RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

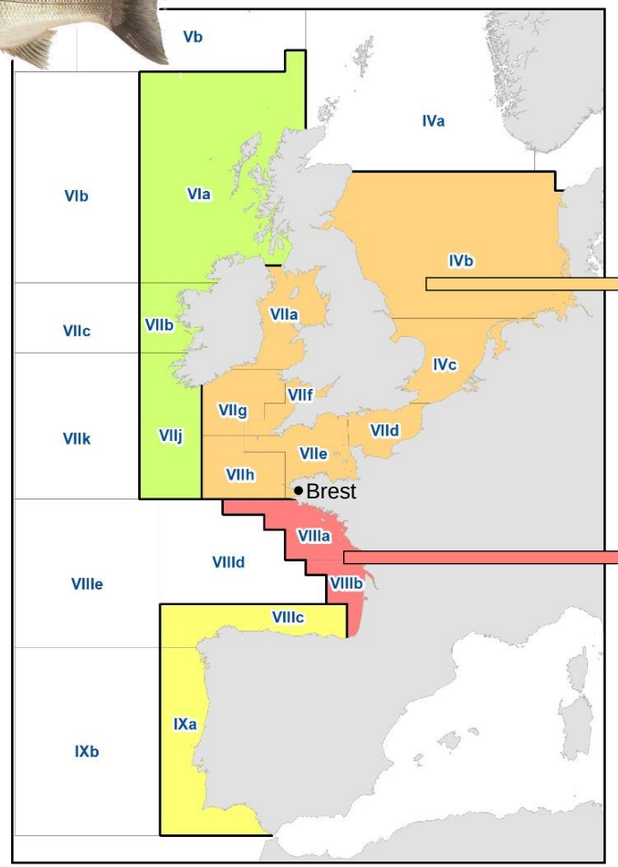
Ifremer

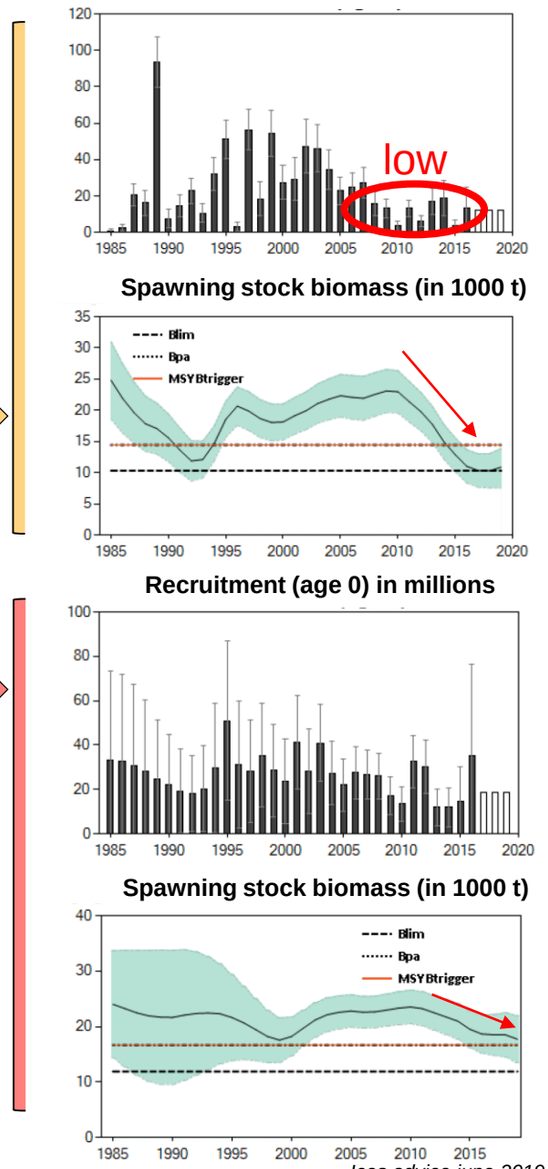
Revealing biocomplexicity of seabass life cycle and connectivity with multidisciplinary approaches

Mathieu Woillez, Michel Bertignac, et al.

17/01/2024

The European seabass

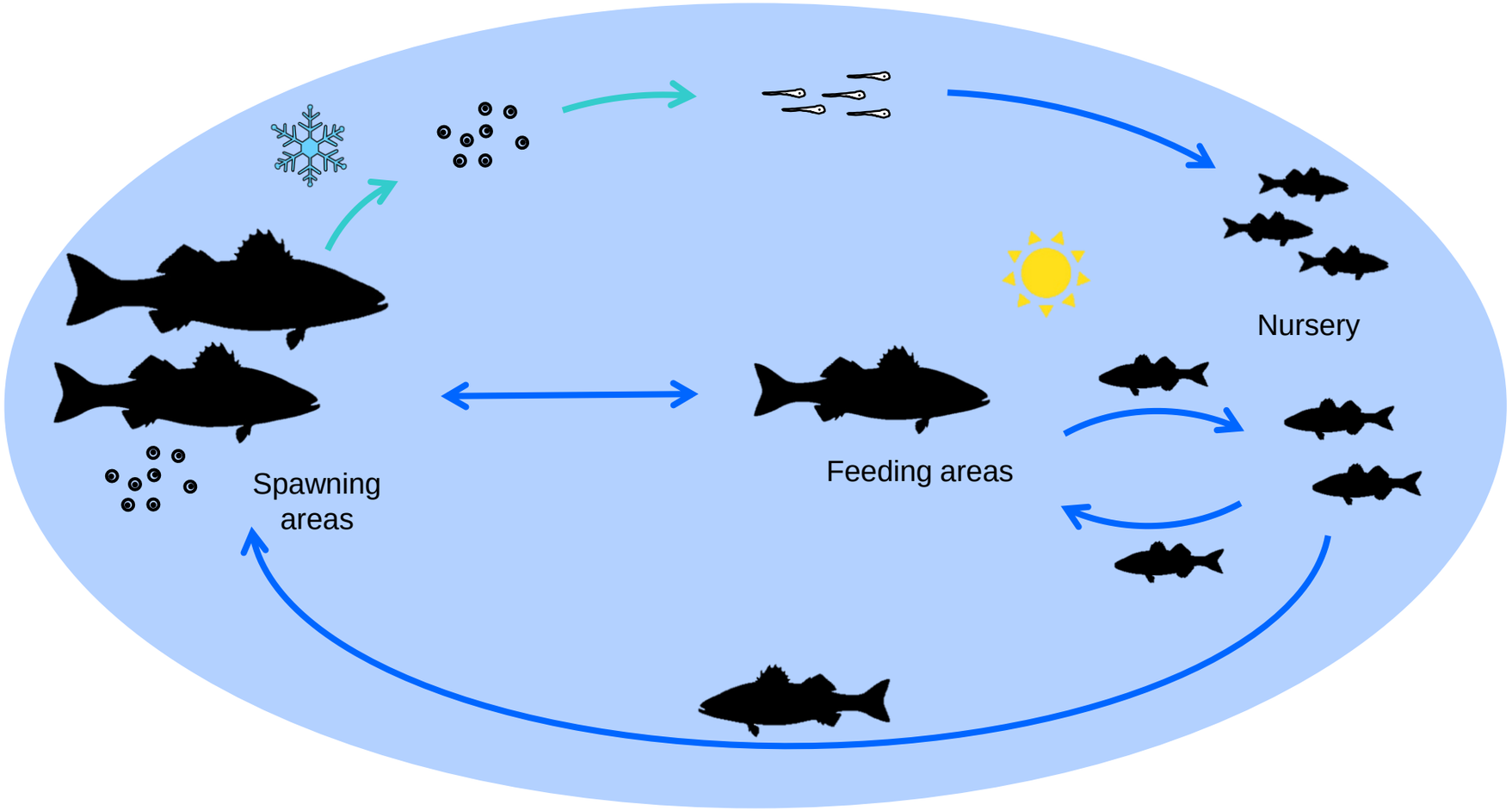




Ices advice june 2019

- A strong socio-economic weight in France : professional and recreative fishing
- Decreasing trends for two seabass stocks
- Northern stock is in a worrying state
  - High fishing pressure
  - Series of low recruitments
- Management measures since 2015
- **Knowledge gaps in the population structure and connectivity** → consequences on its actual states and its management

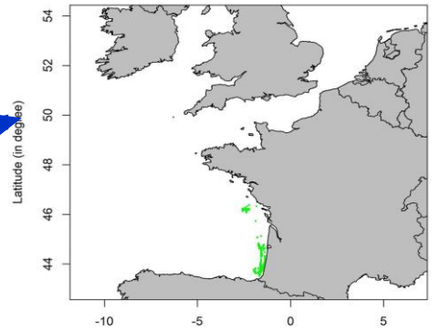
Seabass life cycle



Research on seabass life cycle and connectivity

Large

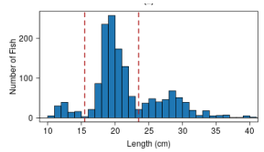
Connectivité larvaire

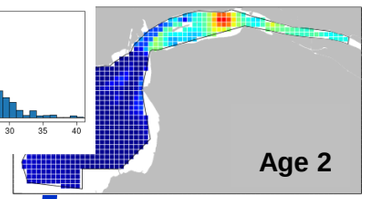


Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

Nourriceries

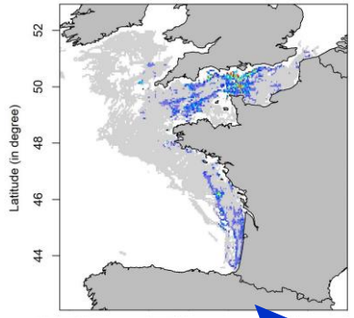




Estimation d'abondance

Roy et al. 2022

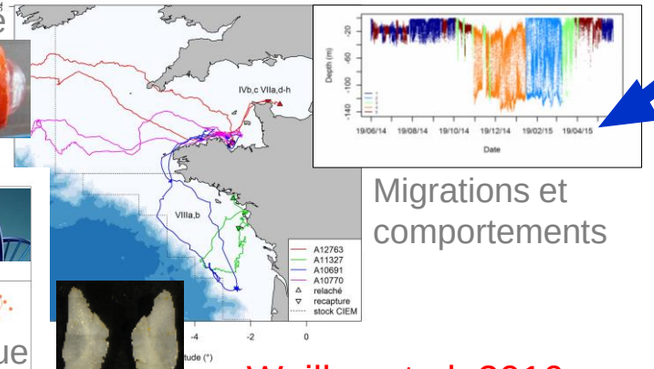
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

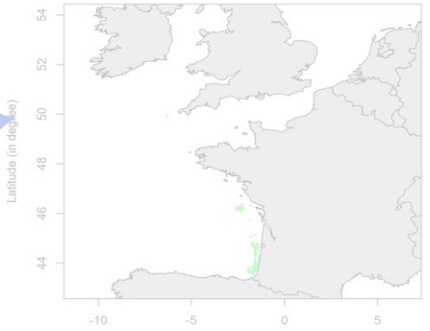
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Research on seabass life cycle and connectivity

Large

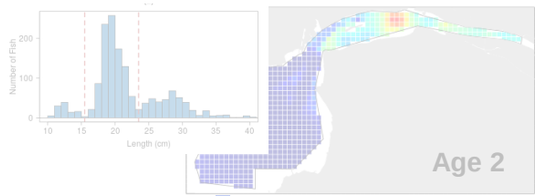
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

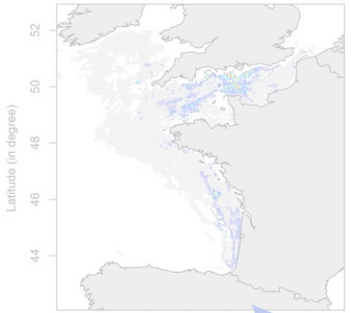
Nourriceries



Estimation d'abondance

Roy et al. 2022

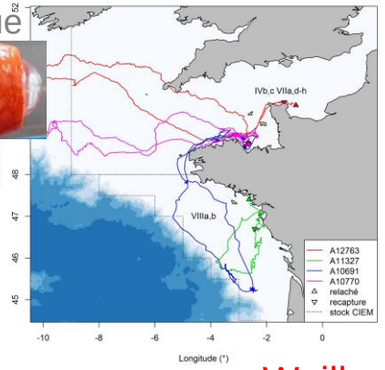
Frayères



Dambrine et al. 2021

Marque électronique

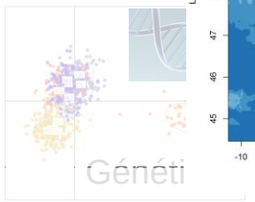
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Généti

Microchimie des otolithes

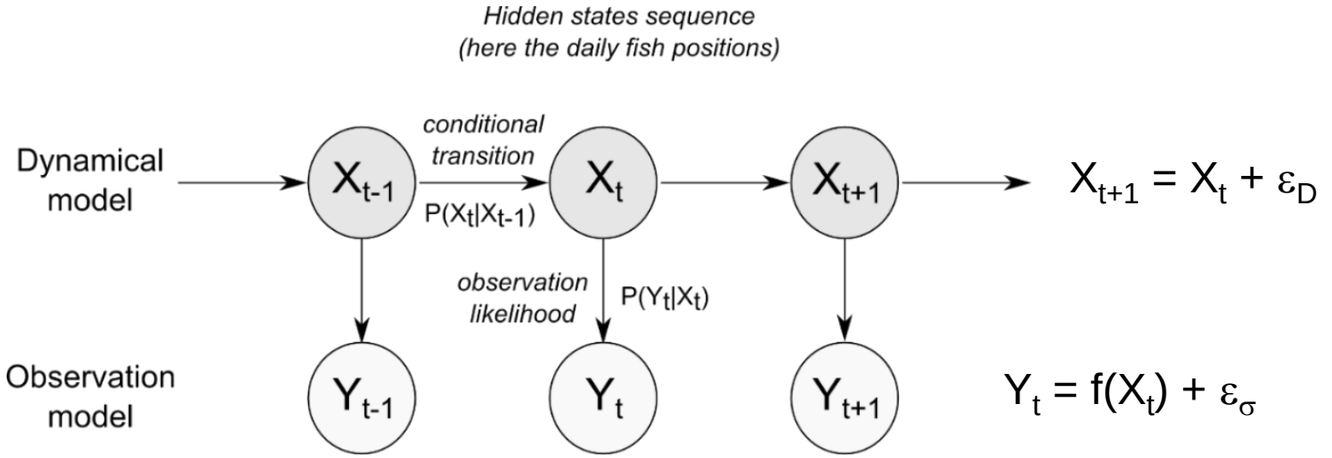
Woillez et al. 2016

Heerah et al. 2017

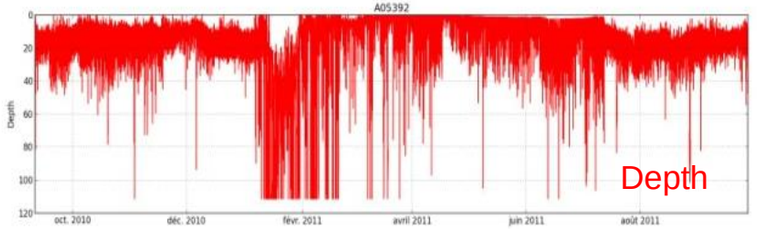
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

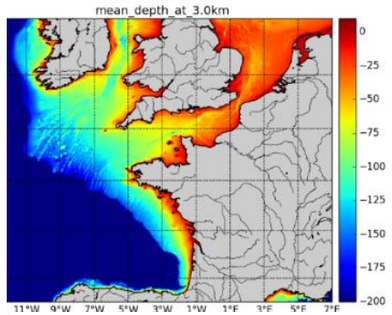
Track reconstruction using Hidden Markov Model



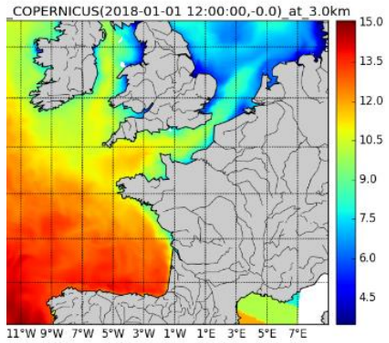
Observations sequence
(here the temperature and depth conditions)



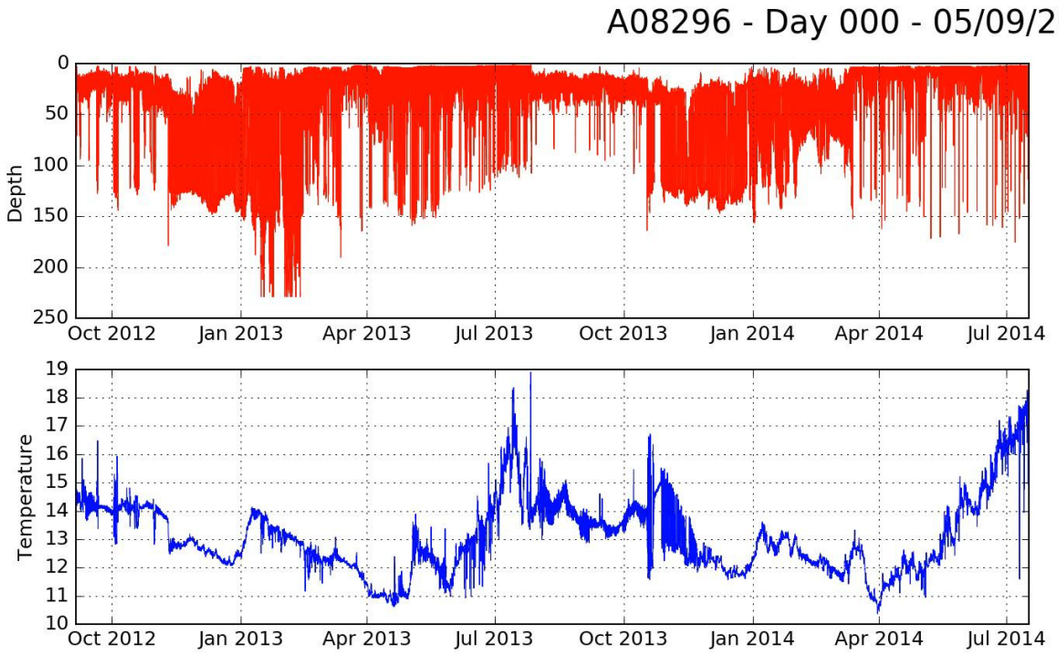
Bathymetry constraints

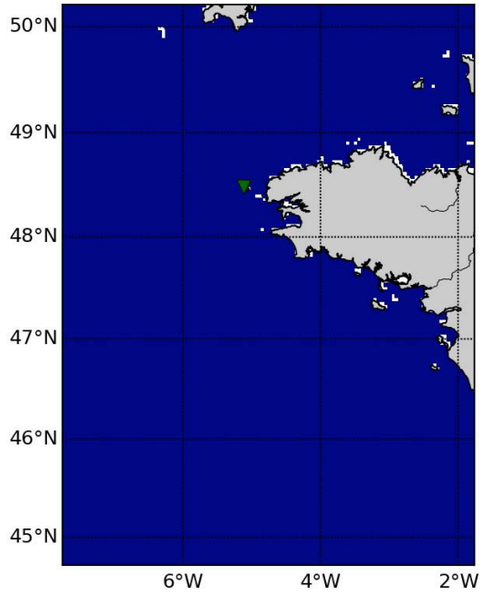


Temperature at depth



Reconstructed track example





Daily *a posteriori* probability distribution of fish position

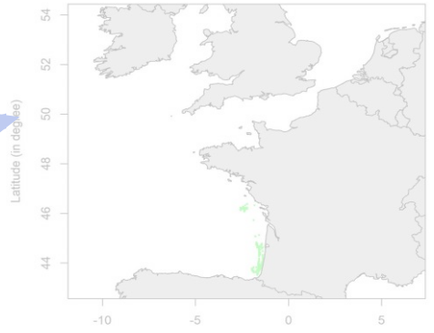
- A fish tagged in summer in Iroise Sea
- Migrates the following winter to the Bay of Biscay
- Returns the following summer to the Iroise Sea
- Migrates again the 2nd winter in the Bay of Biscay

Mouvements are not random

Research on seabass life cycle and connectivity

Large

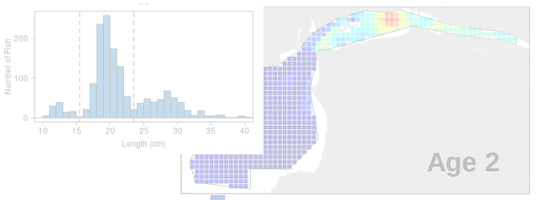
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

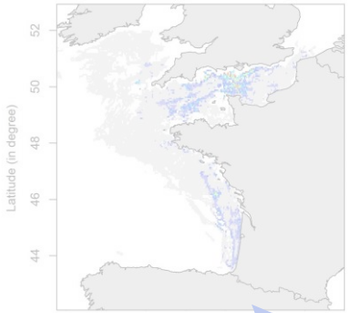
Nourriceries



Estimation d'abondance

Roy et al. 2022

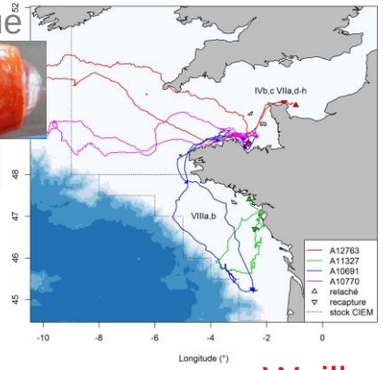
Frayères



Dambrine et al. 2021

Marque électronique

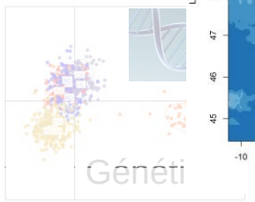
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Généti

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

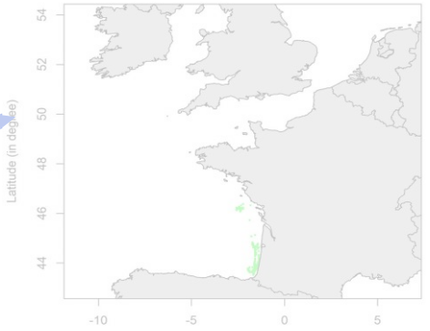
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Research on seabass life cycle and connectivity

Large

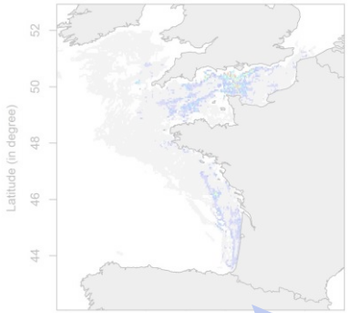
Connectivité larvaire



Approche DEB-IBM

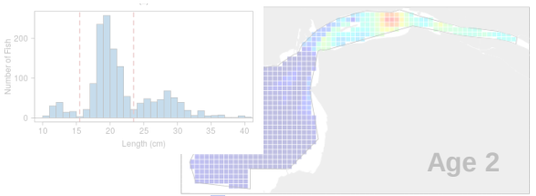
Dambrine et al. 2020; Dambrine 2021

Frayères



Dambrine et al. 2021

Nourriceries

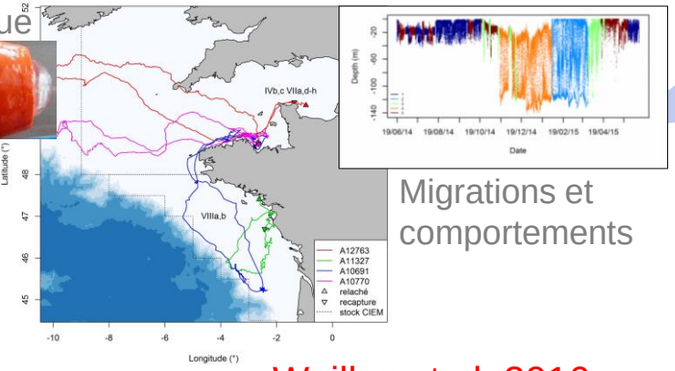


Estimation d'abondance

Roy et al. 2022

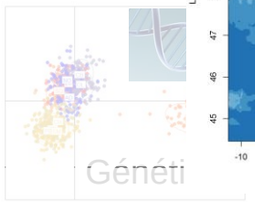
Marque électronique

Connectivité adulte



Migrations et comportements

Gagnaire et al. in prep



Généti

Côte

Microchimie des otolithes

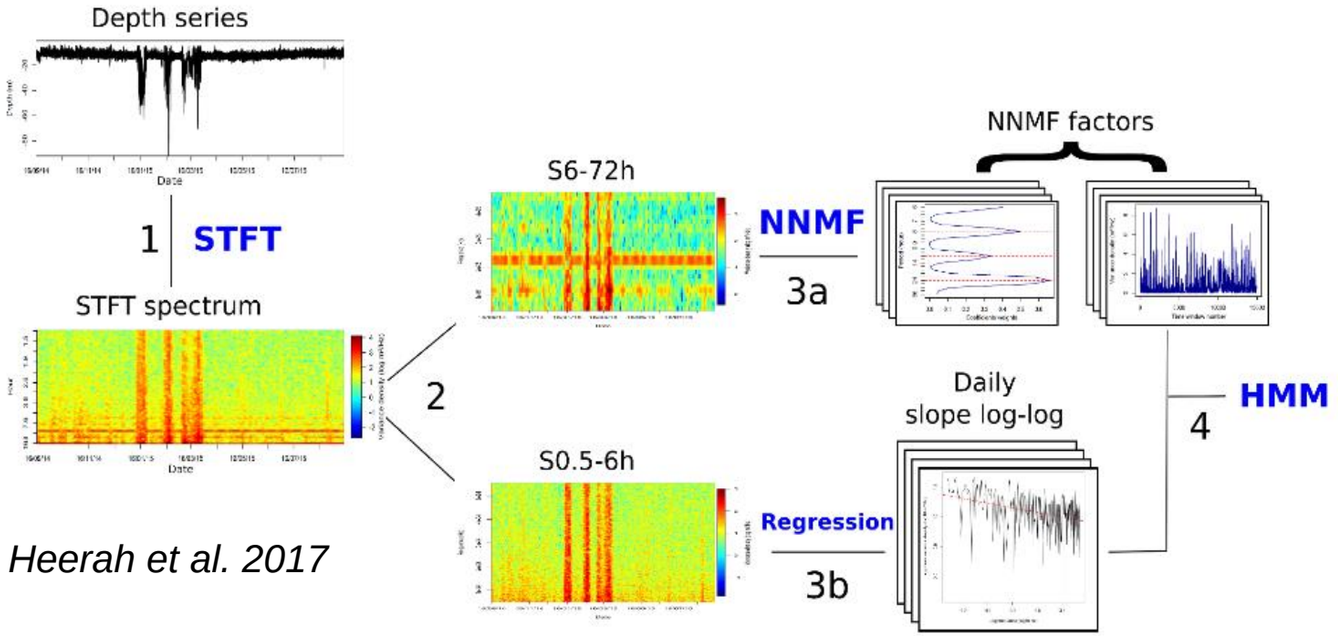
Le Luherne et al. 2022

Woillez et al. 2016

Heerah et al. 2017

de Pontual et al. 2019; 2023

Vertical behaviour using spectral analysis



Heerah et al. 2017

Short term fourrier transform

Extraction of cyclic patterns and activity levels.

Segregation of different movement scales

6-72h: daily movements
0.5-6h: fine scale movements.

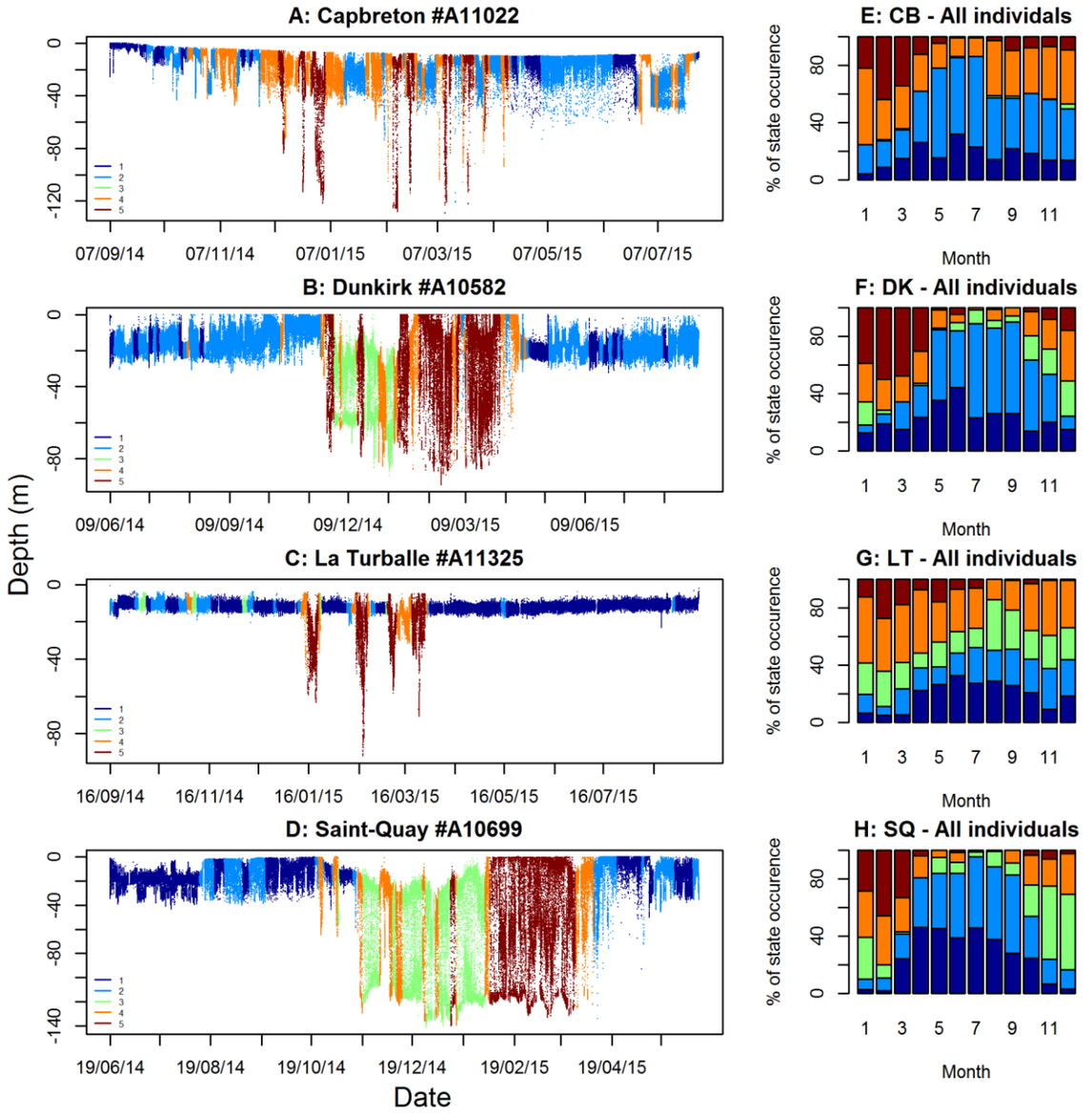
Dimension reduction methods

a. the NNMF summarizes daily patterns in 9 factors;
b. calculation of fine scale movement randomness.

Segmentation with Hidden Markov Model

Into 5 behaviours

Depth series and beavioural classes

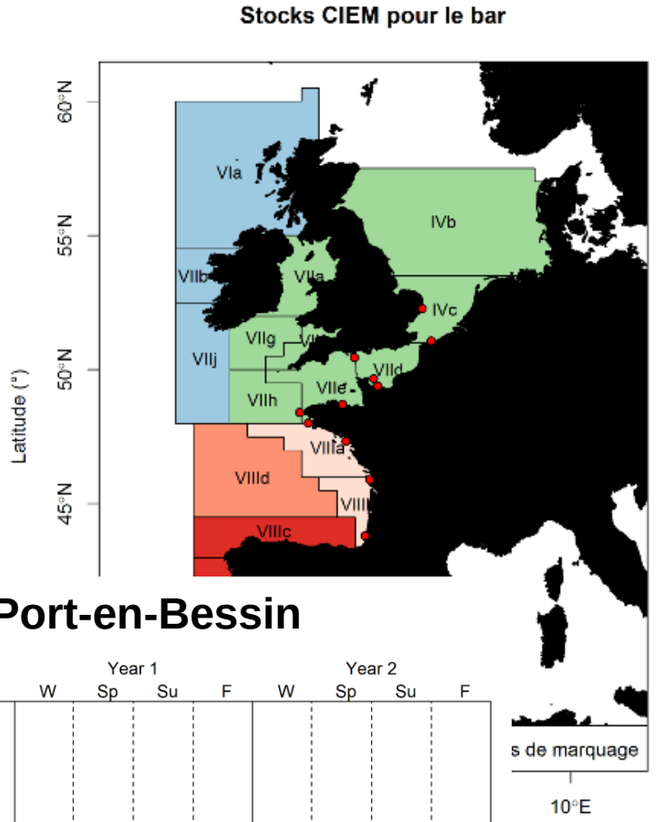


Behavioural states are well defined and appear at similar times throughout annual cycles

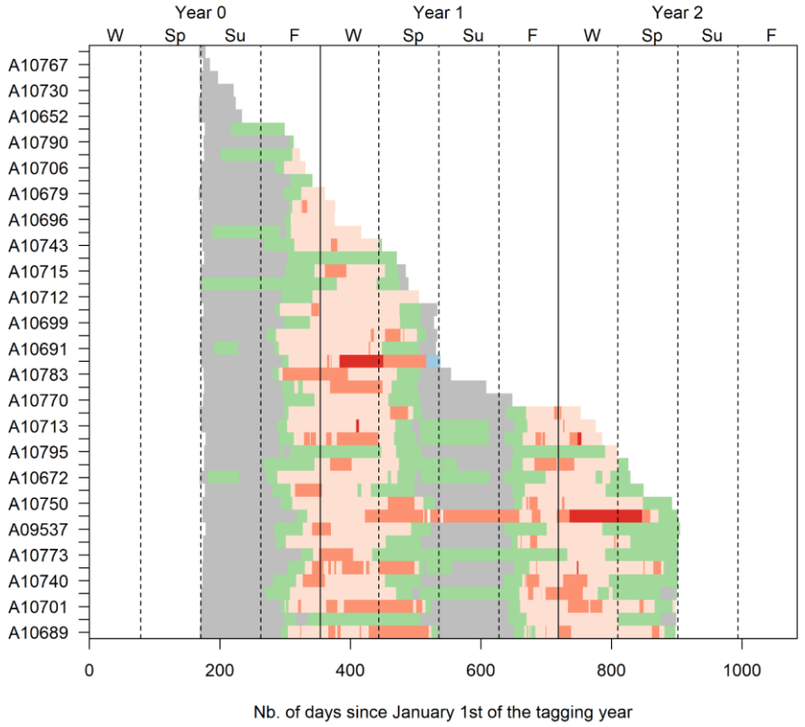
Could be related to seasonnal functionnal behaviour: feeding, migrating, spawning

Migration strategies

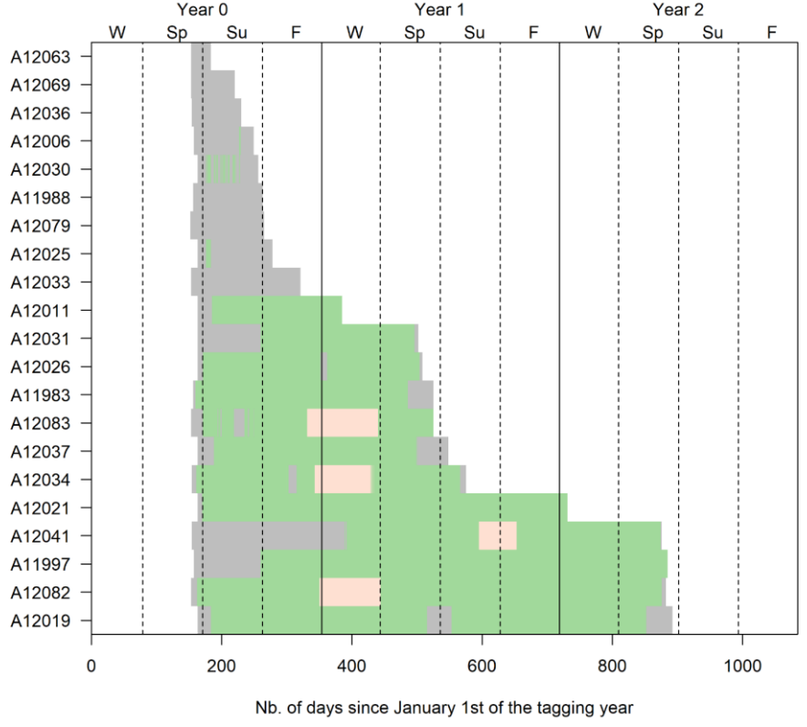
- 1220 adult sea bass tagged; >400 tag returns and >350 track reconstructions
- Behavioural differences: sedentary individuals vs. migratory behavior
- Confirmation of loyalty to spawning and summer feeding grounds for a majority of individuals
- Migration strategy calling into question current stock limits



Saint Quay Portrieux



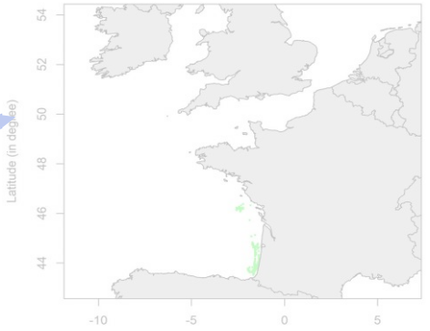
Port-en-Bessin



Research on seabass life cycle and connectivity

Large

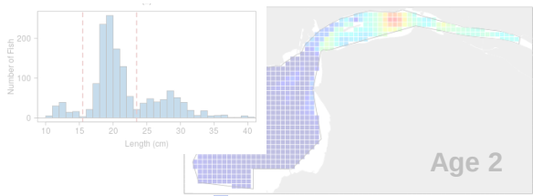
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

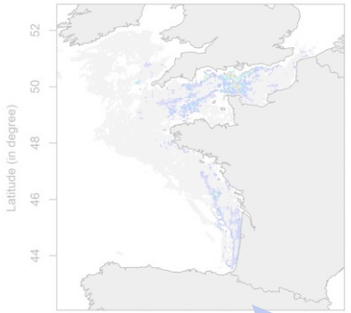
Nourriceries



Estimation d'abondance

Roy et al. 2022

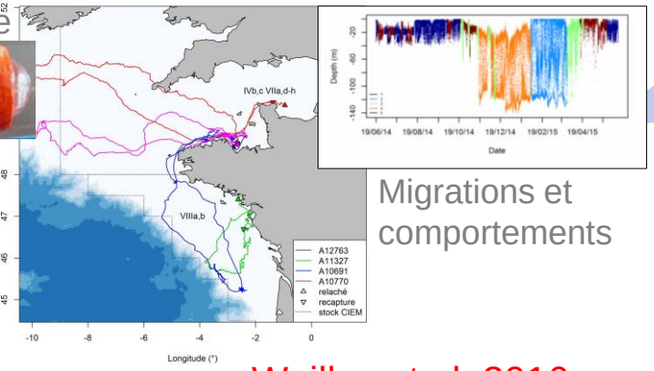
Frayères



Dambrine et al. 2021

Marque électronique

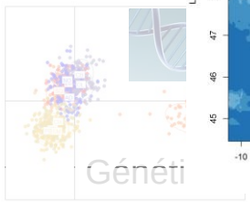
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Généti

Microchimie des otolithes

Le Luherne et al. 2022

Woillez et al. 2016

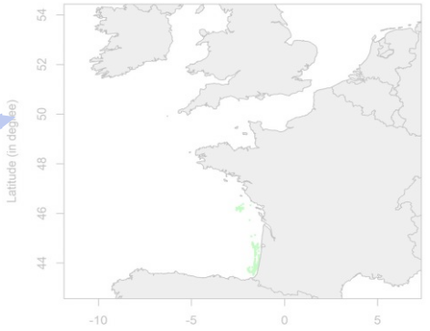
Heerah et al. 2017

de Pontual et al. 2019; 2023

Research on seabass life cycle and connectivity

Large

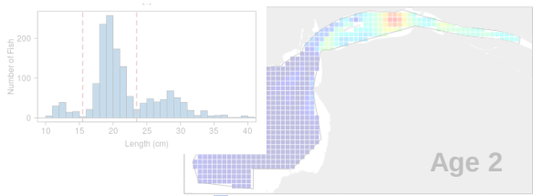
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

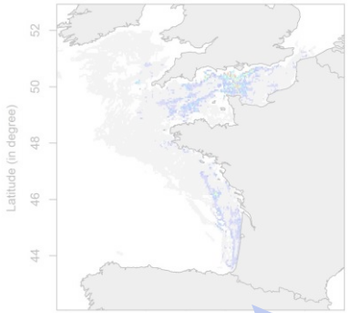
Nourriceries



Estimation d'abondance

Roy et al. 2022

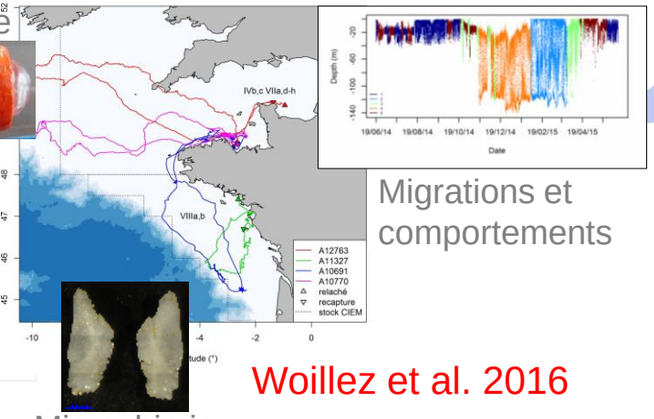
Frayères



Dambrine et al. 2021

Marque électronique

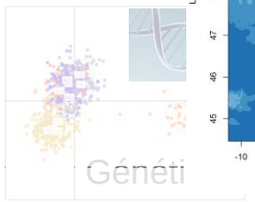
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

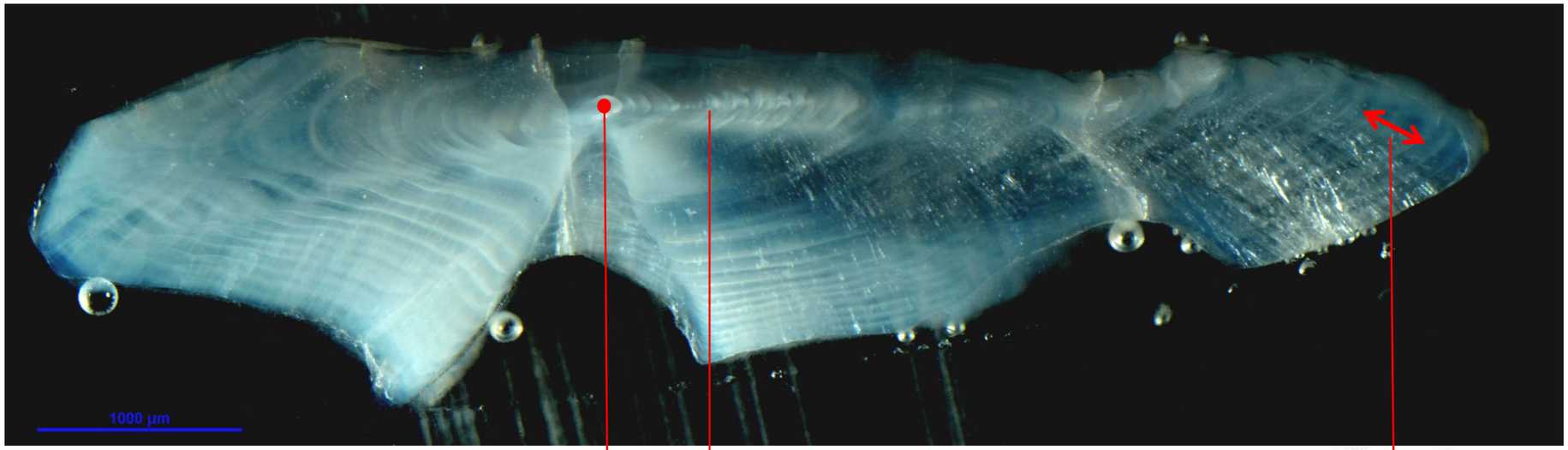
de Pontual et al. 2019; 2023

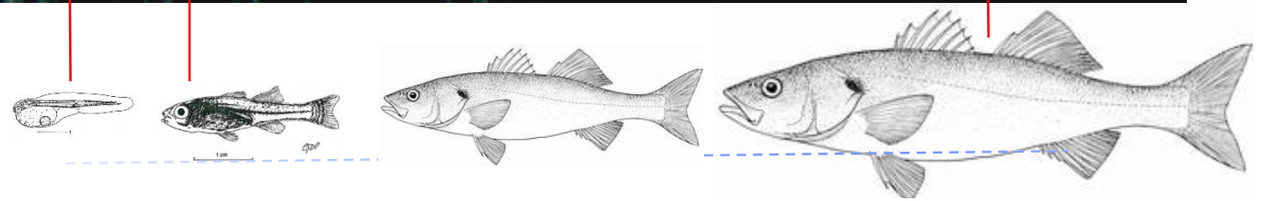
Le Luherne et al. 2022

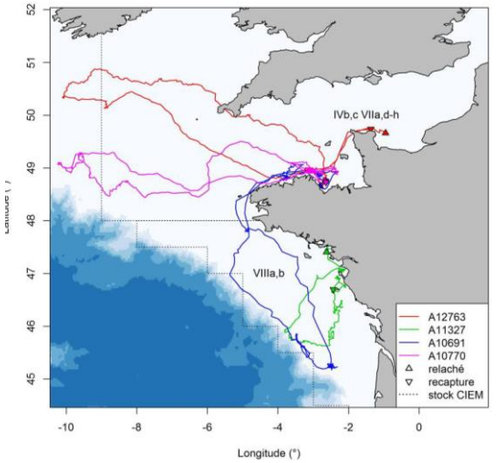
Retrospective analysis using microchemistry

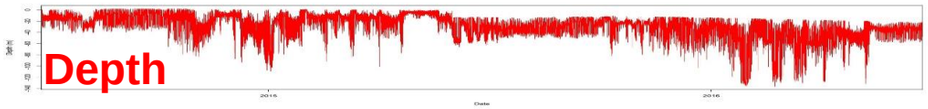
Coupling otolith and data storage tag

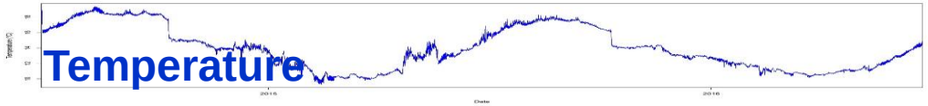
LA ICPMS concentrations ^{31}P, ^{55}Mn, ^{66}Zn, ^{88}Sr, ^{138}Ba and SIMS $\delta^{18}O$ (proxy of temperature)











Adult fidelity to spawning grounds and homing

Random Forest classification model ^{55}Mn, ^{66}Zn, ^{138}Ba
Out of Bag estimate of error rate: 19.12%

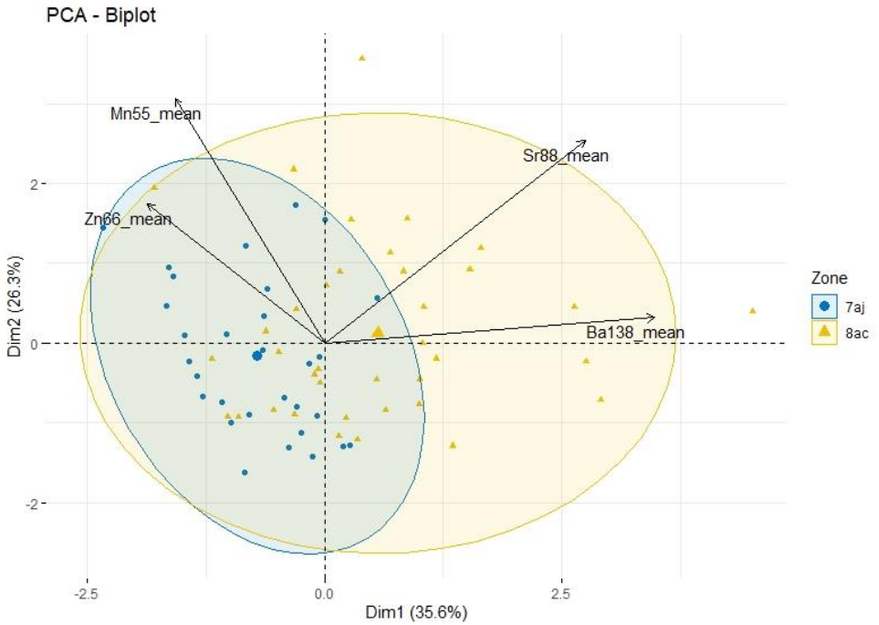
Confusion matrix

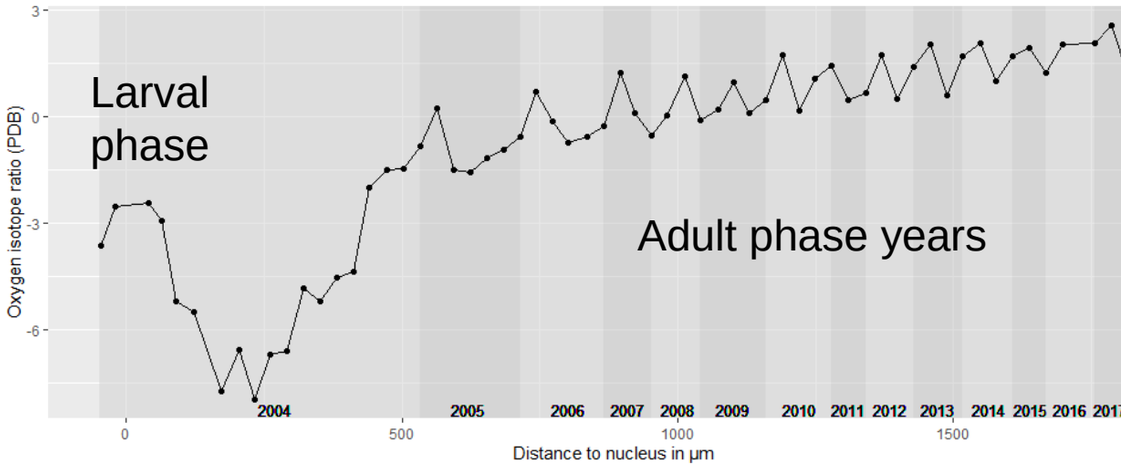
	EC	BOB	class.error
EC	24	6	0,20
BOB	7	31	0,18

Reallocation of winter spawning grounds not tracked by DSTs with this classification model :

Fidelity 27 seabass/35 = 77,14 % of fidelity to spawning ground
Of which 12 seabass attributed to BOB, and 15 seabass attributed to EC. Stock mixing in Northern Brittany.

Do fish loyal to a spawning ground have a larval signature characteristic of their ground ? Results not conclusive…

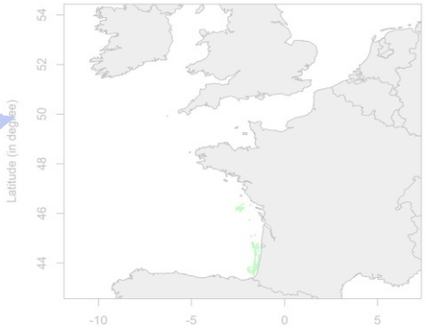




Research on seabass life cycle and connectivity

Large

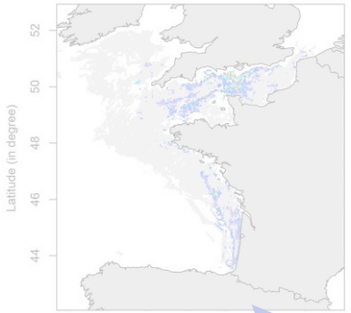
Connectivité larvaire



Approche DEB-IBM

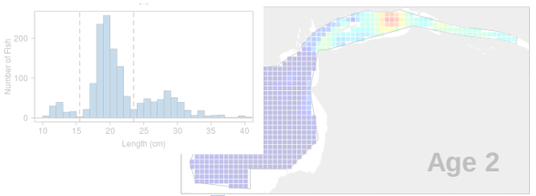
Dambrine et al. 2020; Dambrine 2021

Frayères



Dambrine et al. 2021

Nourriceries

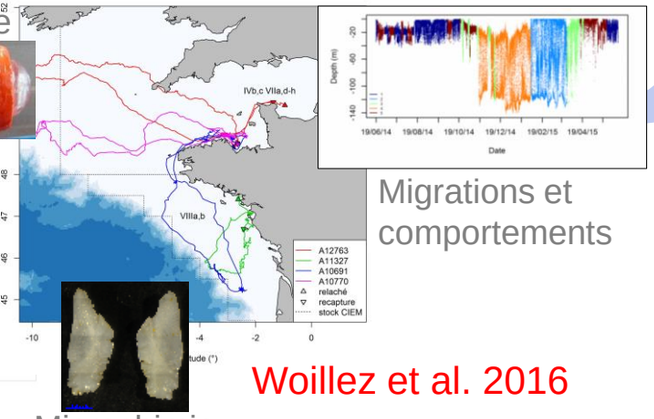


Estimation d'abondance

Roy et al. 2022

Marque électronique

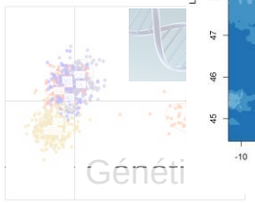
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Microchimie des otolithes

Le Luherne et al. 2022

Woillez et al. 2016

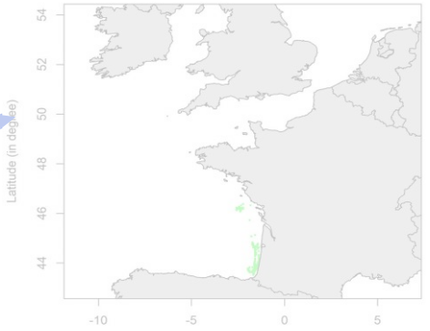
Heerah et al. 2017

de Pontual et al. 2019; 2023

Research on seabass life cycle and connectivity

Large

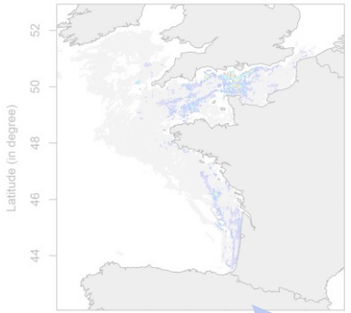
Connectivité larvaire



Approche DEB-IBM

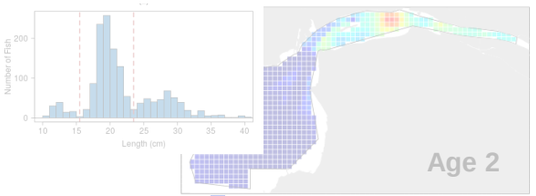
Dambrine et al. 2020; Dambrine 2021

Frayères



Dambrine et al. 2021

Nourriceries

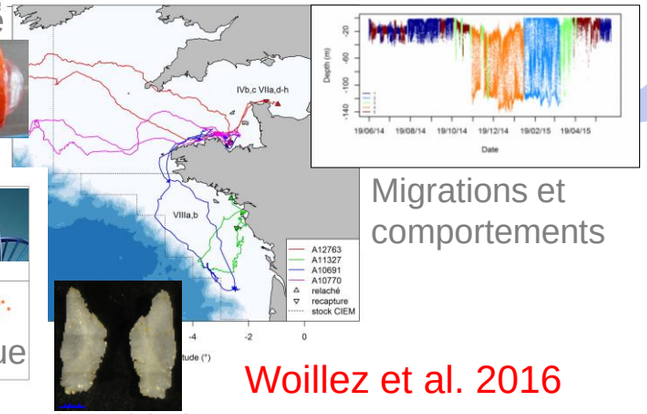


Estimation d'abondance

Roy et al. 2022

Marque électronique

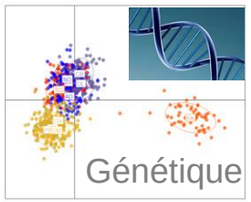
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Génétique

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

de Pontual et al. 2019; 2023

Le Luherne et al. 2022

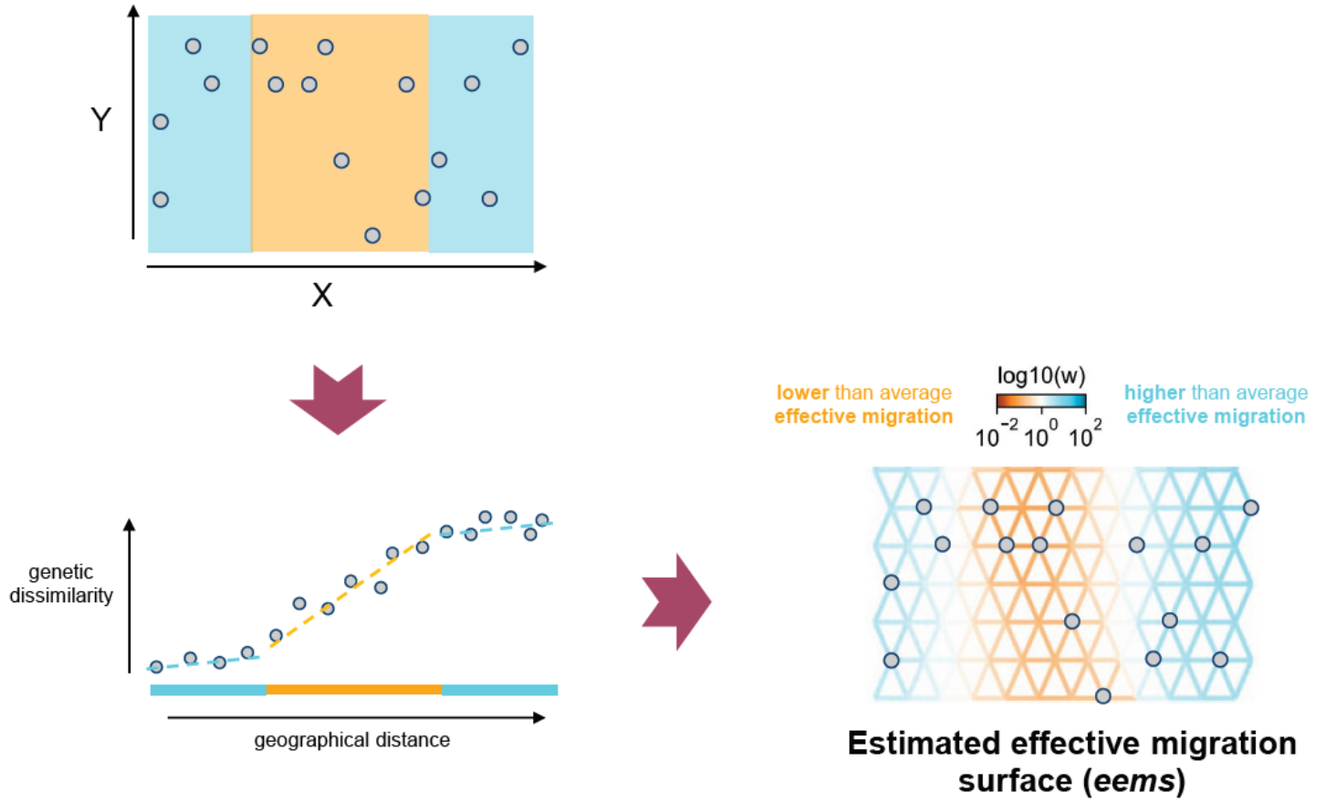
Consequences of the fidelity to essential fish habitats on the genetic structure

Introgression of Mediterrannean alleles into Atlantic population

Use a model of migration and genetic drift (Marcus et al. 2021)

Infer non-homogeneous gene-flow on a geographic map

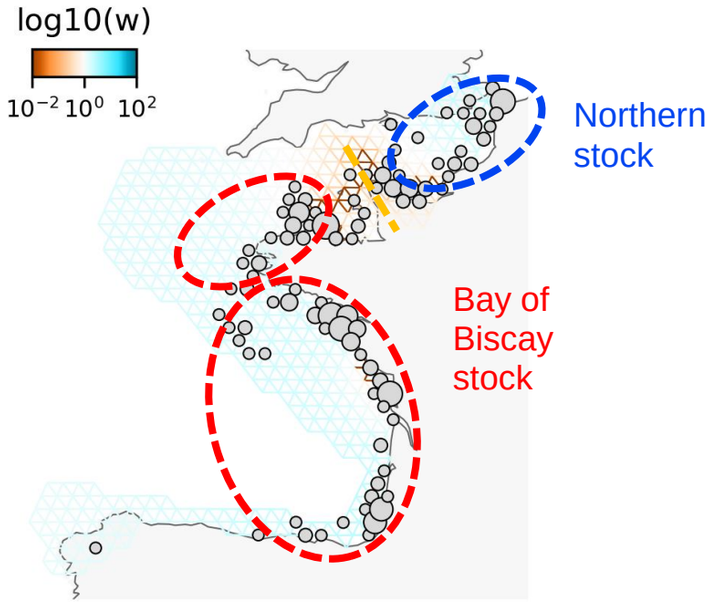
Regions with **low effective migration indicate reduced gene flow** over time



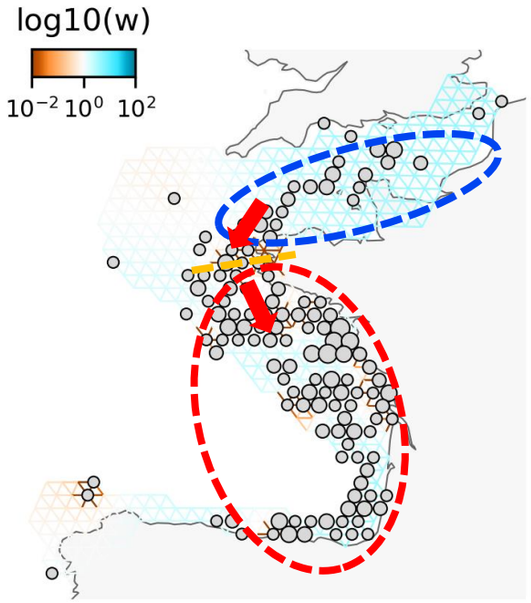
Spatial genetic structure

Combining genetic and tagging data

Using 320 reconstructed positions during
SUMMER 1



Using 248 reconstructed positions during
WINTER 1



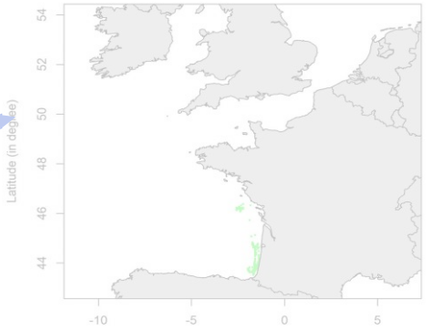
Dynamic spatial structure due to seasonal migrations

The Bay of Biscay stock seems to extend to the western Channel during the feeding season

Research on seabass life cycle and connectivity

Large

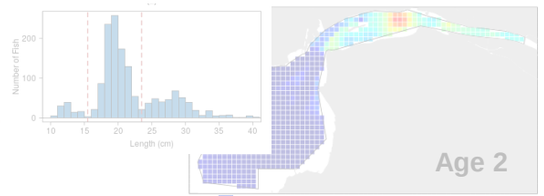
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

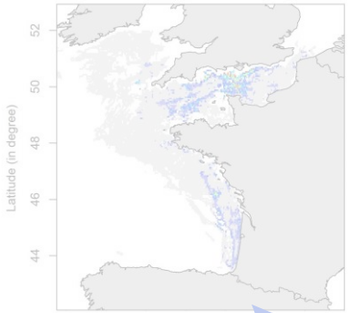
Nourriceries



Estimation d'abondance

Roy et al. 2022

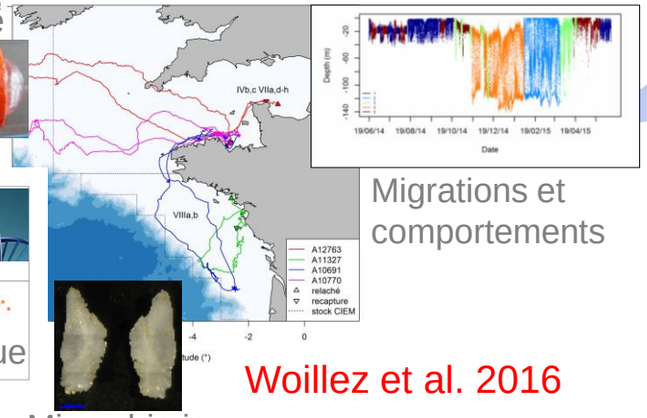
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Génétique

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

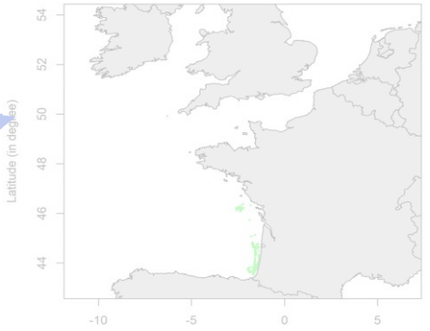
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Research on seabass life cycle and connectivity

Large

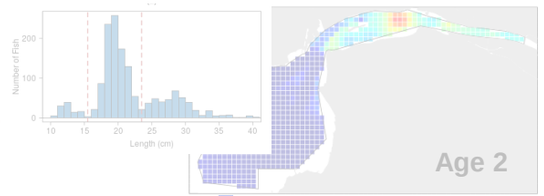
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

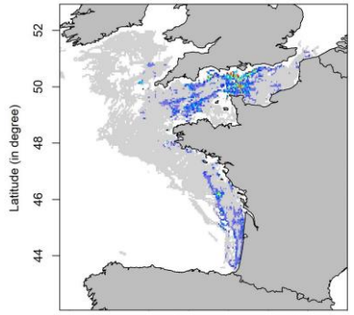
Nourriceries



Estimation d'abondance

Roy et al. 2022

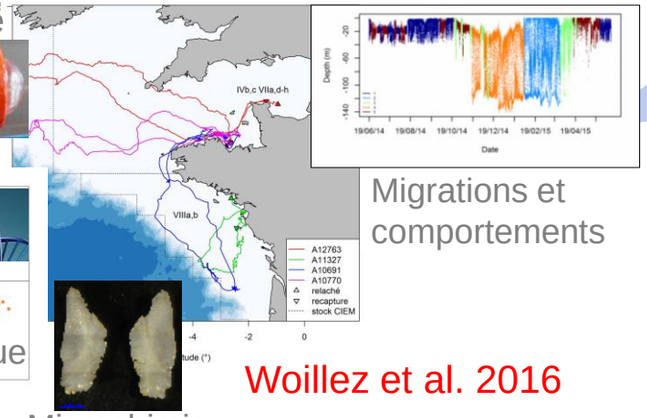
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

de Pontual et al. 2019; 2023

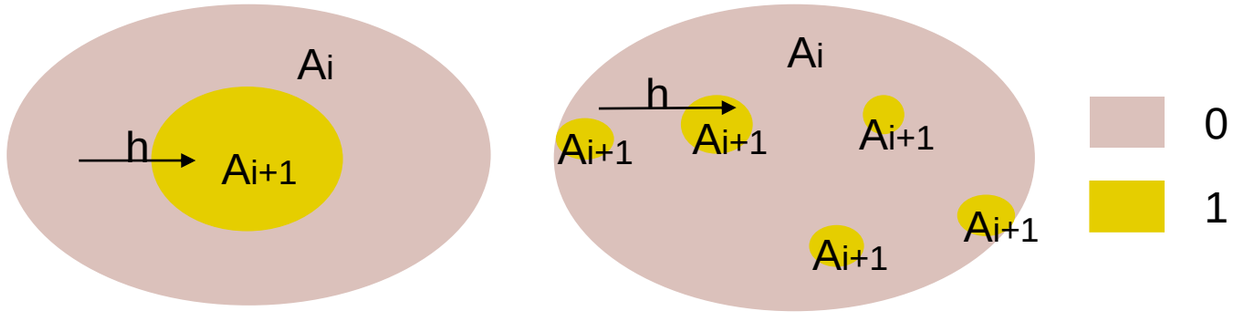
Le Luherne et al. 2022

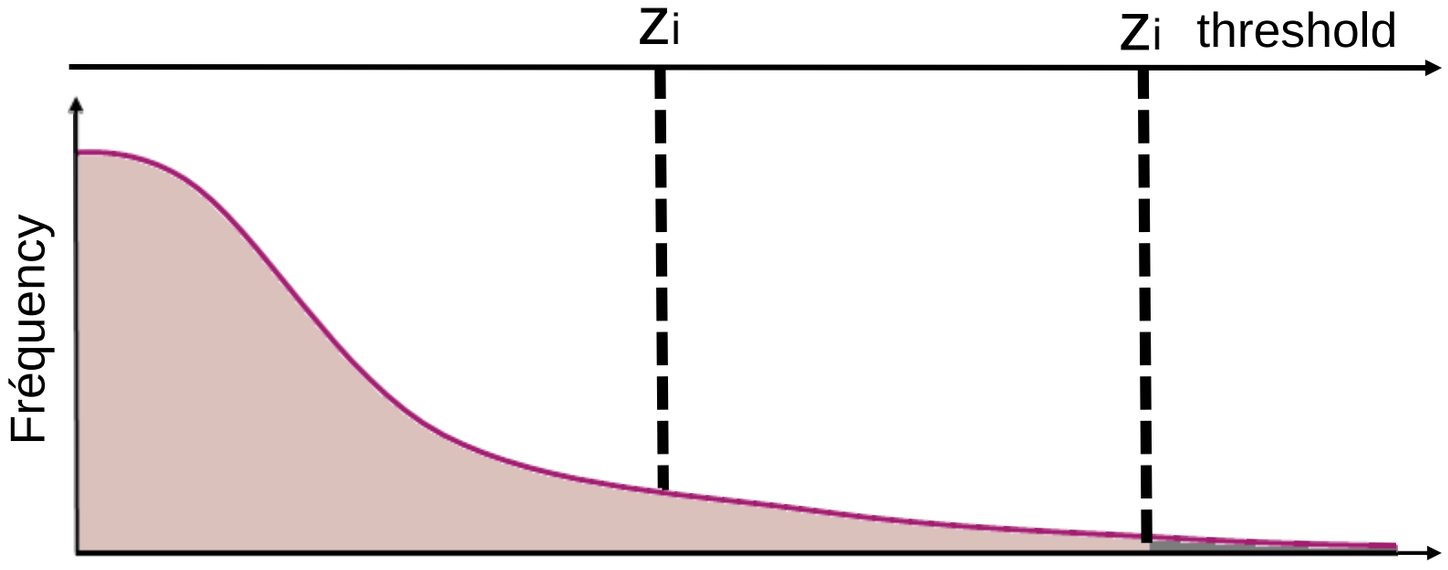
Characterize the spatial distribution of fishery hot spots

No dedicated scientific surveys

Data from geolocalised fishing boats

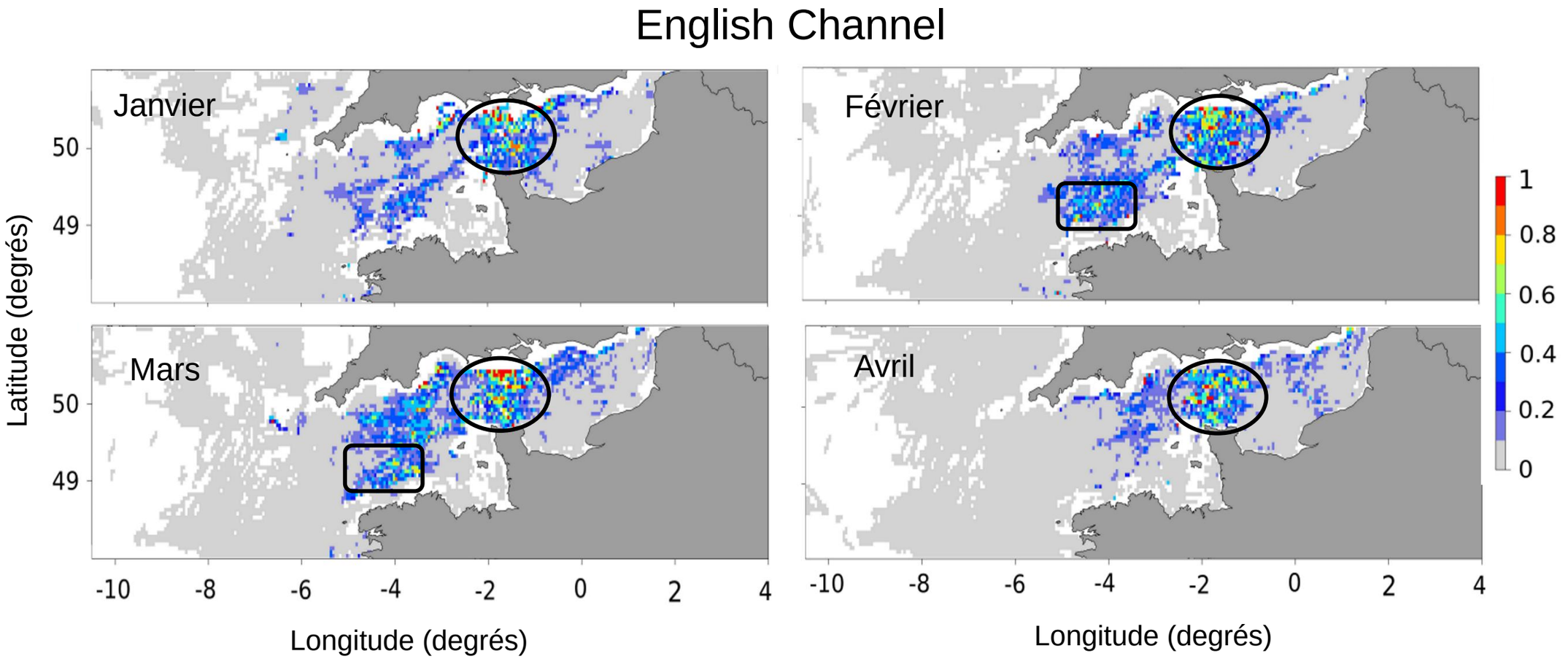
Seabass aggregate in winter for reproduction





4 criteria based on geostatistical structural tools (simple and cross variograms)

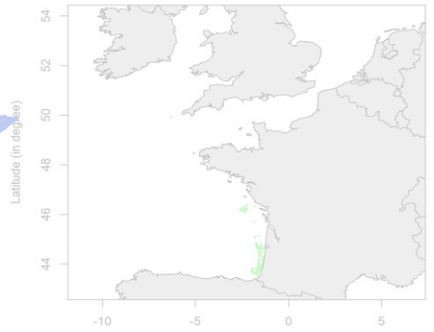
Mapping of spawning grounds



Research on seabass life cycle and connectivity

Large

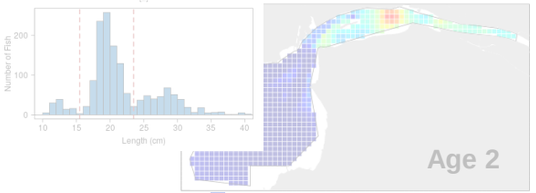
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

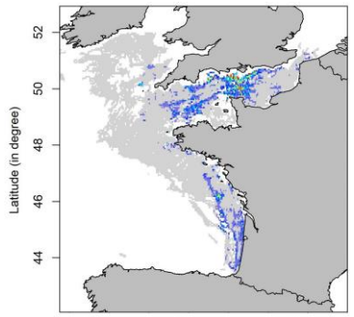
Nourriceries



Estimation d'abondance

Roy et al. 2022

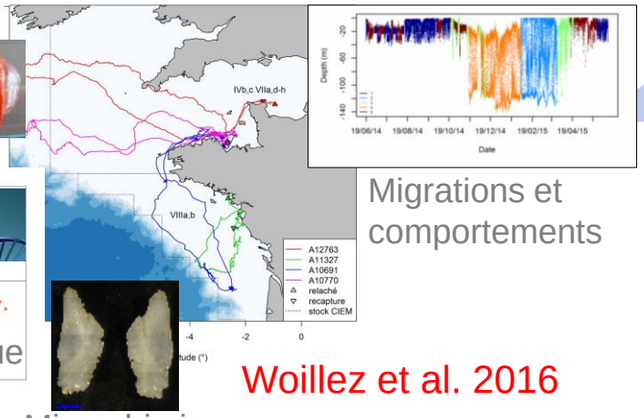
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

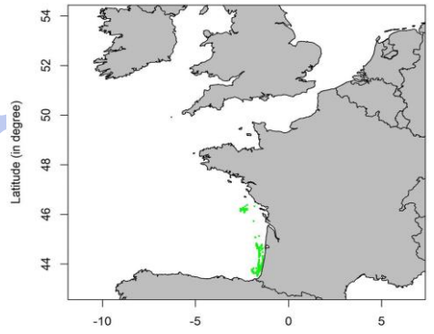
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Research on seabass life cycle and connectivity

Large

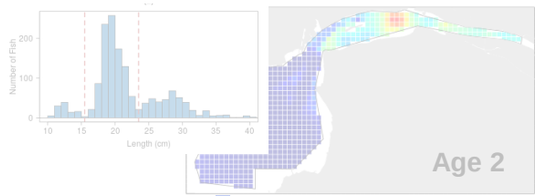
Connectivité larvaire



Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

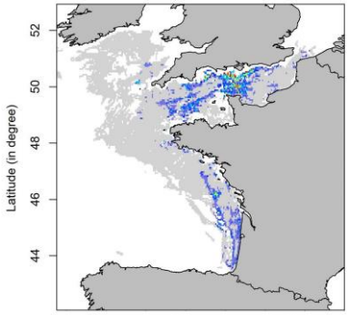
Nourriceries



Estimation d'abondance

Roy et al. 2022

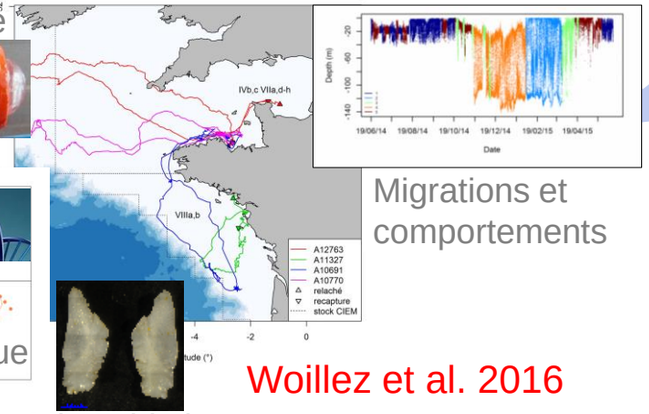
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Microchimie des otolithes

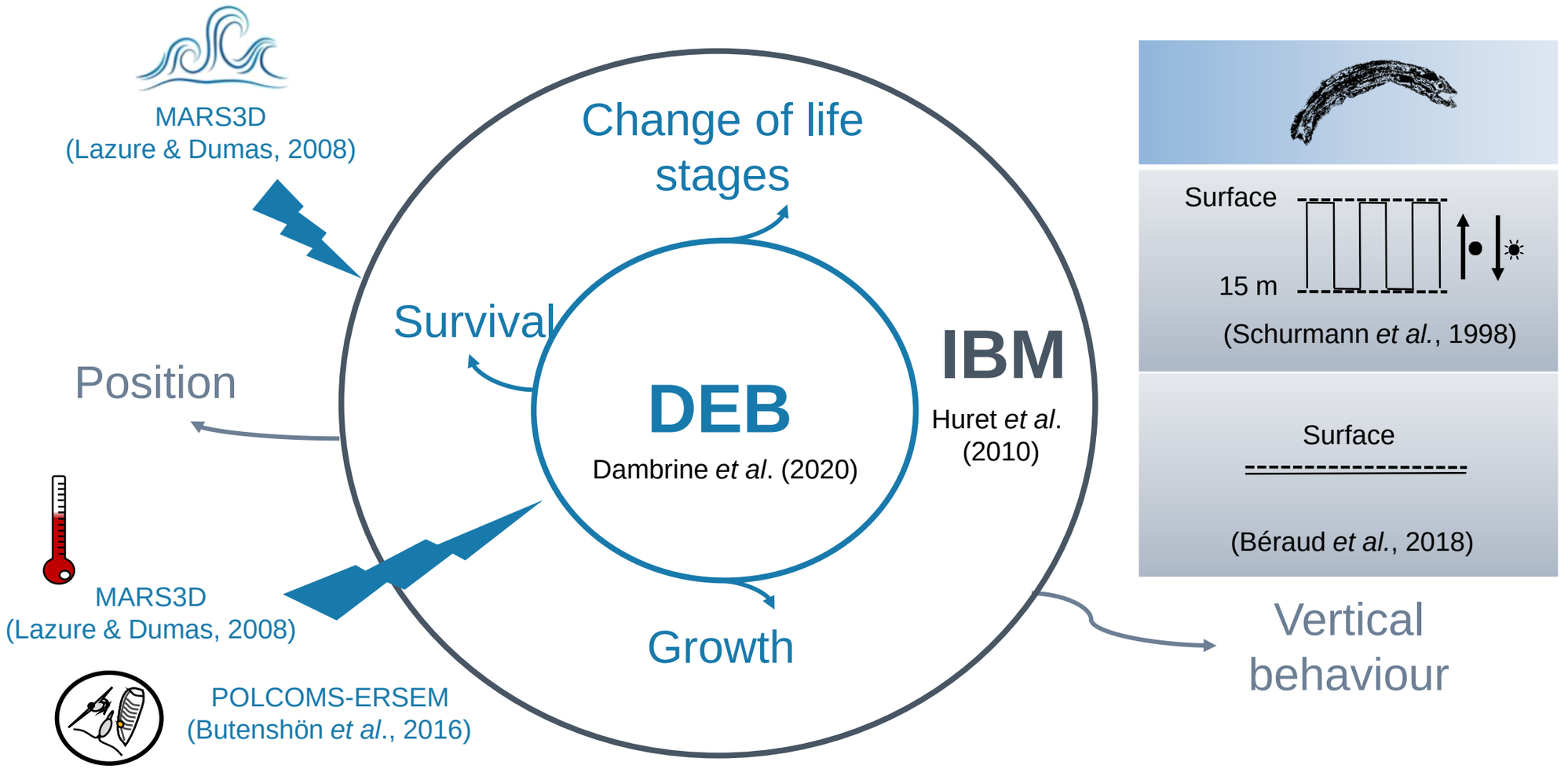
Woillez et al. 2016

Heerah et al. 2017

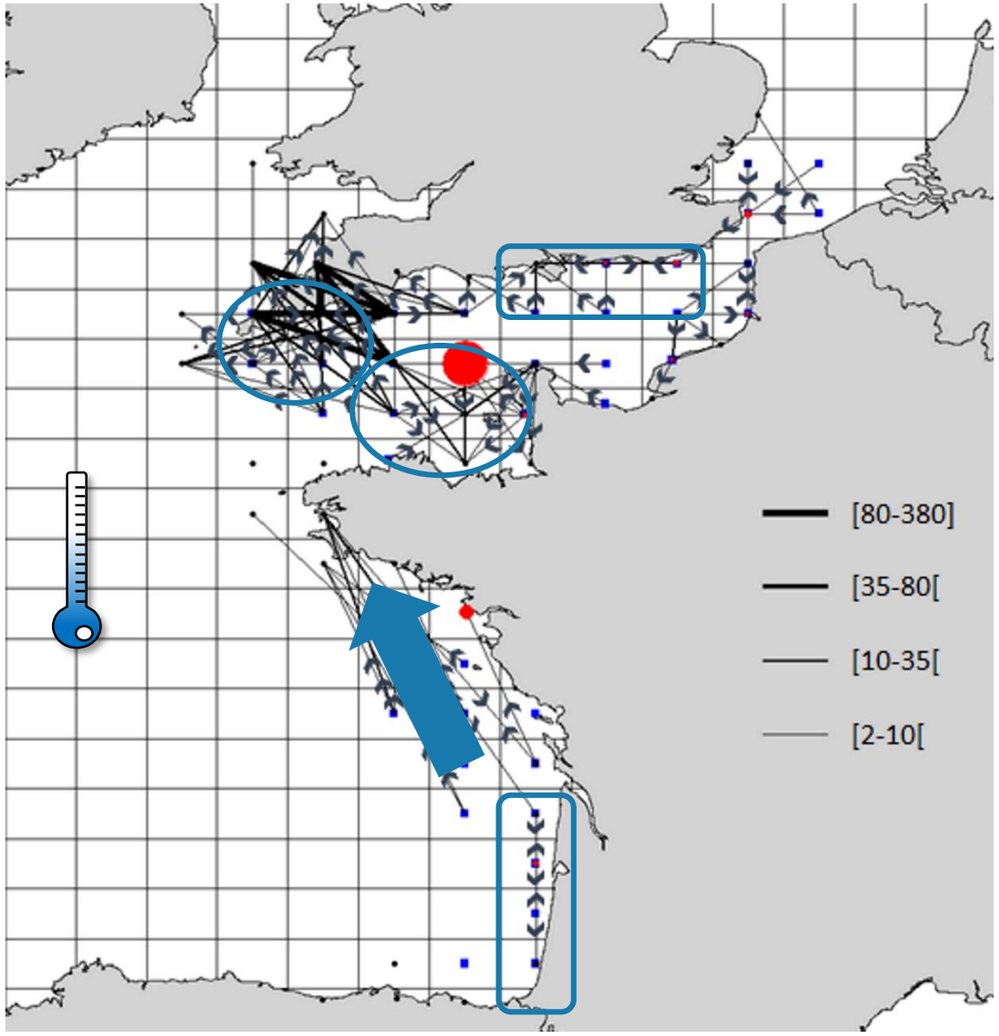
de Pontual et al. 2019; 2023

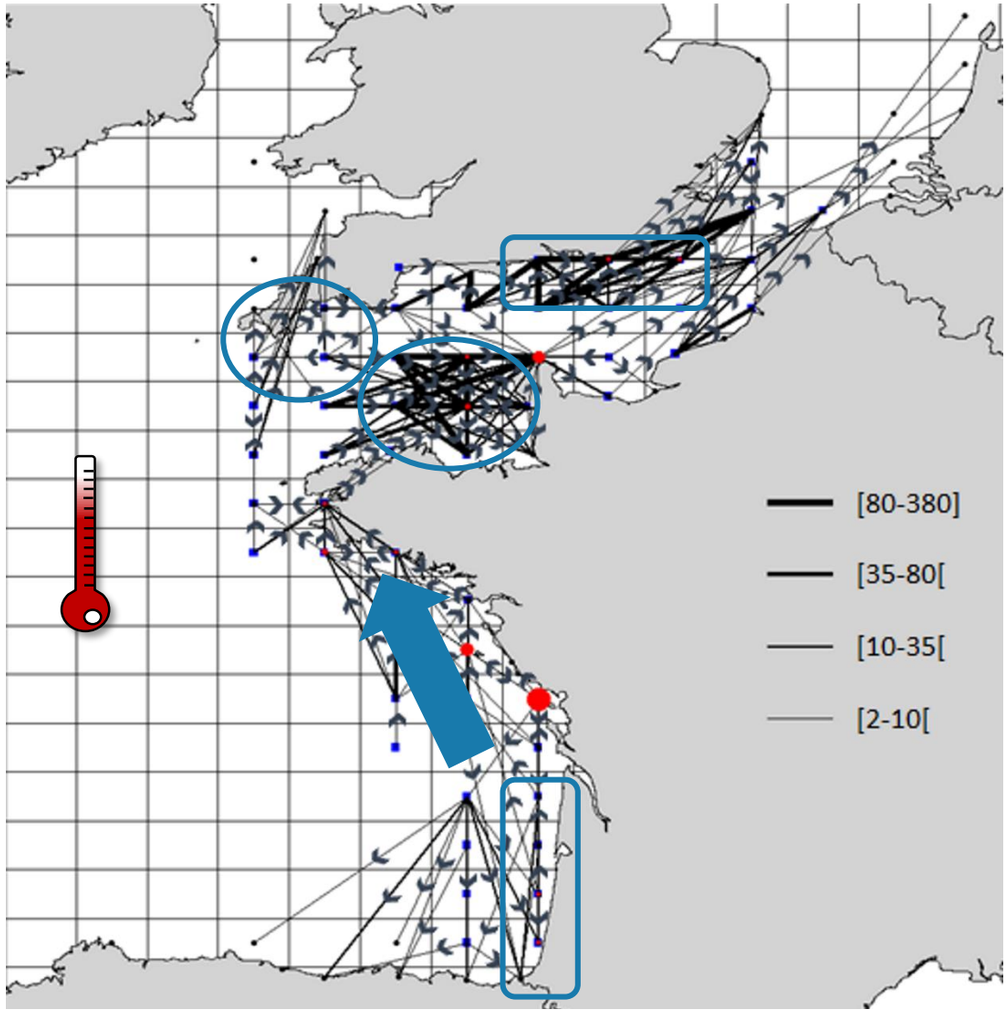
Le Luherne et al. 2022

Modelling egg and larvae drift



Identify important spawning-nursery pairs

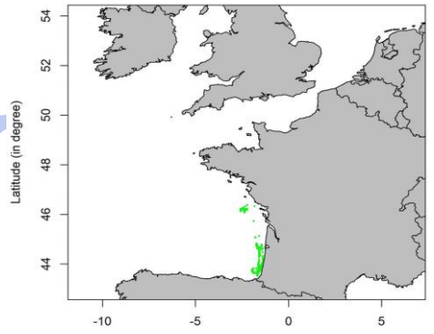




Research on seabass life cycle and connectivity

Large

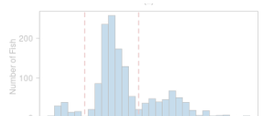
Connectivité larvaire

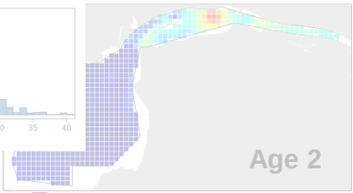


Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

Nourriceries

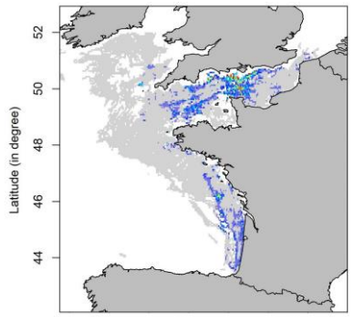




Estimation d'abondance

Roy et al. 2022

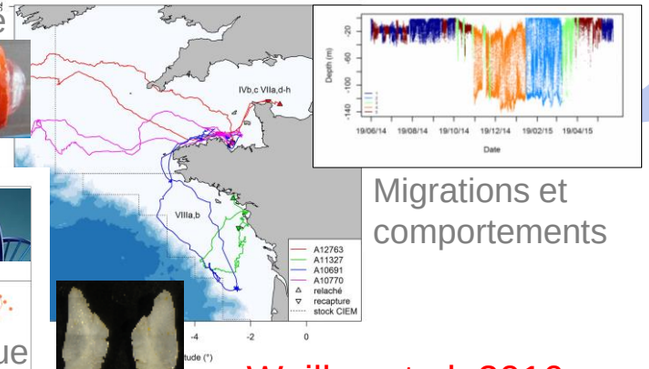
Frayères



Dambrine et al. 2021

Marque électronique

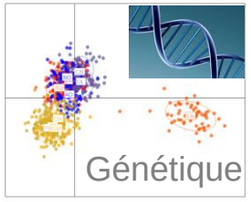
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Microchimie des otolithes

Woillez et al. 2016

Heerah et al. 2017

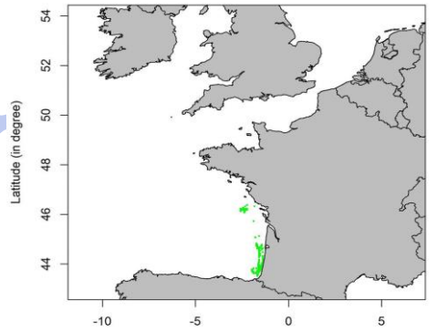
de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Research on seabass life cycle and connectivity

Large

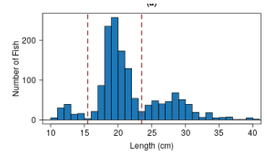
Connectivité larvaire

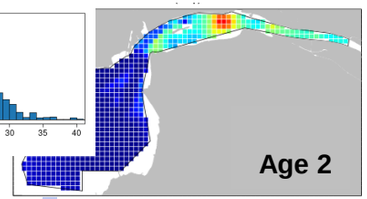


Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

Nourriceries

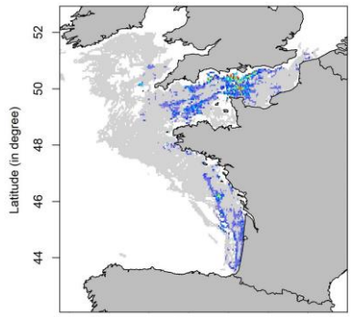




Estimation d'abondance

Roy et al. 2022

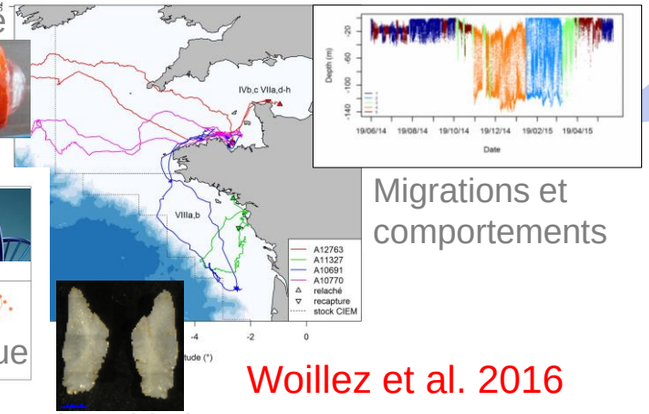
Frayères



Dambrine et al. 2021

Marque électronique

Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep

Microchimie des otolithes

Woillez et al. 2016

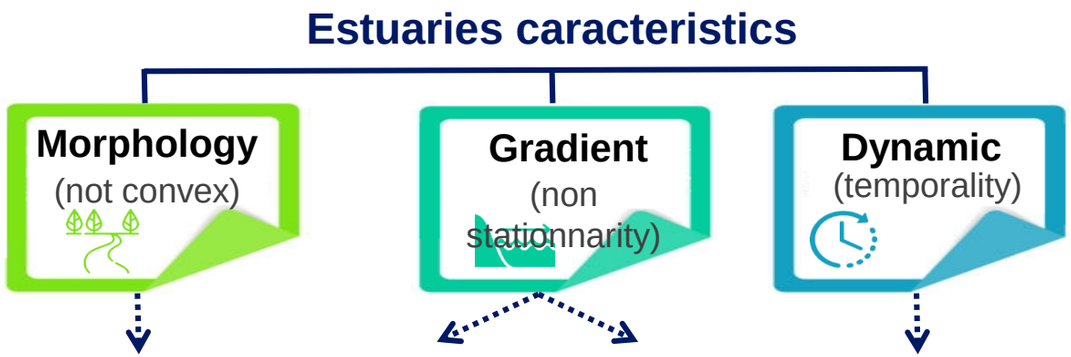
Heerah et al. 2017

de Pontual et al. 2019; 2023

Le Luherne et al. 2022

Estimating abundance using Geostatistics

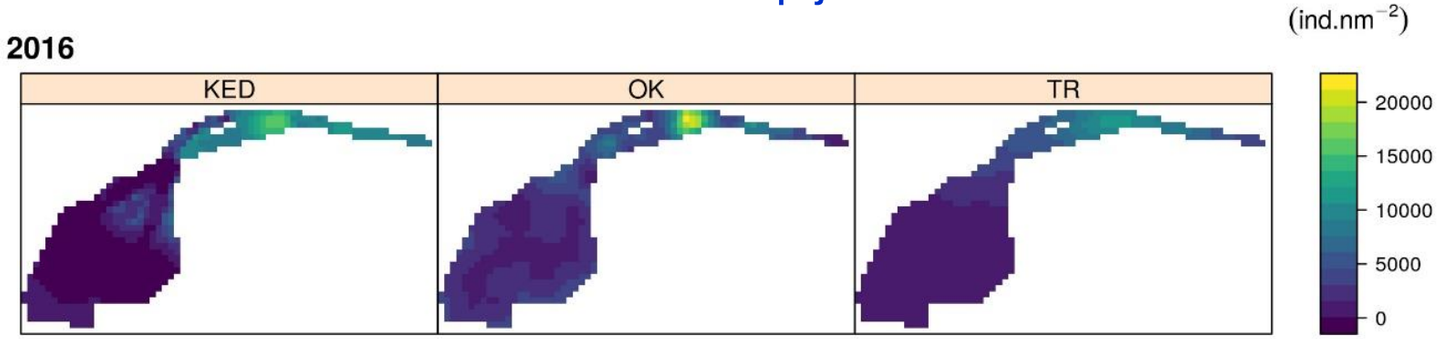
Juvenile seabass are found in estuaries



	Projection	Transitive approach	External drift (depth, salinity)	Time varying variogram
Transitive kriging (TR)	✗	✓	✗	✗
Projected transitive kriging (TRp)	✓	✓	✗	✗
Ordinary kriging (OK)	✗	✗	✗	✓
Projected ordinary kriging (OKp)	✓	✗	✗	✓
Kriging with external drift (KED)	✗	✗	✓	✓
Porjected kriging with external drift (KEDp)	✓	✗	✓	✓

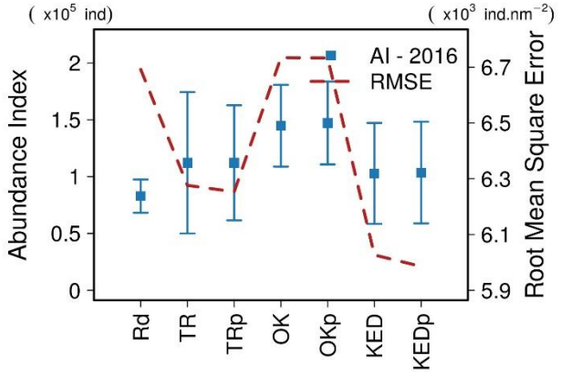
Maps, estimation of abundance and uncertainty

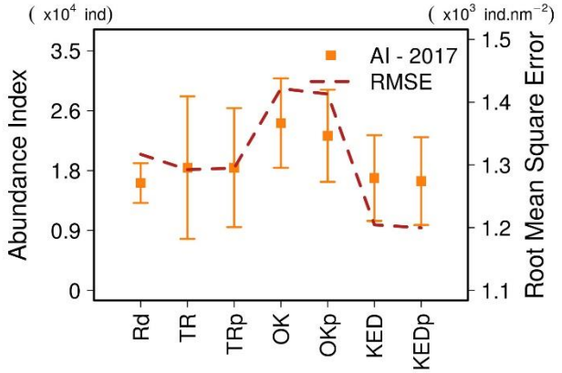
Geostatistical methods allow to map juvenile distribution

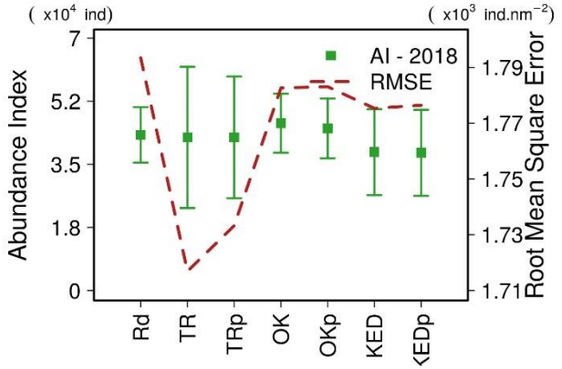


Better predictive capabilities than the stratified random estimator, however their CVs are higher

The stratified random estimator underestimates the different uncertainties and leads to over-optimistic confidence intervals.



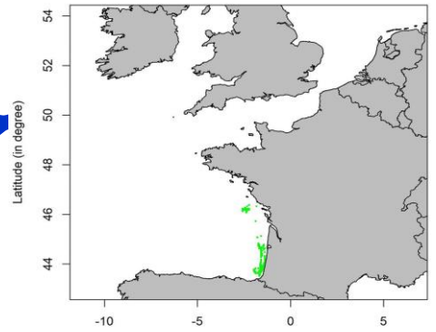




Research on seabass life cycle and connectivity

Large

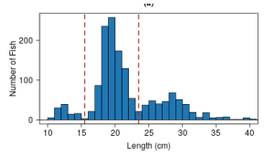
Connectivité larvaire

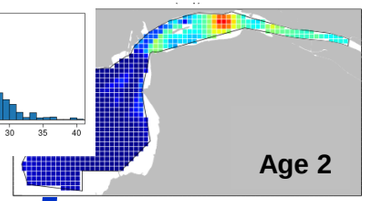


Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

Nourriceries

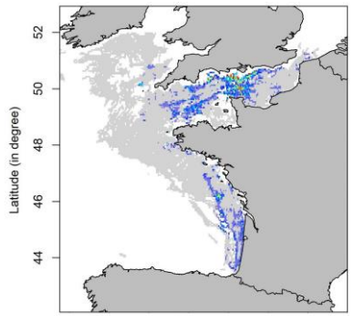




Estimation d'abondance

Roy et al. 2022

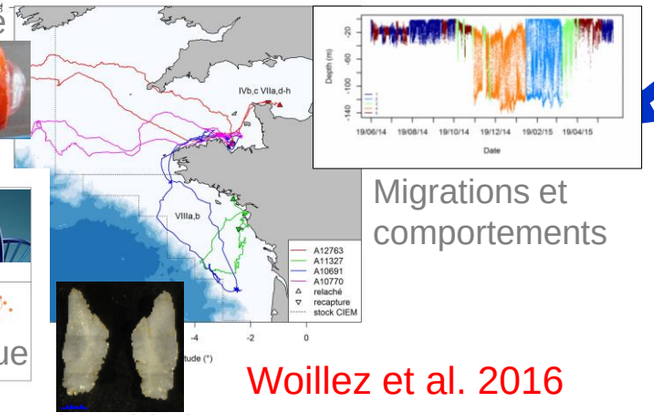
Frayères



Dambrine et al. 2021

Marque électronique

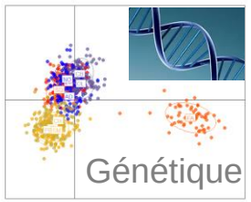
Connectivité adulte



Migrations et comportements

Côte

Gagnaire et al. in prep



Génétique

Microchimie des otolithes

Le Luherne et al. 2022

Woillez et al. 2016

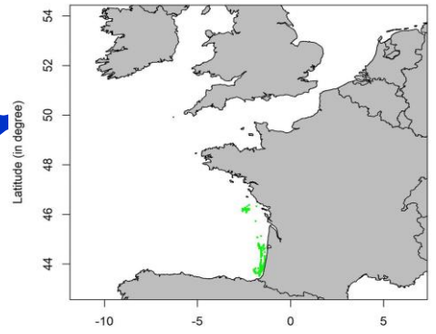
Heerah et al. 2017

de Pontual et al. 2019; 2023

Research on seabass life cycle and connectivity

Large

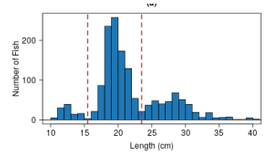
Connectivité larvaire

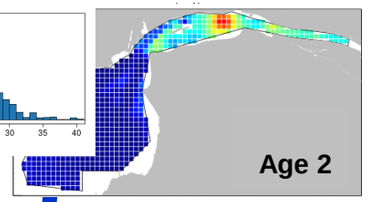


Approche DEB-IBM

Dambrine et al. 2020; Dambrine 2021

Nourriceries

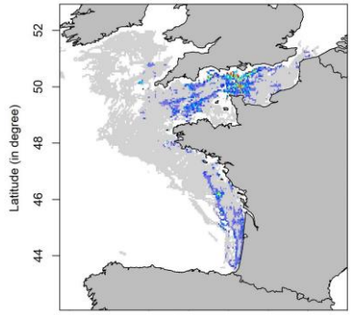




Estimation d'abondance

Roy et al. 2022

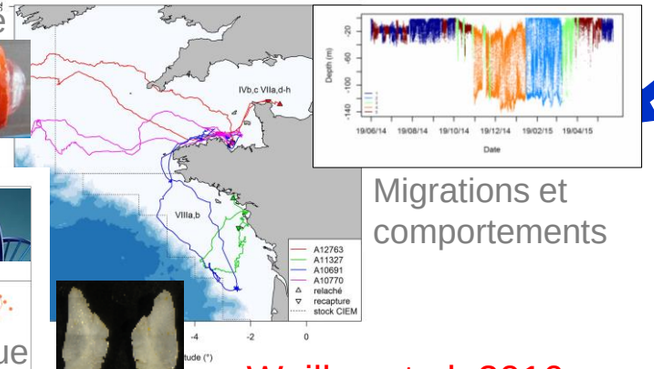
Frayères



Dambrine et al. 2021

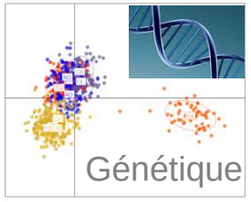
Marque électronique

Connectivité adulte



Migrations et comportements

Gagnaire et al. in prep



Génétique

Microchimie des otolithes

Le Luherne et al. 2022

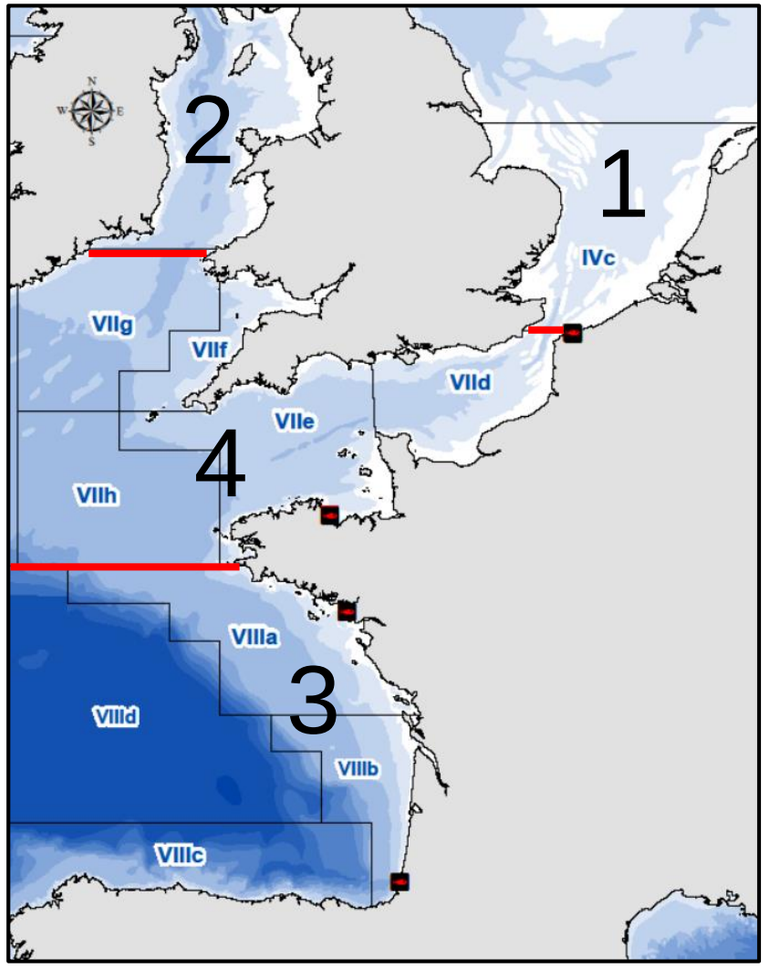
Woillez et al. 2016

Heerah et al. 2017

de Pontual et al. 2019; 2023

Contribution to expertise

Estimating migration rates for the population dynamics model from individual trajectories (from the Hidden Markov Model)



In the context of an ICES benchmark workshop (revision of stock definition)

To analyse the trajectories and estimate movement rate, discretisation of the data:

In space : 4 areas, several hypothesis defined by the benchmark:

- 1 = North sea
- 2 = Irish Sea
- 3 = Bay of Biscay
- 4 = Mixing area (Channel + Celtic sea)

In time : 2 time step sizes:

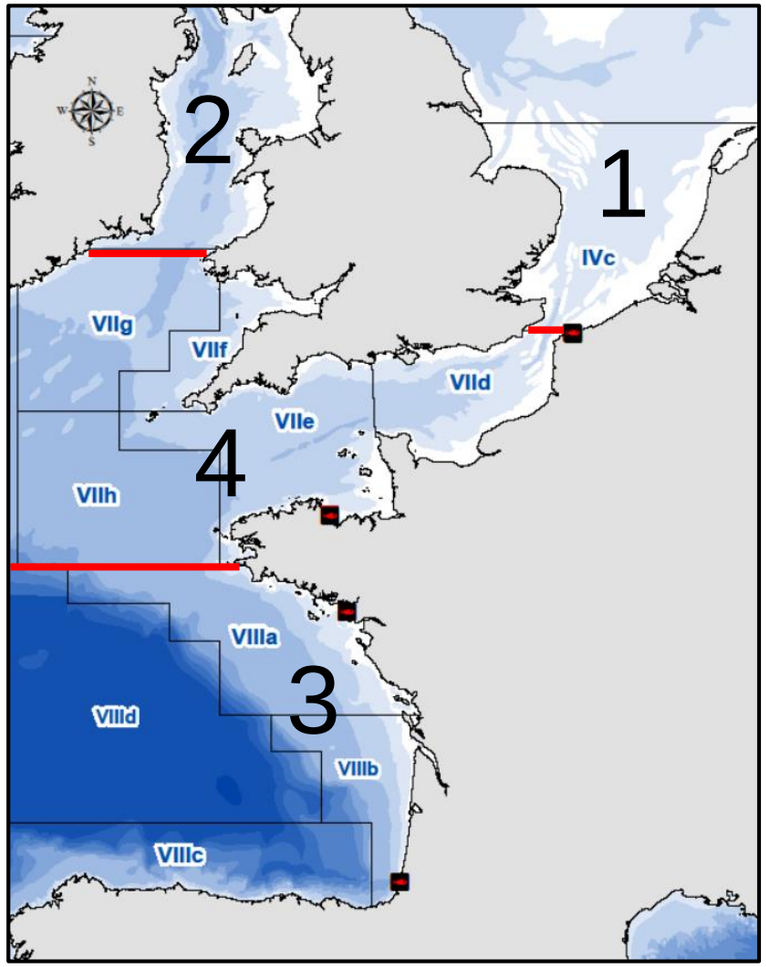
Semester : Winter = 1/10 to 31/03 ; Summer = 1/04 to 30/09

Trimester : Winter = 1/01 to 31/03 ; Spring = 1/04 to 30/06

Summer = 1/07 to 30/09 ; Autumn = 1/10 to 31/12

→ to look at seasonal movements

Estimating migration rates for the population dynamics model from individual trajectories (from the Hidden Markov Model)



In the context of an ICES benchmark workshop (revision of stock definition)

To analyse the trajectories and estimate movement rate, discretisation of the data:

In space : 4 areas, several hypothesis defined by the benchmark:

- 1 = North sea
- 2 = Irish Sea
- 3 = Bay of Biscay
- 4 = Mixing area (Channel + Celtic sea)

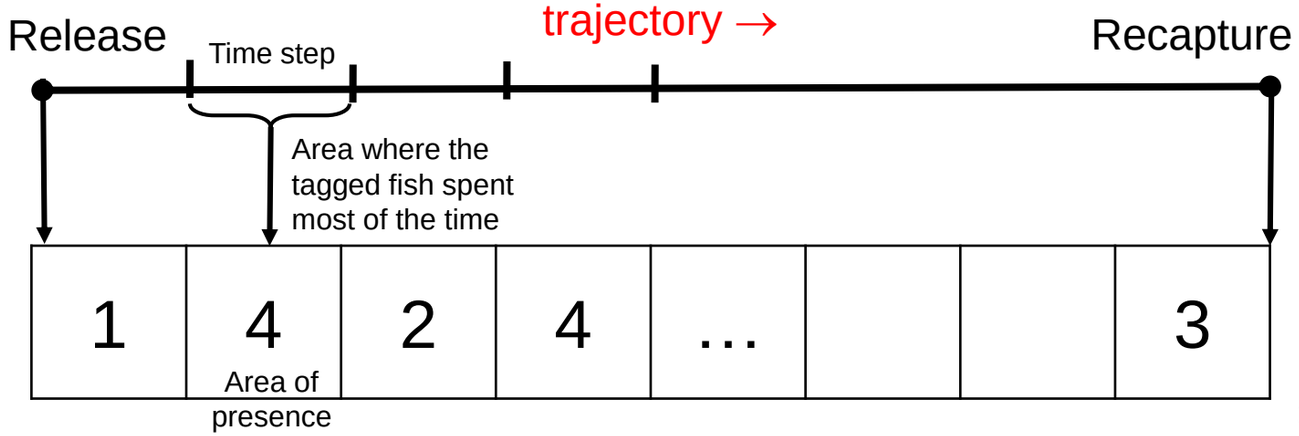
In time : 2 time step sizes:

Semester : Winter = 1/10 to 31/03 ; Summer = 1/04 to 30/09

Trimester : Winter = 1/01 to 31/03 ; Spring = 1/04 to 30/06

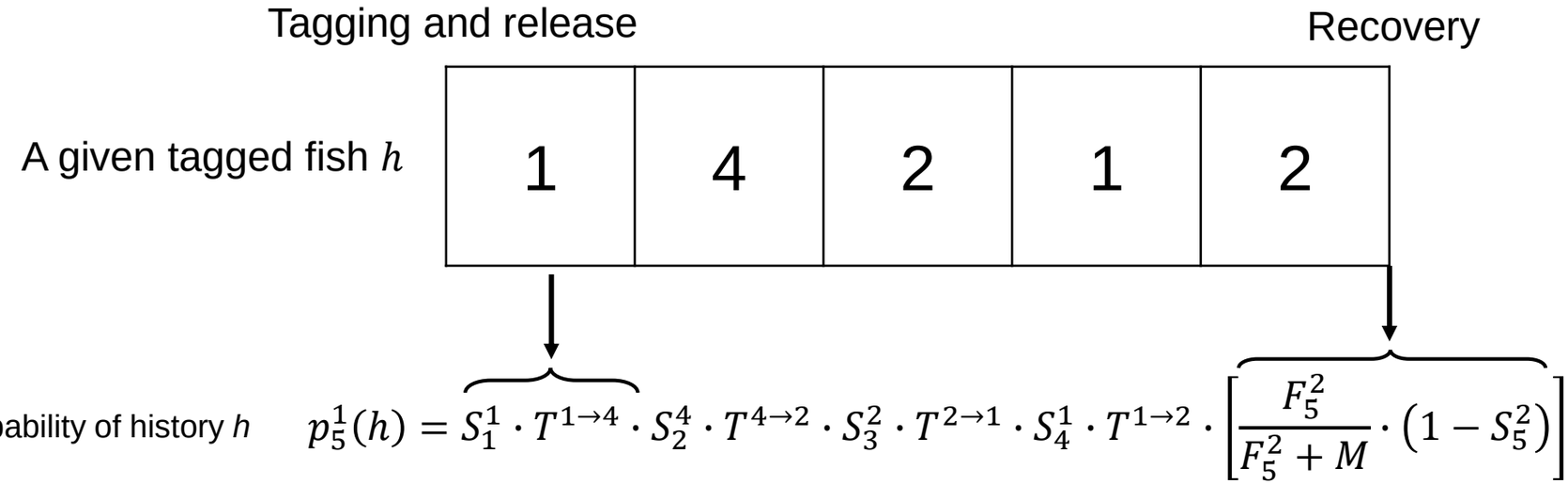
Summer = 1/07 to 30/09 ; Autumn = 1/10 to 31/12

→ to look at seasonal movements



Spatial model of tagged fish: multistate capture-recapture model

Arnason, 1973; Hestbeck et al., 1991; Lebreton et al., 1992; Brownie et al. 1993; Eveson et al. 2012



Probability of history *h* $p_5^1(h) = S_1^1 \cdot T^{1\to4} \cdot S_2^4 \cdot T^{4\to2} \cdot S_3^2 \cdot T^{2\to1} \cdot S_4^1 \cdot T^{1\to2} \cdot \left[\frac{F_5^2}{F_5^2 + M} \cdot \left(1 - S_5^2\right)\right]$

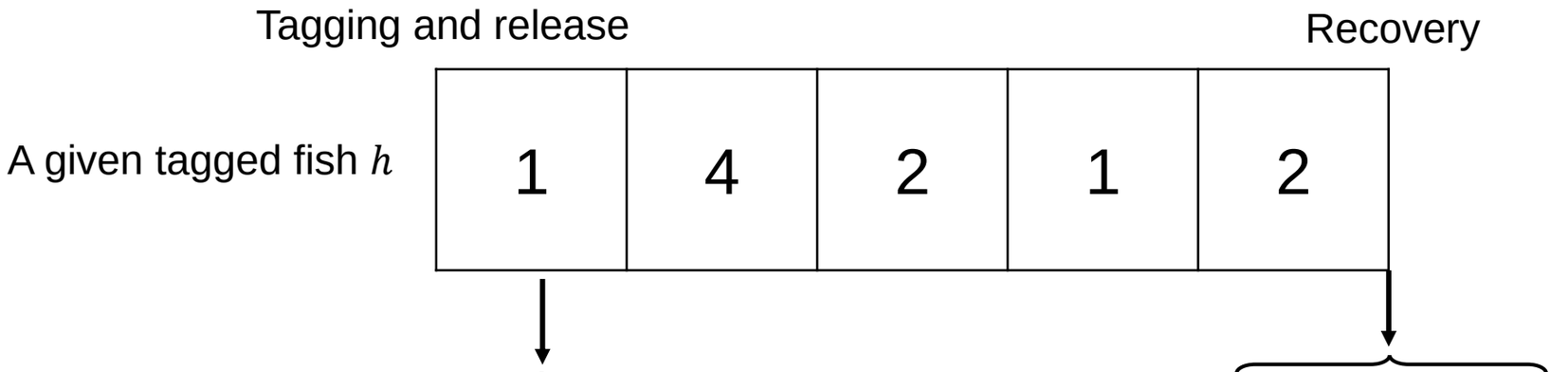
Recapture event

Survival $S_t^1 = e^{-F_t^1 - M}$ *and* $S_t^2 = e^{-F_t^2 - M}$

Instantaneous movement $T^{\mathrm{i}\to\mathrm{j}}$

Spatial model of tagged fish: multistate capture-recapture model

Arnason, 1973; Hestbeck et al., 1991; Lebreton et al., 1992; Brownie et al. 1993; Eveson et al. 2012



Probability of history h $p_5^1(h) = S_1^1 \cdot T^{1\to4} \cdot S_2^4 \cdot T^{4\to2} \cdot S_3^2 \cdot T^{2\to1} \cdot S_4^1 \cdot T^{1\to2} \cdot \left[\frac{F_5^2}{F_5^2 + M} \cdot \left(1 - S_5^2\right)\right]$

Survival $S_t^1 = e^{-F_t^1 - M}$ *and* $S_t^2 = e^{-F_t^2 - M}$

Recapture event

Instantaneous movement $T^{\mathrm{i}\to\mathrm{j}}$

Optimisation with AD model builder

Generalisation of p to all possible trajectories → Multinomial likelihood

$$-\log L = -\sum_{h=1}^{H} n_h \log p_t^z(h) - \left(N - \sum_{h=1}^{H} n_h\right) \log\left[1 - \sum_{h=1}^{H} p_t^z\,(h)\right]$$

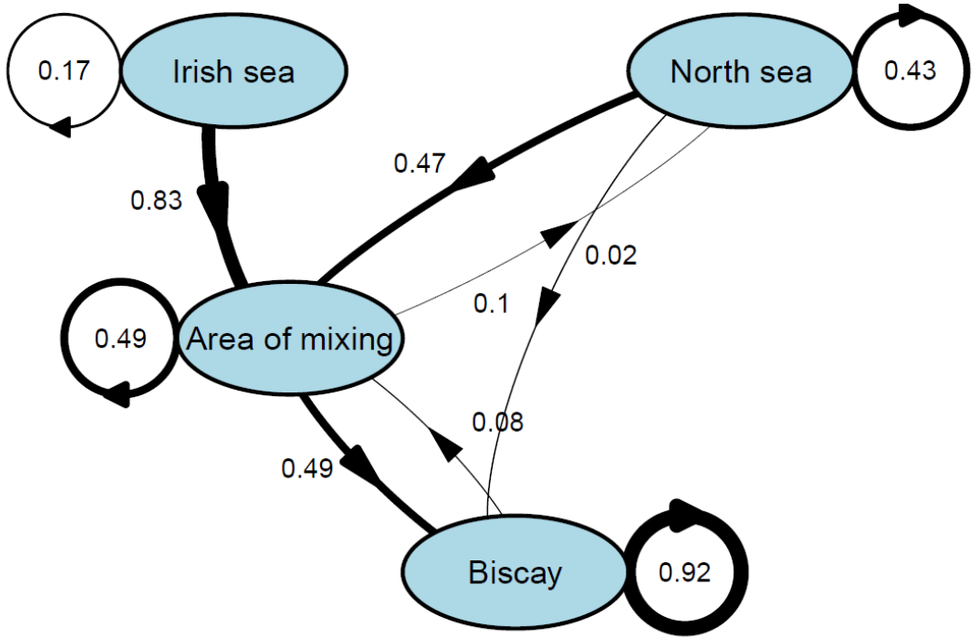
N Total number of tagged fish

H Total number of observed history

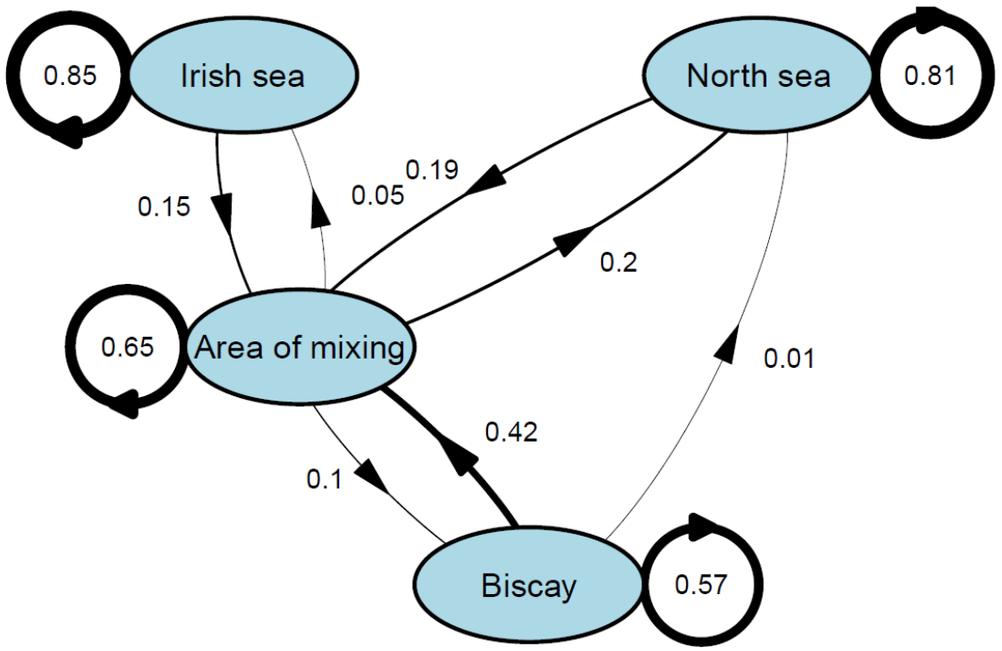
n_h Number of fish with history h

Results – Movement rates

Movement rates by semester – begining of winter – H2



Movement rates by semester – begining of summer – H2



ICES benchmark workshop february/november 2024 will use those estimates.

Parameterisation of a spatialised version of the current population dynamics model used by ICES (Stock Synthesis) and examine several hypothesis on spatial stock structure.

Bayesian approach ?

Perspectives

Upscaling the response at the individual scale to the population scale across space and time

Forecast populations spatial dynamics under different climate and fishing scenarios

Integrating this new knowledge into stock assessment and forecast models to provide reliable scientific advice to achieve an ecosystem approach to fisheries (EAF)

Thanks for your attention