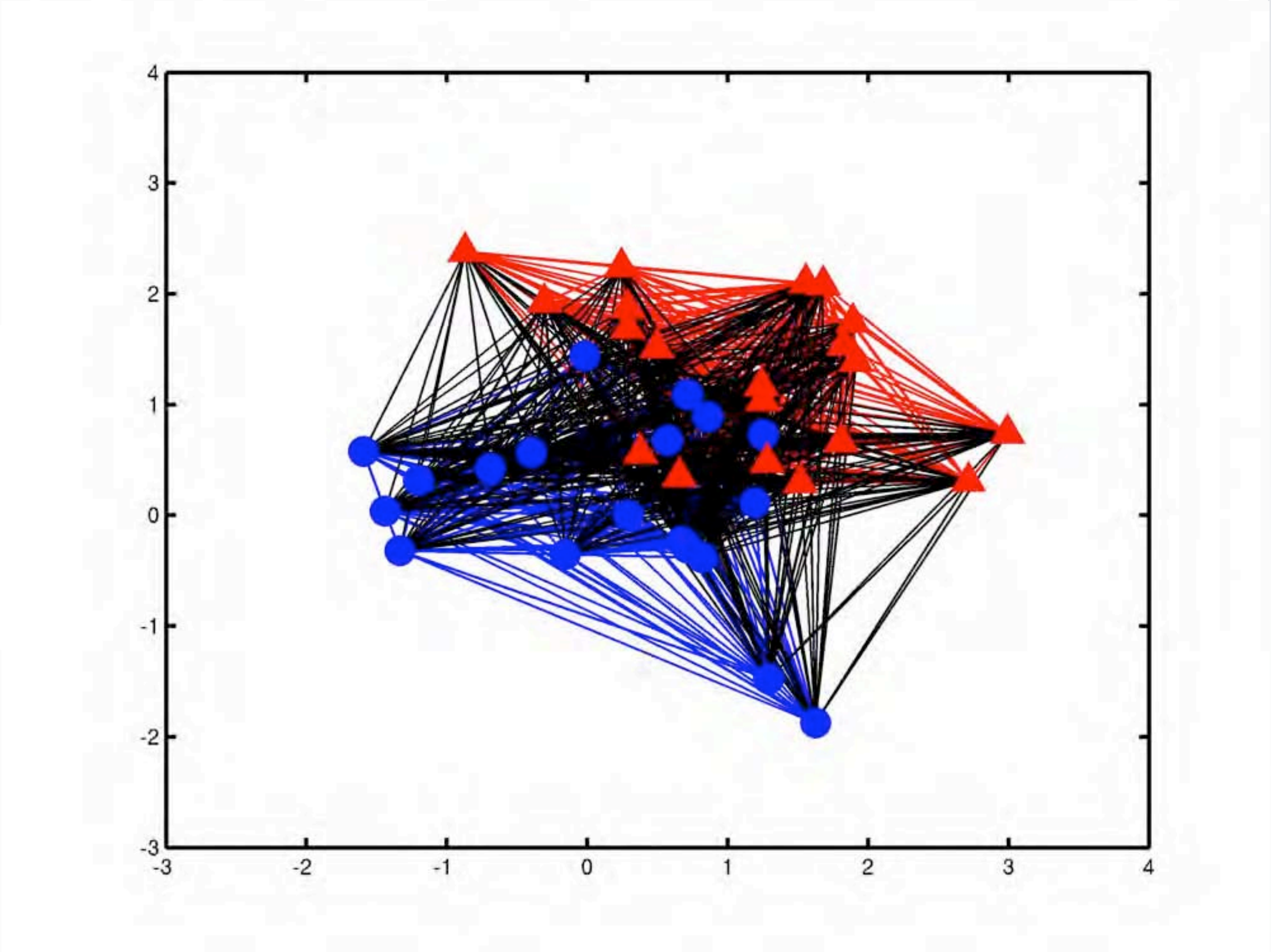


● : 1951-1976 ● : 1977-1998 ● : 1999-2002

Moving poleward
(from cold to warm period)



Randomization test



●: period 1

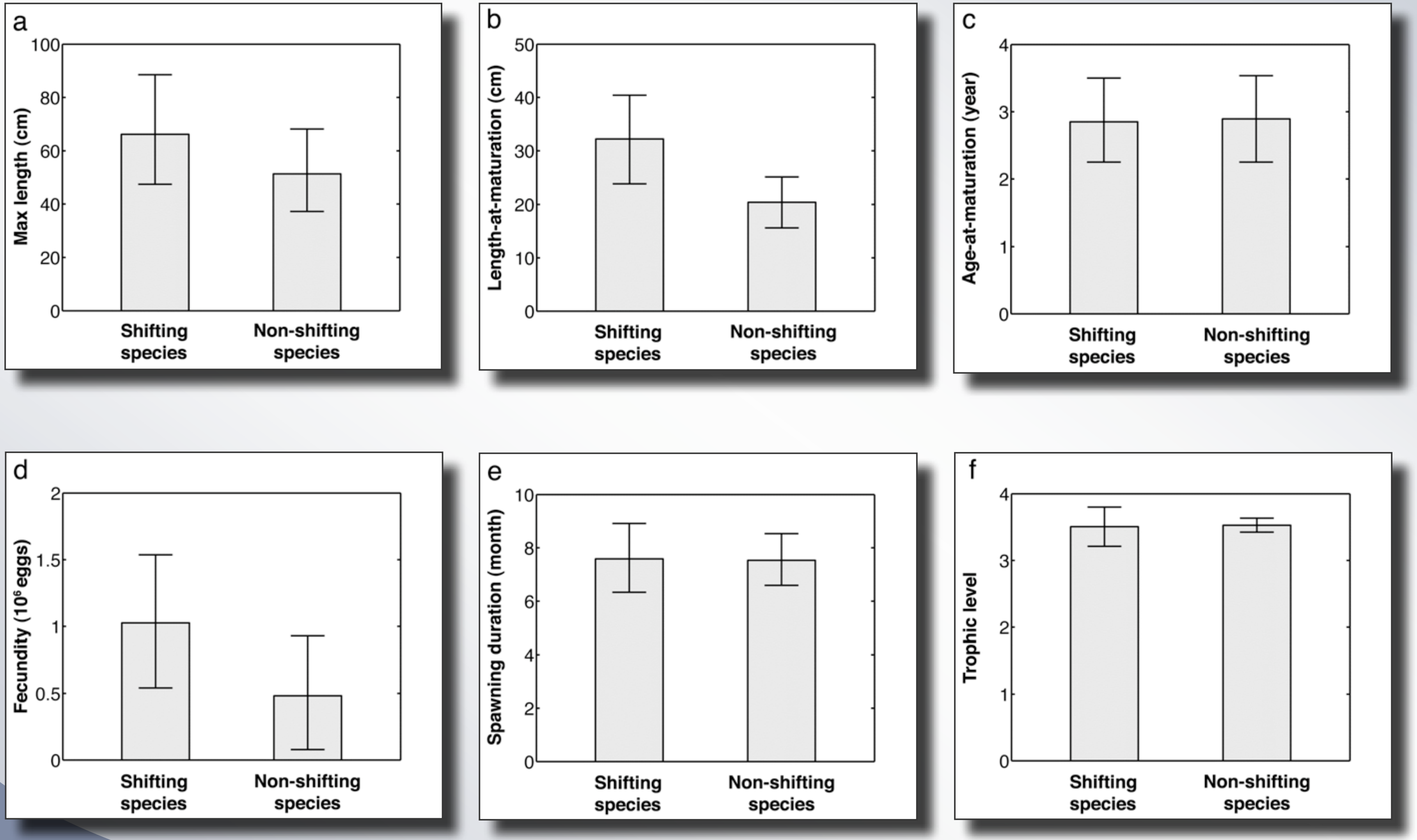
▲: period 2

Pair-wise distances between

mean(dist-within)/mean(dist-between)

	Species	Common name	Mean latitude	Southern boundary	Northern boundary	Shift in domain
Exploited	*Engraulis mordax*[1]	Northern anchovy				0.021
	Merluccius productus[1]	Pacific hake or whiting	0.002*			0.001
	Microstomus pacificus[2]	Dover sole				
	Paralabrax clathratus[3]	Kelp bass	0.035*		0.011	0.009
	Paralichthys californicus[3]	California halibut	0.007			0.043
	Parophrys vetulus[2]	English sole				0.035
	Sardinops sagax[3]	Pacific sardine	0.021		0.003*	0.005
	Sciaenidae[3]	Croakers	0.007			0.007
	Scomber japonicus[3]	Pacific chub mackerel			0.005*	0.020
	Scorpaenichthys marmoratus[2]	Cabezon		0.028†		
	Sebastes aurora[2]	Aurora rockfish				
	Sebastes paucispinis[2]	Bocaccio				
	Sebastes spp. [2]	Rockfishes				0.008
	Sebastolobus spp. [2]	Thornyheads				
	Sphyraena argentea[3]	Pacific barracuda	0.008		0.008	0.003
	Trachurus symmetricus[1]	Jack mackerel				
Unexploited	Agonidae[2]	Poachers				
	Argentina sialis[1]	Pacific argentine	0.044			0.003
	Chromis punctipinnis[3]	Blacksmith			0.017	
	Cololabis saira[1]	Pacific saury				
	Hippoglossina stomata[2]	Bigmouth sole				
	Hypsoblennius jenkins[2]	Mussel blenny				
	Icichthys lockingtoni[1]	Medusafish				
	Leuroglossus stilbius[1]	California smoothtongue				
	Lyopsetta exilis[2]	Slender sole				
	Ophidion scrippsae[3]	Basketweave cusk-eel				
	Oxylebius pictus[2]	Painted greenling				
	Pleuronichthys verticalis[3]	Hornyhead turbot				
	Sebastes jordani[2]	Shortbelly rockfish				
	Symphurus atricaudus[3]	California tonguefish				
	Tetragonurus cuvieri[2]	Smalleye squaretail				
	Trachipterus altivelis[2]	King-of-the-salmon				
	Zaniolepis frenata[2]	Shortspine combfish	0.002^{-}			

Life history traits



Fishing effects

- **Logistic regression**

Model	Variable	P-value
shifting = fishing + geographic affinity + habitat + spawning mode	fishing	0.011
	geographic affinity	0.203
	habitat	0.262
	spawning mode	0.748

Fisheries as a noise filter

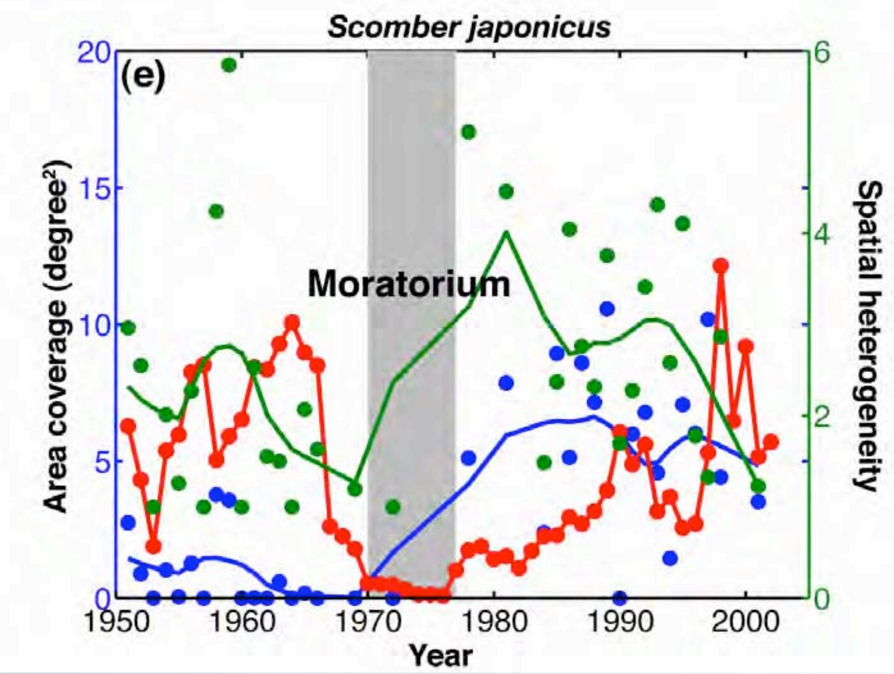
- Fishing-induced constriction of distribution

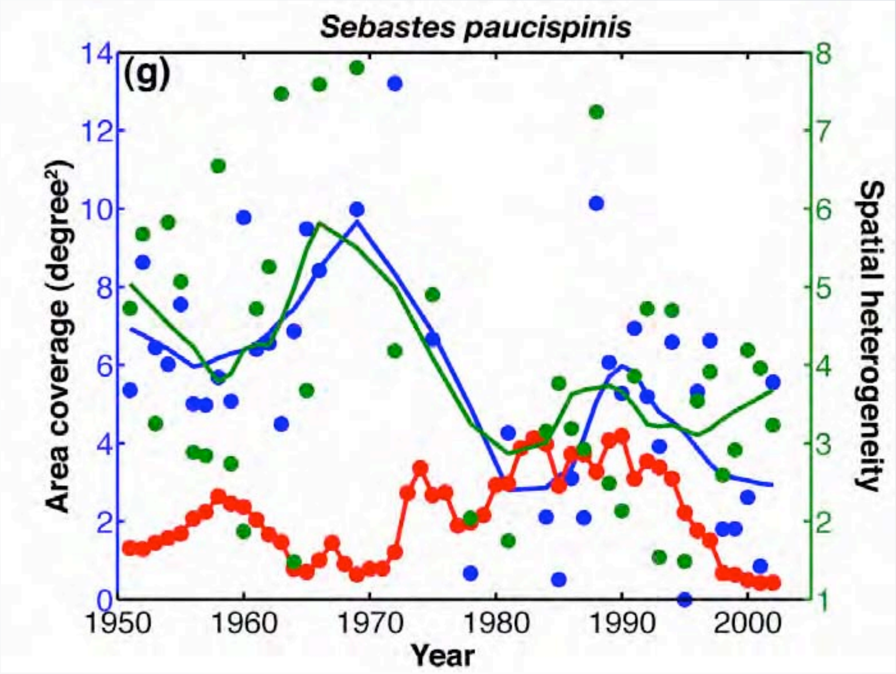
Fishing down size and age

- Fishery-induced age-size truncation reduced age diversity and thus spatial heterogeneity of exploited populations

"Fishing forces fish to put their eggs in single basket"

Fishing effects on spatial coverage and heterogeneity of fish distributions





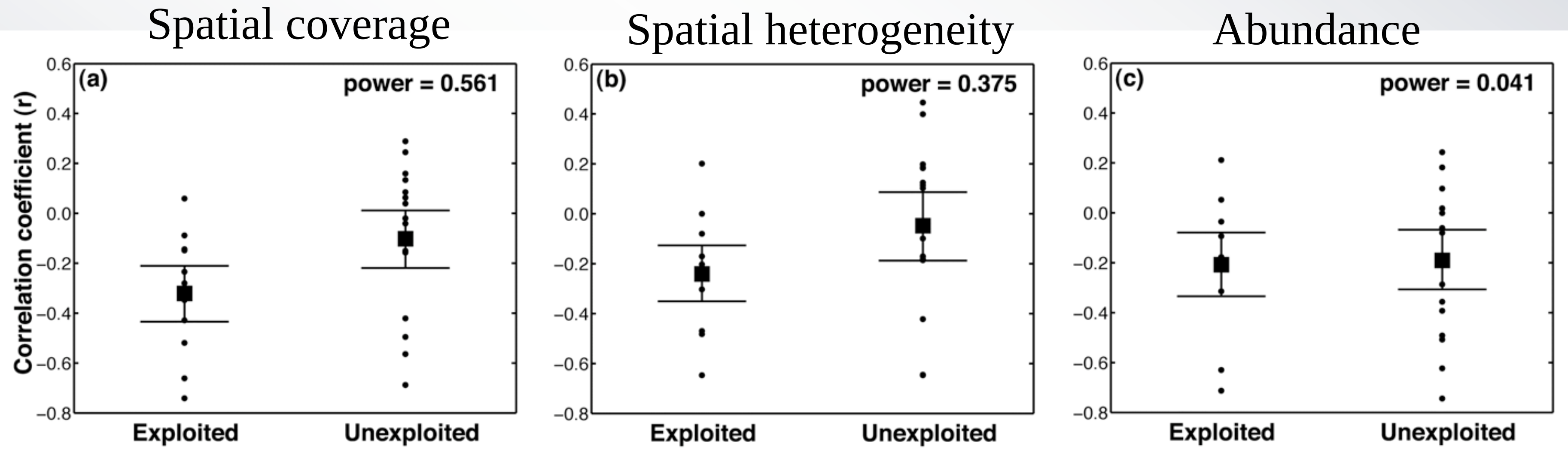
Green: spatial heterogeneity

Blue: spatial area coverage

Red: exploitation fraction (scaled from 0 to 1)

Fishing effects on spatial coverage and heterogeneity of fish distributions

Comparing average trend of exploited versus unexploited species after 1970 when exploitation intensified



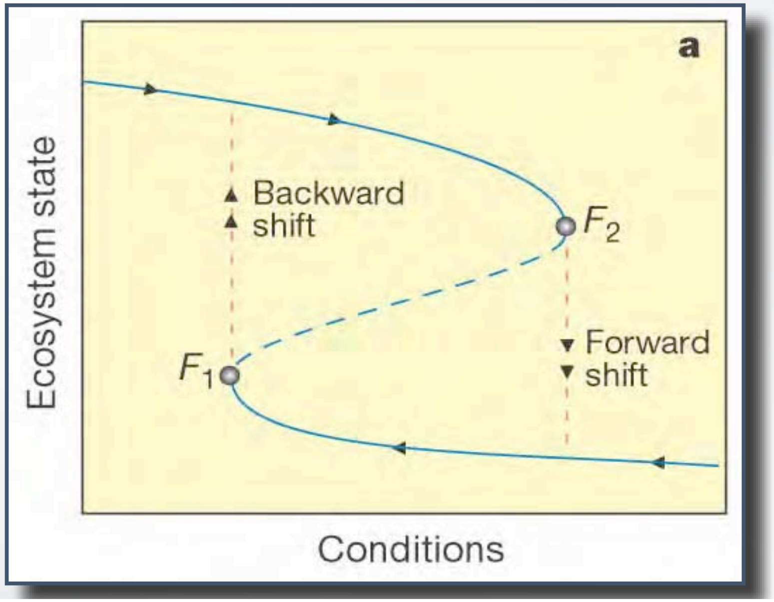
Reduced spatial heterogeneity may happen without a decreasing sign of abundance.

Hsieh et al. 2008 CJFAS 65: 947-061

Potential consequence

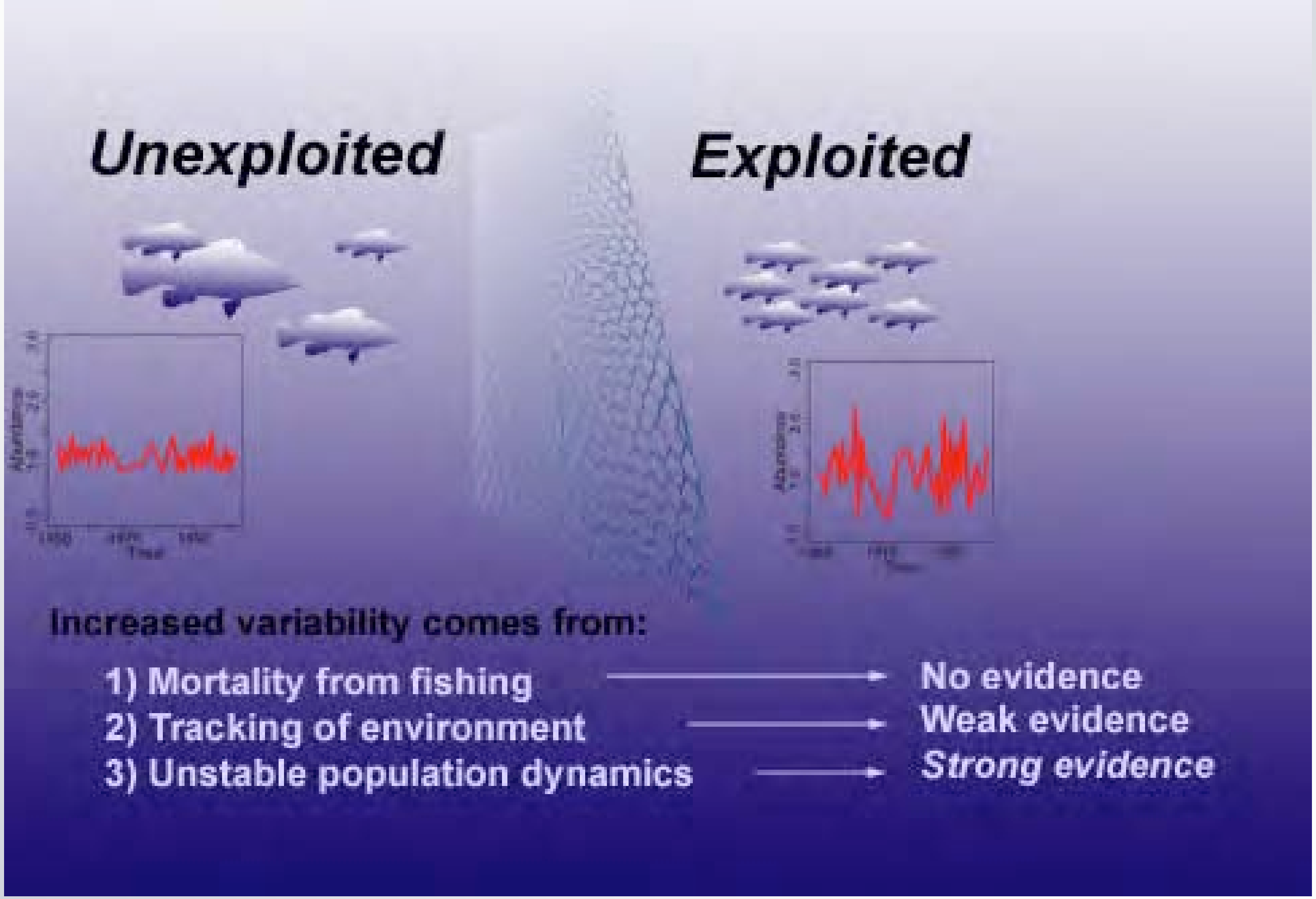
Hsieh, Glaser, Lucas, and Sugihara. (2005) Distinguishing random environmental fluctuations from ecological catastrophes for the North Pacific Ocean. Nature, 435: 336-340.

1. Biological responses to environmental forcings are nonlinear --> signature of instability.
2. Reduced resilience of fish populations due to human disturbance (fisheries) might cause the populations to be more prone to catastrophic shifts.



(Scheffer et al. 2001. Nature, 413: 591-596)

Why fishing magnifies variability?



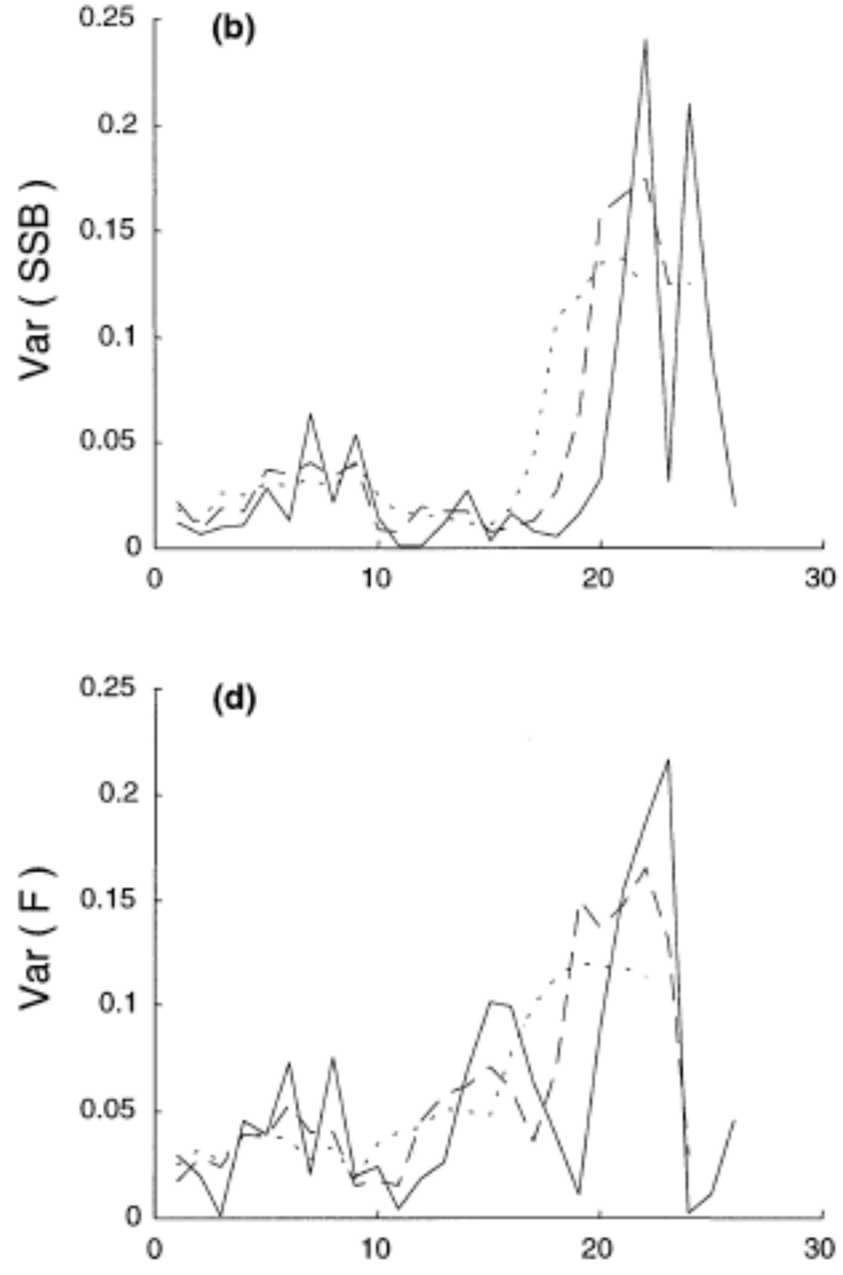
Increased variability comes from:

1) Mortality from fishing → No evidence
2) Tracking of environment → Weak evidence
3) Unstable population dynamics → *Strong evidence*

(Anderson et al. 2008 Nature 452: 935-939)

H1:Variable fishing?

Var calculated by a moving window



Cod as an example

Jonzen et al 2001 MEPS 210: 291-296

Variable fishing

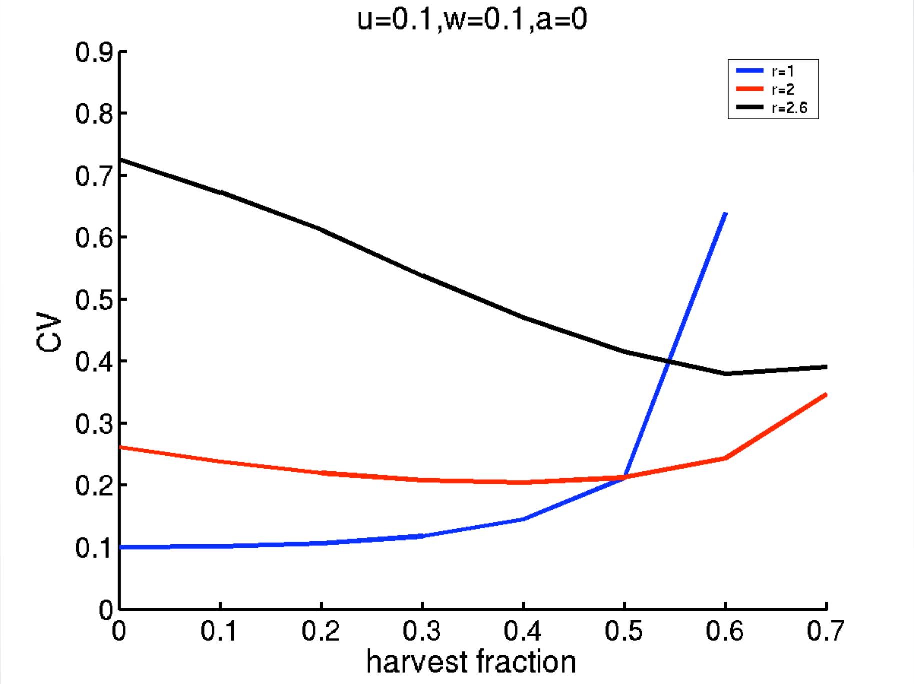
$$N_{t+1}=N_t*\exp\{r*(1+u_t)-b*N_t\}*\{1-h*(1+w_t)\}$$

N: population after harvesting

u_t: environmental stochasticity

w_t: fishing stochasticity

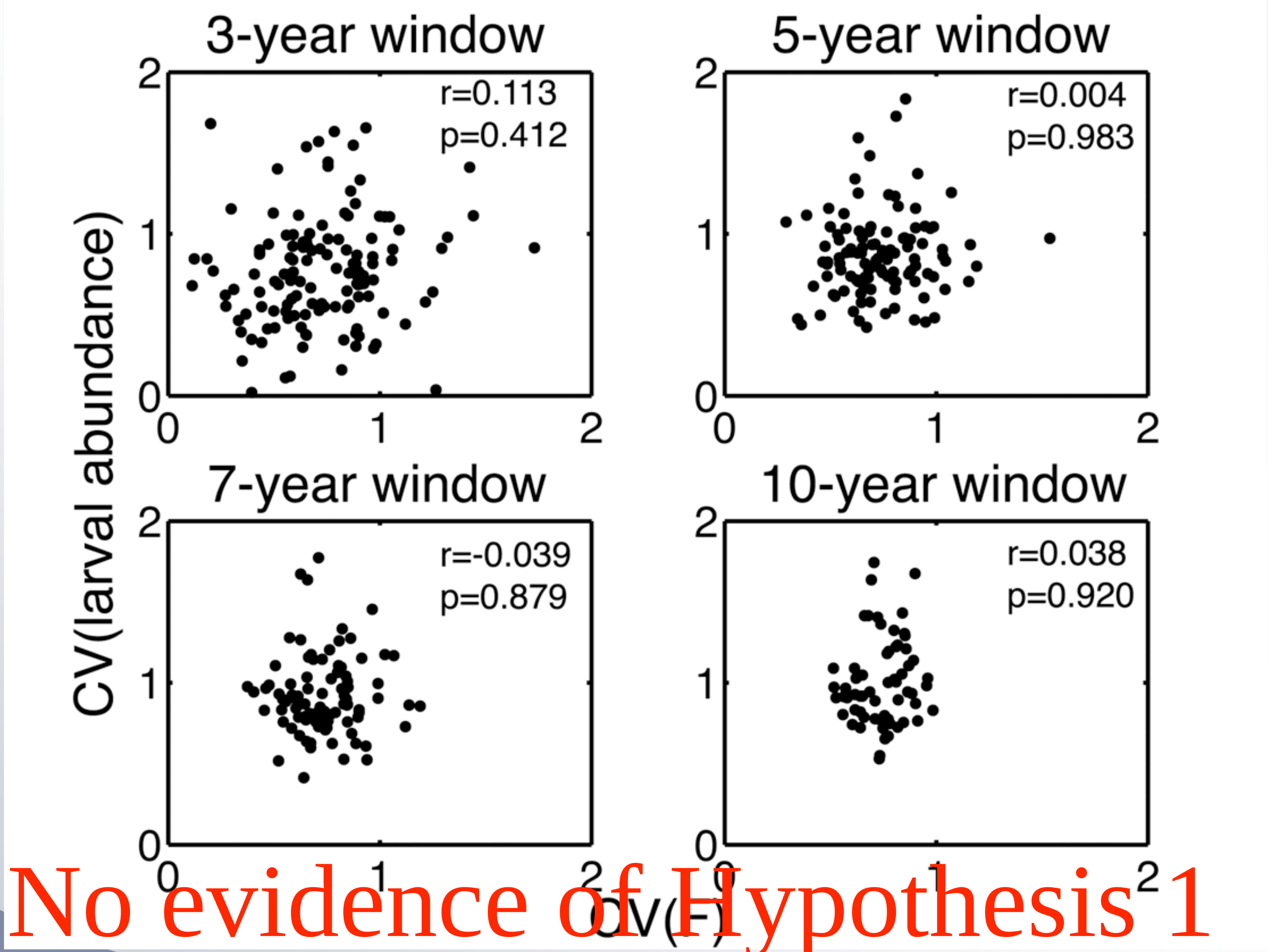
h: harvesting fraction



-- r=1,-- r=2 -- r=2.6

Jonzen et al 2002 Am Nat 159: 427-437

No relationship between CV(fish) and CV(F) in the CalCOFI data



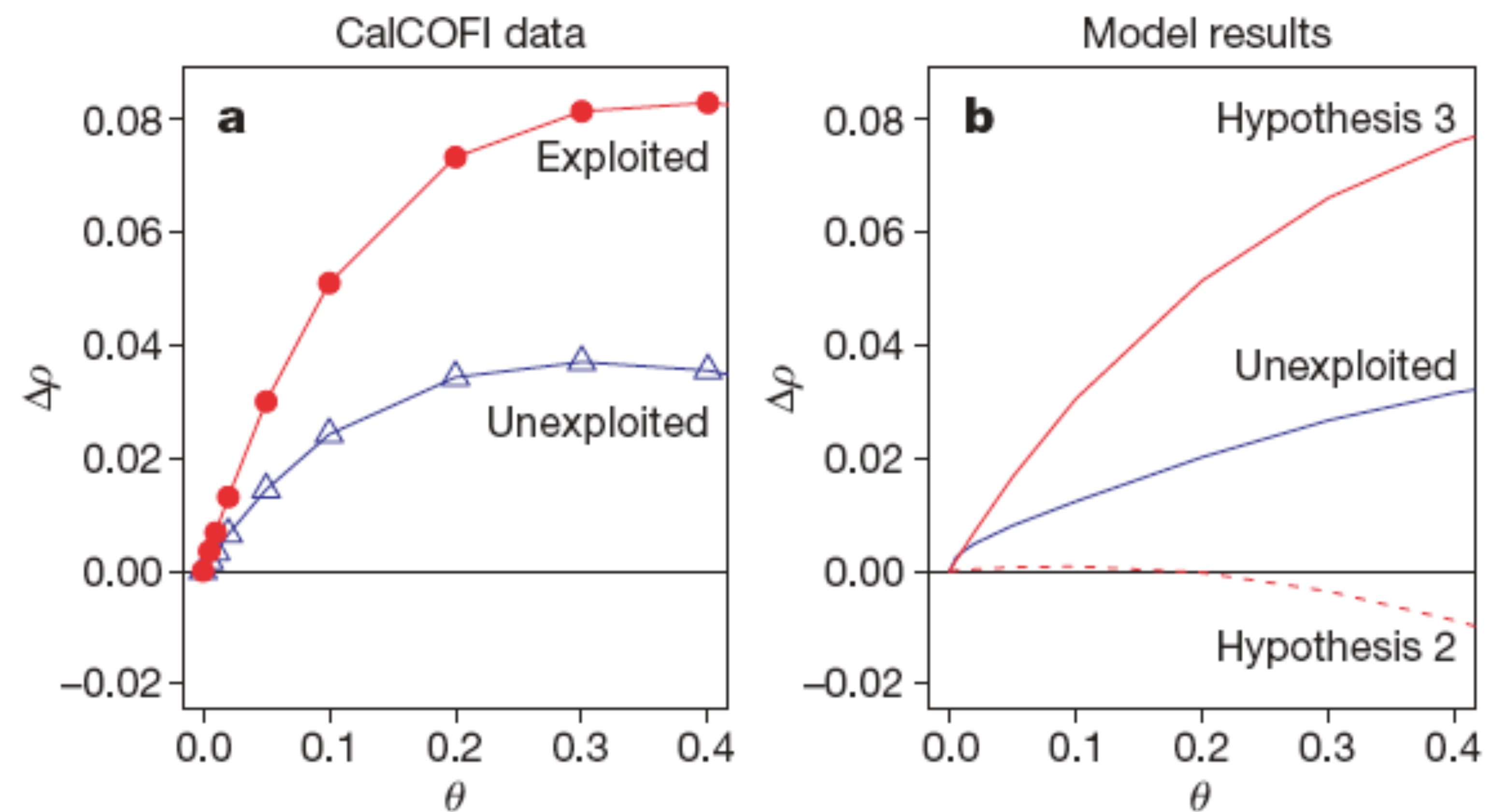
No evidence of Hypothesis 1

Distinguish H2 and H3

- **H2 suggests increased linear tracking**
- **H3 suggests increased nonlinear instability**

These two can be distinguished from measuring the nonlinearility!

Test with empirical data and models



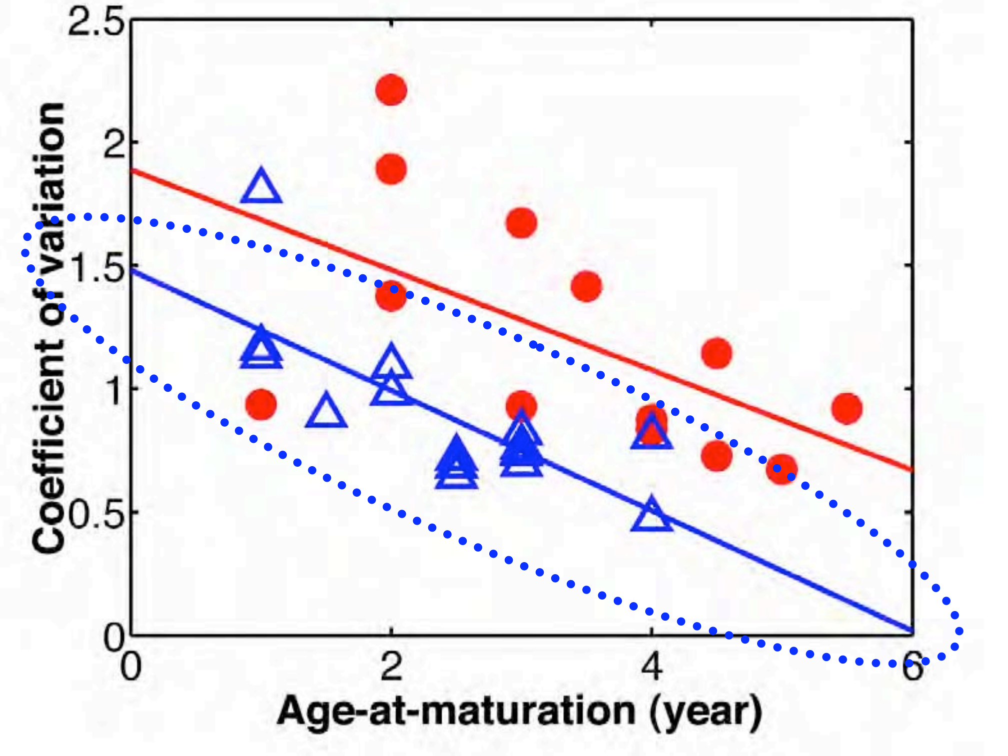
S-map analysis

Model (Ricker-type)

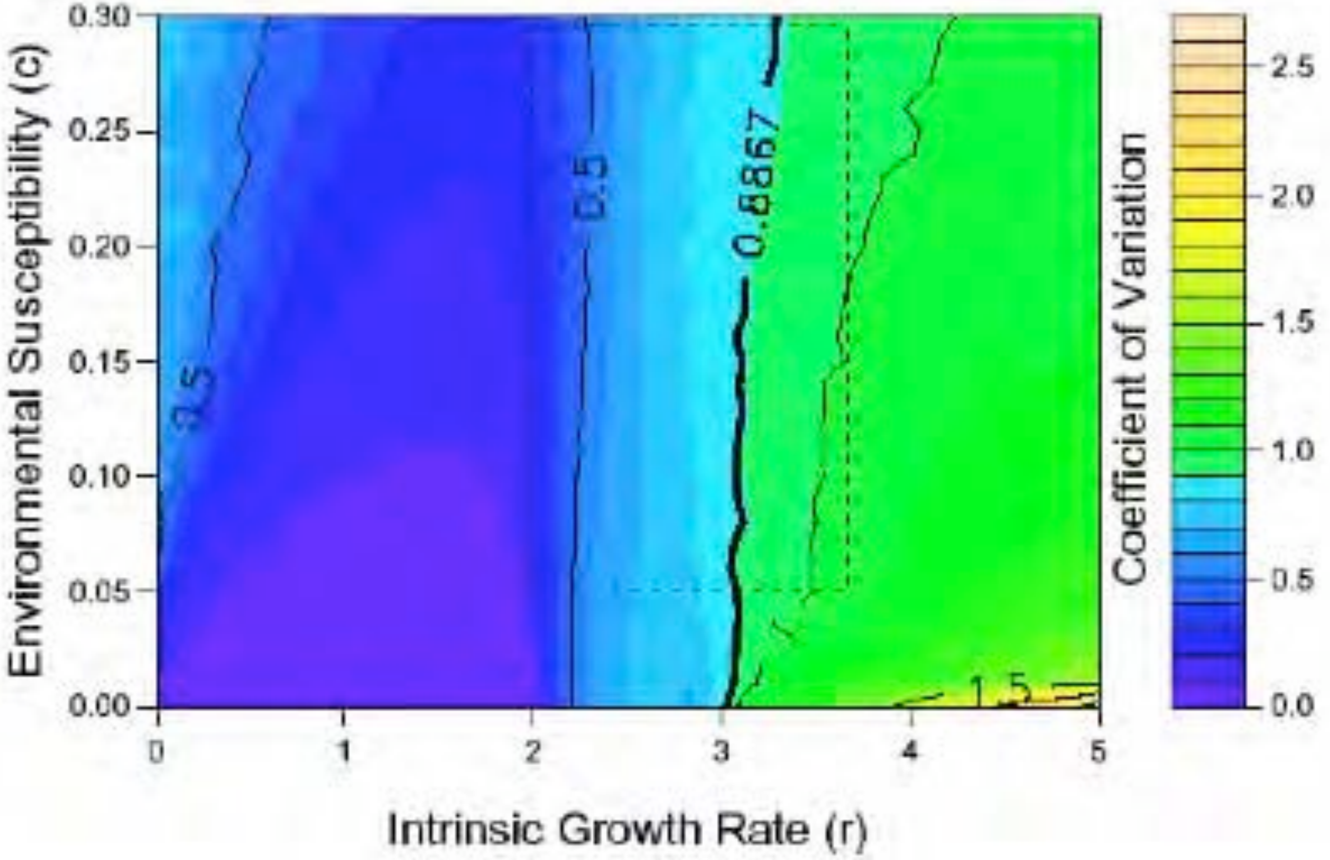
- $N_{t+1}=N_t exp[r(1-N_t)]+c\varepsilon$,

N is the population size, *r* is the population growth rate, ε is environmental variability with unit mean and variance, and *c* is the environmental susceptibility.

Parameterizing the baseline Ricker-form model



CV_i=1.397-0.119α_i, where α_i is the age@maturation of species *i* for the unexploited group



Using $N_{t+1}=N_t exp[r(1-N_t)]+c\varepsilon$ to generated c and r dependent CV surface. We found that within the observed CV range of unexploited species, c is not important and can be dropped.

Thus, $CV=-0.6754+0.4749r$

Model investigation

- **Combine the above:**

Thus, $N_{t+1}=N_t exp[r(1-N_t)]+c\varepsilon$,

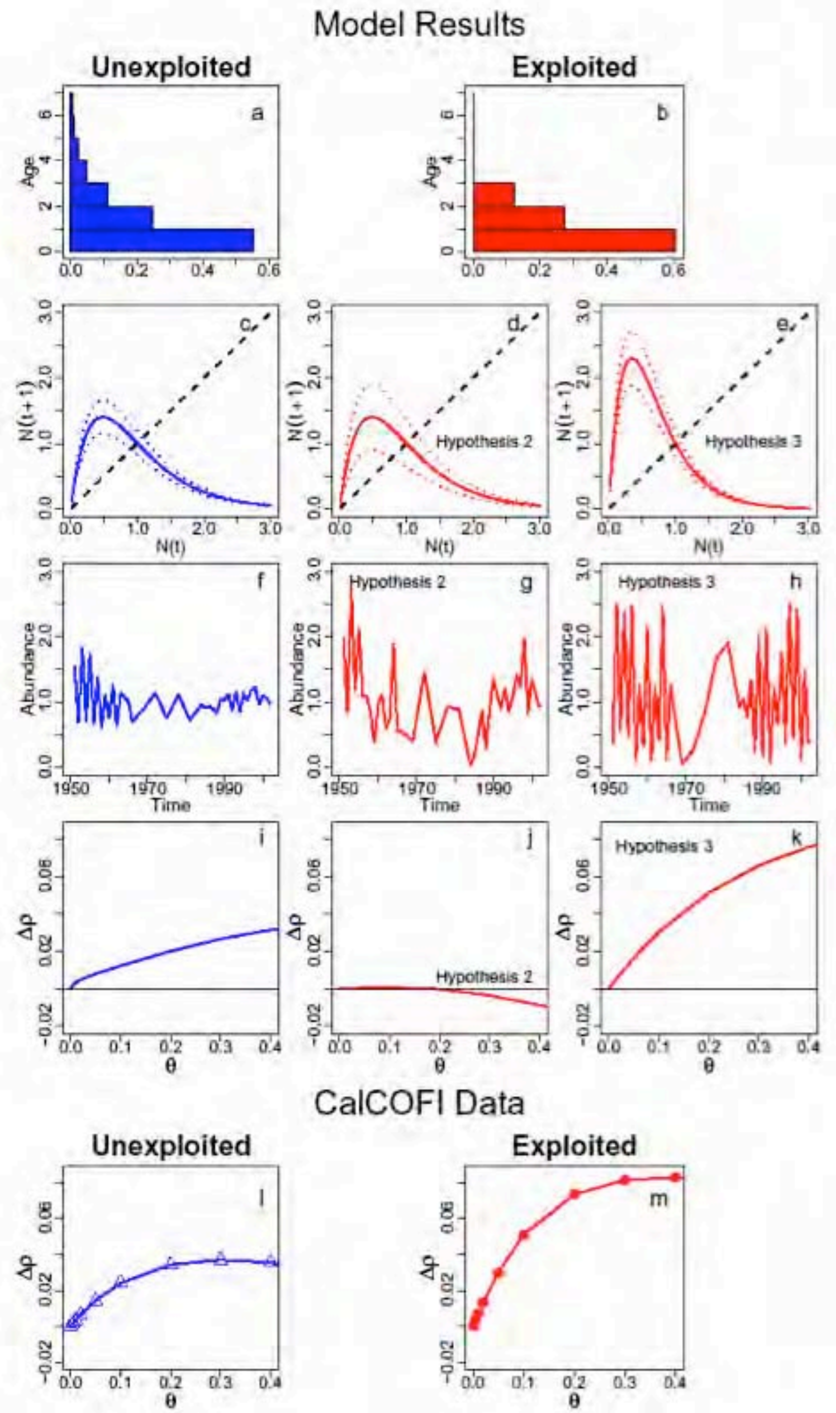
with r_i=4.364-0.419α_i for species *i*.

We then model to mimic the CalCOFI unexploited species data.

Test:

Hypothesis 2: increase *c*

Hypothesis 3: increase *r*



Hypothesis 2: increase *c*

Hypothesis 3: increase *r*

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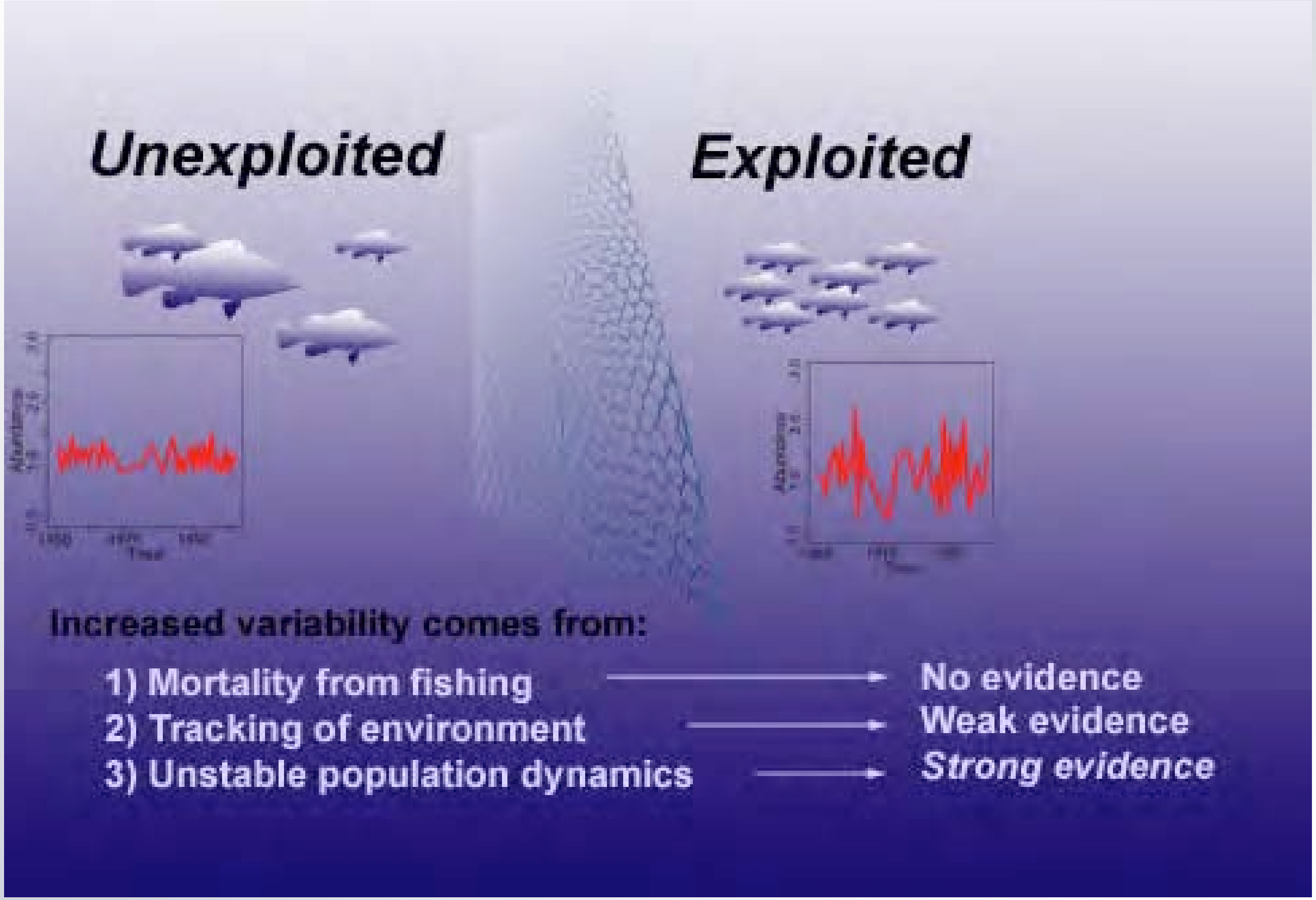

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(Anderson et al. 2008 Nature 452: 935-939)

Implications

- **Precautionary management policies**
- **Conserving population age and spatial structures**
- **Marine reserves**