Estuarine connectivity: Assessing species vulnerability to global change

<u>Guillem Chust</u>[1]. Aitor Albaina[2]. Aizkorri Aranburu[1]. Ángel Borja[1]. Onno E. Diekmann[3]. Andone Estonba[2]. Javier Franco[1]. Joxe M. Garmendia[1]. Mikel Iriondo[2]. Fernando Rendo[2]. J. Germán Rodríguez[1]. Otsanda Ruiz-Larrañaga[2]. Iñigo Muxika[1] and Mireia Valle[1]

(1) AZTI-Tecnalia. Marine Research Division. Pasaia. Spain
(2) Laboratory of Genetics. University of the Basque Country (UPV/EHU). Leioa. Spain
(3) CCMAR-CIMAR. University of Algarve. Faro. Portugal

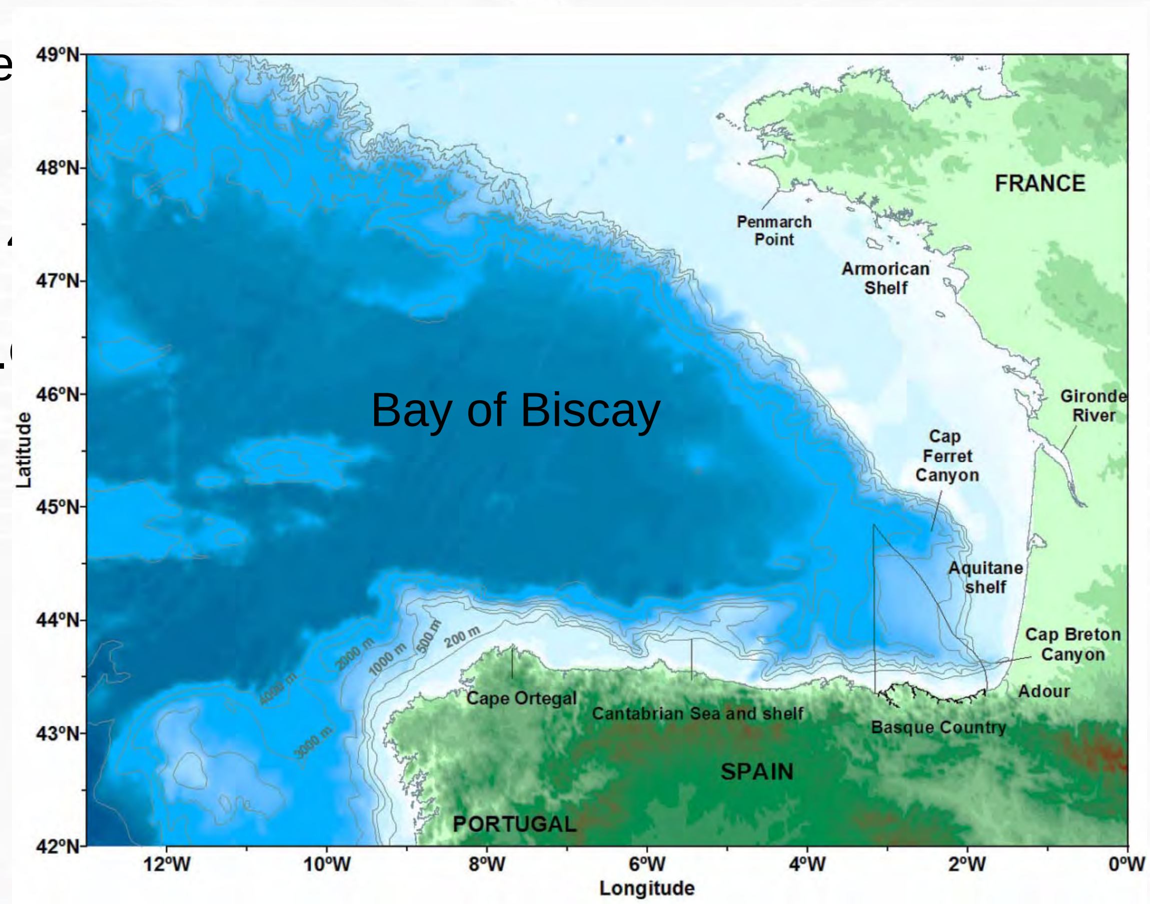
Index

1.Review of climate change in the Basque Country and Bay of Biscay

2.Objetives

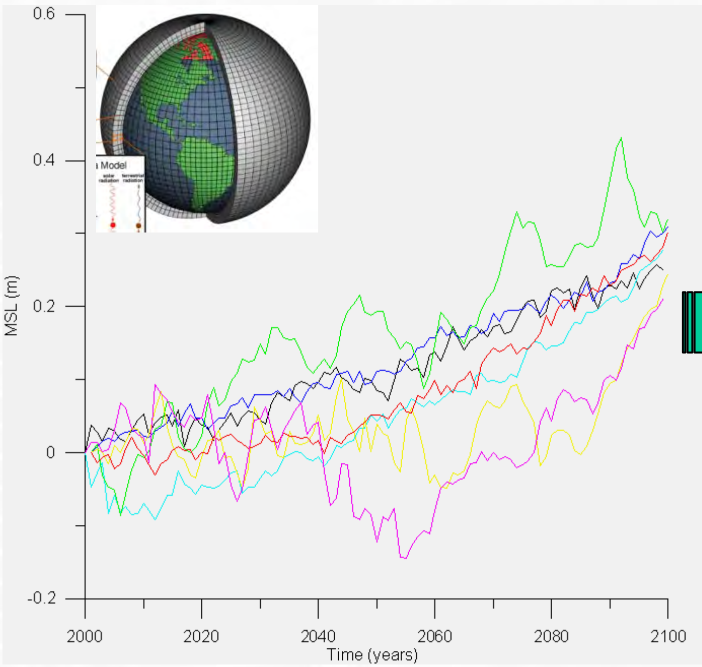
3.Ne

5.

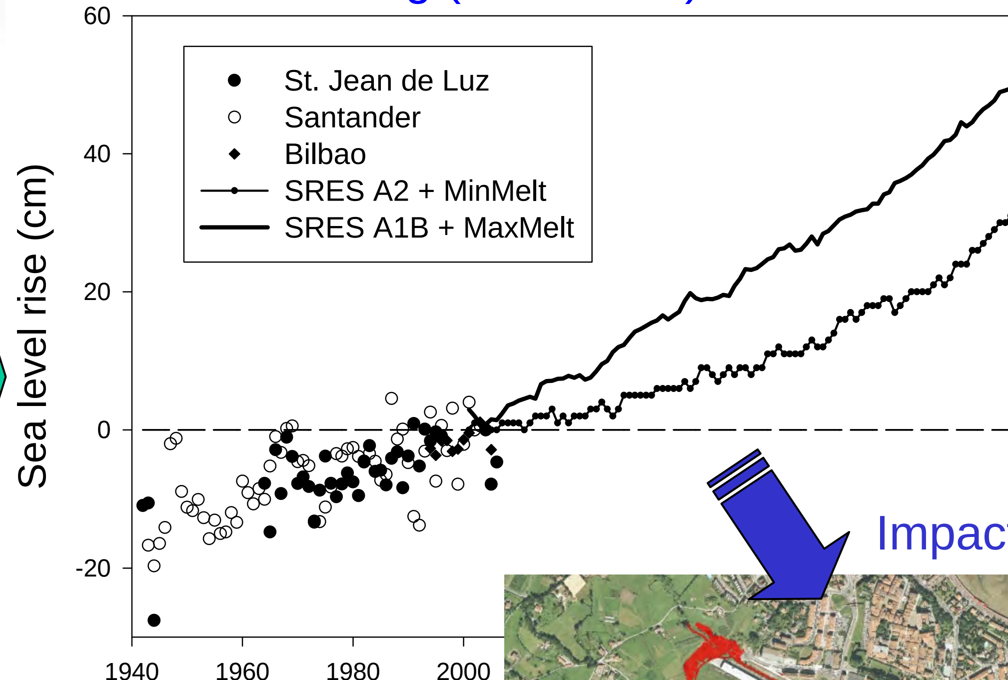


Climate change in the Basque Country

Model Projections from GCMs



+ ice melting (4 to 20 cm) => 29 to 49 cm



Impacts

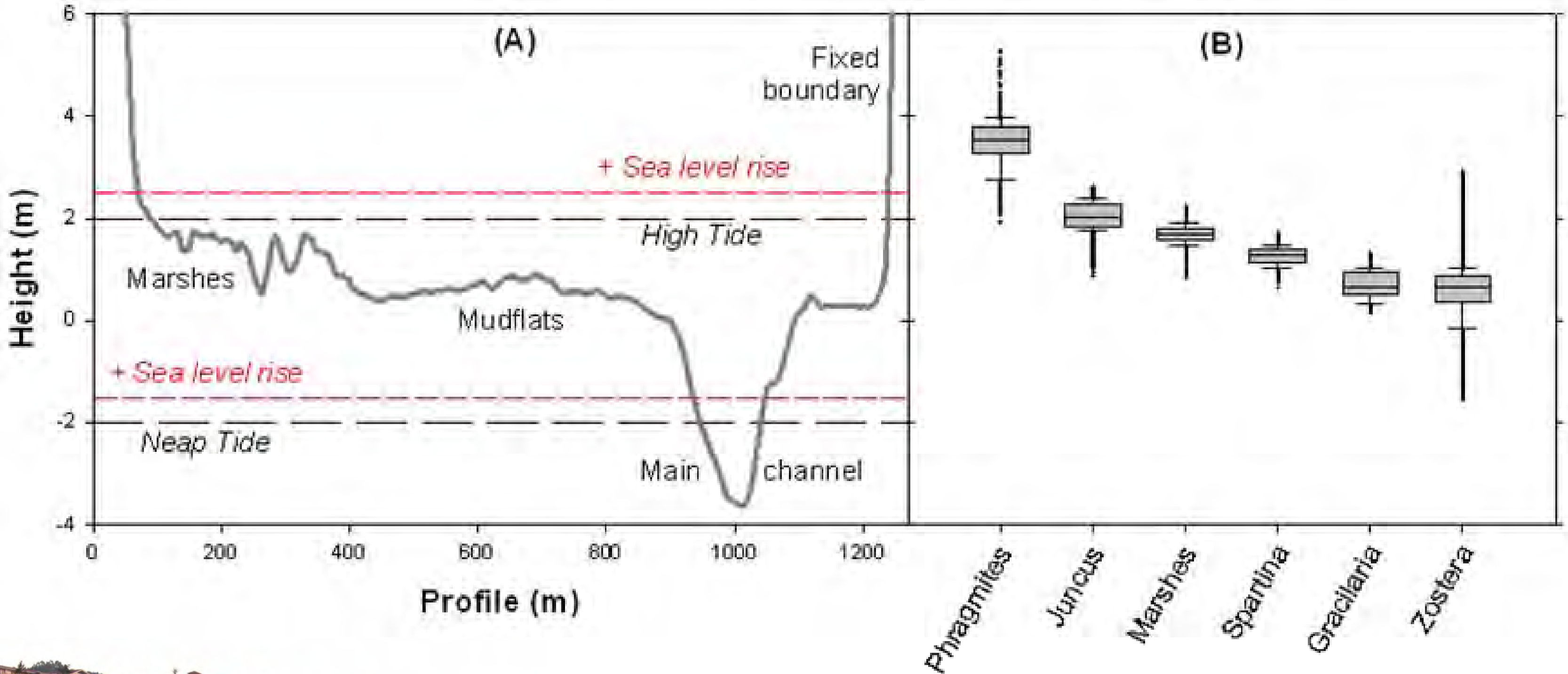
Chust et al. 2009. *Estuarine. Coastal and Shelf Science* 84:453-462.
Chust et al. 2010. *Estuarine. Coastal and Shelf Science* 87:113-124.

Climate change in the Basque Country expected by the end of the century

- Sea level rise: 29 to 49 cm
- Sea level extremes (50 yr return period): +62 cm above high tide
- Warming of surface air (especially heat wave episodes)
- Sea warming (1.5-2.0°C)
- Intensification of extreme daily rainfall of 10%

Chust et al. (2011) Climate Research (Review paper)
Liria et al. (2011) J. Coastal Research
Marcos et al. (2012) Climate Research

Climate change + urbanization + natural boundaries → "Coastal squeeze"



- One of the main adaptation strategies to global change scenarios aiming to preserve ecosystem functioning and biodiversity is to maximise ecosystem **resilience**.

- The resilience is the system's ability to absorb rapid environmental change.

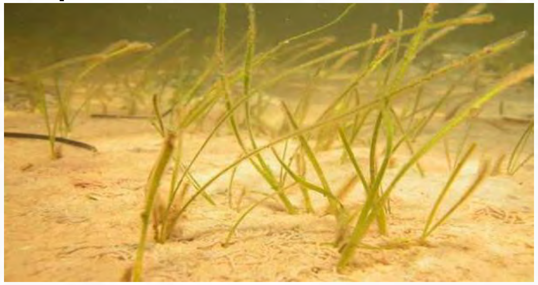
- The resilience of a species metapopulation can be improved by facilitating **connectivity** between local populations. which in turn. will prevent from demographic stochasticity and inbreeding.

Objectives

- To estimate the degree of connectivity among the structural estuarine species (plants. macroalgae. and macroinvertebrates) along the Basque coast (south-eastern Bay of Biscay). in order to assess community vulnerability in the face of downscaled global change scenarios.

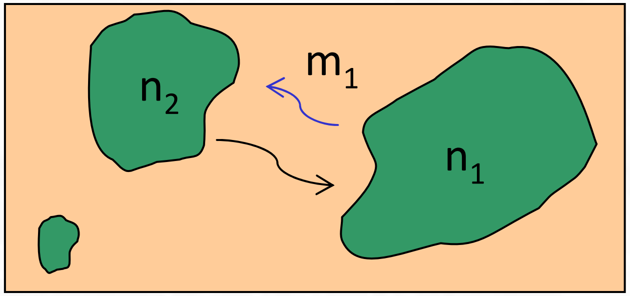
- Approach: two proxies of connectivity have been used based on genetic and ecological drift processes :
  1. Molecular markers for the bivalve cockle (*Cerastoderma edule*) and seagrass *Zostera noltii,* based upon Isolation by Distance theory
  2. Slope of species similarity (i.e. inverse of β-diversity) with geographic distance in estuarine plants and macroinvertebrates, based upon Neutral biodiversity theory

Taxonomic groups and scale of analysis

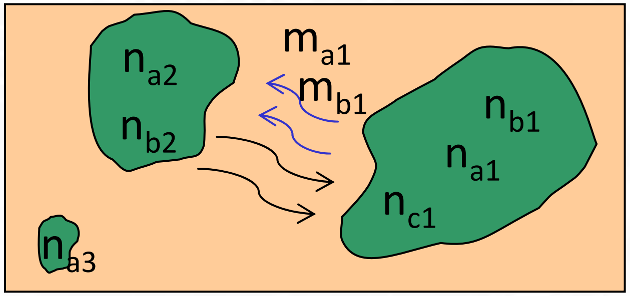
	Saltmarsh and seagrass plants	Macroinvertebrates
Community level	Community: 31 species 	Community: 321 species 
Species	Species: *Zostera noltei* 	Species: *C. edule* 

Connectivity in populations

A **metapopulation** is a group of spatially separated populations (n_1. n_2....) of the same species which interact (ie. migrate *m*) at some level



A **metacommunity** is a set of local communities (species 1. species 2....) that are linked by dispersal (migration) of multiple. potentially interacting species

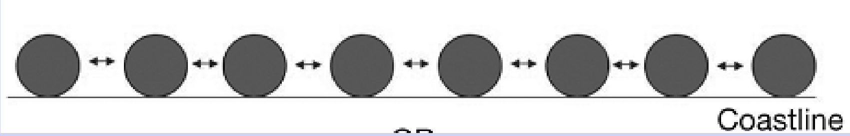


Proxies of connectivity and neutral theories

Species - Evolution

Natural selection / Adaptative process
(Darwin 1859)
versus
Neutral theory of molecular evolution
(Kimura 1983)

- "most of evolutionary changes at the molecular level is the result of randomly genetic drift acting on *neutral* alleles (not affecting fitness)"
- Isolation By Distance (IBD) theory suggests that pairwise genetic variation (e.g. Wright's fixations index F_{ST}) will increase with the geographic distance between the pair of populations under a 'stepping stone model' of dispersal: populations tend to exchange migrants (or propagules) with nearest neighbours along a coastline



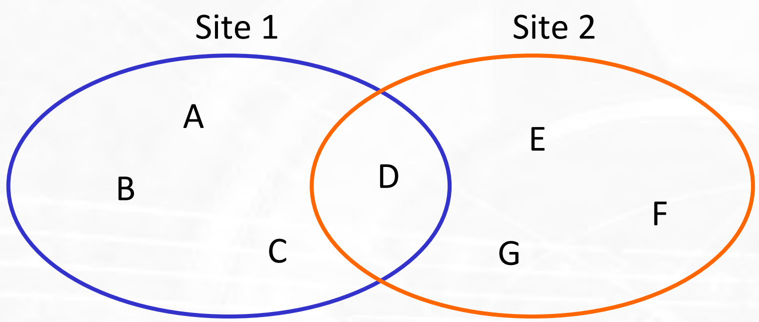
Communities - Ecology

Niche adaptive processes
(Hutchinson 1957)
versus
Neutral theory of biodiversity
(Hubbell 1997, 2001)

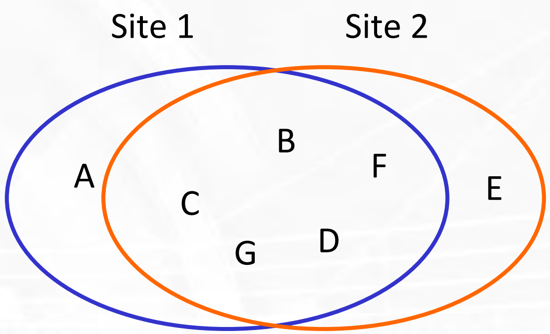
- *neutral*: all individuals are assumed to have the same prospects for reproduction and death
- "In an ecological community of trophically similar species (i.e. neutral), diversity arises at random, as each species follows a random walk"
- when migration rate is low (i.e. species are dispersal limited), species similarity declines with geographical distance (proxy of connectivity)

Dispersal-limited model

- Species composition fluctuates in a random. autocorrelated way.

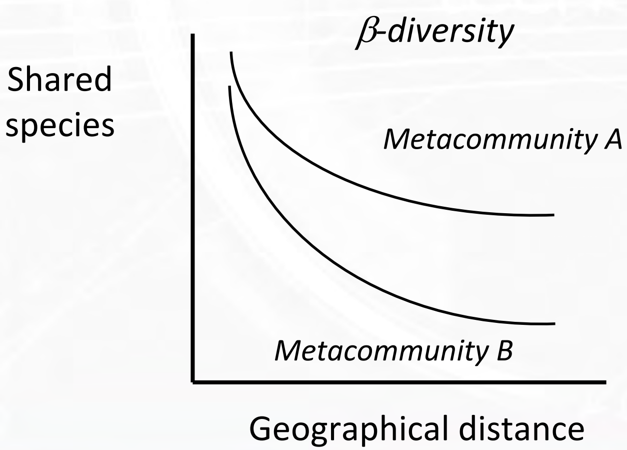


Similarity ↓ : *β-diversity* ↑



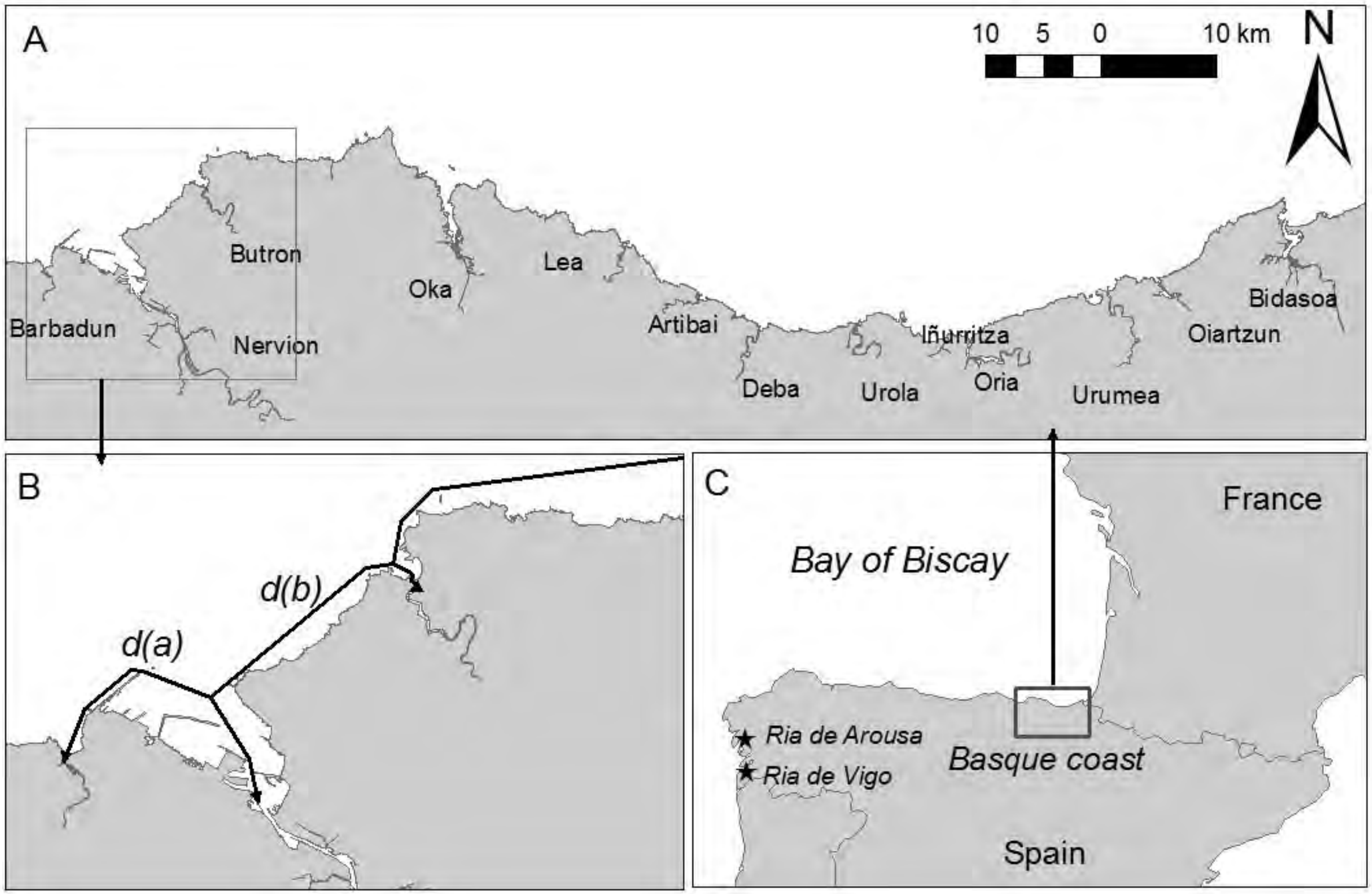
Similarity ↑: *β-diversity* ↓

Distance decay



Metacommunity: a set of local communities that are linked by dispersal of multiple. potentially interacting species

Study Area: Basque estuaries



Community level analysis (floristic and faunal β-diversity)

Biological data from estuarine communities

- 312 Macroinvertebrates (2002-2008) Network of water monitoring (Borja et al.. 2009)
- 31 Marsh and segrass plants collected in 2001 (Silván and Campos. 2002)

Macroinvertebrates

Dispersal mode	Nº of species	%
Planktonic	39	80
Benthic	3	6
No larval phase	2	4
Planktonic and/or Benthic	4	8
Reptant	1	2

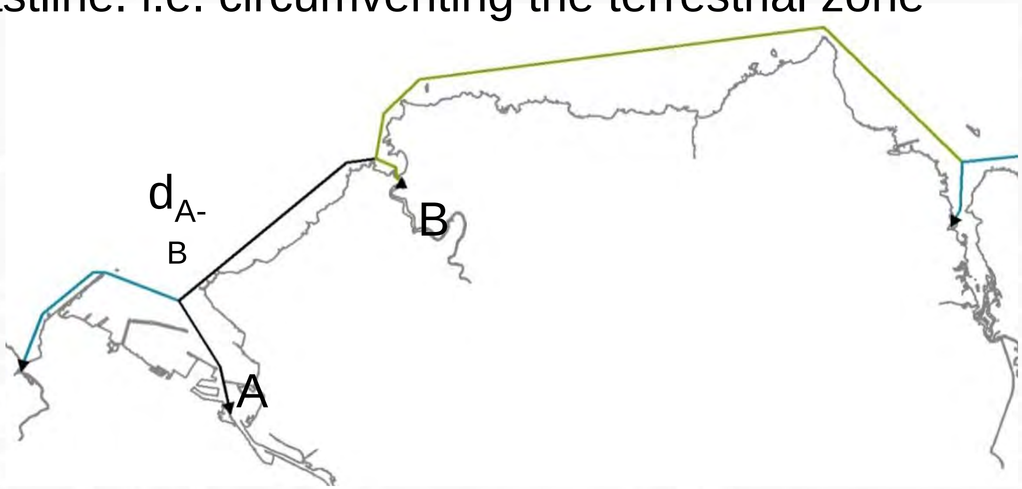
Marsh and segrass plants

Dispersal mode	Nº species	%
Water	13	42
Wind only	5	16
Animal only	4	13
Unassisted only	9	29

Pollination mode	Nº species	%
Water only	2	6
Wind only	20	65
Insect only	7	23
Multiple modes	2	6

Distance indices

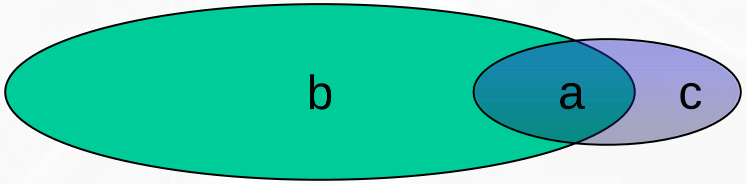
- Oceanographic distance: minimum path distance between two estuaries along the coastline. i.e. circumventing the terrestrial zone



- Pairwise community similarity (β_{sim}) which express the proportion of shared species with respect to the minimum number of species of the two sites (adapted for non-equal sampling areas)

$$\beta_{sim} = 1 - \frac{a}{\min(b,c) + a}$$

(Lennon et al. 2001. J Animal Ecology 70:966-979)



Species Matrix

$$S = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & \cdots & . & . \\ \vdots & . & . & . \\ x_{m1} & . & . & x_{mn} \end{pmatrix}$$

(β_{sim}, …)

β-diversity

$$S_{sim} = \begin{pmatrix} 1 & s_{12} & s_{13} & s_{14} & s_{15} \\ . & 1 & s_{23} & s_{24} & s_{25} \\ . & . & 1 & s_{34} & s_{35} \\ . & . & . & 1 & s_{45} \\ . & . & . & . & 1 \end{pmatrix}$$

Similarity Coefficient / Distance

Mantel Test

$$d_{xy} = \begin{pmatrix} x_1 & y_1 \\ x_2 & \cdots \\ . & \\ . & \\ x_m & y_m \end{pmatrix}$$

Euclidean

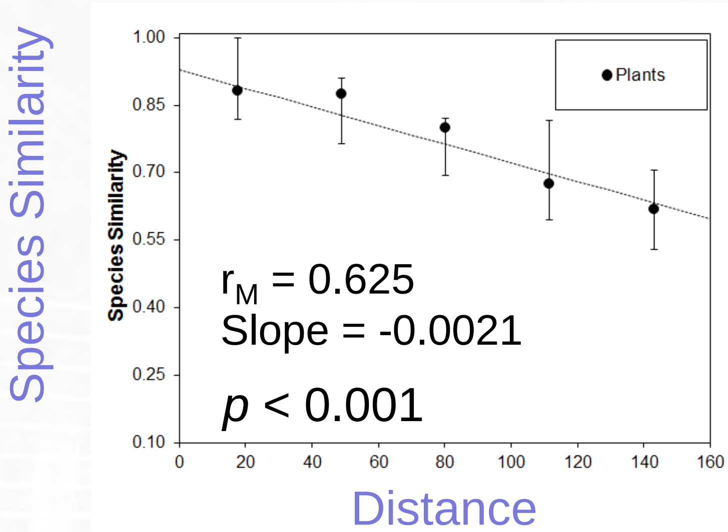
$$d = \begin{pmatrix} 0 & d_{12} & d_{13} & d_{14} & d_{15} \\ . & 0 & d_{23} & d_{24} & d_{25} \\ . & . & 0 & d_{34} & d_{35} \\ . & . & . & 0 & d_{45} \\ . & . & . & . & 0 \end{pmatrix}$$

Site location: x.y

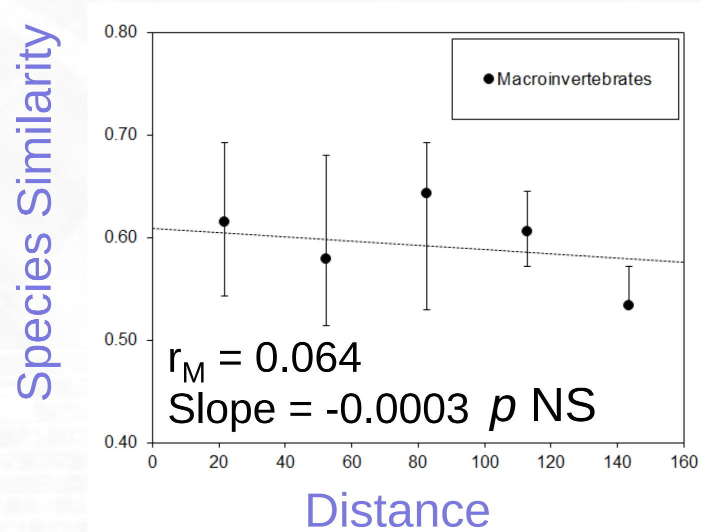
Geographic distance

Results (community level)

Saltmarsh and seagrass plants



Macroinvertebrates



Marsh plant communities differentiate by geographic distance ⇒ Dispersal limited ⇒ the capacity for ecological adaptation to new conditions is limited ⇒ vulnerable to CC

Interpretation (community level)

Marsh and segrass plants

Dispersal mode	Nº species	%
Water	13	42
Wind only	5	16
Animal only	4	13
Unassisted only	9	29

Pollination mode	Nº species	%
Water only	2	6
Wind only	20	65
Insect only	7	23
Multiple modes	2	6

Most of plant species (wind, animal or unassisted modes of seed dispersal, and pollinized by insects) might be constrained to spread in the steep and hilly configuration of the coast, with few salt-marshes restricted to inner parts of the estuaries.

Population level (genetic analysis)

Population genetic analysis

Species:

1. Seagrass *Zostera noltei*
2. Bivalve cockle *Cerastoderma edule*

Methods:

1. Sampling at estuaries
2. Genotyping:
   - 7 microsatellites for *Z. noltei*
   - 12 microsatellites for *C. edule*
3. Statistical analysis: Genetic diversity and divergence
4. Genetic metrics of dispersal
   - Isolation by distance. using Mantel correlation between genetic distance (F_{ST}) and geographic distance matrices
   - Bayesian clustering method implemented in the software STRUCTURE

Results (population genetic level)

Pairwise genetic variation (Wright's fixation index F_{ST})

Z. noltei

Estuaries	Vigo	Oka	Lea	Bidasoa
Vigo	-			
Oka	0.19	-		
Lea	0.26	0.12	-	
Bidasoa	0.33	0.32	0.32	-

- All F_{ST} were significant at $p<0.05$
- High differentiation
- r_M is not significant

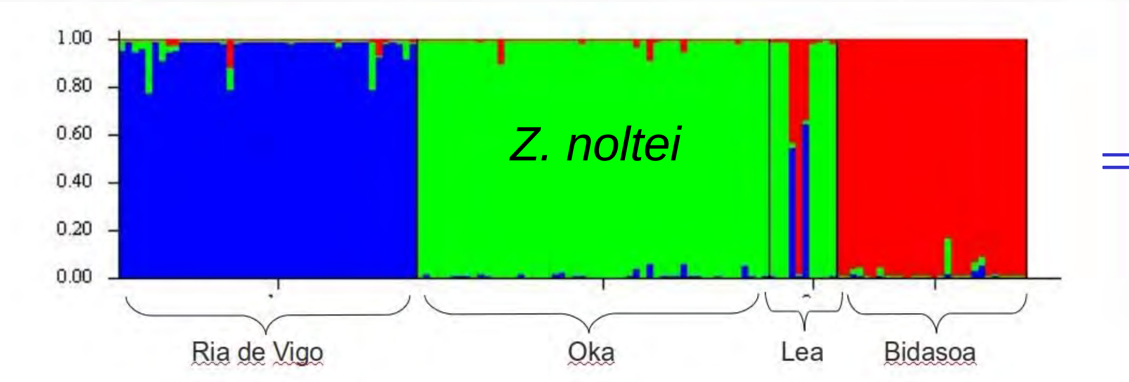
C. edule

	Bidasoa	Deba	Lea	Oka	Butron	Ria de Arousa
Bidasoa						
Deba	0.0043					
Lea	0.0017	0.0038				
Oka	-0.0008	0.0042	0.0013			
Butron	-0.0026	**0.0098**	0.0044	0.0065		
Ria de Arousa	0.0030	0.0031	0.0074	0.0048	**0.0060**	

- Low F_{ST} (majority are NS)
- lack of genetic structure
- panmictic population
- r_M is not significant

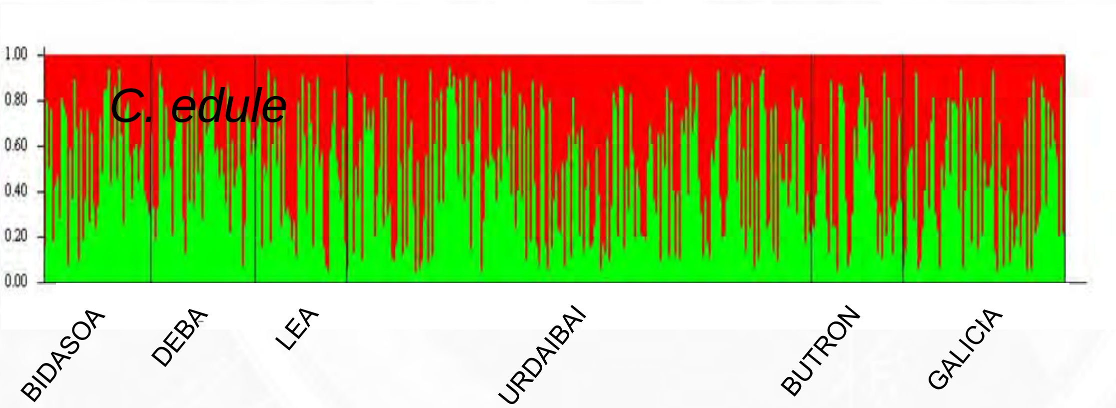
Results (population genetic level)

STRUCTURE analysis:



⇒

- 3 clusters
- Populations genetically fragmented



⇒

Genetically undifferentiated, indicating they own to a unique panmictic population

Conclusions

Saltmarsh and seagrass plants	Macroinvertebrates

Community level

Community: 31 species

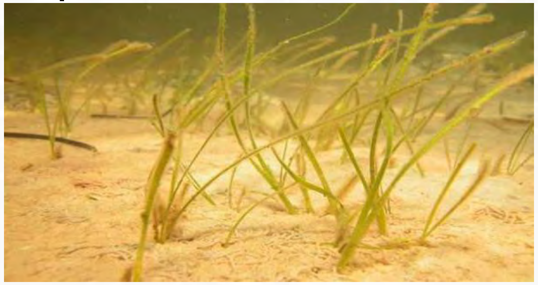
⇒ Dispersal limited

Community: 321 species

⇒ Dispersal Not limited

Species

Species: *Zostera noltei*



⇒ Dispersal limited

Species: *C. edule*

⇒ Dispersal Not limited

Vulnerable to Climate Change

Resilient to Climate Change

Conclusions

- Two proxies of connectivity at community and species levels, based on genetic and ecological neutral theories, respectively, provided similar results in estuarine biota.
- Our findings suggest that saltmarsh plants and seagrass beds of *Z. noltei* are especially vulnerable to expected changes because of their dispersal limitation reported at both community and genetic population levels, respectively.
- In contrast, unstructured spatial pattern found in macroinvertebrate communities and in *C. edule* genetic populations in the area suggests that estuarine soft-bottom macroinvertebrates with planktonic larval dispersal strategies may have a high resilience capacity to moderate changes within their habitats.
- Although salt-marsh and seagrass plants share a sedentary life history with soft-bottom macroinvertebrates and they inhabit in a similar environment, the latter disperse at larger scales and this is attributed to differences in biological dispersal modes between these two taxa.
- Our general approach and locally these specific findings can help environmental managers to prioritise the most vulnerable species and habitats to be restored.

Acknowledgements

- Basque Water Agency (URA). Basque Gouvernement. project « Inundabilidad de los estuarios vascos… »
- Basque Gouvernement (ETORTEK programme. *K-Egokitzen I & II projects*)
- Ministry of Science and Innovation of the Spanish Government (Project Ref.: CTM2011-29473)

Climate Change Documentary: www.vimeo.com/13292409

References

- Chust. G.. Á. Borja. P. Liria. I. Galparsoro. M. Marcos. A. Caballero. and R. Castro (2009). Human impacts overwhelm the effects of sea-level rise on Basque coastal habitats (N Spain) between 1954 and 2004. *Estuarine. Coastal and Shelf Science* 84:453-462.
- Chust. G.. A. Caballero. M. Marcos. P. Liria. C. Hernández. and Á. Borja. 2010. Regional scenarios of sea level rise and impacts on Basque (Bay of Biscay) coastal habitats. throughout the 21st century. *Estuarine. Coastal and Shelf Science* 87:113-124.
- Valle. M.. Á. Borja. G. Chust. I. Galparsoro. and J. M. Garmendia. Modelling suitable estuarine habitats for Zostera noltii. using Ecological Niche Factor Analysis and Bathymetric LiDAR. *Estuarine. Coastal and Shelf Science* 94:144-154
- Chust G. Borja A. Caballero A. Liria P. Marcos M. Moncho R. Irigoien X. Saenz J. Hidalgo J. Valle M. Valencia V. (2011) Climate Change impacts on the coastal and pelagic environments in the southeastern Bay of Biscay. *Climate Research* 48:307–332.
- Marcos. M.. Chust. G.. Jordà. G.. Caballero. A.. 2012. Effect of sea level extremes on the western Basque coast during the 21st century. *Climate Research*. 51. 237-248.
- Chust, G., A. Albaina, A. Aranburu, Á. Borja, O. E. Diekmann, A. Estonba, J. Franco, J. M. Garmendia, M. Iriondo, I. Muxika, F. Rendo, J. G. Rodríguez, O. Ruiz-Larrañaga, E. A. Serrão, M. Valle. Estuarine connectivity, neutral theories, and the assessment of species vulnerability to global change. (*Submitted to Marine Ecology Progress Series in March 2012*).

Thank you for your attention!