Characterising spatio-temporal variability in hydrodynamic connectivity and its contribution to benthic species distributions

(1) Rade de Brest / Mer d'Iroise
(2) Manche / Golfe de Gascogne

Martin Marzloff
IFREMER, DYNECO-LEBCO, 29280 Plouzané

iMarCo2019, September 23-25, Aveiro, Portugal

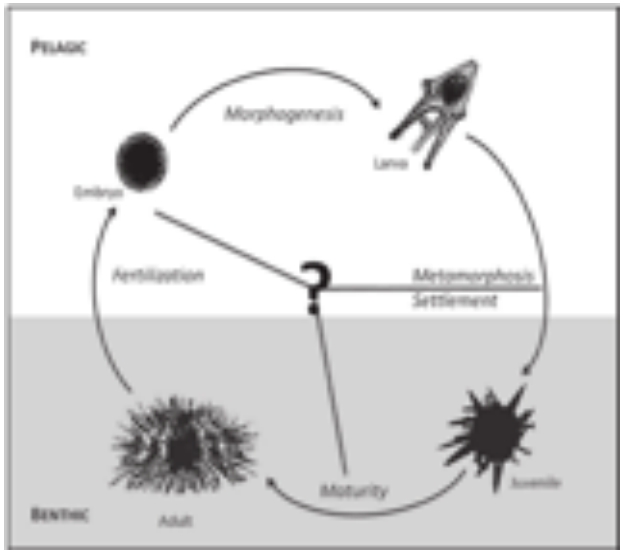
I - Characterising spatio-temporal variability in hydrodynamic connectivity and its contribution to benthic species distributions in the Bay of Brest and Iroise Sea (France)

Philippe Cugier, Martin Marzloff
IFREMER, DYNECO-LEBCO, 29280 Plouzané

AMEDEE, Nantes, Oct. 2019 – (presentation adapted from iMarCo2019)

Context of the study

- Benthic invertebrate populations distribution

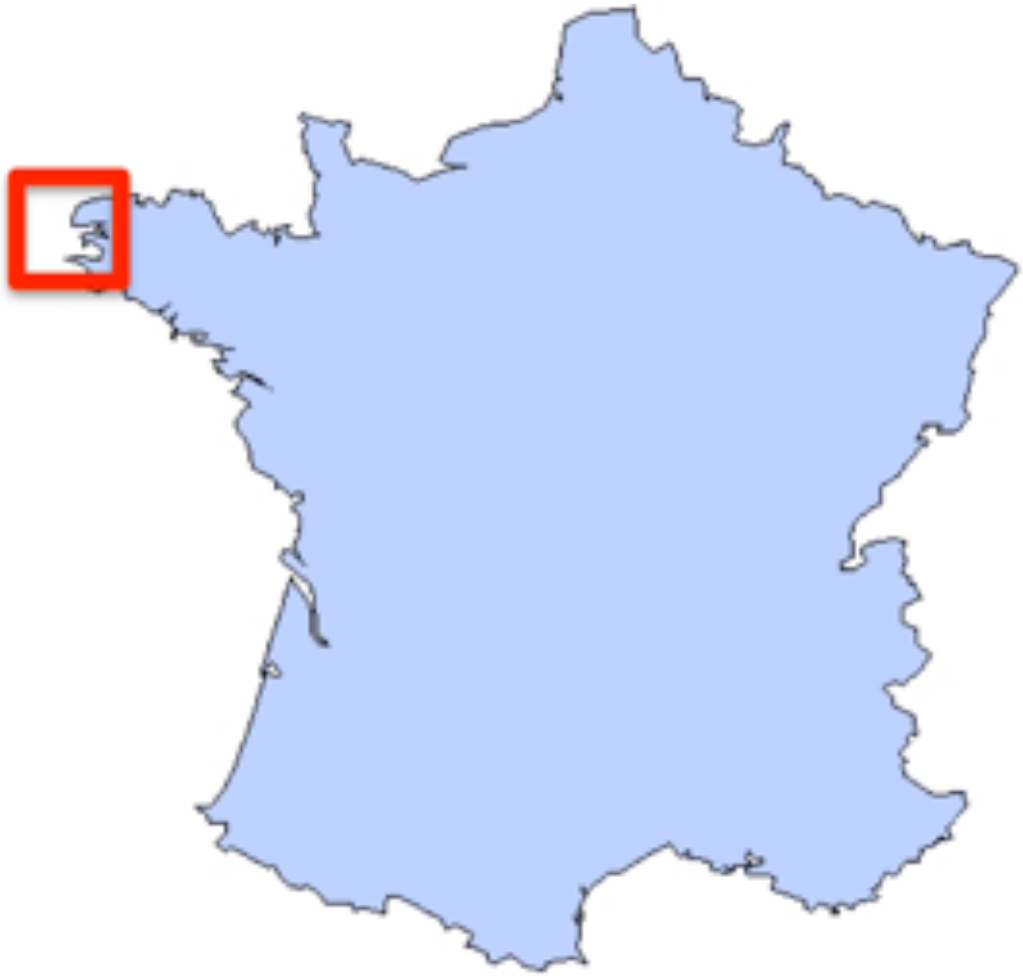


- Larvae dispersal by hydrodynamic is crucial in the population dynamics and spatial distribution of fixed or poorly mobile organisms

- Influence long-term spatial patterns and local inter-annual changes in benthic communities

Context of the study

- Iroise sea and bay of Brest



Context of the study

- Iroise sea and bay of Brest
- Depth < 150m
- High tidal currents (up to 8 knots around Ushant islands during spring tide)
- River inputs in the bay of Brest : Aulne and Elorn

Context of the study

- Iroise sea and bay of Brest

  - High diversity of benthic species of commercial or ecological interest

P. maximus

O. edulis

M. varia

C. fornicata

O. nigra

C. gigas

  - Strong fluctuations in populations distribution in the past decades : environmental and/or anthropic factors

Main objectives of the study: role of connectivity in benthic population dynamics

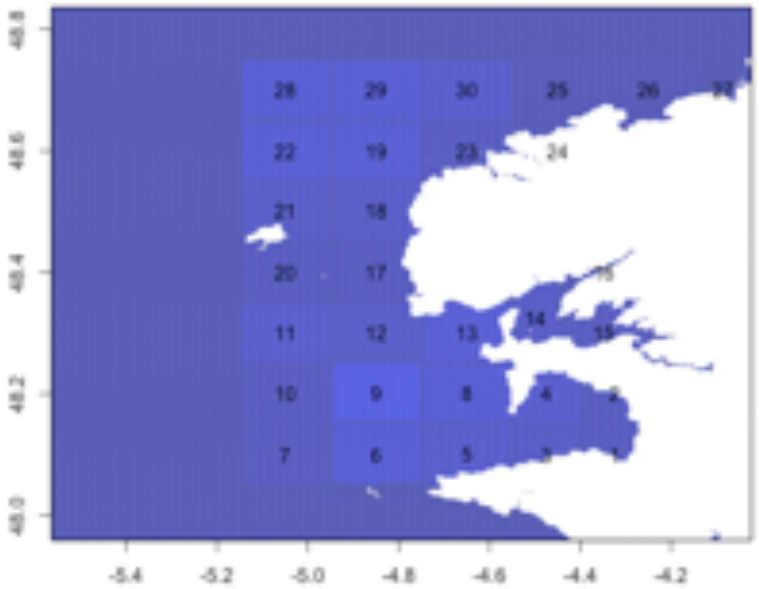
- What are the main connectivity patterns in Iroise sea ?
- Is there any seasonal and/or annual variability of these patterns ?
- Are there areas of preferential source or sink for larvae ?

➢ **biophysical modelling**

Material and methods

➢ **MARS3D hydrodynamical model**

- Horizontal resolution : 250m
- Vertical resolution : 30 sigma layers
- Real tide forced, real river flows of Elorn and Aulne, real meteorological forcing

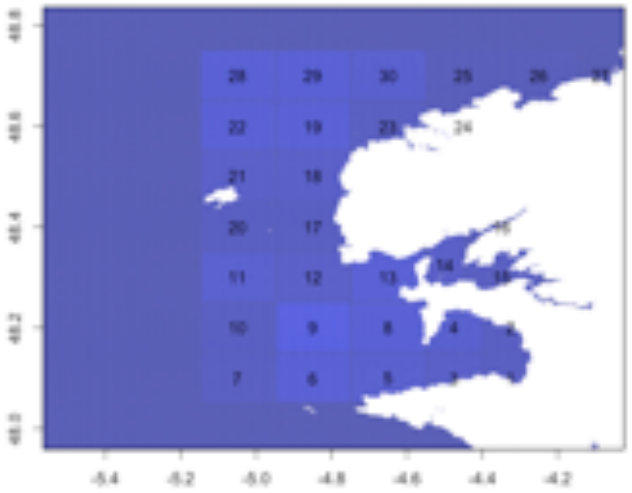


➢ **Tracer simulations**

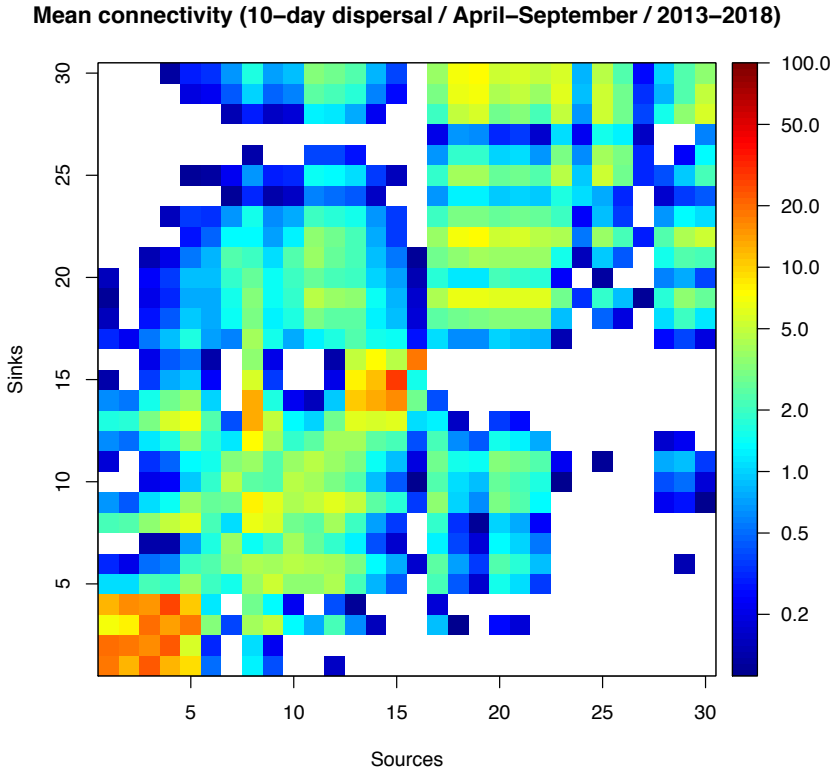
- Domain splitting : 30 areas
- Passive tracers released instantaneously in the bottom layer of each area at the begining of simulation.
- Simulated period 2013-2018
- Monthly simulations : april - september

Results

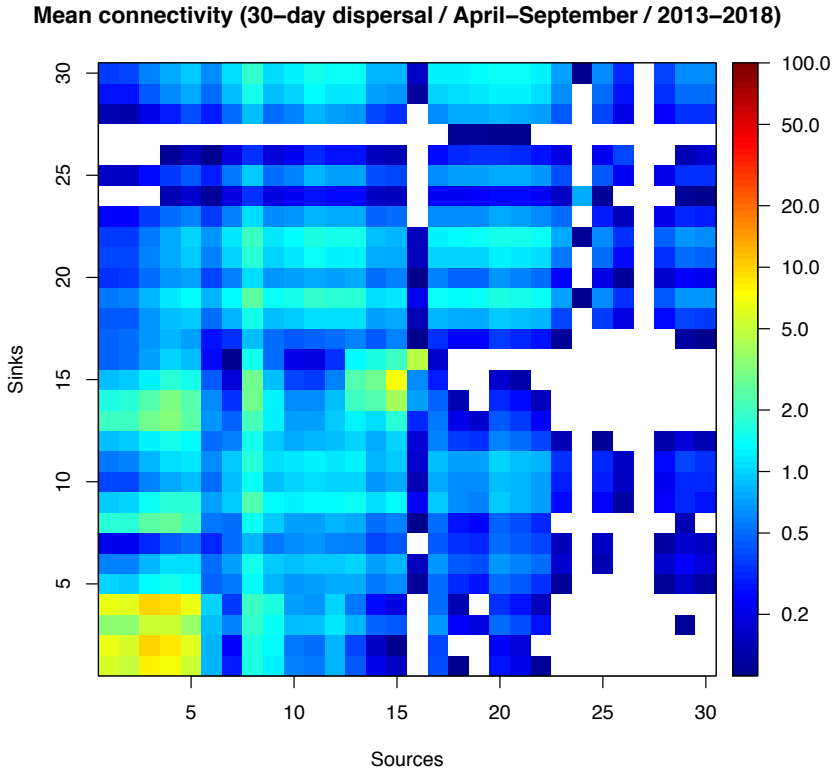
Average connectivity matrix



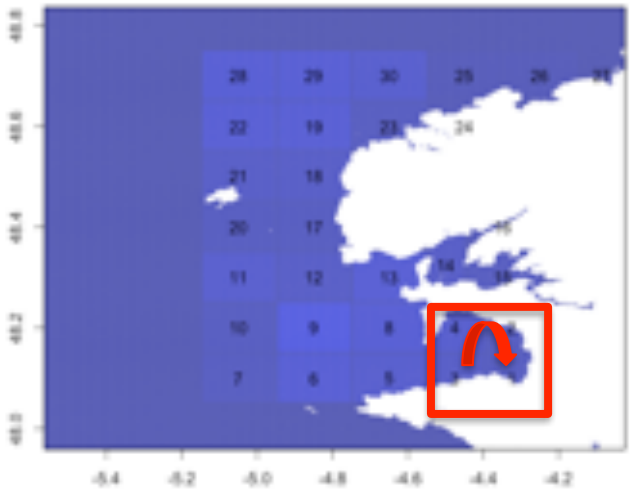
10 days



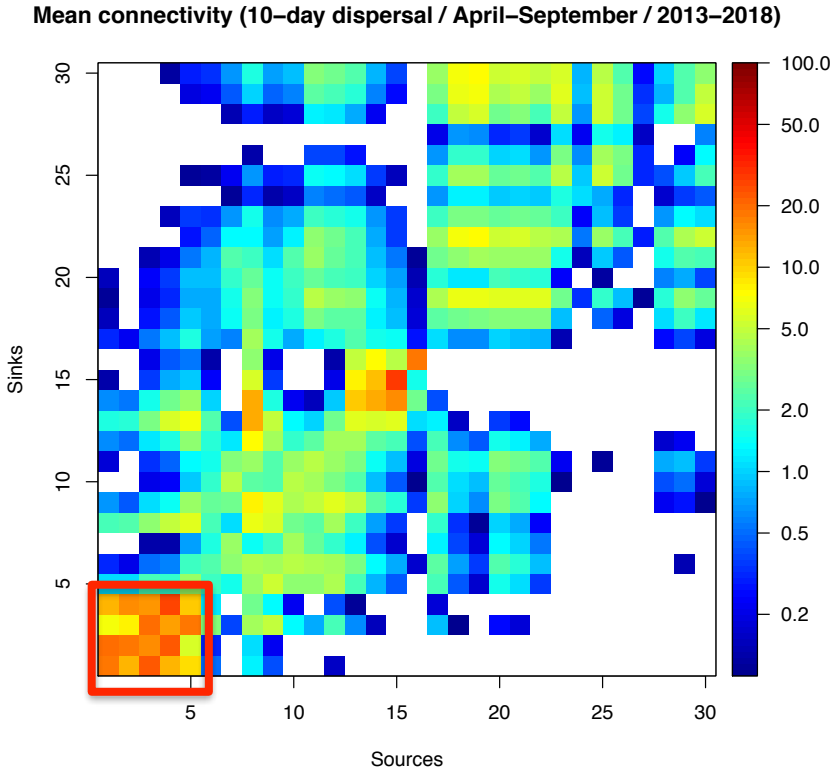
30 days



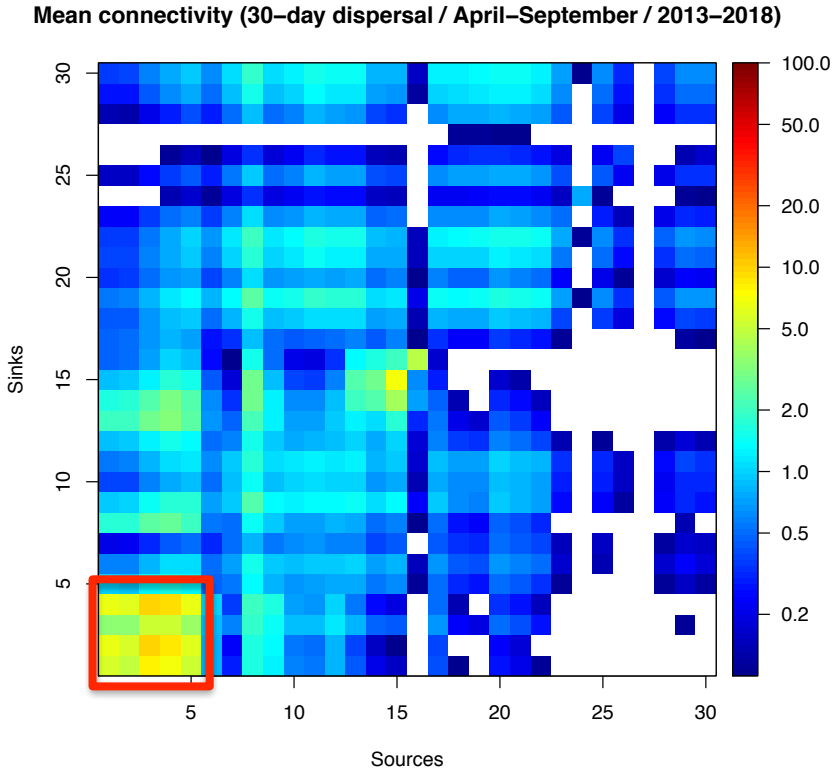
Results : Average connectivity matrix



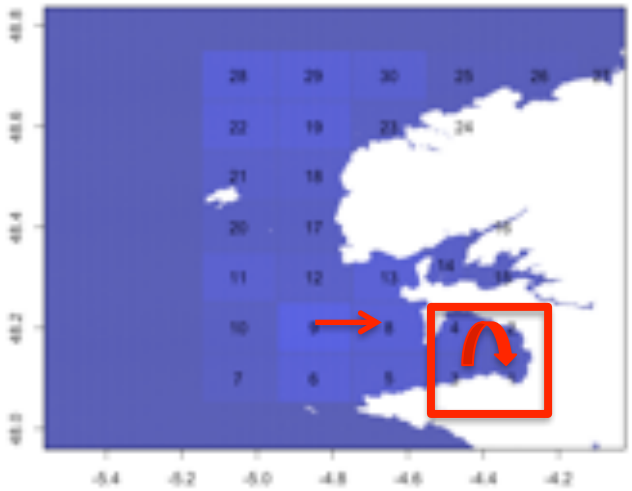
10 days



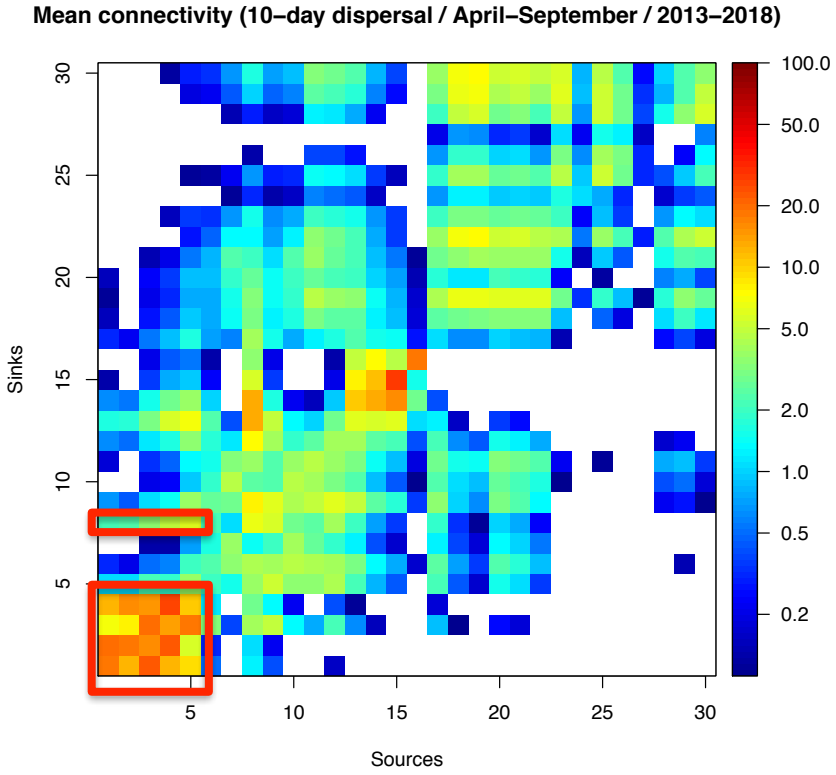
30 days



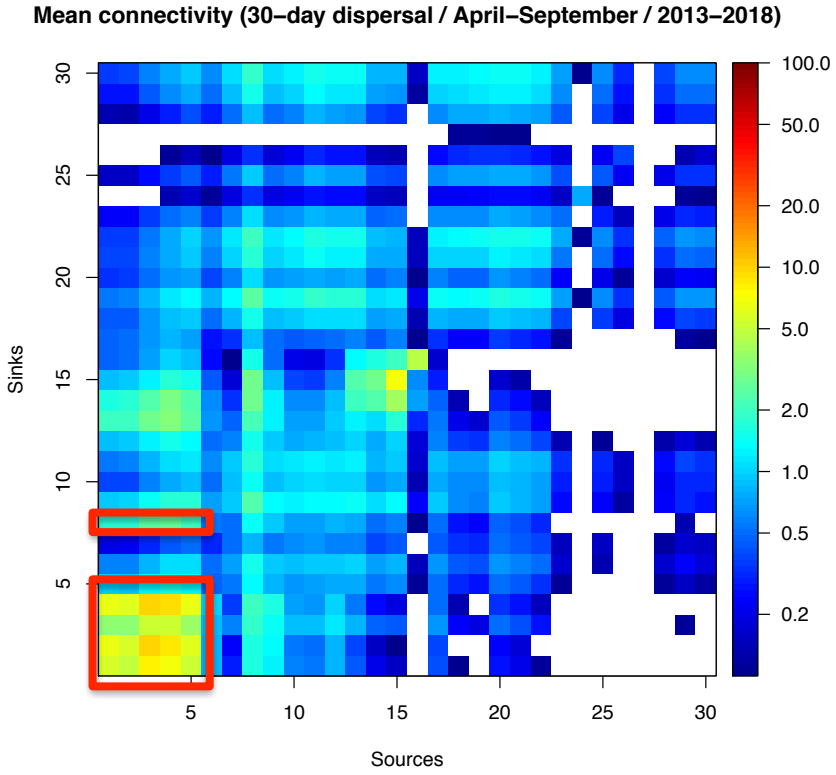
Results : Average connectivity matrix



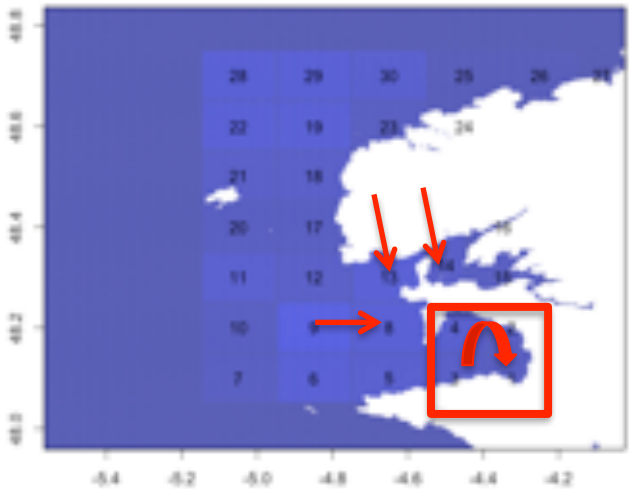
10 days



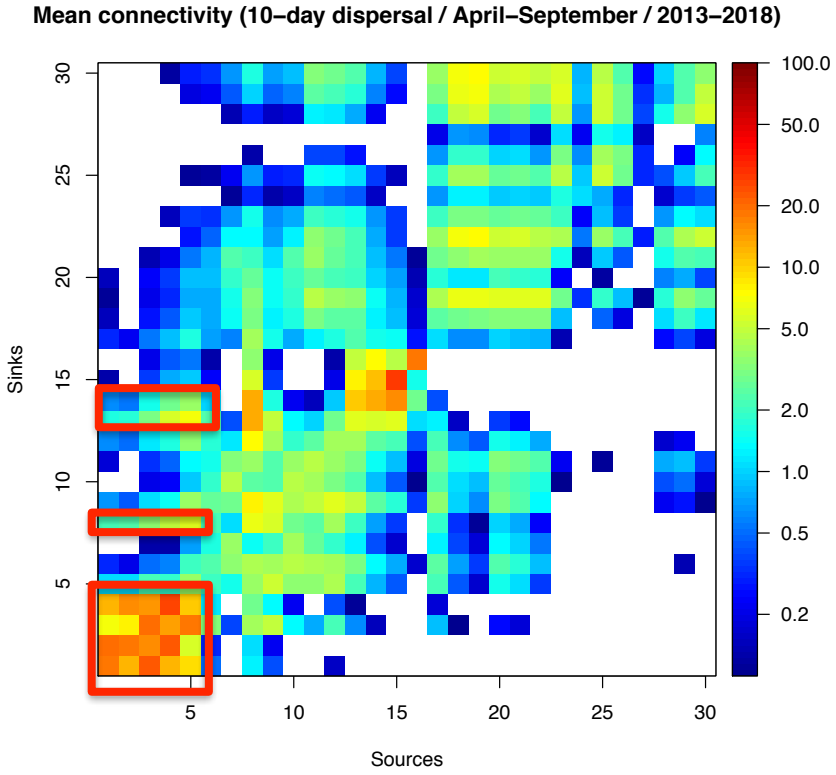
30 days



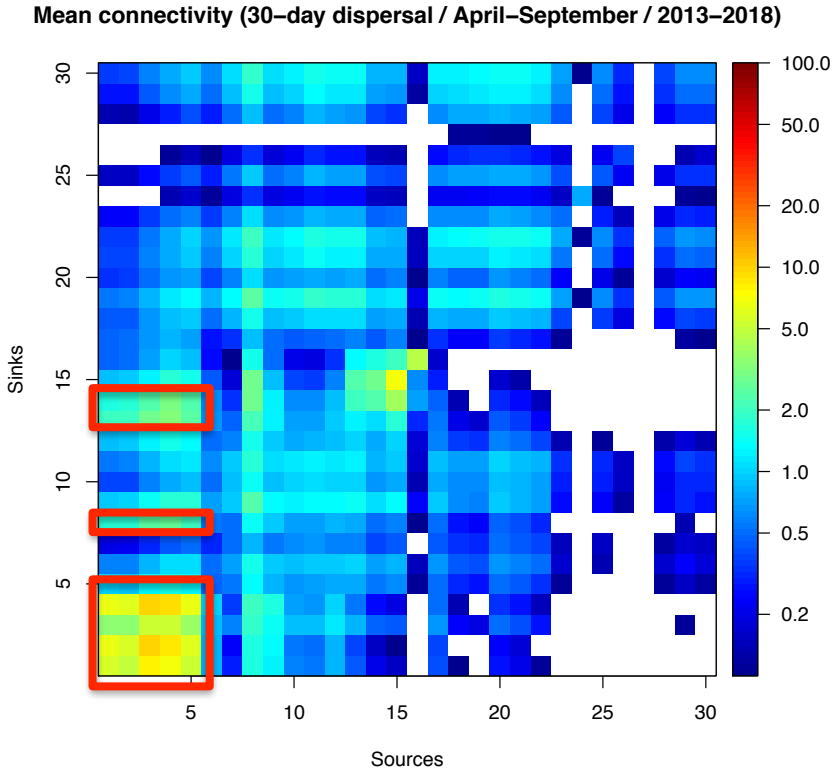
Results : Average connectivity matrix



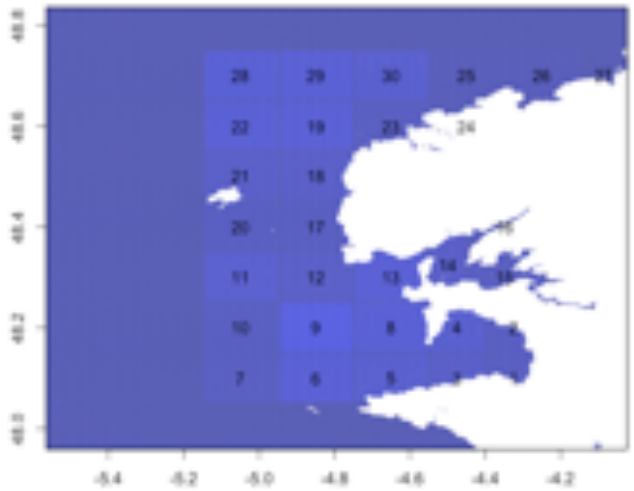
10 days



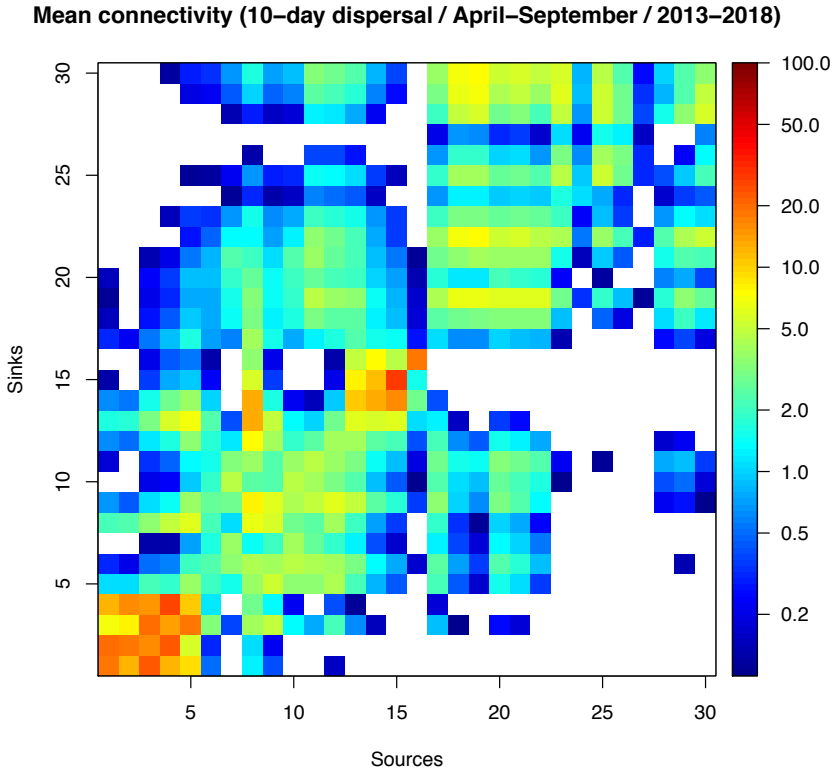
30 days



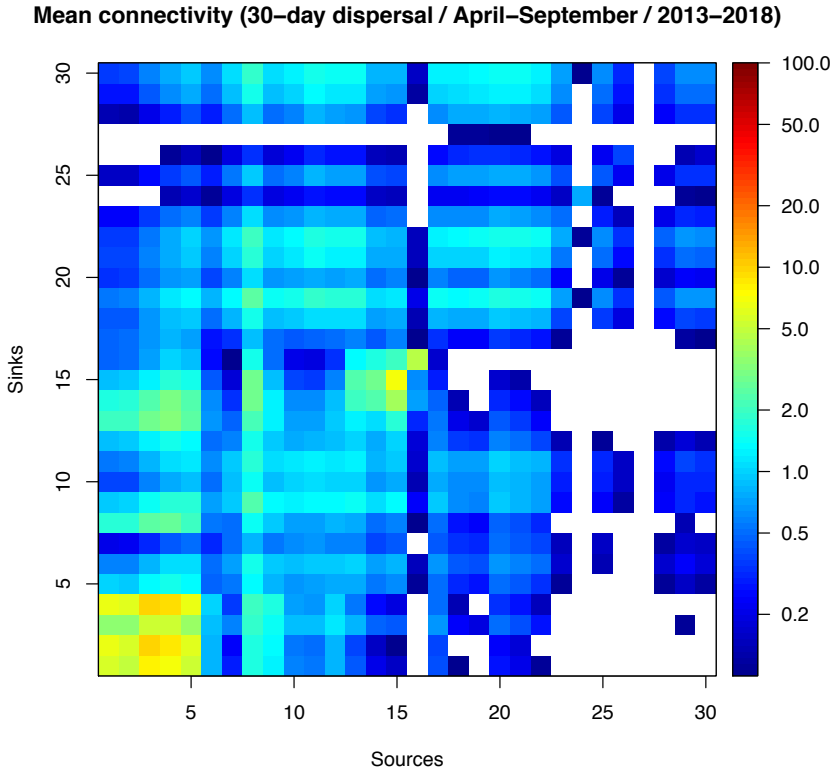
Results : Average connectivity matrix



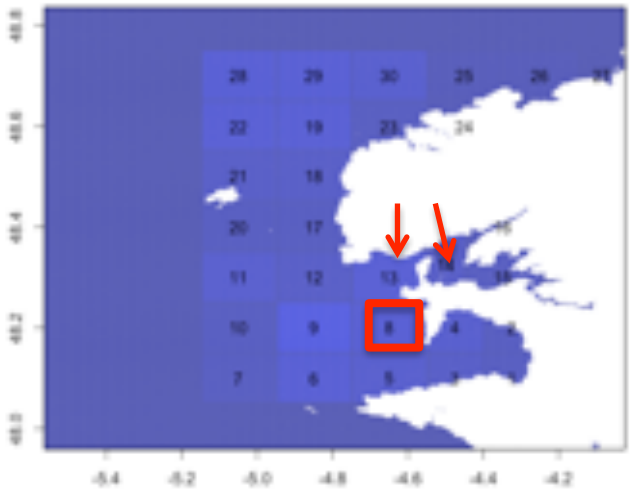
10 days



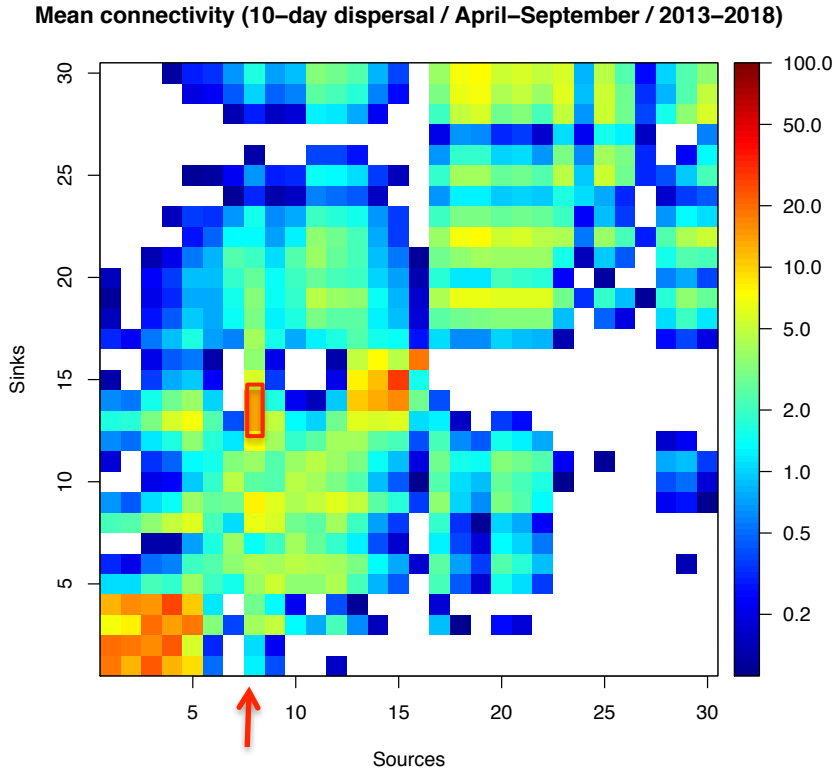
30 days



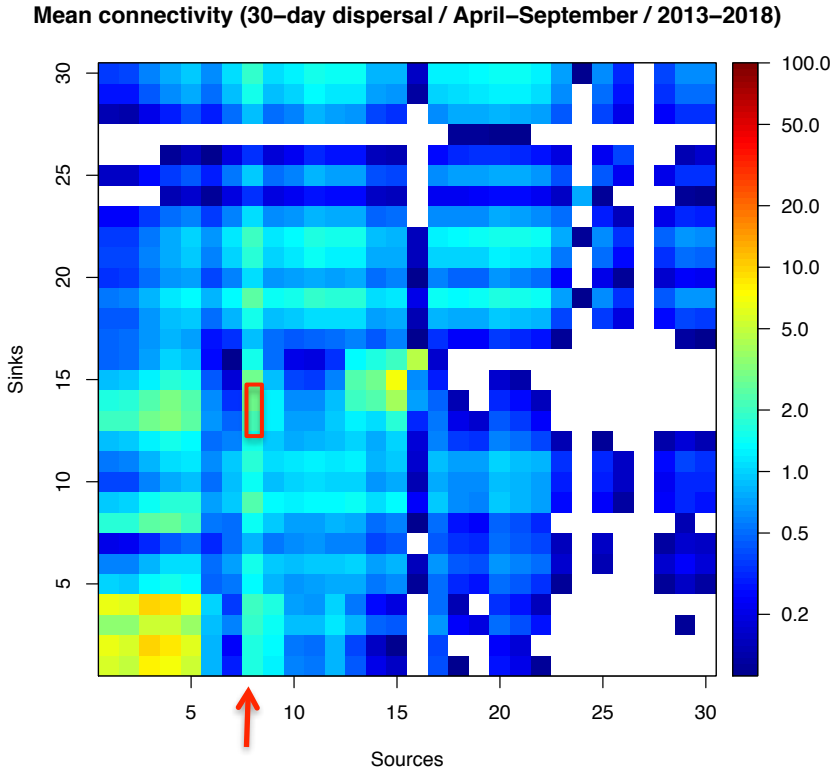
Results : Average connectivity matrix



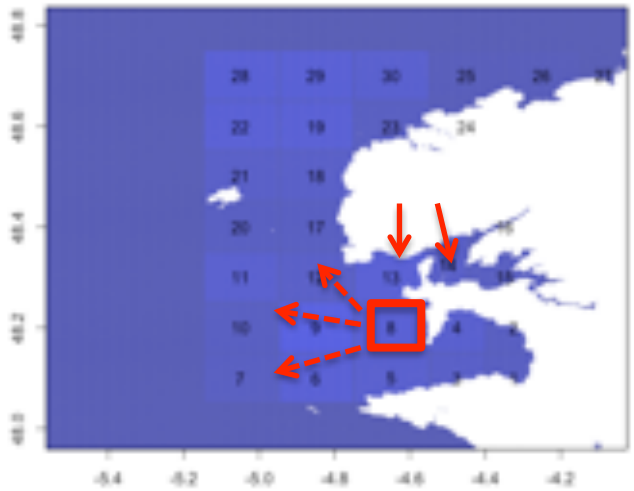
10 days



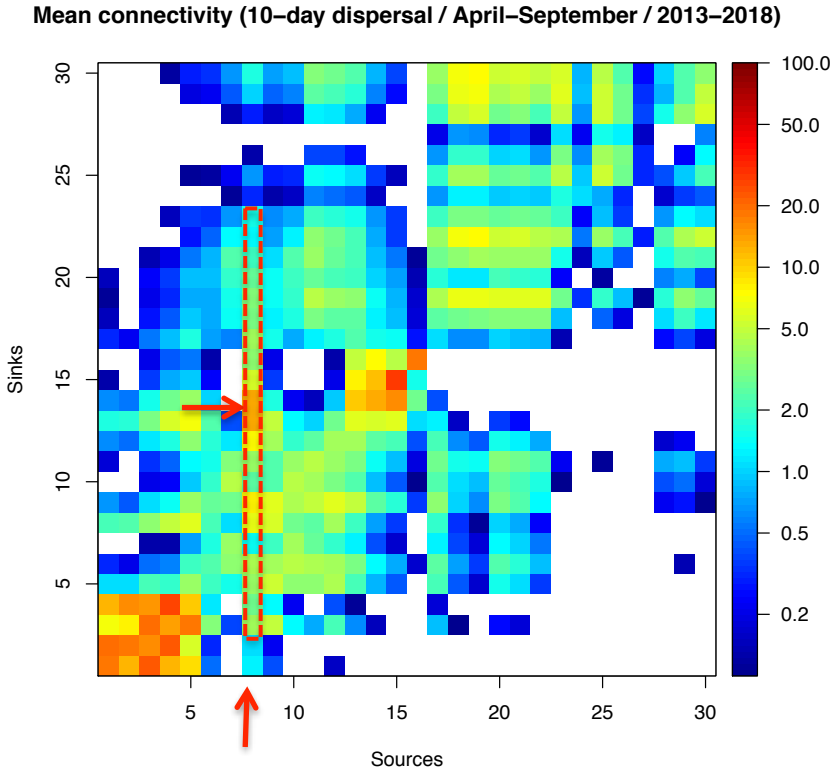
30 days



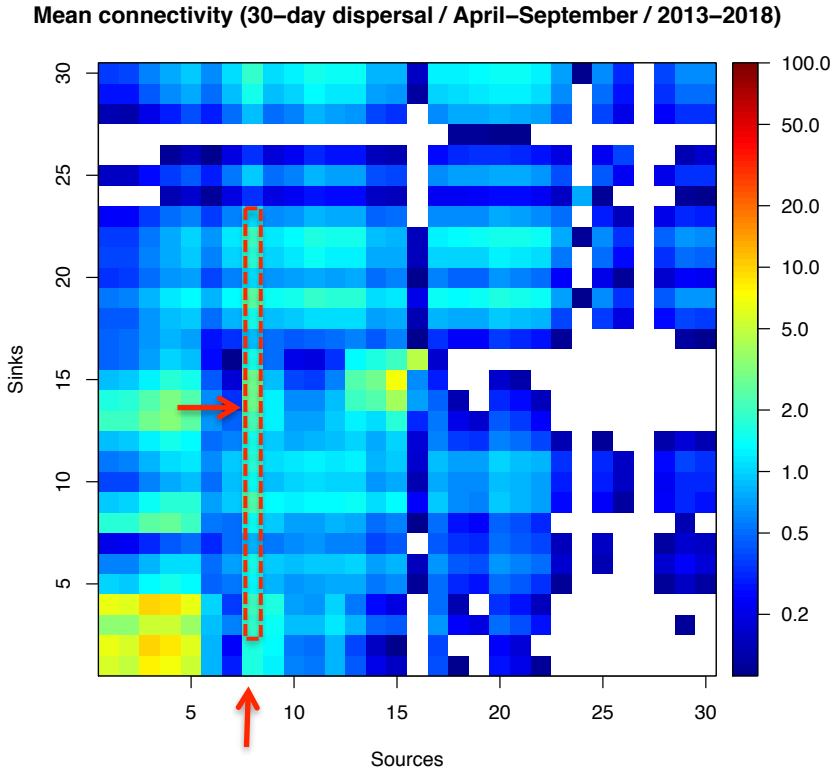
Results : Average connectivity matrix



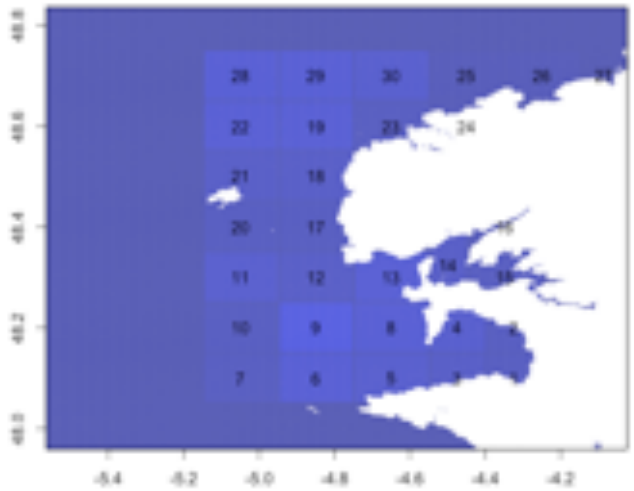
10 days



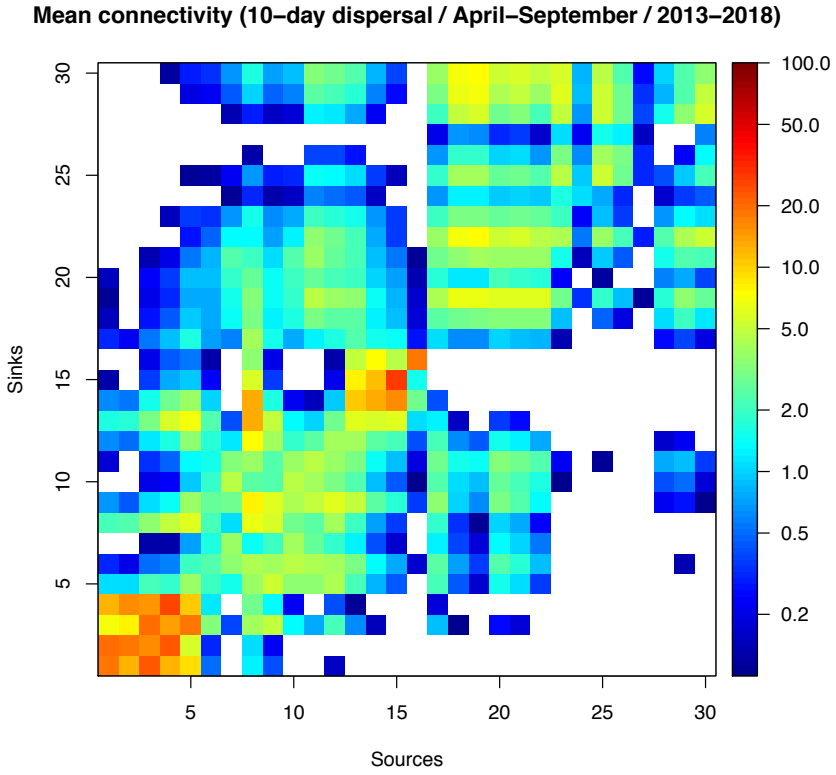
30 days



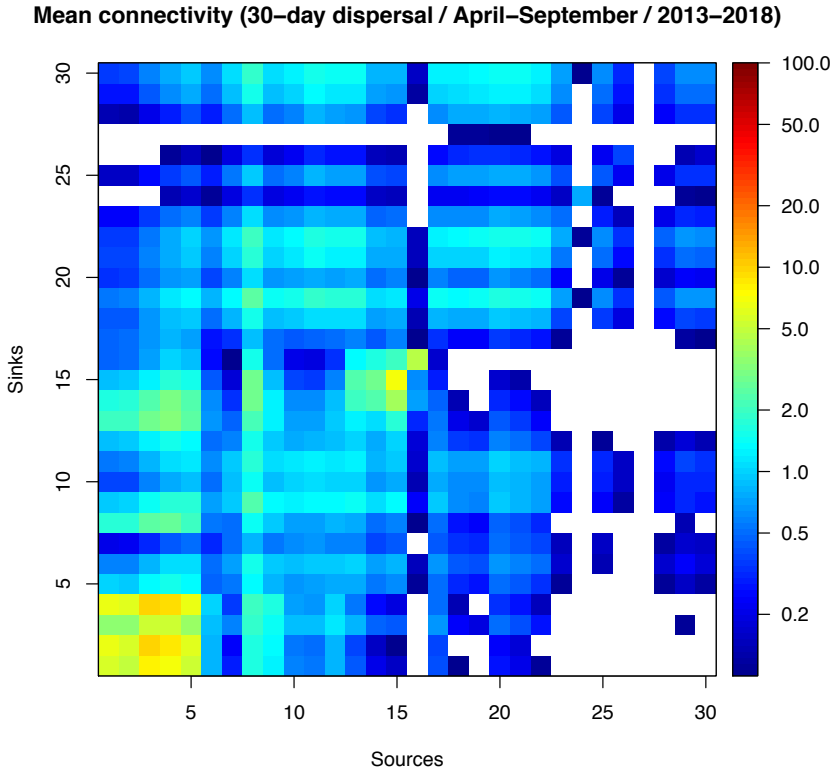
Results : Average connectivity matrix



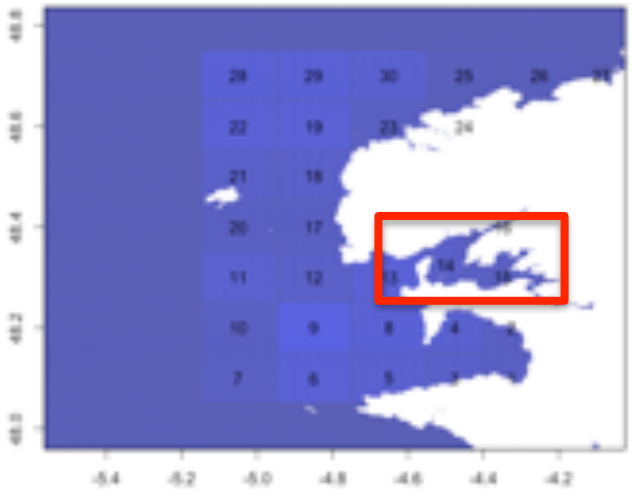
10 days



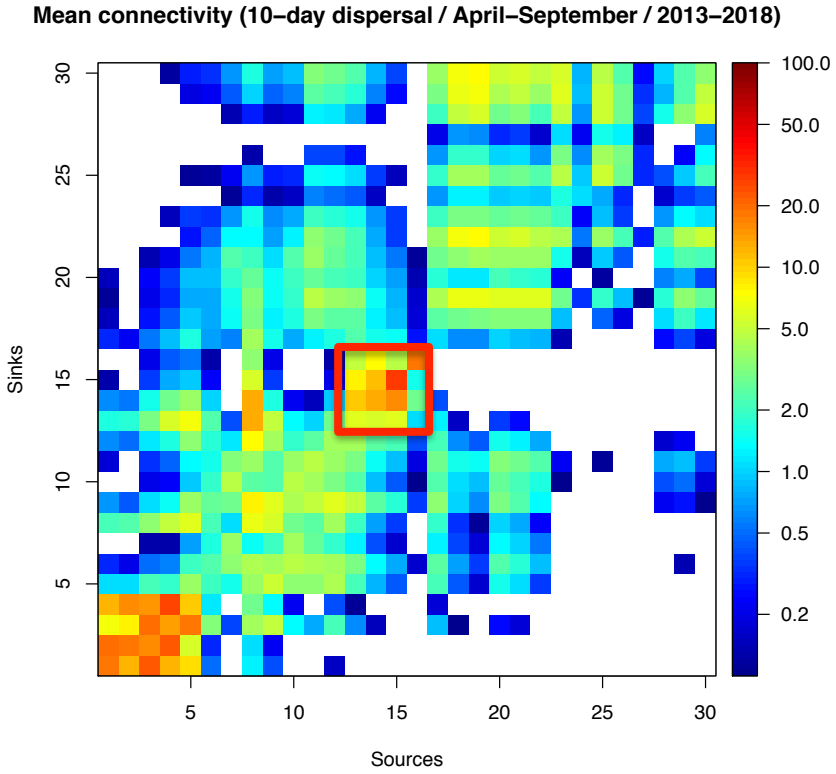
30 days



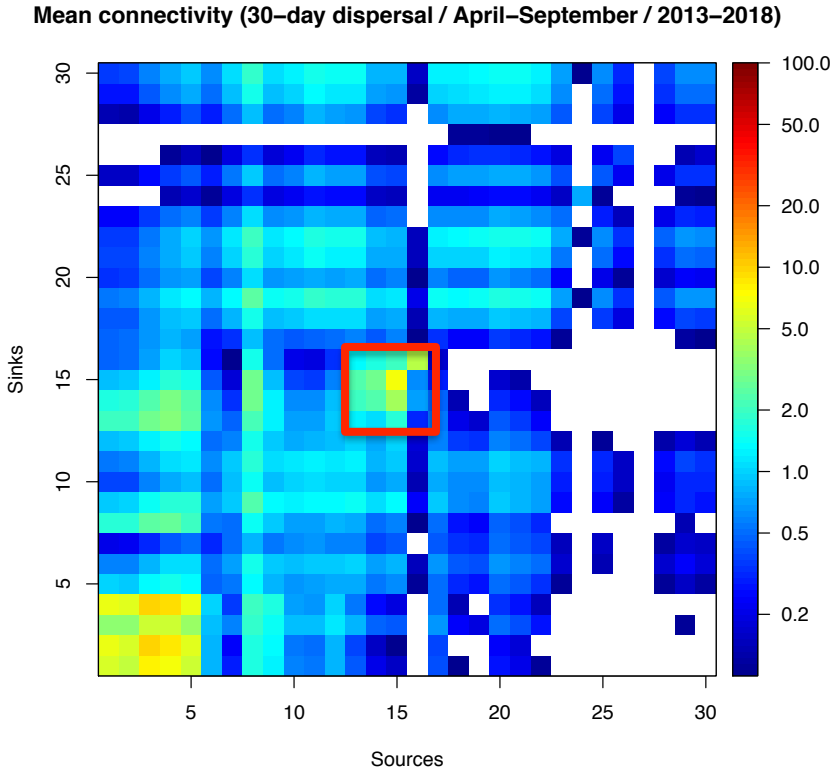
Results : Average connectivity matrix



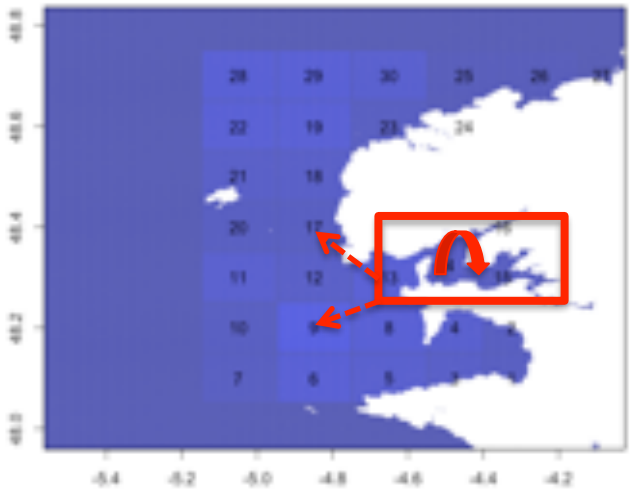
10 days



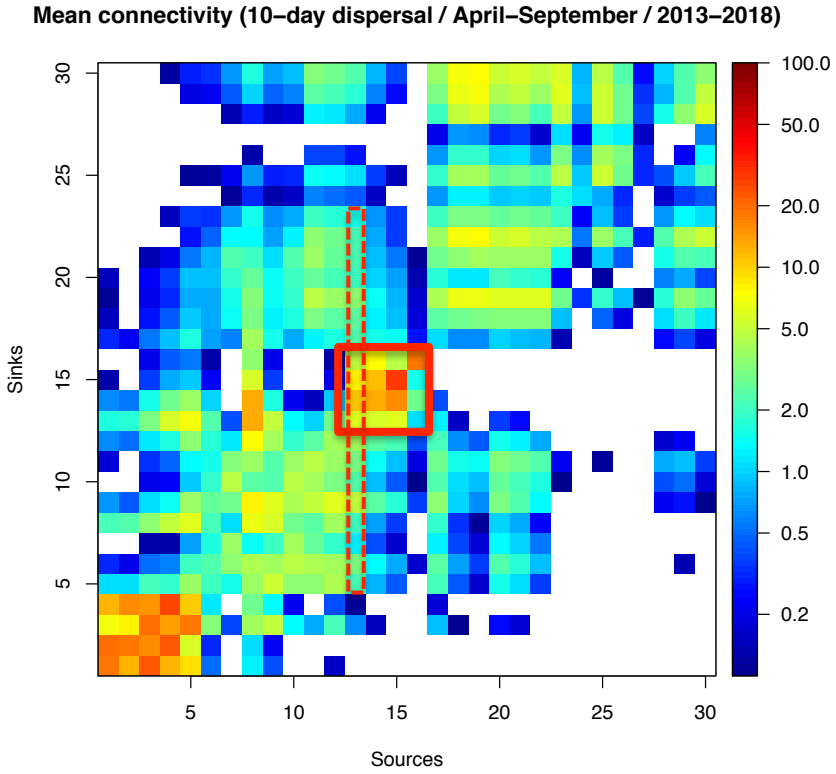
30 days



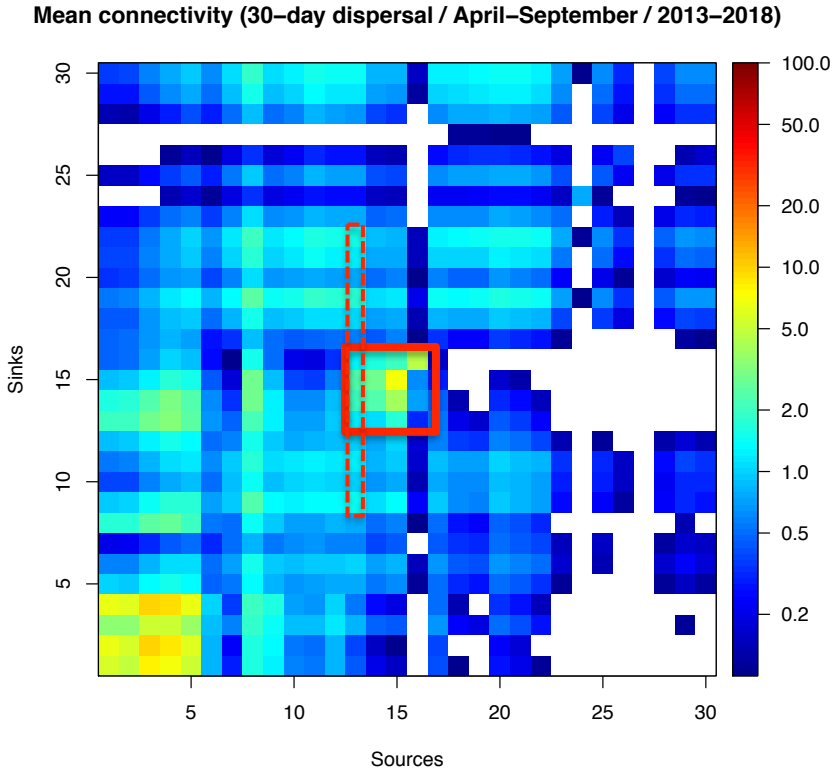
Results : Average connectivity matrix



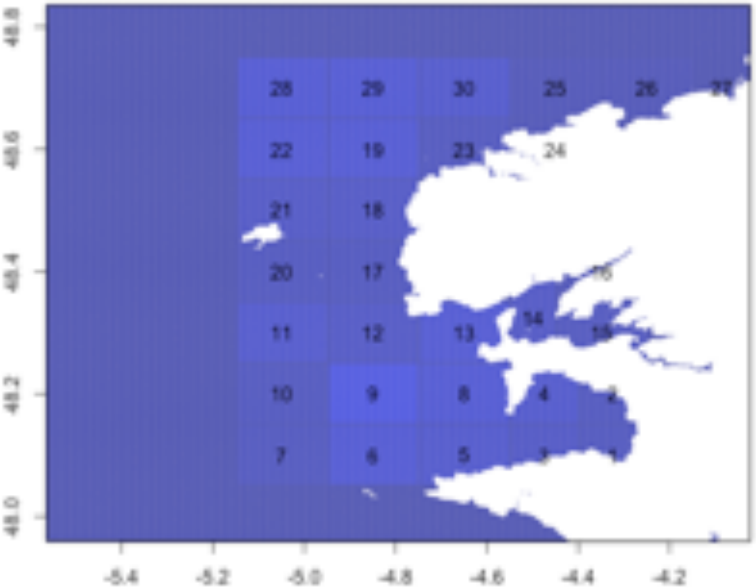
10 days

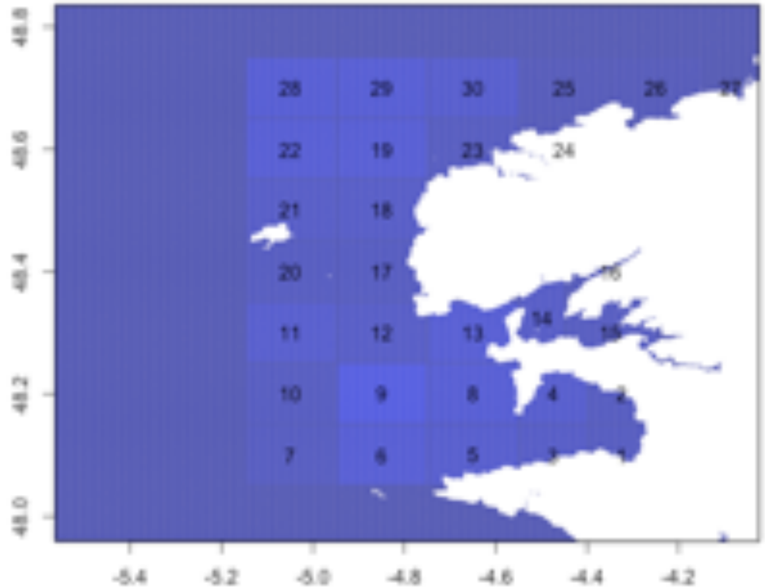


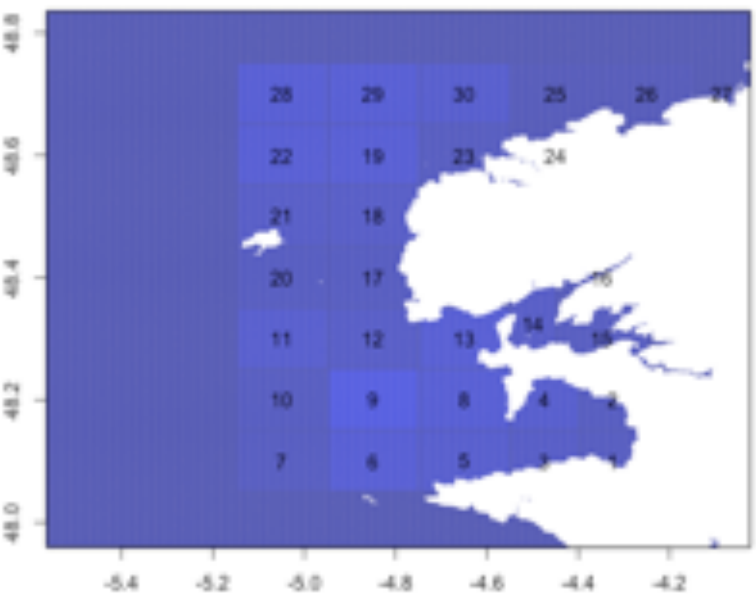
30 days



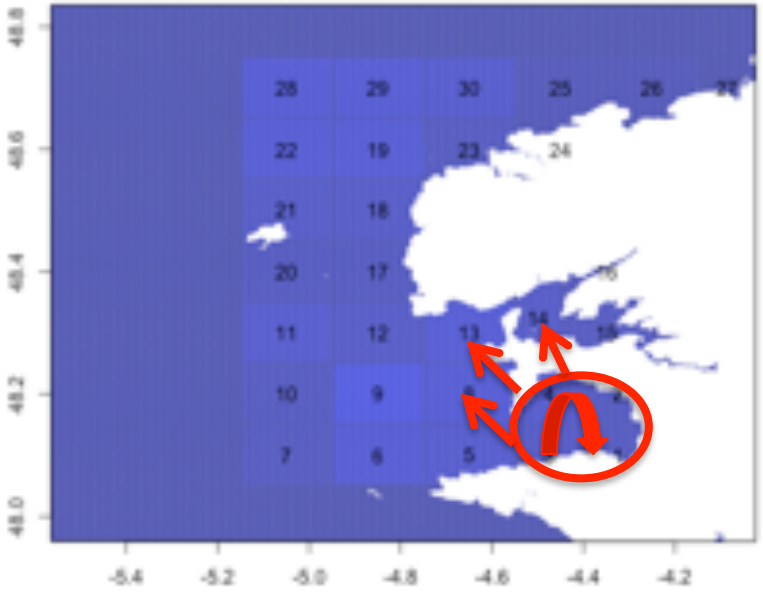
Results : Main connectivity patterns

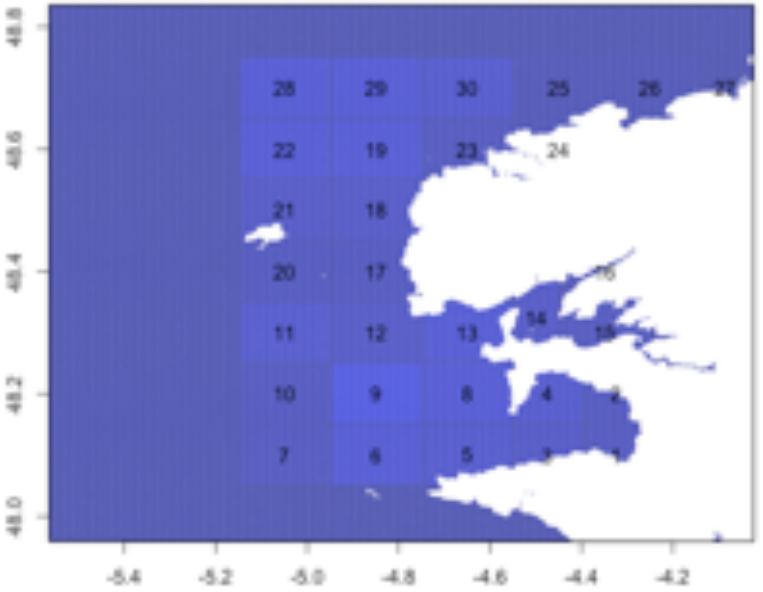


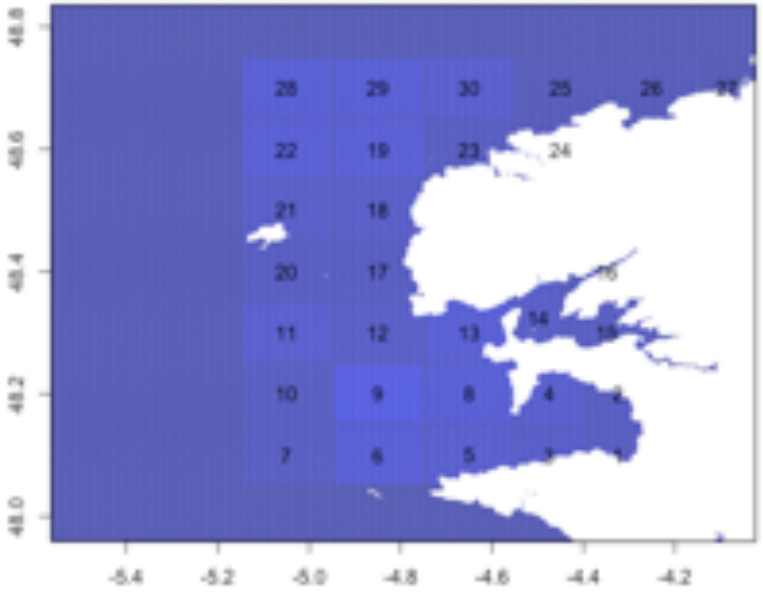




Results : Main connectivity patterns

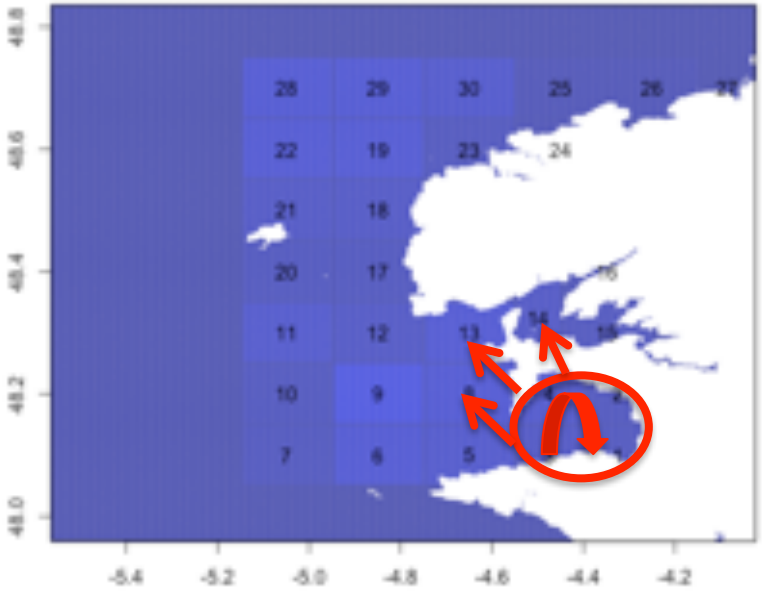


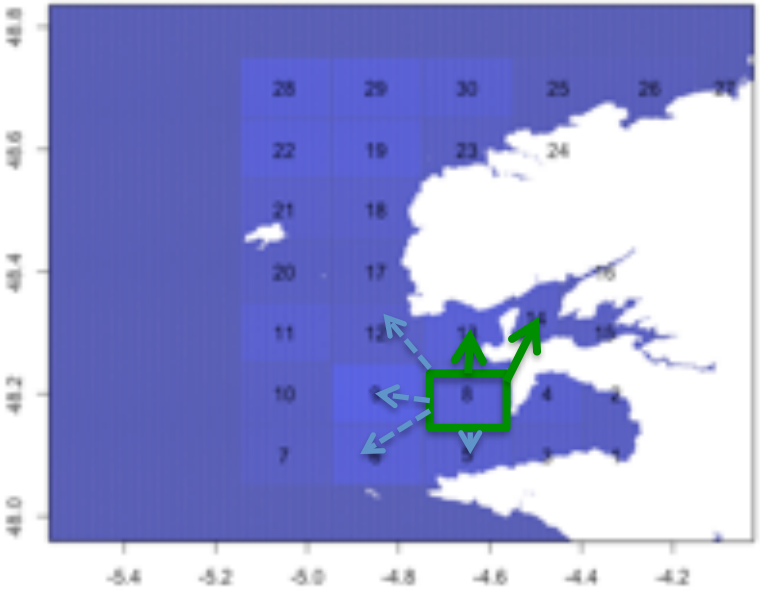


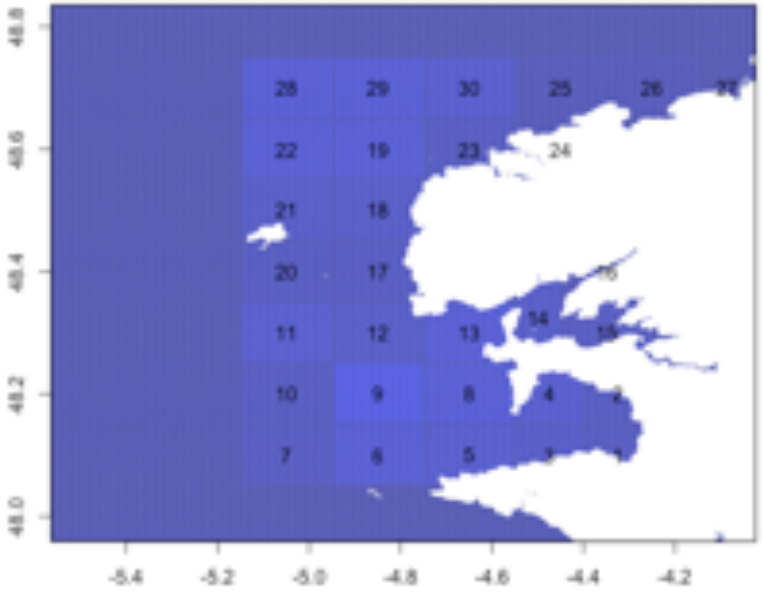


Bay of Douarnenez ➔ BoD (1, 2,3, 4), Crozon Peninsula (8), BoB entrance (13), Cental BoB (14), *Iroise sea*

Results : Main connectivity patterns



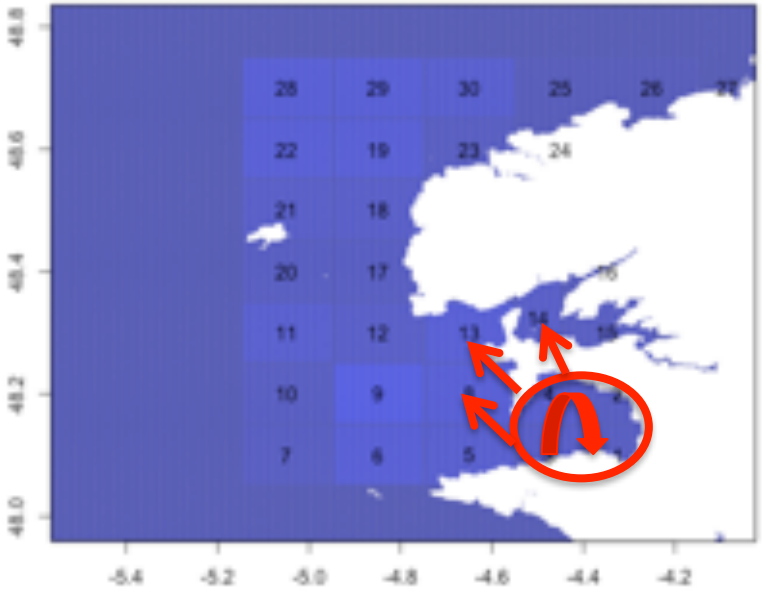


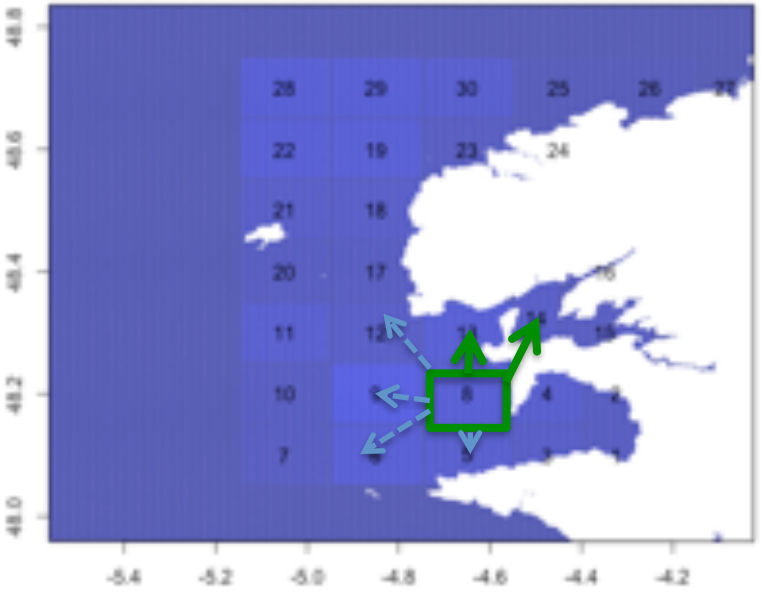


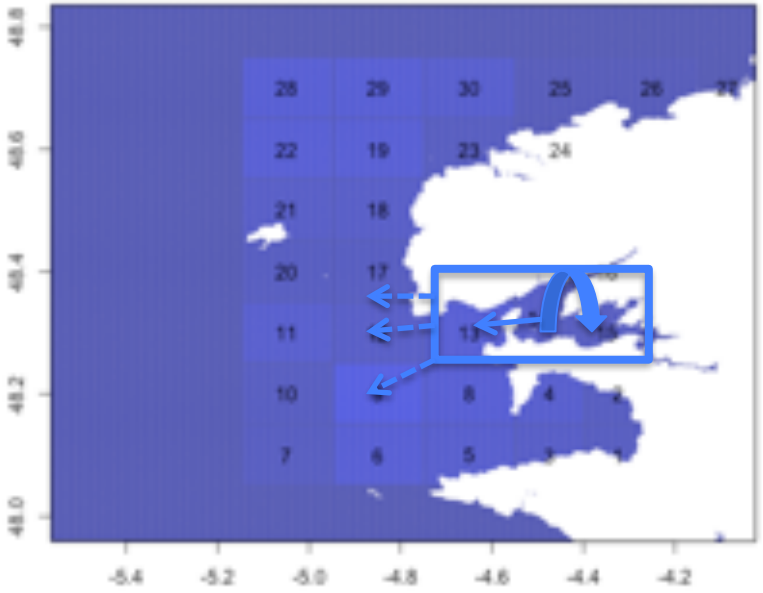
Bay of Douarnenez ➔ BoD (1, 2,3, 4), Crozon Peninsula (8), BoB entrance (13), Cental BoB (14), *Iroise sea*

Crozon peninsula ➔BoB entrance (13), Central BoB (14) , *Iroise sea (6, 8, 10, …)* : HUB of connectivity ?

Results : Main connectivity patterns





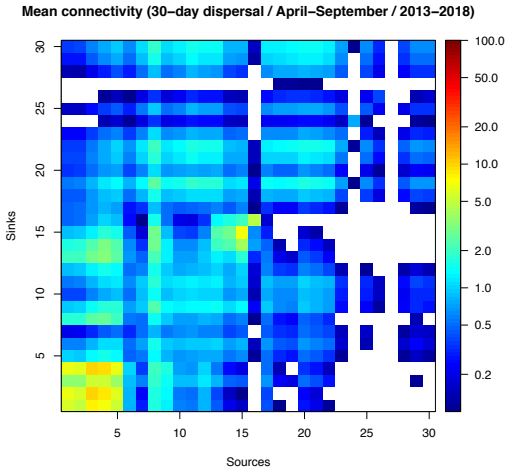


Bay of Douarnenez ➔ BoD (1, 2,3, 4), Crozon Peninsula (8), BoB entrance (13), Cental BoB (14), *Iroise sea*

Crozon peninsula ➔BoB entrance (13), Central BoB (14) , *Iroise sea (6, 8, 10, …)* : HUB of connectivity ?

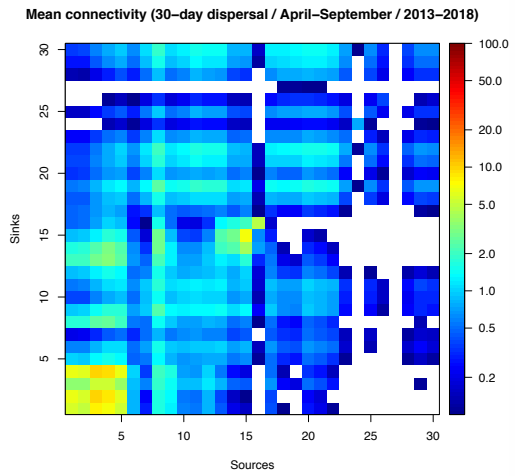
Bay of Brest ➔ BoB (14,15,16), BoB entrance (13), *Iroise sea (9, 12, 17,…)*

Variability in the connectivity patterns ?

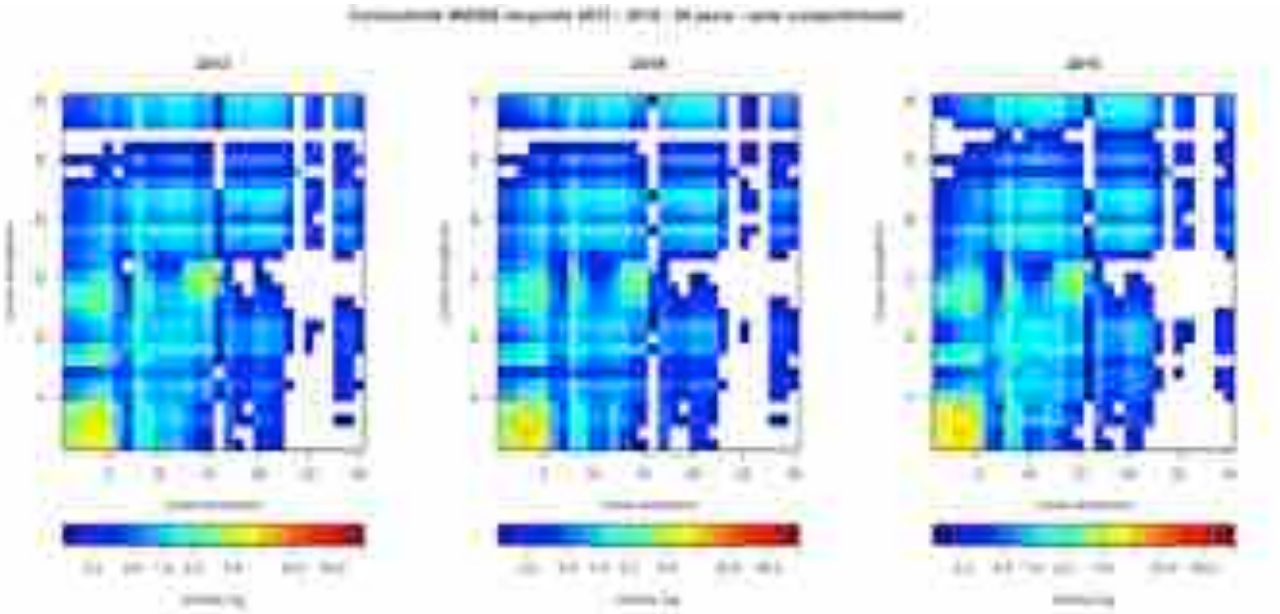


30 days

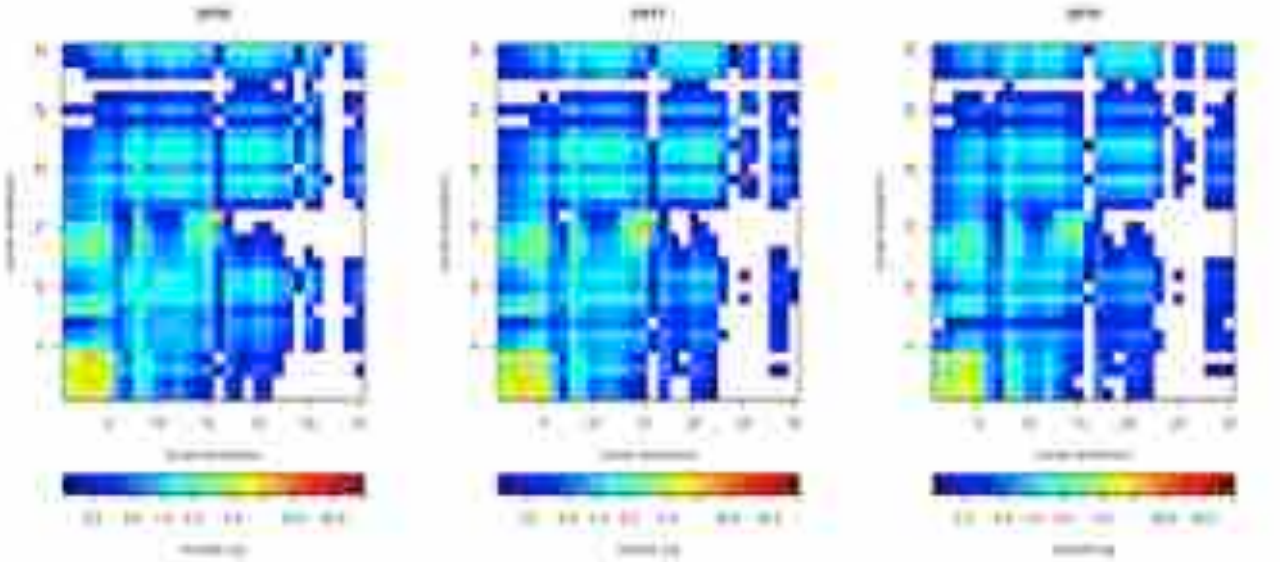
Variability in the connectivity patterns ?



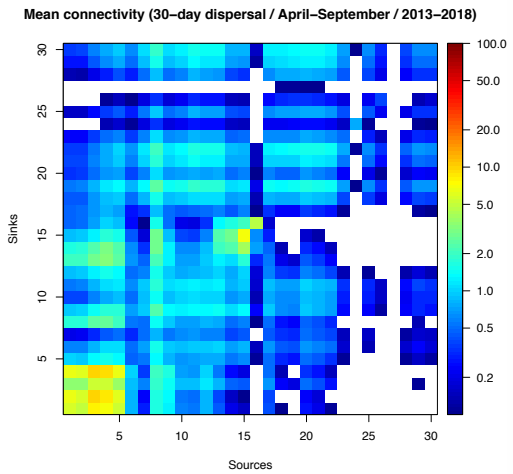
30 days



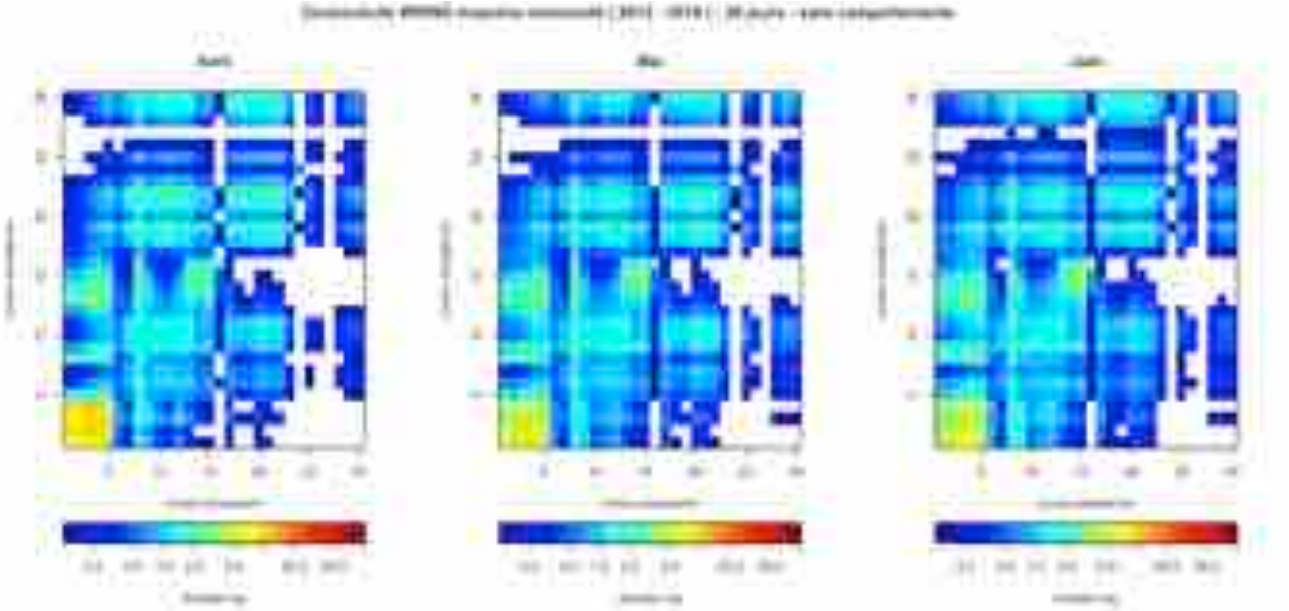
Annual connectivity patterns (April-September average)



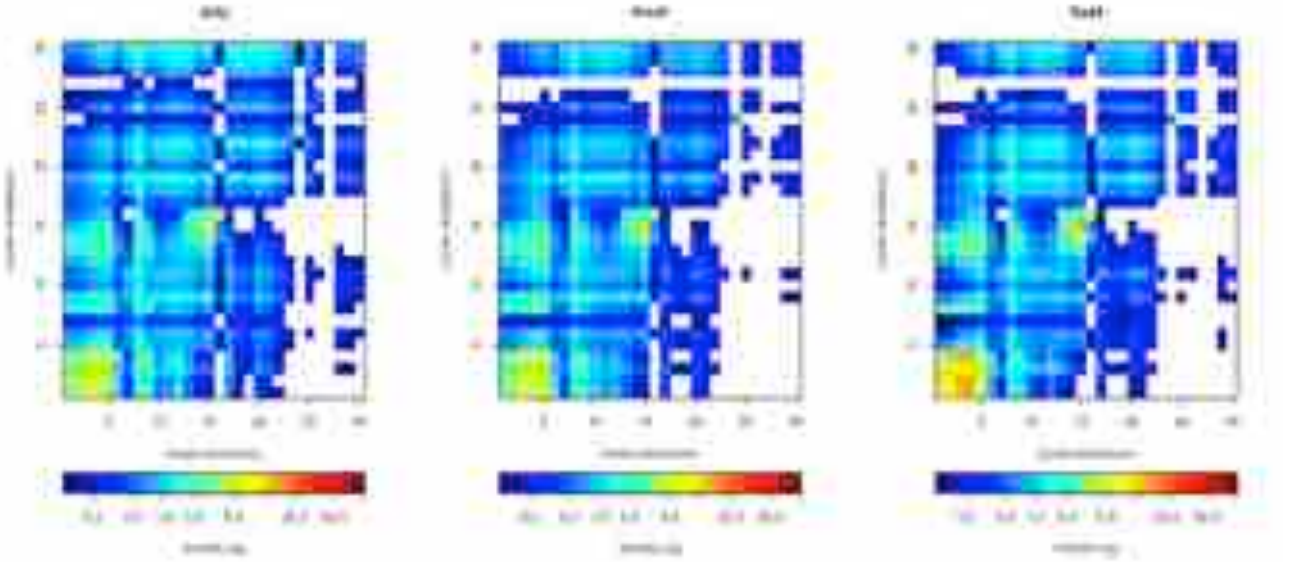
Variability in the connectivity patterns ?



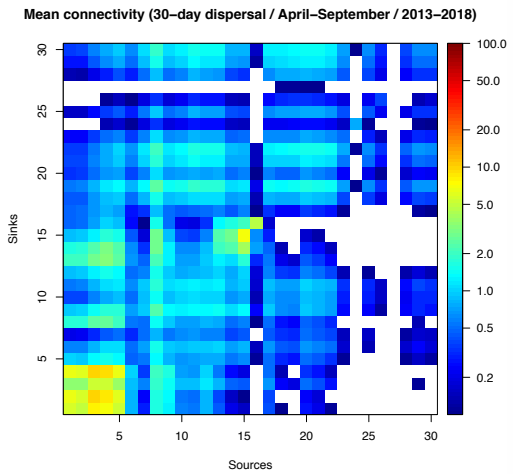
30 days



Monthly connectivity patterns (2013-2018 average)



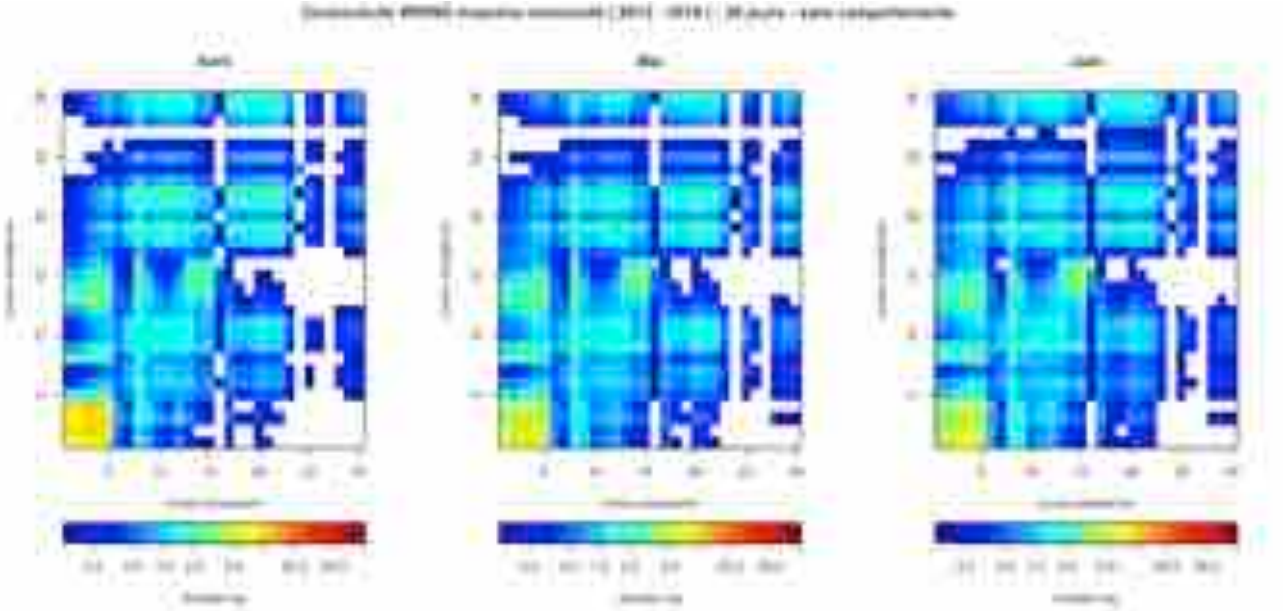
Variability in the connectivity patterns ?



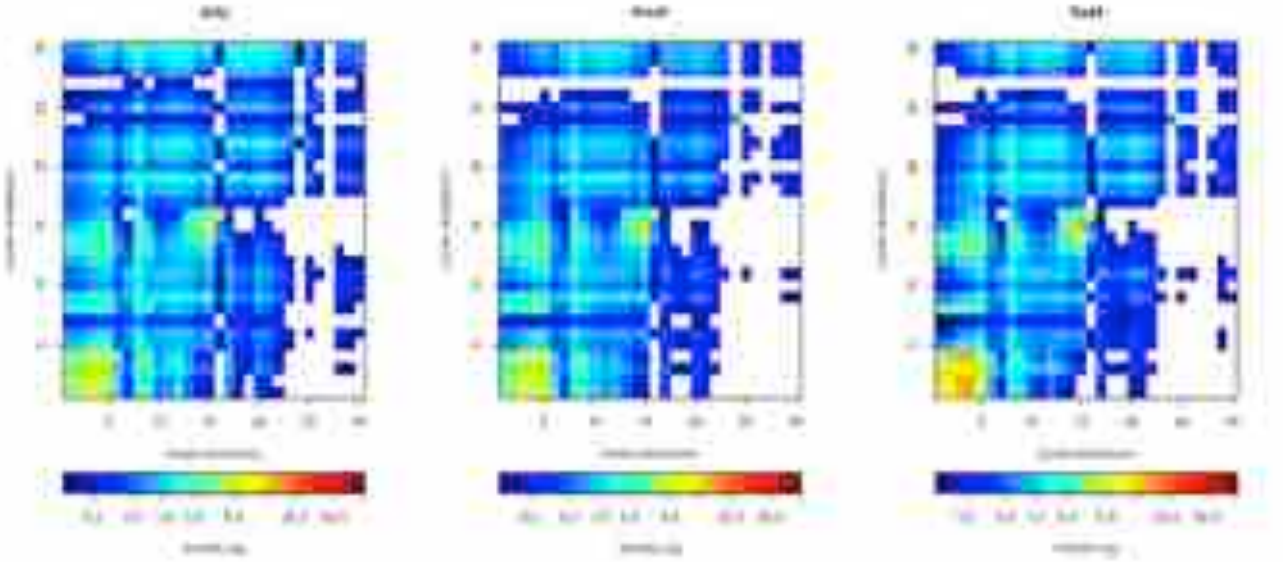
30 days

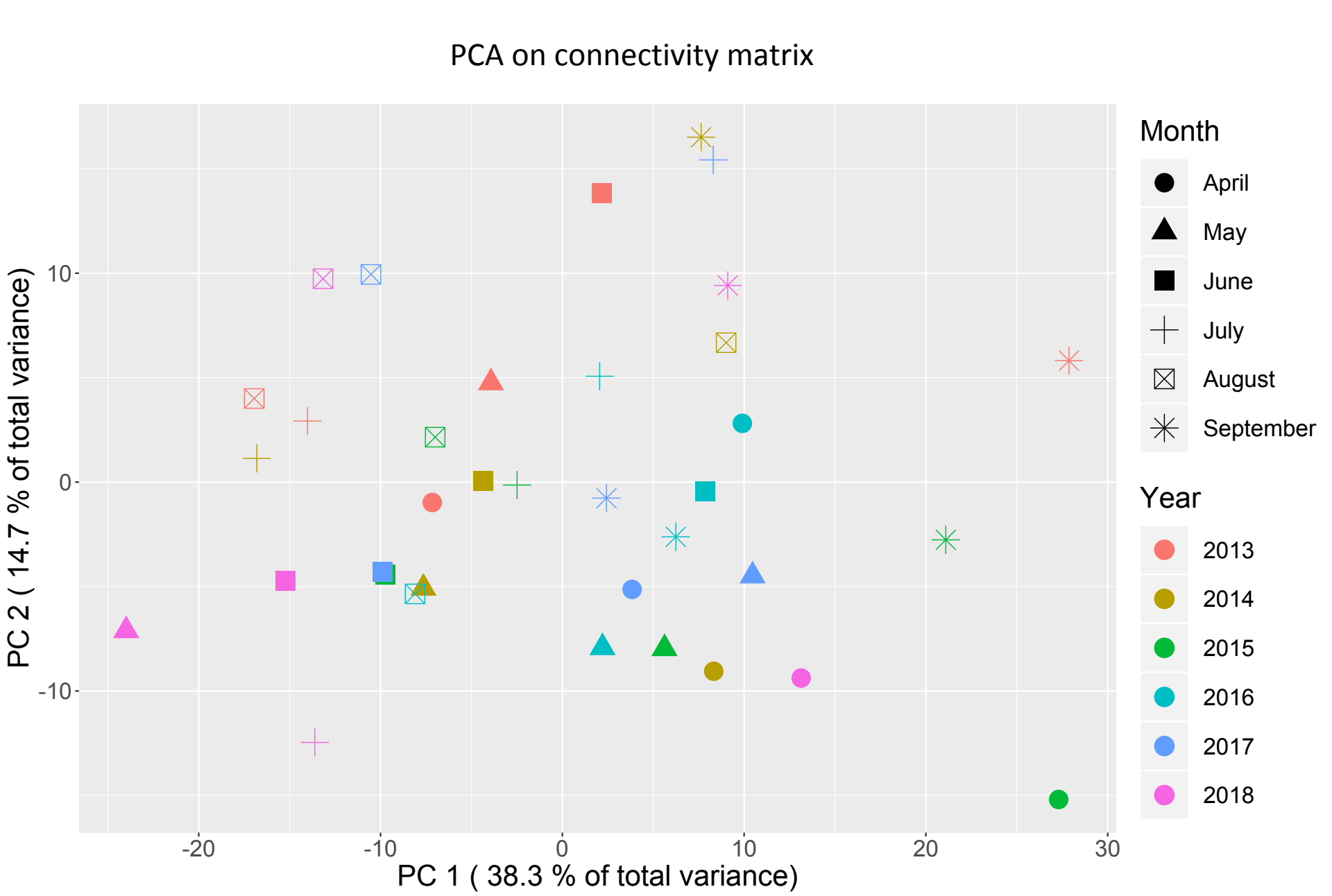
- Robust connectivity patterns

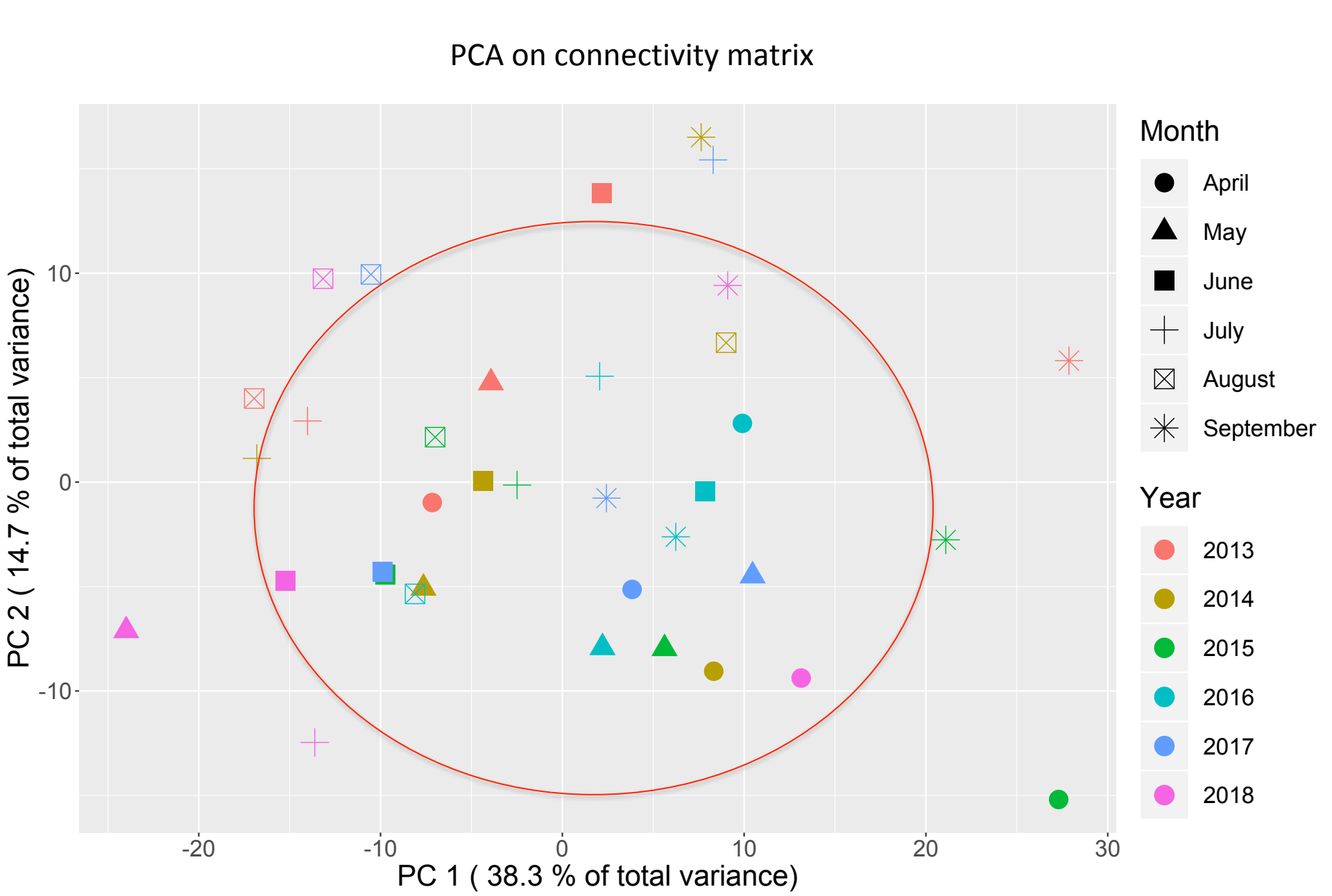
➢ Circulation strongly influenced by tide currents

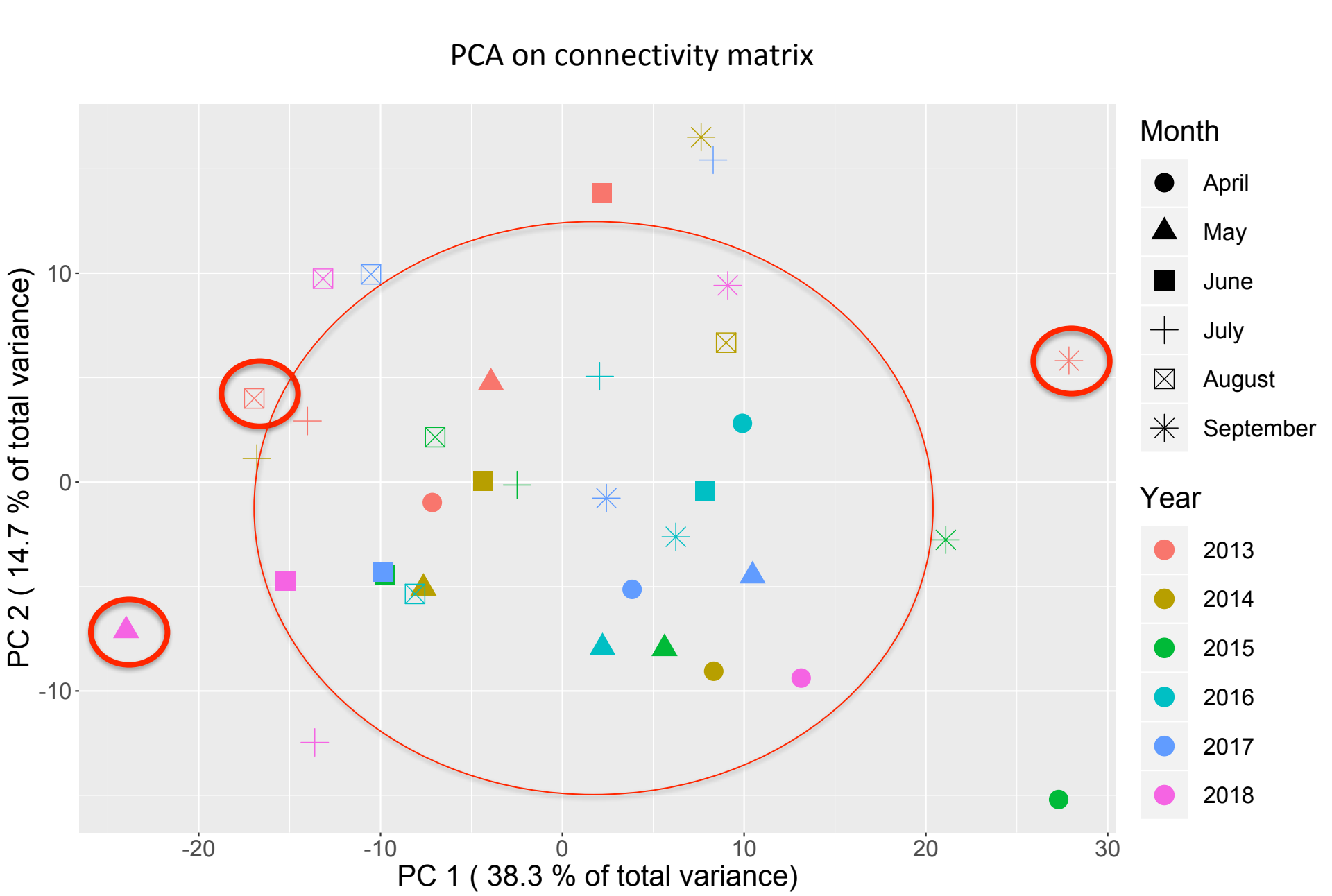


Monthly connectivity patterns (2013-2018 average)



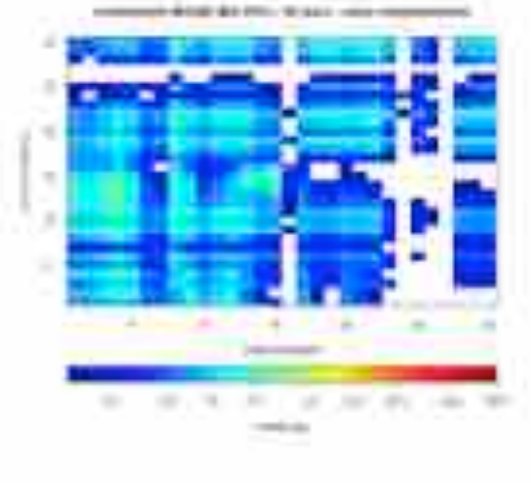

PCA on connectivity matrix
PC 2 (14.7 % of total variance)
PC 1 (38.3 % of total variance)
10
0
-10
-20
-10
0
10
20
30
Month
April
May
June
July
August
September
Year
2013
2014
2015
2016
2017
2018


PCA on connectivity matrix
PC 2 (14.7 % of total variance)
PC 1 (38.3 % of total variance)
10
0
-10
-20
-10
0
10
20
30
Month
April
May
June
July
August
September
Year
2013
2014
2015
2016
2017
2018

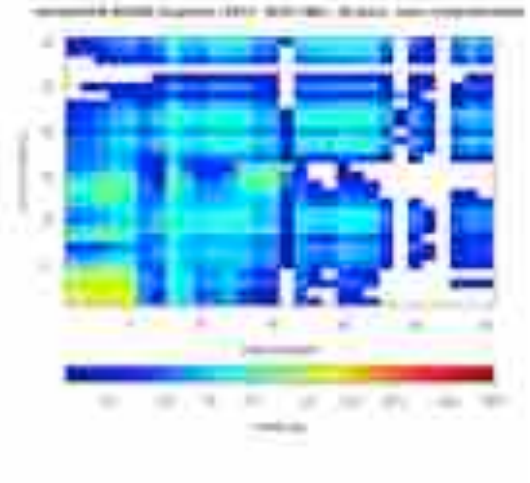

PCA on connectivity matrix
PC 2 (14.7 % of total variance)
PC 1 (38.3 % of total variance)
10
0
-10
-20
-10
0
10
20
30
Month
April
May
June
July
August
September
Year
2013
2014
2015
2016
2017
2018

May 2018 situation

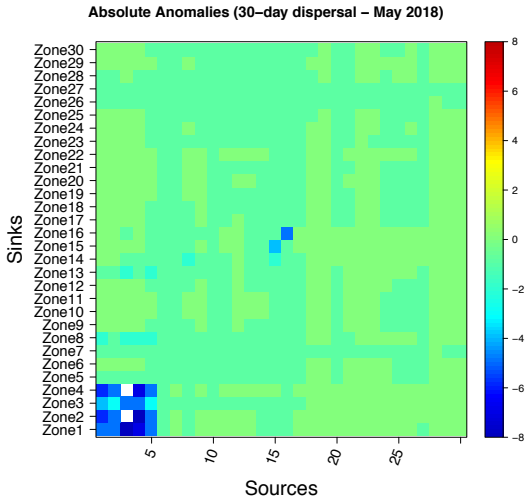
May 2018



Averaged May-Sept 2013-2018

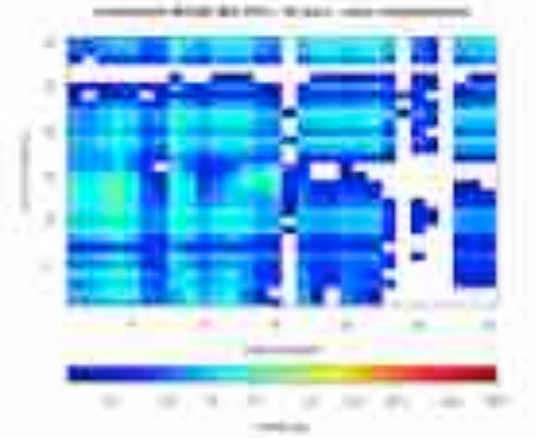


Absolute anomalies

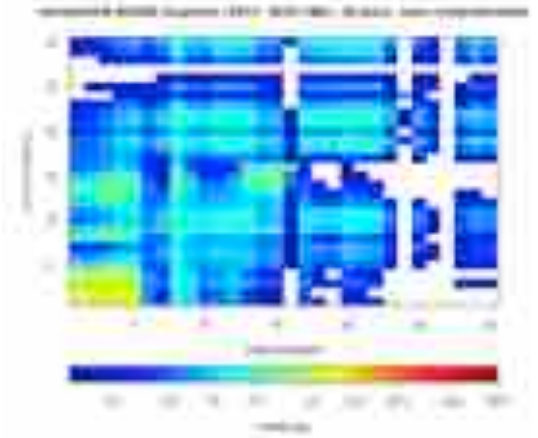


May 2018 situation

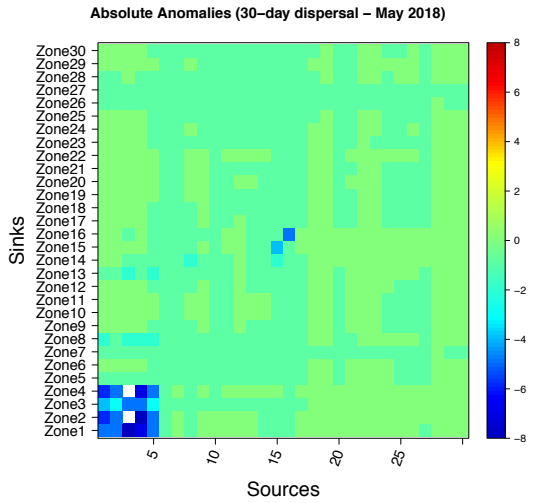
May 2018



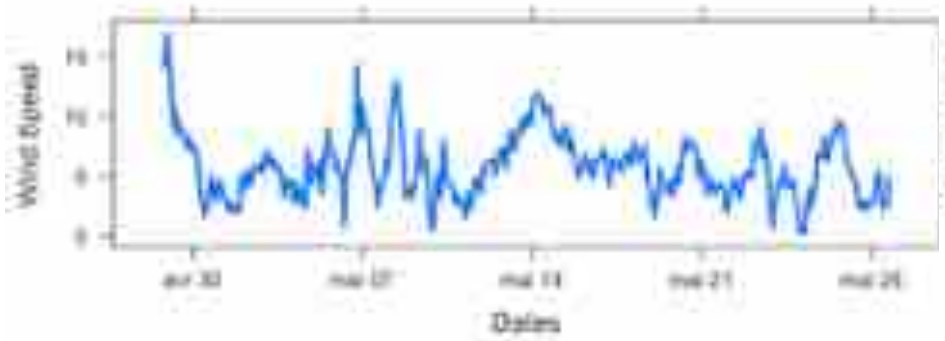
Averaged May-Sept 2013-2018



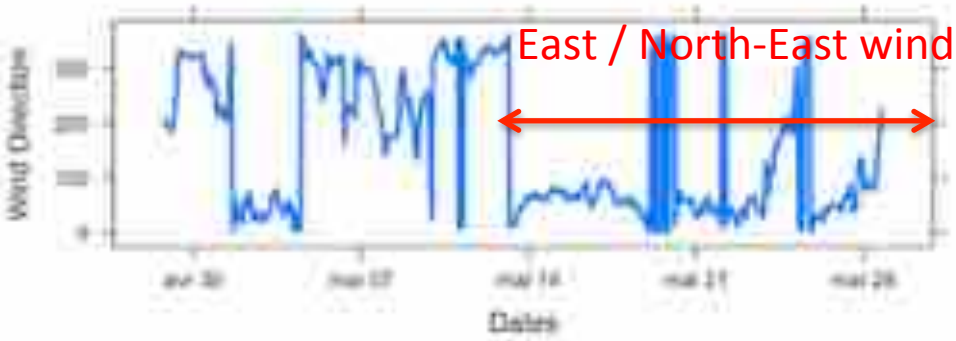
Absolute anomalies



Wind speed May 2018

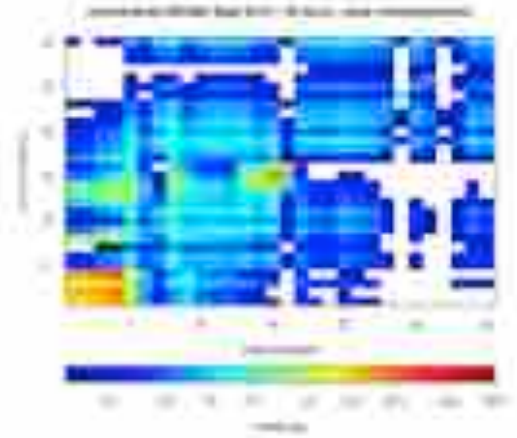


Wind direction May 2018

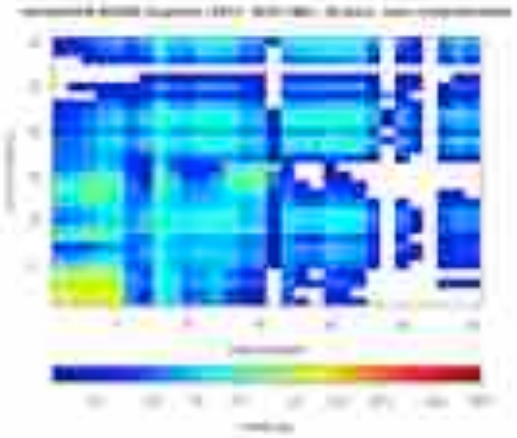


September 2013 situation

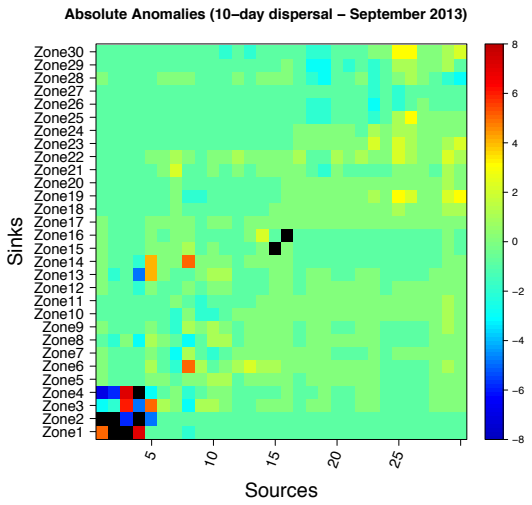
September 2013



Averaged
May-Sept 2013-2018

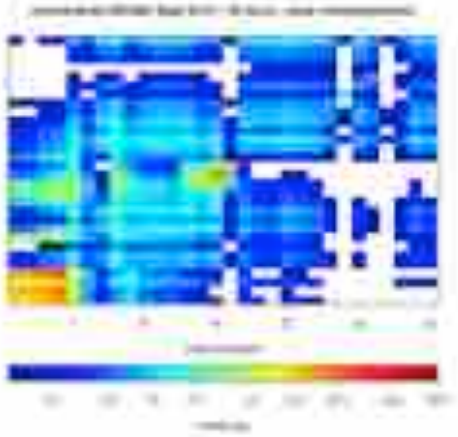


Absolute anomalies

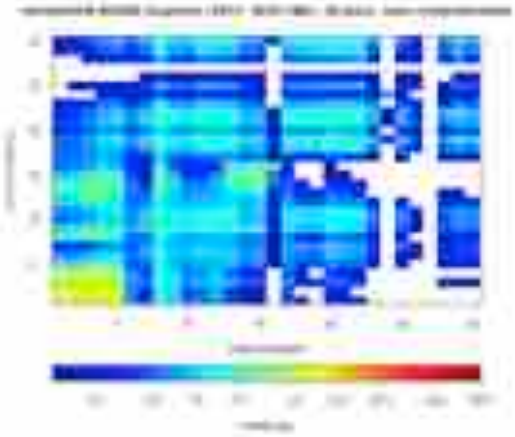


September 2013 situation

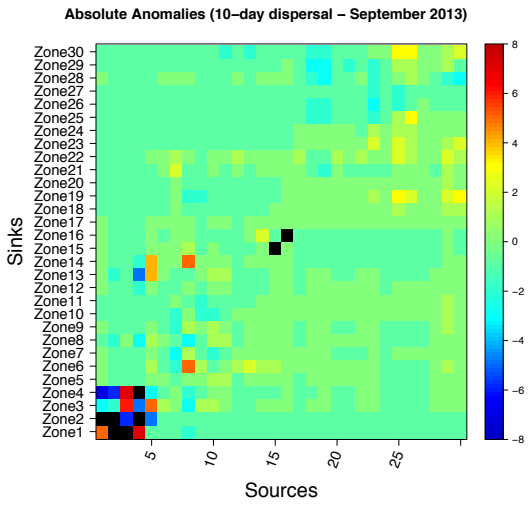
September 2013



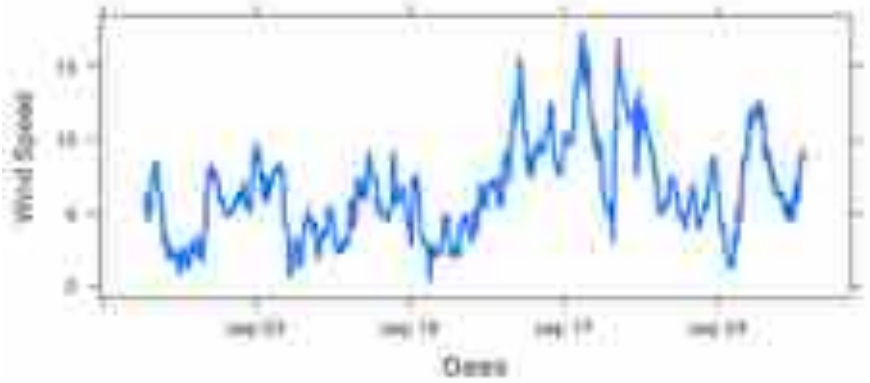
Averaged May-Sept 2013-2018



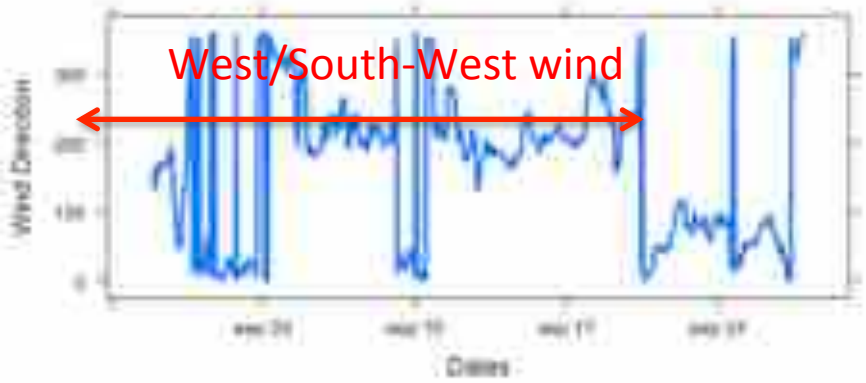
Absolute anomalies



Wind speed Sept 2013

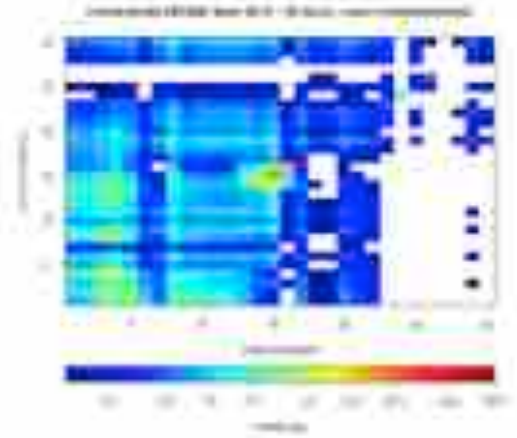


Wind direction Sept2013

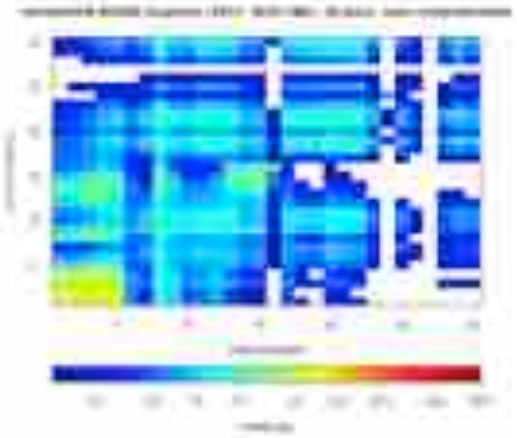


August 2013 situation

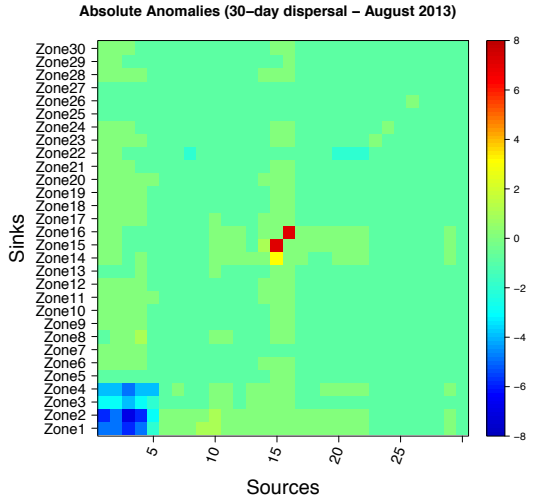
August 2013



Averaged
May-Sept 2013-2018

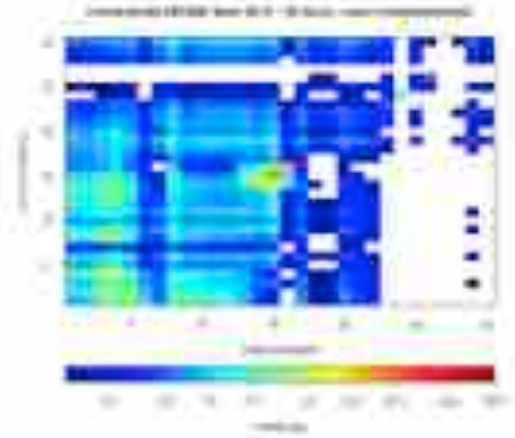


Absolute anomalies

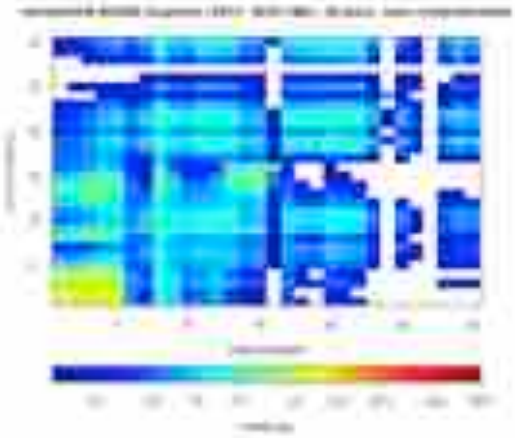


August 2013 situation

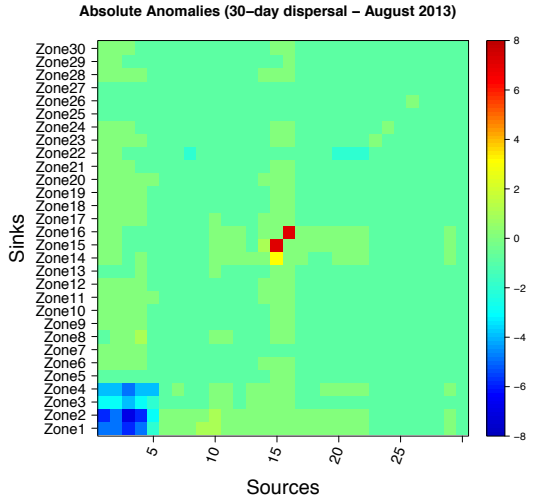
August 2013



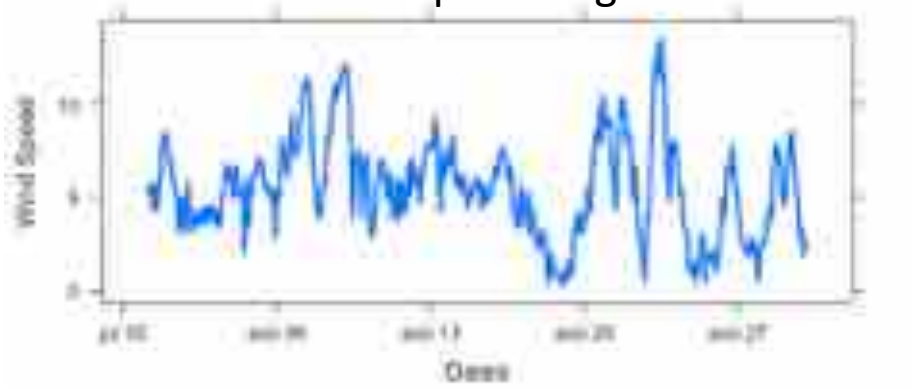
Averaged May-Sept 2013-2018



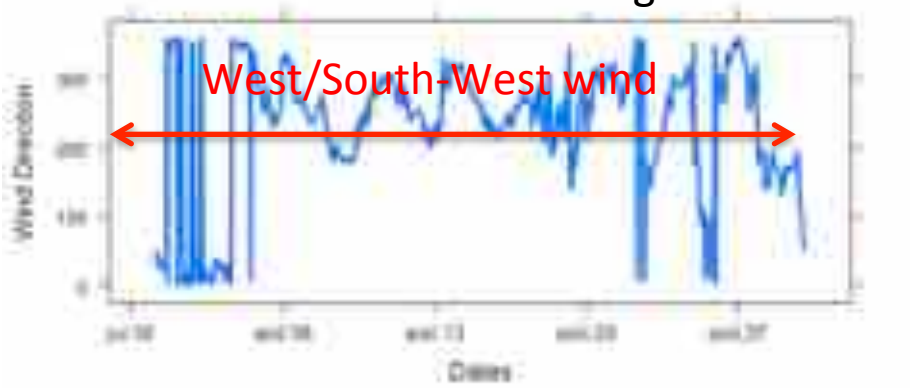
Absolute anomalies



Wind speed Aug 2013

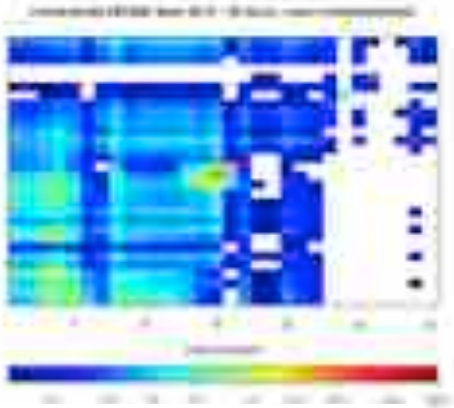


Wind direction Aug 2013

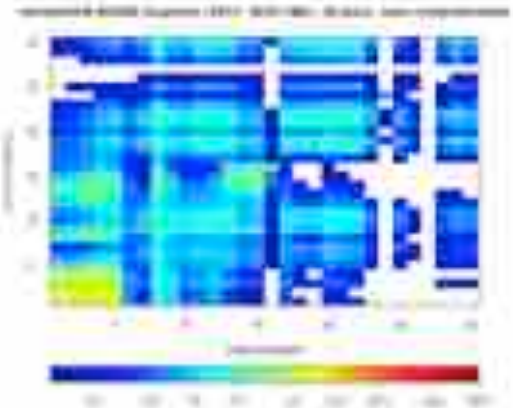


August 2013 situation

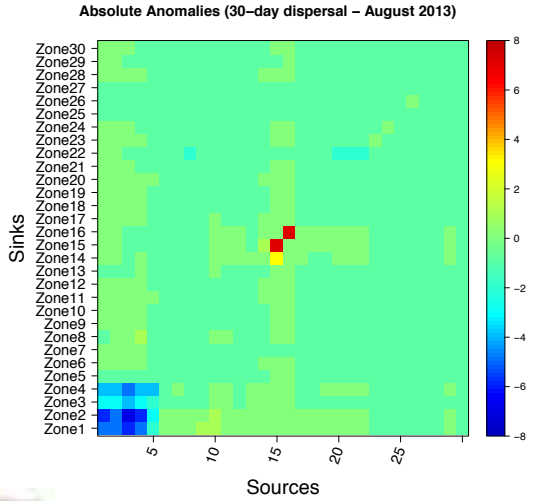
August 2013

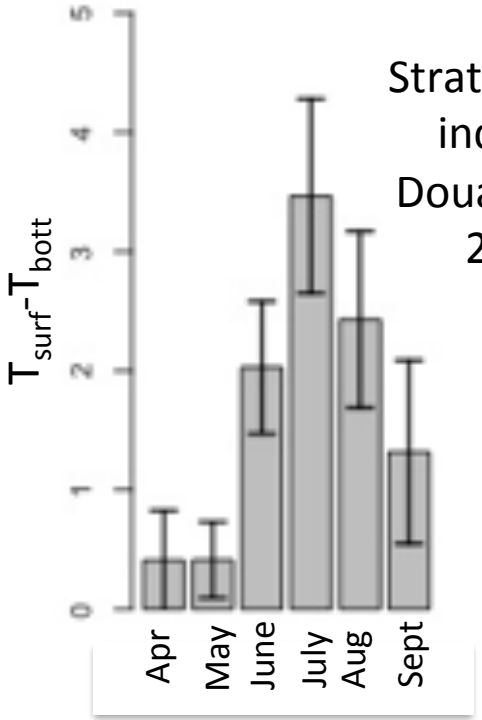


Averaged
May-Sept 2013-2018



Absolute anomalies





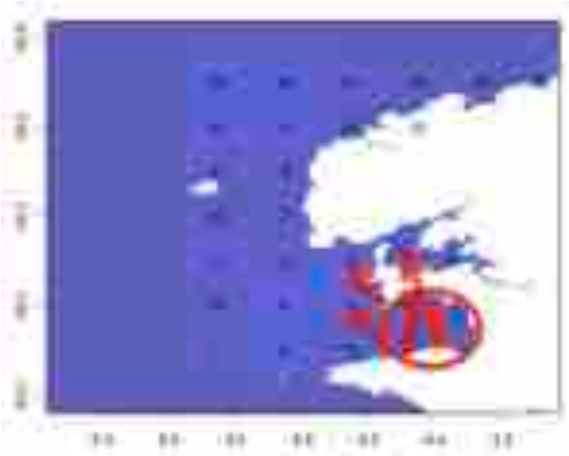
Stratification index in Douarnenez 2013

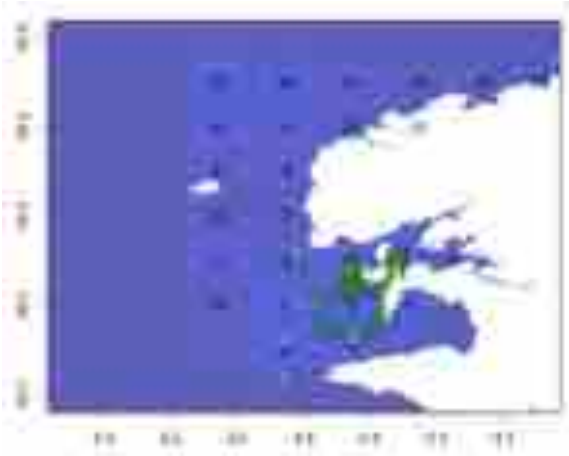
(from Augris et al. 2005)

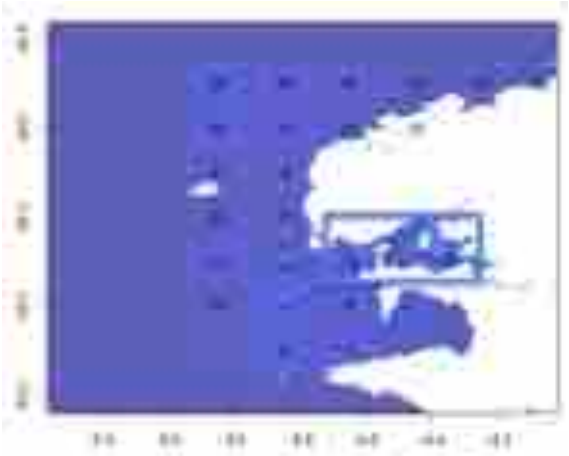
- West/South-West wind > Bottom seaward currents
- Summer stratification > Tracers confined in bottom layers

Conclusions

- Connectivity patterns are robust across seasons and years







- Connectivity patterns can vary locally due to wind and summer stratification, especially in the bay of Douarnenez.

Perspectives

- Generalizing analyses to better characterise variability due to environmental factors : wind speed and direction, stratification index, river flows, intensity of tides,…

- Defining and applying connectivity indices to characterise connectivities and their fluctuations (see Martin talk's of yesterday afternoon)

- Taking into account larvae vertical mouvements (Student master : I. Boudriga, 2017)

- Validating connectivity patterns against other data sources :

- Larvae recruitment on collectors in bay of Brest (2017-2019), MODELISME project

- Larvae distribution in space and time in the water column in bay of Brest and Iroise sea (using metabarcoding, LADIDA project, F. Nunes)

- Genetic data of great scallop population in Iroise sea (Phd W. Handal)

II - Combining Larval Dispersal Modelling And Genetics To Characterise Population Connectivity Of A Reef-forming Invertebrate Along The French Atlantic Coast

Carmen David, **Martin P. Marzloff**, Philippe Cugier, Flavia Nunes, Stanislas Dubois

IFREMER, Coastal Ecosystem Dynamics Research unit (DYNECO)

Martin.Marzloff@ifremer.fr

ISblue The interdisciplinary graduate school for the blue planet

AGENCE FRANÇAISE POUR LA BIODIVERSITÉ
ÉTABLISSEMENT PUBLIC DE L'ÉTAT

Ifremer

Honeycomb reef population connectivity

Biological Model

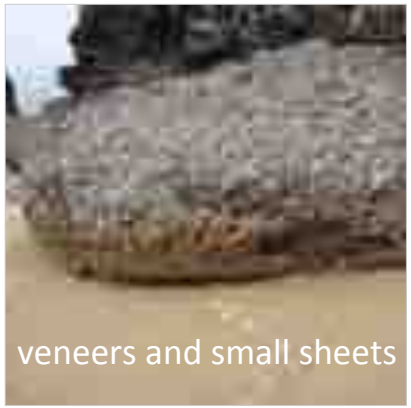
The honeycomb worm *Sabellaria alveolata* Lamarck 1818 (Polychaeta: Sabellariidae)

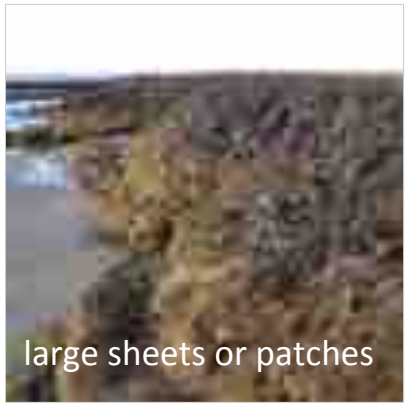
Credits: S. Dubois & A. Guerin

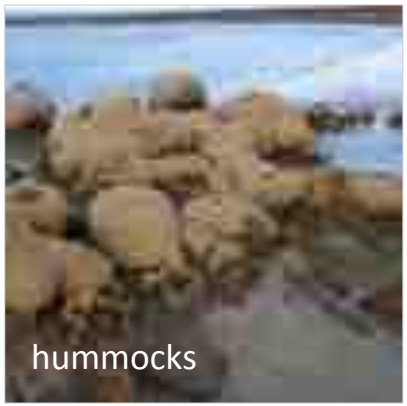
Honeycomb reef population connectivity

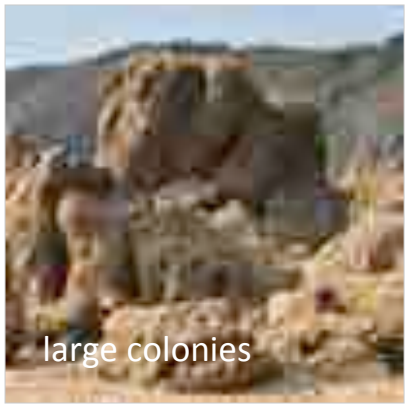
Spatial Distribution

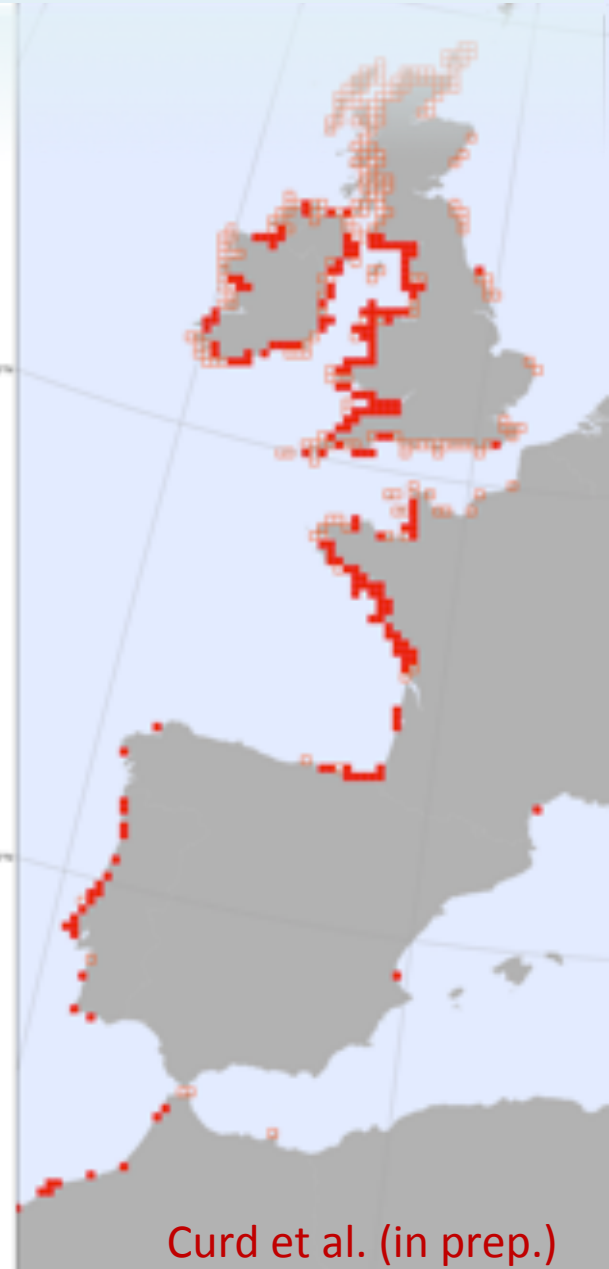
- A common intertidal species
  (from Morocco to Southwest Scotland)
- High variability in shapes and local percentage cover











Curd et al. (in prep.)

Credits: S. Dubois & A. Guerin

Honeycomb reef population connectivity

Ecological Role and Conservation Status

- An important engineering species that forms biogenic reefs

High biodiversity + habitat provision + natural protection against coastal erosion

- Conservation issues (local decline due to trampling, extreme events…)

Champeaux reef (Mont-Saint-Michel Bay) – ca. 1980 (picture Y. Gruet)

Same place (2015)

Honeycomb reef population connectivity

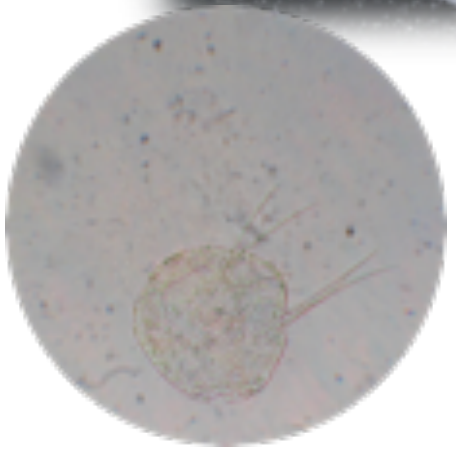
Ecological Role and Conservation Status

- An important engineering species that forms biogenic reefs

High biodiversity + habitat provision + natural protection against coastal erosion

- Conservation issues (i.e. local decline due to trampling, extreme events…)

→ Role of **connectivity** via larval dispersal in maintaining **resilience of**



(1) Regional metapopulation

(2) Local biogenic constructions

Honeycomb reef population connectivity

An Hydrodynamic Dispersal Modelling Study

- Characterise **regional population connectivity**
  along the French coastline (English Channel + Bay of Biscay)
  - Mean connectivity
  - Interannual and seasonal variability
  - Confrontation with earlier genetics studies

- Characterise **local reef contribution to metapopulation**
  - Source *Vs* Sink metrics
  - Network theory metrics
  - Simulations of Alternative node removal scenarios

Honeycomb reef population connectivity

An Hydrodynamic Dispersal Modelling Study

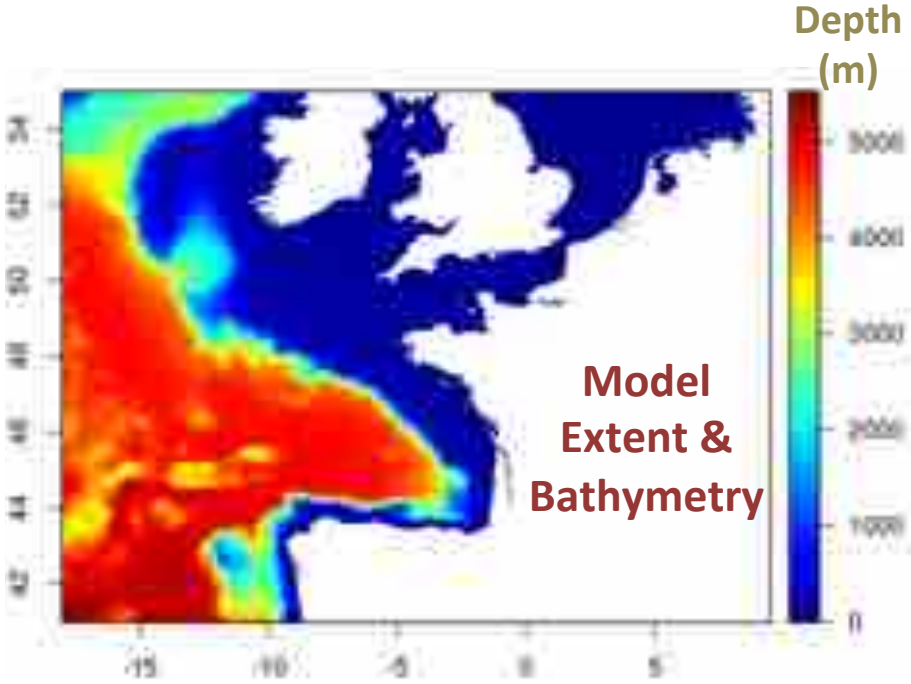
HYDRODYNAMICS SIMULATION CHARACTERISTICS

- MARS3D = 3D Model for Applications at Regional Scale
  (Lazure and Dumas, 2008)
- 2.5 km horizontal resolution, 40 vertical layers (sigma coord.)
- Eulerian approach
- Particule release in the bottom layer
- Variability due to influence of atmospheric, river and tidal inputs
  - **Interannual** = 5 years / 2012 -2016
  - **Seasonal** = 6 months / April – Sept.

LARVAL ECOLOGY

- No vertical behaviour
- 3 PLDs = 3, 4, 6 weeks

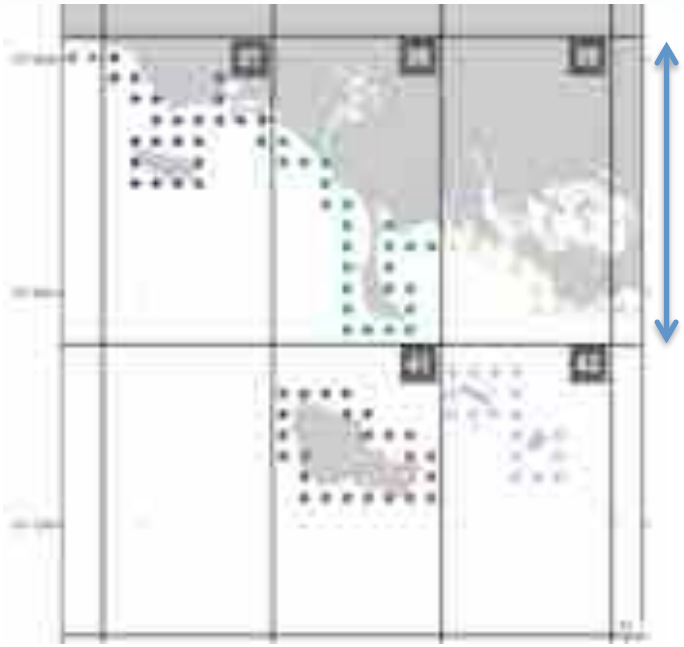
(Here all results based on **4-week PLD)**

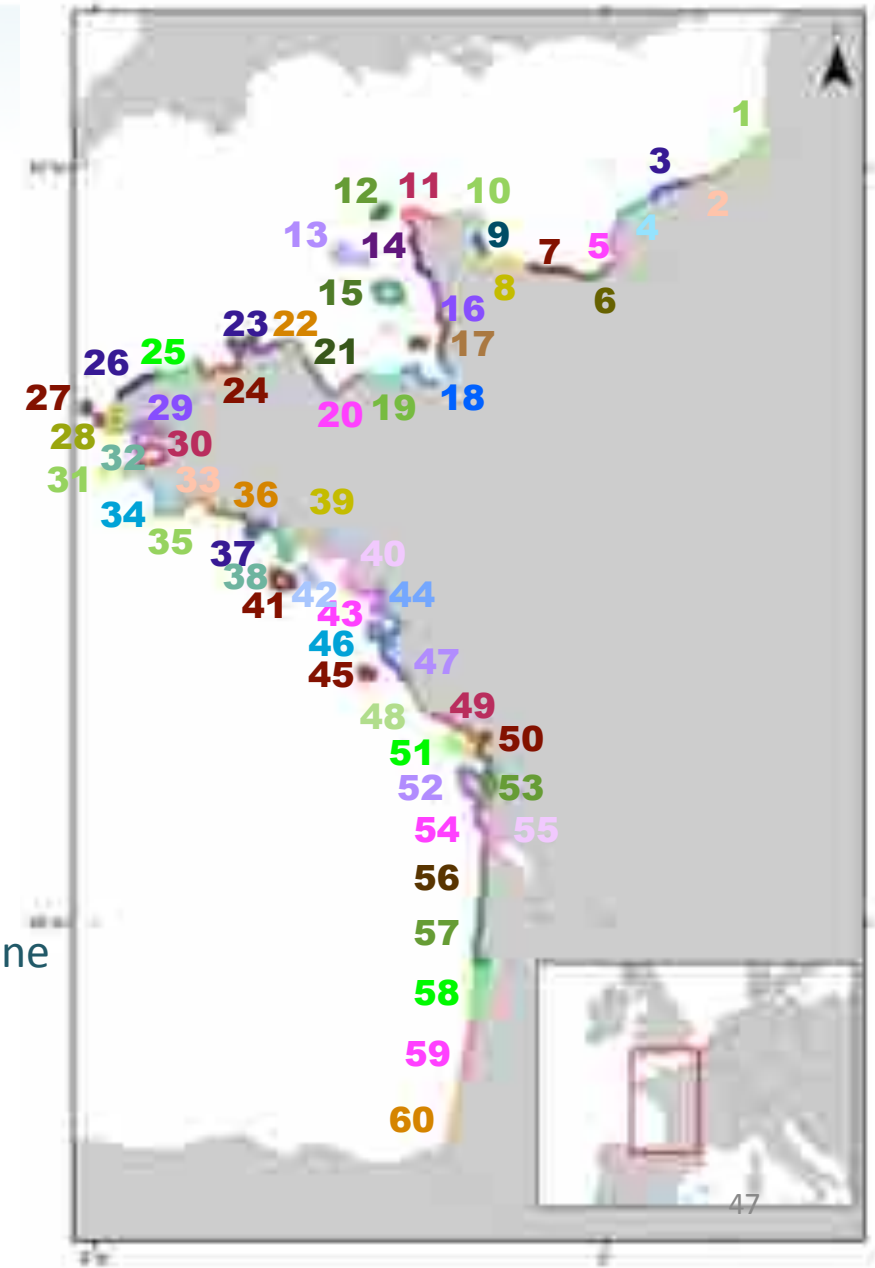


Honeycomb reef population connectivity

An Hydrodynamic Dispersal Modelling Study

Coastline divided into 60 zones





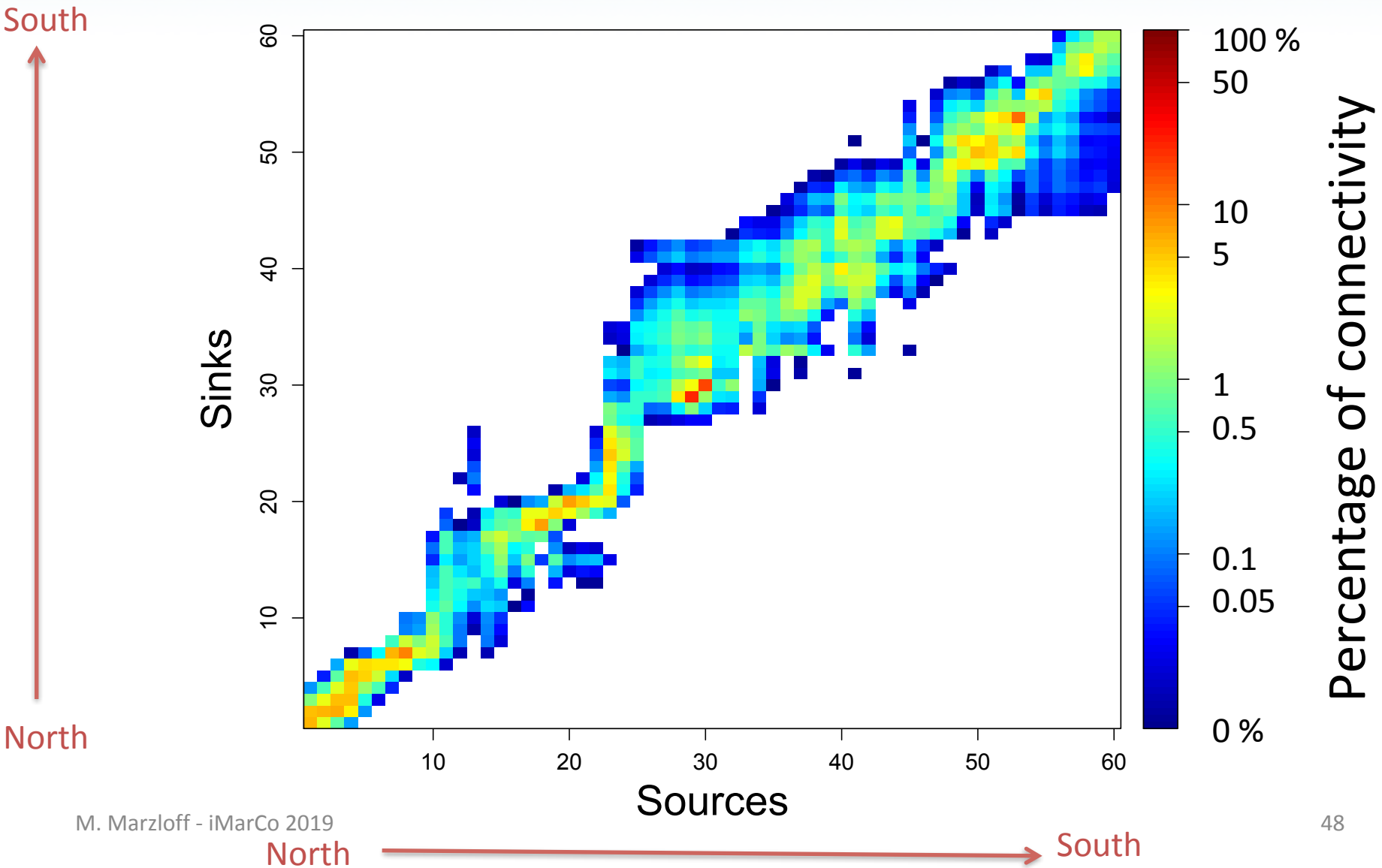
Maps of *S. alveolata* reefs

- Attribution of semi-quantitative scores to each zone
- Reef score estimated from expert knowledge
  - 0 for « no reef »
  - 0.25 / 0.5 / 0.75
  - 1 for « high cover of consolidated reefs »

Regional hydrodynamic connectivity

Mean Connectivity Matrix

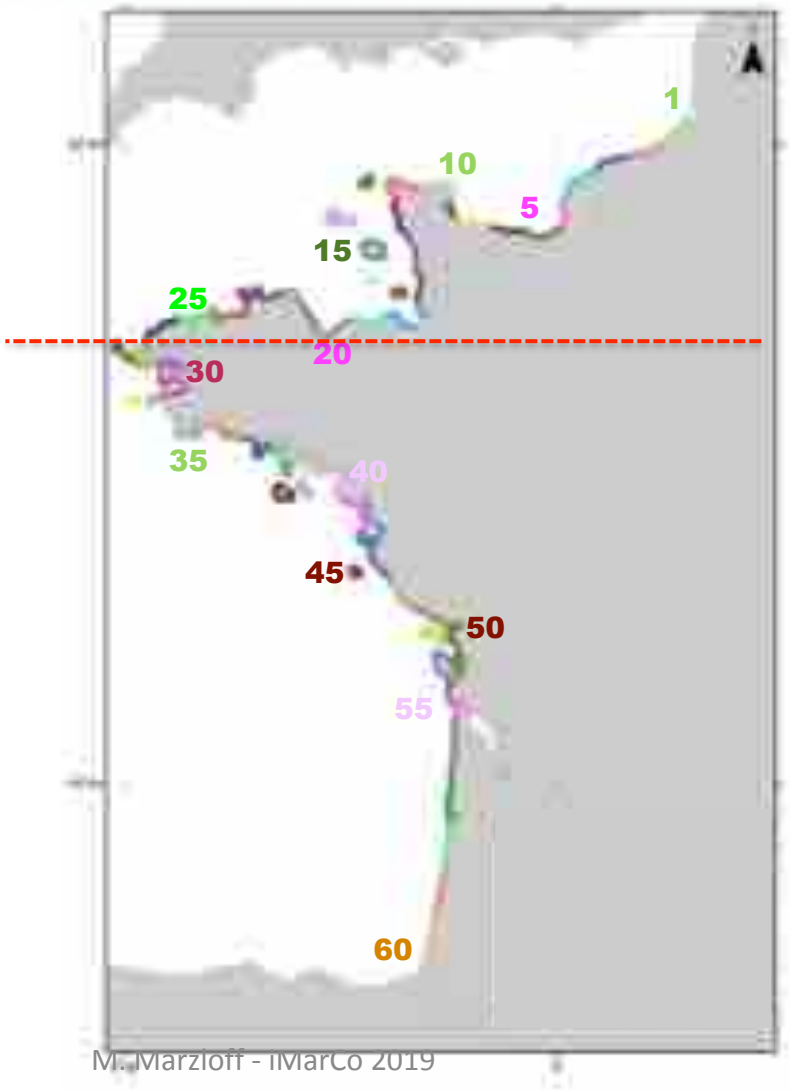
(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

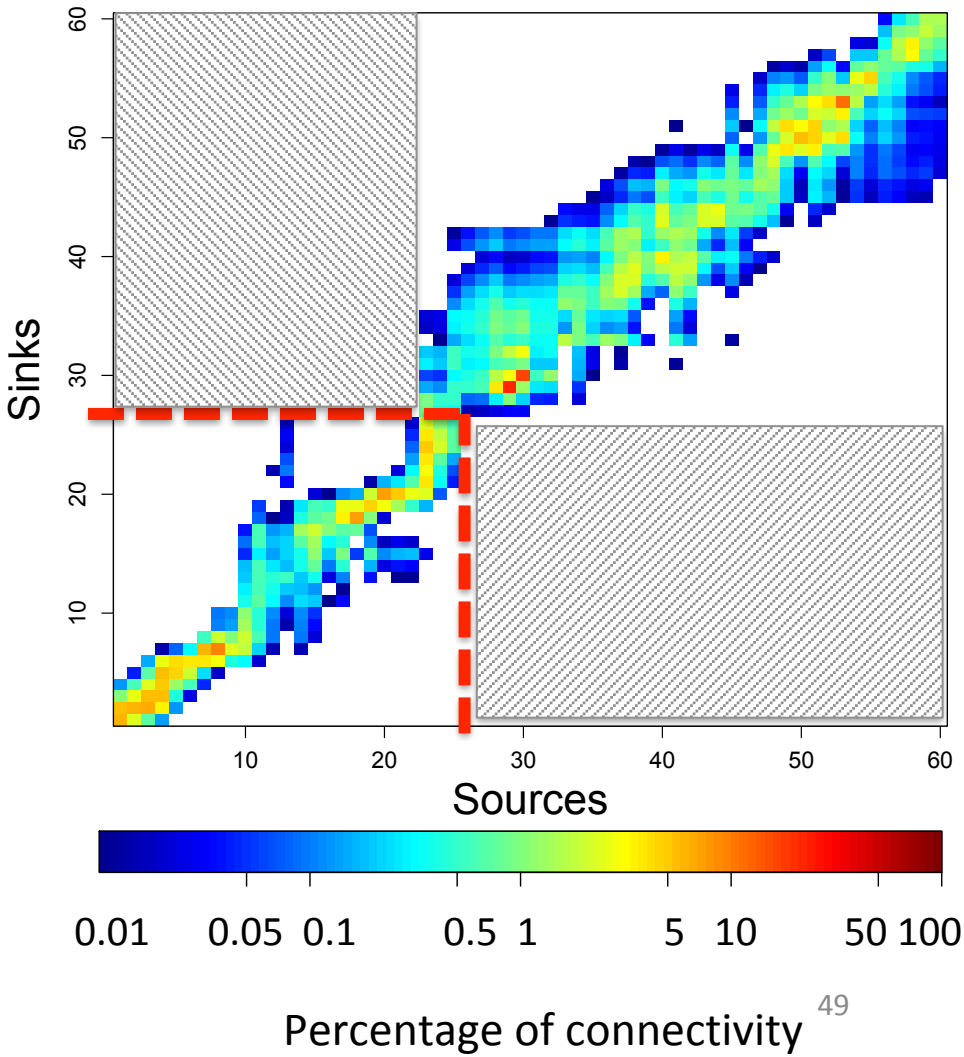


Regional hydrodynamic connectivity

Mean Connectivity Matrix

(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

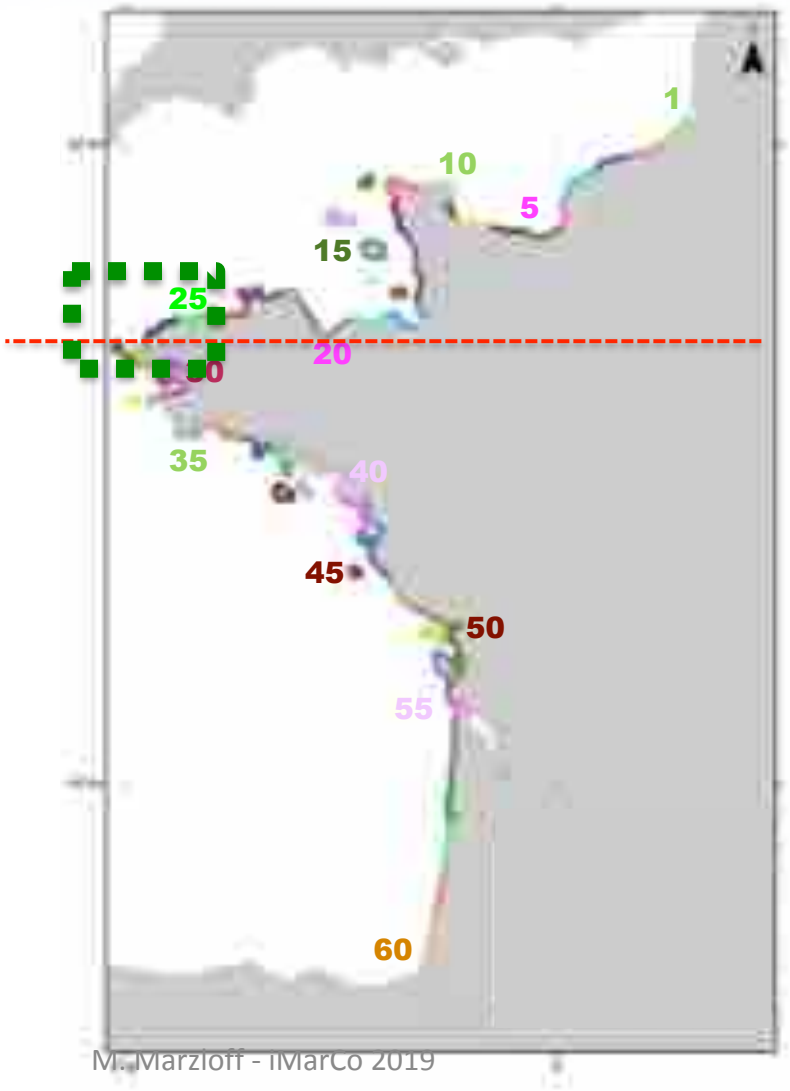


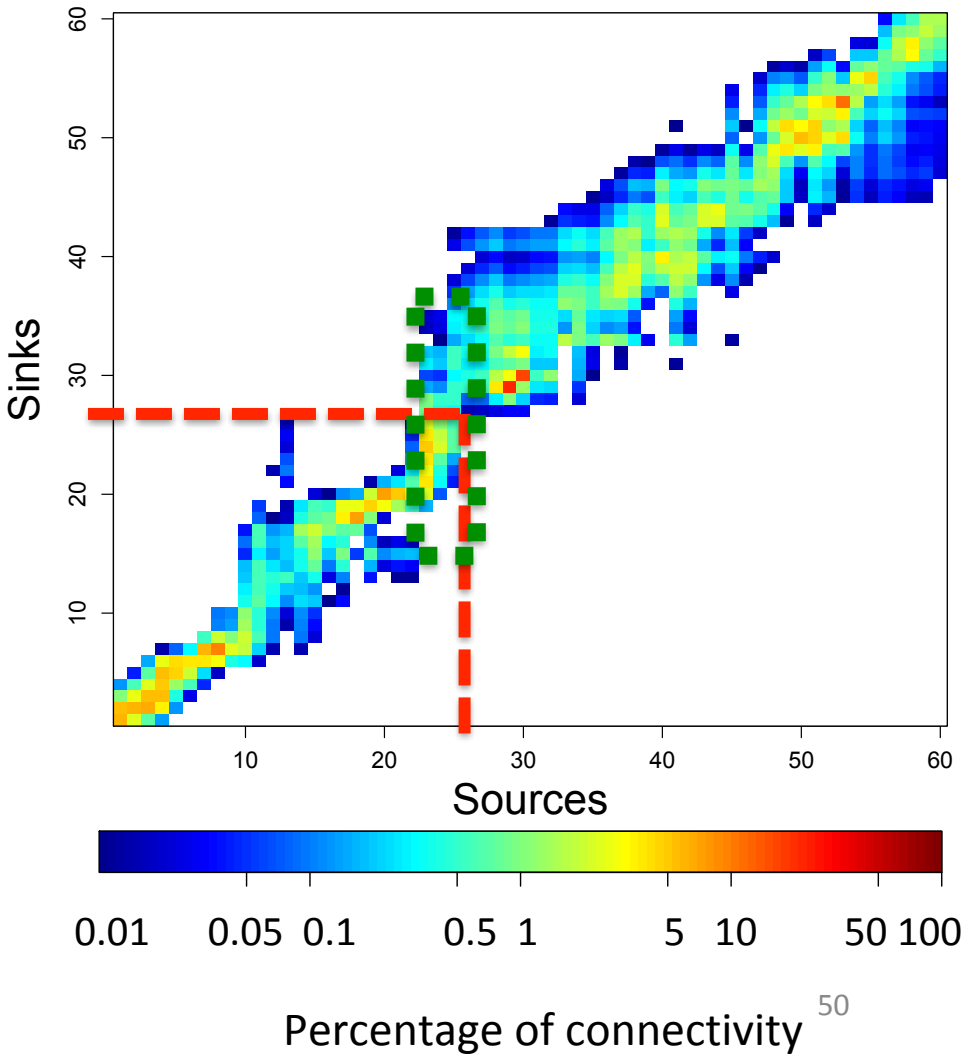


Regional hydrodynamic connectivity

Mean Connectivity Matrix

(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

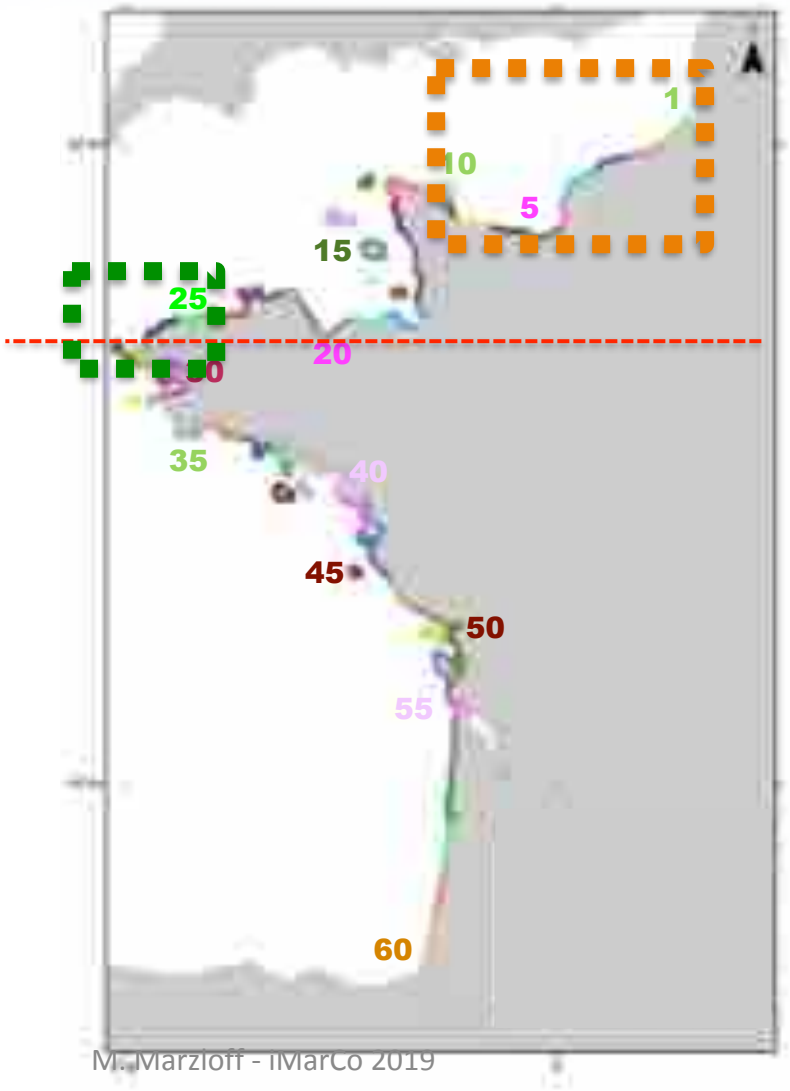


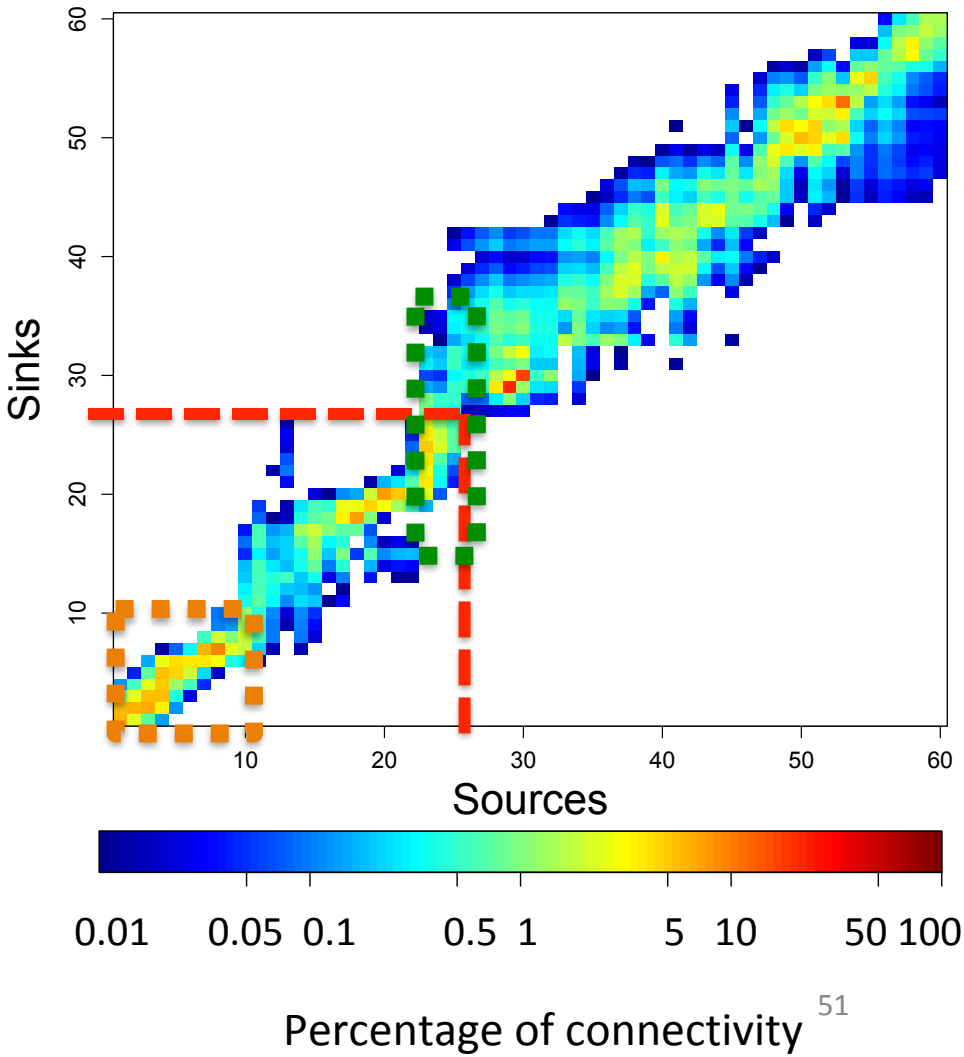


Regional hydrodynamic connectivity

Mean Connectivity Matrix

(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

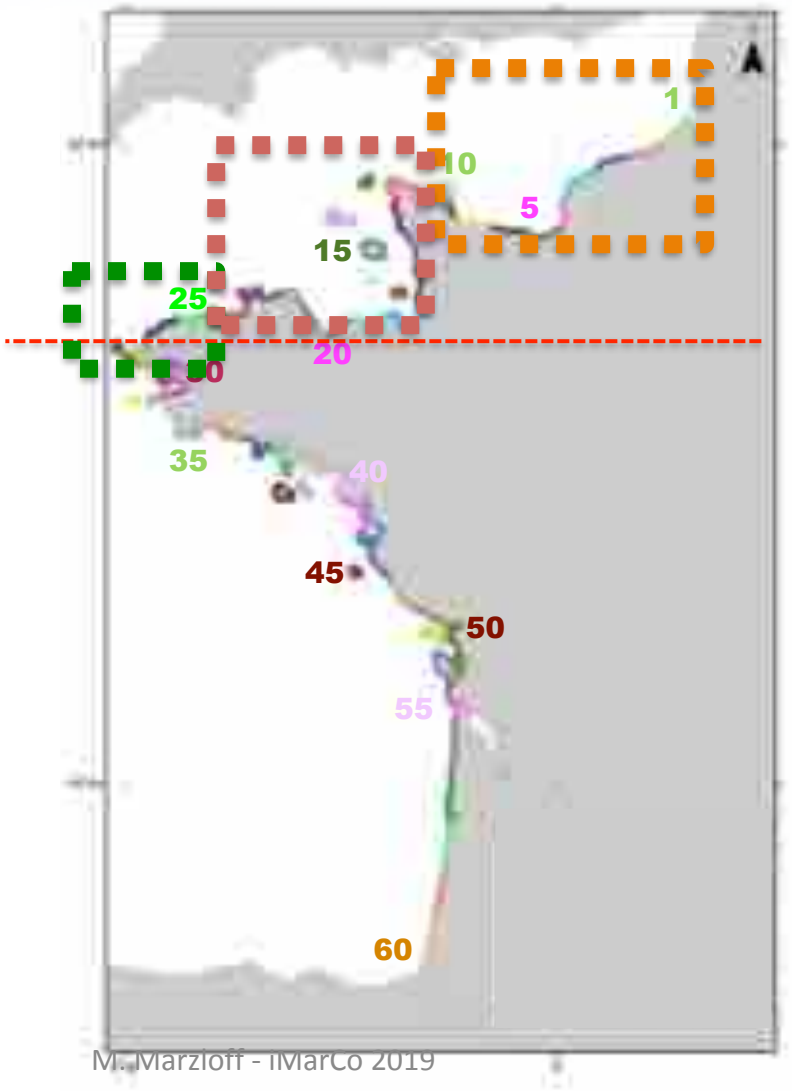


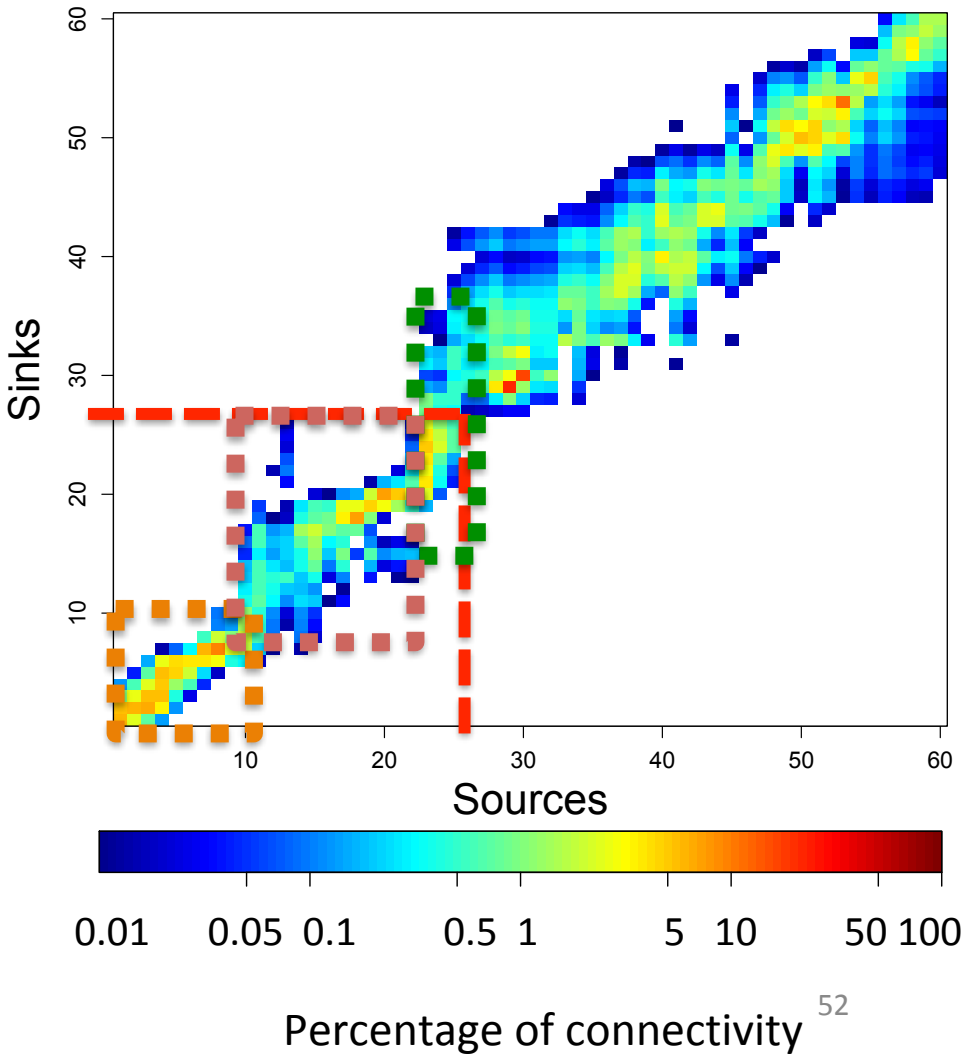


Regional hydrodynamic connectivity

Mean Connectivity Matrix

(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

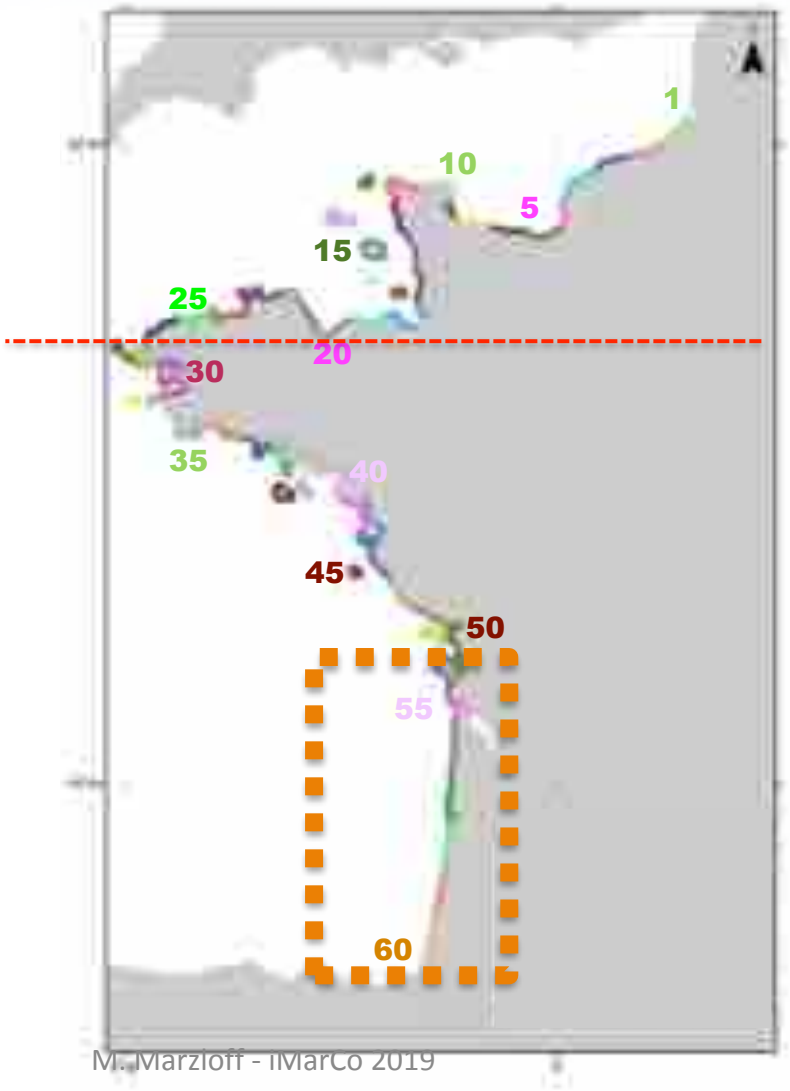


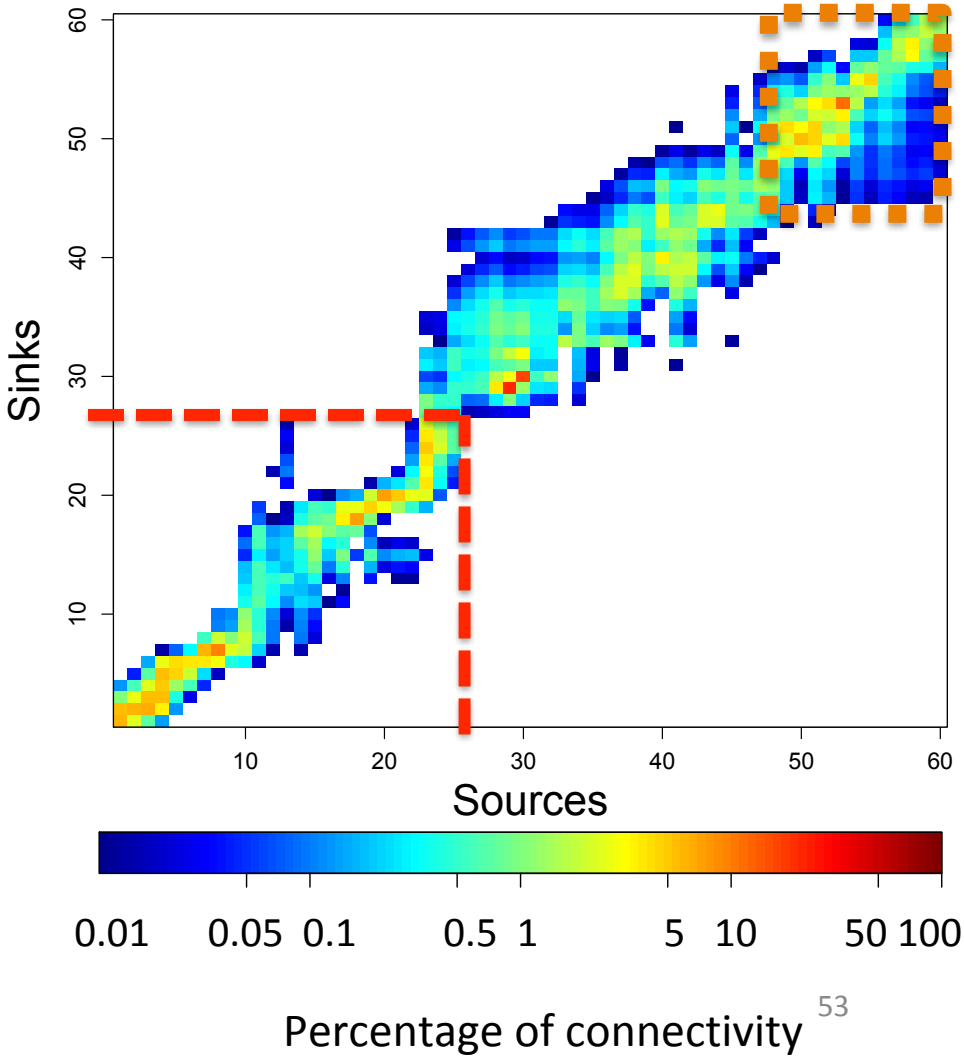


Regional hydrodynamic connectivity

Mean Connectivity Matrix

(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)

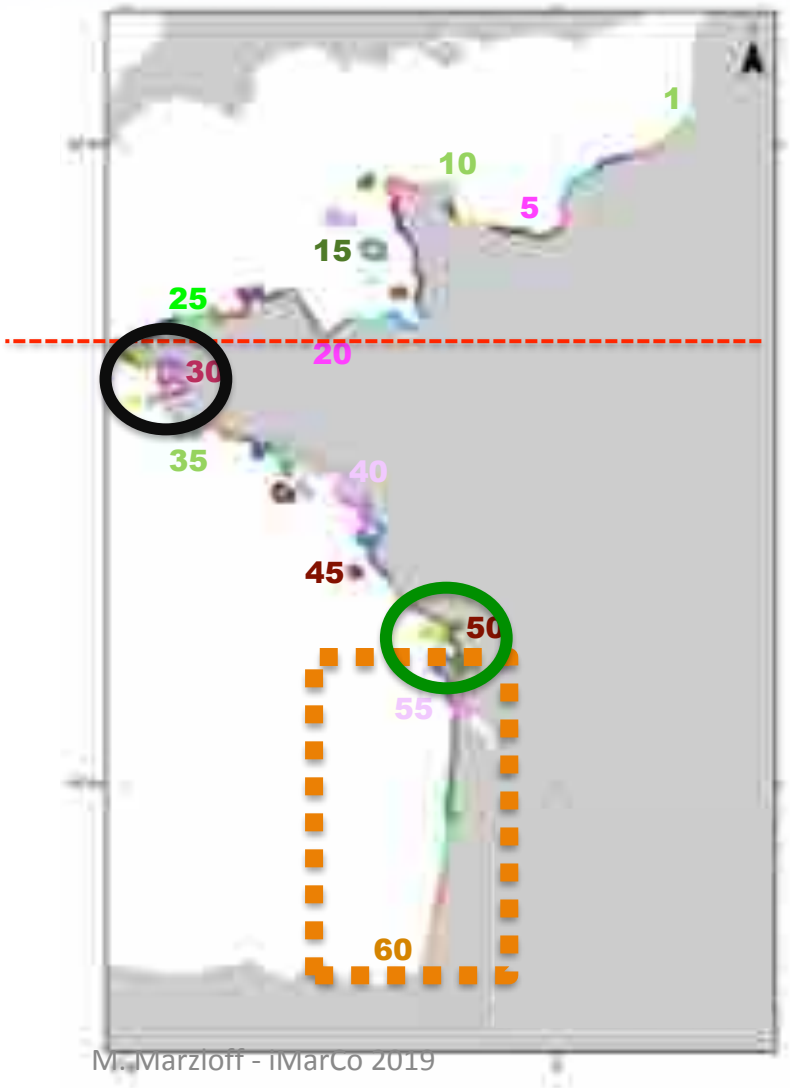


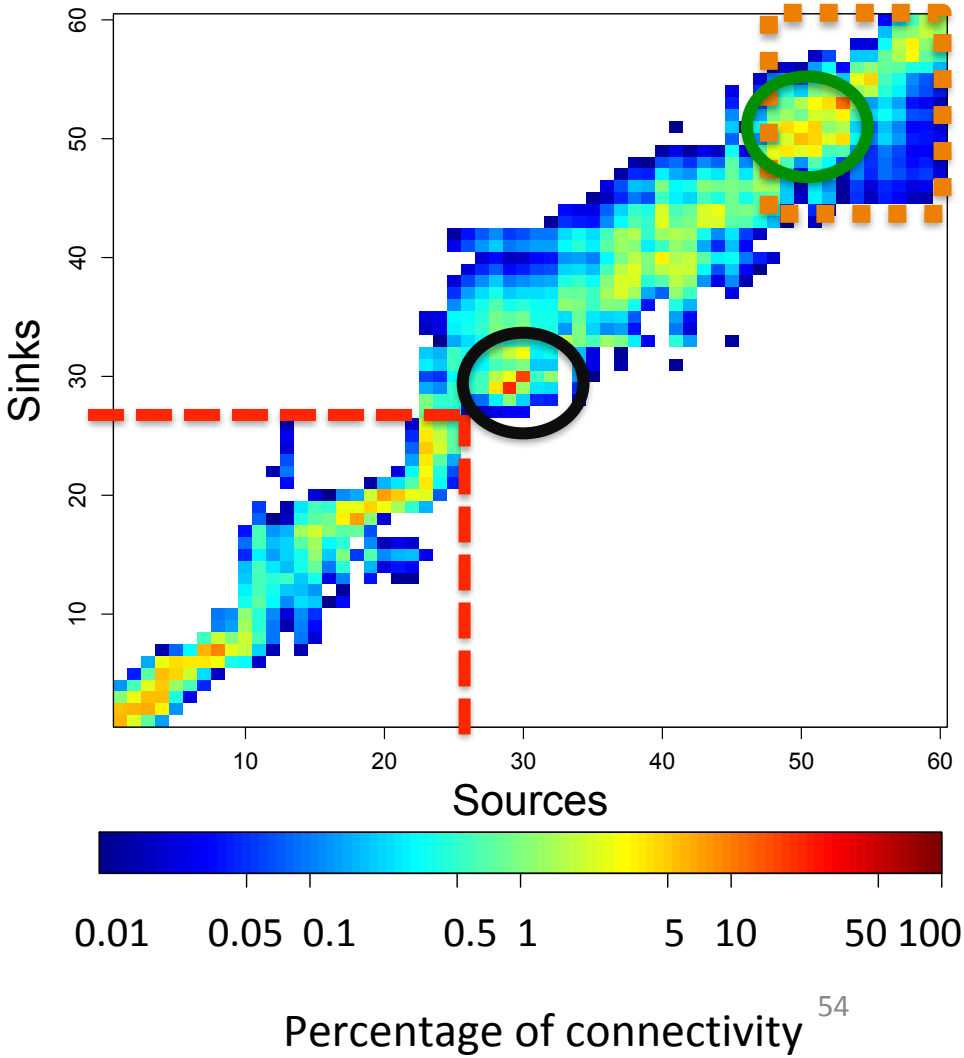


Regional hydrodynamic connectivity

Mean Connectivity Matrix

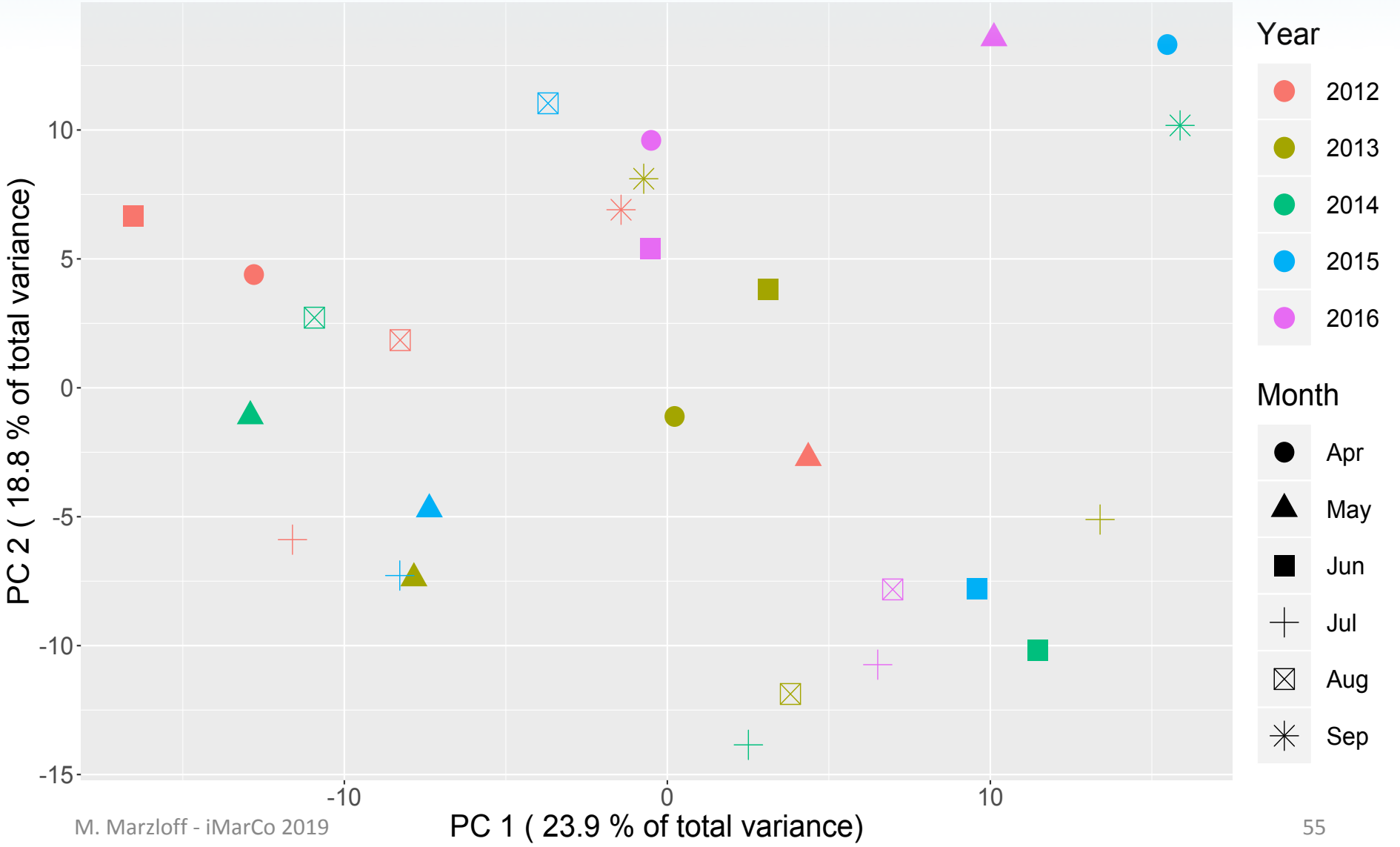
(Monthly mean / April-Sept. / 2012-2016 / 4-week PLD)





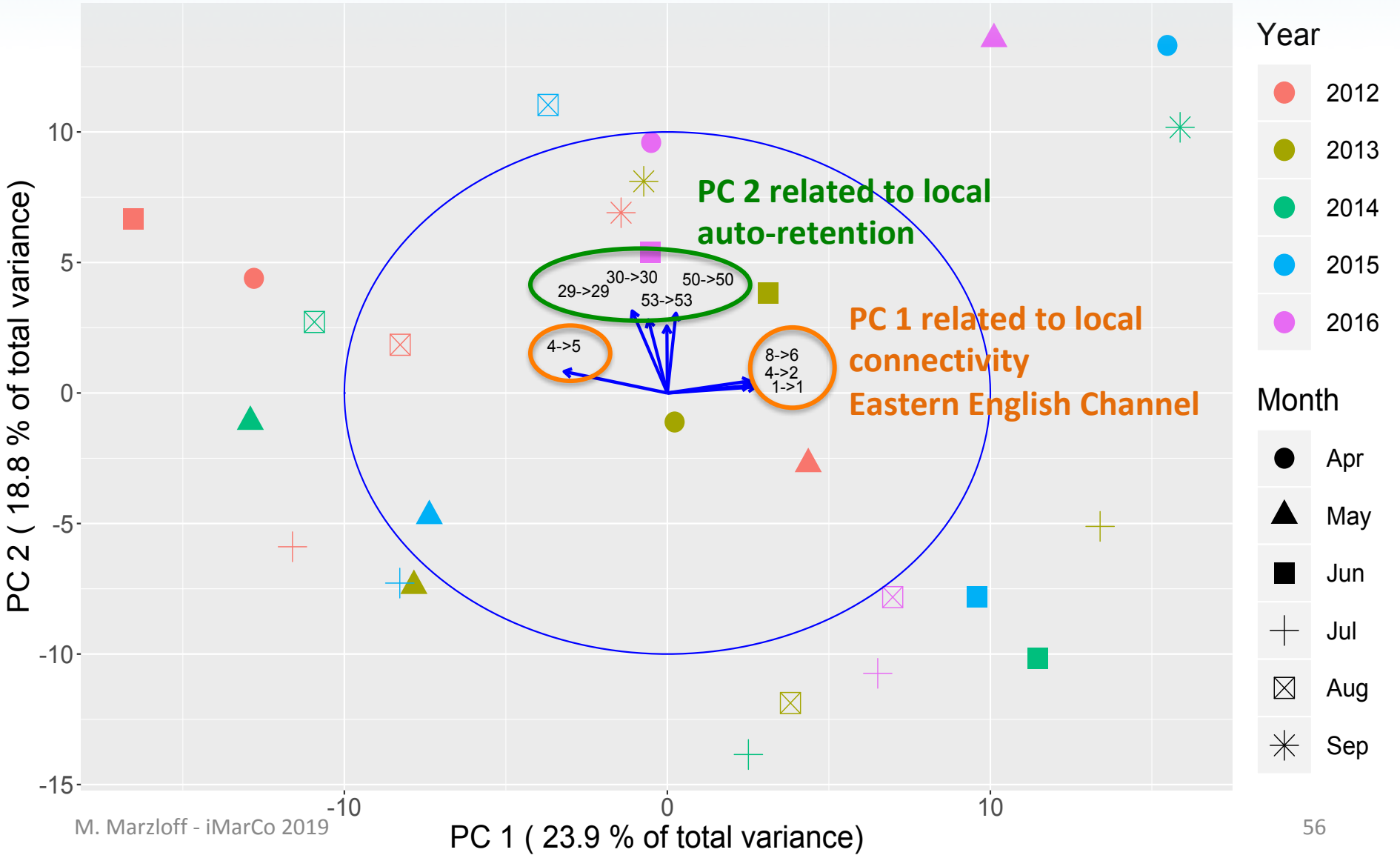
Regional hydrodynamic connectivity

PCA based on Monthly Connectivity Matrices



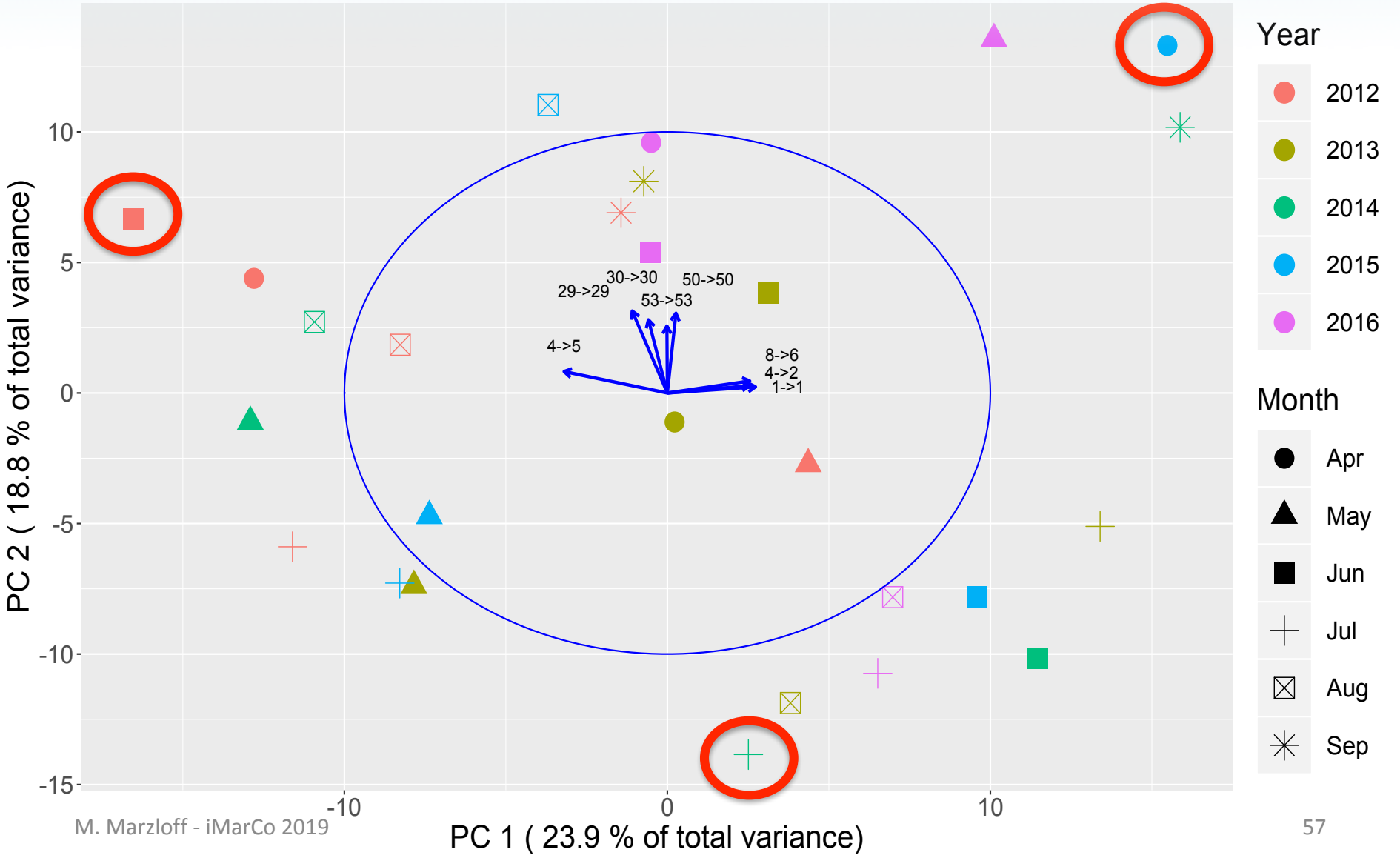
Regional hydrodynamic connectivity

PCA based on Monthly Connectivity Matrices



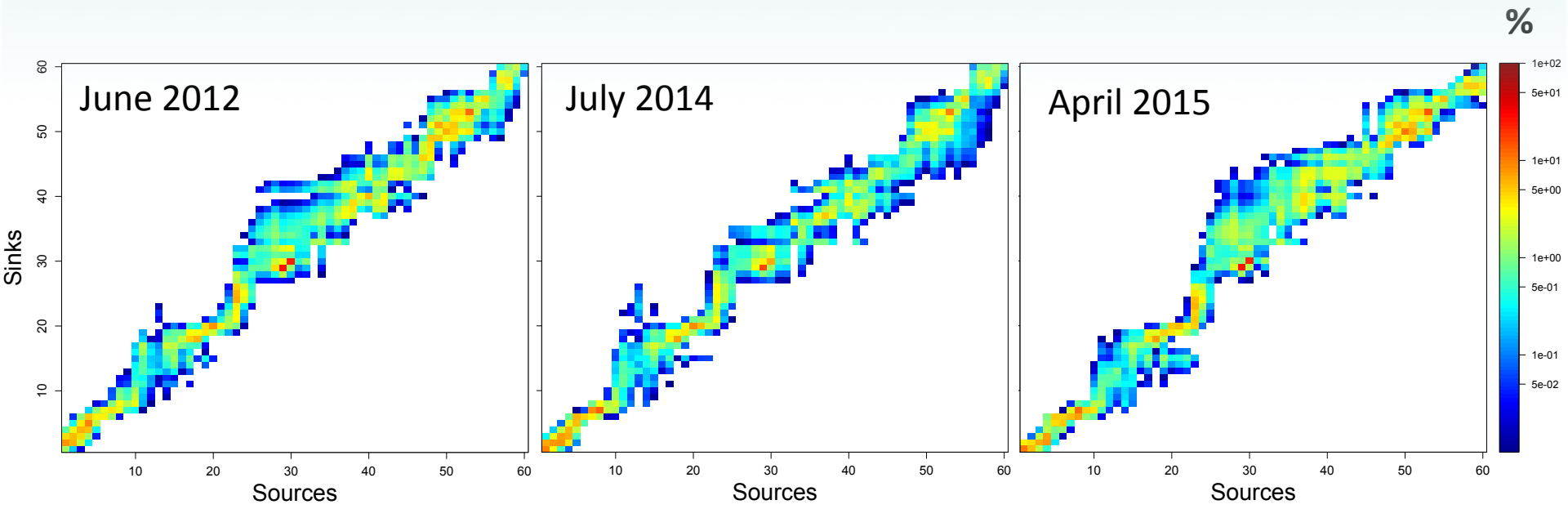
Regional hydrodynamic connectivity

PCA based on Monthly Connectivity Matrices



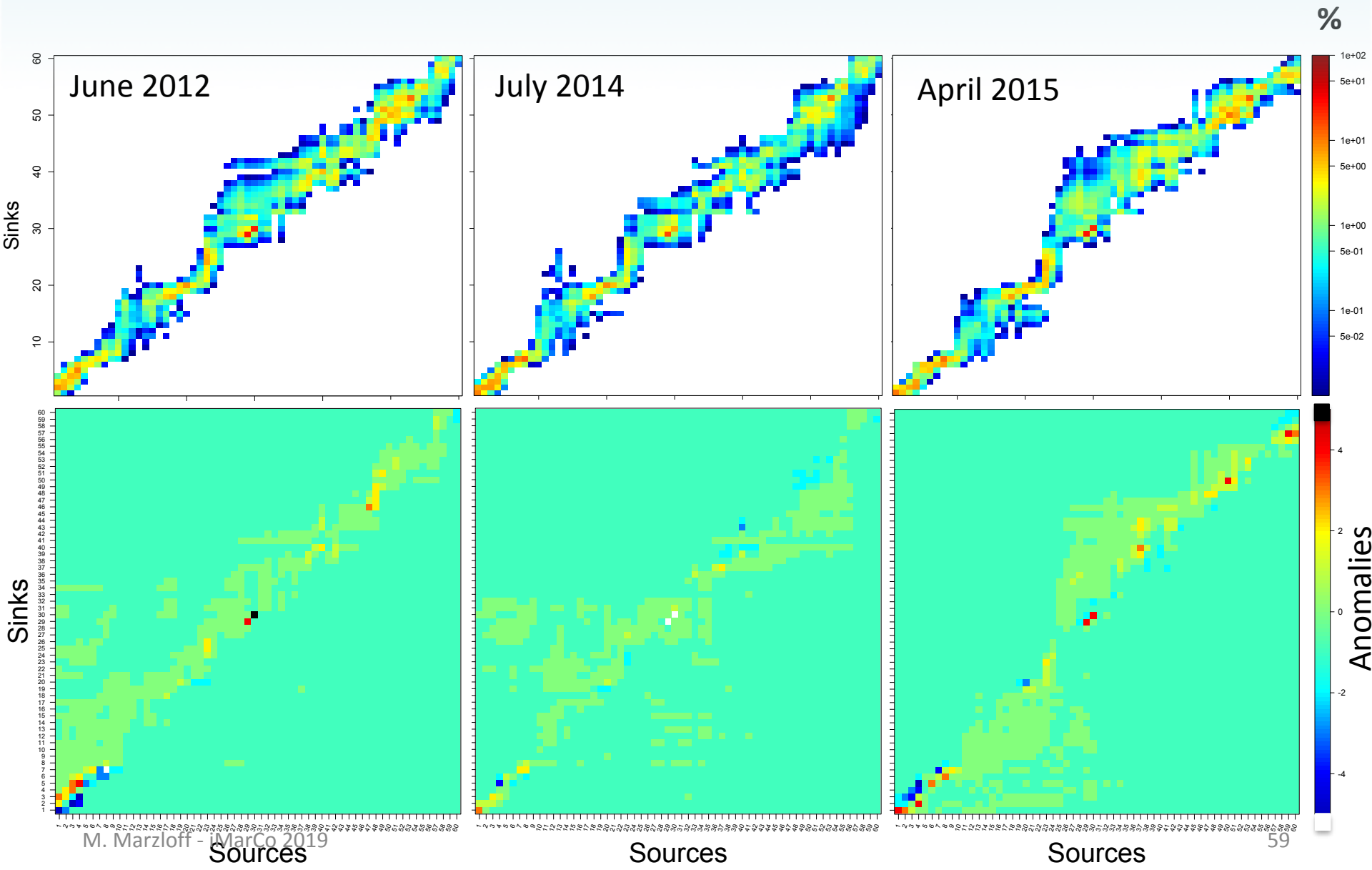
Regional hydrodynamic connectivity

"Extreme" Monthly Connectivity Matrices



Regional hydrodynamic connectivity

"Extreme" Monthly Connectivity Matrices

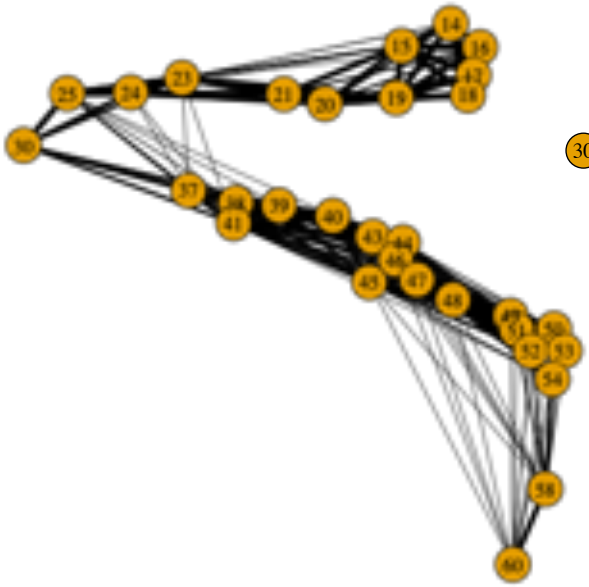


Honeycomb reef population connectivity

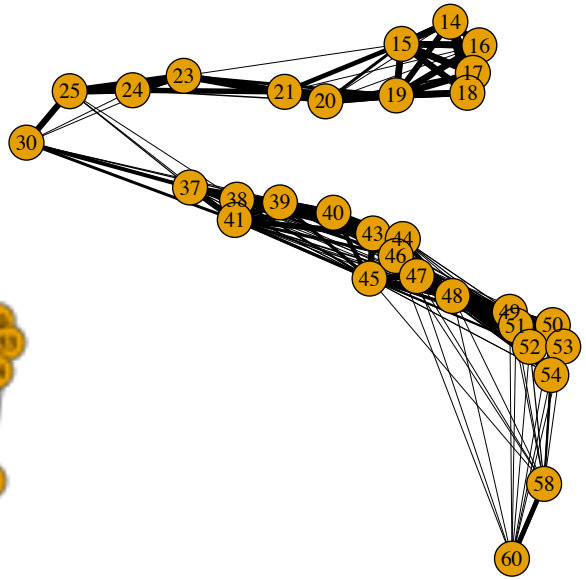
Threshold for effective population connectivity

Considering **31 reef-suitable zones** (based on expert knowledge)

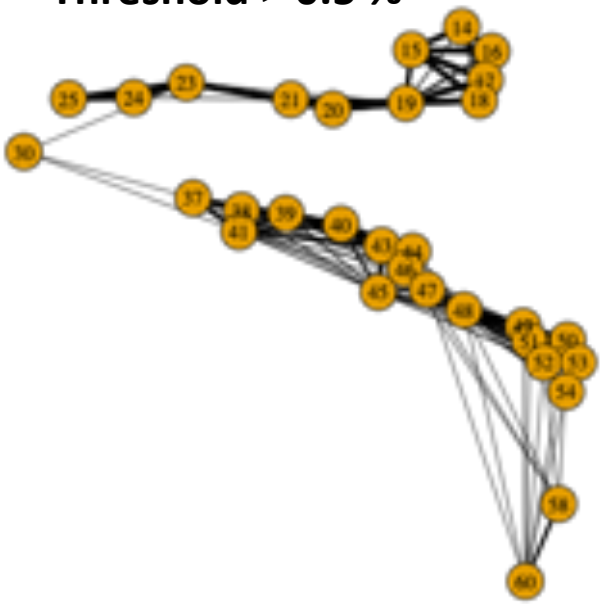
Threshold > 0.01 %



Threshold > 0.1 %



Threshold > 0.5 %



LINK LIKELIHOOD

(Across 30 simulations)

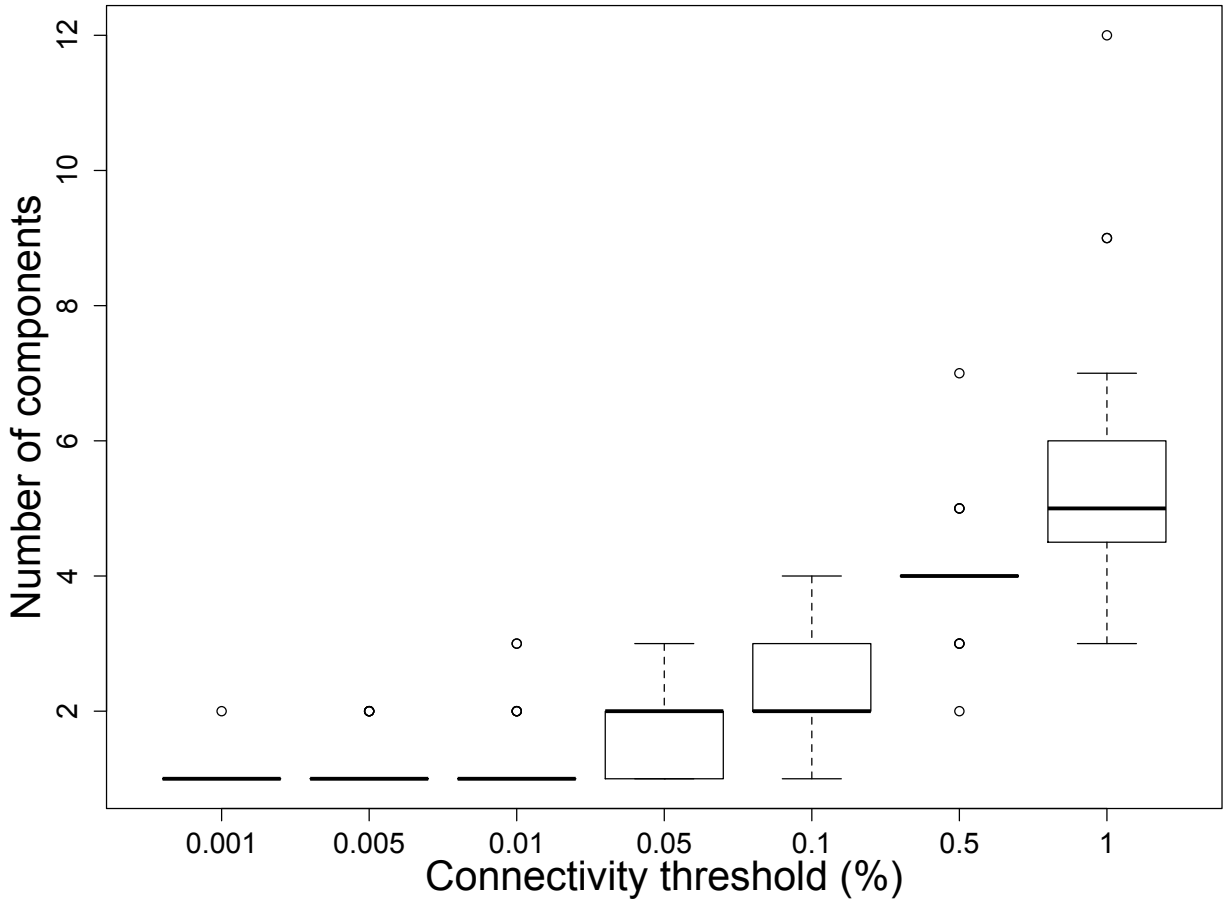
Low

Medium

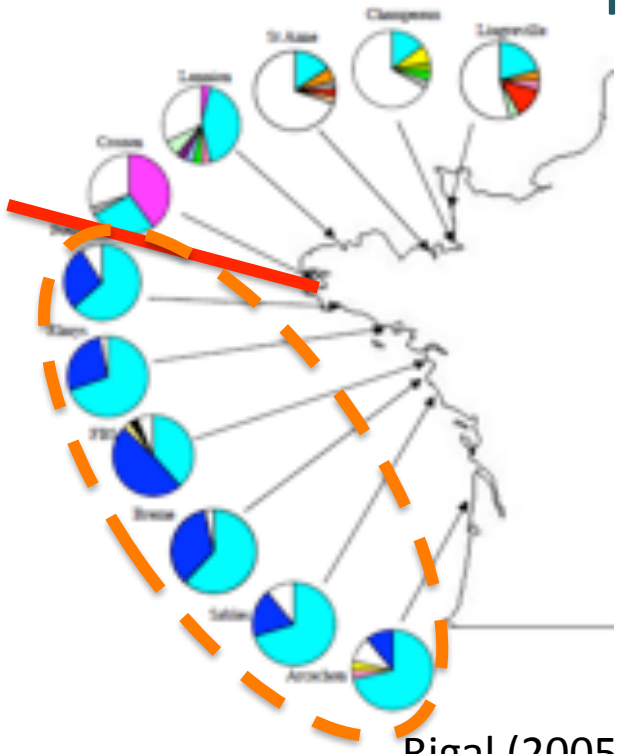
Constant

Honeycomb reef population connectivity

Threshold for effective population connectivity



Contribution from Genetics



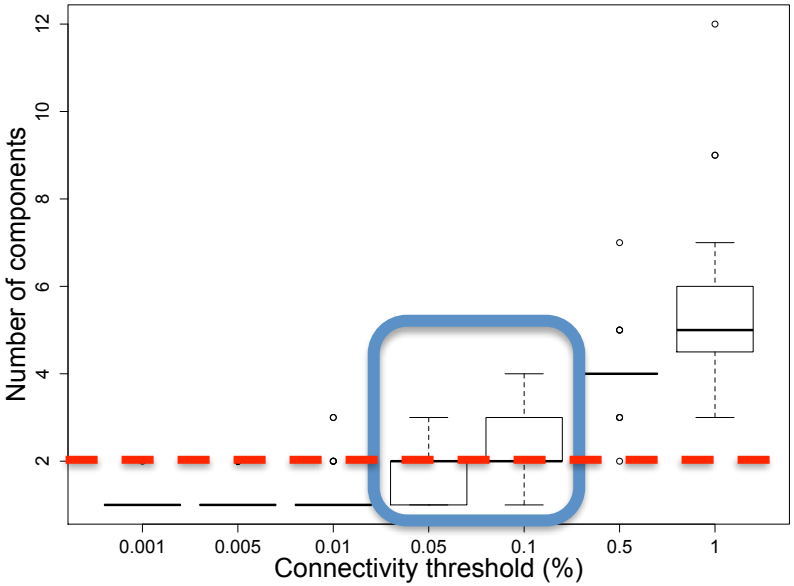
Frequency Of Haplotypes

Rigal (2005 – MSc thesis)

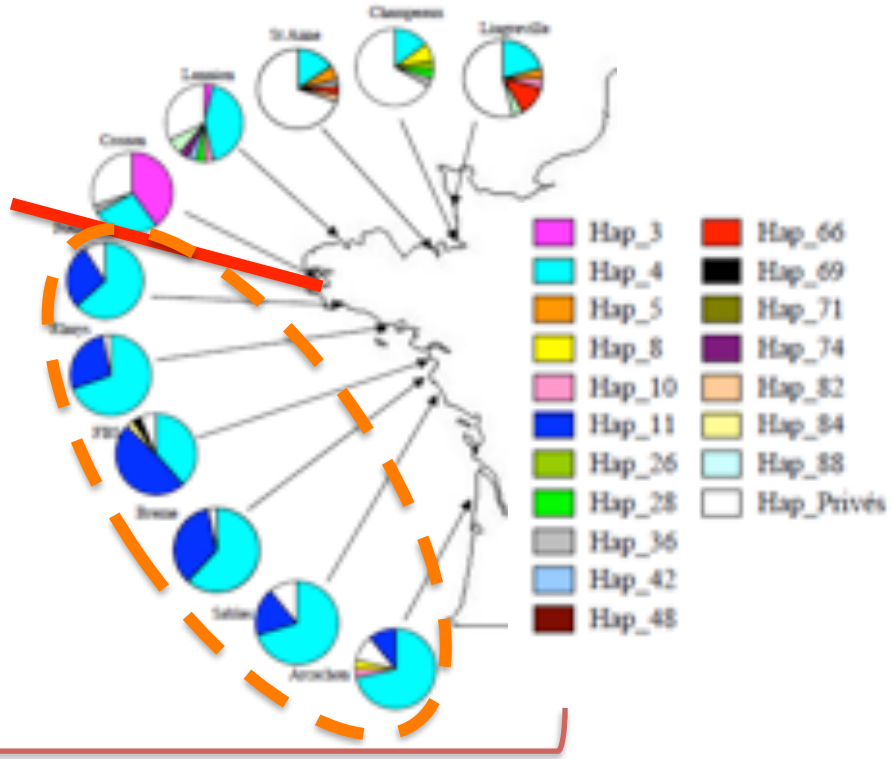
Honeycomb reef population connectivity

Threshold for effective population connectivity

HYDRODYNAMICS *versus* **GENETICS**



Frequency Of Haplotypes

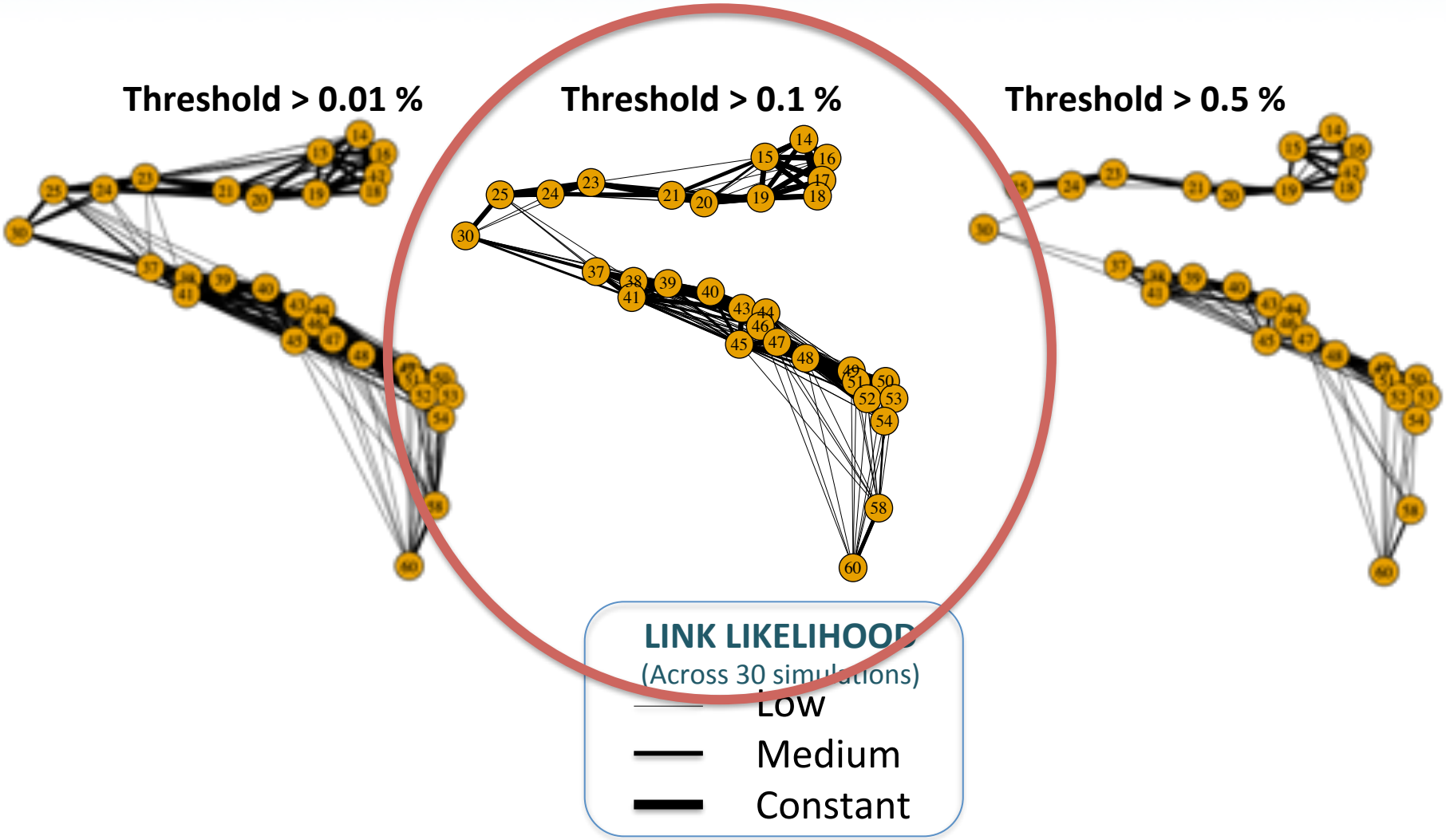


Hydro. Connectivity threshold ~ 0.05 – 0.1 %

Honeycomb reef population connectivity

Threshold for effective population connectivity

Considering **31 reef-suitable zones** (based on expert knowledge)



Honeycomb reef local connectivity

Zone-specific connectivity indices

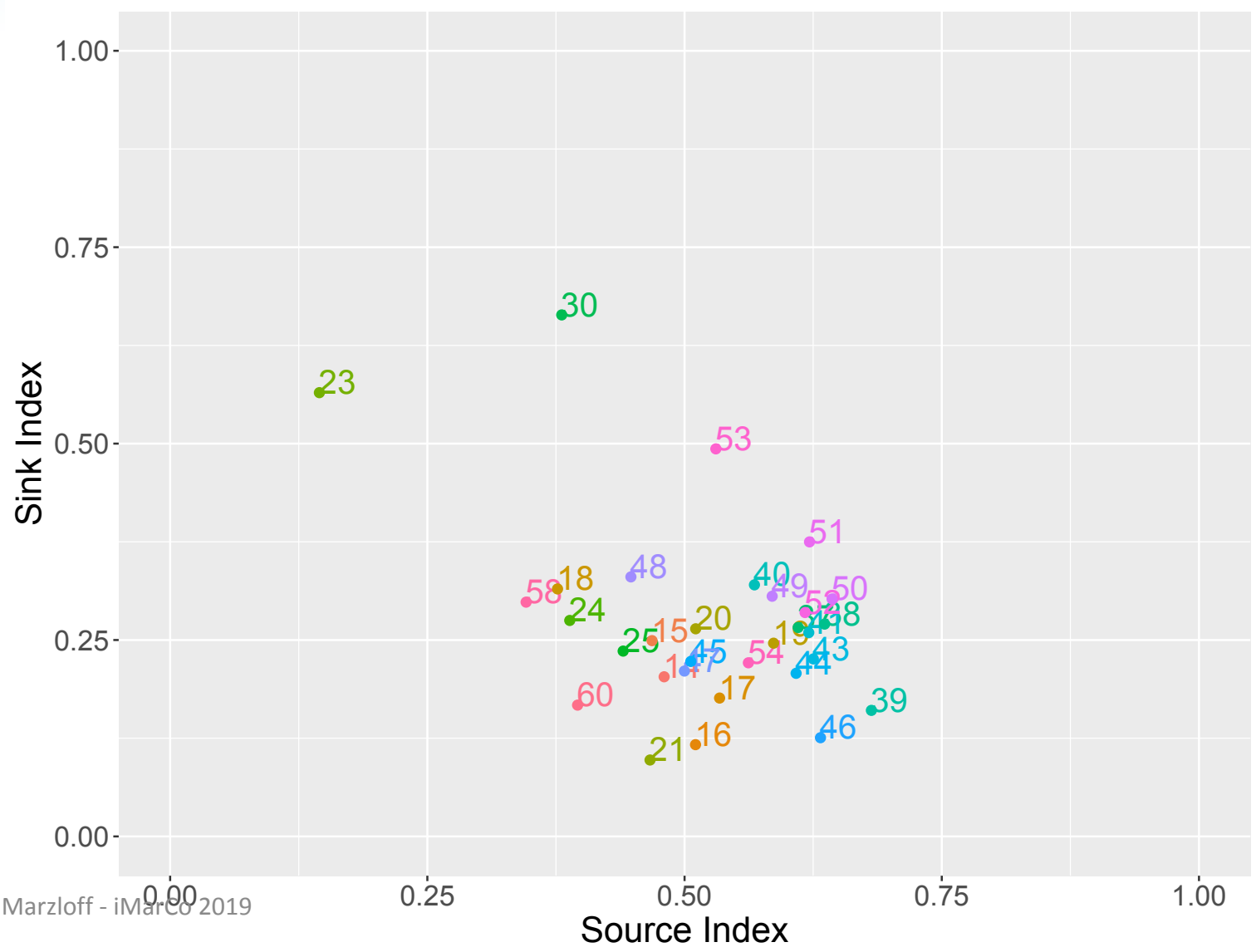
- **Sink index** = Number of incoming connections
  + Successful Incoming Transport (from all zones)
  + Ratio Incoming / Outgoing Transport
  + Rate of Retention (relative to Total Amount Released)
  + Max. distance for incoming substance

- **Source index** = Number of outgoing connections
  + Successful Outgoing Transport
  + Ratio Outgoing / Incoming Transport
  + Rate of Outflow (relative to total amount released)
  + Max. distance for outgoing substance

- Relative estimates (compared to highest score for each metric)

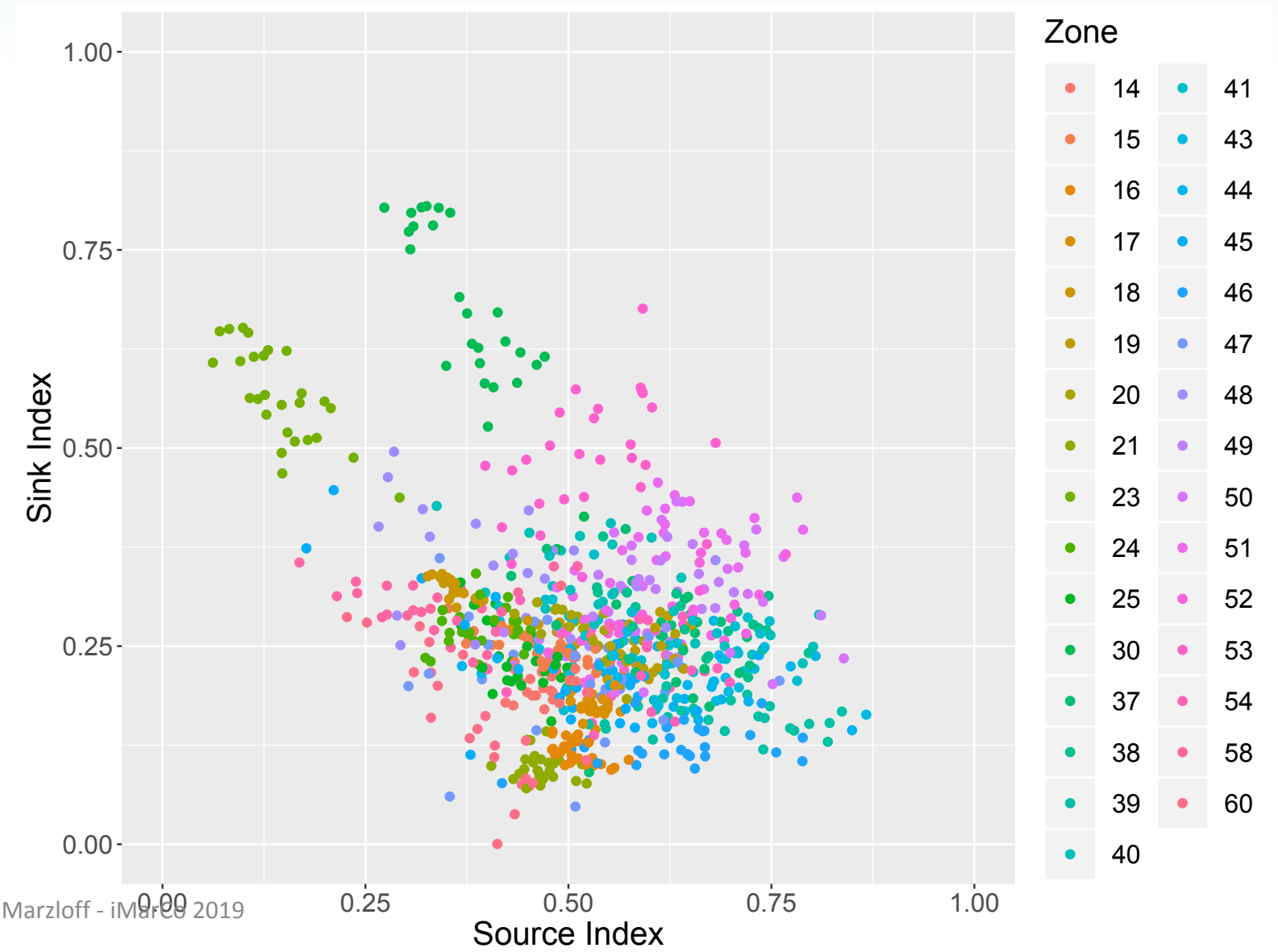
Honeycomb reef local connectivity

Zone-specific connectivity indices



Honeycomb reef local connectivity

Zone-specific connectivity indices

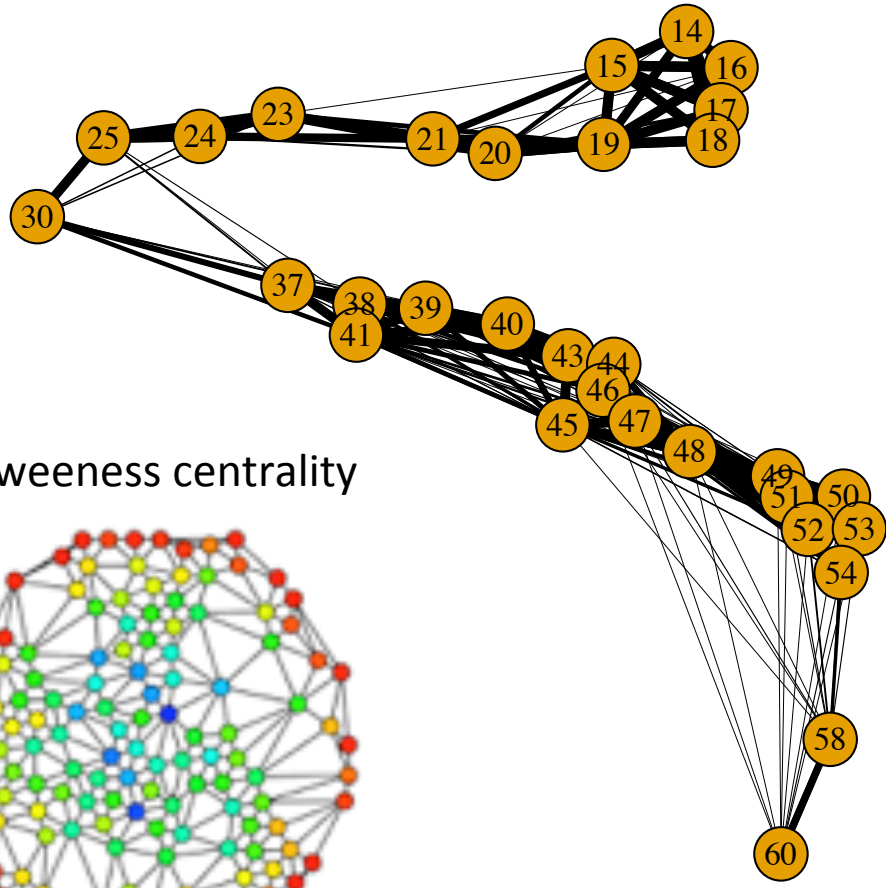


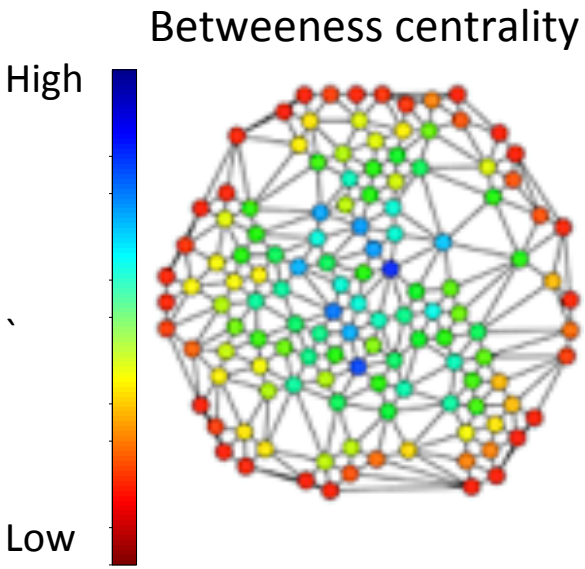
Honeycomb reef meta-population

Zone-specific contributions to network

5 NODE REMOVAL SCENARIOS

- Random
- Endnodes
- Betweeness
- Low reef abund.
- High reef abund.

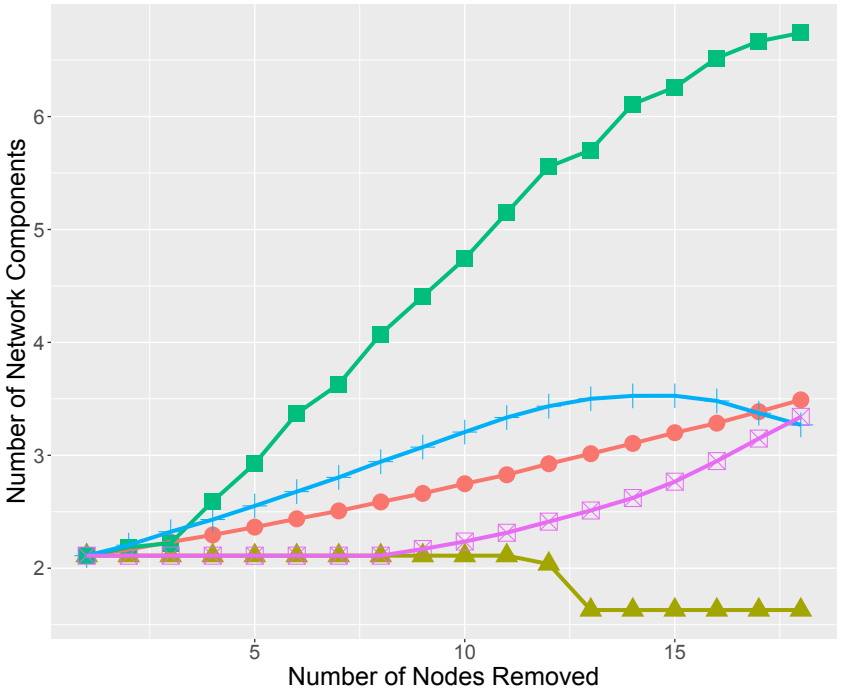


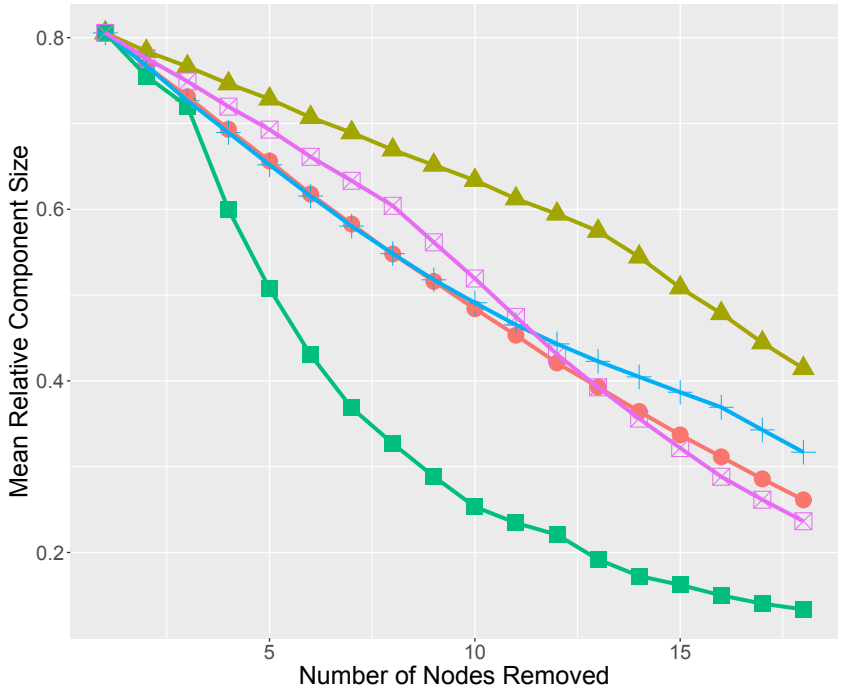


Honeycomb reef meta-population

Zone-specific contributions to network

5 NODE REMOVAL SCENARIOS





Take-home messages

- Regional hydrodynamic connectivity
  - « stepping stone » regional connectivity
  - Marginal interannual/seasonal variability
- Honeycomb reef meta-population connectivity
  - Insights from combining genetics and hydrodynamics modellign
  - 2 main sub-populations: Bay of Biscay Vs English Channel
  - Betweeness centrality index as a reliable indicator of local contribution to network
- Generic approach
  - Transposable to other intertidal species
  - Combination of hydrodynamics modelling, field-based expert knowledge, genetics
- Perpectives - Work in progress…
  - Formal genetics Vs Hydrodynamics statistical comparison
  - Accouting for larval behaviour? Survival? Succesful recruitment?

Thank you

Martin.Marzloff@ifremer.fr

Thank you for your attention

This work was supported by ISblue project, Interdisciplinary graduate school for the blue planet (ANR-17-EURE-0015) and co-funded by a grant from the French government under the program "Investissements d'Avenir"