

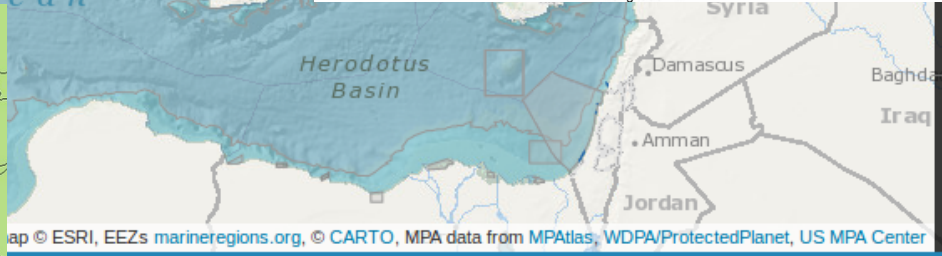
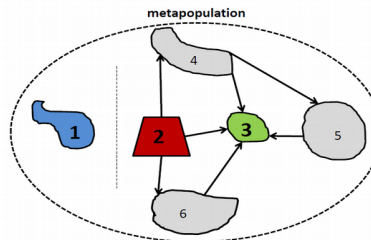
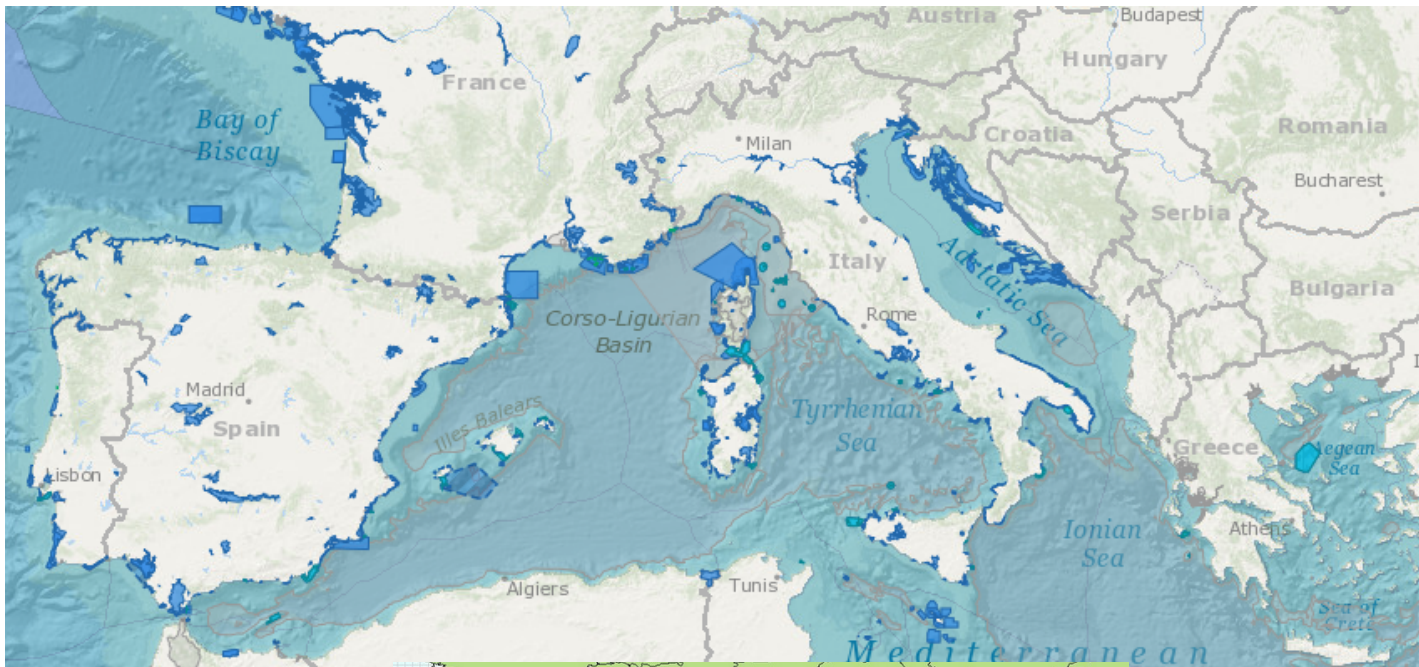
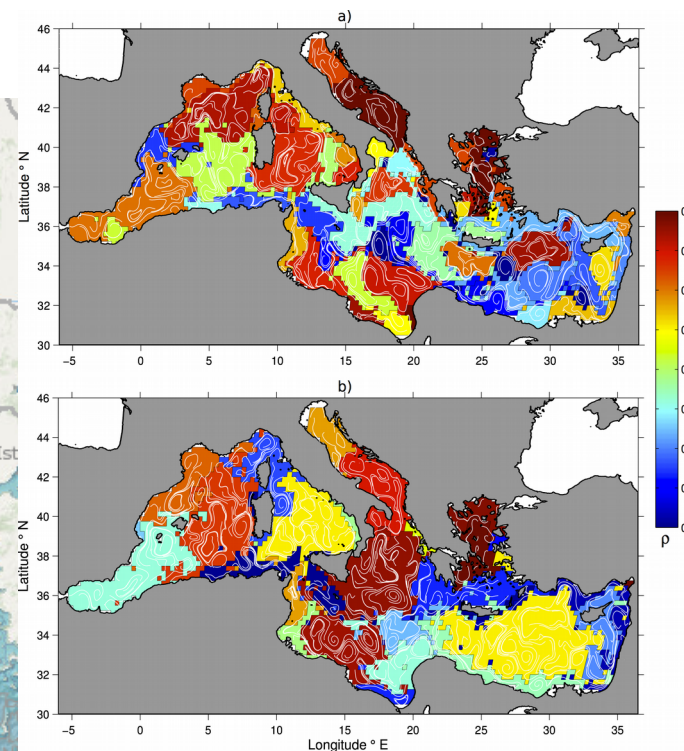


“Evolution des écosystèmes marins en mer Méditerranée: Service climatique pour la définition de réseaux d'aires marines protégées”

WP4 D4

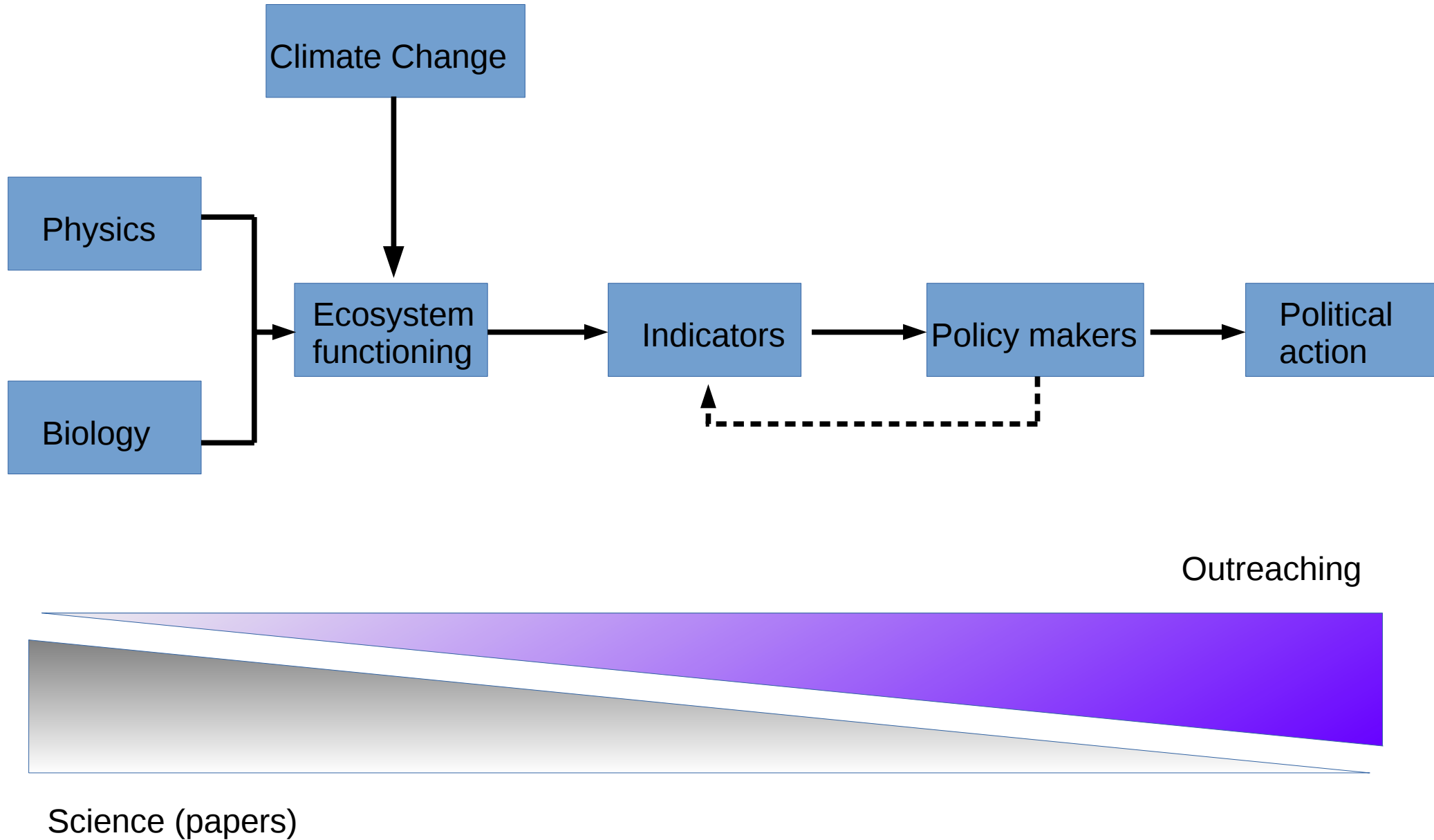


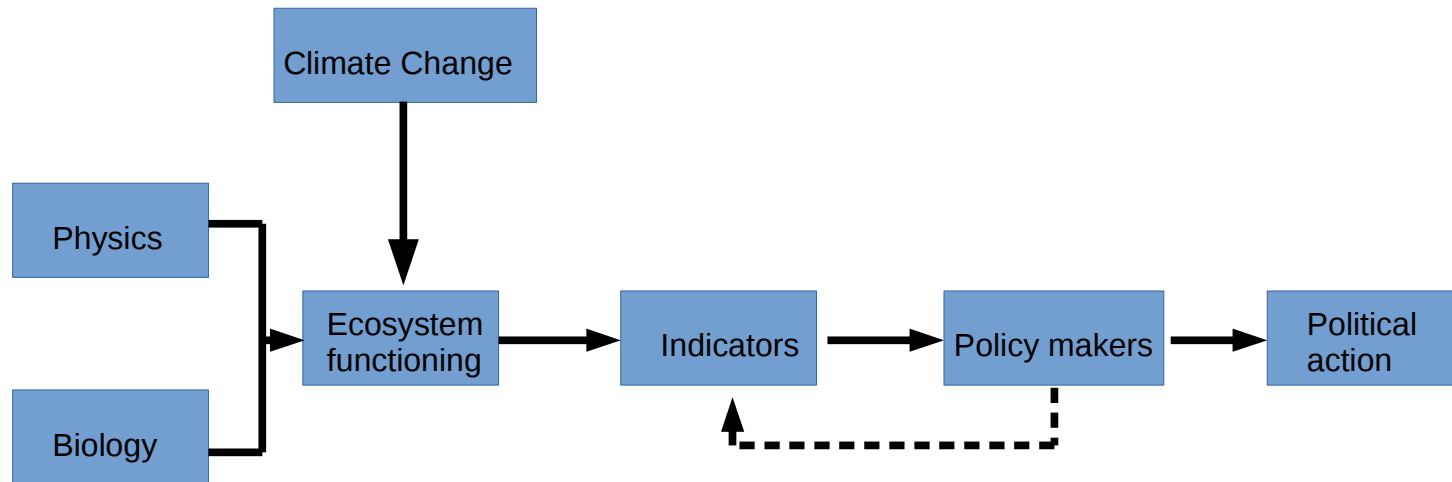
F. d'Ovidio, C. Cotté, L. Mortier, P. Testor (LOCEAN-IPSL), T. Arsouze (IPSL)
CoSC postdoc: E. Ser-Giacomi



Map © ESRI, EEZs marineregions.org, © CARTO, MPA data from MPAtlas, WDP/ProtectedPlanet, US MPA Center

“End-to-end” marine ecology at LOCEAN





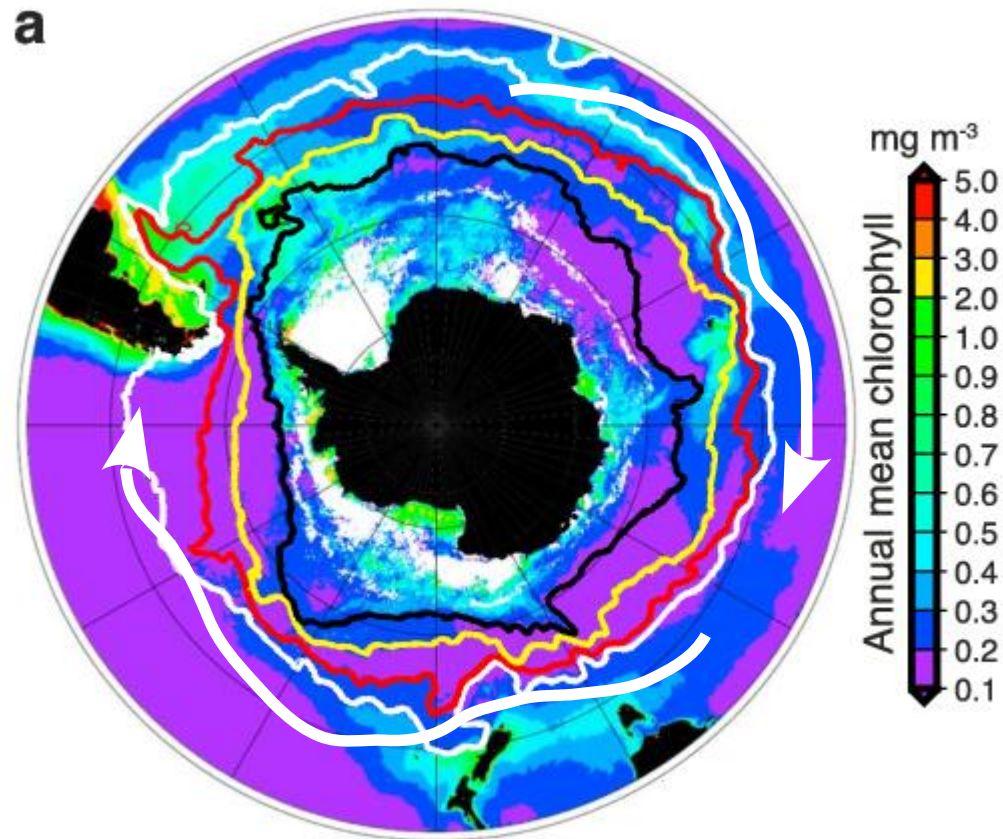
Outline

1. Our experience: Marine Protected Areas in the Southern Ocean (Outre-Mer)

2. WP4 (demonstrateur 4): “Evolution des écosystèmes marins en mer Méditerranée: Service climatique pour la définition de réseaux d’aires marines protégées” **Setup**

Biophysical context

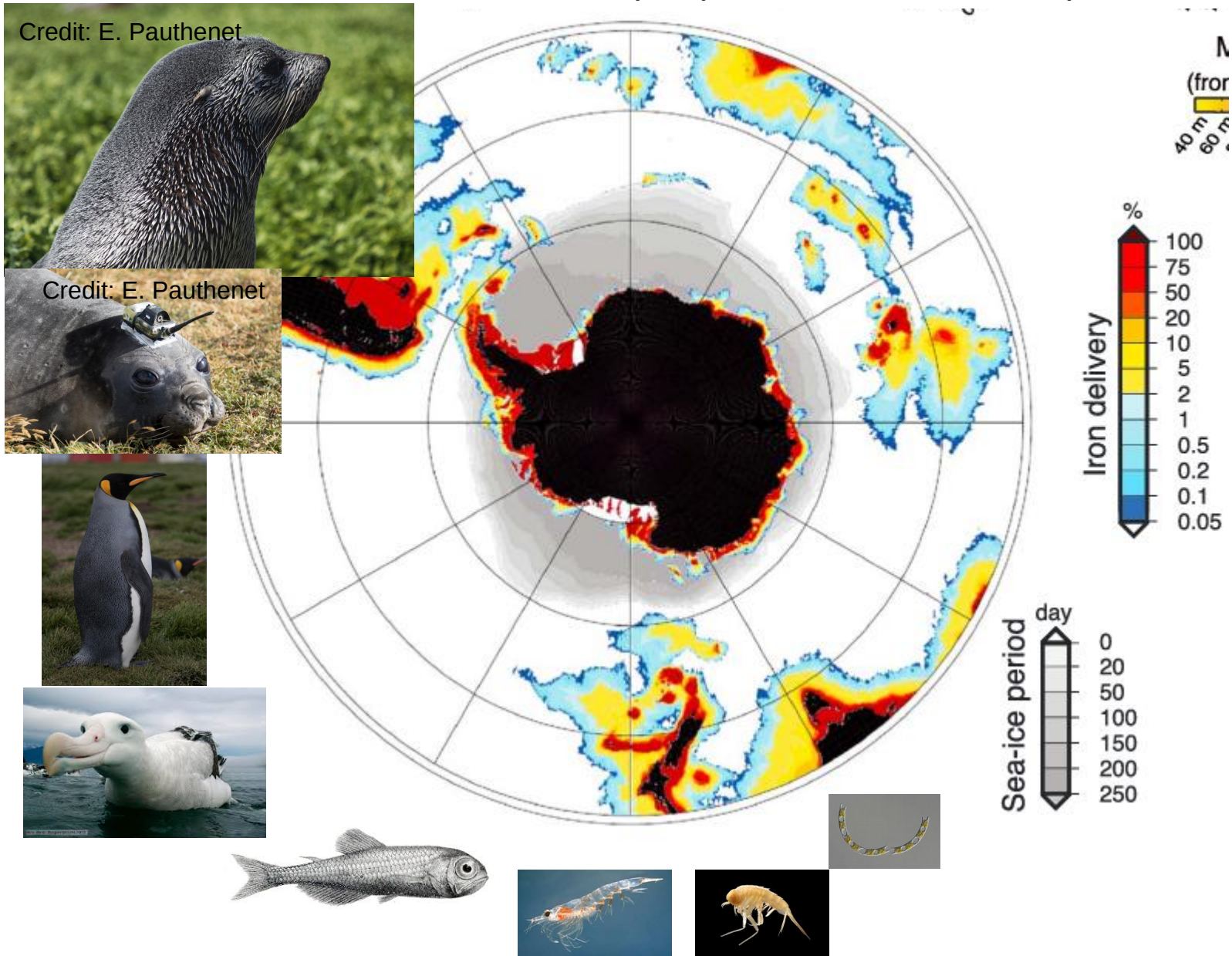
Plankton abundance (satellite-derived chlorophyll)



A desert with some bands of primary production structured by the Antarctic circumpolar current.

Biophysical context

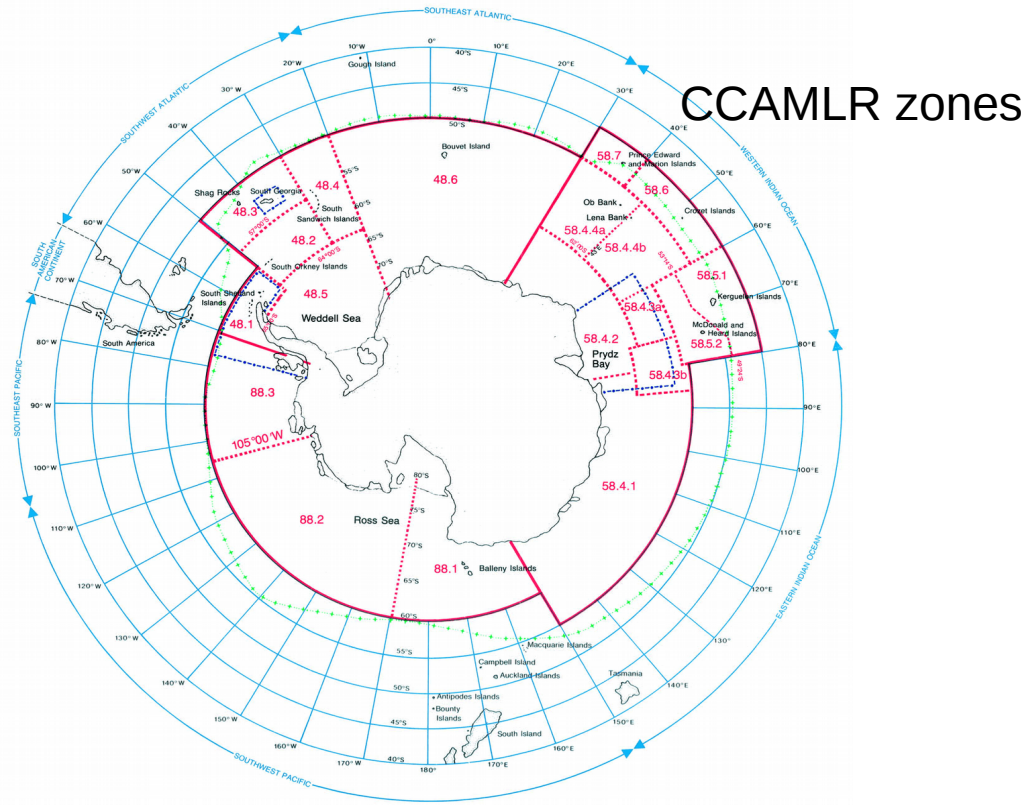
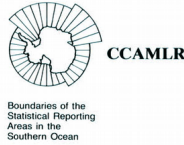
Nutrient abundance (iron) and some endemic species



The main limiting nutrient is iron, whose delivery sustains a rich trophic chain.

Ardyna et al. 2017
Top images: E. Pauthenet

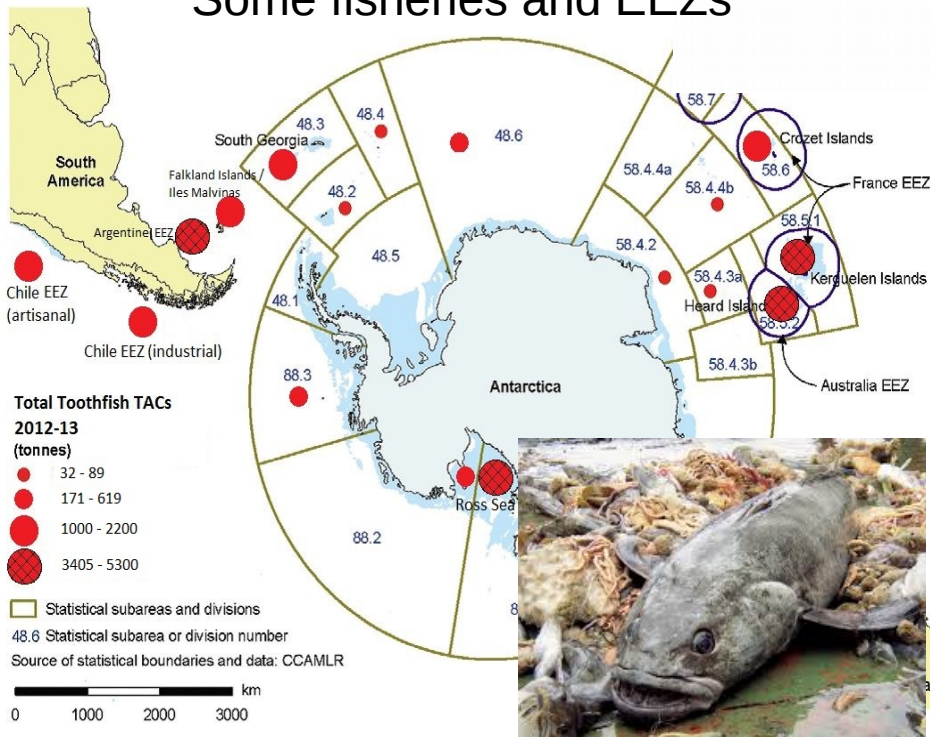
Resources and institutional context



LEGEND

- STATISTICAL AREA
ZONE STATISTIQUE
СТАТИСТИЧЕСКИЙ РАЙОН
AREA ESTADISTICA
- STATISTICAL SUBAREA
SOUS-ZONE STATISTIQUE
СТАТИСТИЧЕСКИЙ ПОДРАЙОН
SUBAREA ESTADISTICA
- ANTARCTIC CONVERGENCE
CONVERGENCE ANตาร์CTIQUE
АНТАРКТИЧЕСКАЯ КОНВЕРГЕНЦИЯ
CONVERGENCIA ANTARCTICA
- CONTINENT, ISLAND
CONTINENT, ILE
МАТЕРИК, ОСТРОВ
CONTINENTE, ISLA
- INTEGRATED STUDY REGION
ZONE D'ETUDE INTEGREE
РАЙОН КОМПЛЕКСНЫХ ИССЛЕДОВАНИЙ
REGION DE ESTUDIO INTEGRADO

Some fisheries and EEZs

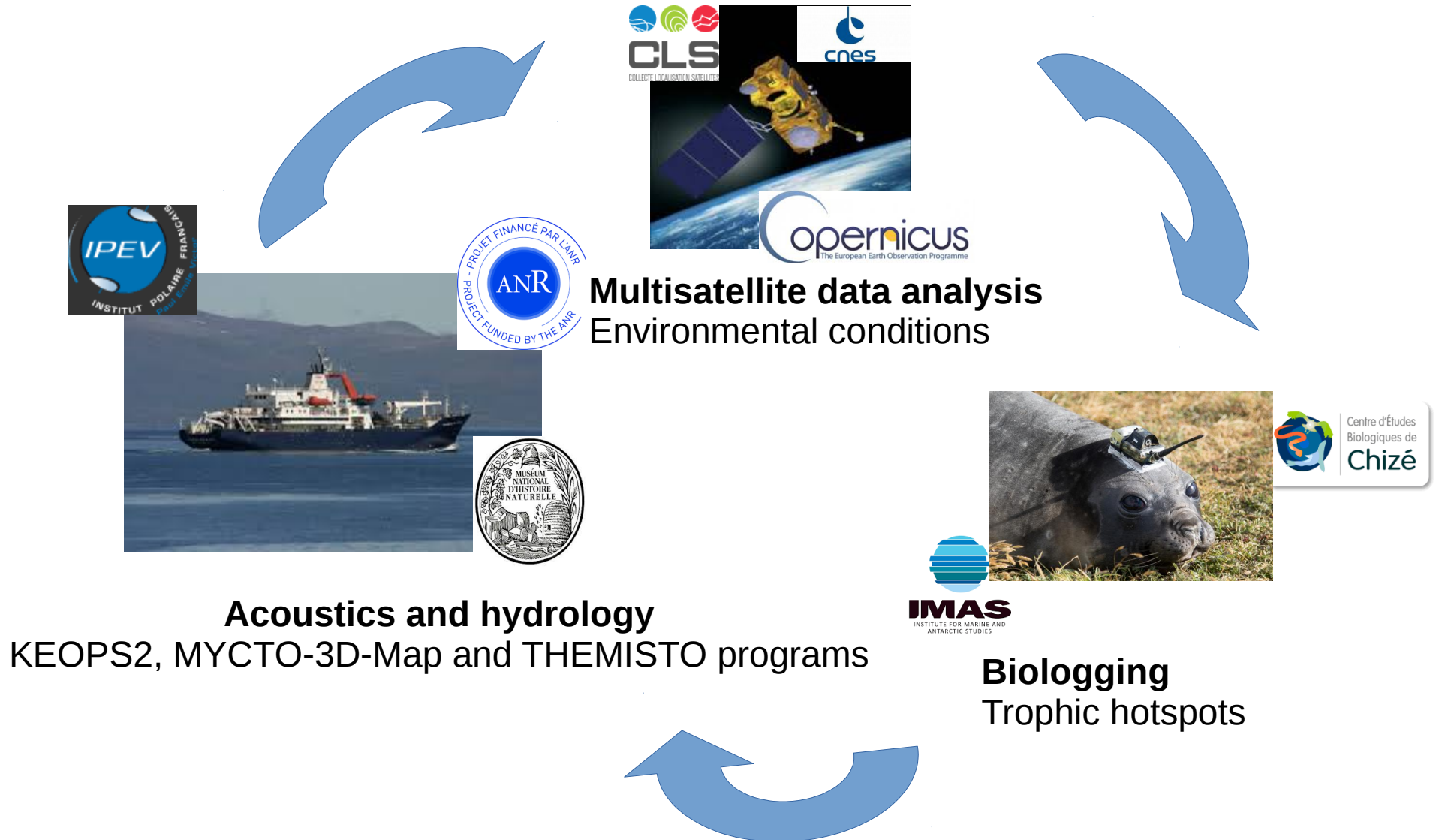


The Southern Ocean hosts important fisheries.

Resource exploitation is regulated by national authorities in the Economic Exclusive Zone and by an international convention in the high seas.

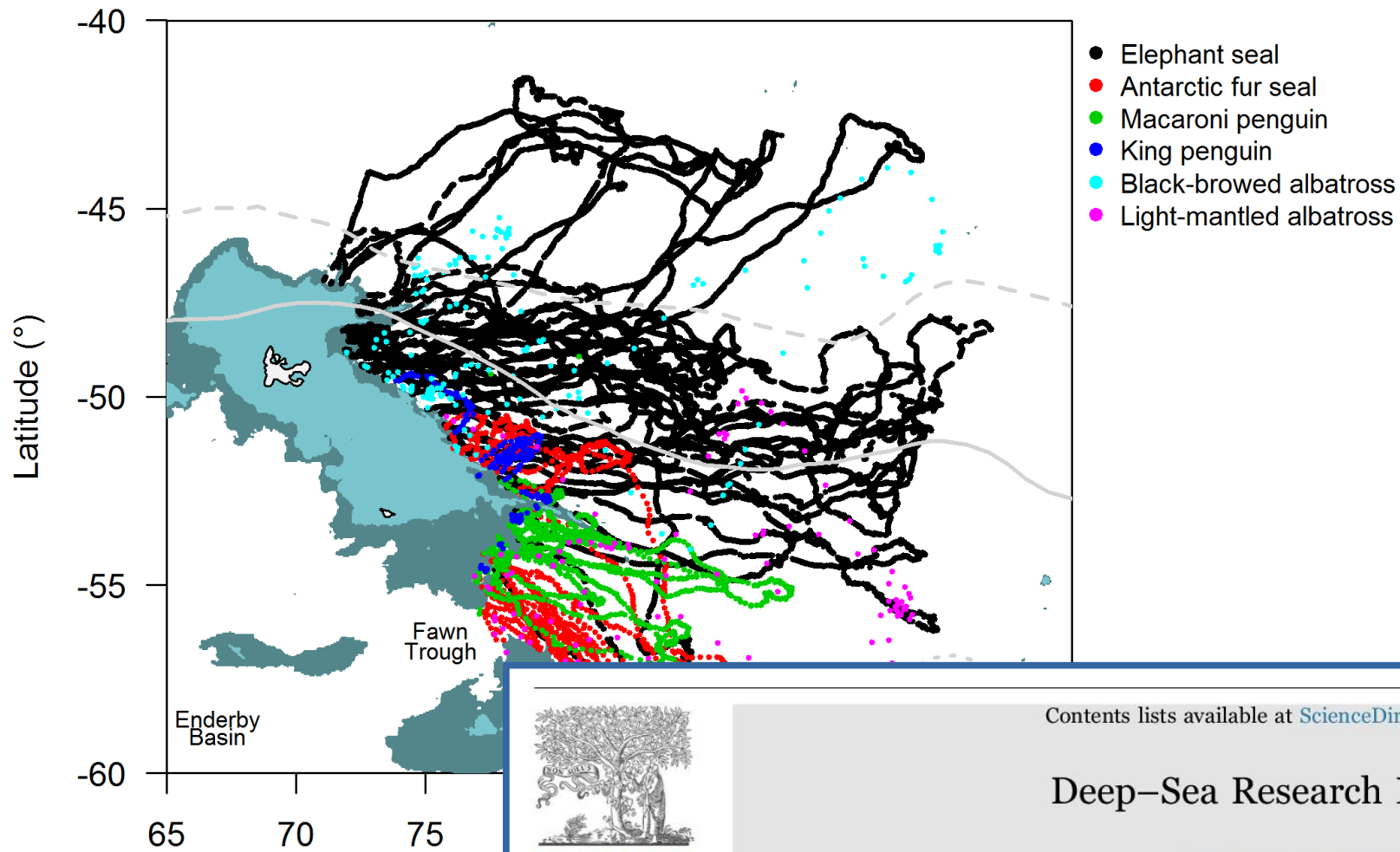
- French EEZ: Réserve Naturelle des Terres Australes et Antarctiques Françaises (**TAAF**)
- high seas: Commission for Conservation of Antarctic Marine Living Resources (**CCAMLR**)

Our multi-species study in the Kerguelen region: data and scientific partners



Ecosystem functioning is derived by integrating in situ, remote sensing, and biologging in collaboration with public and private partners.

From ecological functioning to conservation....



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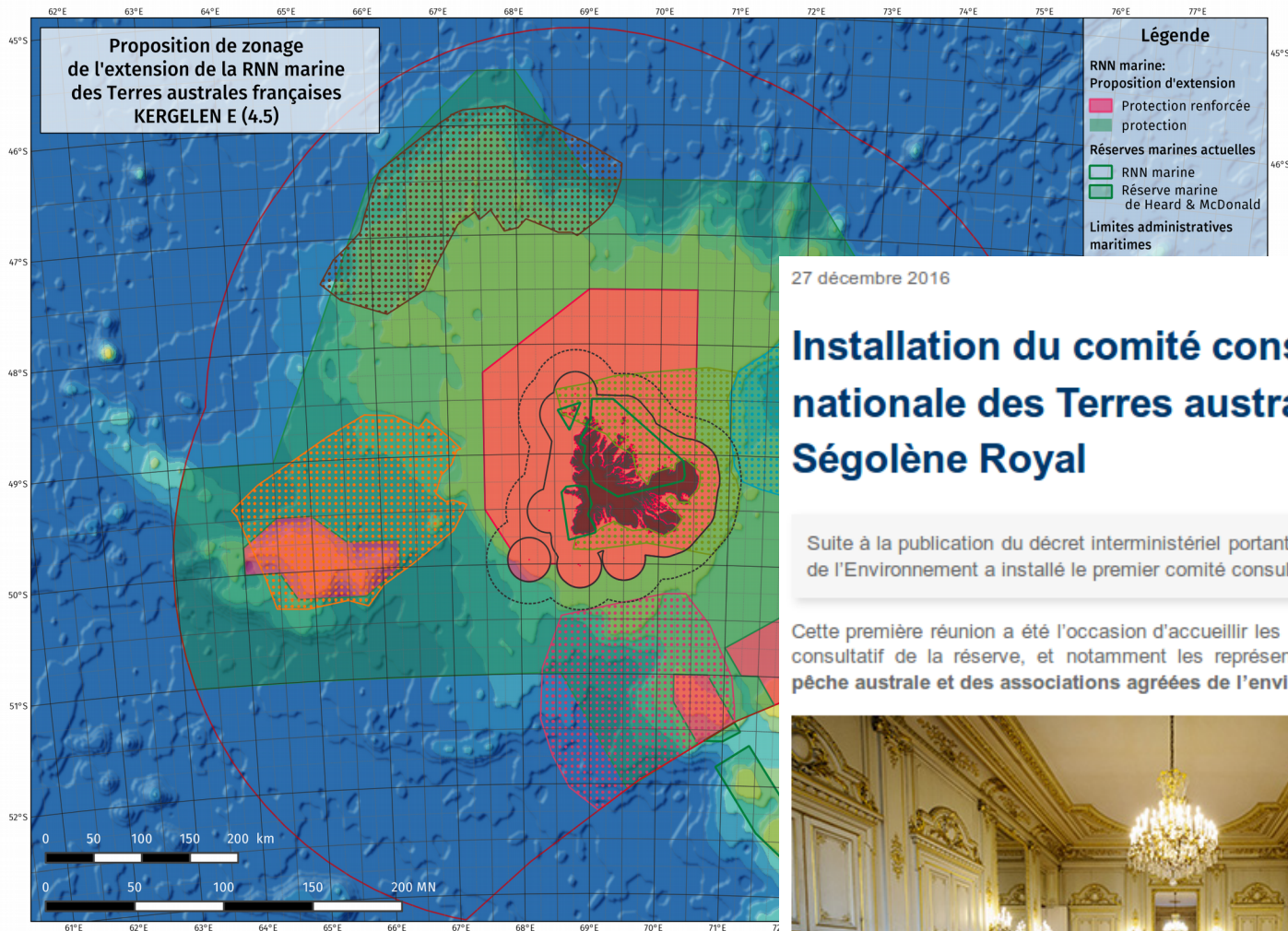
Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Lagrangian analysis of multi-satellite data in support of open ocean Marine Protected Area design

Alice Della Penna^{a,b,c,d,*}, Philippe Koubbi^f, Cedric Cotté^a, Cécile Bon^{a,b,c,d,e,f},
Charles-André Bost^{a,b,c,d,e,f}, Francesco d'Ovidio^a

... to decision makers



Installation du comité consultatif de la réserve naturelle nationale des Terres australes françaises par la Ministre Ségolène Royal

Suite à la publication du décret interministériel portant extension de la réserve naturelle des Terres australes, la Ministre de l'Environnement a installé le premier comité consultatif de la nouvelle réserve le 15 décembre dernier.

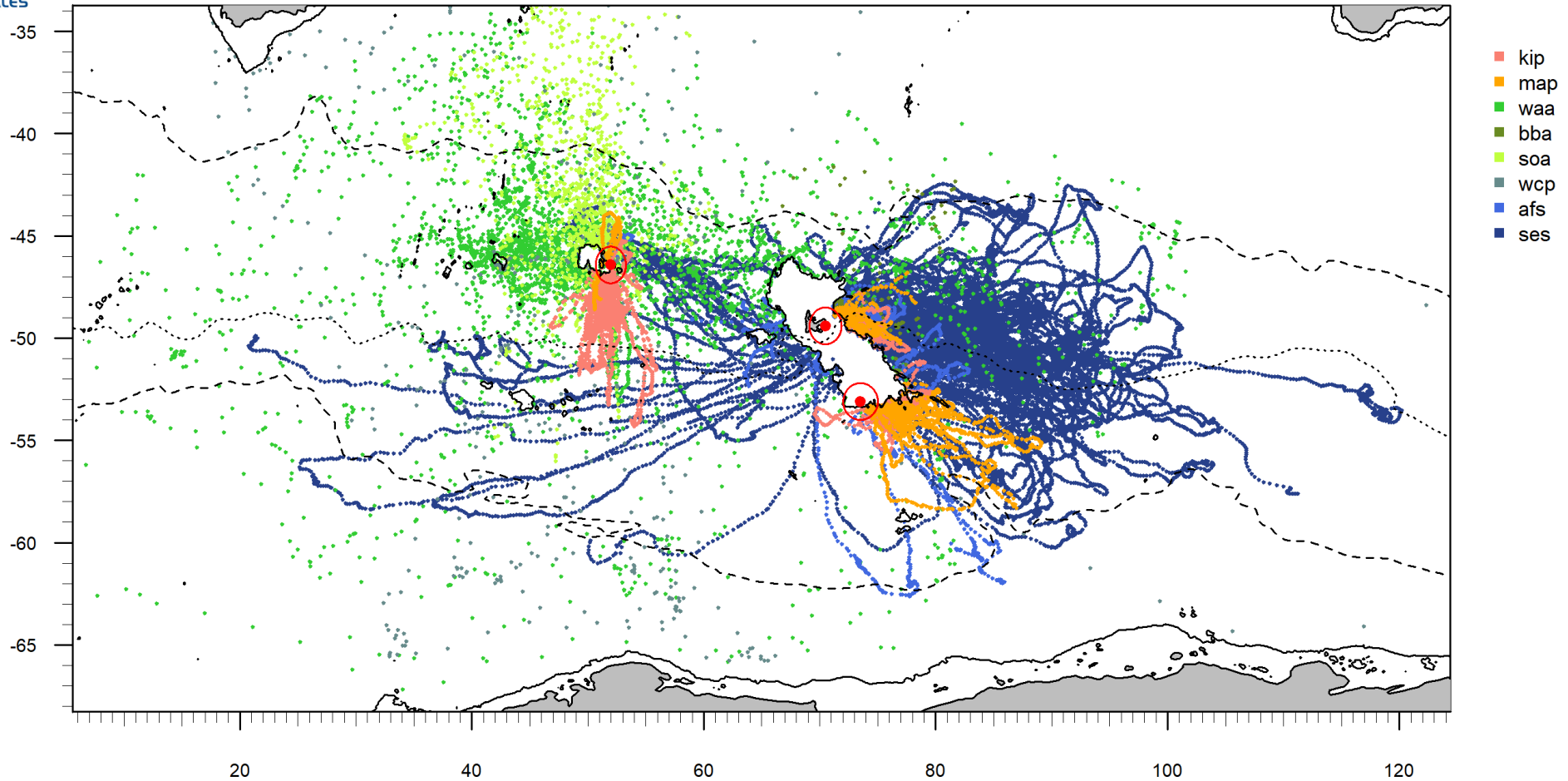
Cette première réunion a été l'occasion d'accueillir les nouveaux membres du comité consultatif de la réserve, et notamment les représentants des armements de la pêche australe et des associations agréées de l'environnement.



Our results are part of the report with the scientific basis used for extending the Kerguelen and Crozet natural reserves (acted on Dec. 15 2016; Work group leaders: C. Guinet, P. Koubbi).

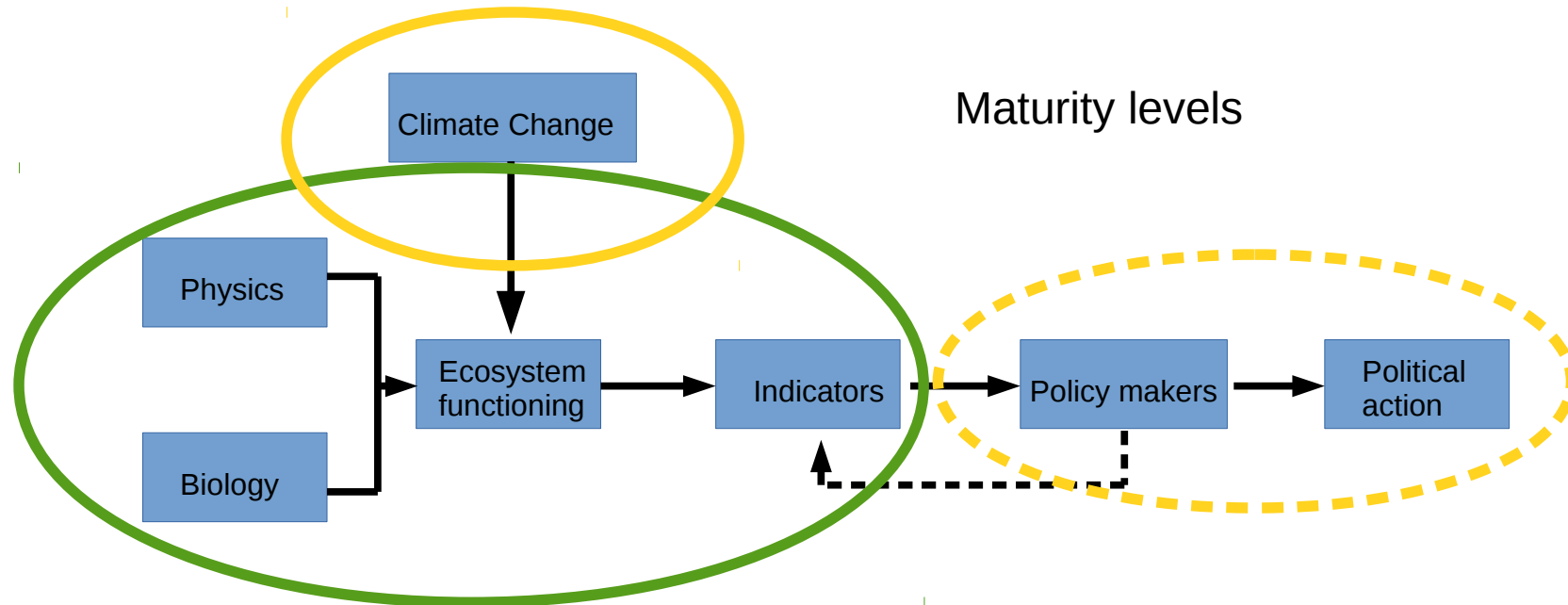
LAECOS project

(PIs: F.d'Ovidio, C. Cotté, LOCEAN-IPSL; postdoc: M. O'Toole)



Now we are working for proposing a large Marine Protected Area in international waters (CCAMLR region).

WP4 dem. 4: *Evolution des écosystèmes marins en mer Méditerranée: Service climatique pour la définition de réseaux d'aires marines protégées*



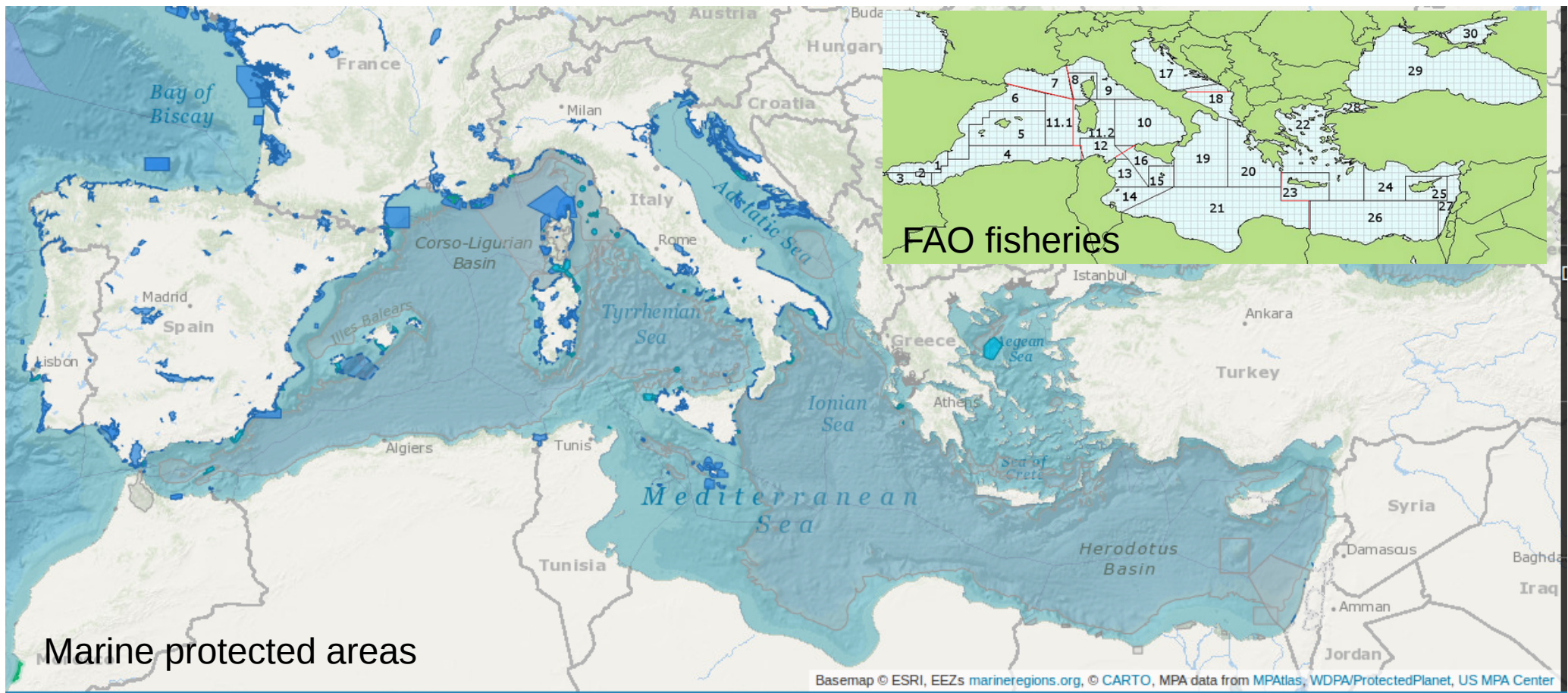
- Analyze temporal variability in connectivity of Mediterranean marine protected areas
- Identify possible future trends

The Mediterranean

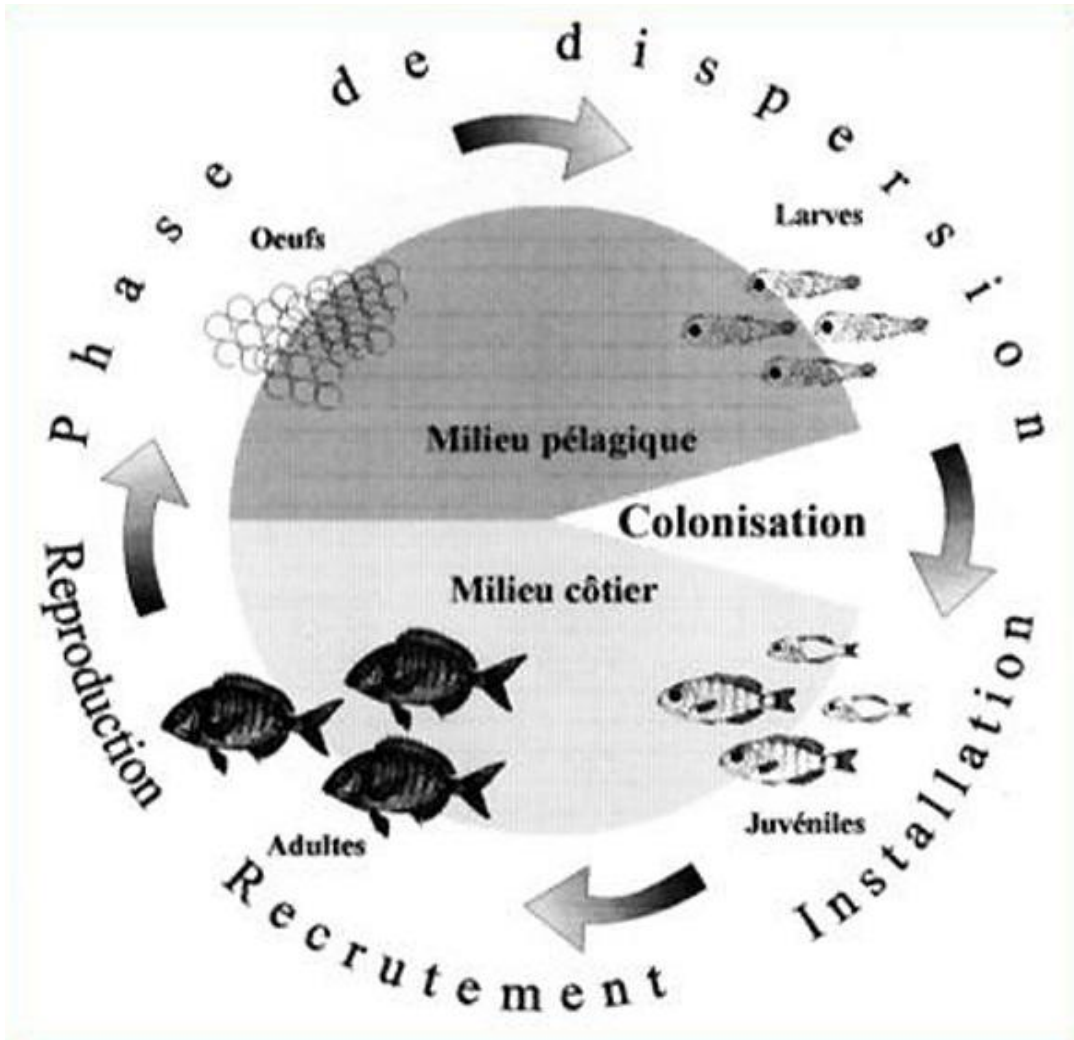
The Mediterranean: a “pocket ocean” under huge anthropic pressure

Several marine protected areas in a complex geopolitical context

Existence of an international framework for regulating conservation: UNEP MAP



A key question in Mediterranean conservation: connectivity



Marine Connectivity:

- spawning strategy
- larval dispersal
- habitat interactions
- adult movements

BUT for most marine species:

Territorial adults

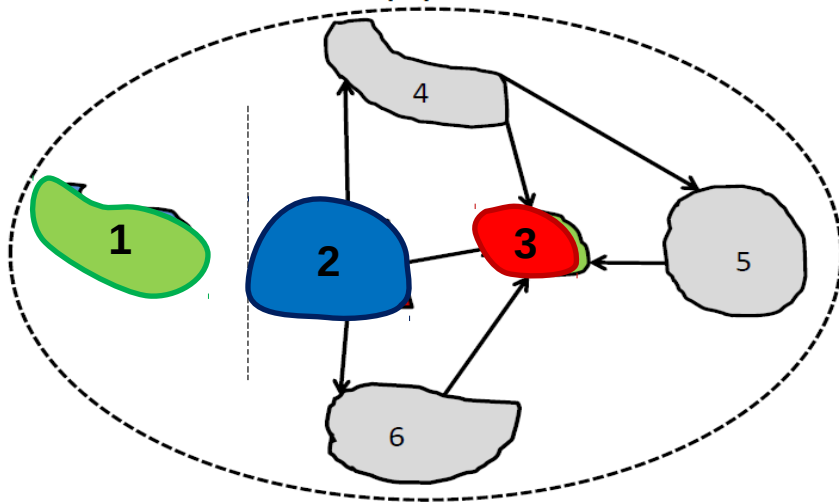
(limited movements)

Planktonic pelagic larvae

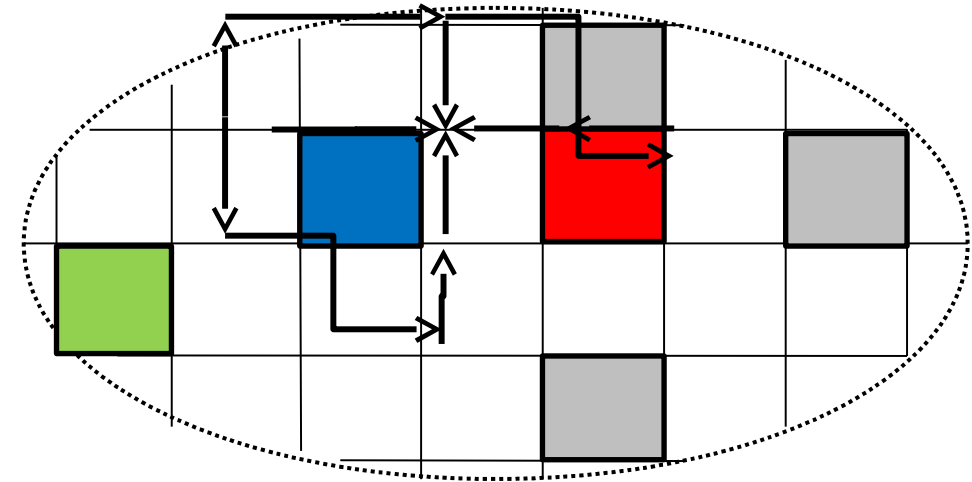
(efficient dispersion by currents)

Larval Flow Network interpretation

Metapopulation



Flow Network basin



Ecological objectives

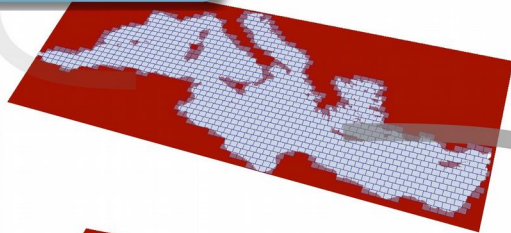
Describe the **direction and quantity of larvae** exchanged between sub-populations

Flow Network equivalent

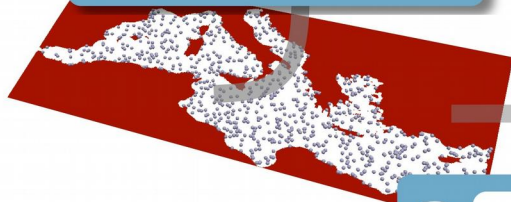
Describe the **direction and weights of the links** existing between flow network nodes

From ocean currents to connectivity patterns

1 Grid construction



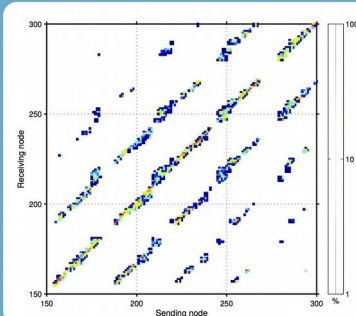
2 Lagrangian engine



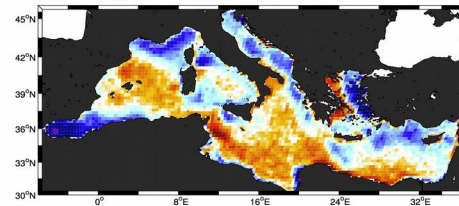
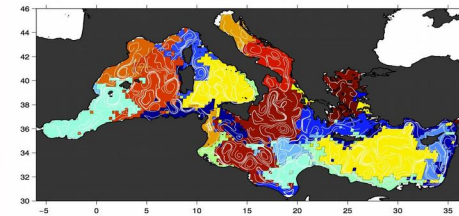
Parameters

- Domain
- Velocity field
- Node size
- Starting time
- Integration time
- Layer

3 Net Construction



4 Analysis



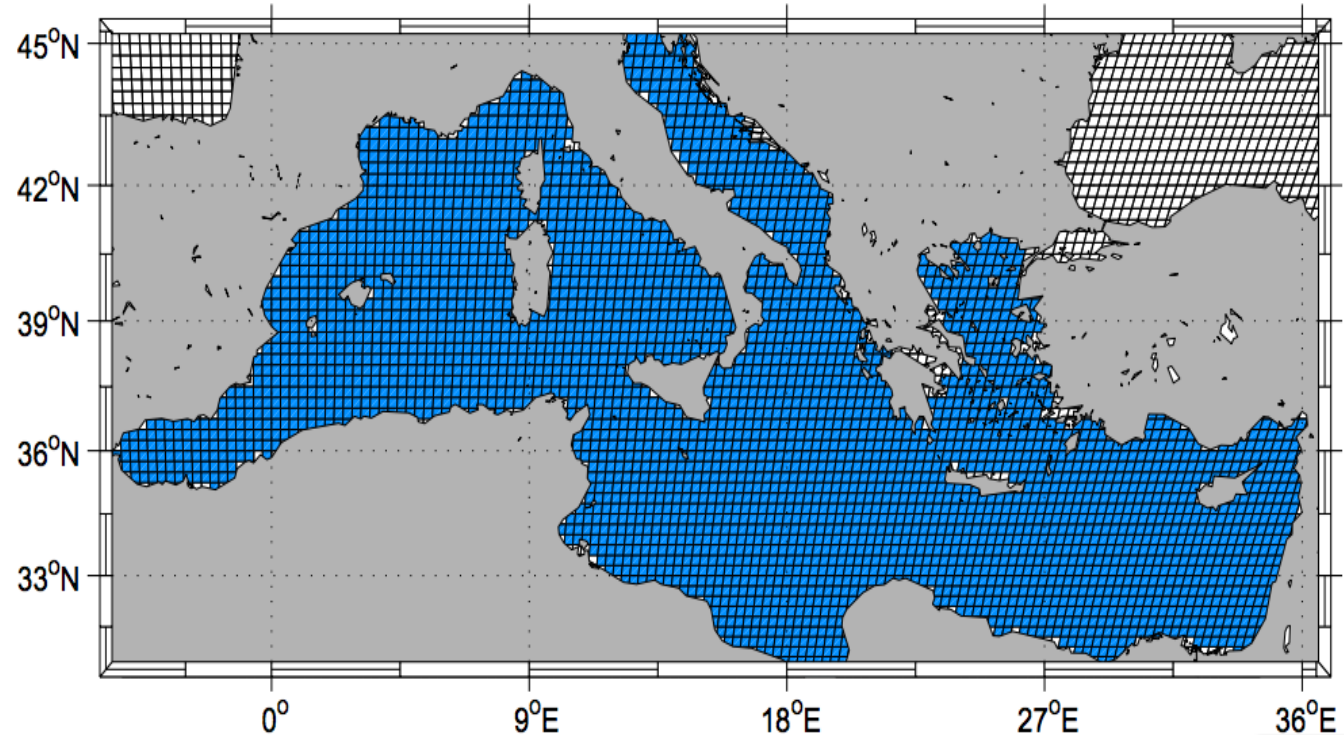
Work of E. Ser-Giacomi with V. Rossi (MIO), E.-H. Garcia & C. Lopez (IFISC)

Discretization & data: oceanic setup

Velocity field:

Currently: Daily operational Eddy-resolving model NEMO (2002-2011).

To be ported to:
Altimetry & MED-Cordex



Network grid:

- 3270 quasi-square nodes in sinusoidal projection
- $\Delta = 27.78 \text{ km}$

Lagrangian simulation:

- 500 particles each node
- time step = 1 *day*

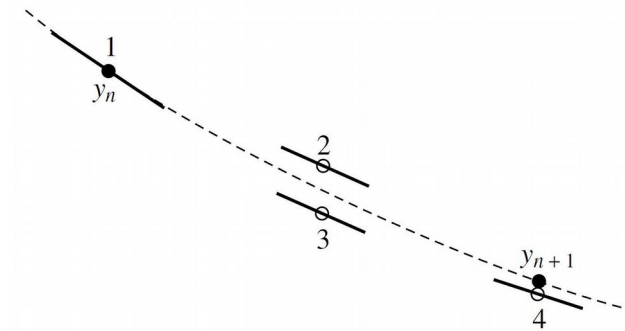
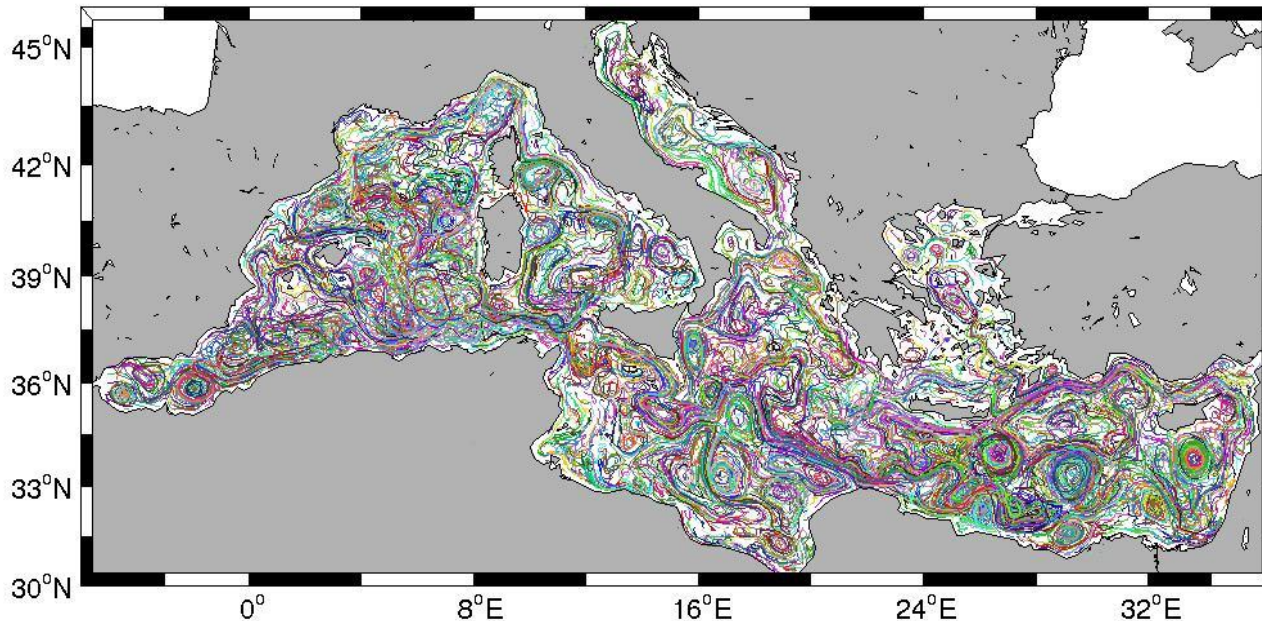
Network construction

Lagrangian point of view

How to estimate the amount of fluid exchanged among different regions by currents?

- Time dependent velocity field (2-dim)
- Fill each box B_i with **ideal fluid particles** (tracers)

Particle trajectories / Current day: 31-Jan-2011



→ Lagrangian simulations

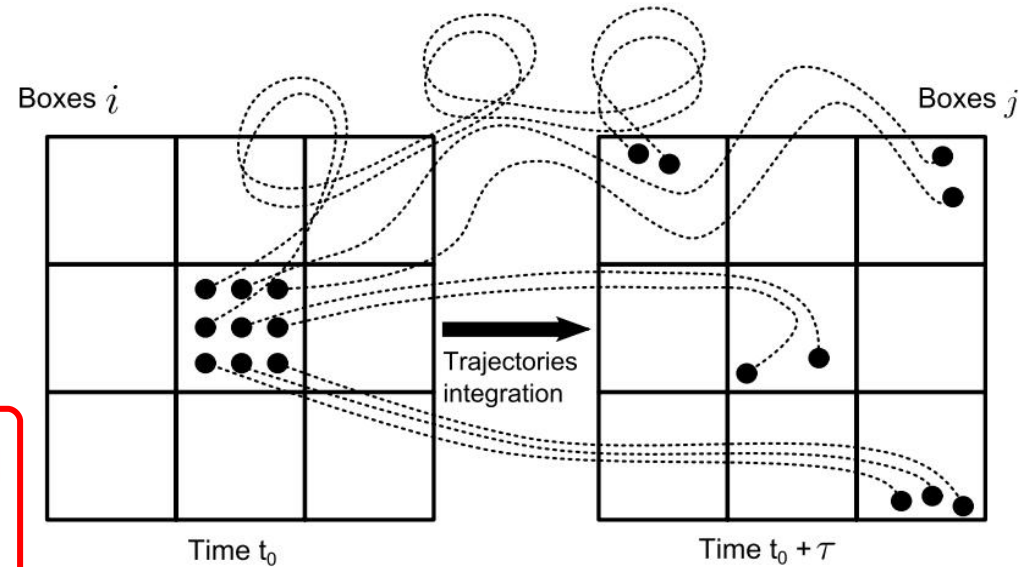
Using a **RK4 algorithm** we reconstruct trajectories of particles advected by the flow.

Network construction

Transport matrix construction

Once we obtained the trajectories we are able to build a **transport matrix P**:

$$P_{ij} = \frac{\# \text{ tracers from box } i \text{ to box } j}{\# \text{ tracers of box } i}$$



Normalization:

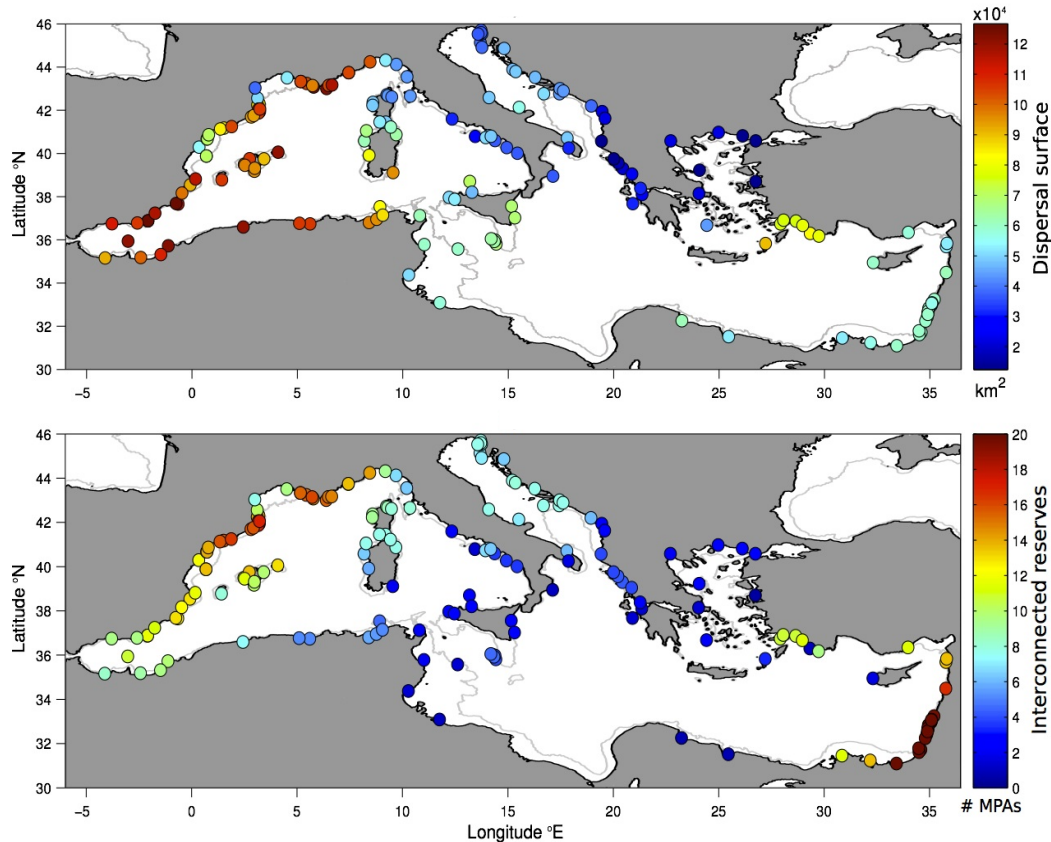
- Tracers leaving the domain.
- Differences in node sizes.

Network perspective:

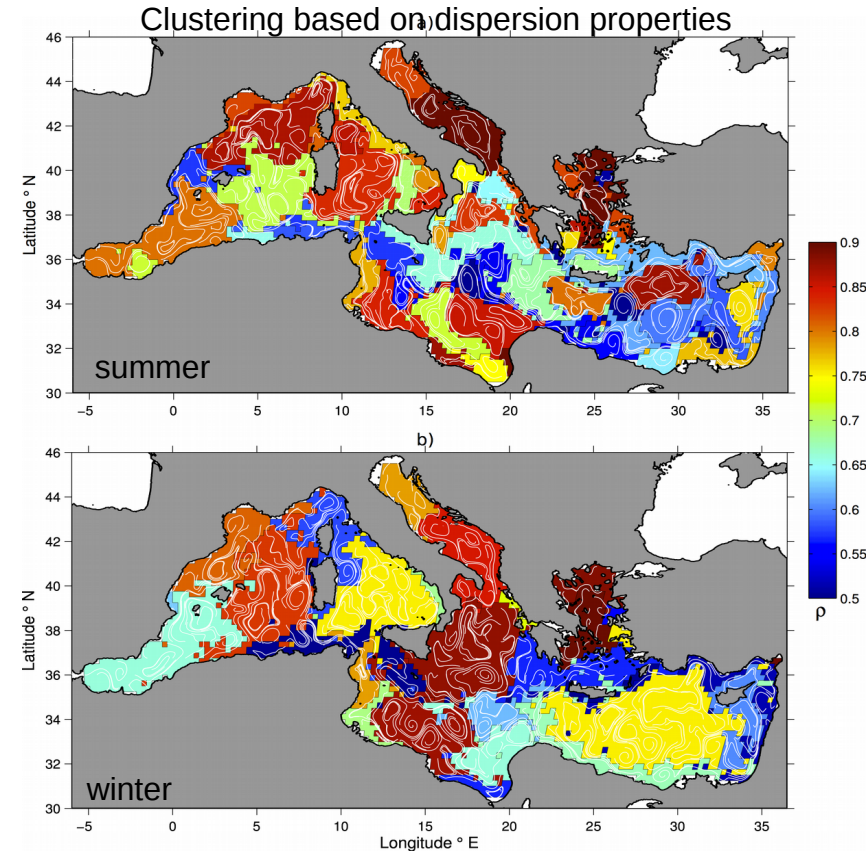
- \mathbf{P} → Adjacency Matrix
- B_i → Node i
- P_{ij} → Weight of link $i-j$

Global: Marine Protected Areas (MPAs)

From community partition of the whole network we distinguish **connectivity features of MPAs** across the seascape.



(Rossi et al. (2014), GRL 41, 2883–2891)

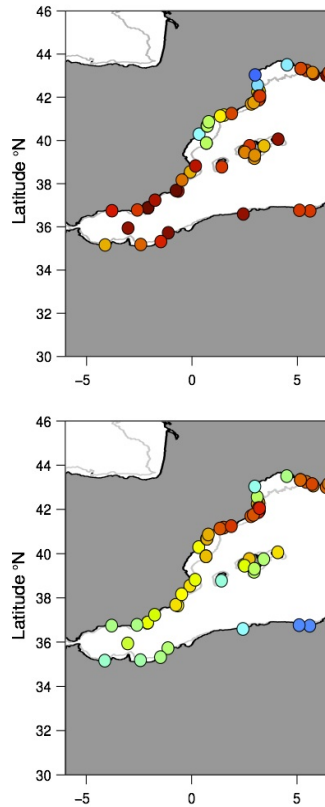


- **Dispersal surface:**
Mean **area of the province** containing an MPA
- **Interconnection:**
Mean **number of other reserves** in the province containing an MPA

Work of E. Ser-Giacomi with V. Rossi (MIO), E.-H. Garcia & C. Lopez (IFISC)

Global: Marine Protected Areas (MPAs)

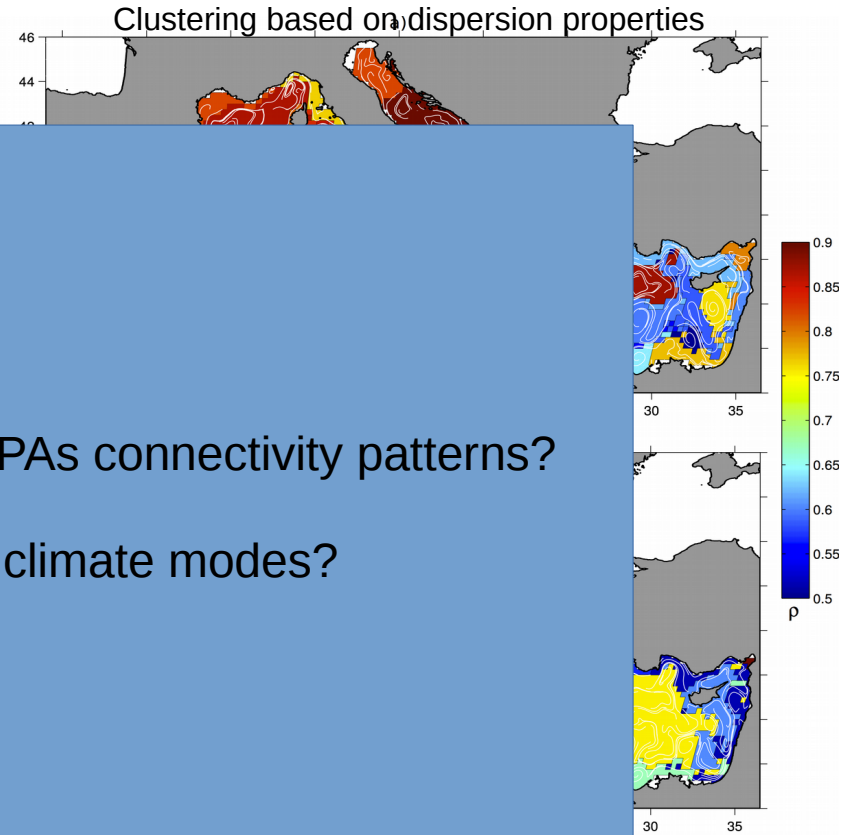
From community partition of the whole network we distinguish **connectivity features of seascape**.



(Rossi et al. (2014), GRL 41, 2883–2891)

New CS questions:

- What is the variability of the MPAs connectivity patterns?
- How the variability is tuned by climate modes?
- Are there expected trends?

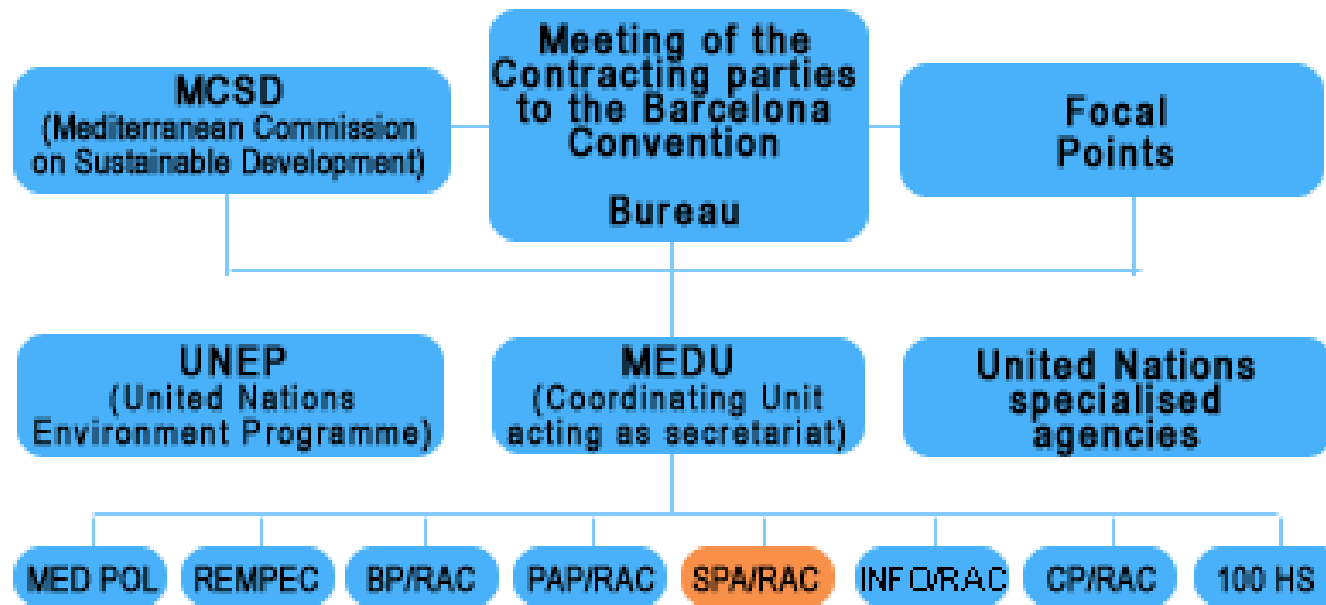


mean number of other reserves in the province containing an MPA

Work of E. Ser-Giacomi with V. Rossi (MIO), E.-H. Garcia & C. Lopez (IFISC)

Mediterranean Action Plan

MAP INSTITUTIONAL STRUCTURE



The legal framework: the Barcelona Convention and its Protocols

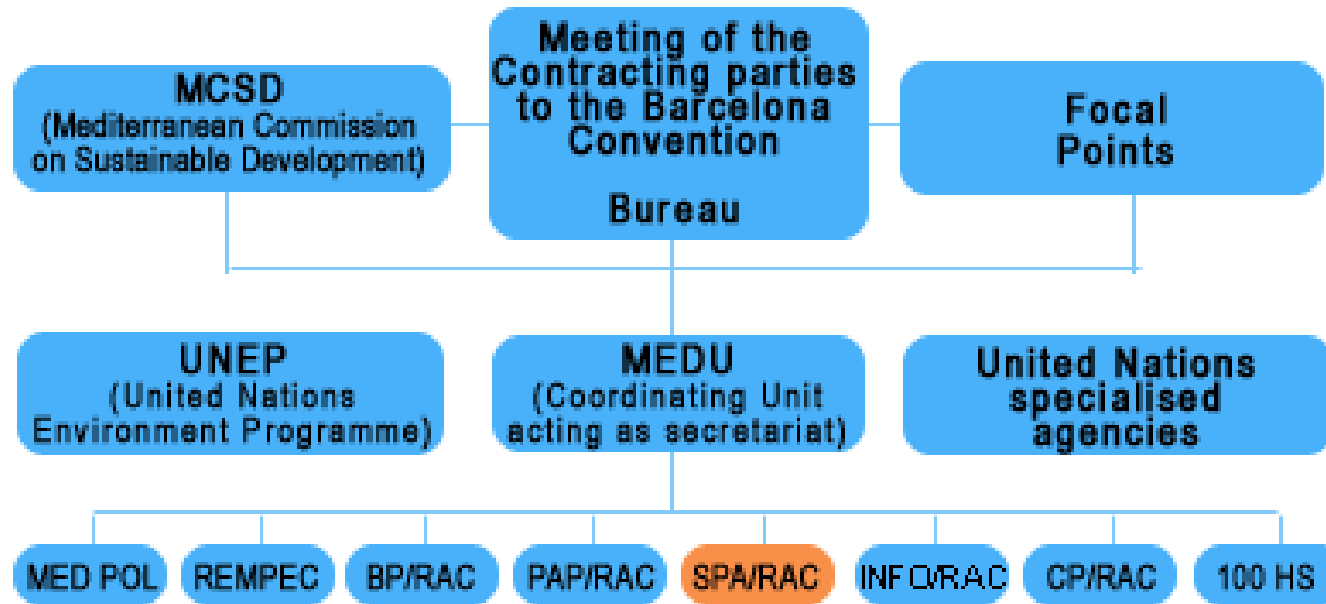
The "Convention for the Protection of the Mediterranean Sea against Pollution" (the Barcelona Convention) was adopted in 1976 and came into force in 1978.

The Contracting Parties amended it in 1995, calling it "The Convention for the Protection of the Mediterranean Marine and Coastal Environment".

The Convention and its seven Protocols, including the SPA/BD Protocol, form what is known as the Barcelona system, the MAP's legal framework.

From science to decision makers: the Mediterranean Action Plan

MAP INSTITUTIONAL STRUCTURE



Regional activity Center for Specially Protected Areas

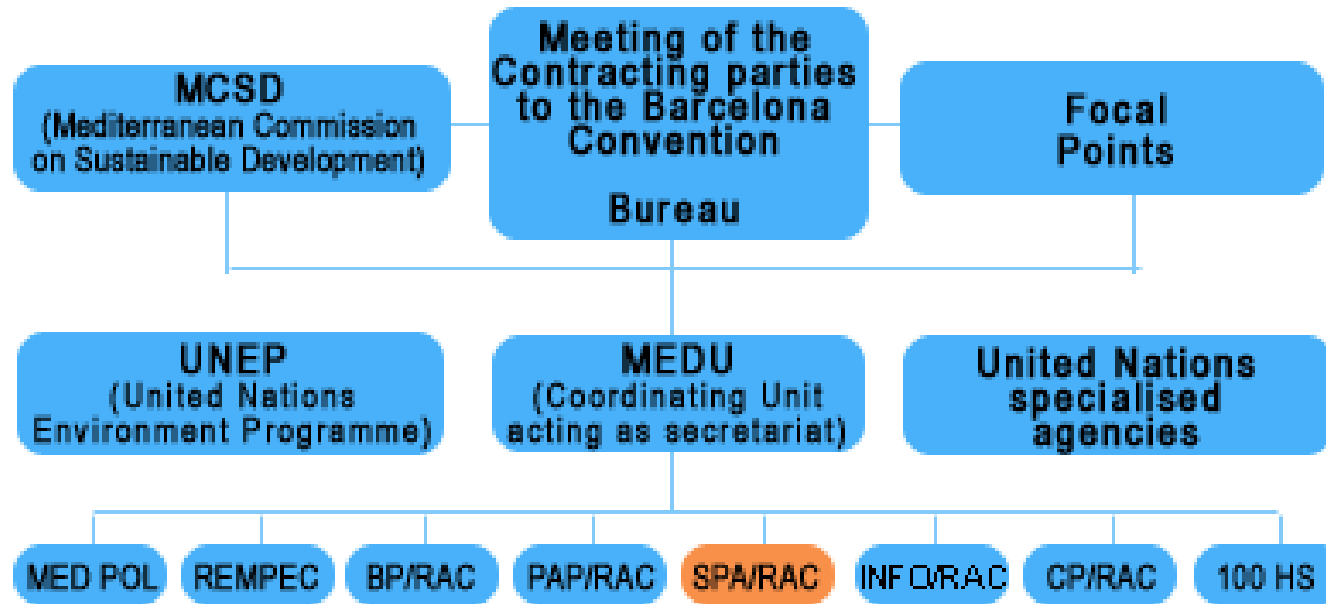
SPA/RAC French Focal Point

Mrs Maud CASIER

Direction de l'Eau et de la Biodiversité (DGALN/DEB)

From science to decision makers: the Mediterranean Action Plan

MAP INSTITUTIONAL STRUCTURE



Regional activity Center for Specially Protected Areas

SPA/RAC French Focal Point

Mrs Maud CASIER

Direction de l'Eau et de la Biodiversité (DGALN/DEB)

Other contacts with Agence d'Aires Marines Protégées



BLUEMED

Une initiative et un accord des Etats Membres (Min. Recherche) endossé par la CE pour adopter des priorités de recherche et d'innovation communes et les financer. L'Agenda Rstratégique BLUEMED identifie 12 défis clés déclinés en grand objectifs et en actions dont 2 directement en lien avec la Convention. BLUEMED est soutenue par une CSA H2020 pendant 4 ans. L'INSU et IFREMER sont PI pour la France. www.bluedmed-project.eu

Bluedmed

Research and innovation initiative for blue jobs and growth in the Mediterranean area

Strategic research and innovation agenda

Mediterranean Sea ecosystems: services, resources, vulnerability and resilience to natural and anthropogenic pressures

GOAL	ACTION	SCOPE	LEVEL	DURATION
Climate services for the Mediterranean	Develop, enhance and deliver user-friendly tools for disseminating climate information related to Mediterranean atmosphere, coastal and deep ocean areas	R&I activities, knowledge transfer	EU, national	Medium
Promoting sustainable exploitation of biotic and abiotic resources	Implement managing solutions and conservation plans, including networks of Marine Protected Areas, for coastal to deep-sea ecosystems and their relationship with natural and anthropogenic changes in the environment	R&I activities, knowledge transfer	National, regional	Medium

WP4 dem. 4: *Evolution des écosystèmes marins en mer Méditerranée: Service climatique pour la définition de réseaux d'aires marines protégées*

Discussion

The project joins our “end-to-end” marine ecology experience of the Kerguelen area with recent results applying network theory to conservation in the Mediterranean.

The project will focus on connectivity among marine protected areas in the Mediterranean and its future expected variability.

The methodological and regional setup is mature, but some work needs to be done for including climate change scenarios (Med-Cordex) and for outreaching to decision makers.

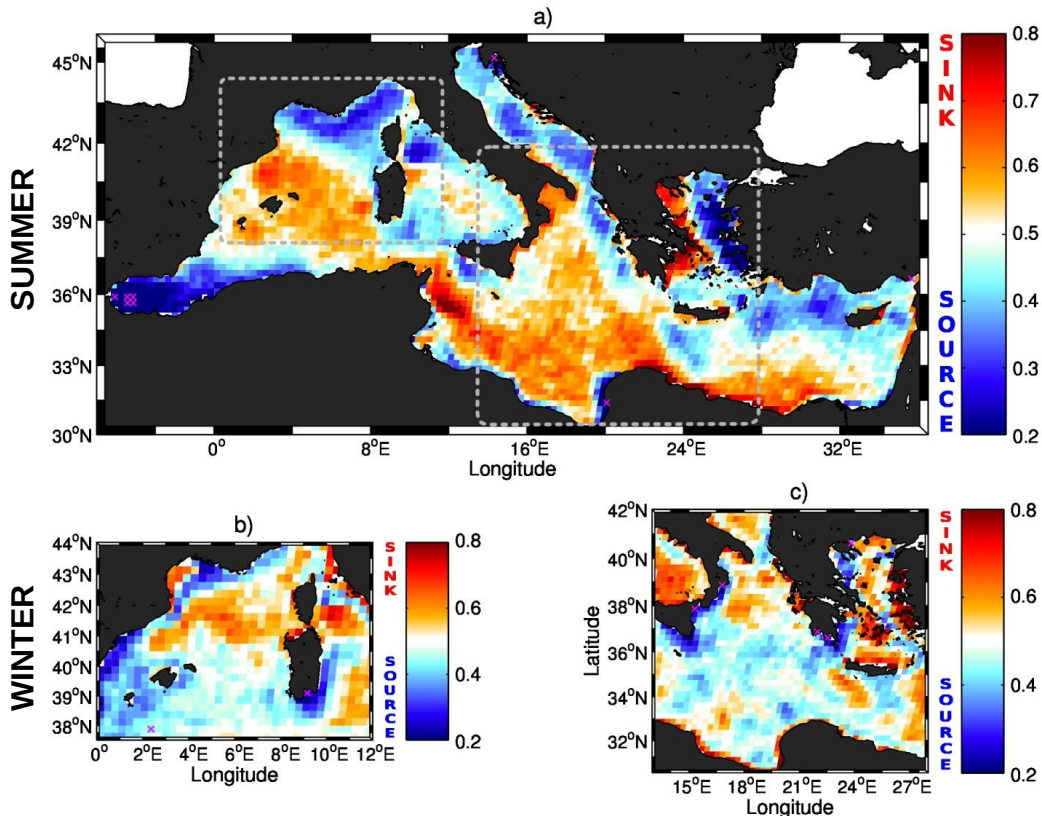
Local: Source/Sink dynamics

A network-based local metric allowing **sub-populations characterization** across the basin:

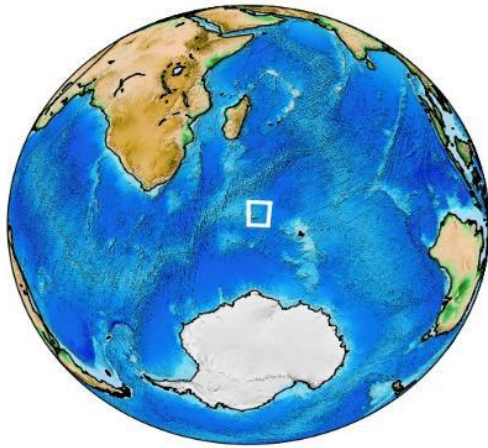
$$\text{Source Sink-degree}_i = SS_i^d = \frac{IN_i^d}{IN_i^d + OUT_i^d} \in [0, 1]$$

Average source/sink plot:

- Import/Export heterogeneity measure
- Seasonal and inter-annual variabilities observed
- Implications for protection strategies and genetics



a

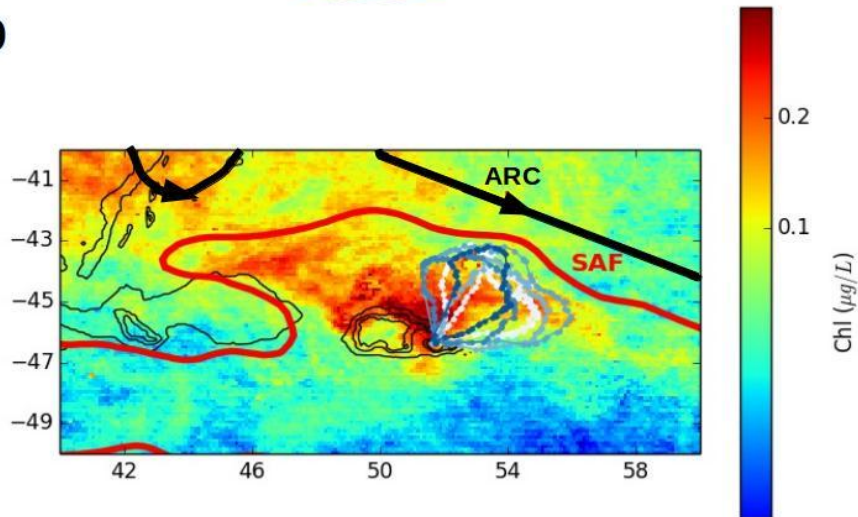


Example of a biologging+multisatellite analysis in support of the creation of the Marine Protected Area of Crozet

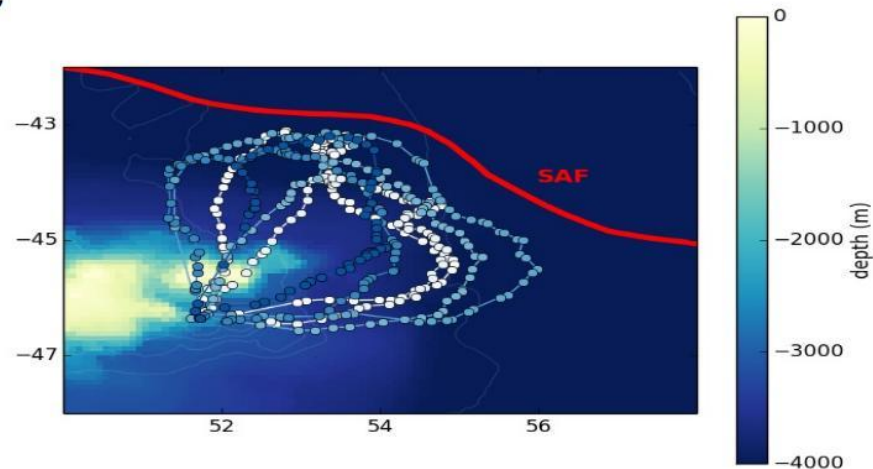
Collaboration with MNHN (P. Koubbi)

Biologging from C. Bost, C. Bon, C. Guinet

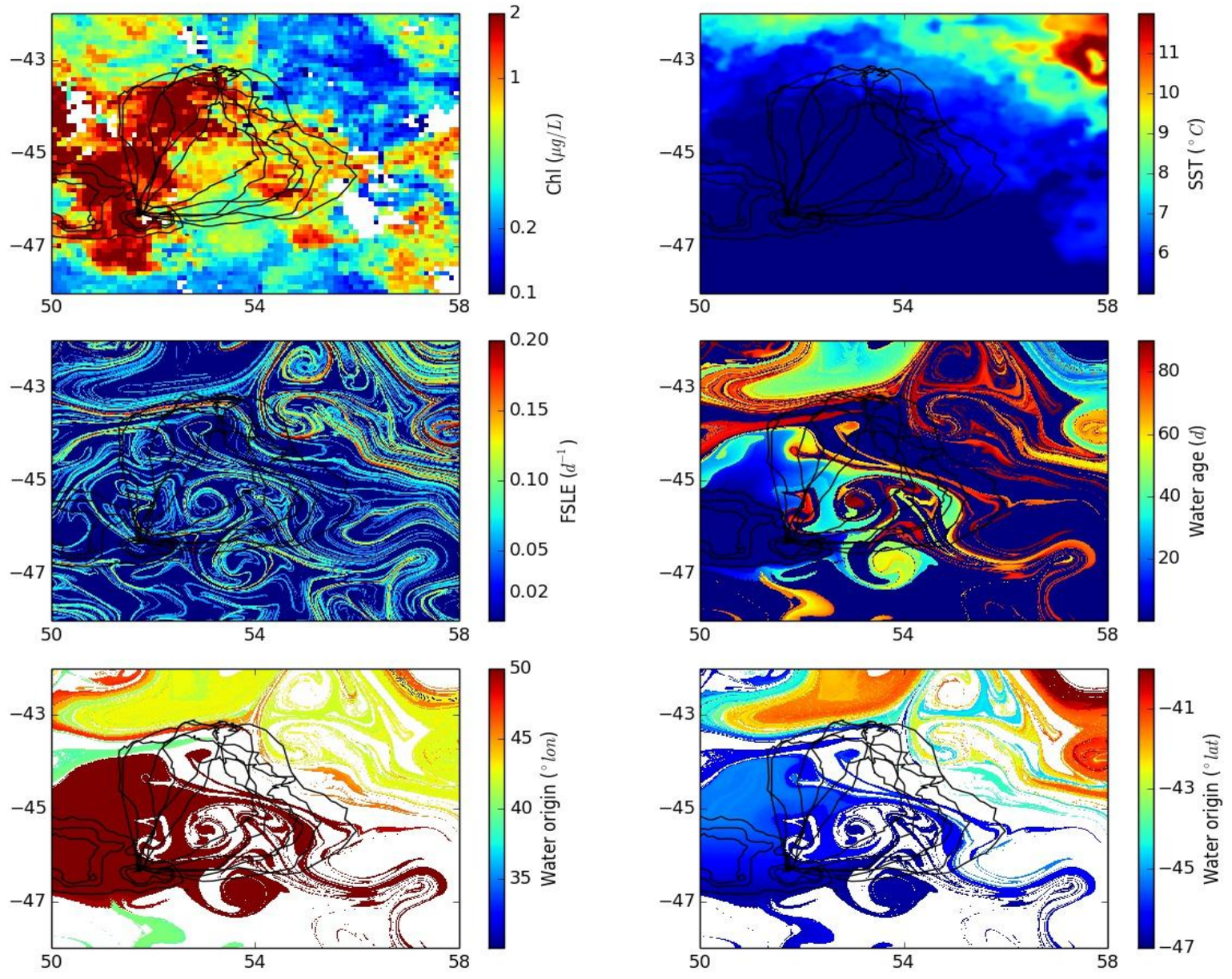
b



c

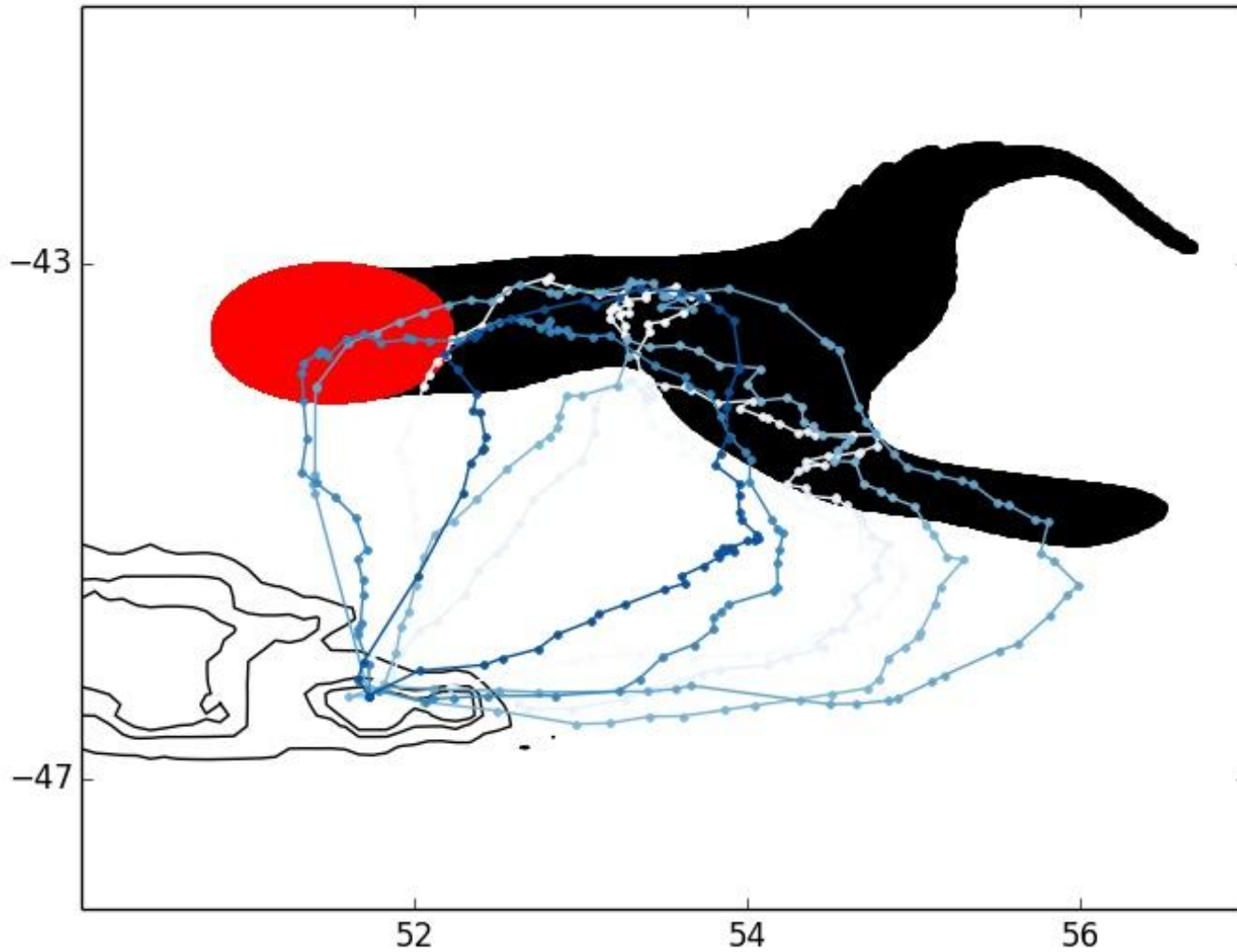


Characterisation of the foraging region

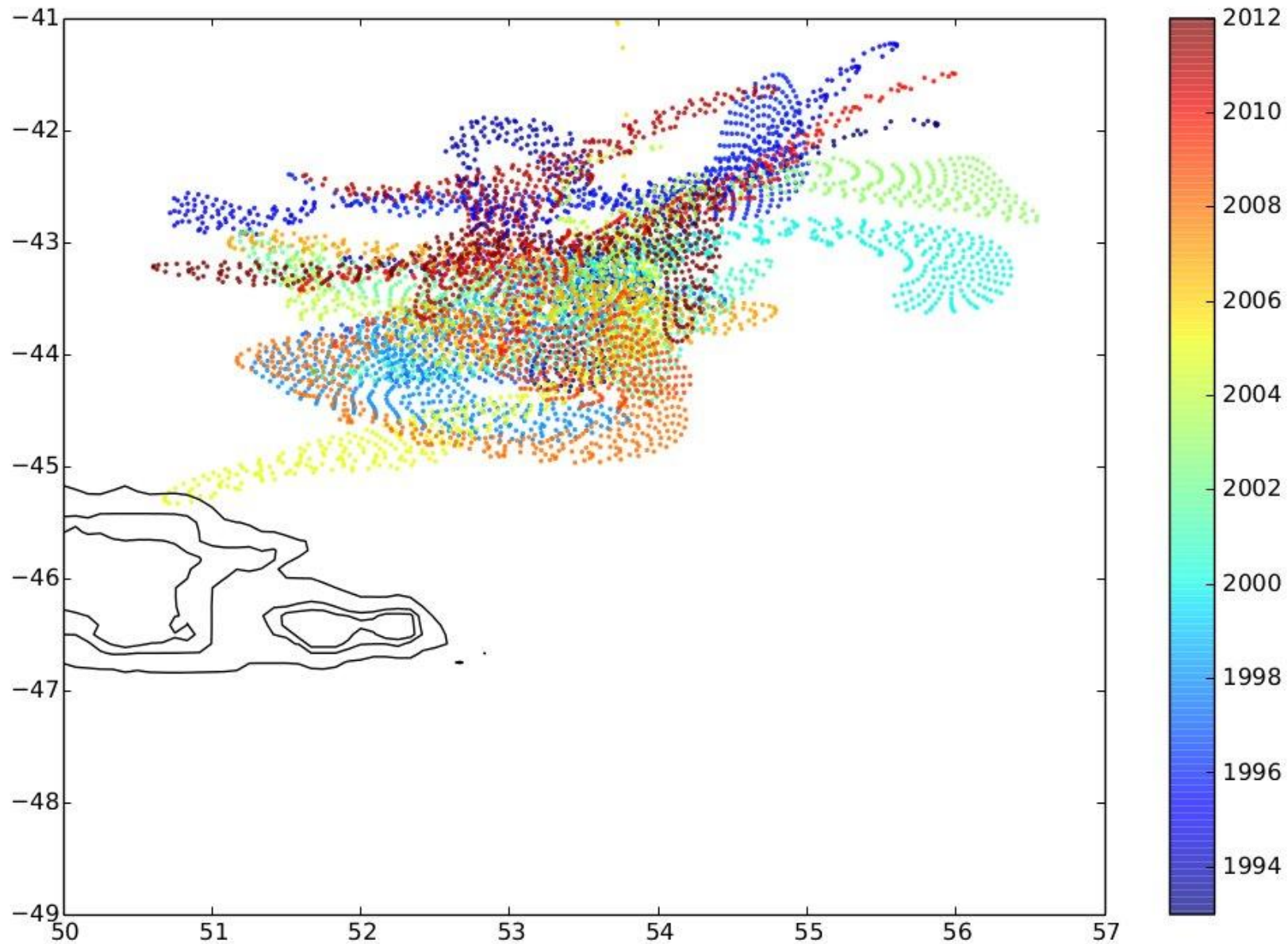


Conclusion: Macaroni penguins seem to target a front which delimits the chlorophyll-rich coastal waters dispersed in the open ocean

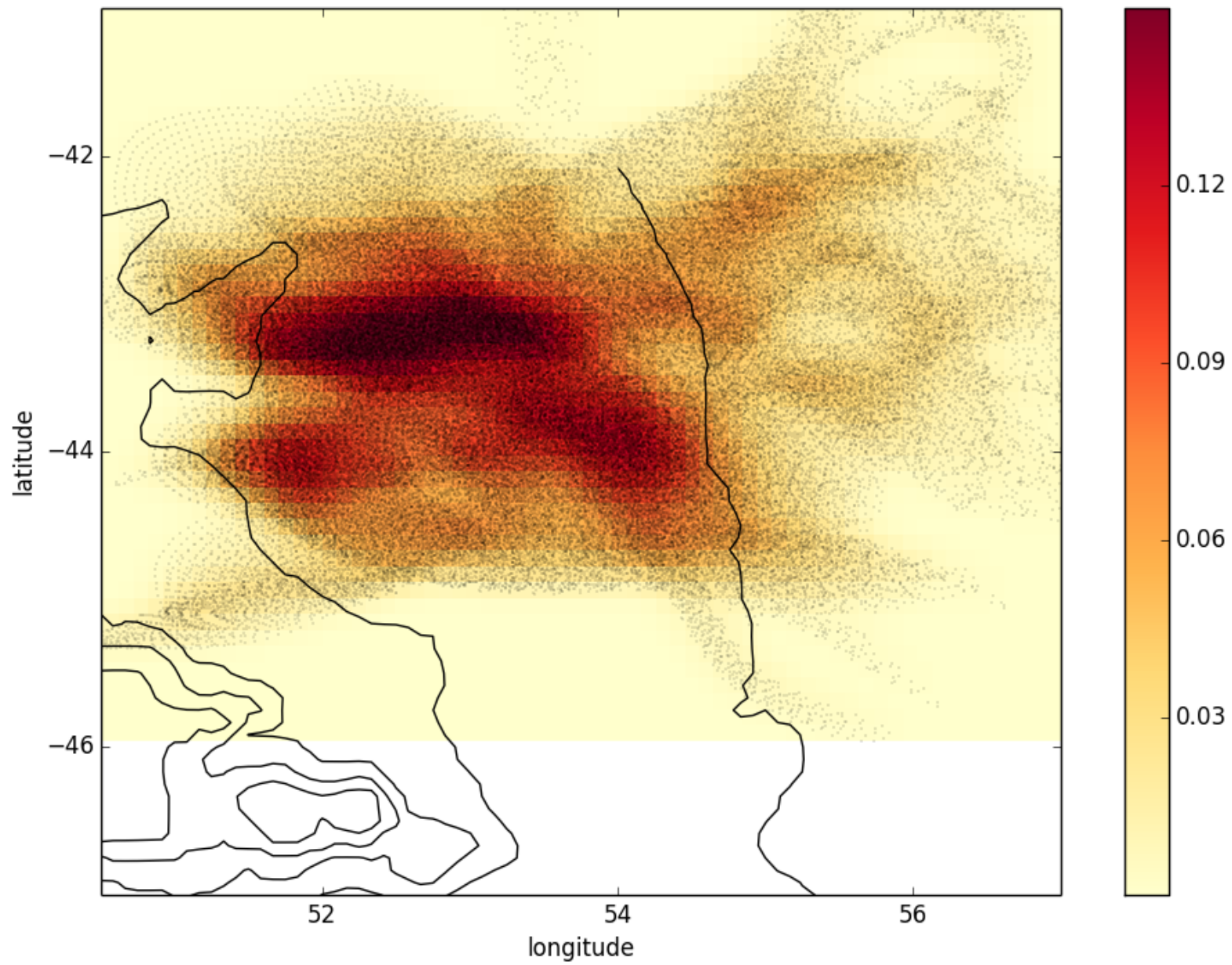
We develop an algorithm to track the foraging region over satellite data, shadowing a Lagrangian Coherent Structure



Interannual variability



We use the satellite-based definition of the foraging region to study its position beyond the year of biologging data. We try to identify drift of the region due to climate change, by computing its response to a mode of climatic variability; we find the internal variability dominating over the climatic signal



Density plot of the foraging region