Beta, alpha and gamma benthic diversity on estuaries: What to expect?

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Estuaries: functions and multiple services

	Service								
Function	Carbon sequestration	Climate regulation	Fisheries production	Pharmaceutical	Pollution buffering	Recreational	Tourism	Aquaculture production	Erosion control
Biodiversity	**X**		**X**	**X**		**X**	**X**		
Carbon Cycling	**X**	**X**							
Nursery área			**X**			**X**	**X**		
Sediment trapping					**X**			**X**	**X**
Wave attenuation									**X**

Adapated from Granek et al 2010 Cons. Biol.

An estuary is a partially enclosed coastal body of water that is either **permanently or periodically open to the sea** and which...

...receives **at least periodic discharge from a river(s)**, and thus, while its **salinity is typically less than that of natural sea water and varies temporally and along its length**,...

...it can become hypersaline in regions when evaporative water loss is high and freshwater and tidal inputs are negligible.

Potter et al 2010 ECSS

Estuarine Quality Paradox

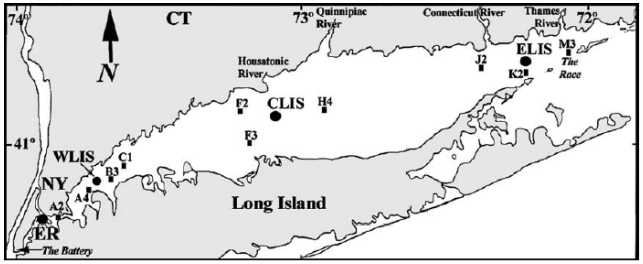
High degree of variability in their physico-chemical characteristics (e.g. oxygen, temperature and salinity) in the water column and bed sediment dynamics

Natural stress ≈ Anthropogenic stress

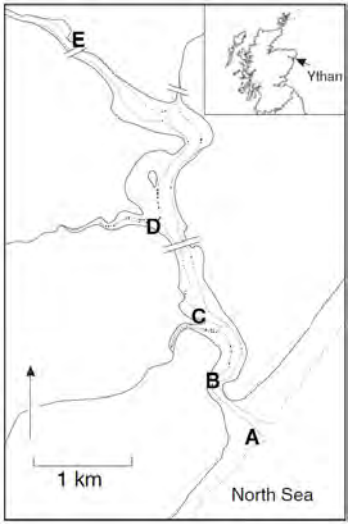
Detection of the anthropogenic stress more difficult than in other systems (e.g. marine, freshwater)

Elliott and Quintino 2007 ECSS

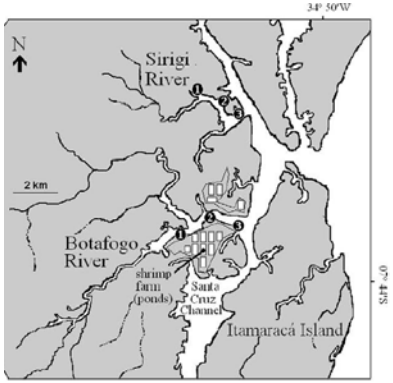
Many studies described the variation on the structure of biological assemblages (e.g. mangroves trees, salt-marshes, benthic invertebrates, benthic diatoms, bacteria, phytoplankton, fish) **along estuarine systems**



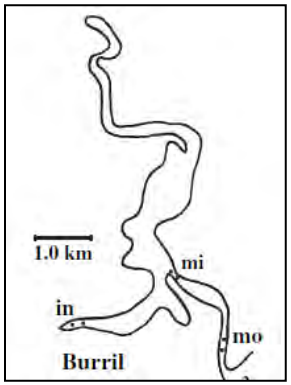
Gobler et al 2006



Freitag et al 2006



Carvalho et al 2010



Dye and Barros 2005

Hampel et al 2004

1. **Estuaries are really importante (function, services)**

2. **Different types os estuaries (large variability between)**

3. **Large variability (large variability within)**

4. **Different sample designs (“*technical*” variability)**

1. **Estuaries are really importante (function, services)**

+

2. **Different types os estuaries (large variability between)**

+

3. **Large variability (large variability within)**

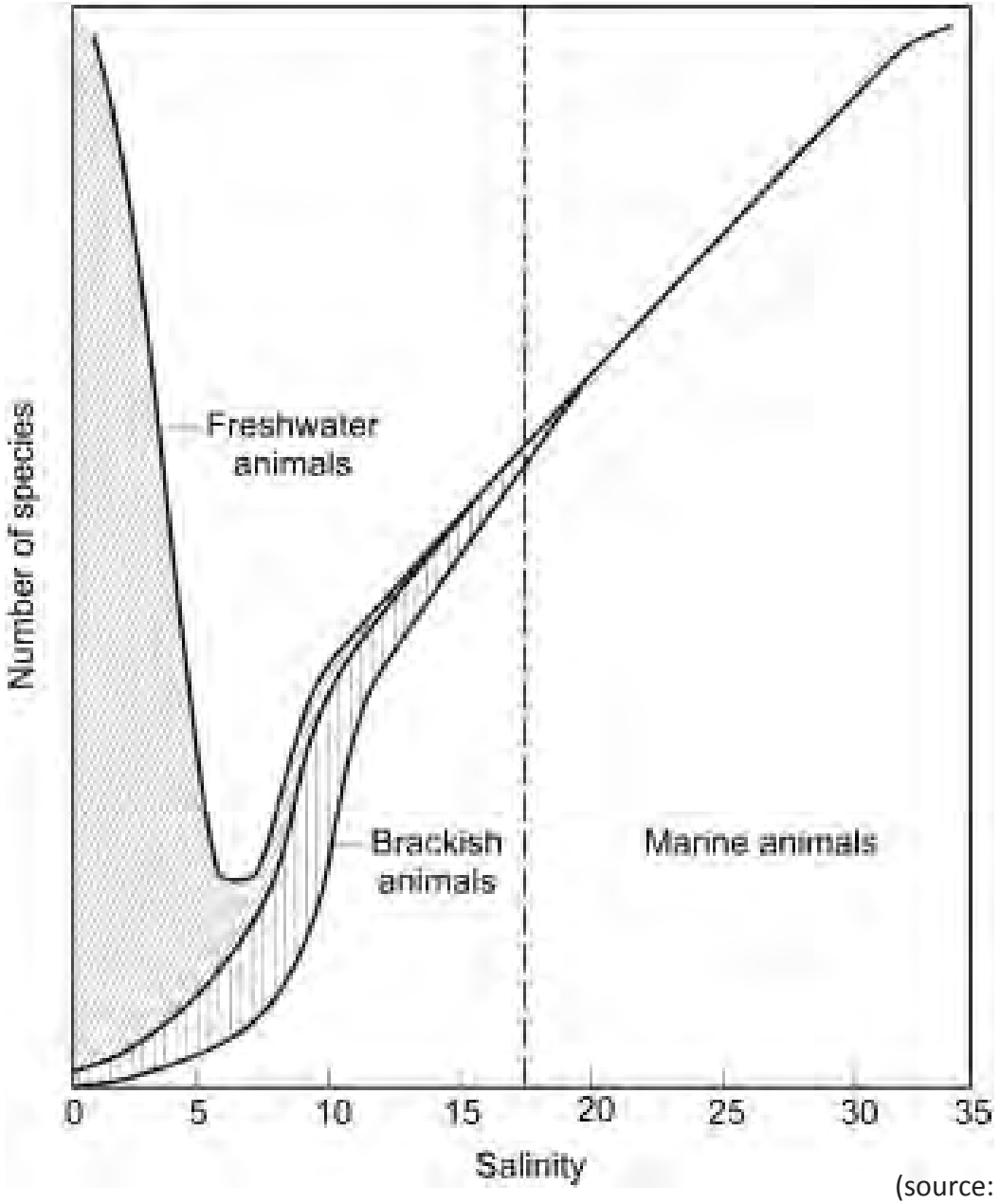
+

4. **Different sample designs (“*technical*” variability)**

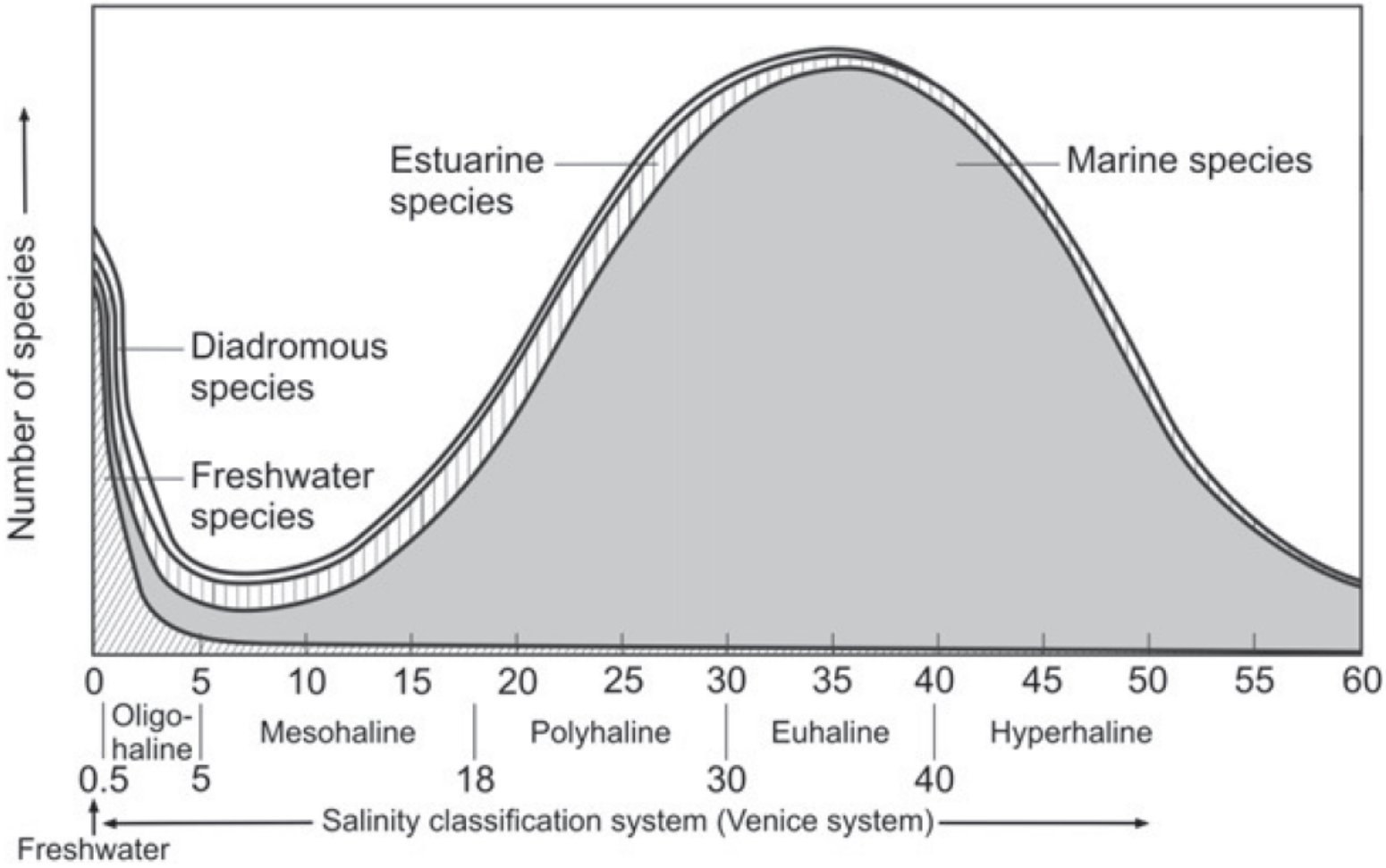
General models hard to built

Estuarine diversity model

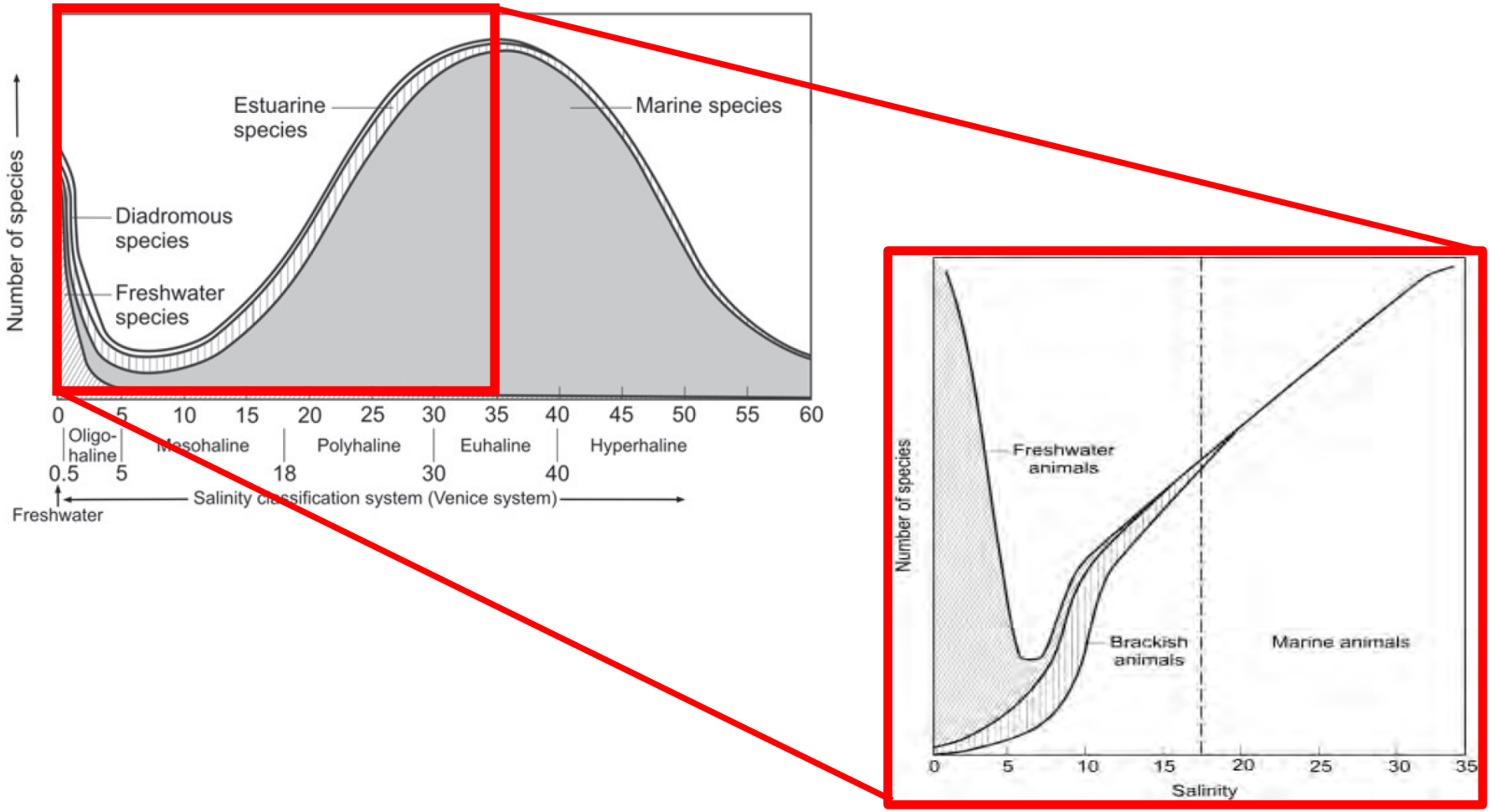
Remane 1934



(source: Whitfield et al 2012 ECSS)



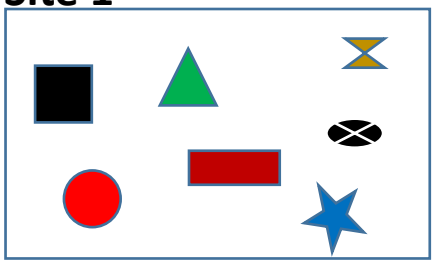
(Whitfield et al 2012 ECSS)


Number of species
Estuarine species
Marine species
Diadromous species
Freshwater species
0 5 10 15 20 25 30 35 40 45 50 55 60
Oligo-haline
Mesohaline
Polyhaline
Euhaline
Hyperhaline
0.5 5 18 30 40
Salinity classification system (Venice system)
Freshwater
Number of species
Freshwater animals
Brackish animals
Marine animals
0 5 10 15 20 25 30 35
Salinity

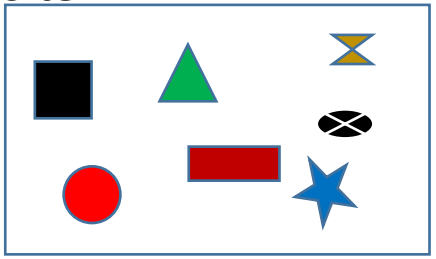
Beta, alpha and gamma diversity…

Region A

Site 1

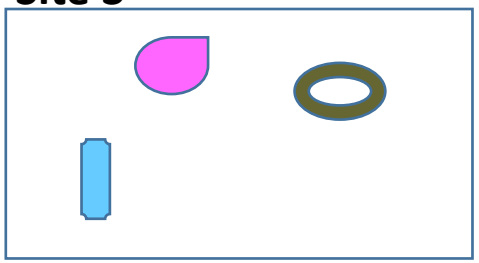


Site 2

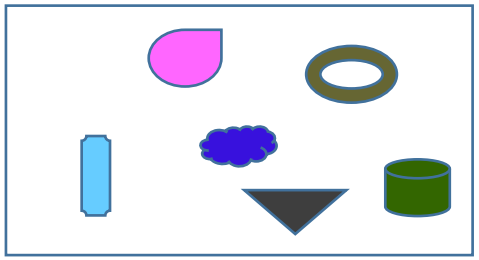


Region B

Site 3



Site 4



Gamma diversity: Region A > Region B

Alpha diversity: Site1 = Site2 > Site 4 > Site 3

Beta diversity: Between sites in Region B > Between sites in Region A

Beta diversity may reflect two different phenomena:

1 - turnover (or sps replacement)

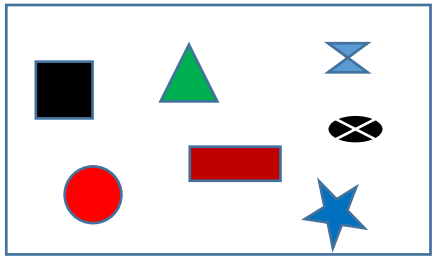
2 - nestedness

Baselga 2010, Glob.Ecol.Biog.

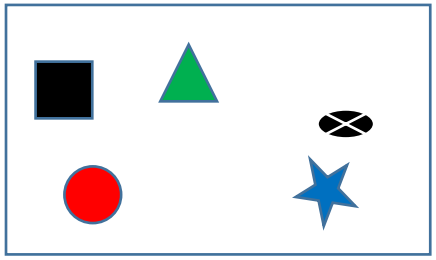
Baselga and Orme 2012 Met.Ecol.Evol.

Nestedness

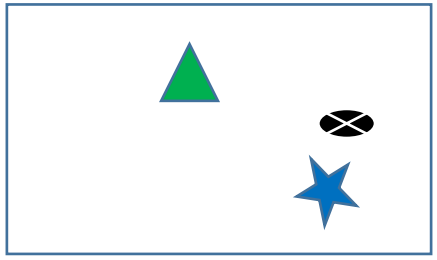
Site 1



Site 2

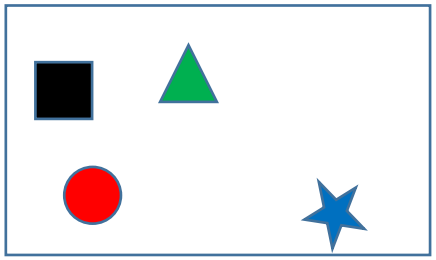


Site 3

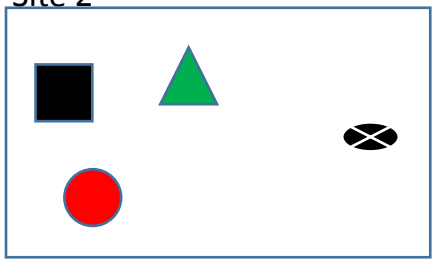


Turnover (replacement)

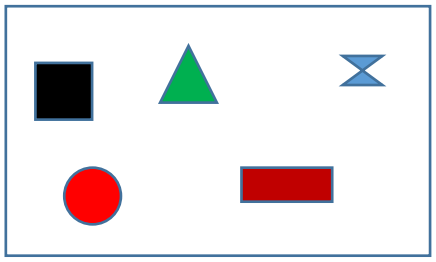
Site 1



Site 2



Site 3



≠ Strategies to Conserve Biodiversity

Existing theory…

Baselga 2010 (beetles)

Dobrovolsky et al, 2012 (birds, mammals and amphibians)

In areas with greater effects of glaciation (i.e. stronger glaciation) beta diversity will be mostly driven by nestedness than turnover

stronger glaciation in temperate - - -

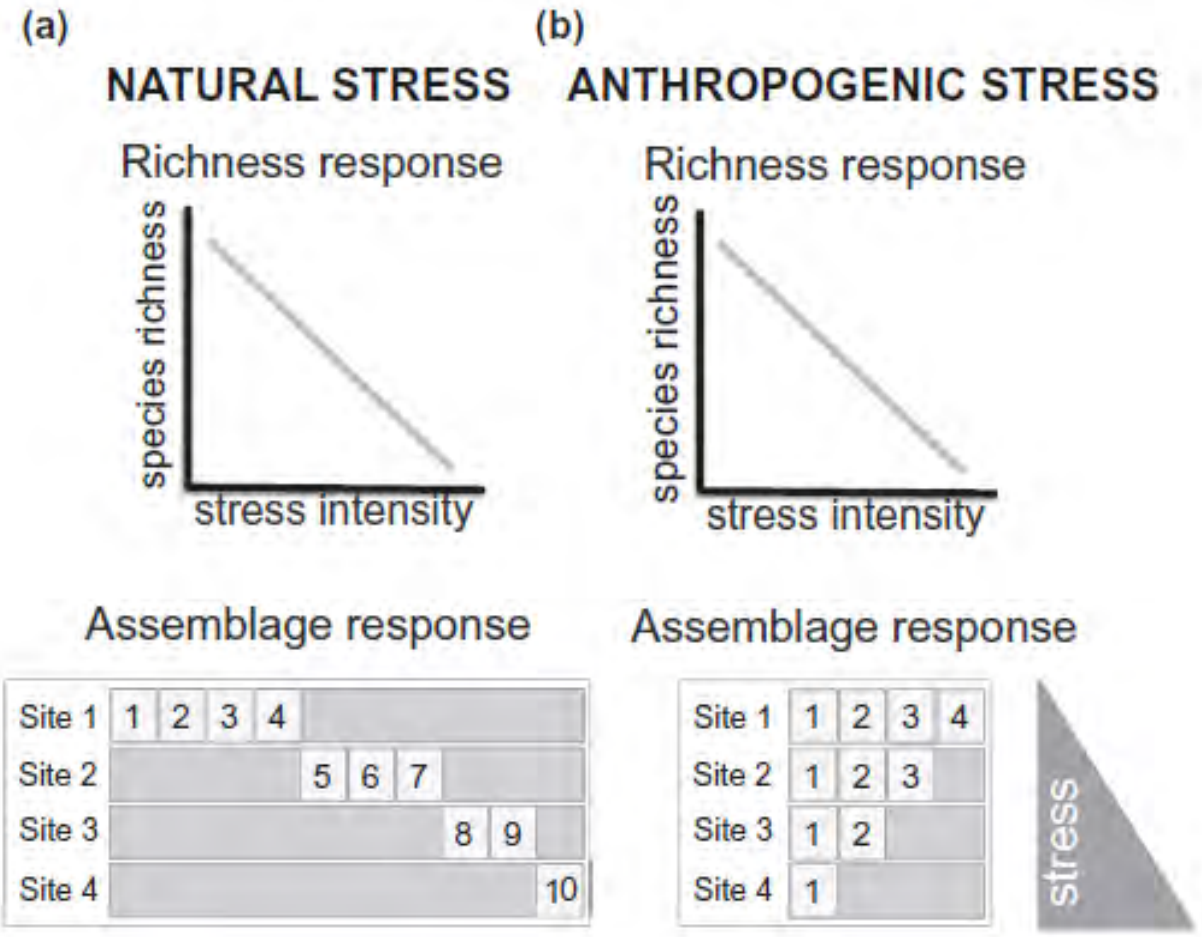
extinctions and colonization - high nestedness

weaker effects of glaciation in tropics - - -

high endemism - high turnover

Existing theory… **Gutiérrez-Cánovas, et 2013, Glob. Ecol. Biog.**

Benthic invertebrates in rivers



(i) to evaluate if benthic macrofaunal assemblages would show higher turnover than nestedness in tropical than in temperate estuarine systems;

(ii) to evaluate whether impacted estuaries would show greater nestedness than pristine (or less polluted) systems;

(iii) to propose a framework for studying benthic macrofaunal beta diversity along estuaries and suggest potential modifications due to climate changes.

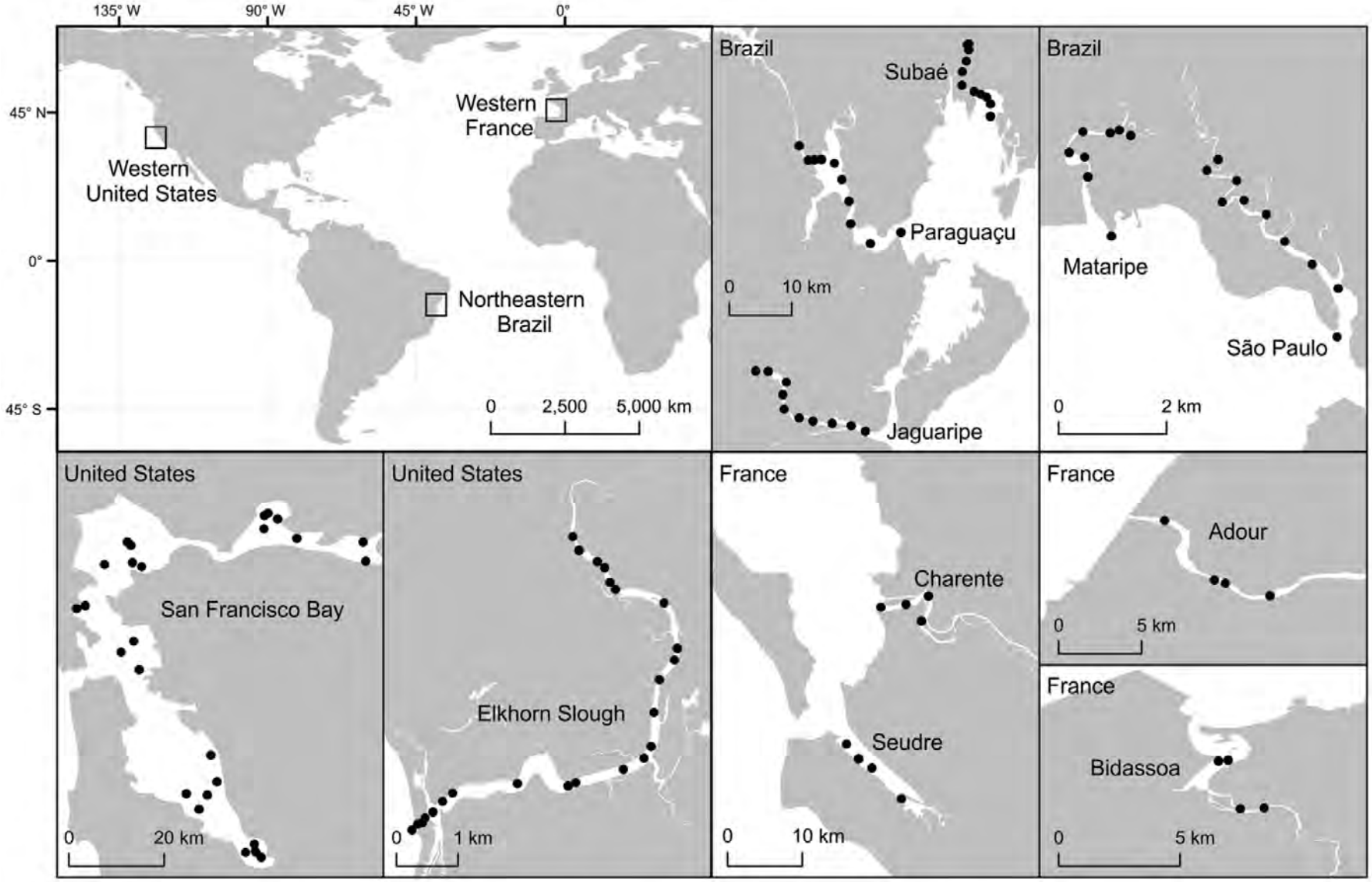


Fig. 1. Map showing sampled estuaries and stations (black dots).

Where the data come from?

San Francisco Bay

Regional Monitoring Program (RMP)
San Francisco Estuary Institute largest program.

Elkhorn Slough

Several projects Benthic Ecology Lab at Moss Landing Marine Labs, CA, US

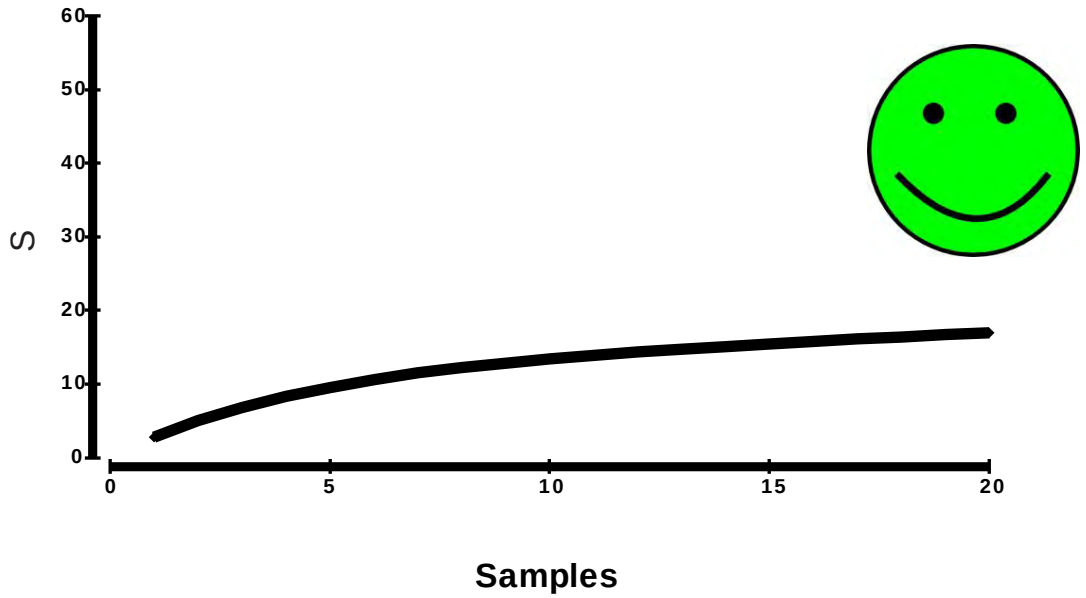
French Estuaries

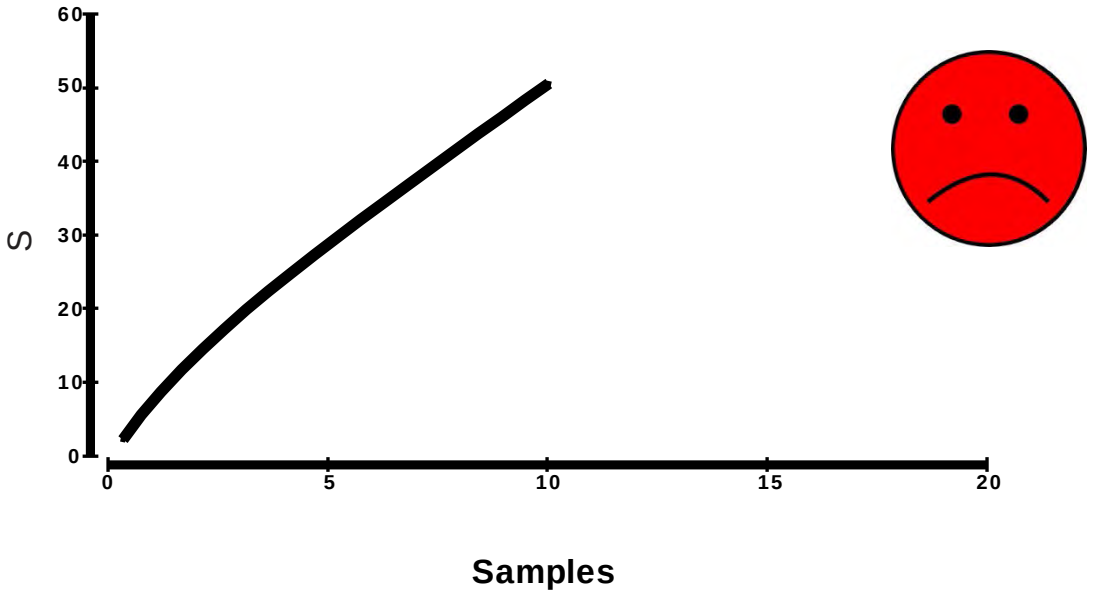
French Adour-Garonne Water Agency (Agence de l'Eau Adour-Garonne), France

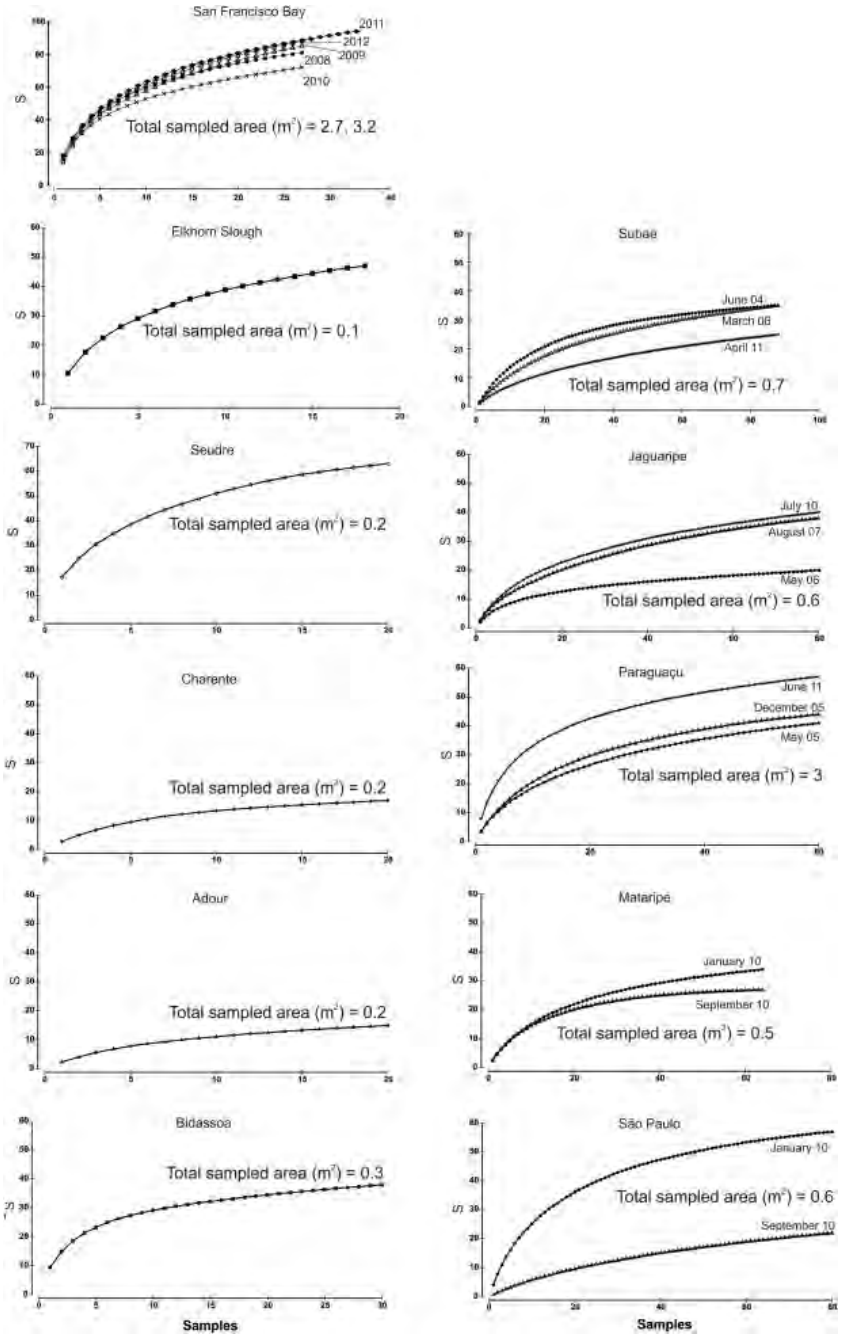
Brazilian Estuaries

Several projects CNPq, FAPESB, Brasil

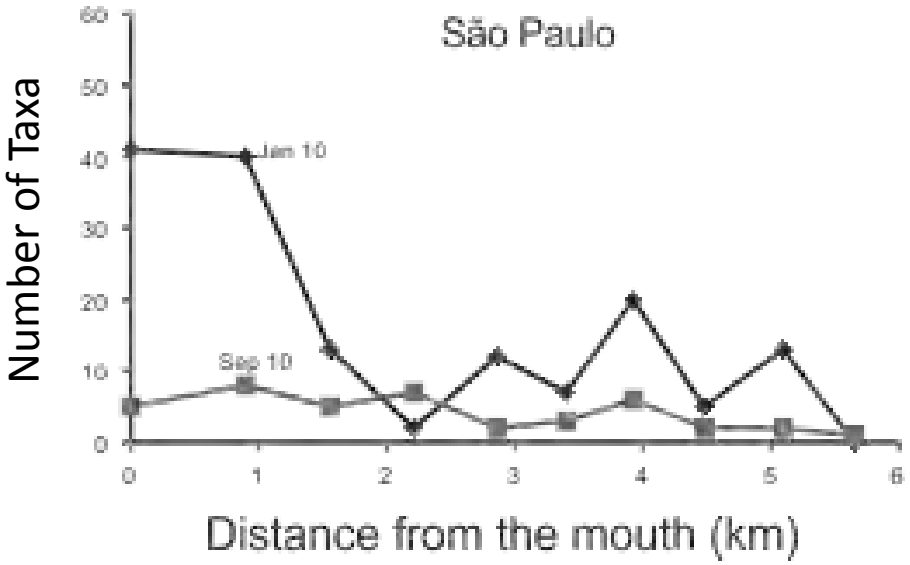
Did you sample enough?



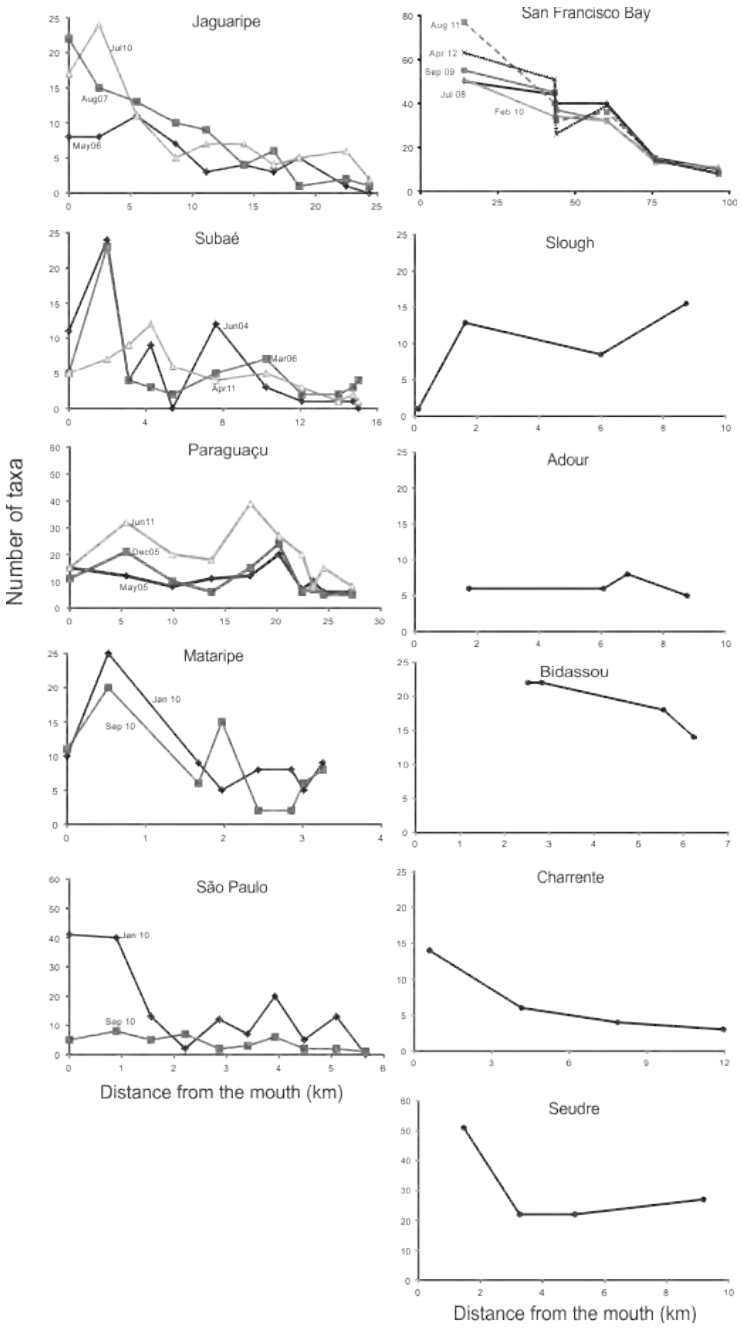


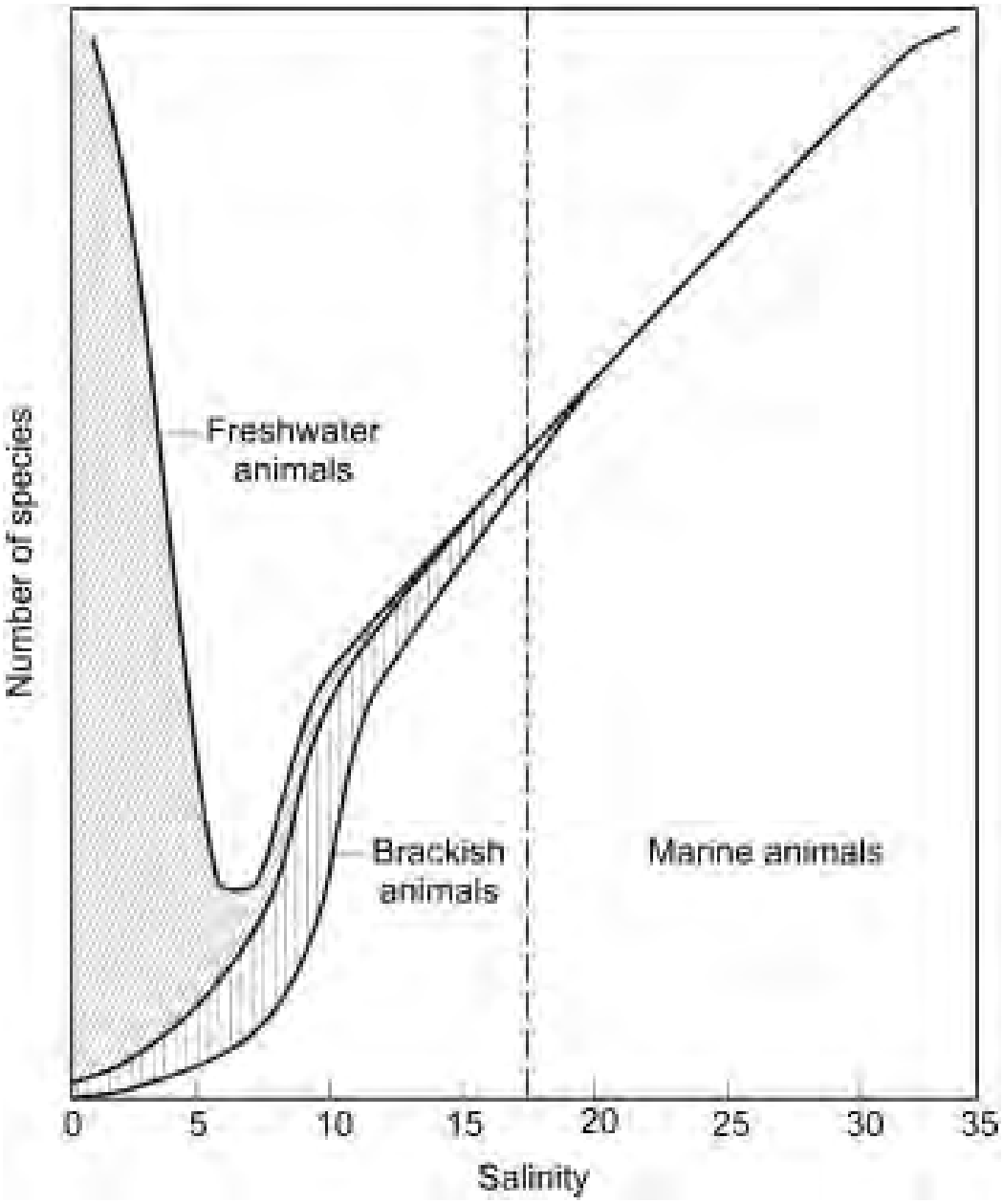

San Francisco Bay
2011
2012
2009
2008
2010
Total sampled area (m²) = 2.7, 3.2
Elkhorn Slough
Total sampled area (m²) = 0.1
Subae
June 04
March 08
April 11
Total sampled area (m²) = 0.7
Seudre
Total sampled area (m²) = 0.2
Jaguaripe
July 10
August 07
May 06
Total sampled area (m²) = 0.6
Charente
Total sampled area (m²) = 0.2
Paraguaçu
June 11
December 05
May 05
Total sampled area (m²) = 3
Adour
Total sampled area (m²) = 0.2
Mataripe
January 10
September 10
Total sampled area (m²) = 0.5
Bidassoa
Total sampled area (m²) = 0.3
São Paulo
January 10
Total sampled area (m²) = 0.6
September 10
S
Samples

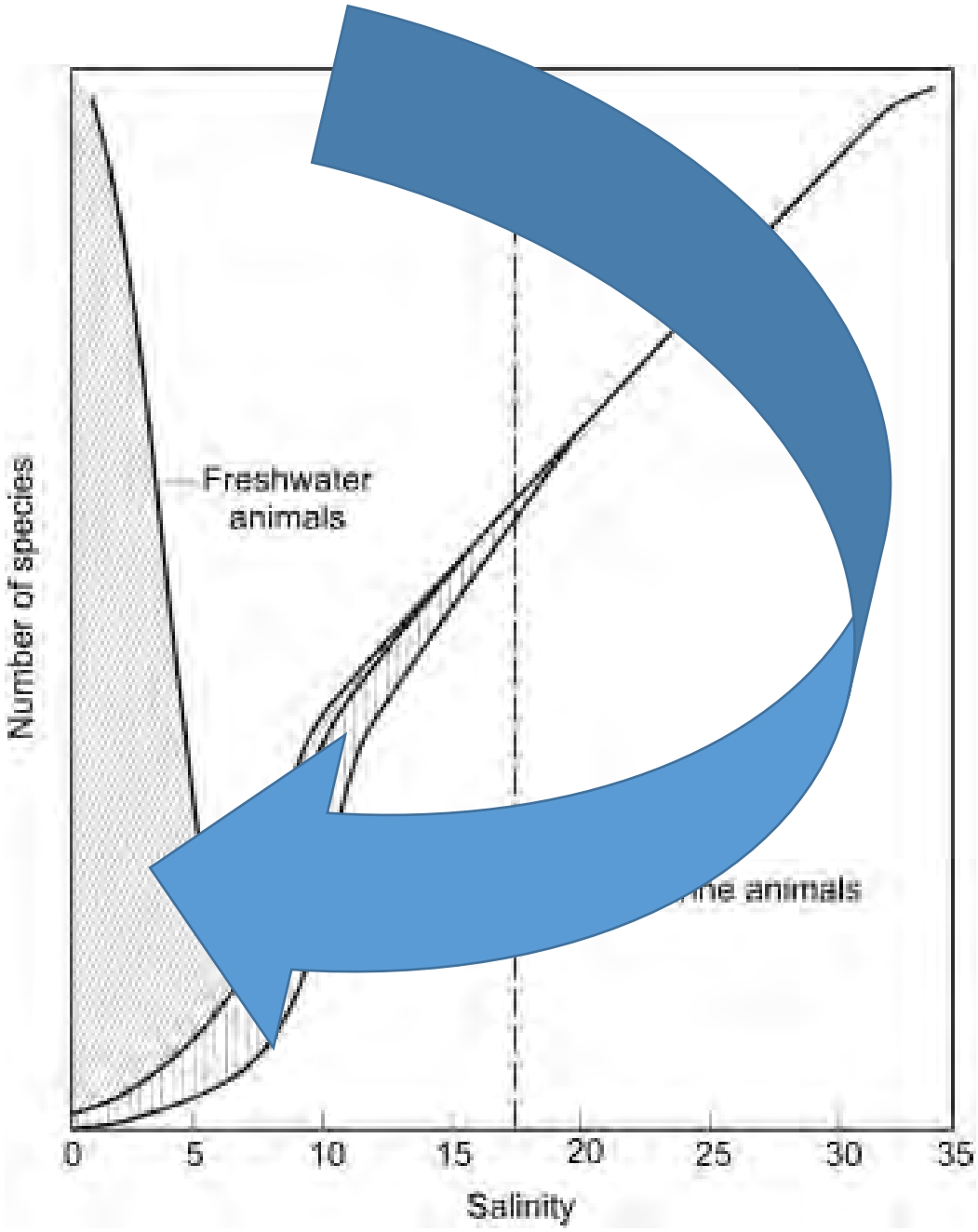
Alpha


São Paulo
Number of Taxa
Distance from the mouth (km)
Jan 10
Sep 10
0
10
20
30
40
50
60
0
1
2
3
4
5
6

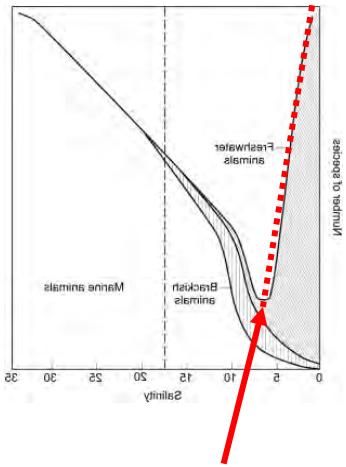
Alpha


Jaguaripe
Jul10
Aug07
May06
San Francisco Bay
Aug 11
Apr 12
Sep 09
Jul 08
Feb 10
Subaé
Jun04
Mar06
Apr11
Slough
Paraguaçu
Jun11
Dec05
May05
Adour
Mataripe
Jan 10
Sep 10
Bidassou
São Paulo
Jan 10
Sep 10
Charrente
Seudre
Number of taxa
Distance from the mouth (km)
Distance from the mouth (km)

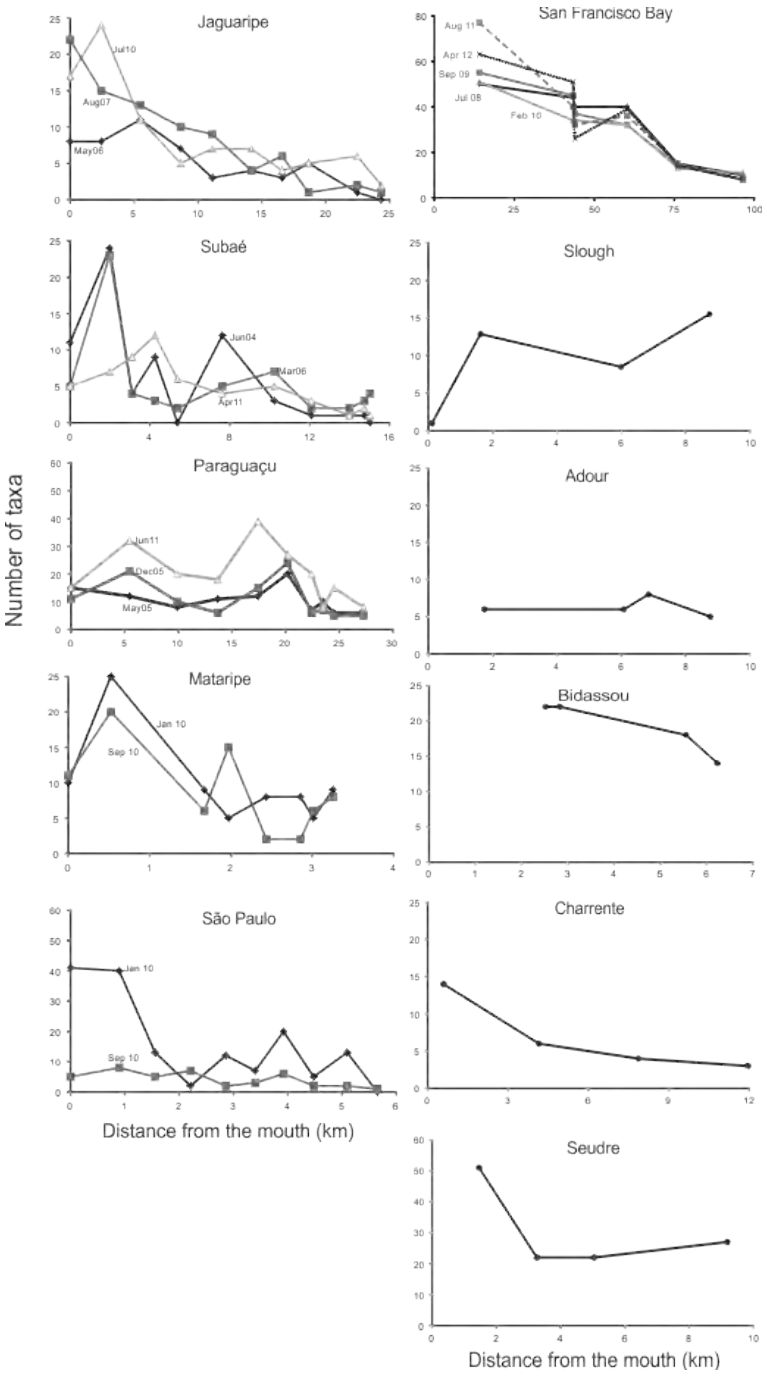

Number of species
Freshwater animals
Brackish animals
Marine animals
0
5
10
15
20
25
30
35
Salinity


Number of species
Freshwater animals
ine animals
0
5
10
15
20
25
30
35
Salinity

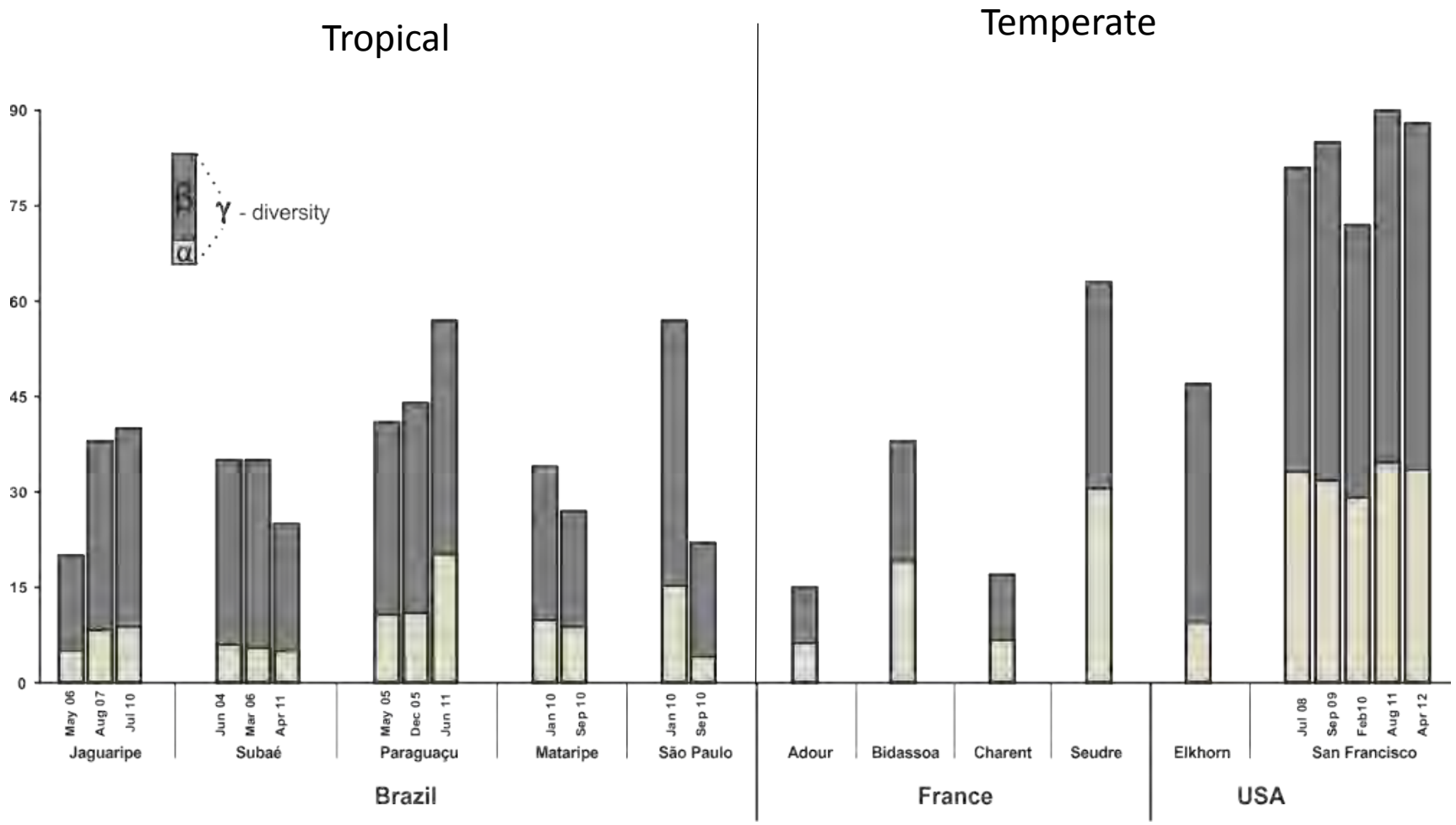
Alpha



Not a general pattern



Gamma


Tropical
Temperate
β
γ - diversity
α
90
75
60
45
30
15
0
May 06
Aug 07
Jul 10
Jaguaripe
Jun 04
Mar 06
Apr 11
Subaé
May 05
Dec 05
Jun 11
Paraguaçu
Jan 10
Sep 10
Mataripe
Jan 10
Sep 10
São Paulo
Brazil
Adour
Bidassoa
Charent
Seudre
France
Elkhorn
USA
Jul 08
Sep 09
Feb10
Aug 11
Apr 12
San Francisco

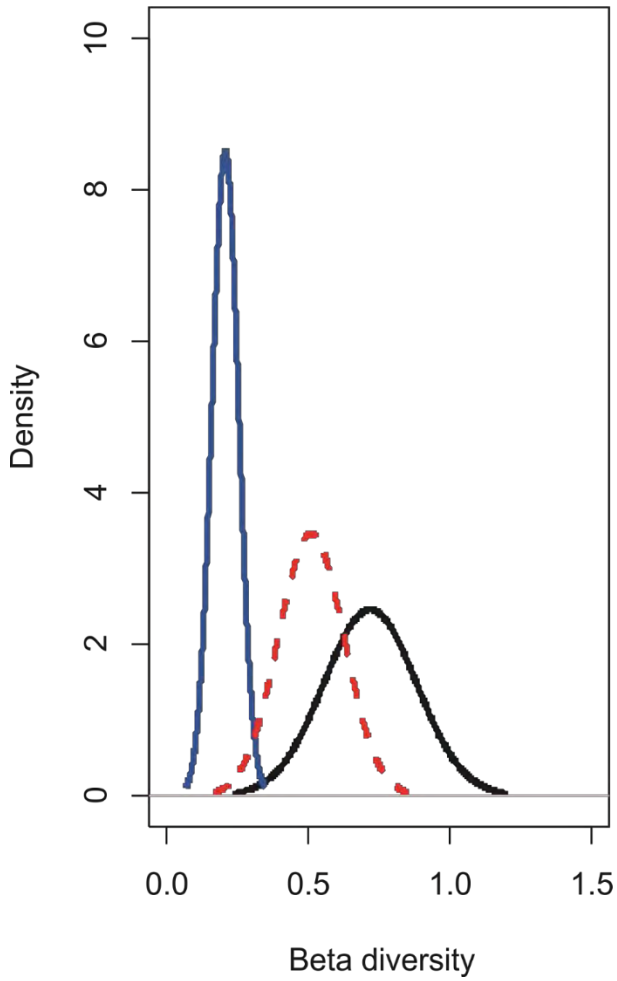
R package for computing total dissimilarity as Sørensen index, as well as it turnover and nestedness components

Baselga and Orme 2012 Met.Ecol.Evol.

turnover nestedness

$$\beta_{sor} = \beta_{sim} + \beta_{sne} \equiv \frac{b+c}{2a+b+c} = \frac{b}{b+a} + \left(\frac{c-b}{2a+b+c}\right)\left(\frac{a}{b+a}\right)$$

Example….



β_{SOR} → TOTAL BETA =

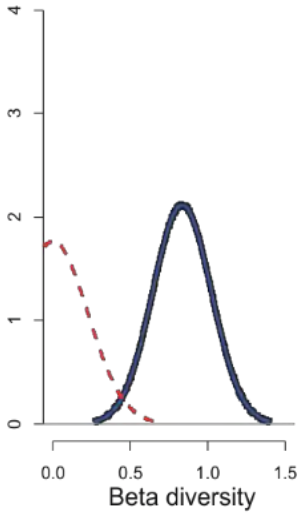
β_{SNE} → Nestedness component

+

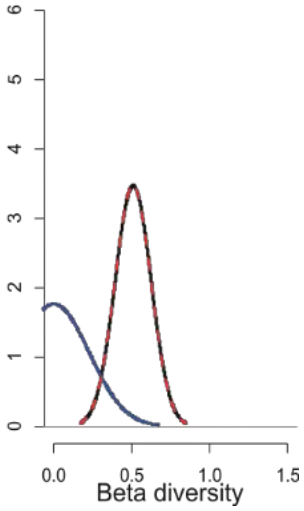
β_{SIM} → Turnover component

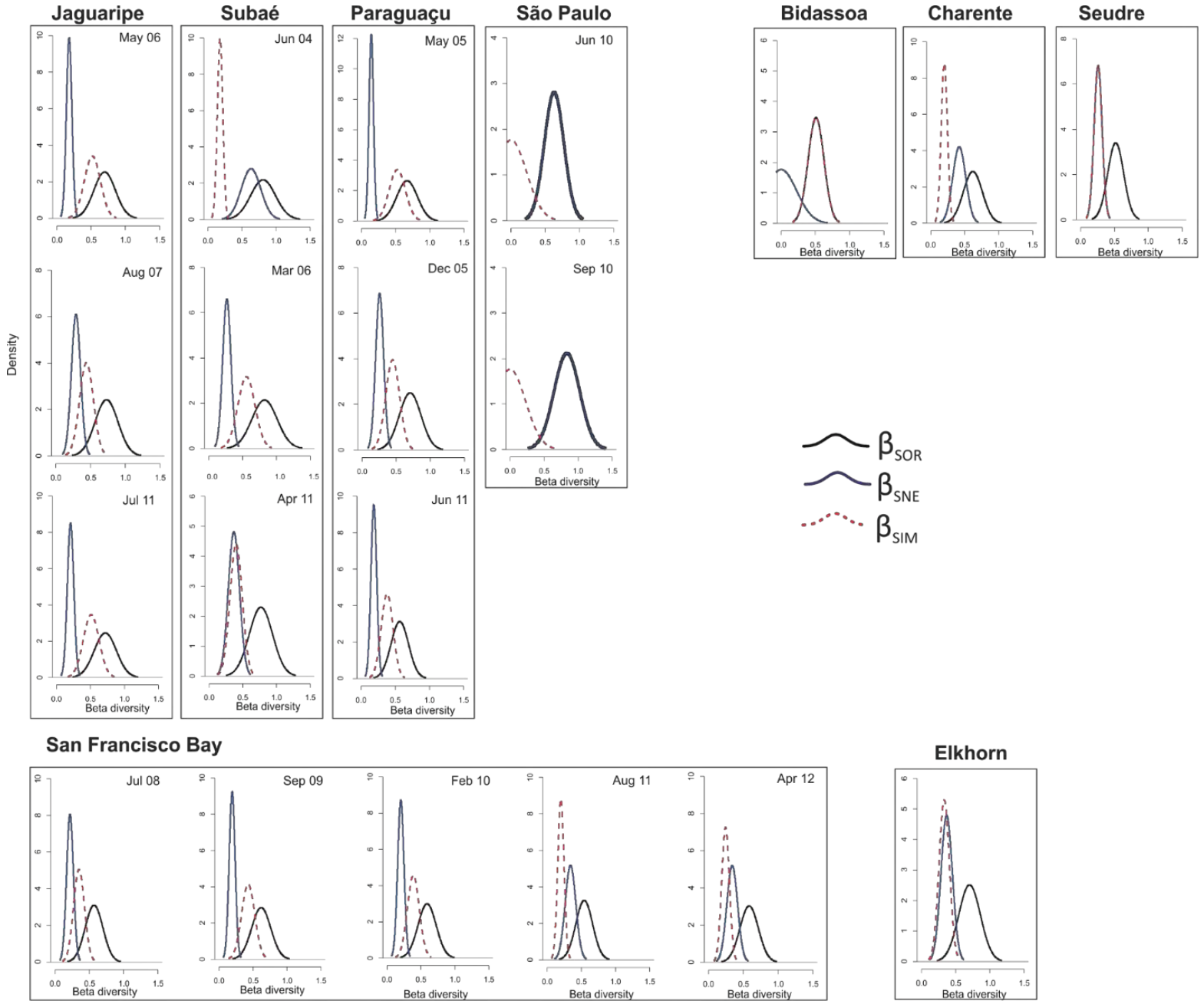
← "Mostly turnover (replacement) situation"

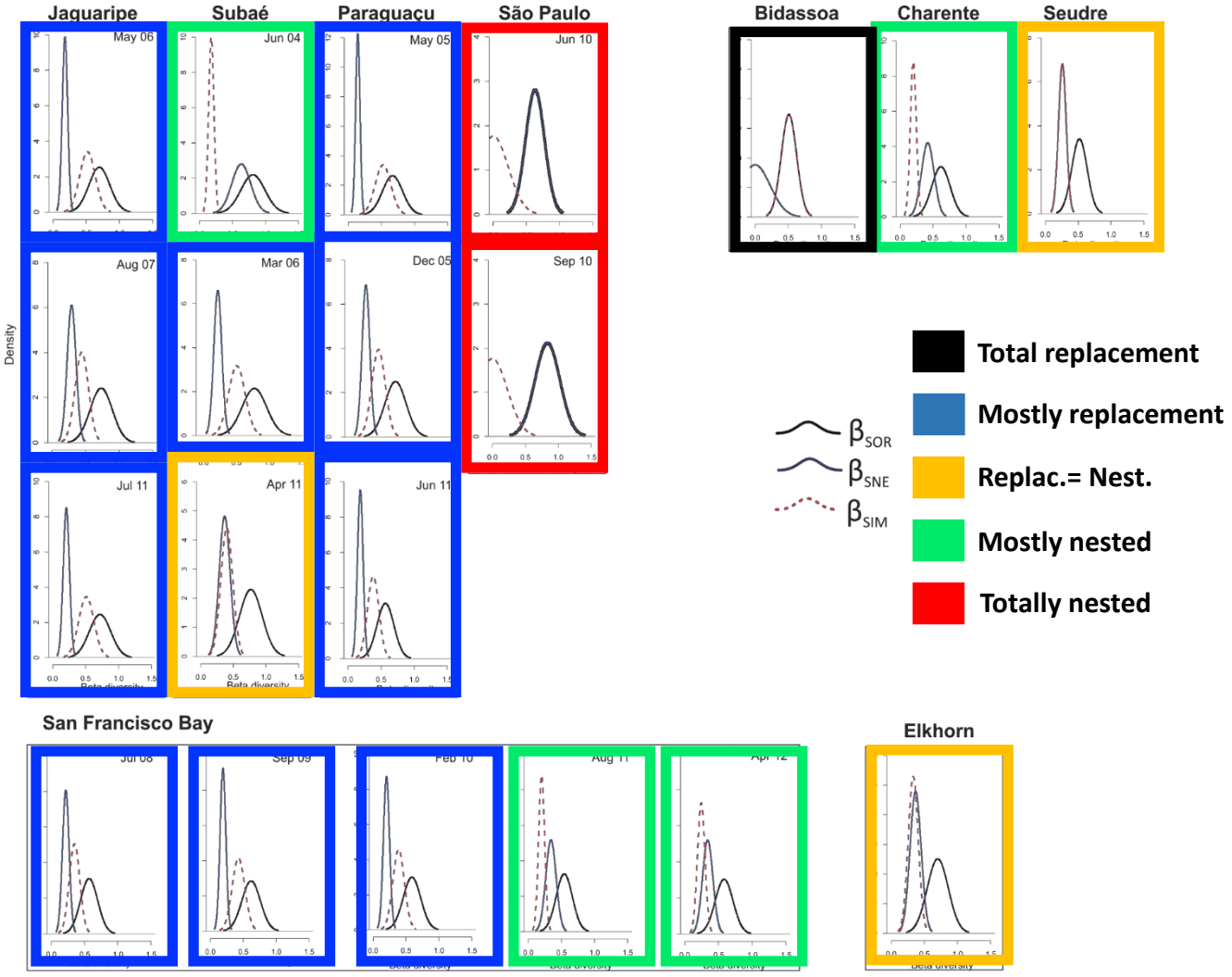
Totally nested

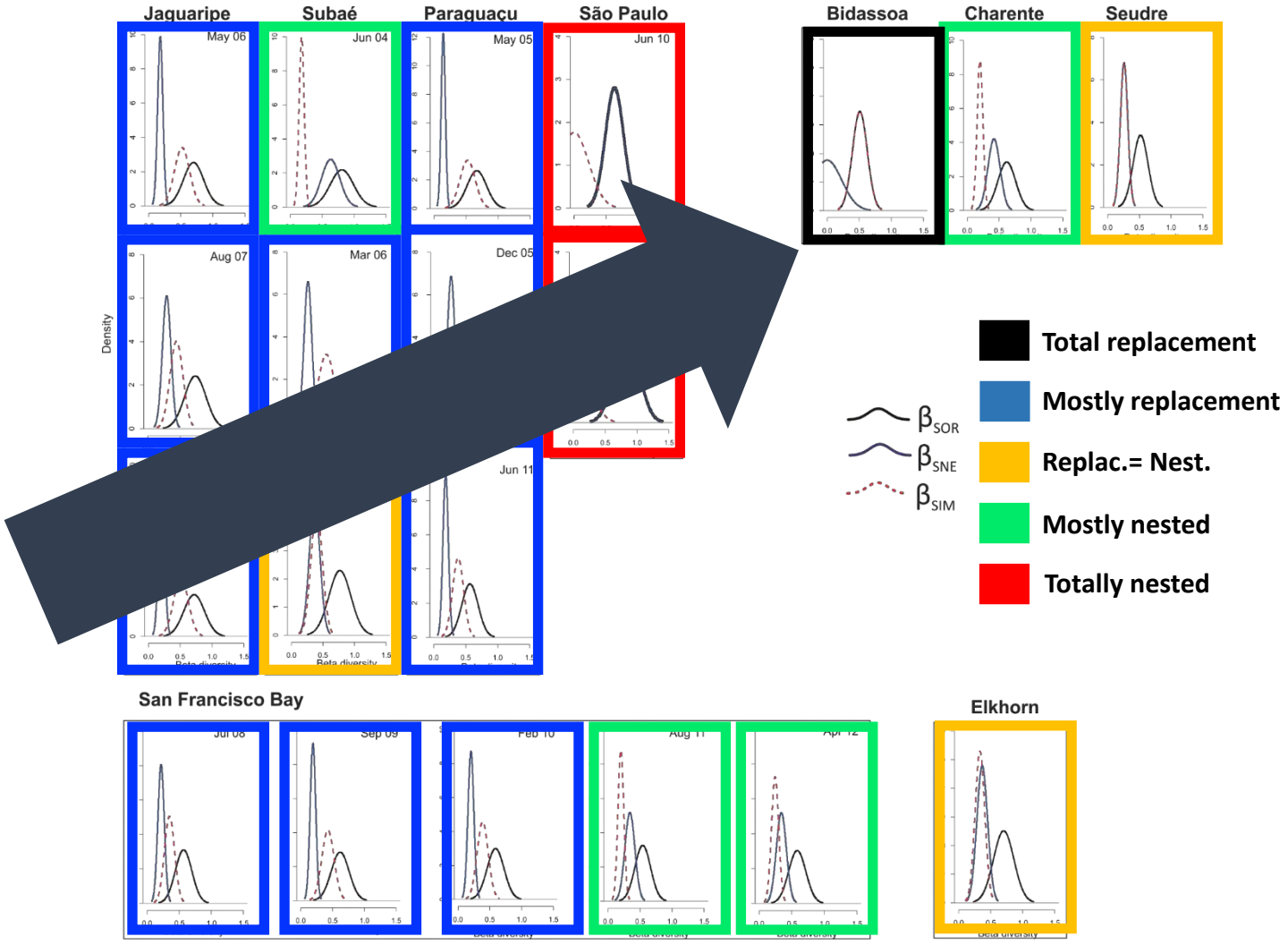


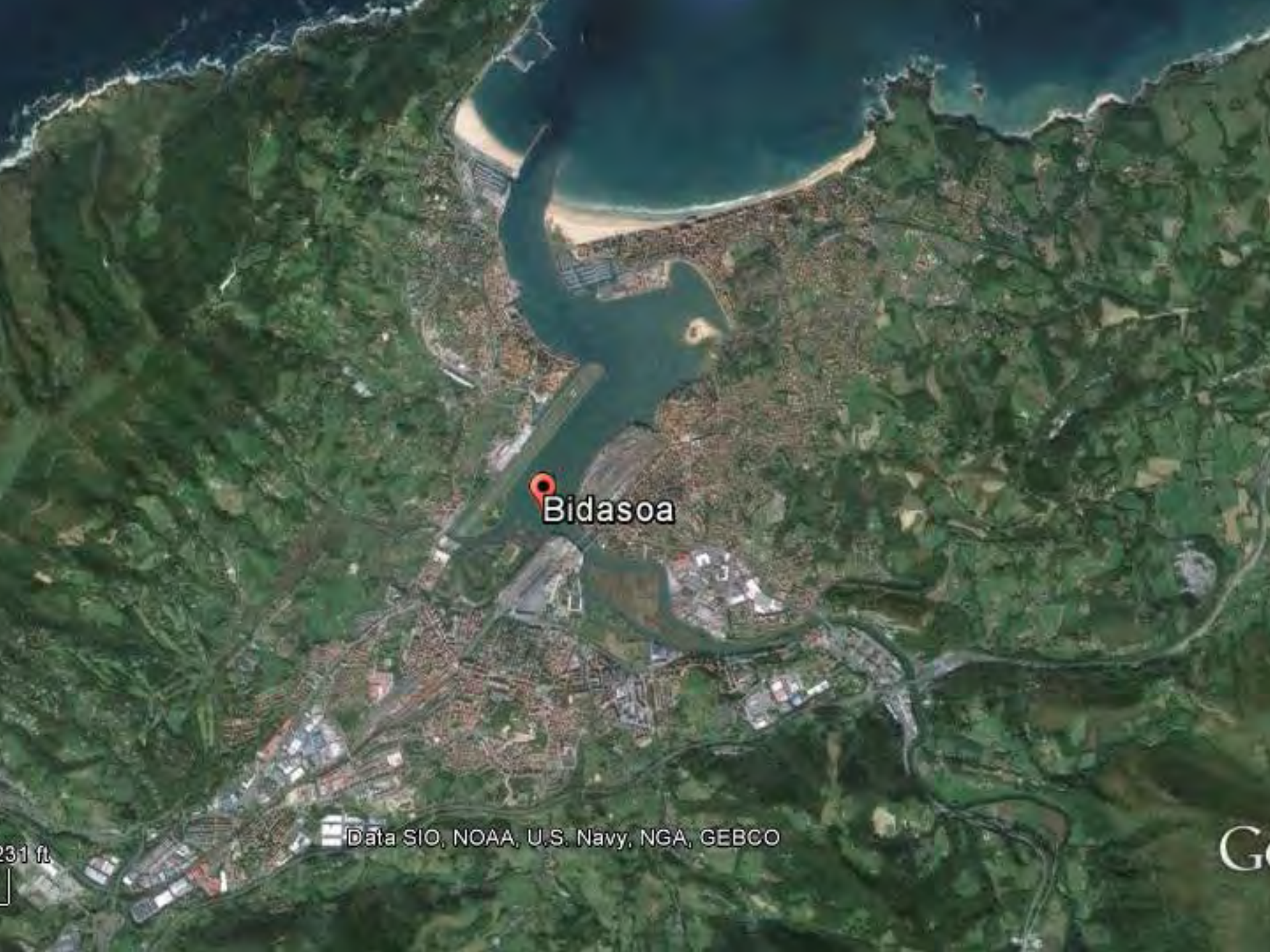
Total replacement (Turnover)

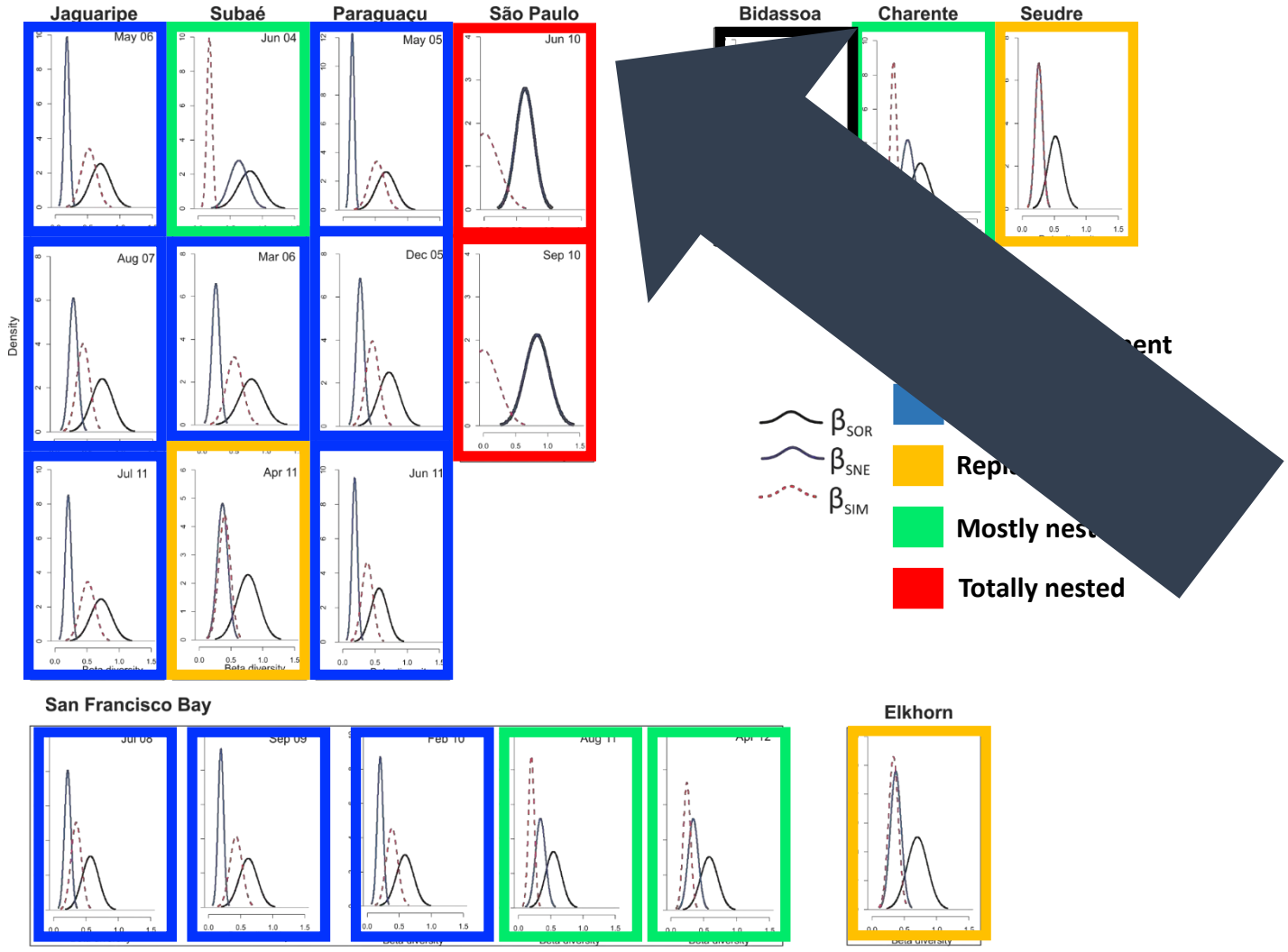


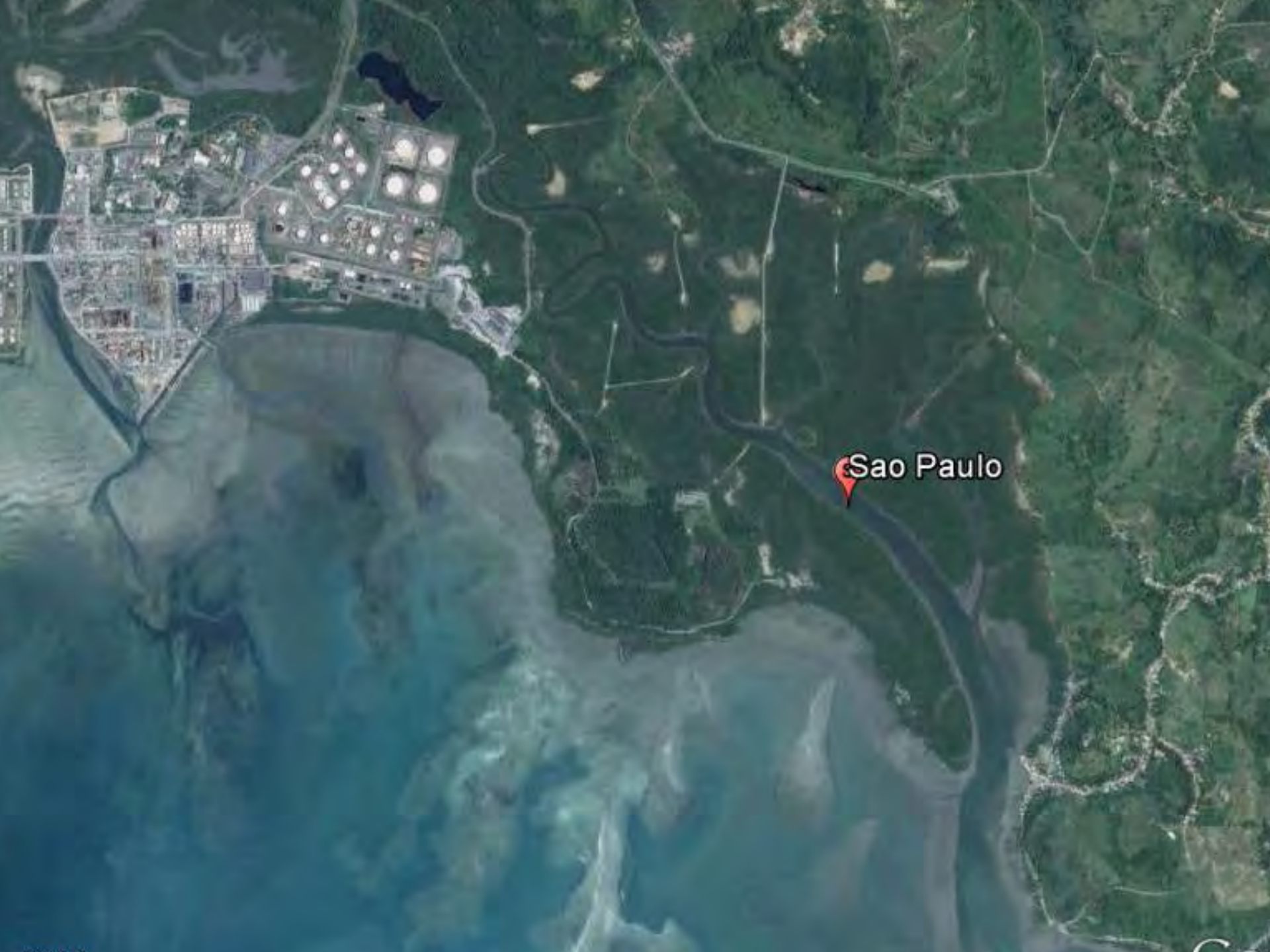

Jaguaripe
Subaé
Paraguaçu
São Paulo
Bidassoa
Charente
Seudre
May 06
Jun 04
May 05
Jun 10
Aug 07
Mar 06
Dec 05
Sep 10
Jul 11
Apr 11
Jun 11
Density
Beta diversity
β_{SOR}
β_{SNE}
β_{SIM}
San Francisco Bay
Jul 08
Sep 09
Feb 10
Aug 11
Apr 12
Elkhorn

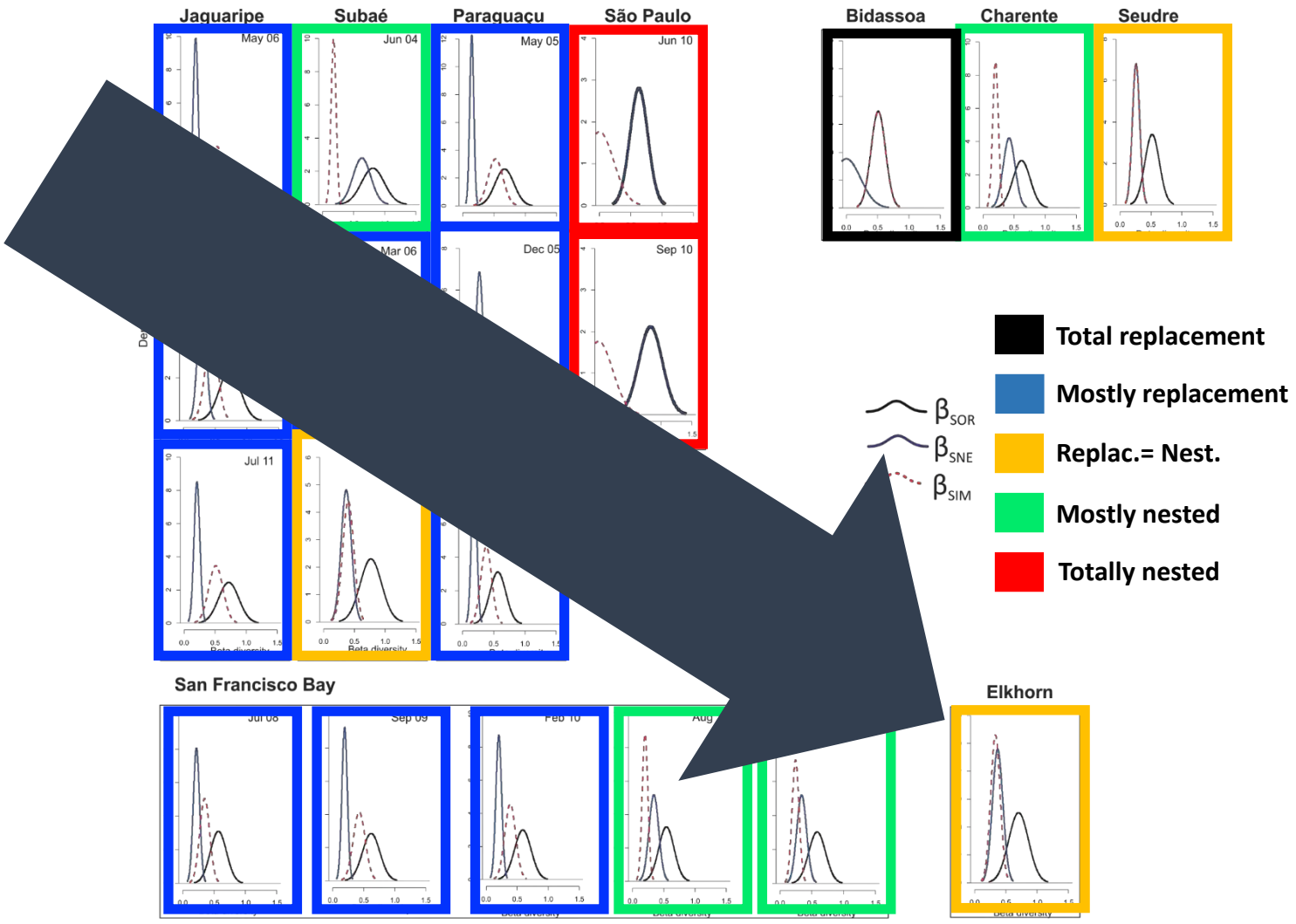

Jaquaripe
Subaé
Paraguaçu
São Paulo
May 06
Jun 04
May 05
Jun 10
Aug 07
Mar 06
Dec 05
Sep 10
Jul 11
Apr 11
Jun 11
Density
Bidassoa
Charente
Seudre
β_{SOR}
β_{SNE}
β_{SIM}
Total replacement
Mostly replacement
Replac.= Nest.
Mostly nested
Totally nested
San Francisco Bay
Elkhorn


Jaquaripe
Subaé
Paraguaçu
São Paulo
Bidassoa
Charente
Seudre
May 06
Jun 04
May 05
Jun 10
Aug 07
Mar 06
Dec 05
Jun 11
Density
Total replacement
Mostly replacement
Replac.= Nest.
Mostly nested
Totally nested
β_{SOR}
β_{SNE}
β_{SIM}
San Francisco Bay
Elkhorn

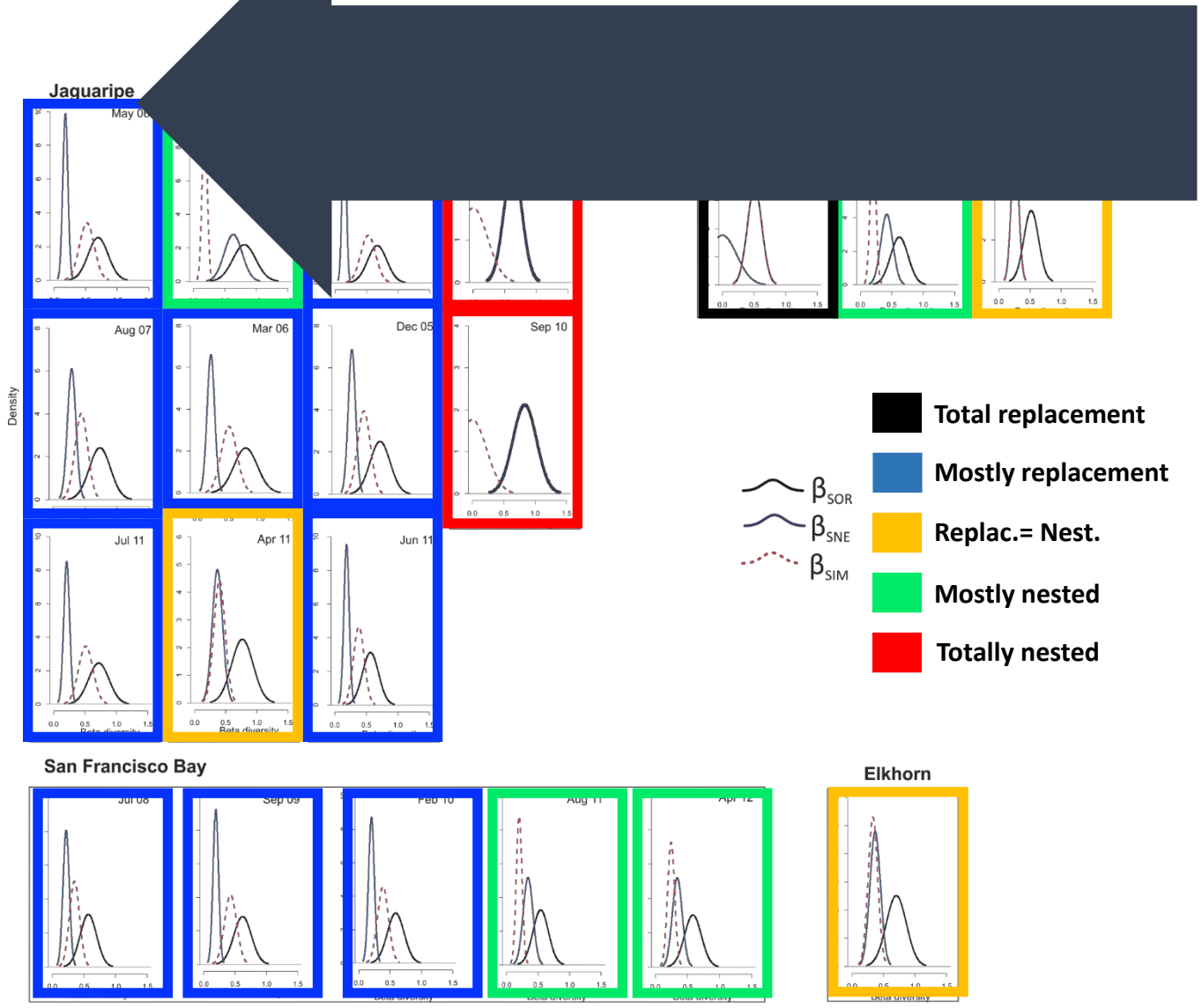

Bidasoa
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
231 ft

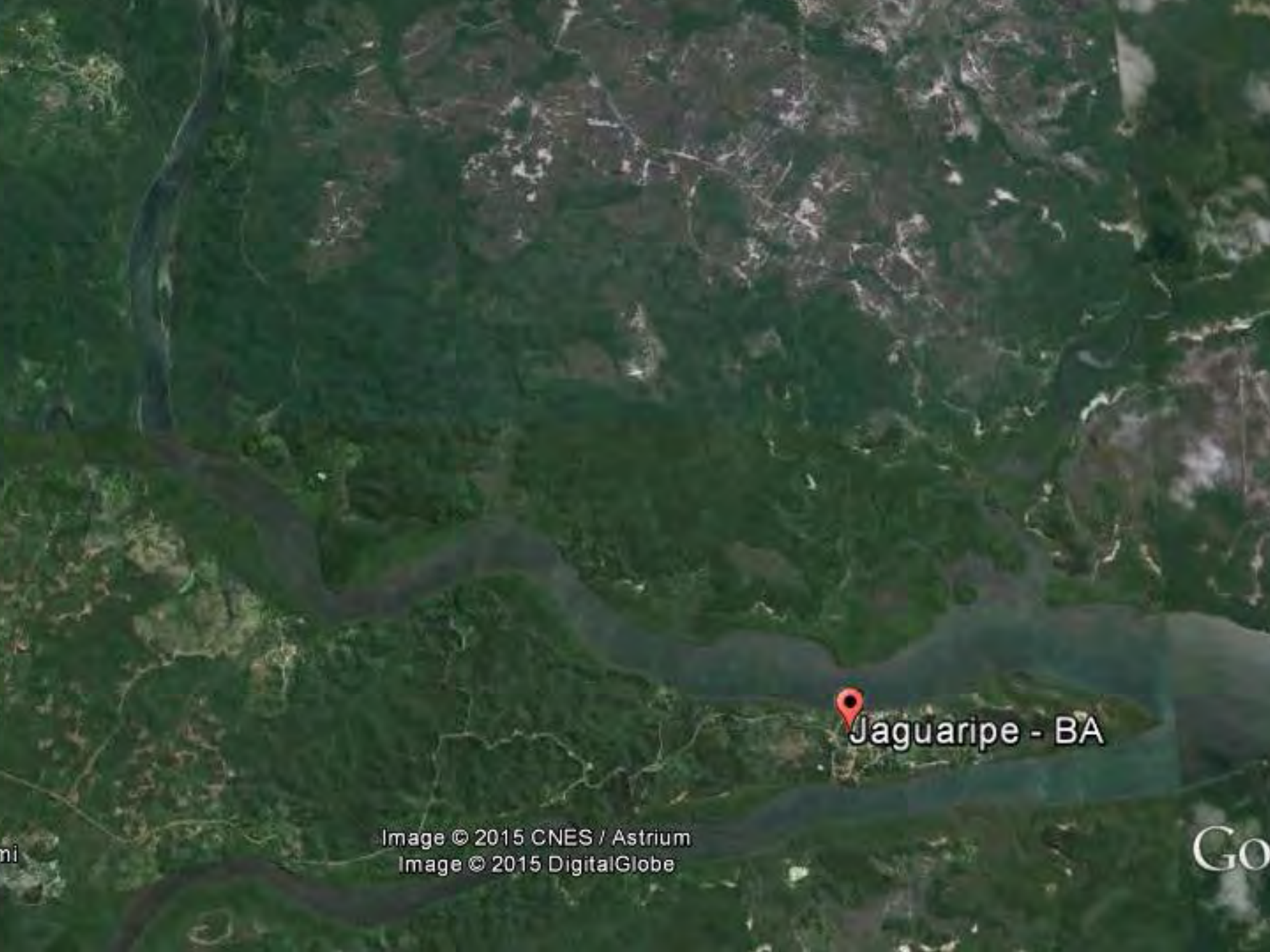

Jaquaripe
Subaé
Paraguaçu
São Paulo
Bidassoa
Charente
Seudre
May 06
Jun 04
May 05
Jun 10
Aug 07
Mar 06
Dec 05
Sep 10
Jul 11
Apr 11
Jun 11
Density
Beta diversity
β_{SOR}
β_{SNE}
β_{SIM}
Totally nested
San Francisco Bay
Elkhorn


Sao Paulo


Jaguaripe
Subaé
Paraguaçu
São Paulo
May 06
Jun 04
May 05
Jun 10
Mar 06
Dec 05
Sep 10
Jul 11
Bidassoa
Charente
Seudre
San Francisco Bay
Elkhorn
β_{SOR}
β_{SNE}
β_{SIM}
Total replacement
Mostly replacement
Replac.= Nest.
Mostly nested
Totally nested

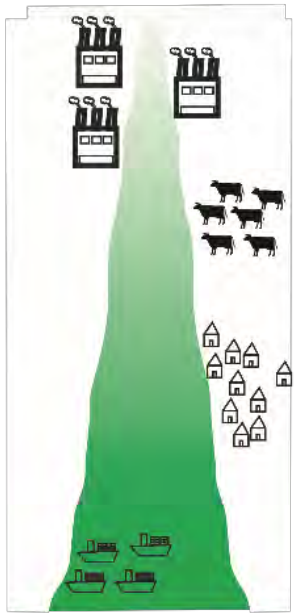

Elkhorn Slough
Data CSUMB SFML, CA OPC


Jaquaripe
Density
Aug 07
Mar 06
Dec 05
Sep 10
Jul 11
Apr 11
Jun 11
Total replacement
Mostly replacement
Replac.= Nest.
Mostly nested
Totally nested
β_{SOR}
β_{SNE}
β_{SIM}
San Francisco Bay
Elkhorn


Jaguaripe - BA
Image © 2015 CNES / Astrium
Image © 2015 DigitalGlobe

Highly impacted estuaries

Diverse localized impacts



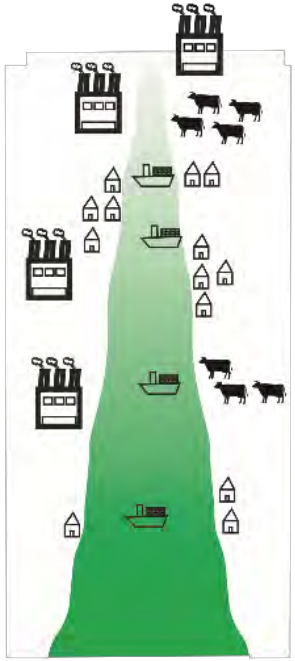
Total replacement

Pristine / low impacted estuaries

Mostly replacement

Highly impacted estuaries

General system impact



Total nestedness

Benthic macrofaunal assemblages do not show higher turnover than nestedness in tropical than in temperate estuarine systems

Preserved (less impacted) estuaries show greater turnover than nestedness

Climate changes:

Extreme events: increasing in rain/heavy drought

Habitat compression and/or habitat shifting

Changes in salinity will likely shortening estuarine gradient (together with existing anthropogenic impacts) will push estuarine systems even far from their natural states

To understand the effects of climate changes on estuaries we need to:

- Preserve entire estuarine systems

- Monitoring programs at preserved and not preserved estuaries around the globe

Obrigado

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