RITA CASTILHO

WHY BIOGEOGRAPHY MATTERS?

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MARINE BIOGEOGRAPHY AND EVOLUTION

SARDINE'S EVOLUTION

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SARDINE'S EVOLUTION

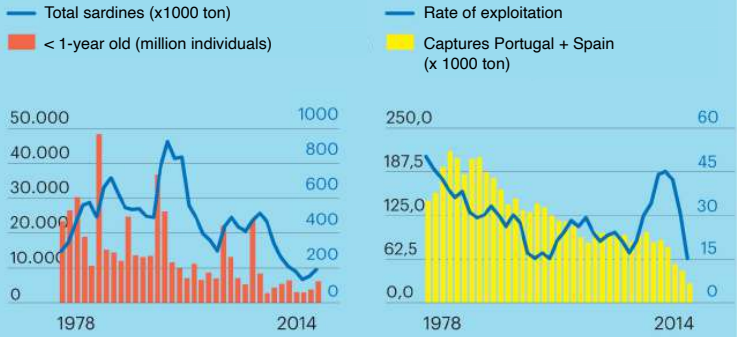
Case study: sardine evolution A primer

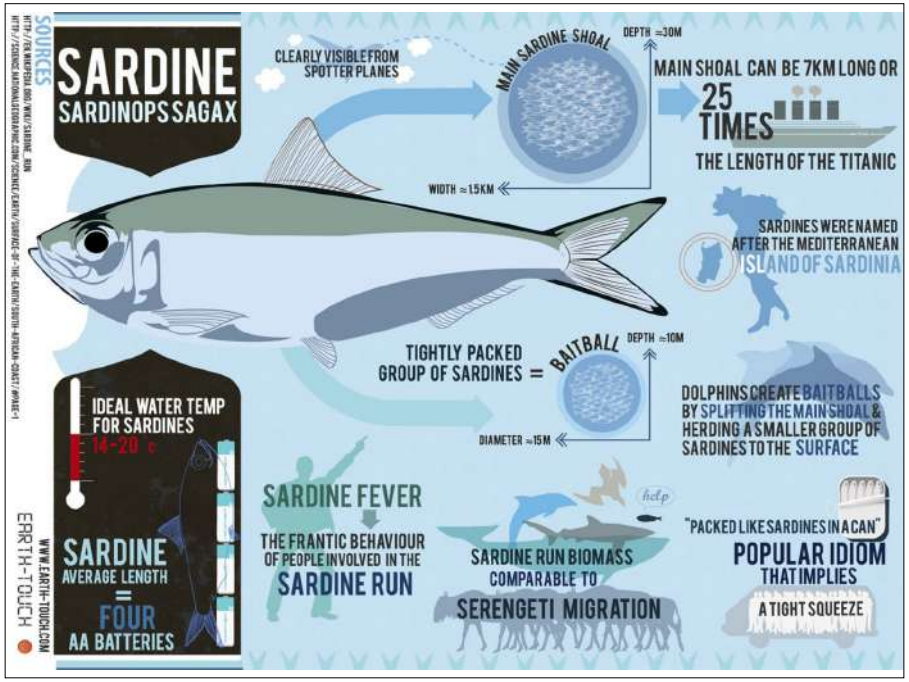
outline

GEOGRAPHIC DISTRIBUTION
MOLECULAR DATA
PHYLOGENETIC ESTIMATION
HISTORICAL DEMOGRAPHY
PALEOGEOGRAPHIC EVENTS

Distribution
Sardina pilchardus is the only sardine species in the Northeastern Atlantic and Mediterranean.

Stock status
Reproduction is declining (left), and captures represent an extremely high effort on the stock (right).

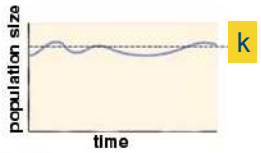


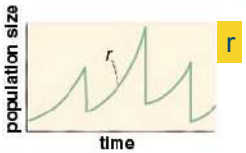


Sardine life-cycle and strategy

CHARACTERISTICS OF K-SELECTED AND r-SELECTED SPECIES

K-selected equilibrium species ⟷ r-selected opportunist species



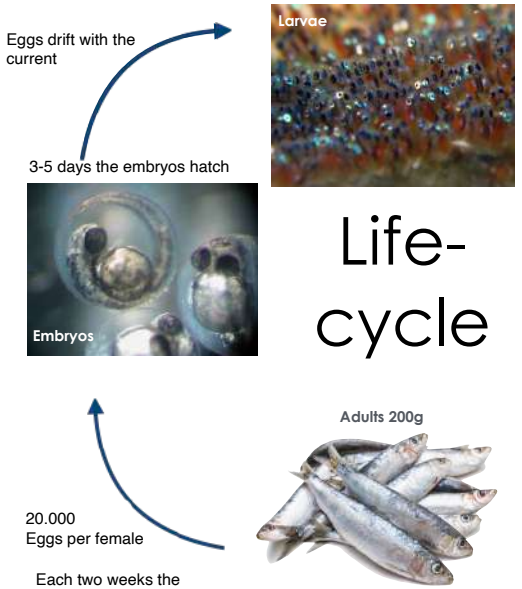


population size:
- limited by carrying capacity (K)
- density dependent
- relatively stable

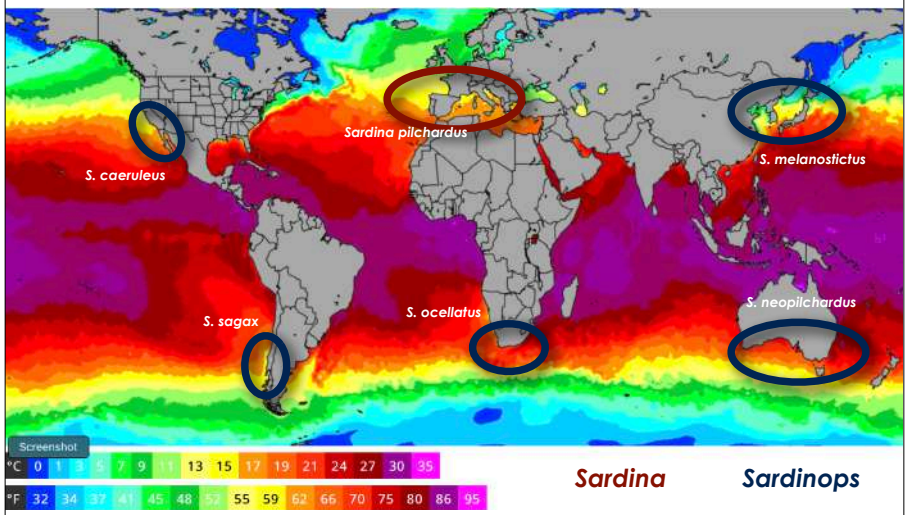
organisms:
- larger, long lived
- produce fewer offspring
- provide greater care for offspring

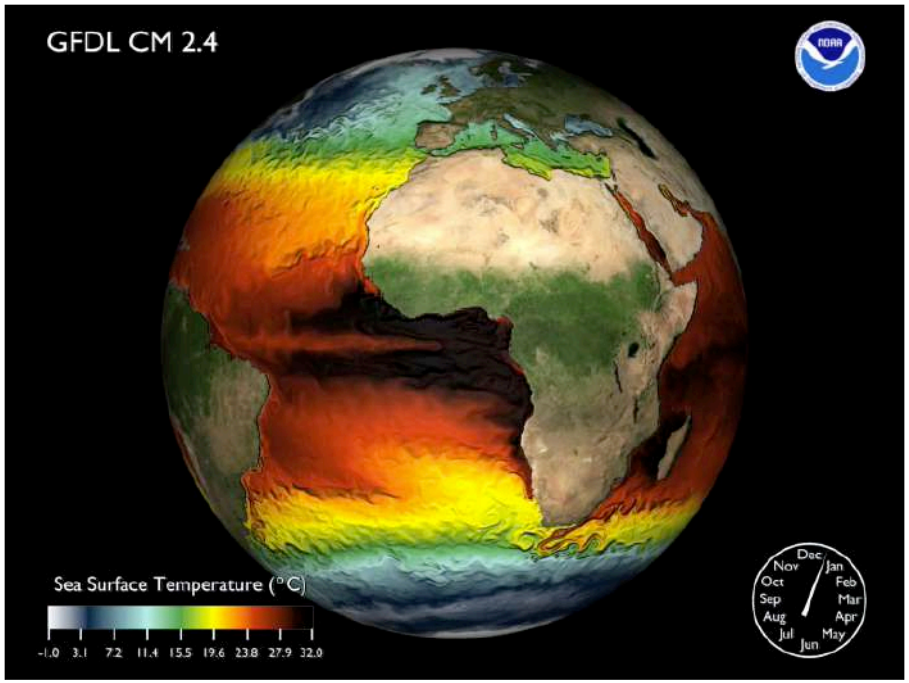
population size:
- limited by reproductive rate (r)
- density independent
- relatively unstable

organisms:
- smaller, short-lived
- produce many offspring
- provide no care for offspring



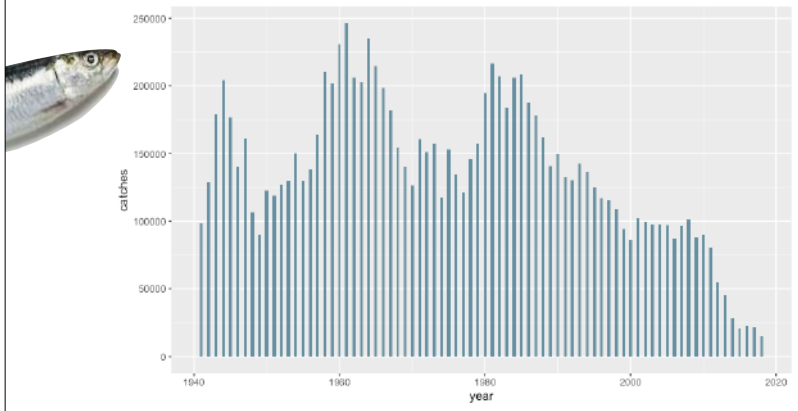
Geographic distribution of sardines





Sardine population fluctuations

ICES considers that the Iberian sardine stock is in a state of collapse which has resulted in low recruitment for the last decade.
This is likely caused by a combination of fisheries and environmental changes.

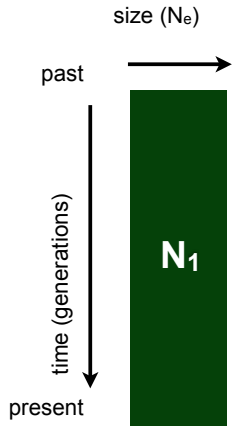


Effects of demographic fluctuations on the genetic make-up of organisms

What happens to the population size over time?

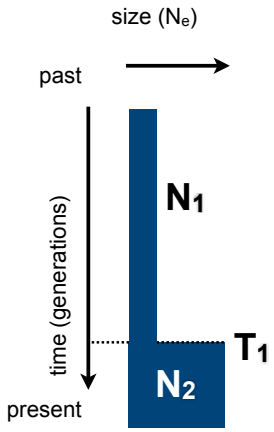
Historical Demography

Stationary



Historical Demography

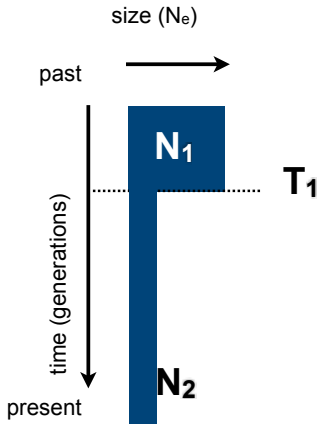
Expansion

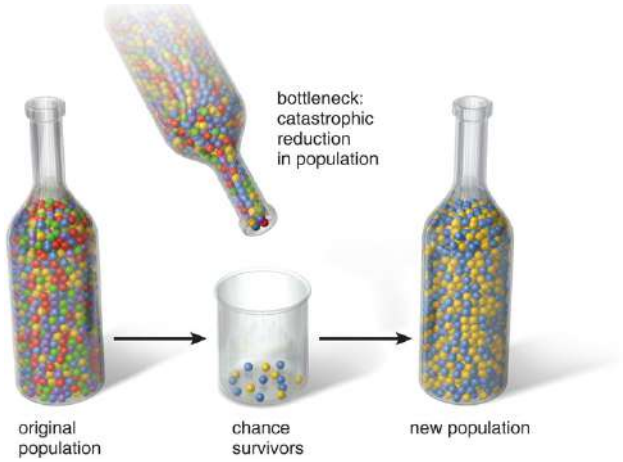


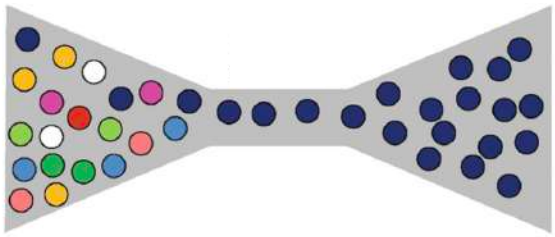
When populations crash, what happens?

Historical Demography

Collapse

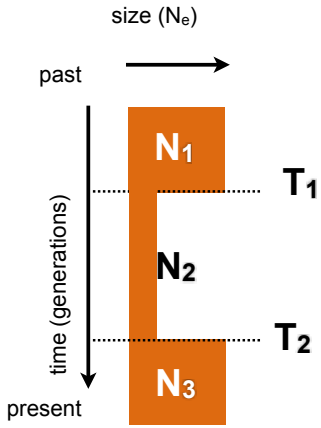


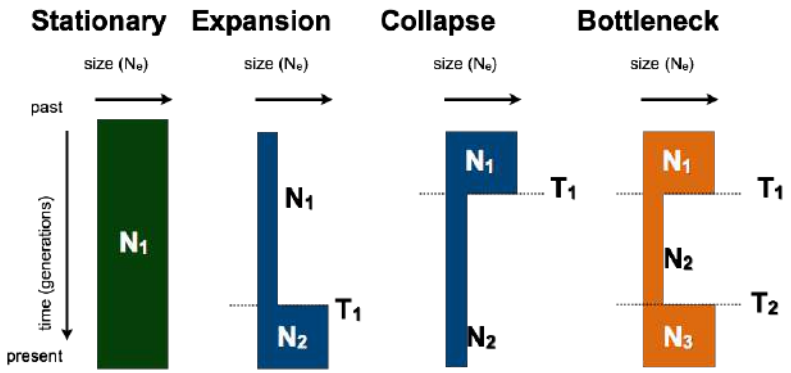




Historical Demography

Bottleneck

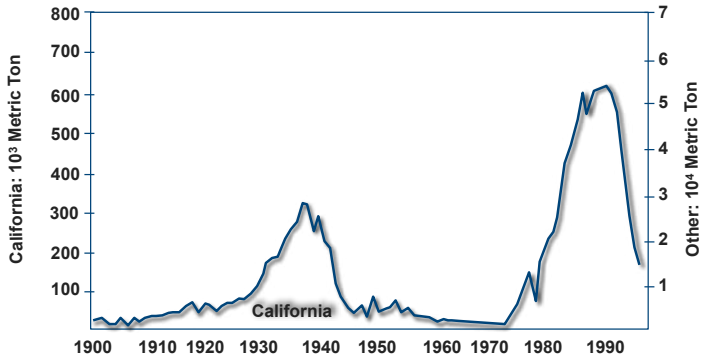




But can we infer the ***past demography*** of a species without having a census ?

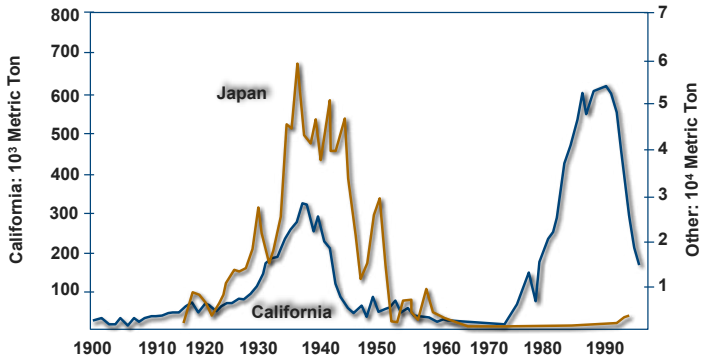
Method 1

Apparent oceanwide synchrony in **Pacific** Sardines



Sources: U.S. GLOBEC, FAO 1998

Apparent oceanwide synchrony in **Pacific** Sardines



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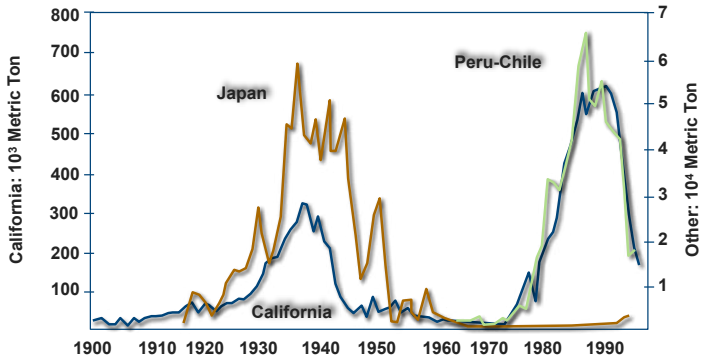

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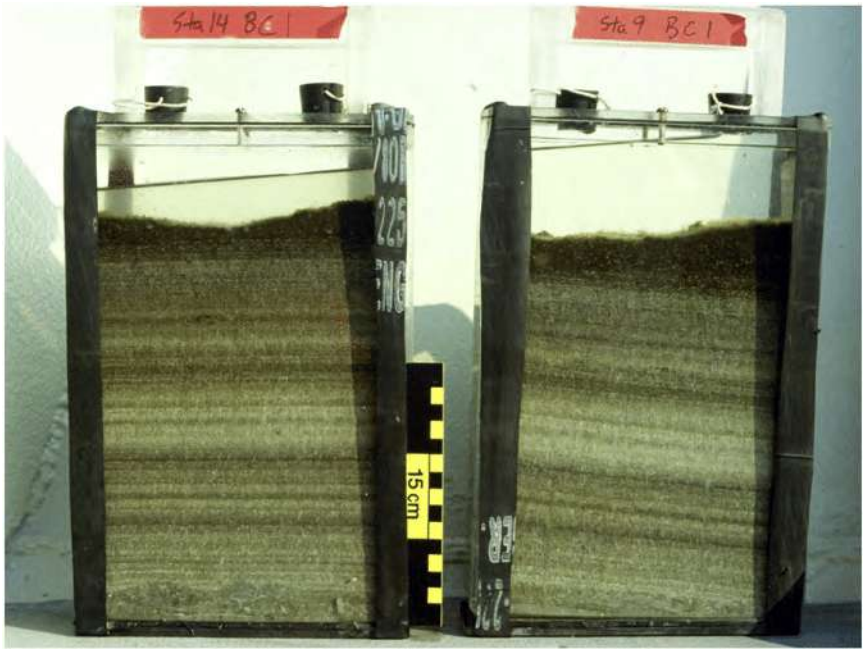
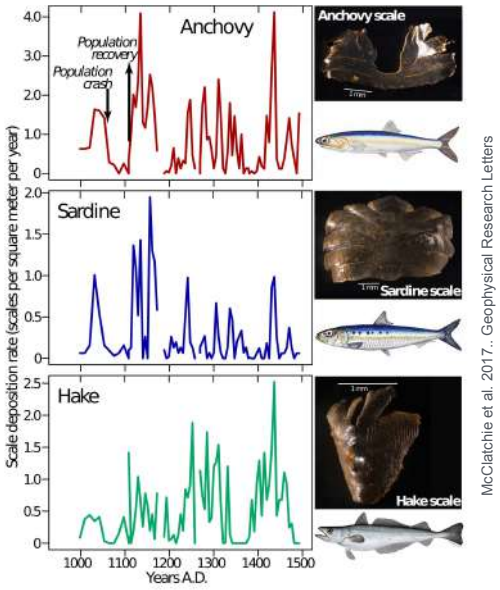


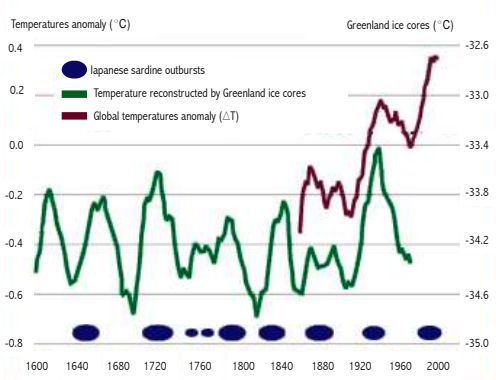
https://news.umich.edu/new-methods-further-discern-extreme-fluctuations-in-forage-fish-populations/

Collapse and recovery of forage fish populations prior to commercial exploitation



McClatchie et al. 2017.. Geophysical Research Letters

Cyclic temperature fluctuations and Japanese sardine outbursts



Sardine and anchovy populations reconstructed from the data on fish scales in *varved* sediment cores.

Method II

Population size

genetic consequences

haplotype networks

Haplotypes

Identical sequences from haploid genomes (e.g. mtDNA) are an haplotype

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Several individuals with identical sequences are said to share the same haplotype

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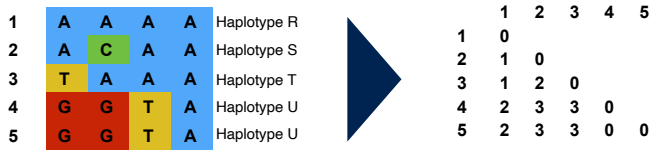

Haplotype networks

Haplotype network construction is a widely used approach for analysing and visualizing the relationships among DNA sequences within a population or species.

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	R	S	T	U
R	0			
S	1	0		
T	1	2	0	
U	2	3	3	0

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	R	S	T	U
R	0			
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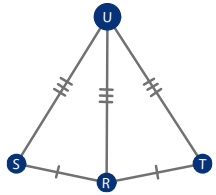
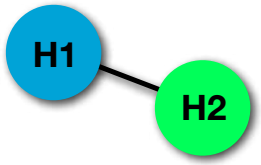
U	2	3	3	0

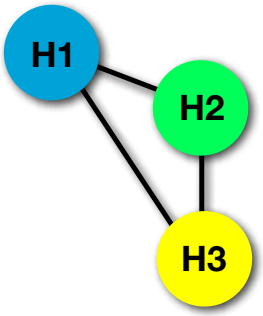


H1 A A T G T C G T A

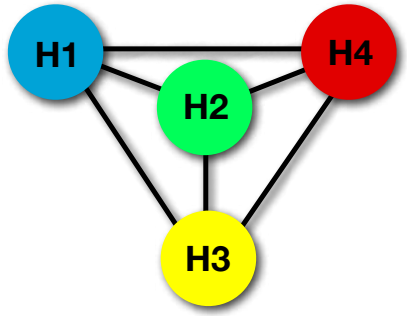
H1 A A T G T C G T A
H2 A A C G T C G T A



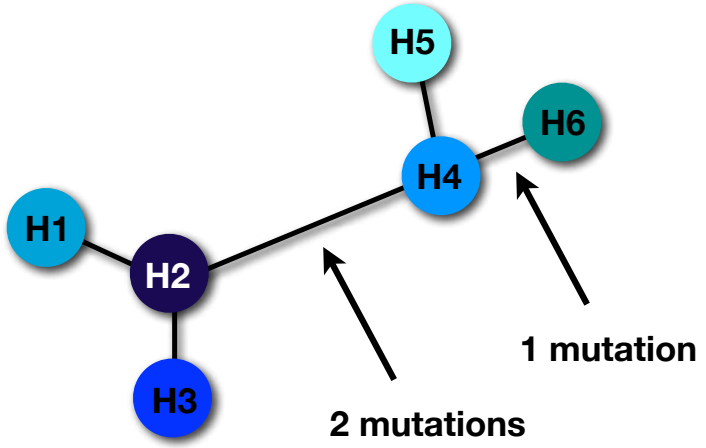
H1 A A T G T C G T A
H2 A A C G T C G T A
H3 A A G G T C G T A



```
H1  A A T G T C G T A
H2  A A C G T C G T A
H3  A A G G T C G T A
H4  A A A G T C G T A
```

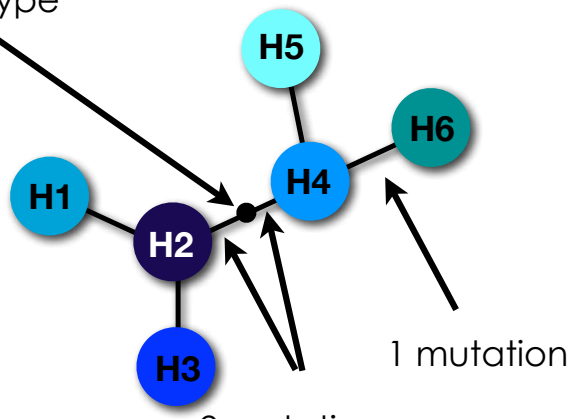


Haplotype networks

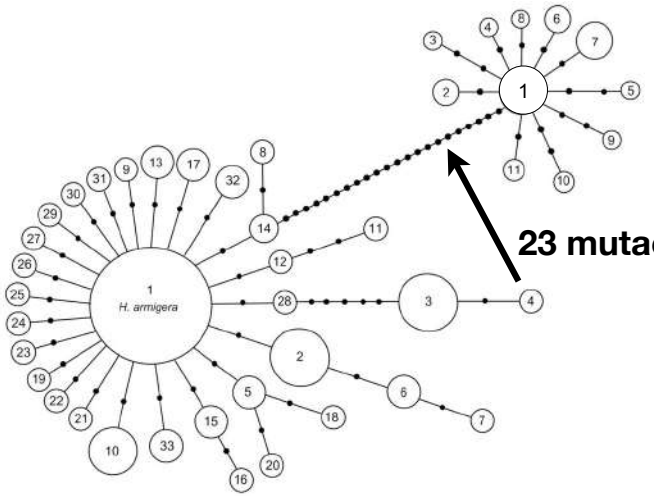


Haplotype networks

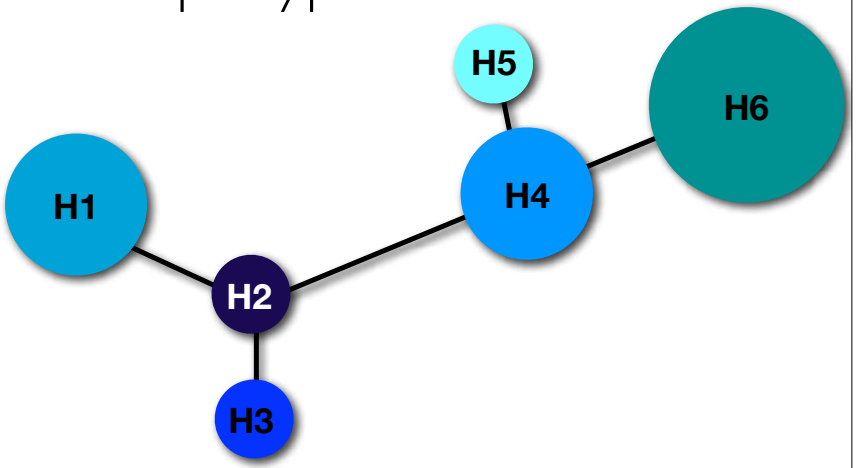
"unkown haplotype"



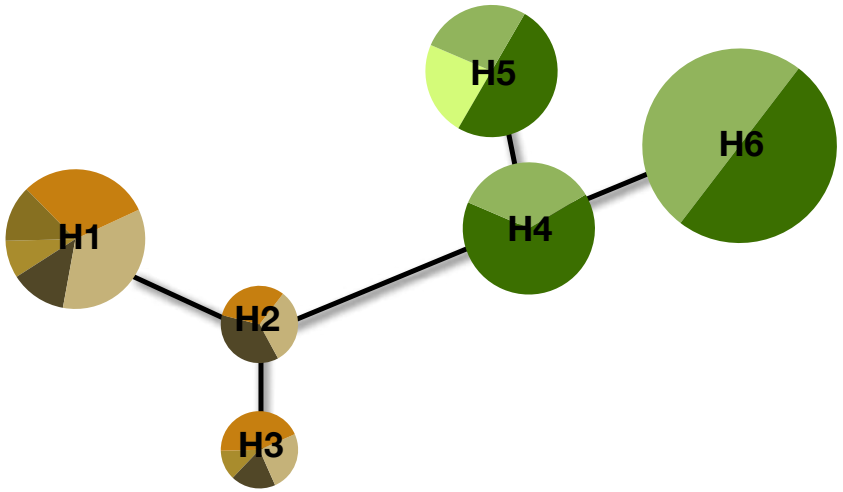
Haplotype networks



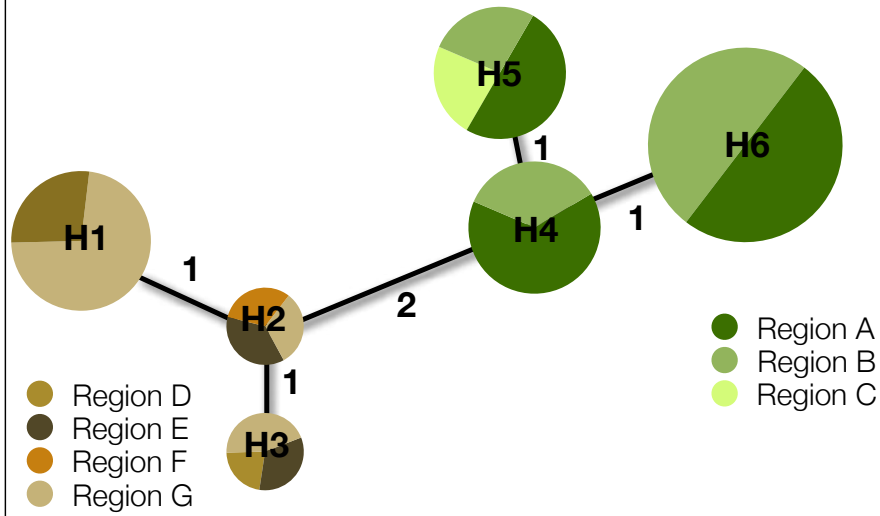
Haplotype networks



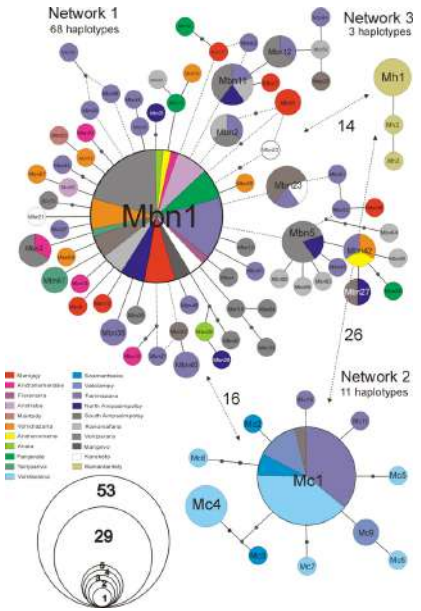
Haplotype networks



Haplotype networks

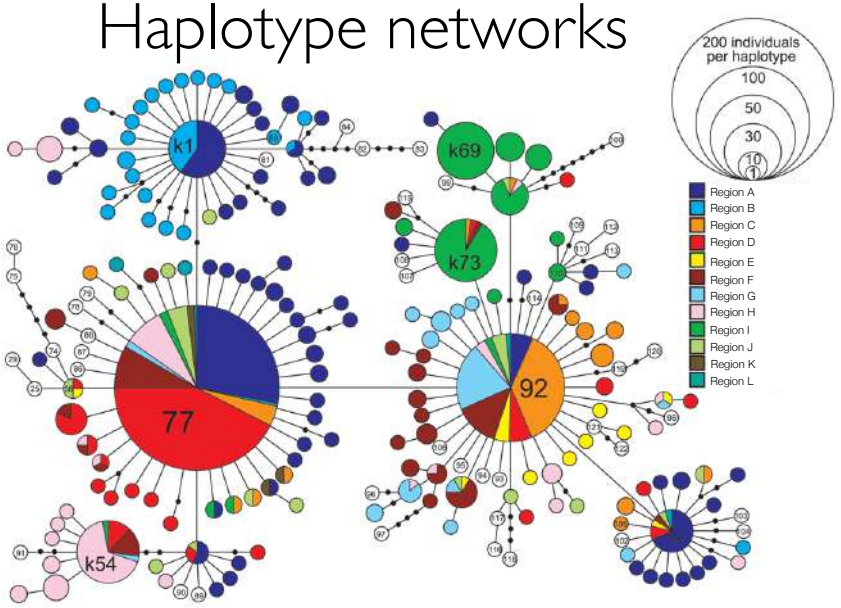


Haplotype networks



Rabemananjara 2007. Frontiers in Zoology

Haplotype networks



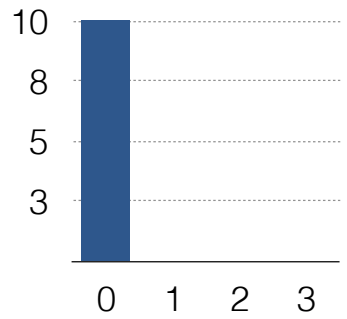
Population size

genetic consequences

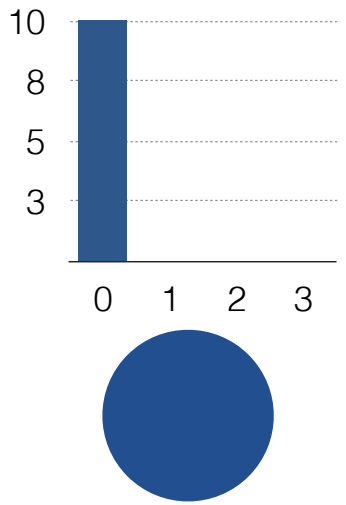
Mismatch analysis
Demography and
Haplotype networks

Number of differences	Counts
0	10
1	0
2	0
3	0

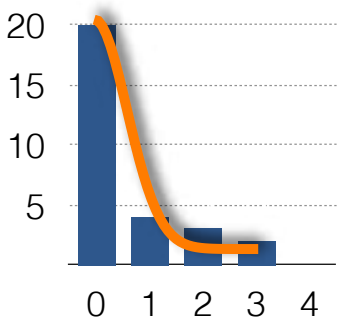
Number of differences	Counts
0	10
1	0
2	0
3	0



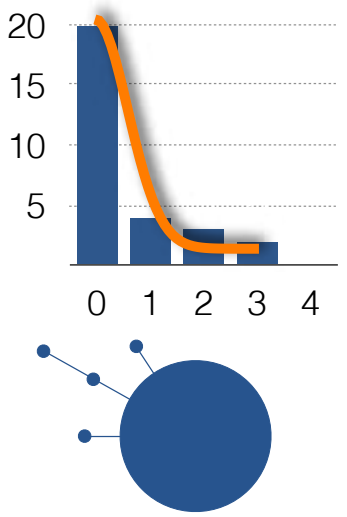
Number of differences	Counts
0	10
1	0
2	0
3	0

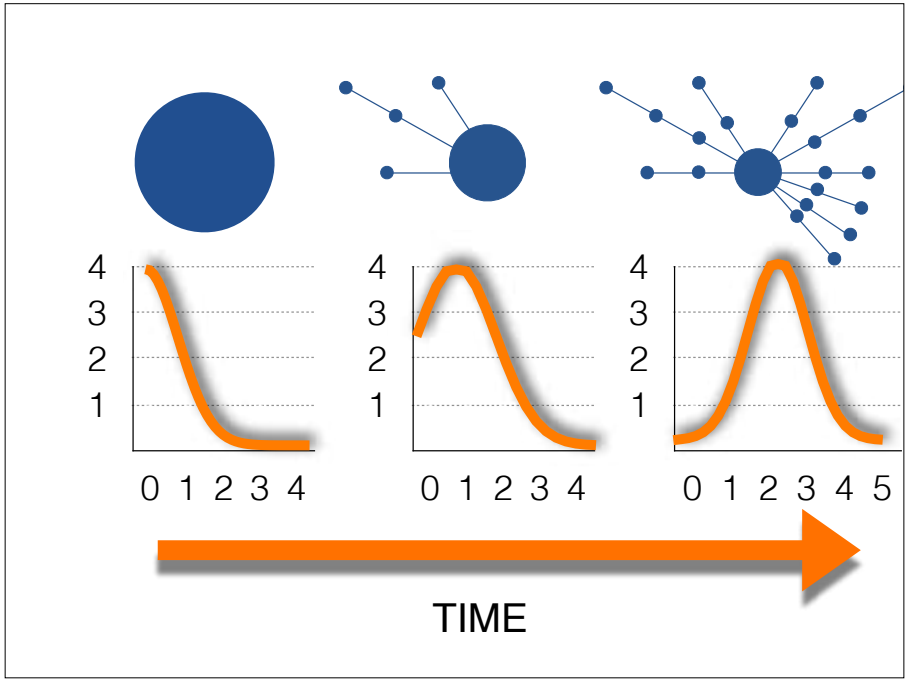


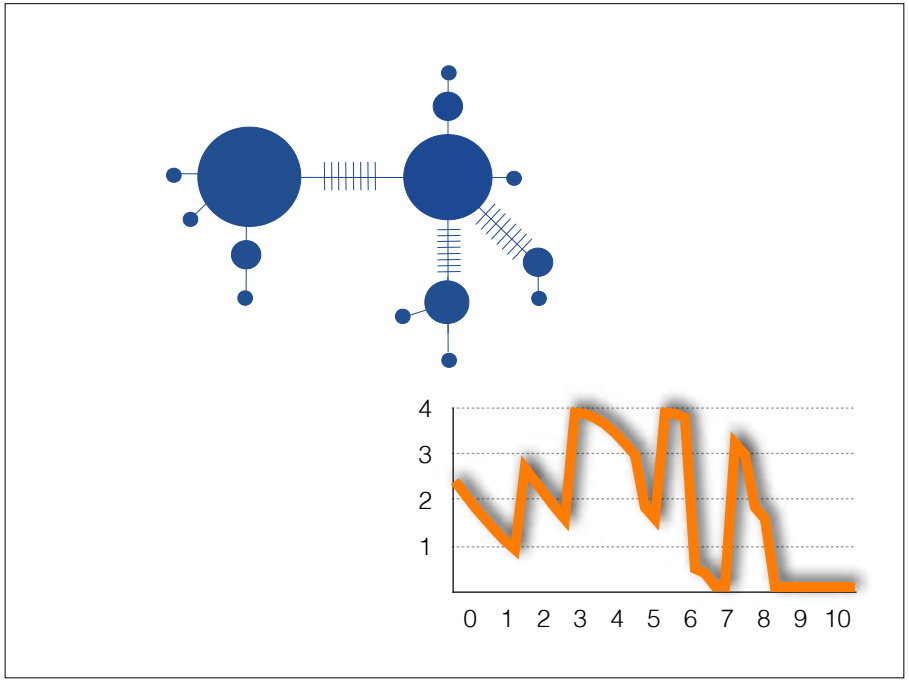
Number of differences	Counts
0	20
1	4
2	3
3	2
4	0

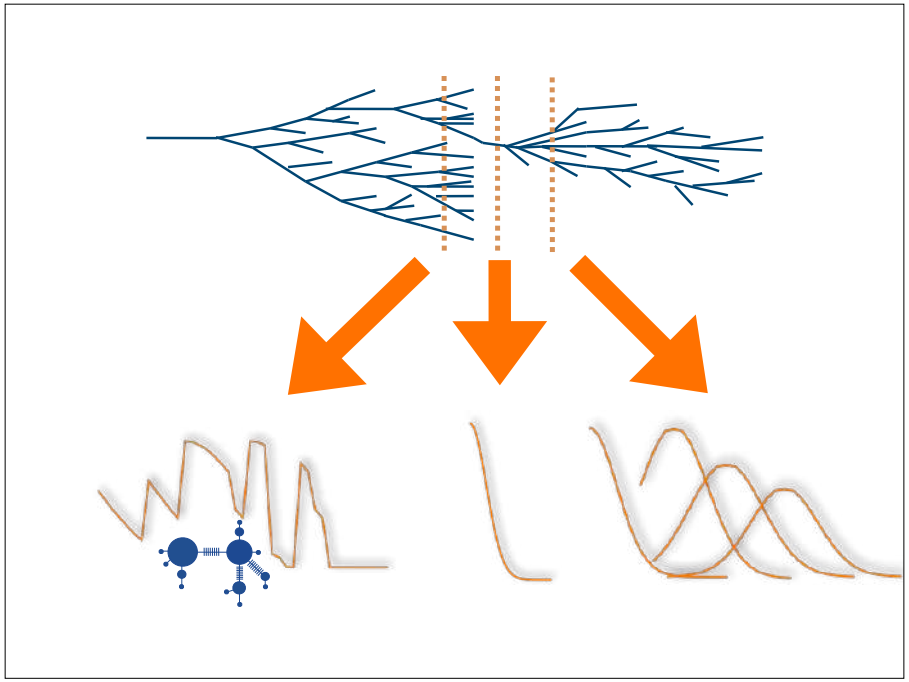


Number of differences	Counts
0	20
1	4
2	3
3	2
4	0



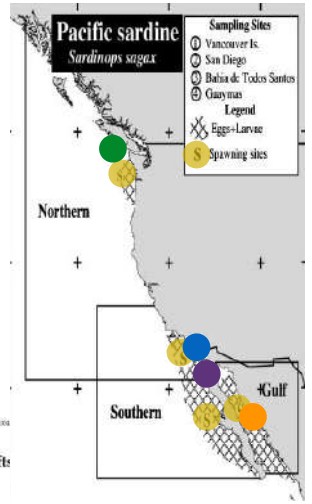






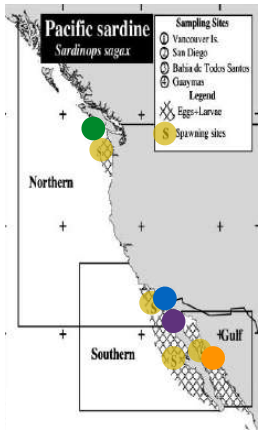
AGE OF POPULATIONS?

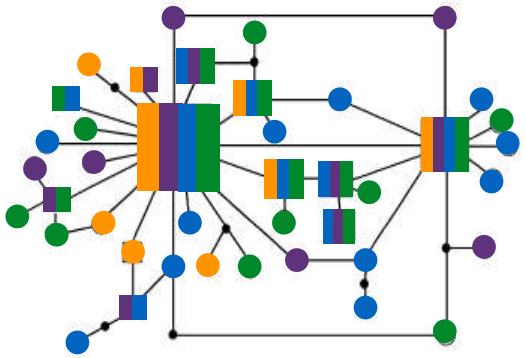
- Vancouver
- San Diego
- Baja California
- Gulf of California



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

AGE OF POPULATIONS?



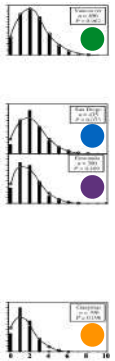


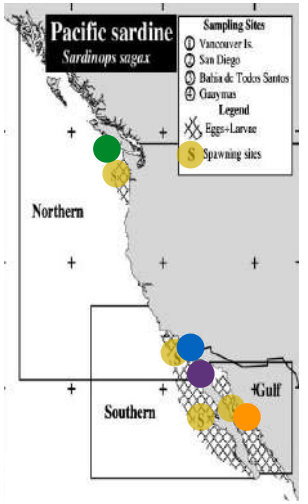
Vancouver
San Diego
Baja California
Gulf of California

Lecomte *et al.* (2004)

AGE OF POPULATIONS?

Vancouver
San Diego
Baja California
Gulf of California

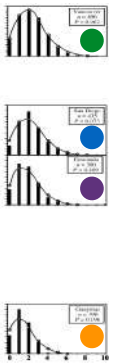


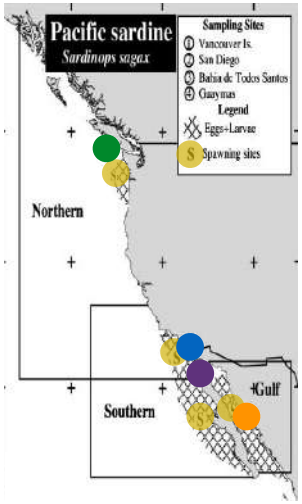


Lecomte *et al.* (2004)

AGE OF POPULATIONS?

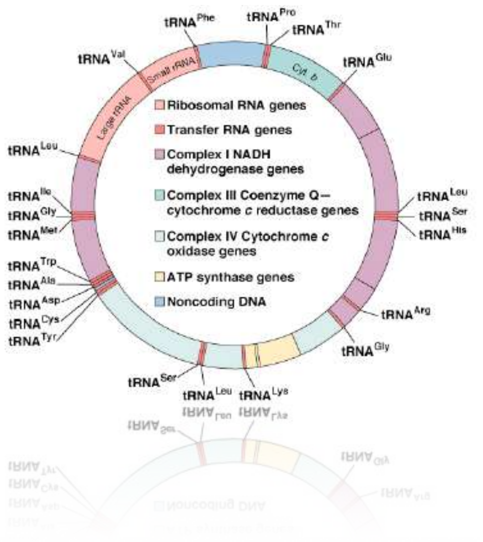
Pacific	Age
Vancouver	276 000
San Diego	241 000
Baja	218 000
Gulf	176 000
Global	229 000



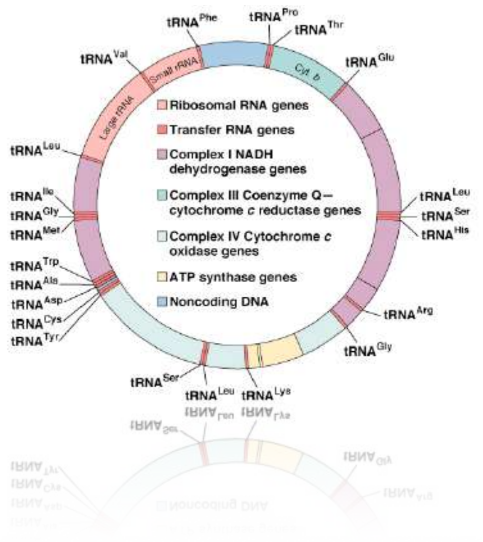


Lecomte *et al.* (2004)

Genetics of sardines

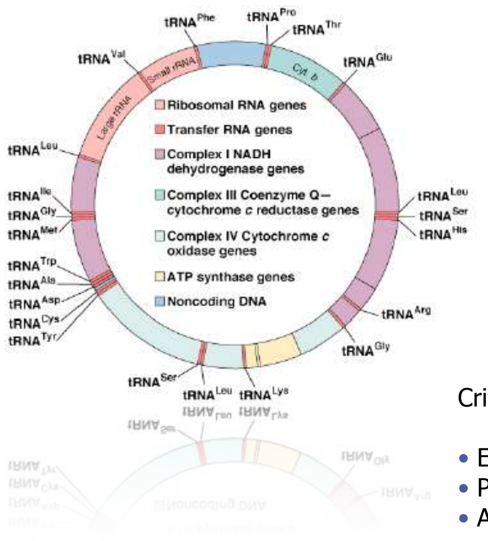


Molecular methods



Mitochondrial DNA
maternal inheritance
(usually)

Molecular methods



Mitochondrial DNA
maternal inheritance
(usually)

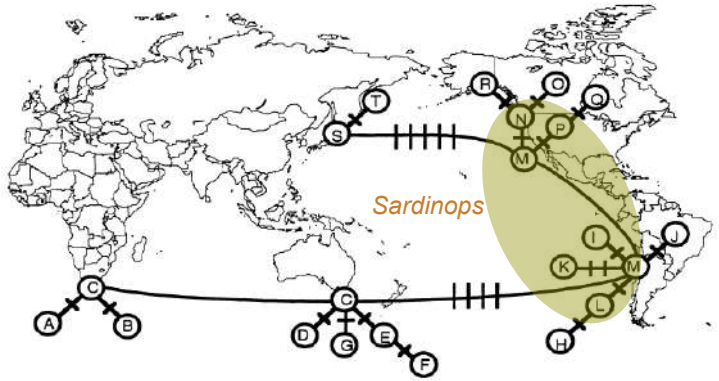
Criteria:

- Easy to assay
- Polymorphic
- Appropriate time scales

mtDNA Control Region 500 bp - **transversions**

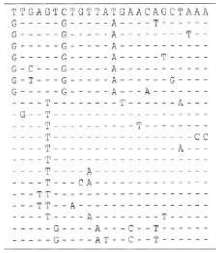
Haplotype	Position 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 4 4 4 2 7 7 1 3 7 7 8 9 2 2 2 3 3 4 8 8 0 5 7 8 6 7 8 9 0 1 9 2 3 8 5 1 5 6 9 4 8 2 2 8 9 4 6 7 0 6 9	Location: SA	AU	CH	CA	JA
CON	T T G A G T C T G T T A T G A A C A G C T A A A					
A	G - - - - - G - - - - - A - - - - T - - - - - -	1				
B	G - - - - - G - - - - - A - - - - - - - - T - -	1				
C	G - - - - - G - - - - - A - - - - - - - - - - -	13	10			
D	G - - - - - G - - - - - A - - - - - T - - - - -		2			
E	G - C - - - G - - - - - A - - - - - - - - - - -		1			
F	G - T - - - G - - - - - A - - - - - - G - - - -		1			
G	G - - - - - G - - - - - A - - - A - - - - - - -		1			
H	- - - - T - - - - - - - - T - - - - - - A - - -			1		
I	- G - - T - - - - - - - - - - - - - - - - - - -			1		
J	- - - - T - - - - - - - - - - T - - - - - - - -			1		
K	- - - - T - - - - - - - - - - - - - - - - - C C			1		
L	- - - - T - - - - - - - - - - - - - - - A - - -			4		
M	- - - - T - - - - - - - - - - - - - - - - - - -			10	6	
N	- - - - T - - - - A - - - - - - - - - - - - - -				5	
O	- - - - T - - - C A - - - - - - - - - - - - - -				1	
P	- - - T T - - - - - - - - - - - - - - - - - - -				1	
Q	- - - T T - - A - - - - - - - - - - - - - - - -				1	
R	- - - - T - - - - A - - - - - - - - T - - - - -				1	
S	- - - - - G - - - - A - - C - - T - - - - - - -					17
T	- - - - - G - - - - A T - - C - - T - - - - - -					1

Bowen & Grant (1997)



Grant & Leslie (1996)

Bowen & Grant (1997)



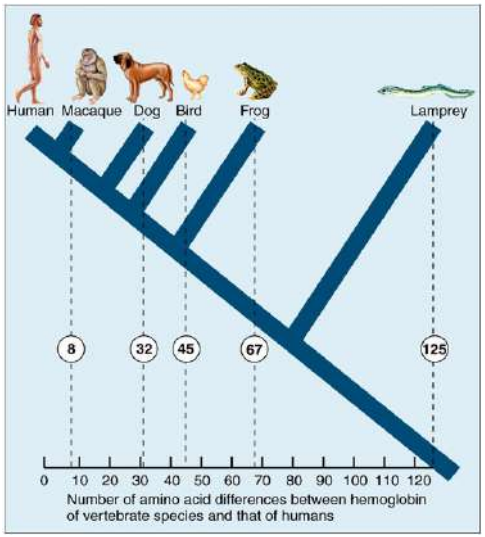
Genetic distances (+ standard errors)

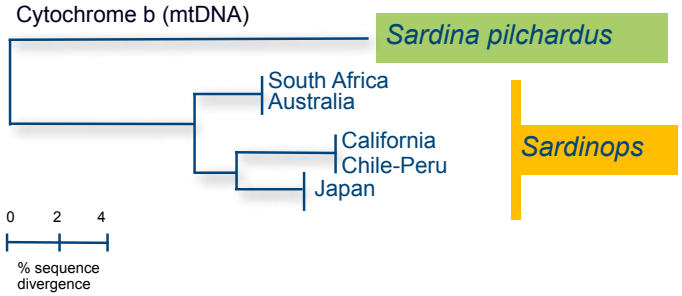
-	0.017	0.183	0.235	0.279	0.292	0.296	0.292
0.003	-	0.185	0.230	0.279	0.292	0.296	0.291
0.698	0.708	-	0.192	0.272	0.293	0.299	0.293
1.069	1.040	0.851	-	0.208	0.196	0.209	0.213
1.311	1.309	1.273	0.911	-	0.013	0.029	0.033
1.356	1.362	1.360	0.852	0.033	-	0.029	0.036
1.414	1.413	1.436	0.967	0.065	0.059	-	0.020
1.388	1.387	1.382	0.969	0.051	0.078	0.049	-

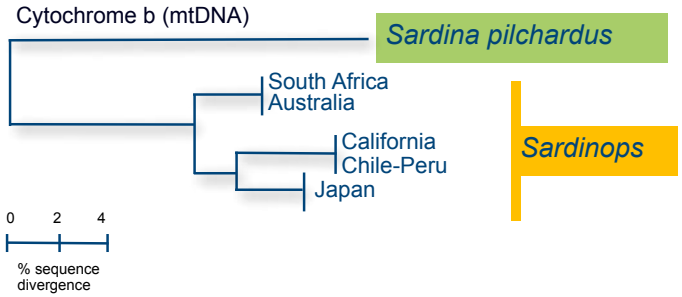
(Grant, Leslie & Bowen 2005)

Molecules reflect evolutionary divergence

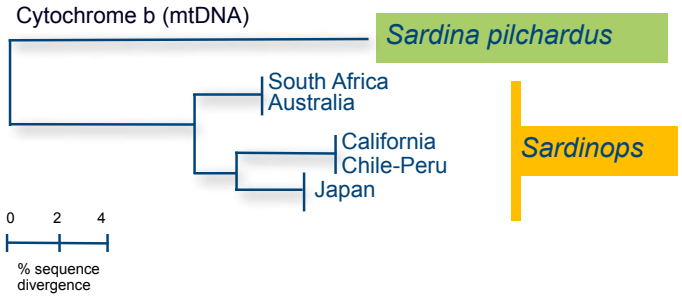
Molecular clock





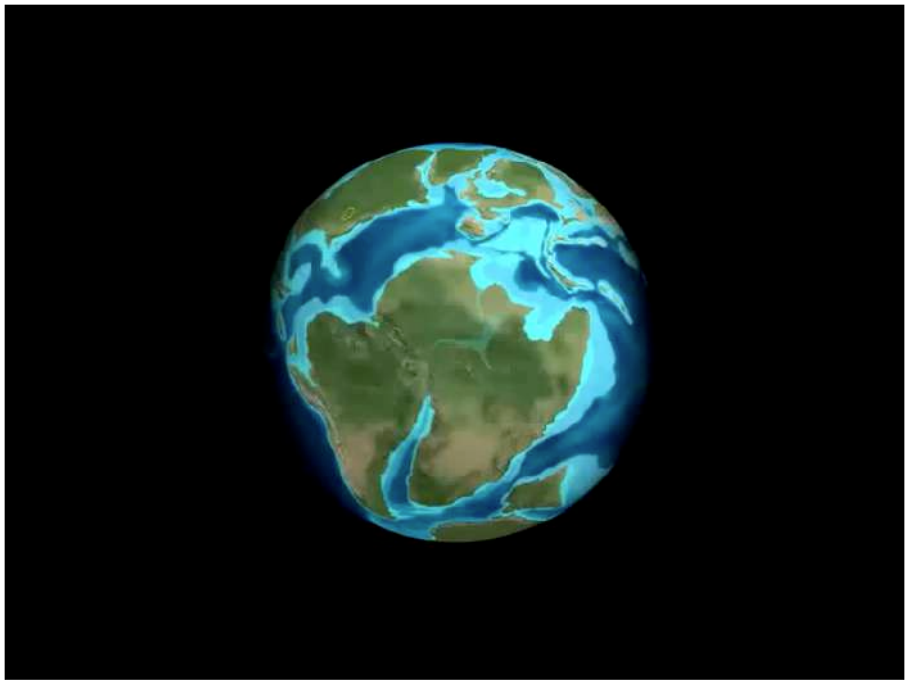


Cytochrome b molecular clock: 1% = 1 MY

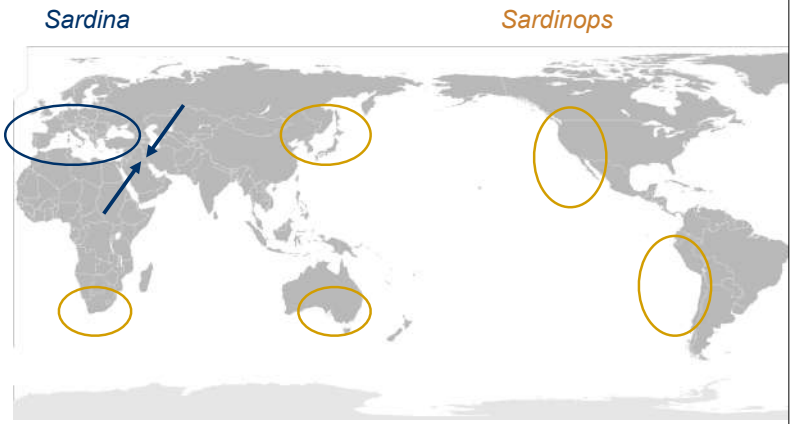


Cytochrome b molecular clock: 1% = 1 MY

Distance *Sardinops-Sardina* = ca. 23% = 23MY



Allozyme distances between *Sardina* and *Sardinops* are consistent with 18 MY closure of eastern Tethys Sea

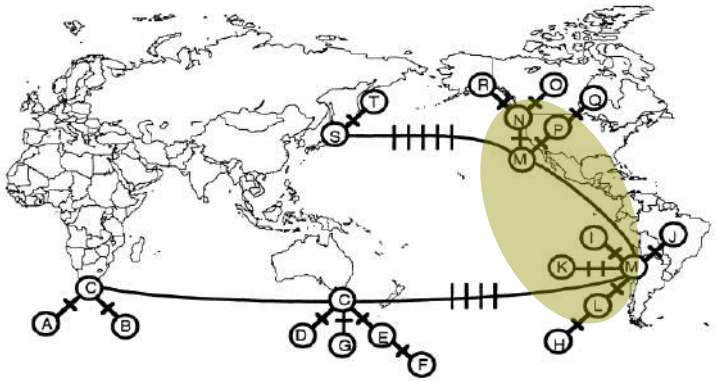


Grant & Leslie (1996)

Bowen & Grant (1997)

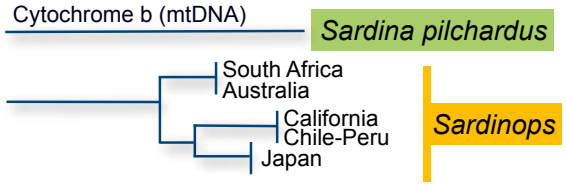
- *Sardinops*: mtDNA divergences consistent with Pleistocene dispersal
- Greatest haplotype diversity in 'center' of distribution

Sardinops



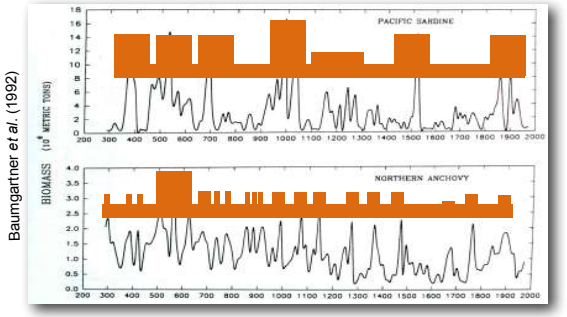
Grant & Leslie (1996)

Bowen & Grant (1997)



Why is there only shallow population structure in a 18 MY old species?

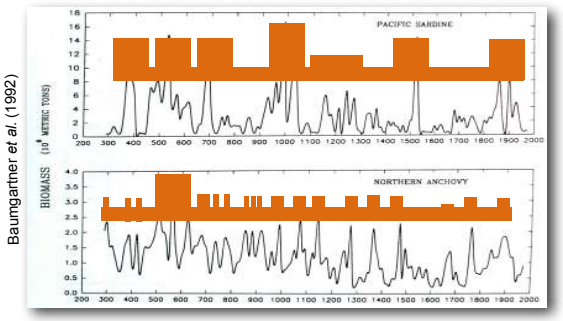
Why shallow population structure in a 18 MY old species?



Baumgartner *et al.* (1992)

Temporal abundance strong variation

Why shallow population structure in a 18 MY old species?



Baumgartner *et al.* (1992)

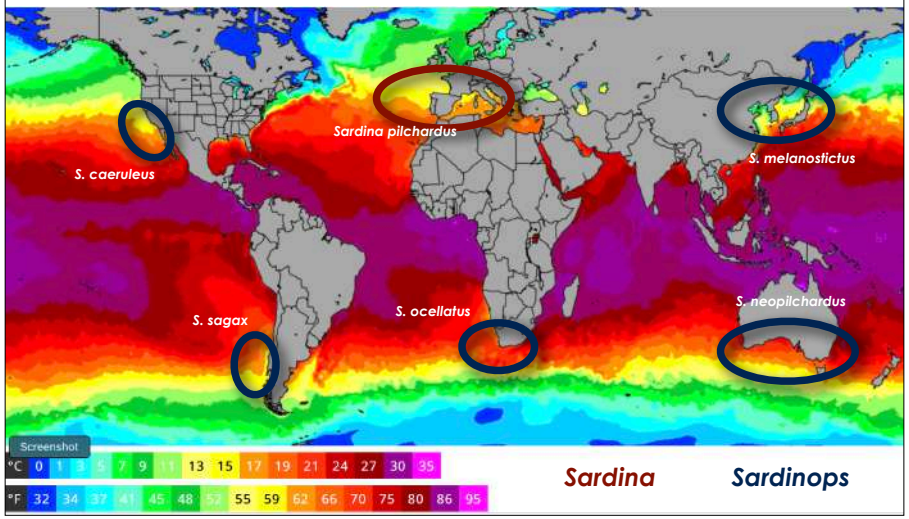
Temporal abundance strong variation

Lineage sorting = lineage extinctions + new mutations

Re-cap

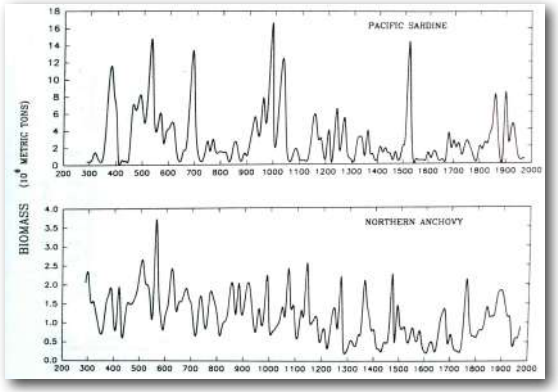
Re-cap

Sardines do not tolerate temperatures below 13 and above 25 degrees celsius



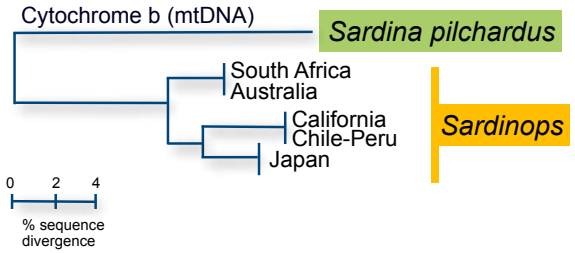
Re-cap

Global scale changes in climate are possibly influencing the abundance of the resource



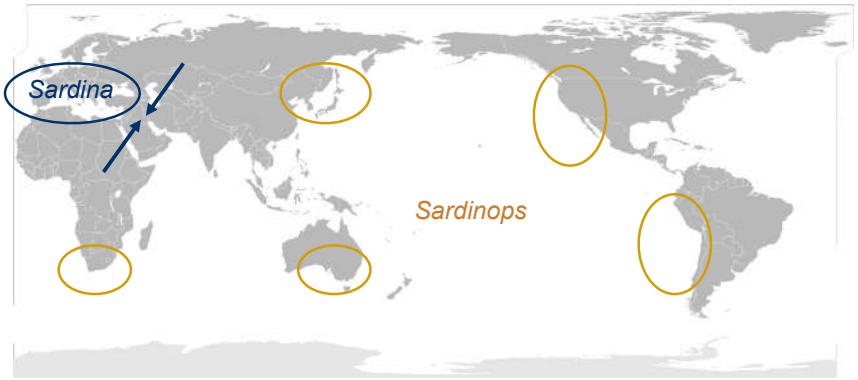
Re-cap

The genetic distances between regional populations (South Africa and Australia, and Chile and California) are small and imply recent divergences between populations



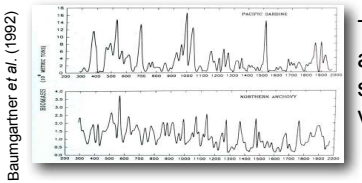
Re-cap

Allozyme distances between *Sardina* and *Sardinops* are consistent with 18 MY closure of eastern Tethys Sea



Re-cap

Shallow population structure in a 18 MY old species because…..



Temporal abundance strong variation

Lineage sorting = lineage extinctions + new mutations

outline

GEOGRAPHIC DISTRIBUTION

MOLECULAR DATA

PHYLOGENETIC ESTIMATION

HISTORICAL DEMOGRAPHY

PALEOGEOGRAPHIC EVENTS