ISIS-fish model: Assumptions, limitations and issues of spatial dynamics for simulating management scenarios: illustrations with a Mediterranean case study

Mathematics for bio-Economics and Sustainability of fiSHeries
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Charlotte Sève & Stéphanie Mahévas

charlotte.m.seve@gmail.com

Ifremer

Importance of spatial in conservation ecology

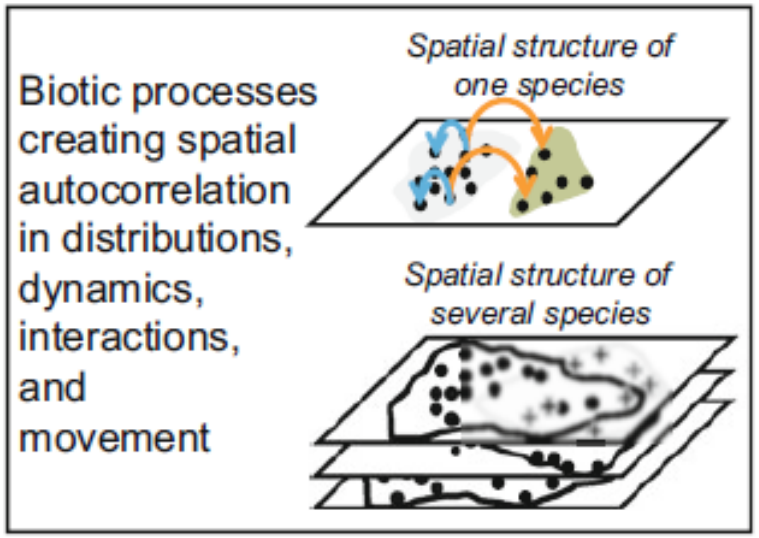
Space in ecology

- Space influence ecological patterns and processes:
  - resource availability
  - displacement
  - Interactions
- Most often **non-uniform** distribution
- Among species and for age/length groups

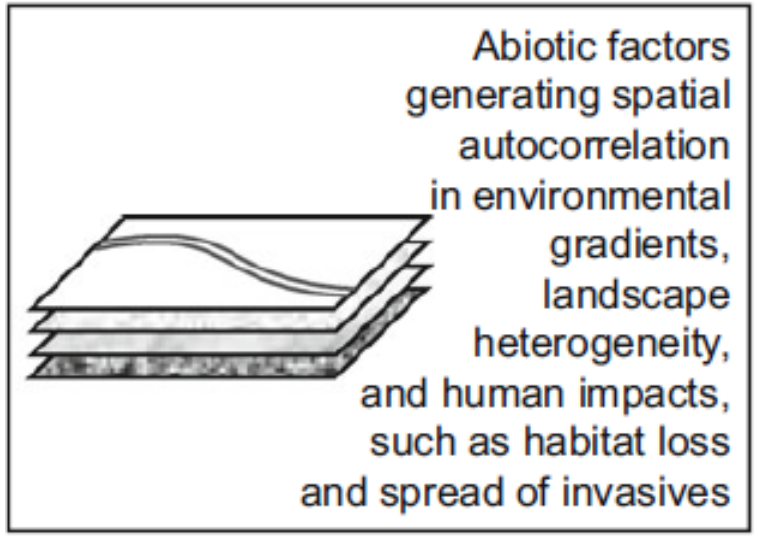
Space in conservation

- Main goal: **protect biodiversity**
- Other spatial dimensions
  - Ecosystem services
  - Human uses
  - Abiodic factors
- Facilitate effective **prioritization** of areas for conservation
- Help finding **trade-off**
- Guidance for mitigating effects of environmental changes

Ecological responses



Environmental covariates



From Fletcher et al. (2018). Introduction to spatial ecology and its relevance for conservation (chapter 1)

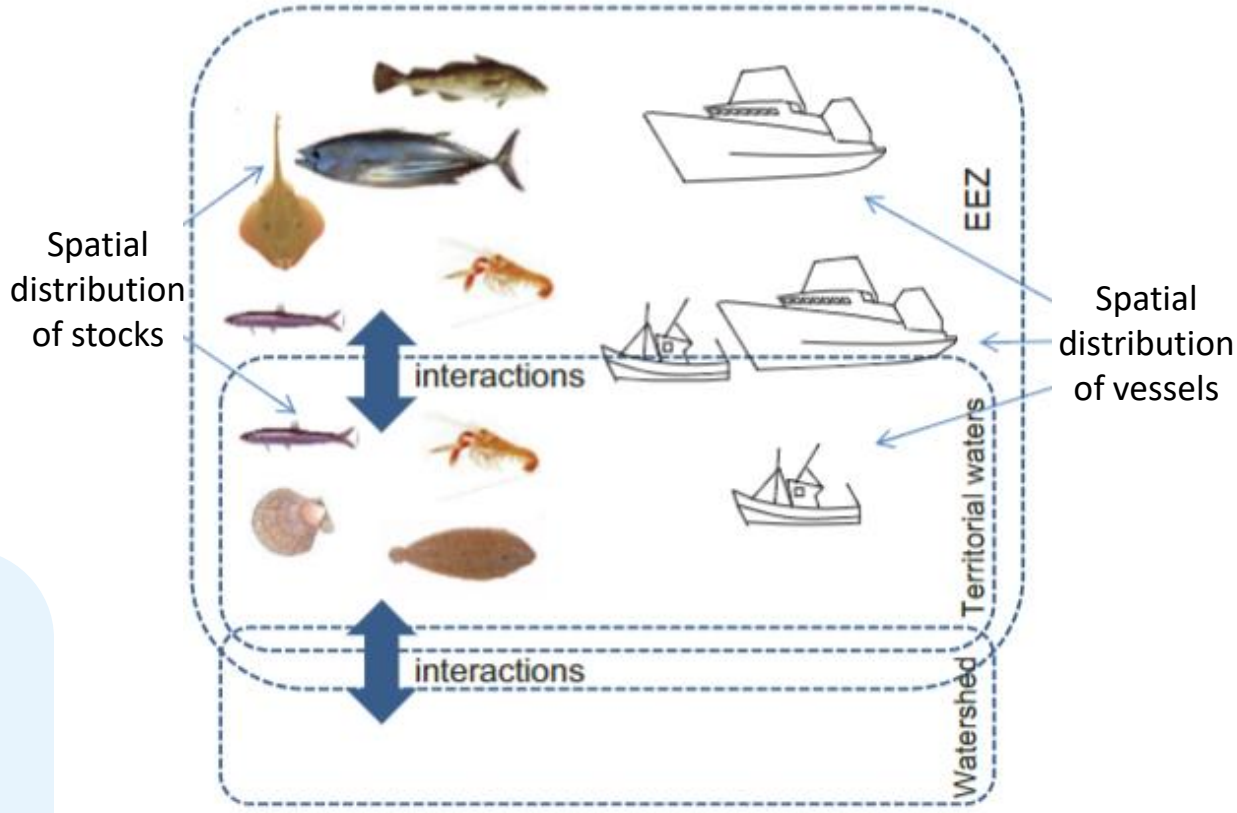
Importance of spatial in fisheries management

A complexe activity

- **Most stocks** subjected to fishing → **spatial heterogeneity**
- **Mixed fisheries**
  - complex interactions between species and fleet
  - at various spatial scales
- **Spatial overlaps**
  - between population, métier and management zones
  - It determine fishing effort allocation

A complexe management strategy

- Different spatial scales
  (ecological, economic, legal and institutional zones)
- Institutional frameworks are informed by **spatial dynamics** for effective management
- **Spatial delimitation** in fisheries management (quotas, TURF)
- Influence of the creation of MPAs or human activities (OWF)



From Le Floc'h et al. (2018), Aquat. Living Resour.

Pelletier é Mahévas, (2005), Fish and Fisheries; Punt (2019), Fisheries Research

Increasing spatial complexity in patch models

Non-spatial

- **No spatial distribution, movement** of organisms, **ecological processes**
- Focus on the dynamics and interactions of populations

  Example: Impact of MPAs on yields?
  - optimization model
  - no spatial distribution, density dependent growth

  → MPAs can produce similar maximal yields than managed harvest

Hastings & Botsford (1999), Science

Spatial

Spatially implicit models

- Several patches representing spatial aspects
- **Ignore spatial arrangement** of patches

  Example: test of protecting source or sink locations

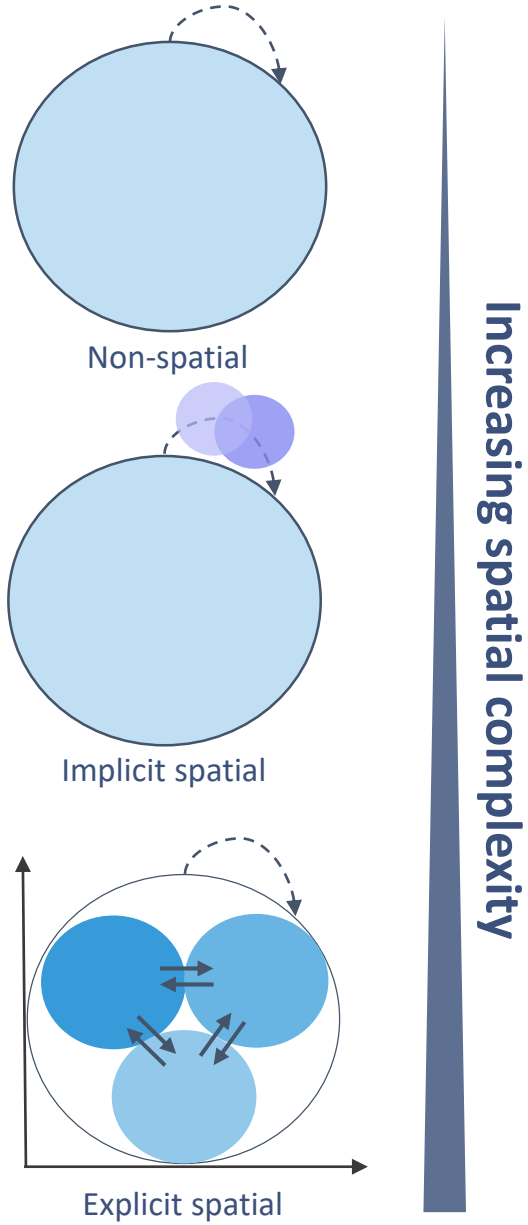
  → More effective to protect sources
- Limits: pop with spatial distribution, movements

  + exploitation features with non-uniform space distribution

Spatially explicit models

- **Geo-referenced patches** with associate information
- Account for movement patterns
- Test MPA location, reserve size, shape, fishing effort distribution

Sanchirico & Wilen (2001), Jour. Env. Eco. And Manag.



Inspired from Goethel & Berger (2017), Canadian Jour. of Fish. and Aqu. Sc.

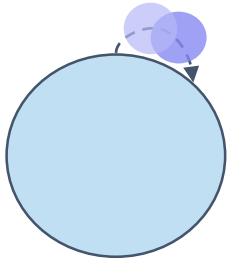
A spatially explicit demographic model : ISIS-fish

- **Spatially explicit** (grid)
- Multi-species
- **Multi-fleet**
- Mixed fisheries
- **Migration**
- Spatial overlaps

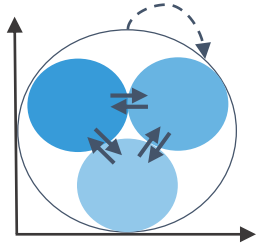
Three case study with different spatial approaches

ISIS-fish

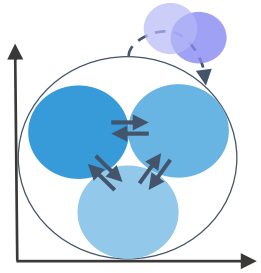
1 **Restauration of nursery habitat in Bay of Toulon**



2 **Multi-levels MPA networks in Golfe du Lion MP**



3 **Restauration of nursery habitat and other management strategy in Marseille**



What are the possible impacts of increasing spatial complexity ?

How to define a modelling strategy?

Question

- Objectives
- Indicators
- Ambition

Processes

- **List of needs**
- Species
- Fleet
- Processes

Data

- Which data are available?
- Their resolution
- For each group

Modelling strategy

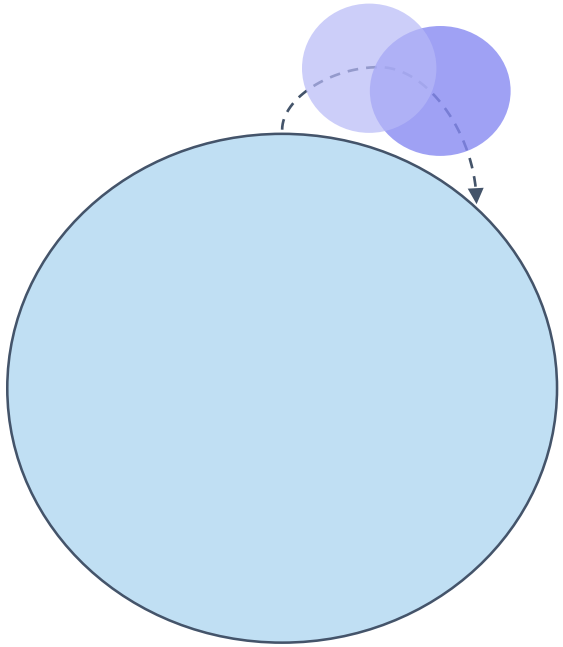
- Model choice
- Spatial complexity
- Coherence of scales
- Group dynamics, processes
- Overlaps between groups

ISIS-fish

First case study

1

Restauration of nursery habitat in Bay of Toulon



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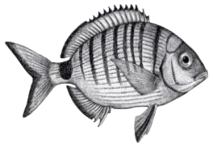
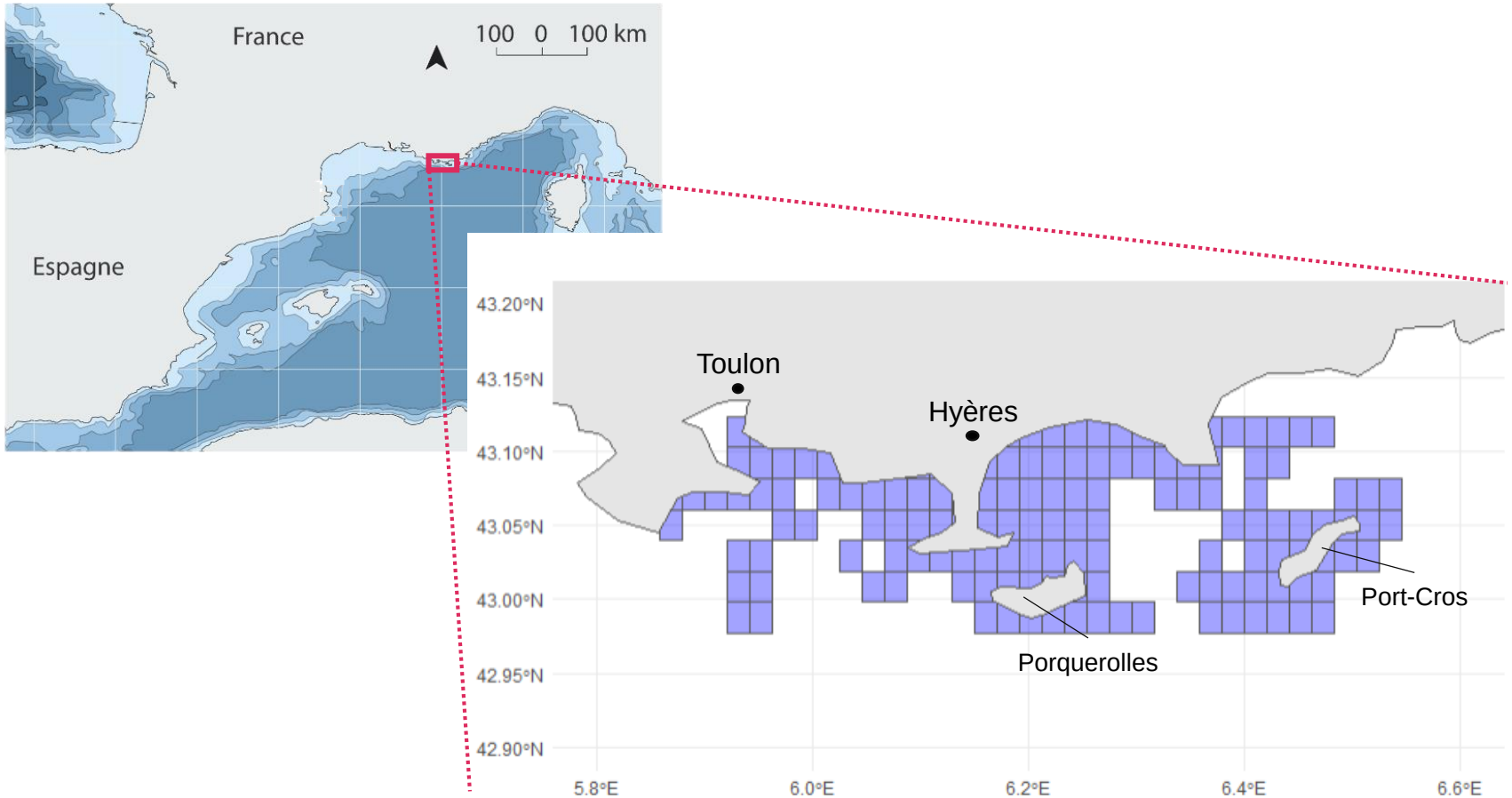
Restauration of nursery habitats in Bay of Toulon

Question

- What impact does the installation of **artificial nurseries** have on adult fish **populations**?
- How effective are they compared with other management measures?





Joubert et al. (in prep)

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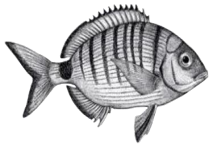

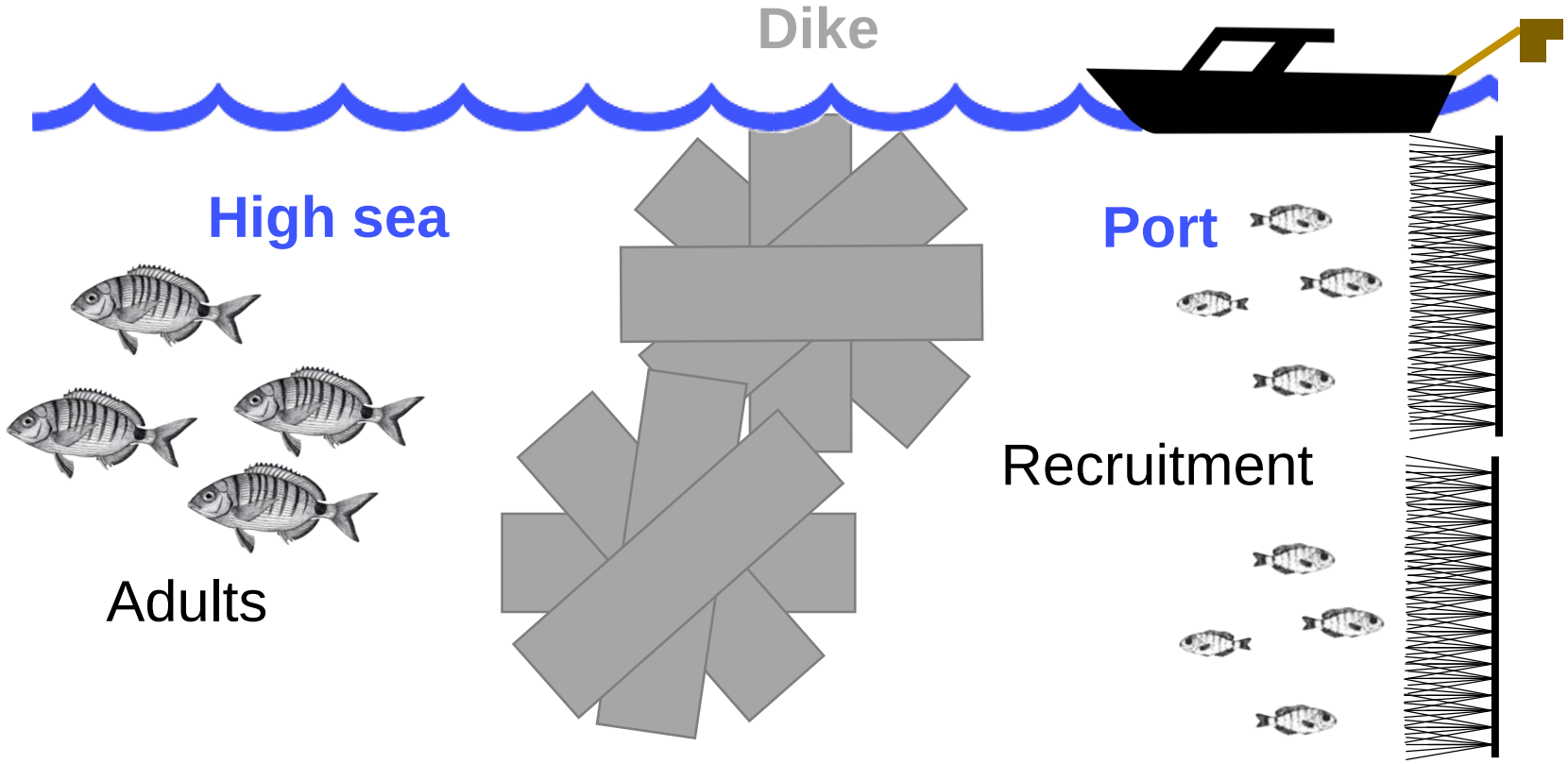

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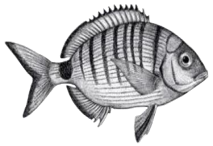


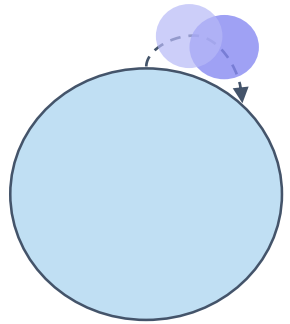
Processes

- Population dynamic (reproduction, recruitment…)
- Fishing mortality
- Spatial component

Data

- No data about abundance at fine scale (restauration modules ~ 200m)

➔ Use a spatially implicit modeling strategy



Implicit spatial

Joubert et al. (in prep)

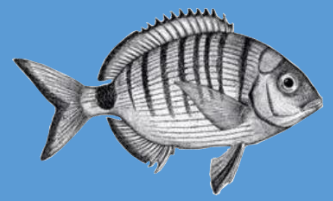
1

Restauration of nursery habitats in Bay of Toulon

Strategy

- Population dynamic
- Spatially implicit nursery area

Adult area



14 age group

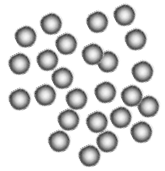
Natural mortality (26%)

Fishing effort

- Professional fishing
- Recreational fishing

Reproduction

Eggs



Eclosion

Larvae

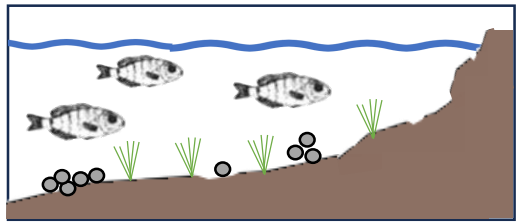
Mortality (99%)

Benthic installation

10 ind/m

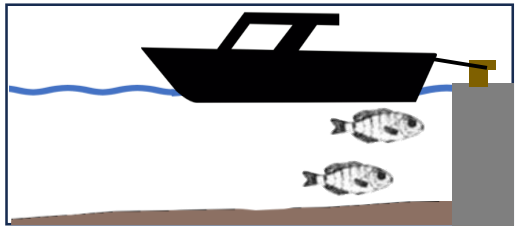
Nursery area

Natural (~ 56 km)



Mortality (80%)

Port (~ 25 km)



Mortality (99%)

Joubert et al. (in prep)

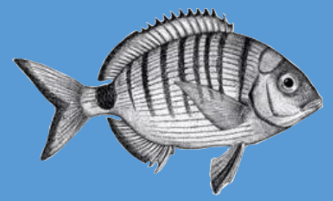
1

Restauration of nursery habitats in Bay of Toulon

Strategy

- Population dynamic
- Spatially implicit nursery area
- Hyp: restaured port area mortality = natural area mortality

Adult area



14 age group

Natural mortality (26%)

Fishing effort
- Professional fishing
- Recreational fishing

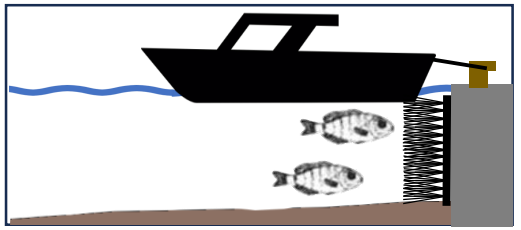
Scenario 1

Restauration of **10%** of port linear (6km)

Scenario 2

Restauration of **100%** of port linear (60km)

Restaured port linear



Mortality (80%)

Scenario 3

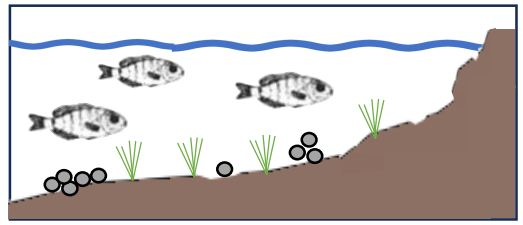
No illegal fishing (no individual <23cm caught)

Scenario 4

Scenario 2 + 3

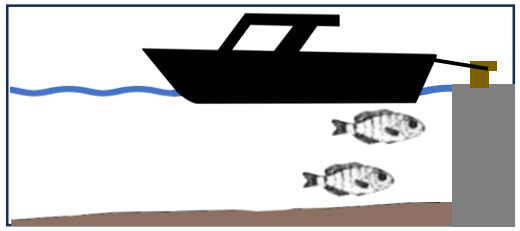
Nursery area

Natural (~ 56 km)



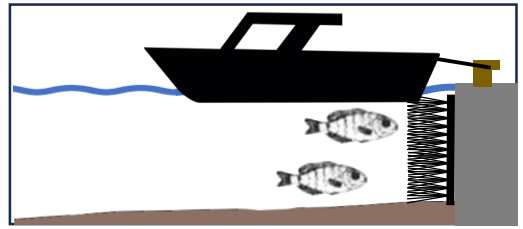
Mortality (80%)

Port (~ 25 km)



Mortality (99%)

Restaured



Mortality (80%)

1

Restauration of nursery habitats in Bay of Toulon

Ecological gains
(population abundance)

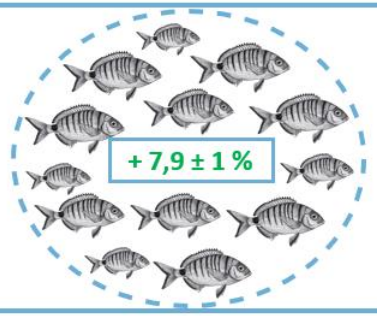
+ 109 %

+ 79 %

+ 16 %

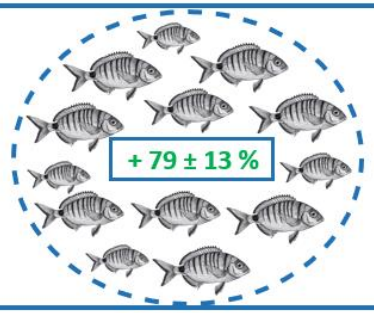
+ 7,9 %

S1: + 6 080 m de quais réhabilités

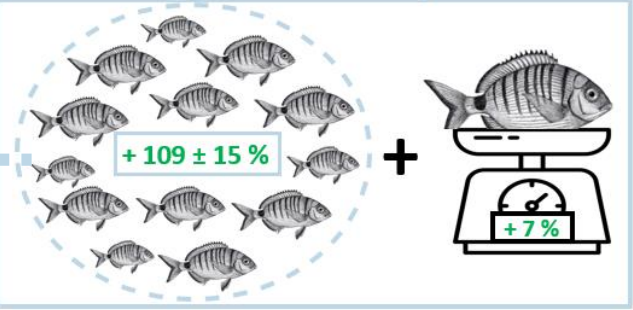


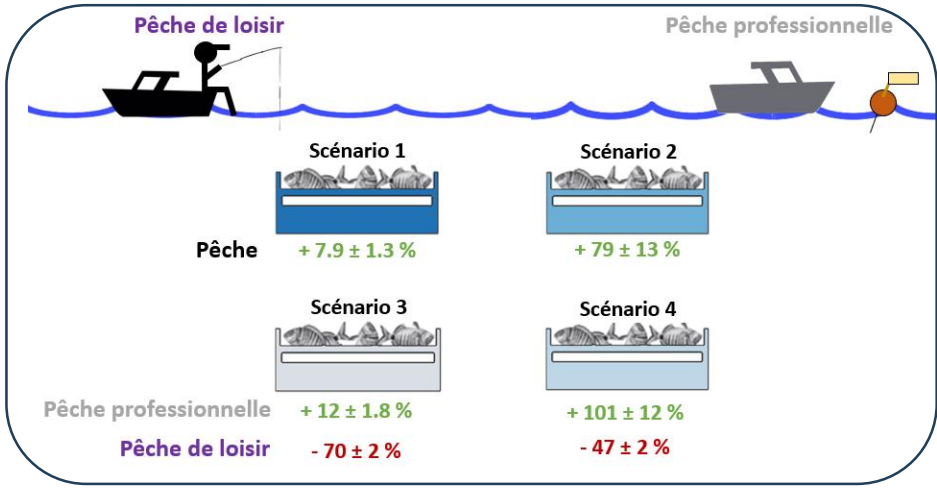
S3: Pas de pêche des individus < 23cm

S2: + 60 800 m de quais réhabilités



S2 + S3

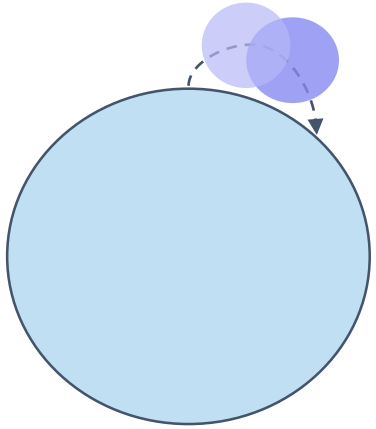




Limits

1 Restauration of nursery habitat in Bay of Toulon

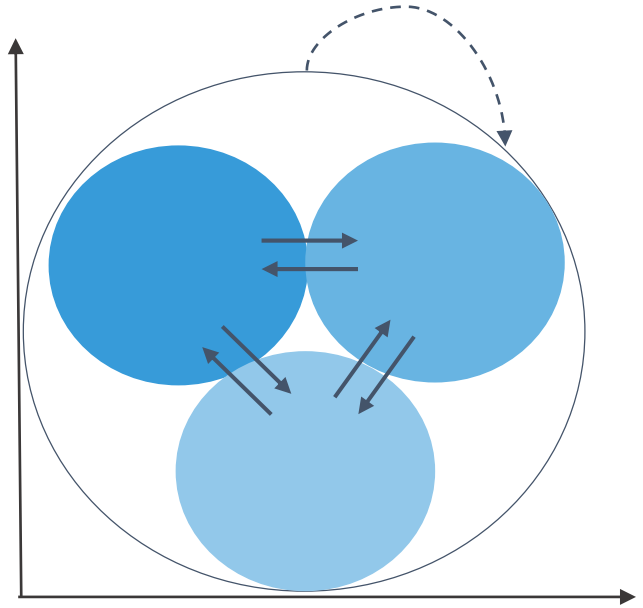
- **Uniform** adult and juvenil **distribution**
- **Uniform fishing activity**
- **No larval dispersal** representation
- General results to be taken with caution



Second case study

2

Multi-levels MPA networks in Golfe du Lion MP



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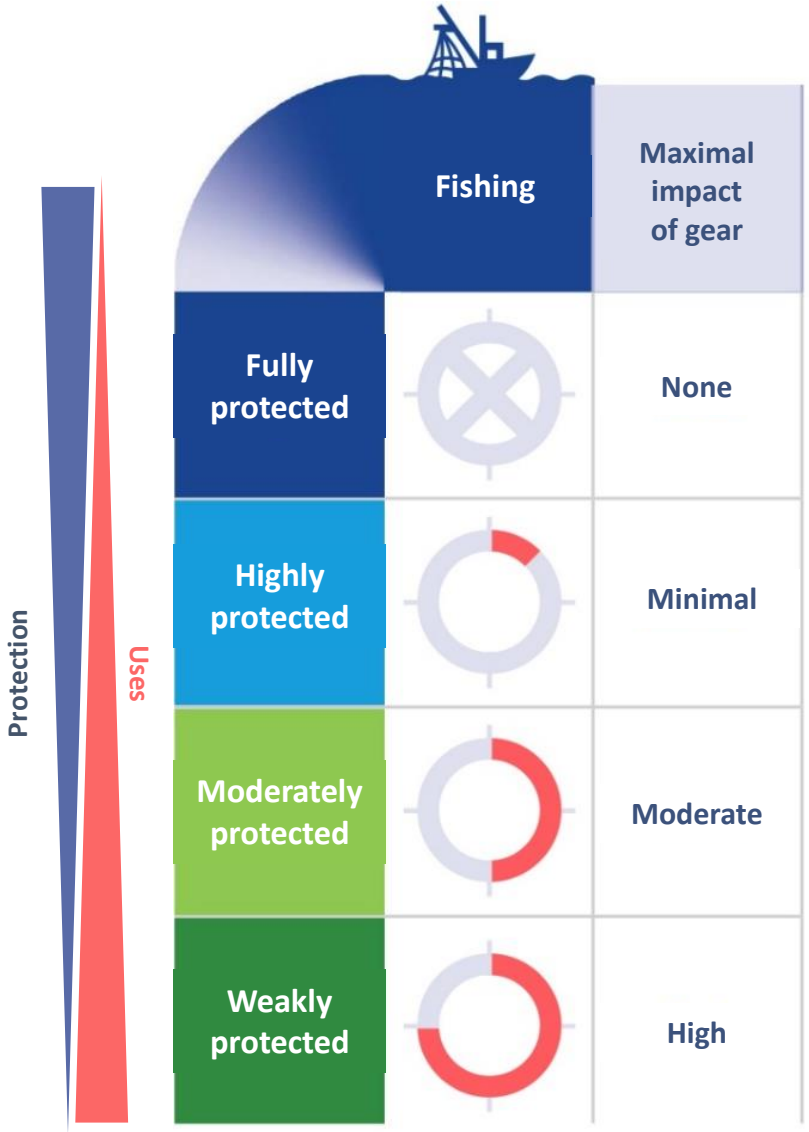

Question

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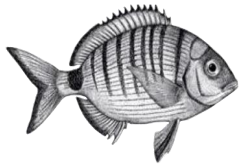
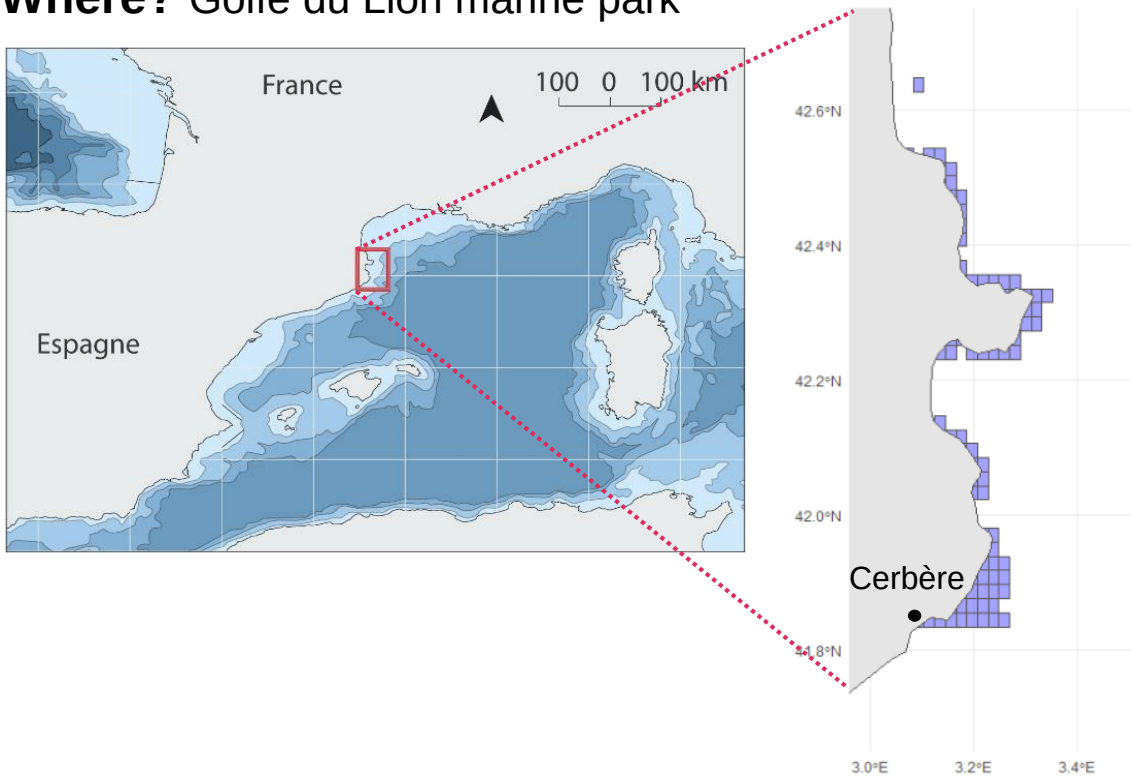
- What is the **impact on specific gear types**?

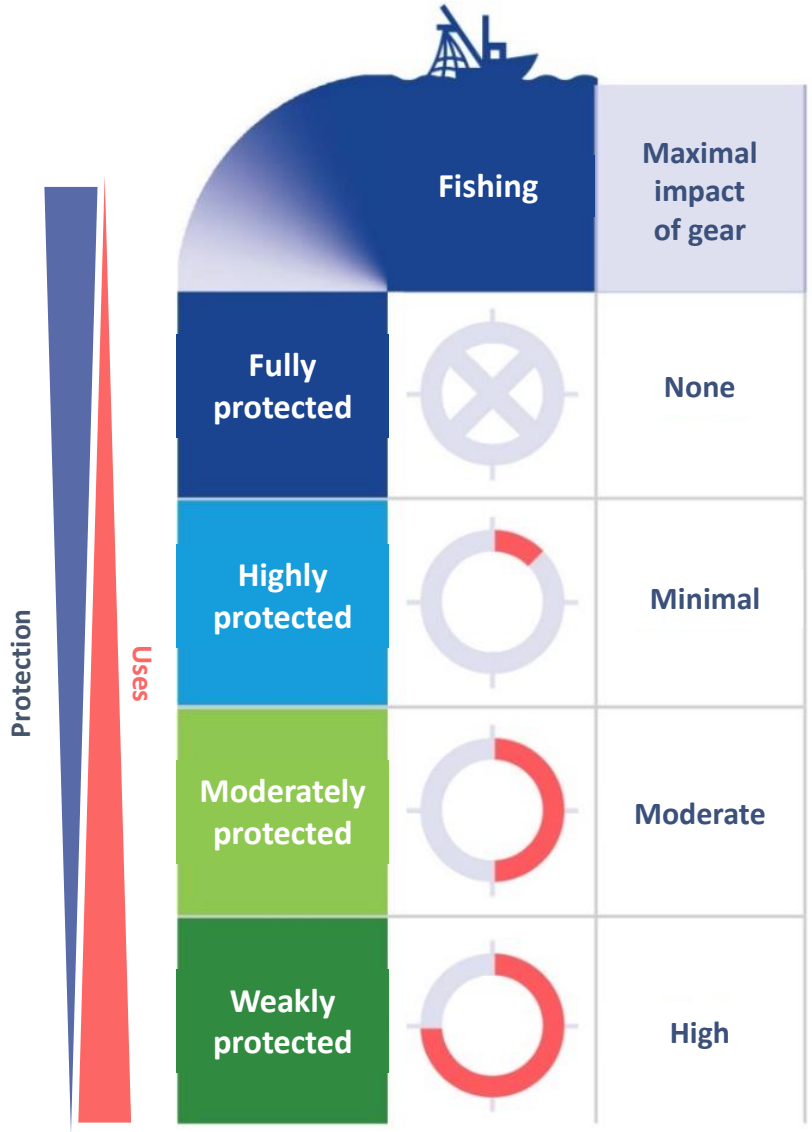


Where? Golfe du Lion marine park



The MPA Guide

Multi-levels MPA networks in Golfe du Lion MP



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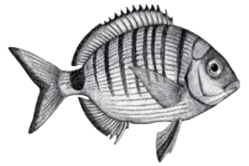


Processes

- Population dynamic
- **Multi-fleet** fisheries
- **Larval dispersal**
- Spatially explicit

Data

- Connectivity matrix for a resolution 2x2km
  → *Influence our resolution choice*
- No data data on spatial allocation of fishing effort
  → *Homogeneous fishing effort (hypothesis)*

The MPA Guide

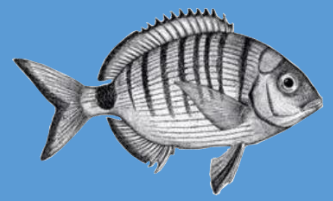
2

Multi-levels MPA networks in Golfe du Lion MP

Strategy

- Adult areas and spatial variability of abundance
- Fishing effort associated with each metier

Adult area



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Fishing effort

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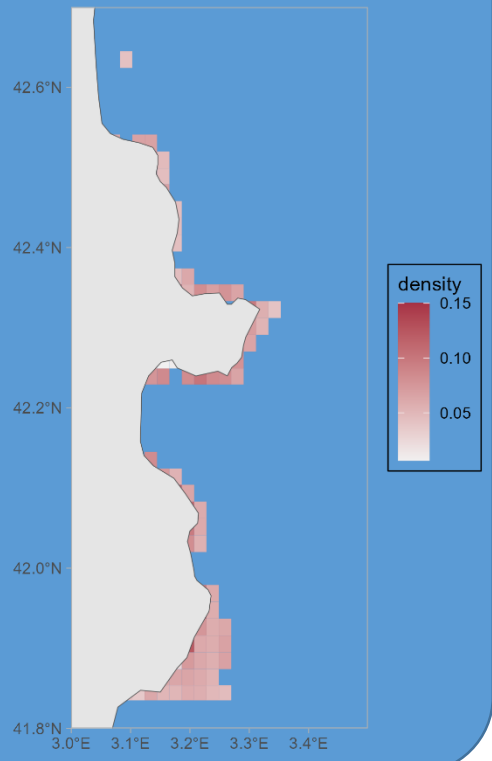
Variable abundance

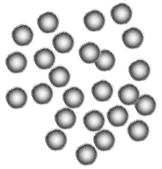


Reproduction

Eclosion

Dispersal

Eggs



Larvae

Mortality (99%)

Connectivity matrix

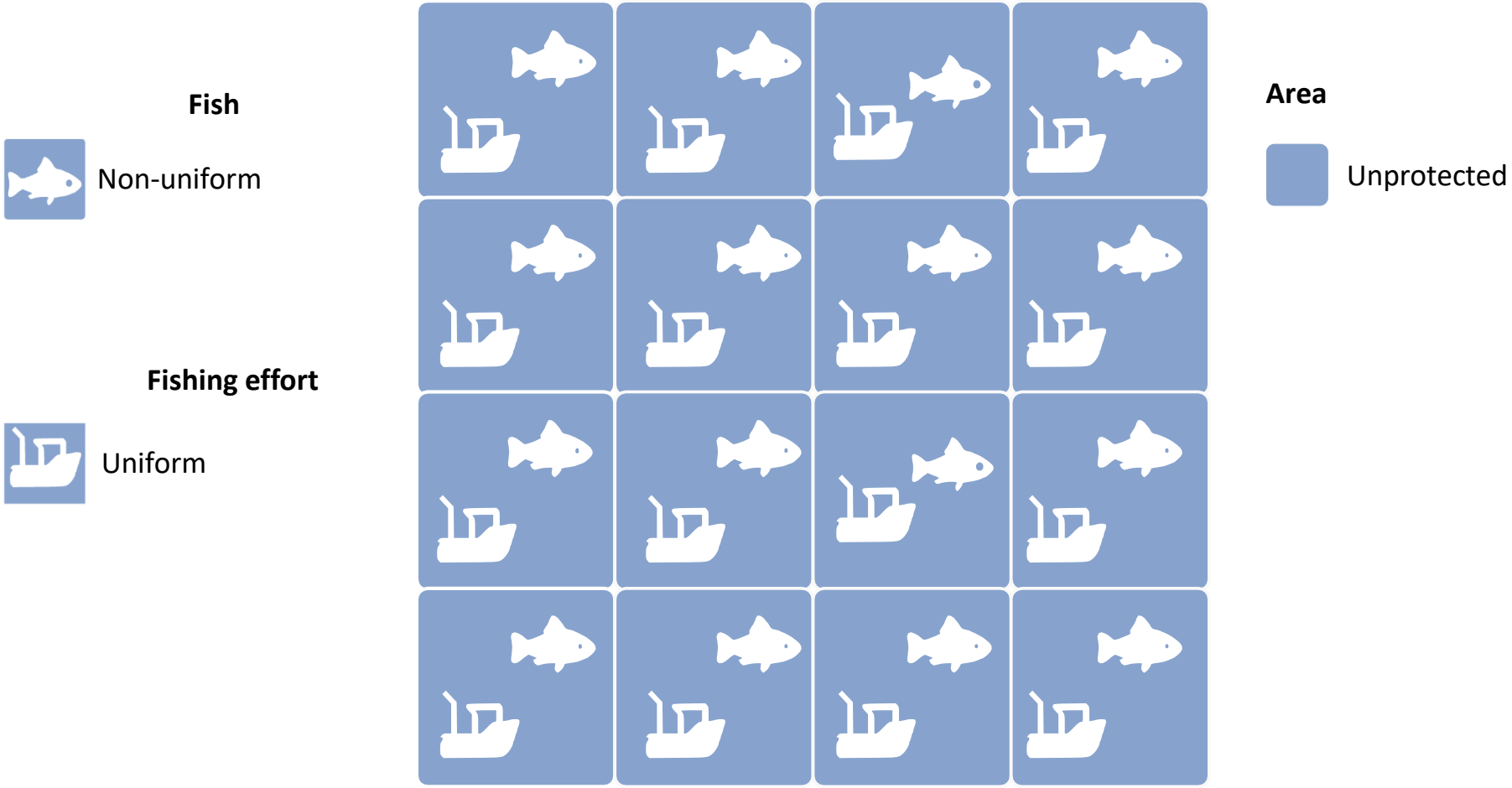
Nursery area

2

Multi-levels MPA networks in Golfe du Lion MP

Strategy

- Adult areas and spatial variability of abundance
- Fishing effort associated with each metier
- MPAs and fishing effort displacement



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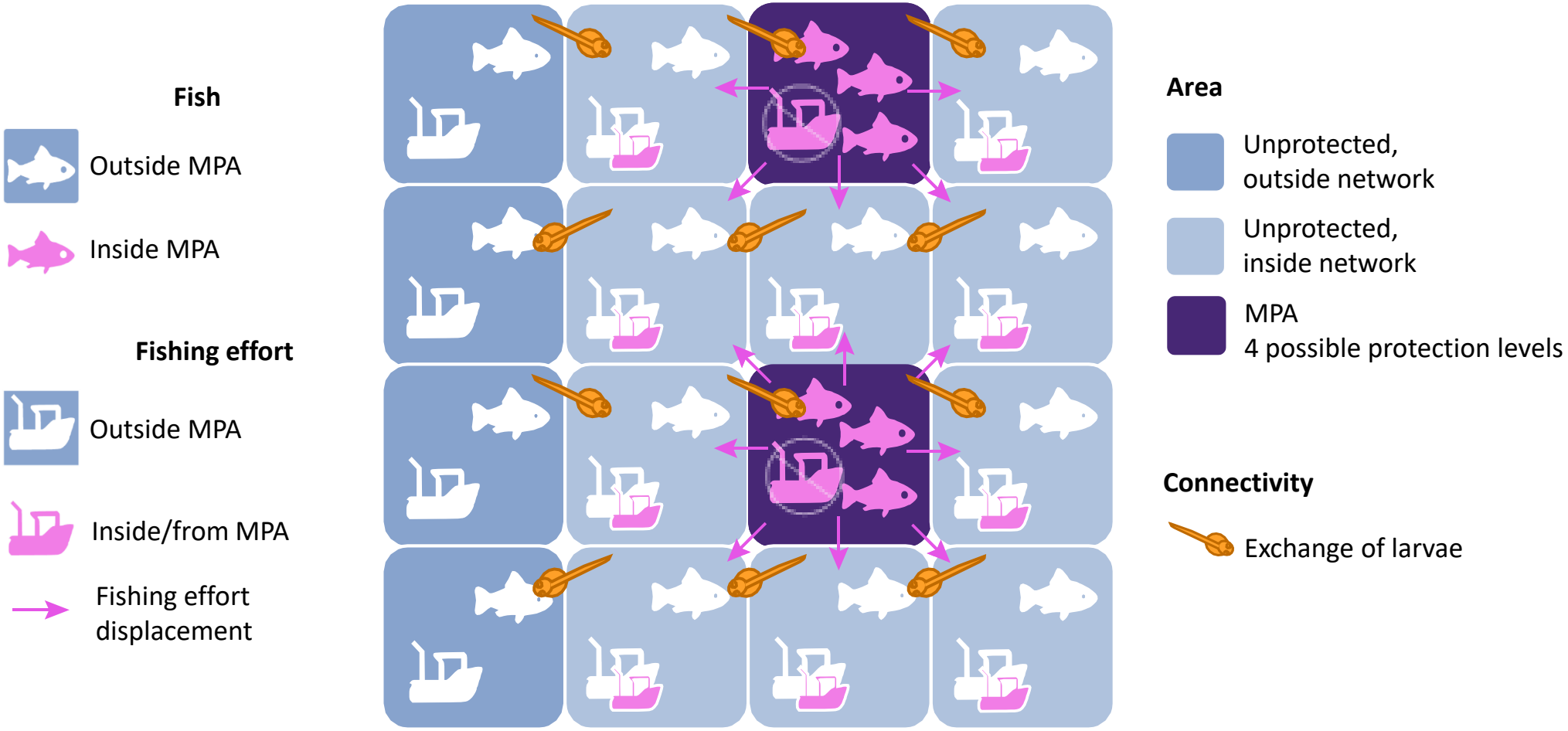

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Multi-levels MPA networks in Golfe du Lion MP

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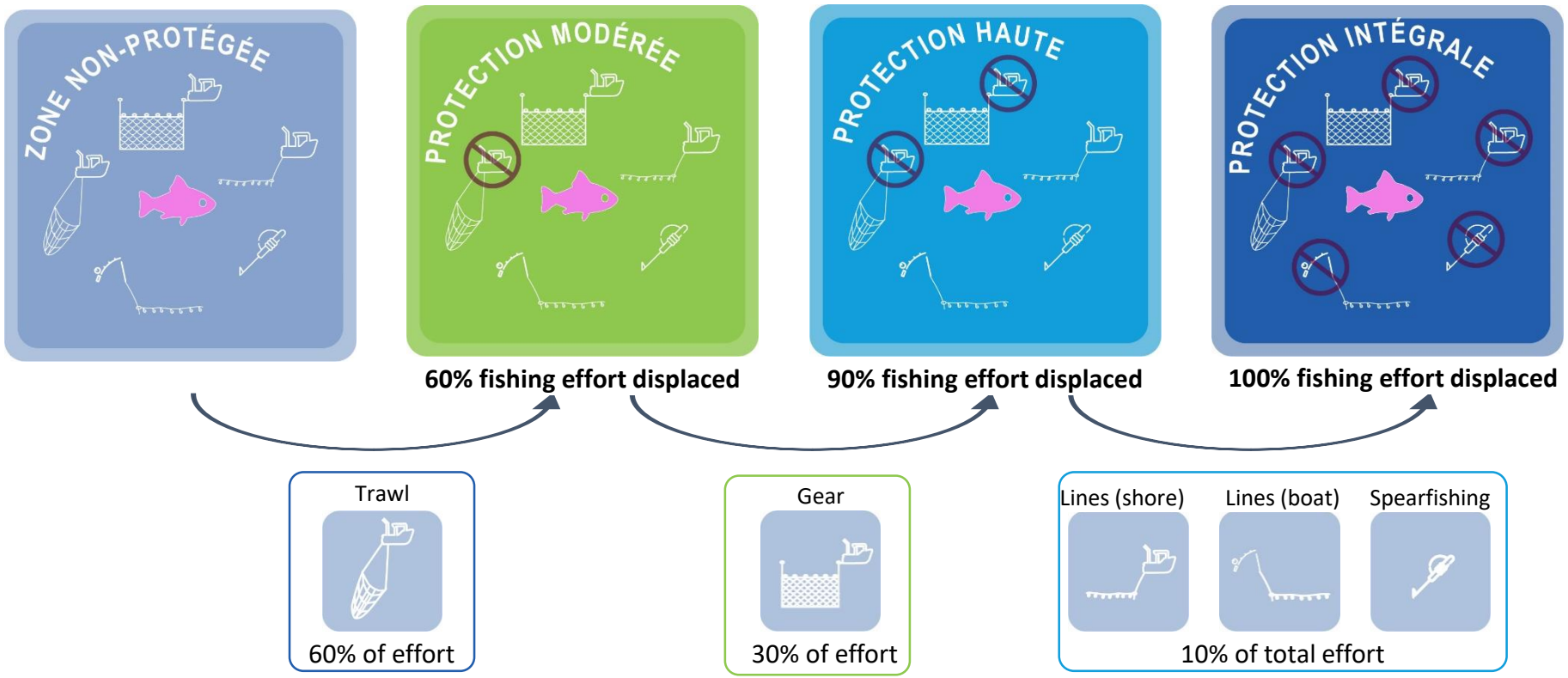
- Fishing effort associated with each metier
- MPAs and fishing effort displacement
- Levels of protection



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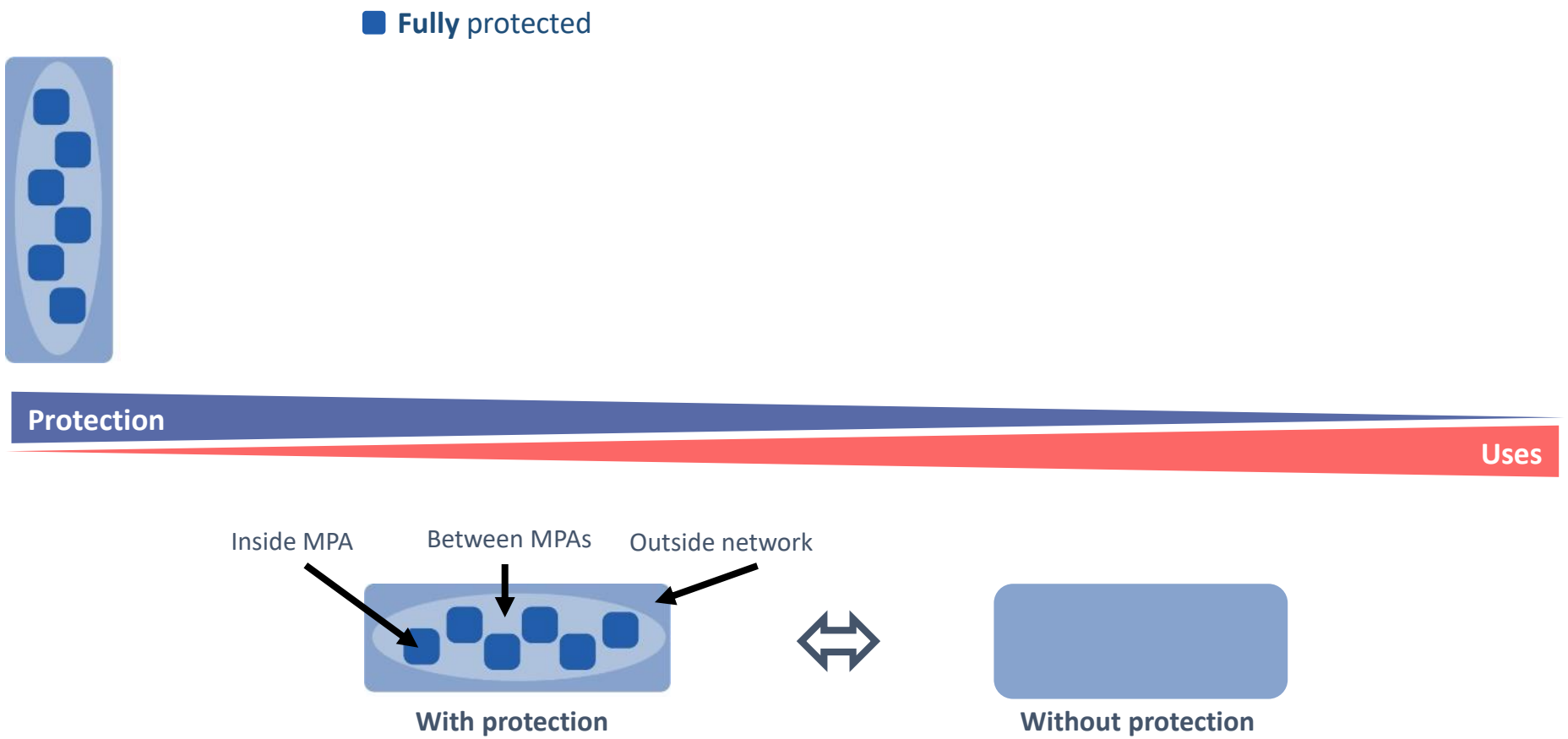
Multi-levels MPA networks in Golfe du Lion MP

Strategy

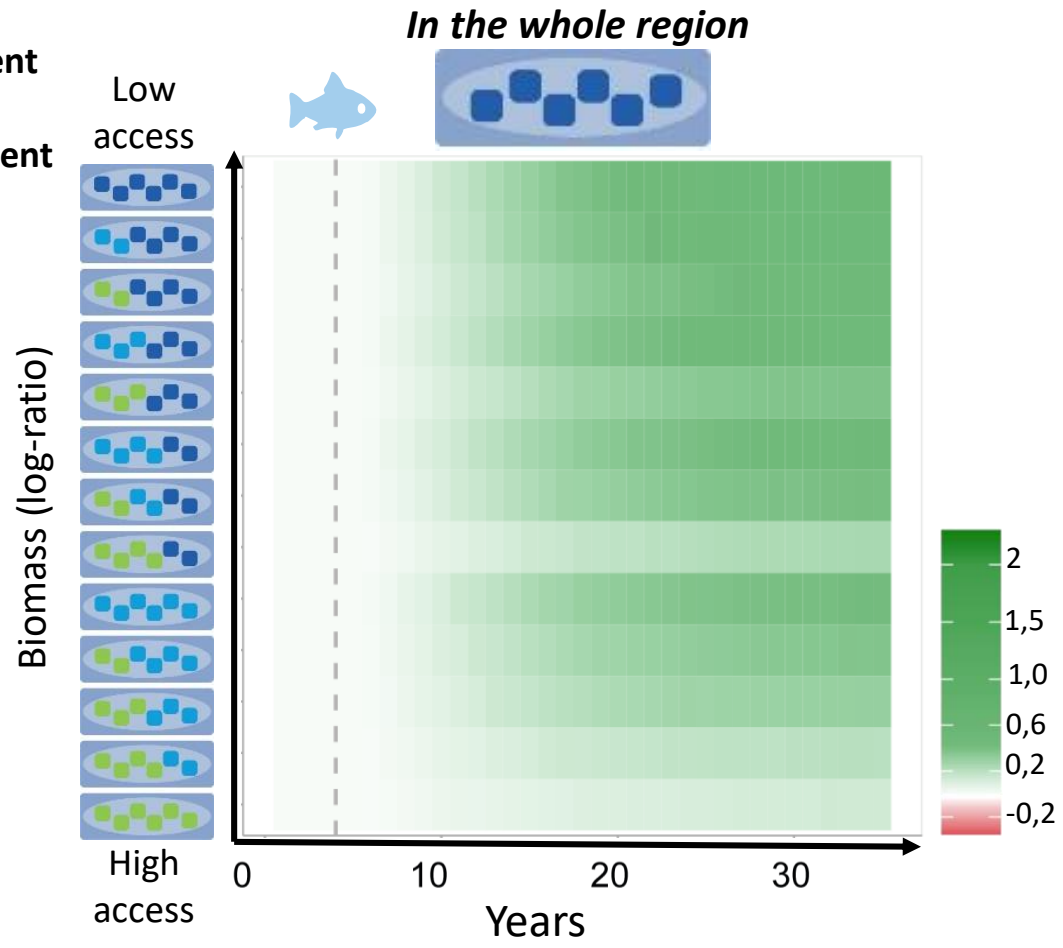
- Adult areas and spatial variability of abundance
- Fishing effort associated with each metier
- MPAs and fishing effort displacement
- Levels of protection
- Management scenarios

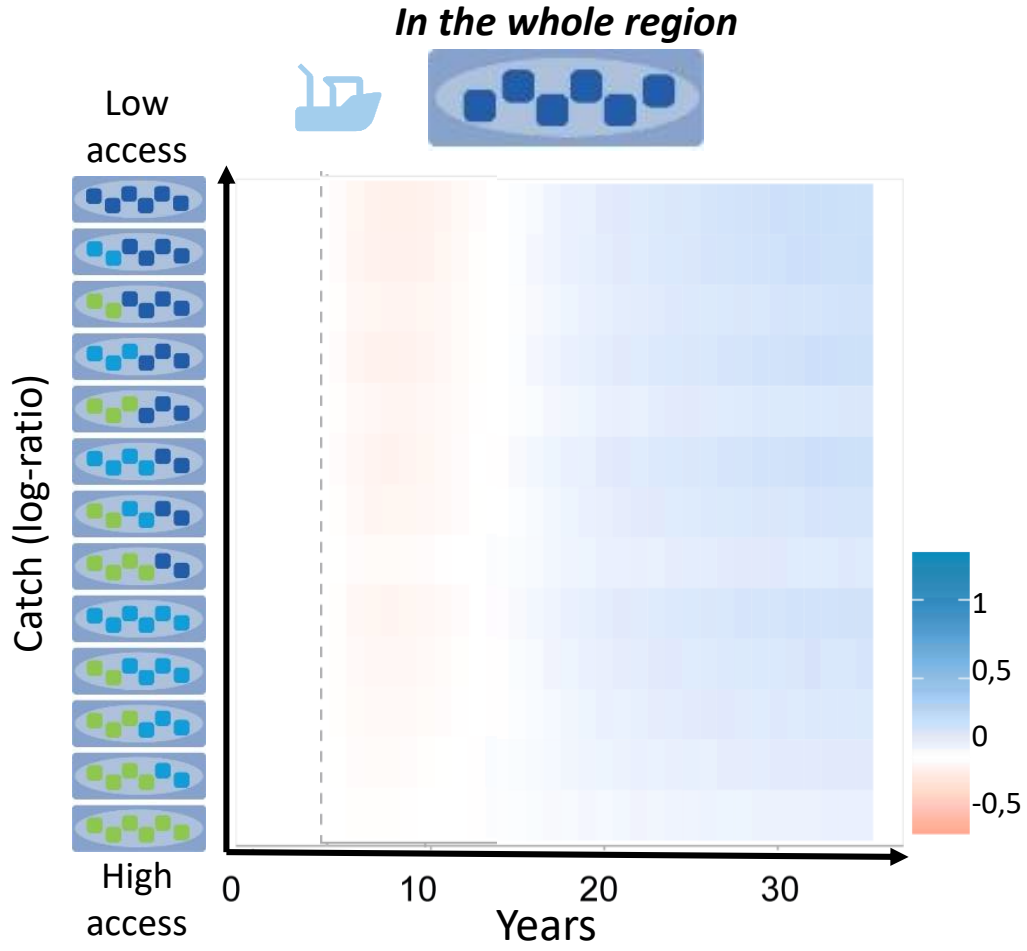


2

Multi-levels MPA networks in Golfe du Lion MP

Management
vs.
Ø management





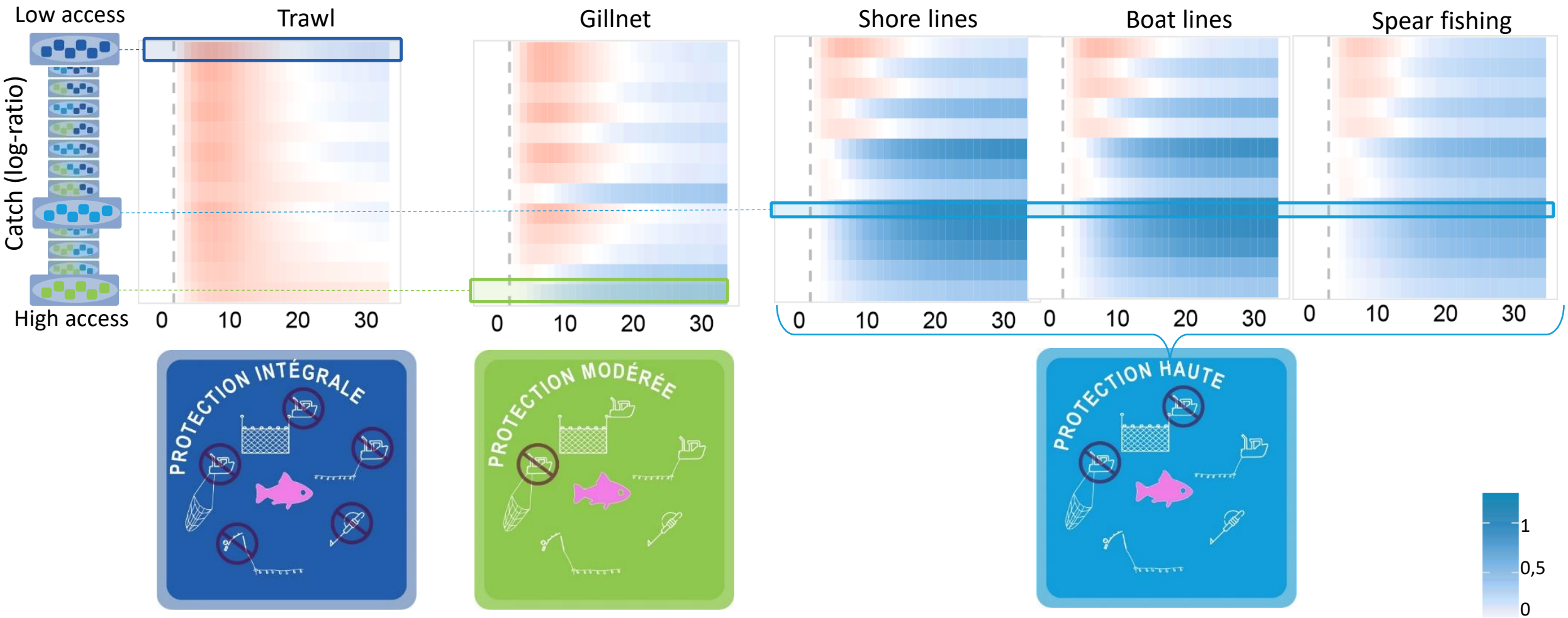
Maximum gains are long term with full and high protection

Catch losses in the short term and gains in the long term

2

Multi-levels MPA networks in Golfe du Lion MP

Management *vs.* **Ø management**



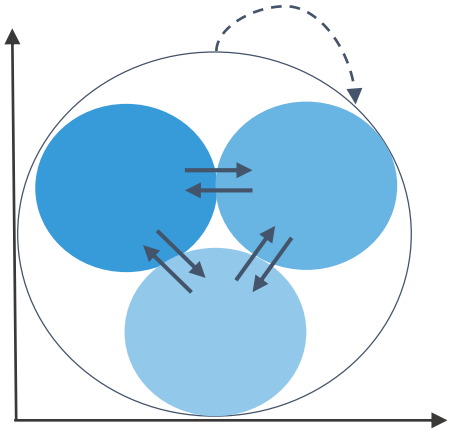
The impact of protection differ with métiers

Limits

2

Multi-levels MPA networks in Golfe du Lion MP

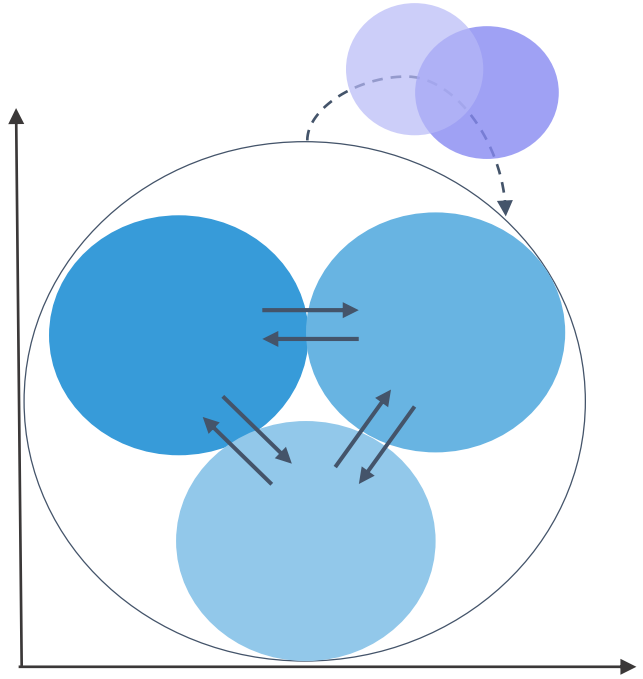
- Uniform fishing activity
  (but reallocation of fishing effort)
- Mono-species case study
- Futur development of endogeneous fishing behaviour / bio-economic model



Third case study

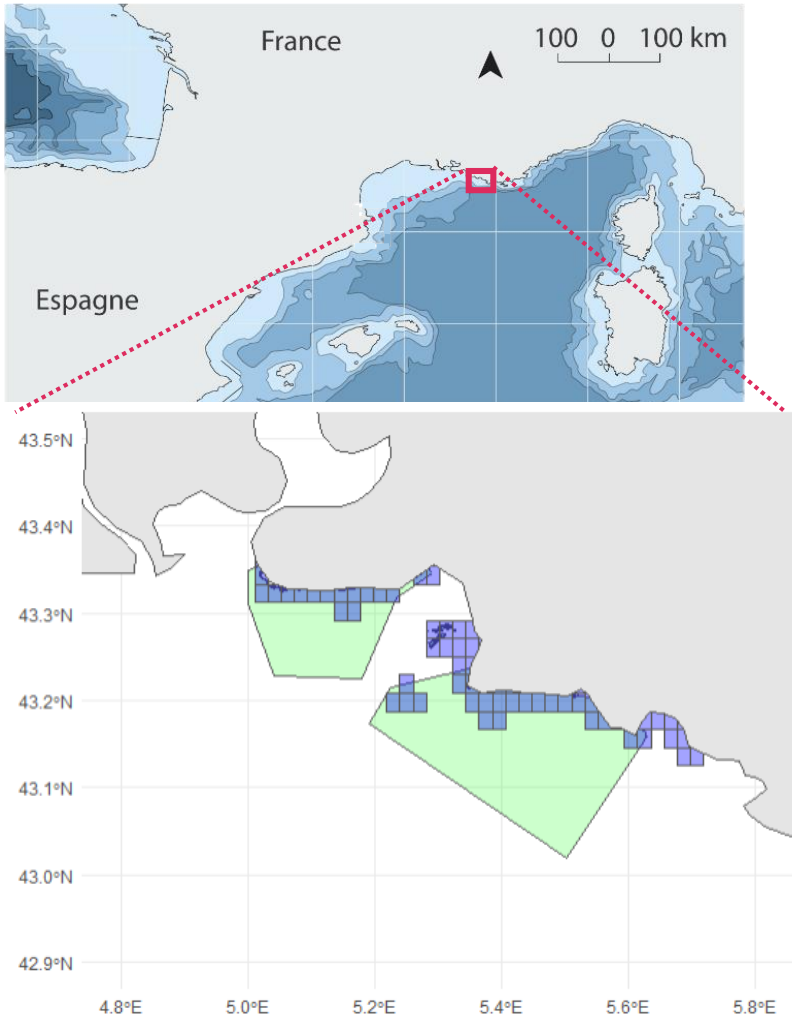
3

Restauration of nursery habitat and other management strategy in Marseille

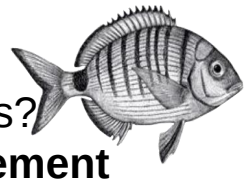


Restauration and management in Marseille

Where? Marseille



Question



- Can we describe **more precisely** the impact of **restauration** process?
- What are the impacts on population **compared to other management measures at larger scale?**

Processes

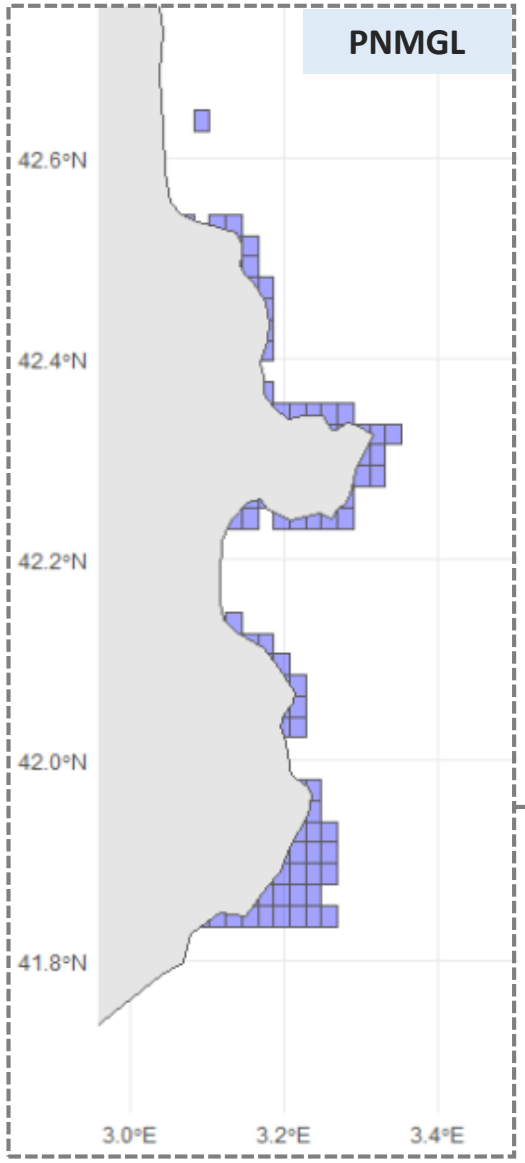
- Possibility to compare with Golfe du Lion MP model
- Larval connectivity in Marseille
- Adult and larval spatial abundance

Data

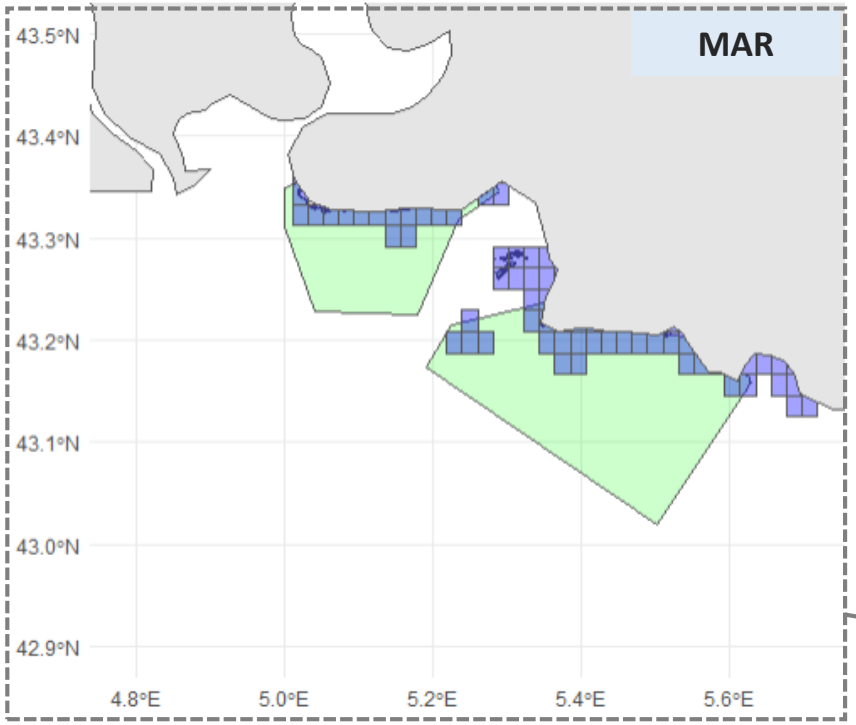
- Connectivity data at the NWM scale
- Model testing multi-level MPAs in Golfe du Lion

Do we need a new, bigger model, including Marseille and Banyuls?
i.e. Can the two zones be considered independent?

3 Restauration and management in Marseille



Résolution: 2,3 km de côté



Résolution: 2,3 km de côté

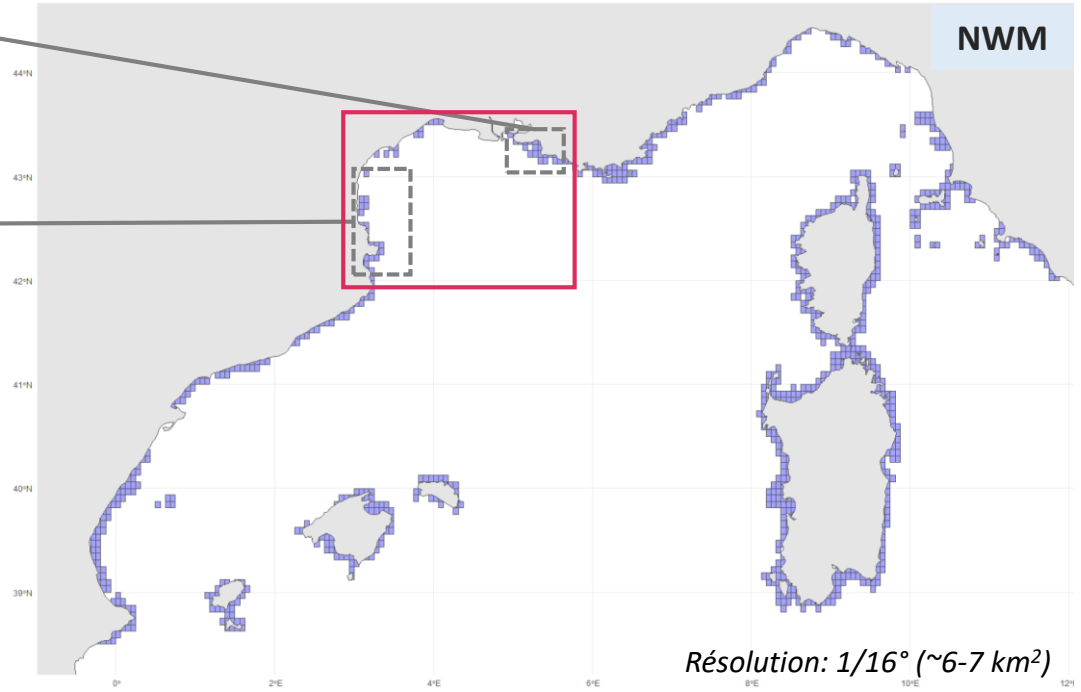
Strategy

- Determine spatial scale

2 sub-models

1 larger model

→ Need to study the connectivity of the region



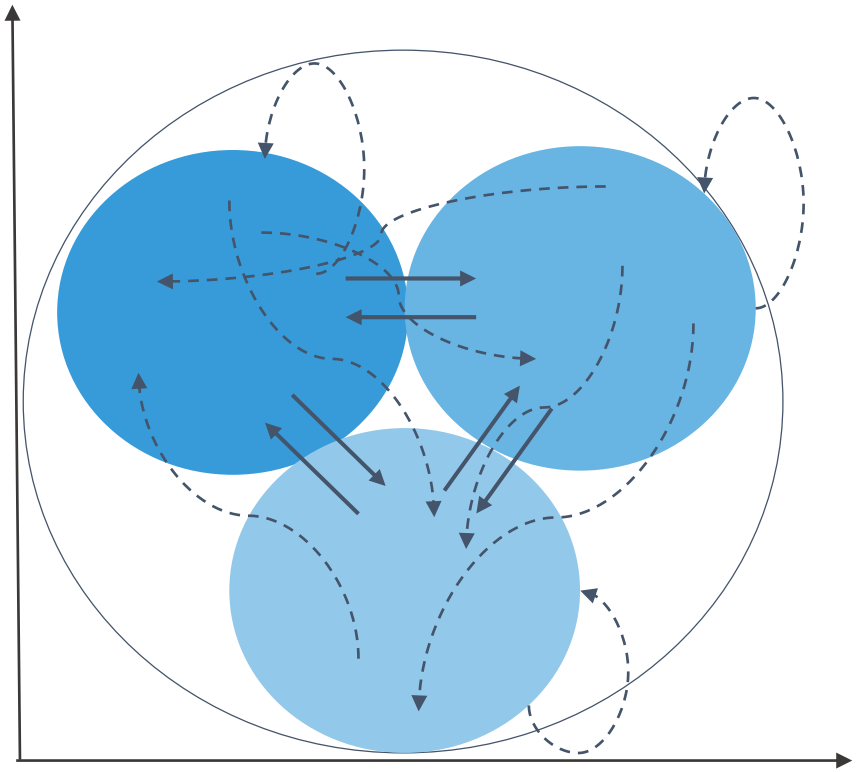
Résolution: 1/16° (~6-7 km²)

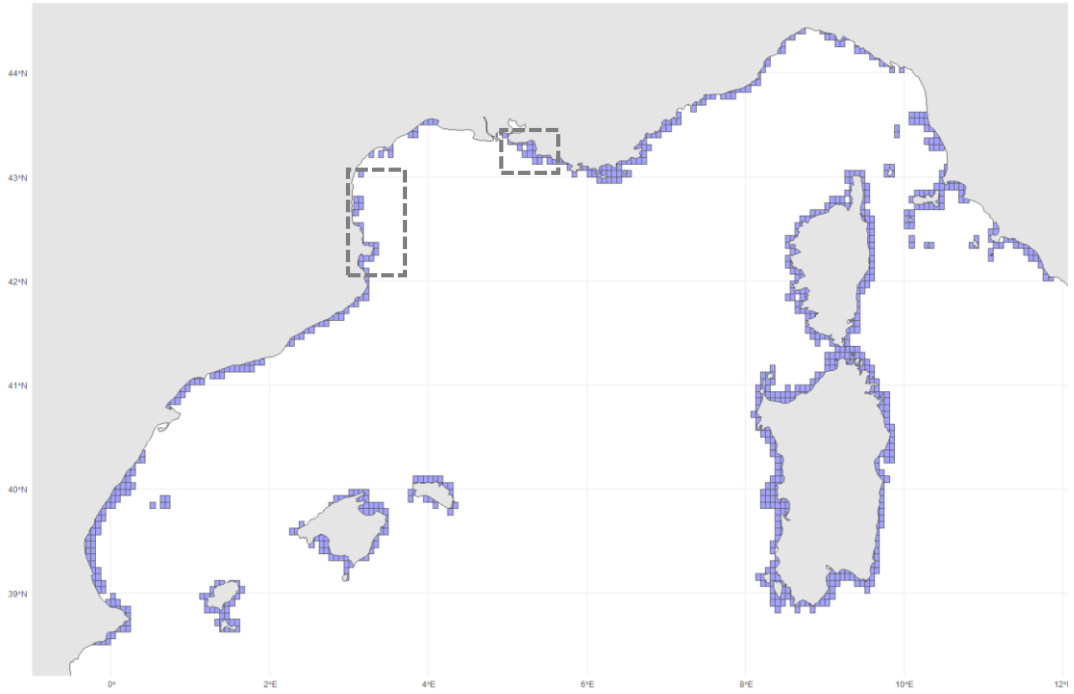
Restauration and management in Marseille

Strategy

- Determine spatial scale

Lagrangian model → Study larval connectivity in the area



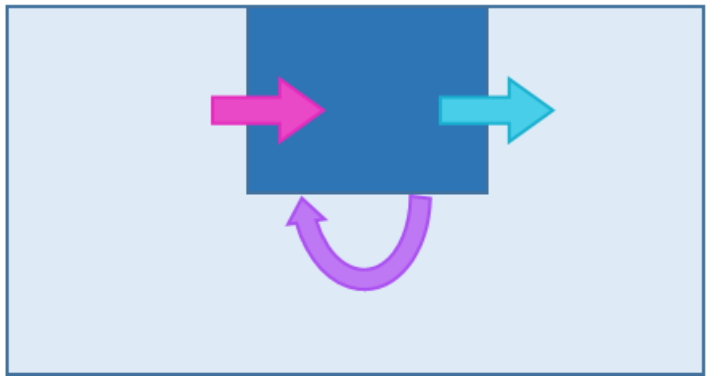


Restauration and management in Marseille

Strategy

- Determine spatial scale
  - Langrangian model
  - Indicator calculation

Flux



Importation

Exportation

Local production

$$Imp = \frac{\sum_{i \in z_M} A_i}{\sum_{i=1}^{N} A_i}$$

Number of particle arrived into the area

Number of particle arrived anywhere

$$Exp = \frac{\sum_{i \in z_M} D_i}{\sum_{i=1}^{N} D_i}$$

Number of particle produced in the area

Number of particle arrived anywhere

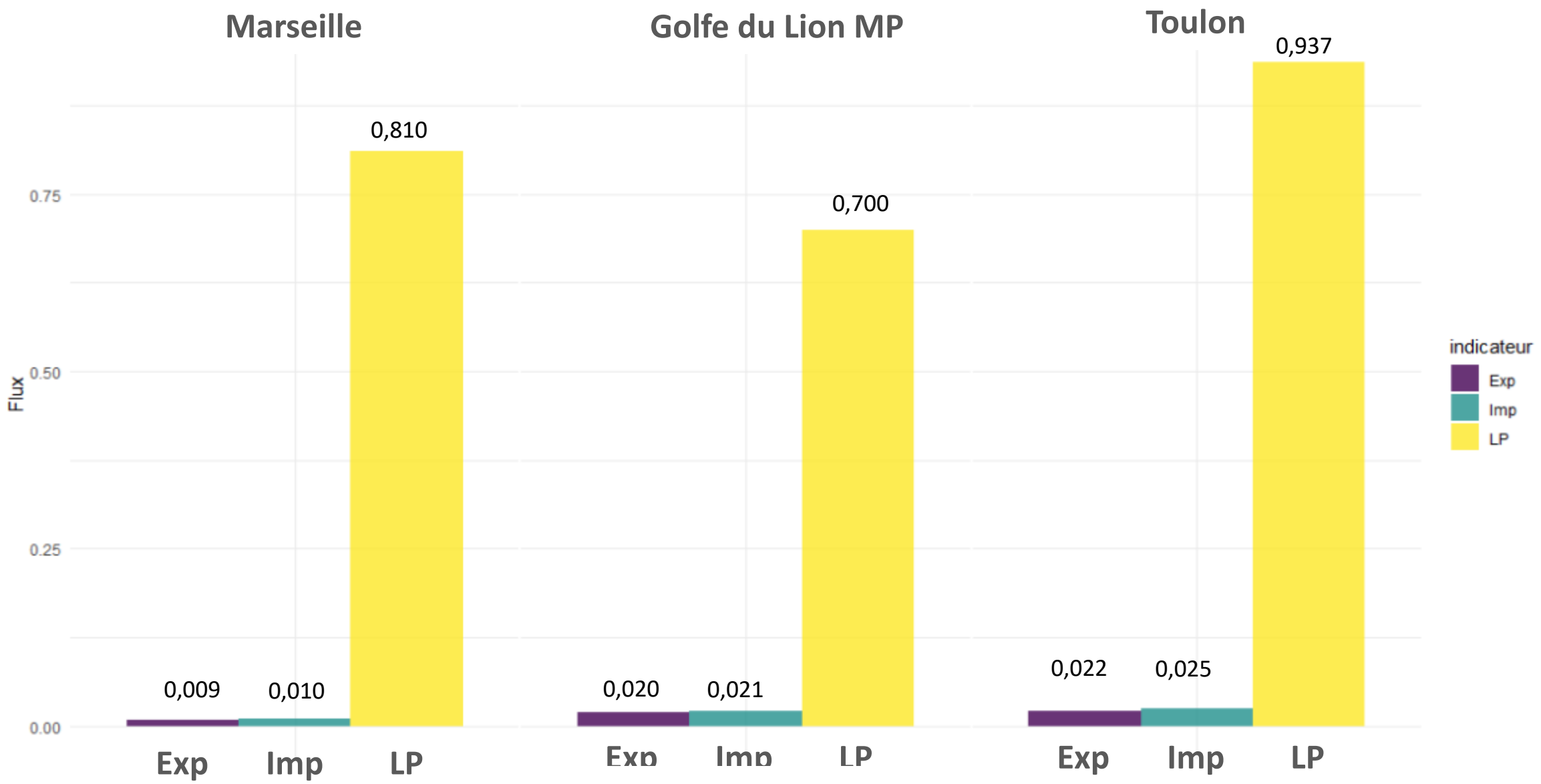
$$LP = \frac{\sum_{i,j \in z_M} A^*_{i,j}}{\sum_{i \in z_M} A_i}$$

Number of particle released in the area that stay in the area

Number of particle released in the area

3

Restauration and management in Marseille



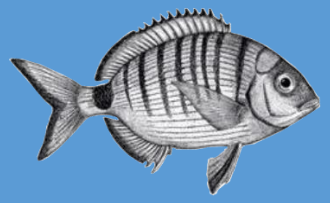
3

Restauration and management in Marseille

Strategy

- Determine spatial scale
- Build Marseille sub-model

Adult area



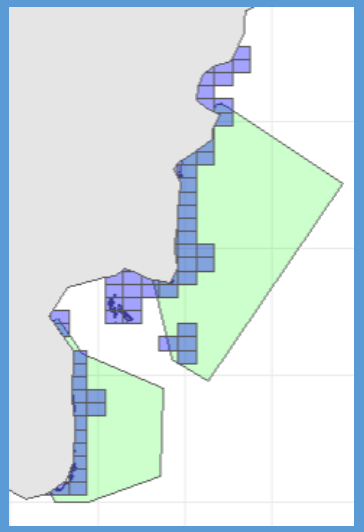
14 age group

Natural mortality (26%)

Fishing effort

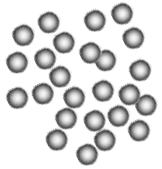
- Professional fishing
- Recreational fishing

Variable abundance



Reproduction

Eggs



Eclosion

Larvae

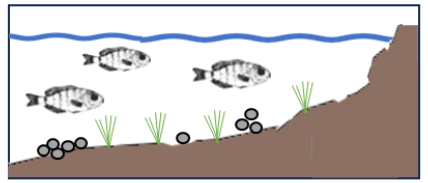
Mortality (99%)

Dispersal

Connectivity matrix

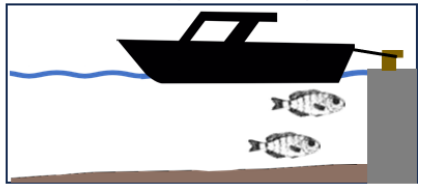
Nursery area

Natural (~ 56 km)



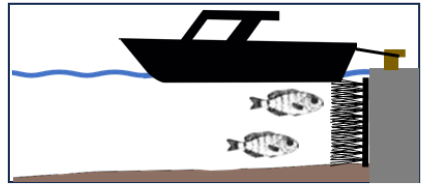
Mortality (80%)

Port (~ 25 km)



Mortality (99%)

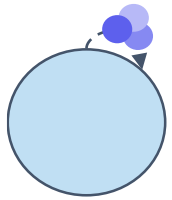
Restaured



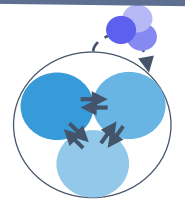
Mortality (80%)

Conclusion

Increasing spatial complexity

Marseille 

Golfe du Lion MP

Toulon 

Question	Impact of **artificial nurseries** at the fish **populations level**?	Impact of **multi-level MPA networks** on a fish population?	**Comparing** mpact of **artificial nurseries** with MPA networks in a wider area?
Processes	• Spatial model • Population dynamic • Recruitment	• Spatial model • Multi-fleet • Larval connectivity	• Spatial model • Multi-fleet • Larval connectivity • Recruitment
Data	• No fine scale pop data	• Spatial model • Multi-fleet • Larval connectivity	• Spatial model • Multi-fleet • Larval connectivity
Conclusion	• Spatially implicit strategy • Limits: uniform adullt and fishing effor distribution, no larval dispersal	• Spatially explict strategy • Resolution drived by available data • Limits: uniform fishing effort	• Spatial implicit and explicit (different strategy for different process) • Hyp: 2 independent sub models

THANK YOU FOR YOUR ATTENTION

Mathematics for bio-Economics and Sustainability of fiSHeries

MESSH 2024

Brest, France

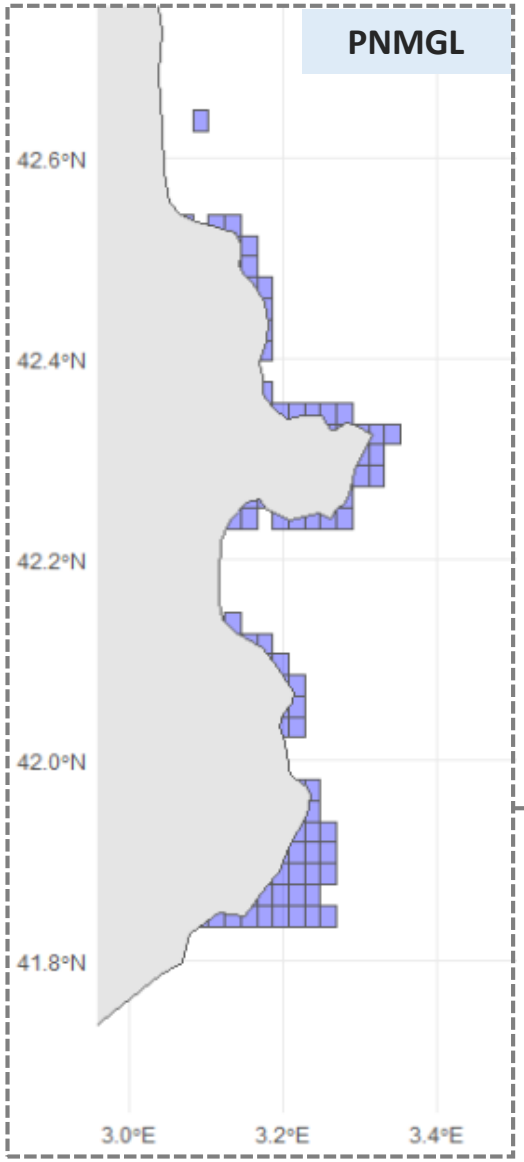
Charlotte Sève & Stéphanie Mahévas

charlotte.m.seve@gmail.com

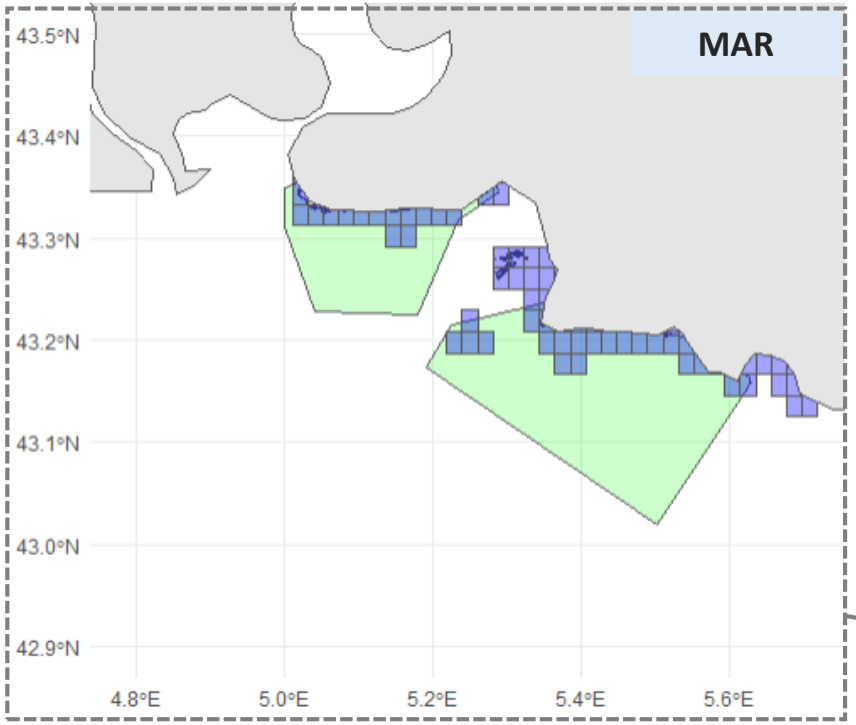
Ifremer

3

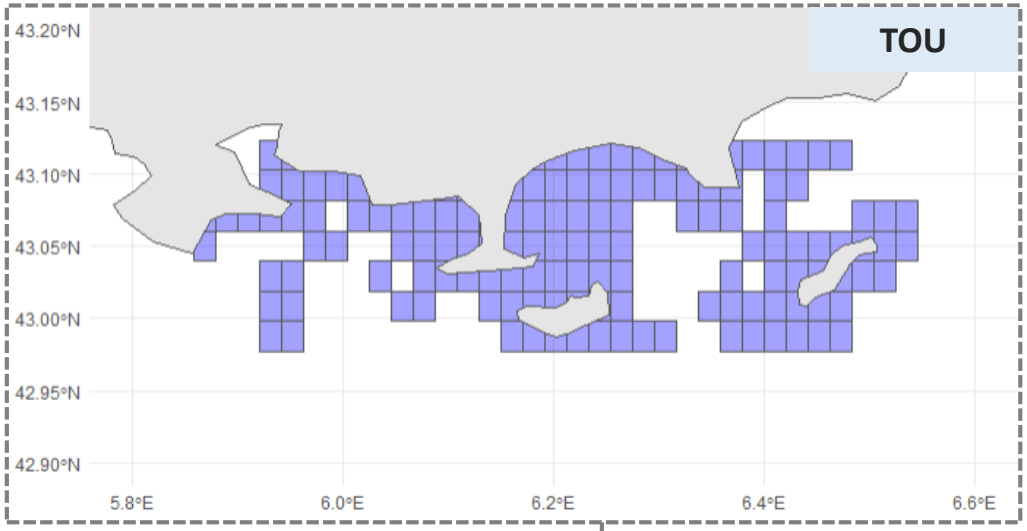
Restauration and management in Marseille



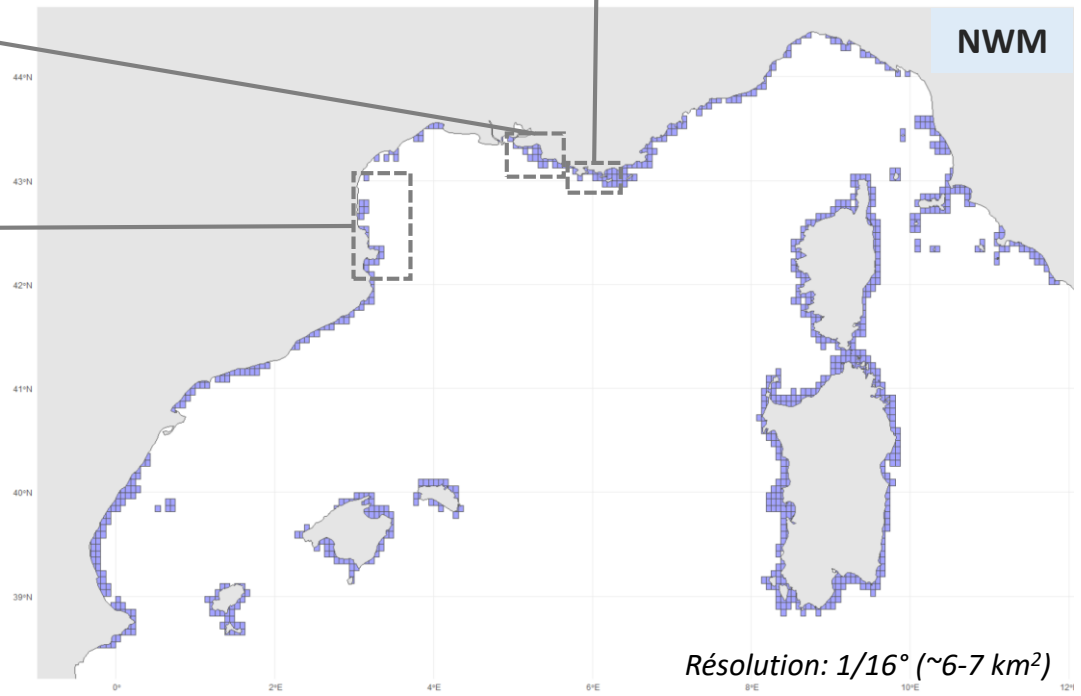
Résolution: 2,3 km de côté



Résolution: 2,3 km de côté



Résolution: 2,3 km de côté



Résolution: 1/16° (~6-7 km²)

Définition d'indicateurs de flux larvaires

D_i Nombre de particules lachées de i

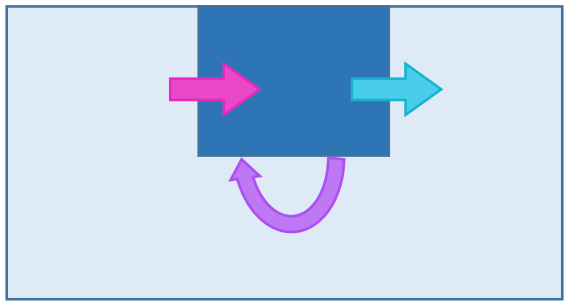
A_i Nombre de particules arrivées en i

$A^*_{i,j}$ Nombre de particules lachées en i et arrivées en j

$C_{i,j}$ Proportion de particules lachées en i qui arrivent en j

$$C_{i,j} = \frac{A^*_{i,j}}{D_i}$$

$Flux$



Importation

Exportation

Production locale

Flux d'importation standardisé (Imp)

Quantité de larves produites hors de la zone et arrivant au sein de la zone

Nombre de p arrivées en zm

$$Imp = \frac{\sum_{i \in z_M} A_i}{\sum_{i=1}^{N} A_i}$$

Nombre de p arrivées partout

Définition d'indicateurs de flux larvaires

D_i Nombre de particules lachées de i

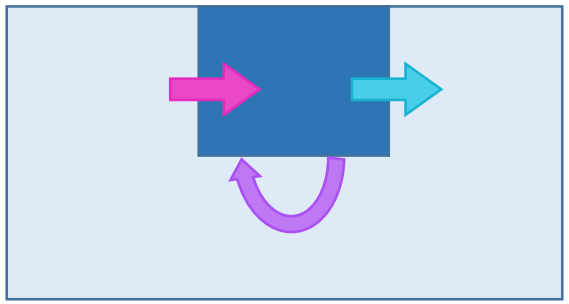
A_i Nombre de particules arrivées en i

$A^*_{i,j}$ Nombre de particules lachées en i et arrivées en j

$C_{i,j}$ Proportion de particules lachées en i qui arrivent en j

$$C_{i,j} = \frac{A^*_{i,j}}{D_i}$$

$Flux$



Importation

Exportation

Production locale

Flux d'exportation standardisé (Exp)

Quantité de larves produites au sein de la zone et s'exportant hors de la zone

$$Exp = \frac{\sum_{i \in z_M} D_i}{\sum_{i=1}^{N} D_i}$$

Nombre de p produites en zm

Nombre de p arrivées partout

Définition d'indicateurs de flux larvaires

D_i Nombre de particules lachées de i

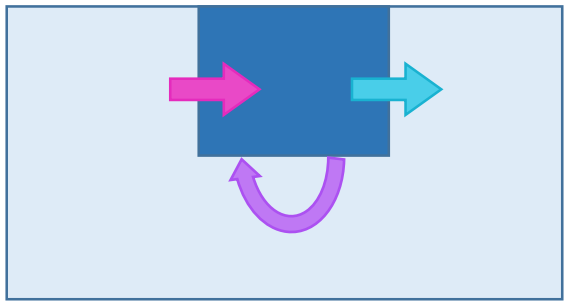
A_i Nombre de particules arrivées en i

$A^*_{i,j}$ Nombre de particules lachées en i et arrivées en j

$C_{i,j}$ Proportion de particules lachées en i qui arrivent en j

$$C_{i,j} = \frac{A^*_{i,j}}{D_i}$$

Flux



Importation

Exportation

Production locale

Production locale (LP)

Quantité de larves produites au sein de la zone et s'installant dans la zone

Nombre de p produites dans zm et arrivées dans zm (*autoproduites*)

$$LP = \frac{\sum_{i,j \in z_M} A^*_{i,j}}{\sum_{i \in z_M} A_i}$$

Nombre de p lachées en Zm