Investigating temporal and spatial impacts of mixed fisheries fleets on the Celtic Sea ecosystem in the frame of climate change through trophic modeling

Mikaëla POTIER

25/11/2021
Amédée
Encadrants: Didier GASCUEL, Marianne ROBERT et Marie SAVINA-ROLLAND

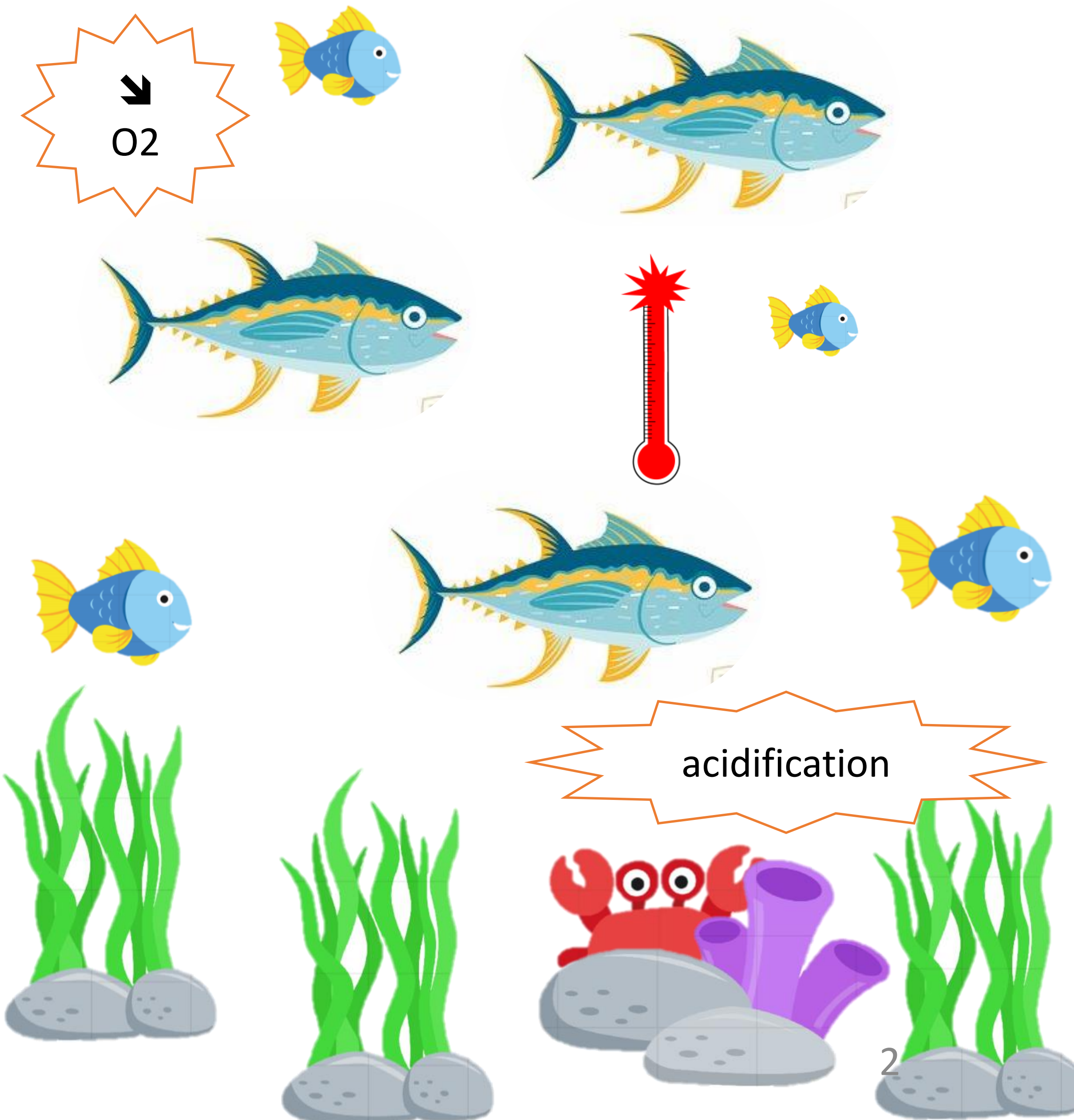
Climate change impacts on marine ecosystems

Changes in abiotic factors (IPCC, 2020) **:**

- Increase in water temperature
- Decrease in disolved O2
- Acidification ...

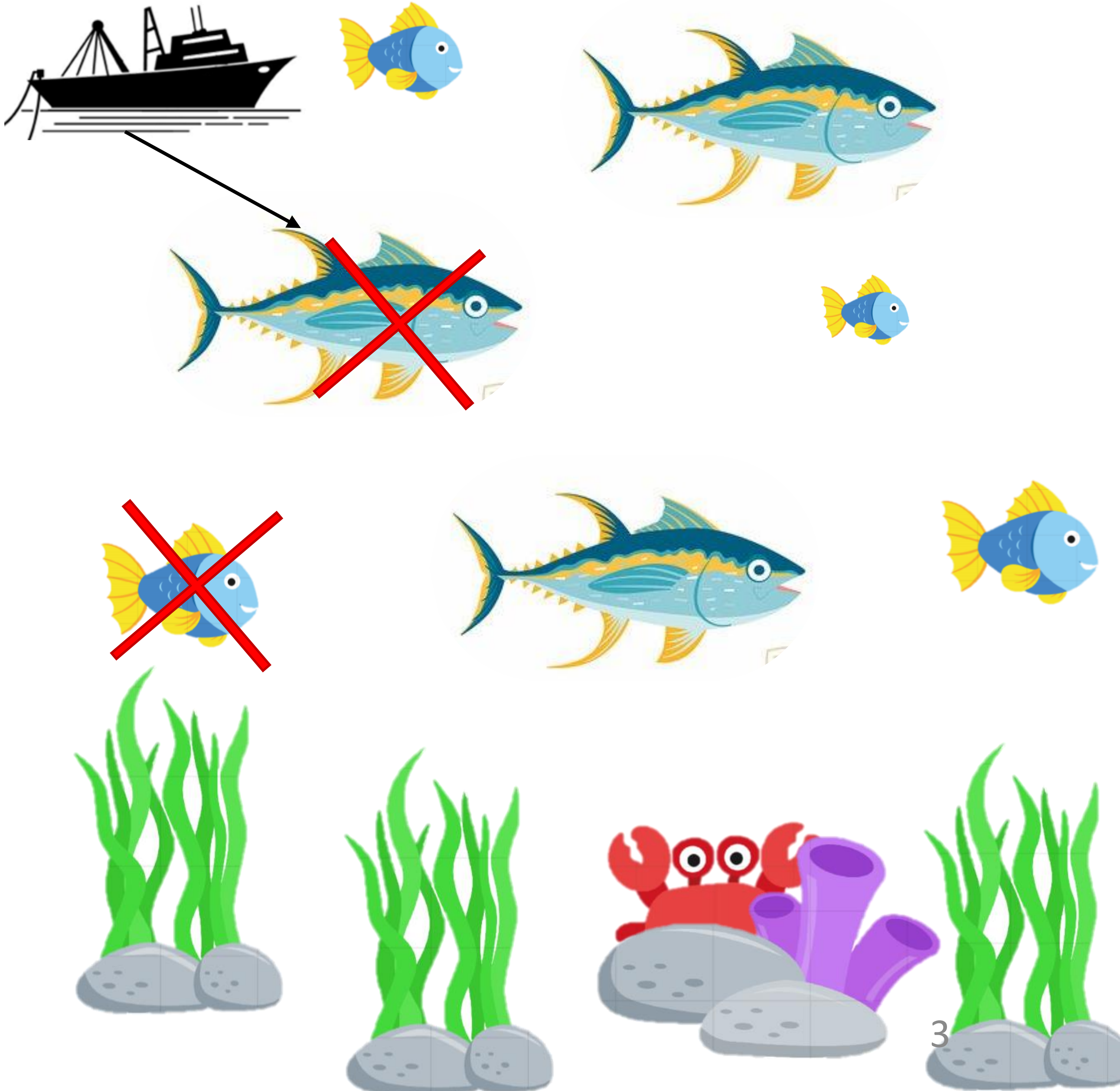
Changes in biotic components (Dulvy et al. 2008, Bindoff et al. 2019) **:**

- Changes in species distribution patterns
- Changes in productivity ...



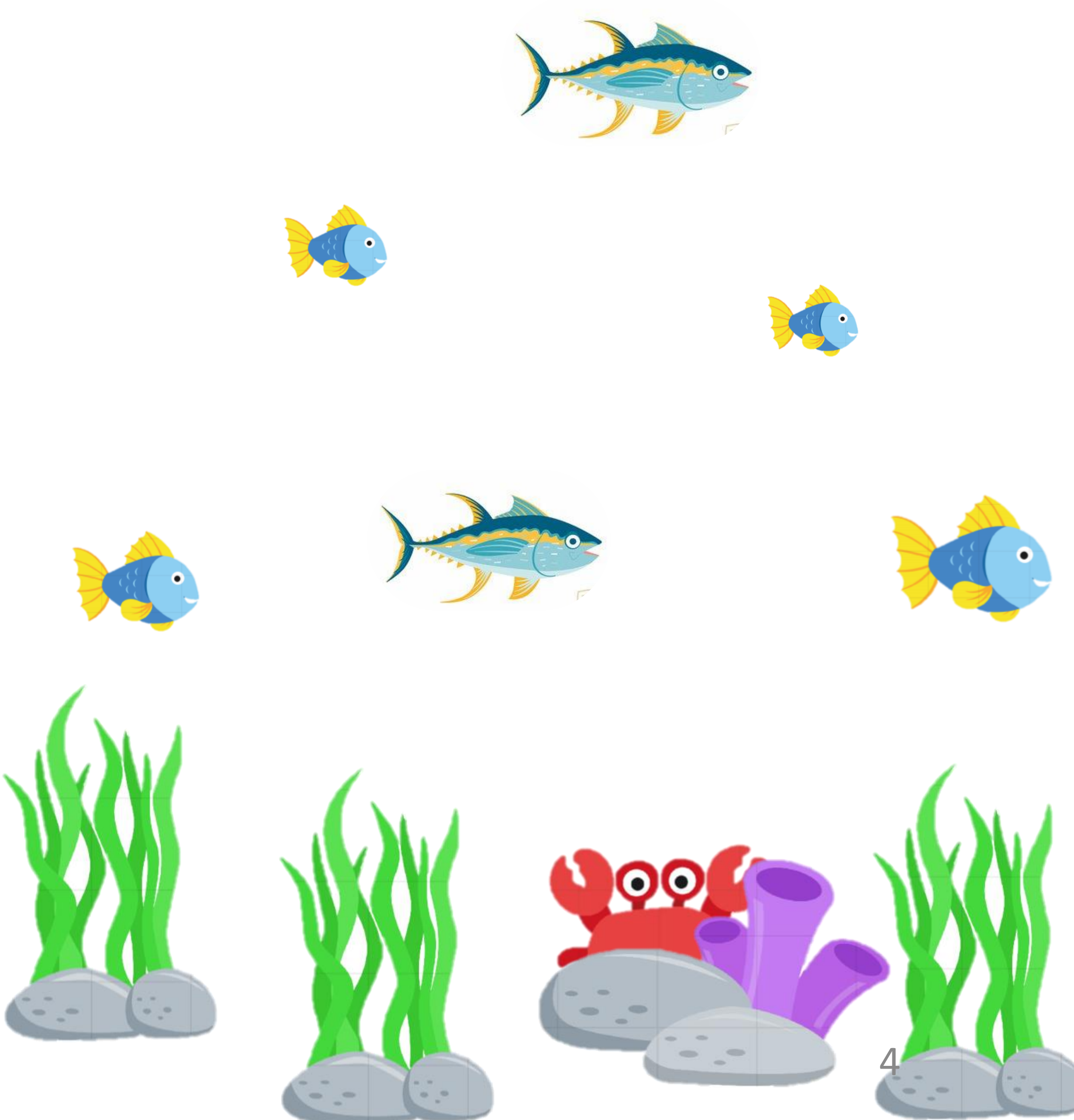
Fishing impacts on ecosystems

- Decrease in the biomass of exploited species



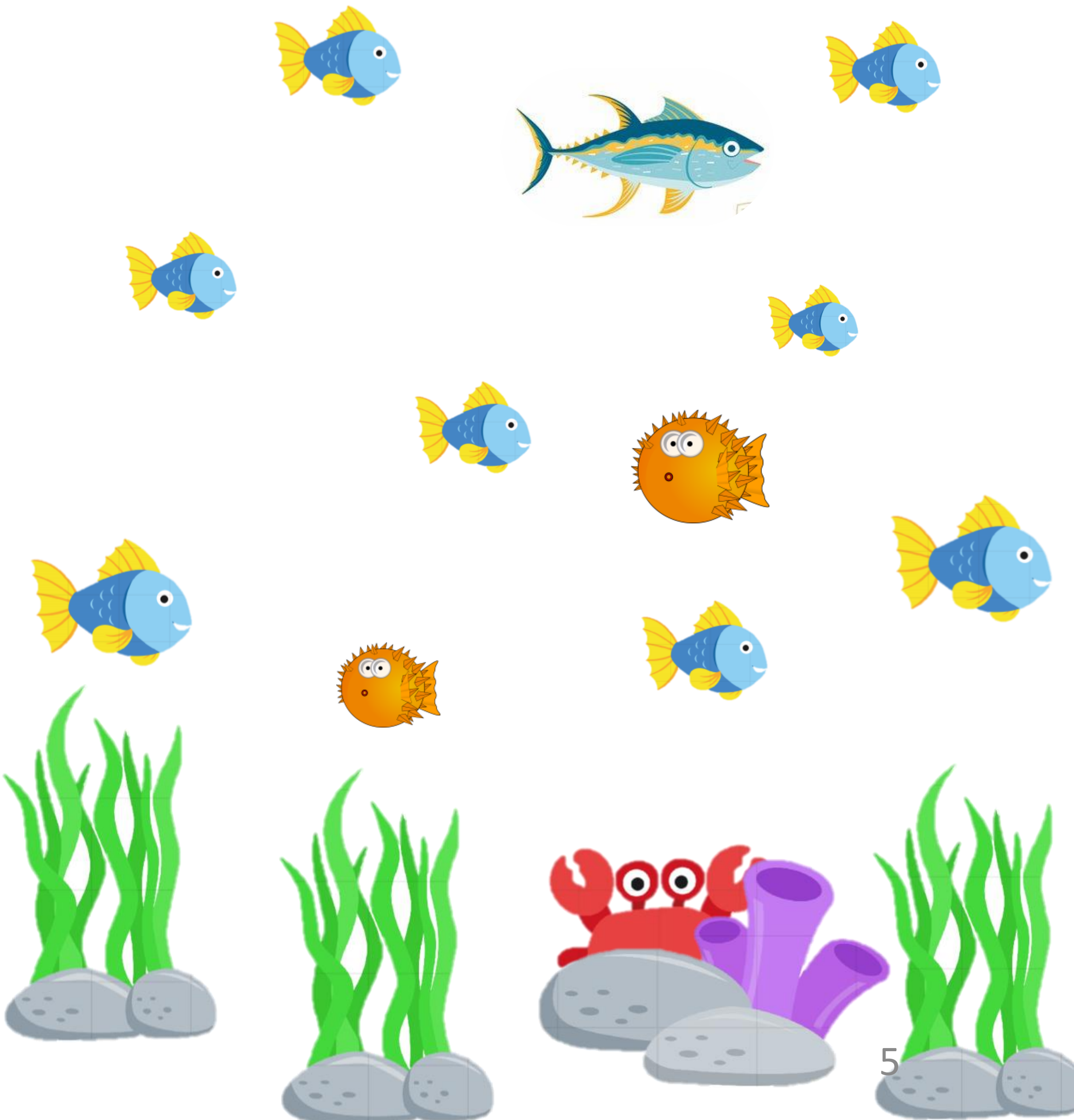
Fishing impacts on ecosystems

- Decrease in the biomass of exploited species
- Drop of the mean length of individuals (Bindoff et al. 2019)



Fishing impacts on ecosystems

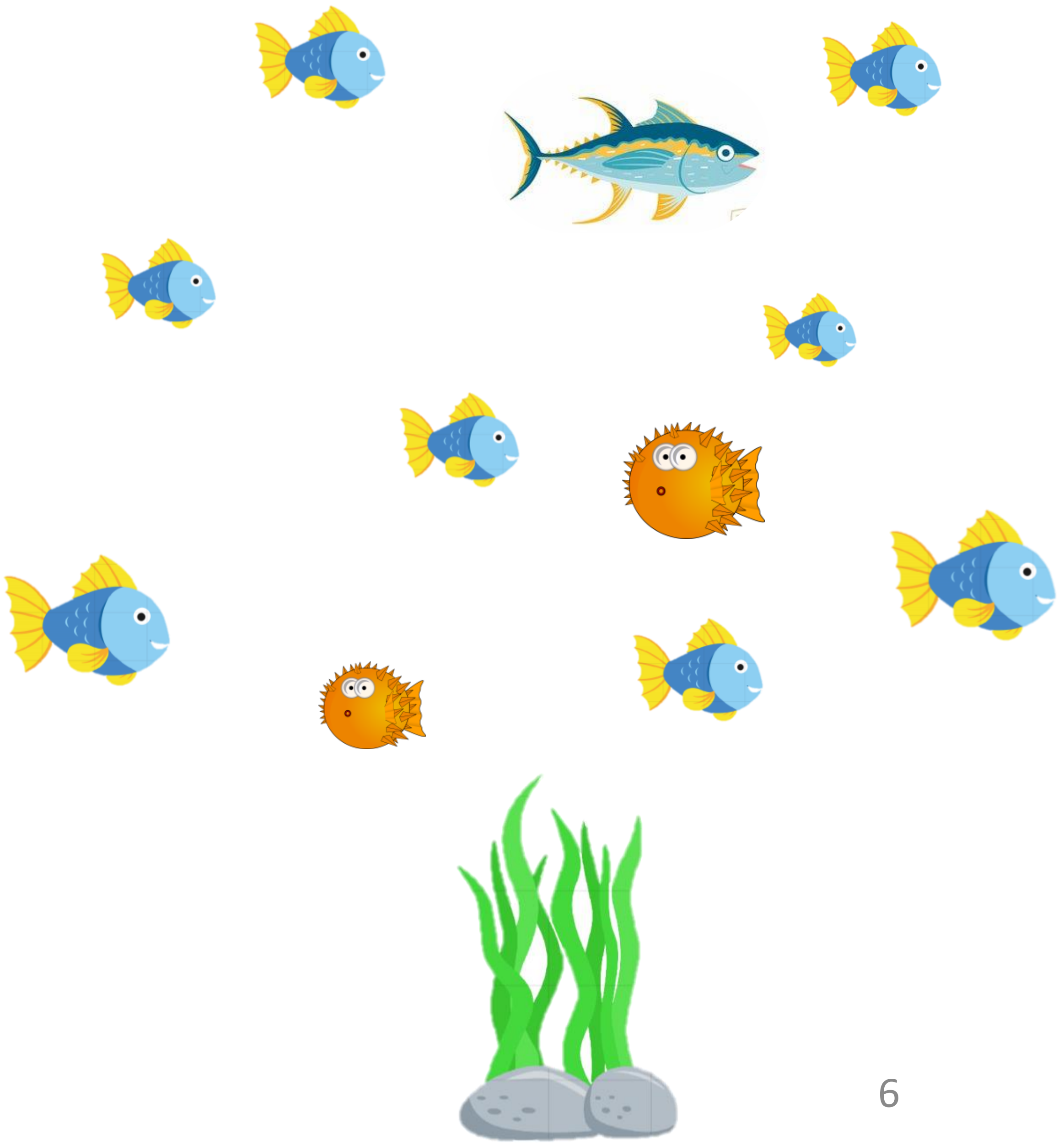
- Decrease in the biomass of exploited species
- Drop of the mean length of individuals (Bindoff et al. 2019)
- Changes in species assemblages (Bindoff et al. 2019)



Fishing impacts on ecosystems

- Decrease in the biomass of exploited species
- Drop of the mean length of individuals (Bindoff et al. 2019)
- Changes in species assemblages (Bindoff et al. 2019)
- Habitat’s modification and destruction

-> loss of productivity … (Collie et al. 2017)

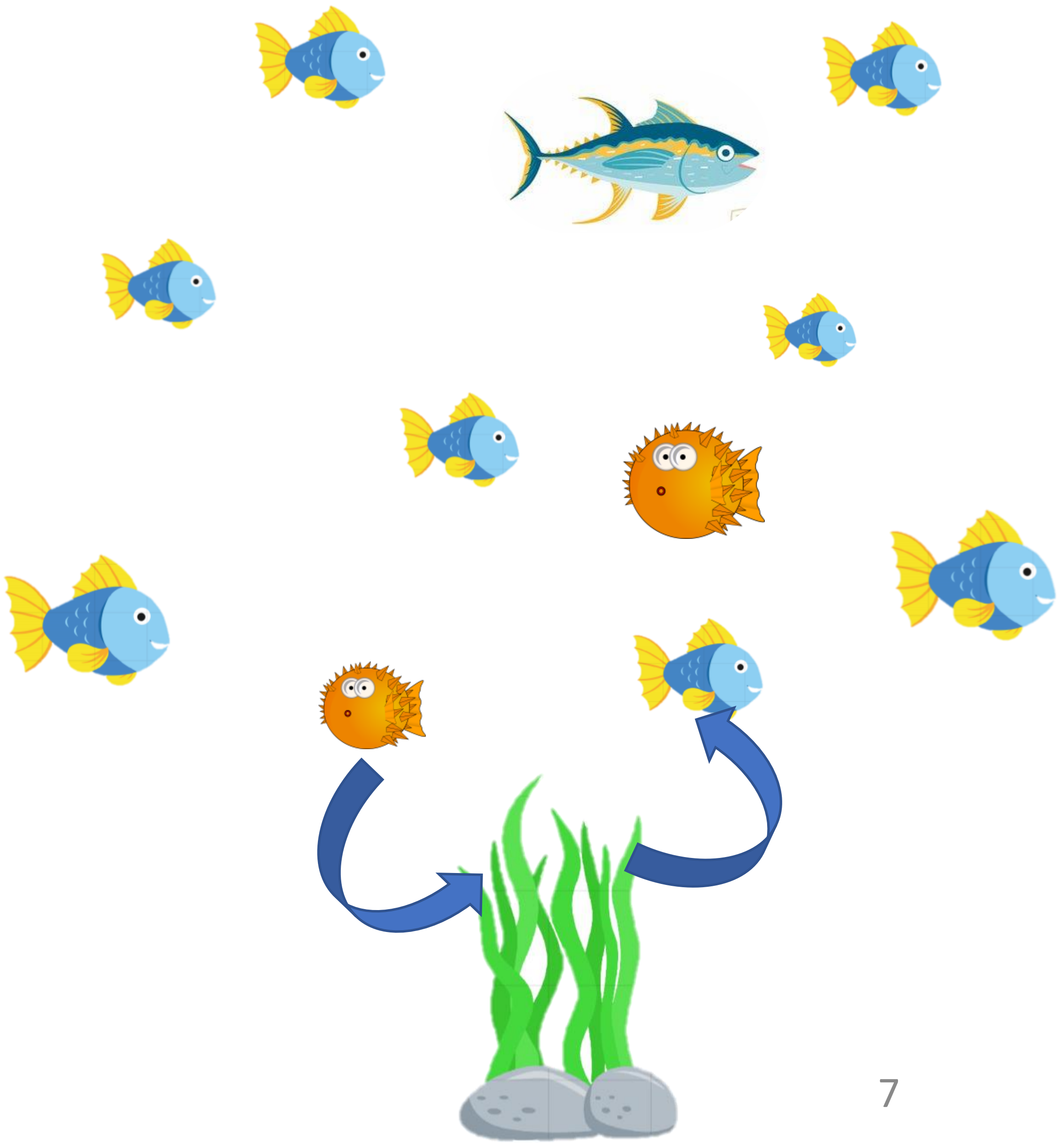


Fishing impacts on ecosystems and ecosystem approach to fisheries

- Decrease in the biomass of exploited species
- Drop of the mean length of individuals (Bindoff et al. 2019)
- Changes in species assemblages (Bindoff et al. 2019)
- Habitat's modification and destruction

-> loss of productivity … (Collie et al. 2017)

- Interactions between species -> implementation of an multispecies management -> tools
  (Garcia & Cochrane 2005, Cury et al. 2015)



Ecosystem modelling: an adapted tool to disentangle these impacts

Ecosystem model
e.g. ECOPATH

Understand climate change and fishing impacts

Reconstruction of past evolution and simulation of future evolution

Ecosystem-based fisheries management implementation

(Coll et al, 2015)

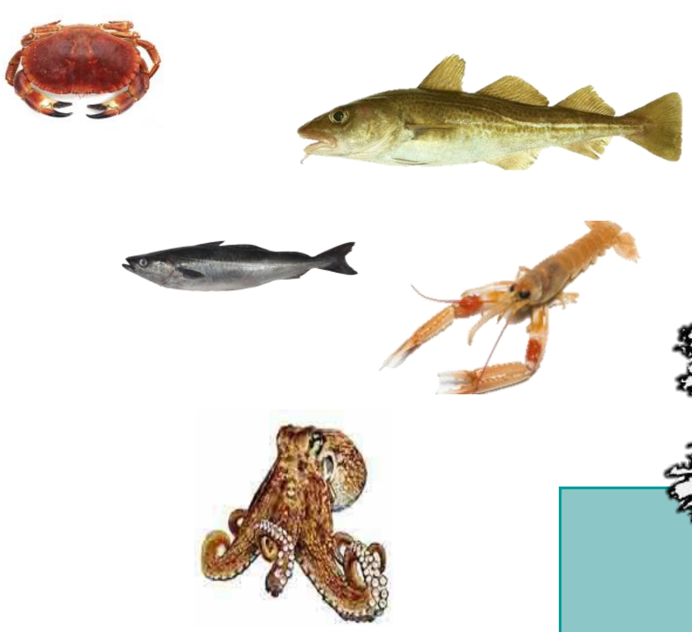
The Celtic Sea: fisheries zone heavily exploited

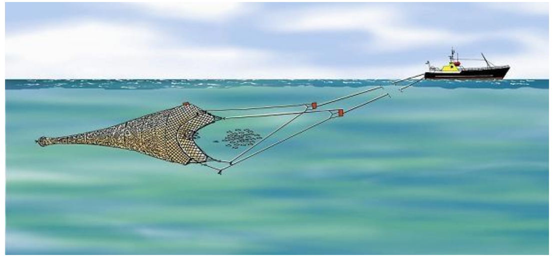
(Hernvann & Gascuel, 2020; Mateo et al. 2017, Moore et al. 2019, ICES 2020)

- Heavily exploited

- Fishing pressure 50s -> 90s
- 2010s -> management to stop the drop of some stocks

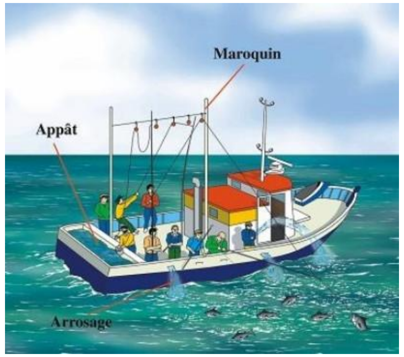
- Mixed fisheries -> dependance between species catch





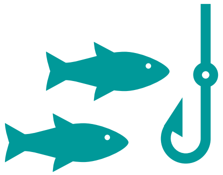
Pelagic trawl

Purse seine



Lines

The Celtic Sea: difficulties to manage mixed fisheries



Stock-based management

- Today’s fishing management (e.g., fishing quotas…)
- No ecosystem approach

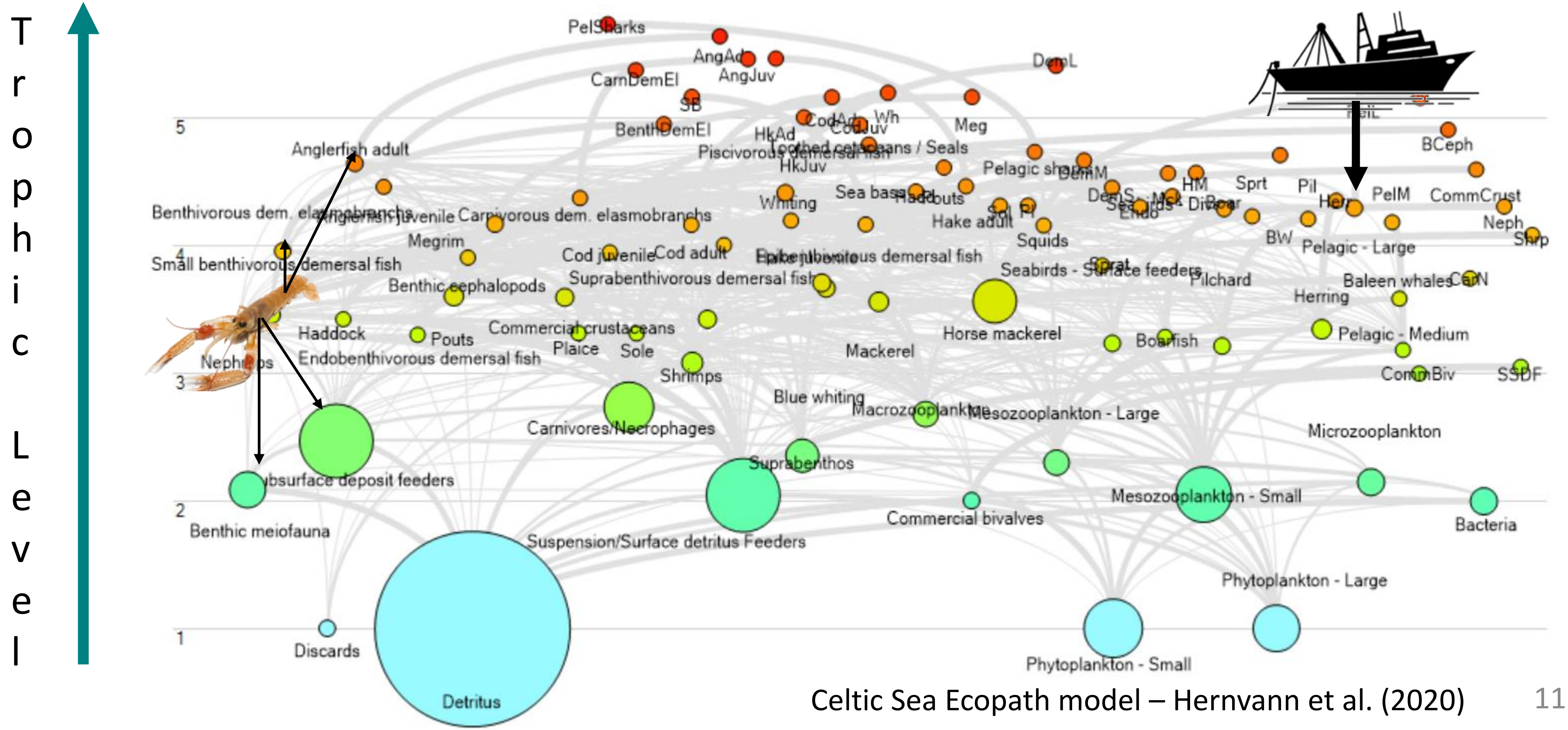
Fleet-based management

- Under consideration
- Ecosystem approach to fisheries

References: (Gascuel et al. 2012, Ulrich et al. 2017)

A pre-existing ecosystem model for the Celtic Sea

Fleet targeting medium pelagic fish



Celtic Sea Ecopath model – Hernvann et al. (2020)

ISSUE

1 fleet = 1 targeted species

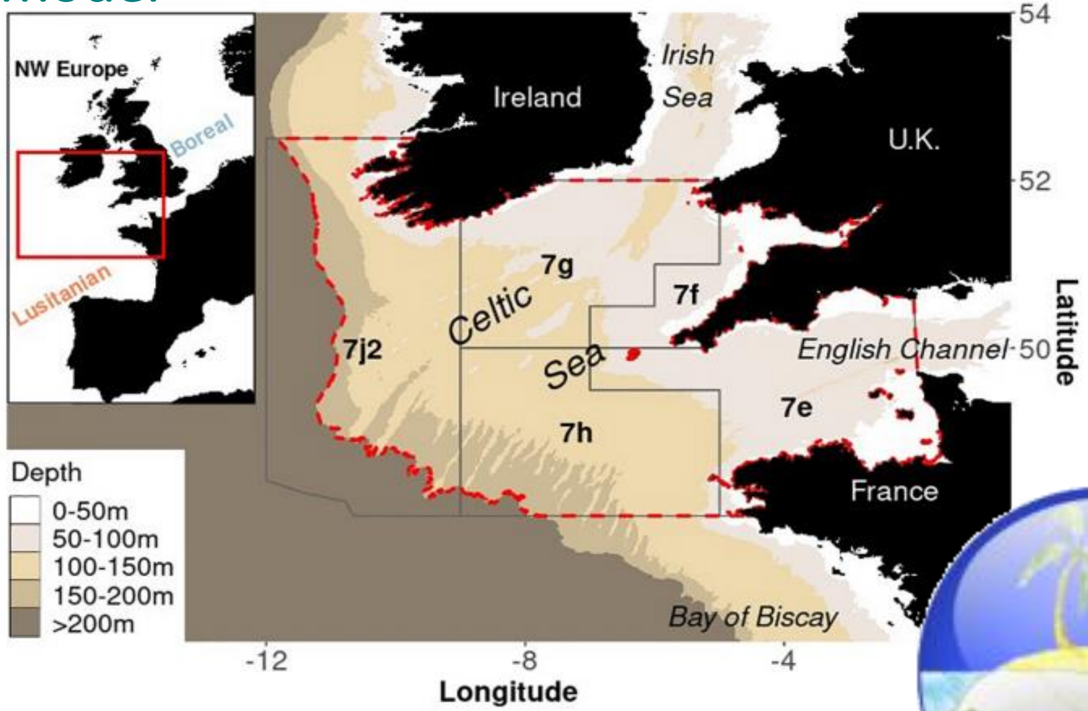
Need for a realistic representation of Celtic Sea mixed fisheries

What are the ecosystem effects of each of the Celtic Sea fleets and their interactions via food webs in the context of climate change?

And vice versa: how is climate change (CC), through its ecosystem effects, likely to affect each of the Celtic Sea fleets?

Ecosystem modeling via Ecopath software

Description of Hernvann et al. Ecopath model



- **Year:** 1985
- **Area:** the Celtic Sea (< 200m)
- **Functional groups:** 48

Ecopath (Polovina 1984, Christensen & Pauly 1992)

Production = Predation + Other mortalities + Catches + Exportations + Biomass Accumulation

Consumption = Production + Respiration + Unassimilated Food

Snapshot of the ecosystem for a given year

Ecosim = dynamic component

- Reconstruction of past evolution & simulation of future trends
- Serie of differential equations
- **Impact of fishing:** fishing mortality/ effort or catches time series
- **Climate effects:**
environmental conditions + functional responses to environmental conditions

Description of Hernvann et al. Ecosim model

- **Period:** 1985 – 2016
- **Impact of fishing:** fishing mortality and catches time series
- **Climate effects:** Temperature + functional responses

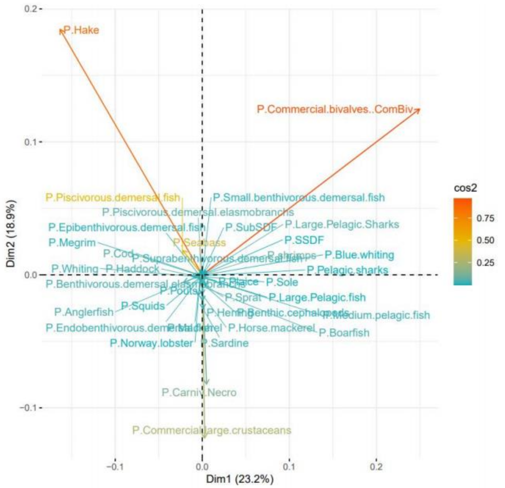
❶ Modifications of the 1985-2016 EwE model

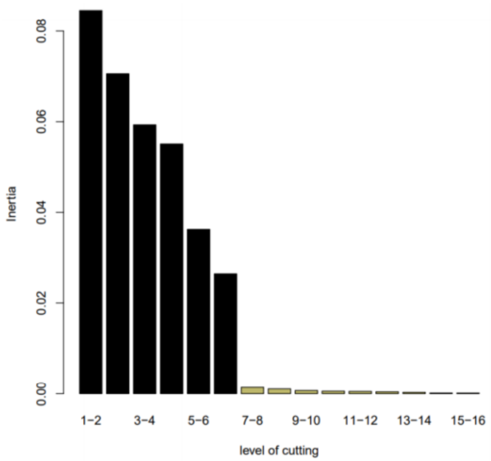
- Definition of Celtic Sea fleets

Data: International landings data agregated by country, gear, target species assemblage and vessel length

Method: Statistical analysis (PCA + clustering)

Definition criterion: fleets have similar landings profiles





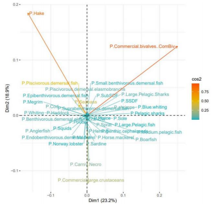
❶ Modifications of the 1985-2016 EwE model

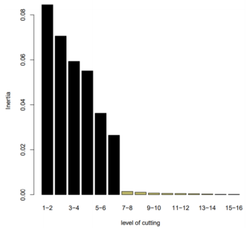
- Definition of Celtic Sea fleets

Data: International landings data agregated by country, gear, target species assemblage and vessel length

Method: Statistical analysis (PCA + clustering)

Definition criterion: fleets have similar landings profiles

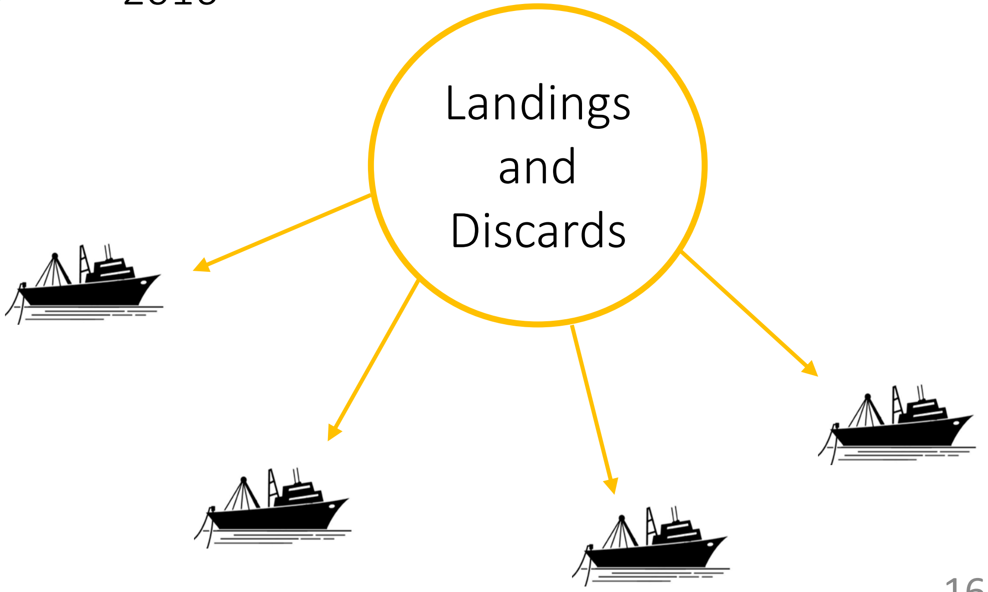




- Repartition of catches of the 1985 Ecopath between fleets

Method: Analysis of international mean catches data (STECF) in 2016

Hypothesis: Same distribution in 1985 than in 2016



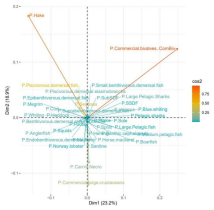
❶ Modifications of the 1985-2016 EwE model

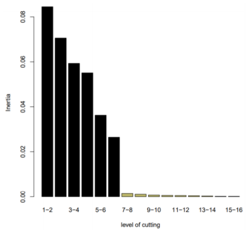
- Definition of Celtic Sea fleets

Data: International landings data agregated by country, gear, target species assemblage and vessel length

Method: Statistical analysis (PCA + clustering)

Definition criterion: fleets have similar landings profiles

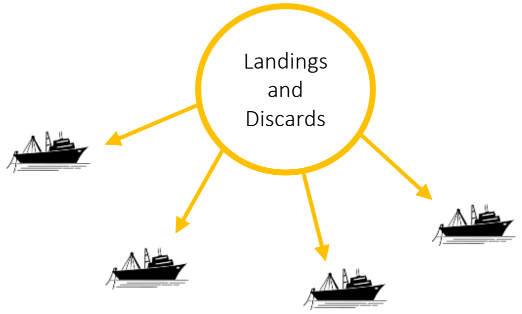




- Repartition of catches of the 1985 Ecopath between fleets

Method: Analysis of international mean catches data (STECF) in 2016

Hypothesis: Same distribution in 1985 than in 2016



- Modification of catches time series in fishing mortality time series

❶ Modifications of the 1985-2016 EwE model

❷ Assess the impact of fleets on the ecosystem in 2016

Use of various usual impact indicators:

Direct impacts

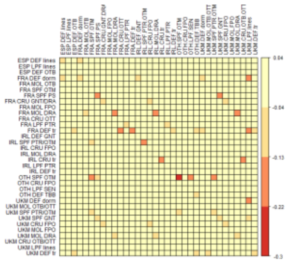
- Fishing mortalities = Catches / Biomass

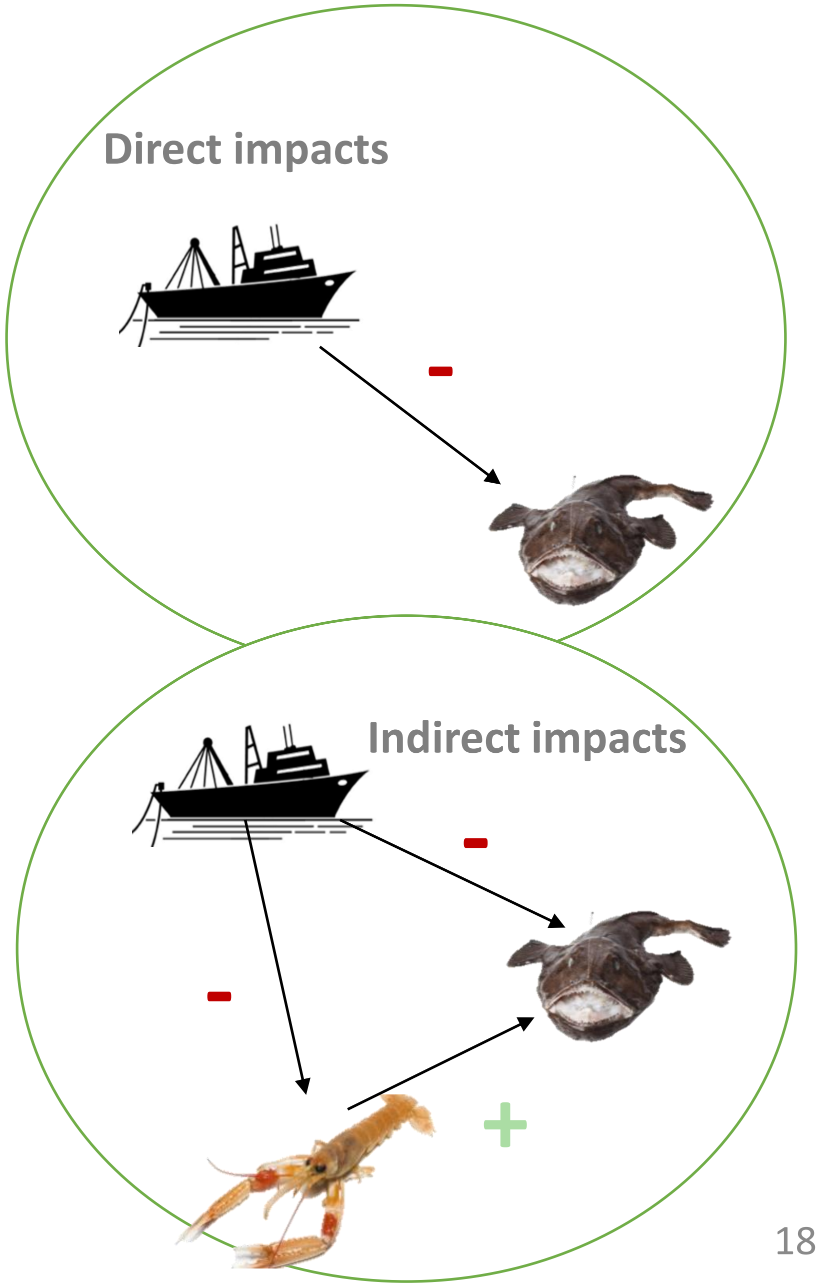
- Fishing loss = Catches / production

Indirect and direct impacts

- Mixed trophic impact analysis

Fleet = predator





❶ Modifications of the 1985-2016 EwE model

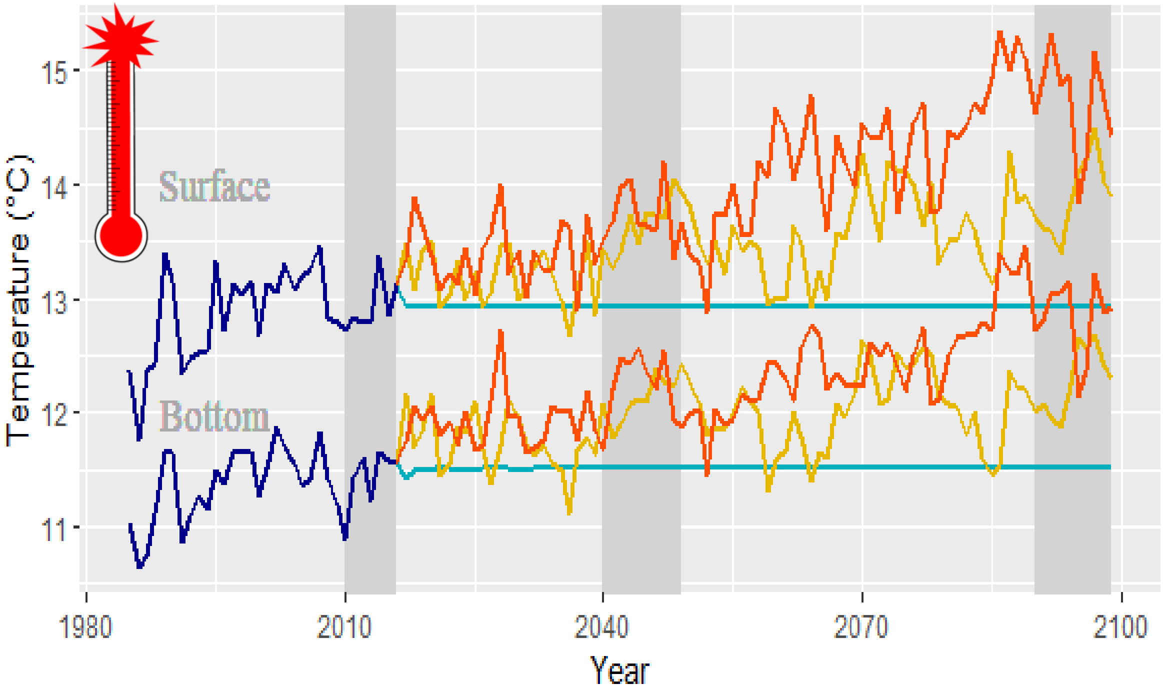
❷ Assess the impact of fleets on the ecosystem in 2016

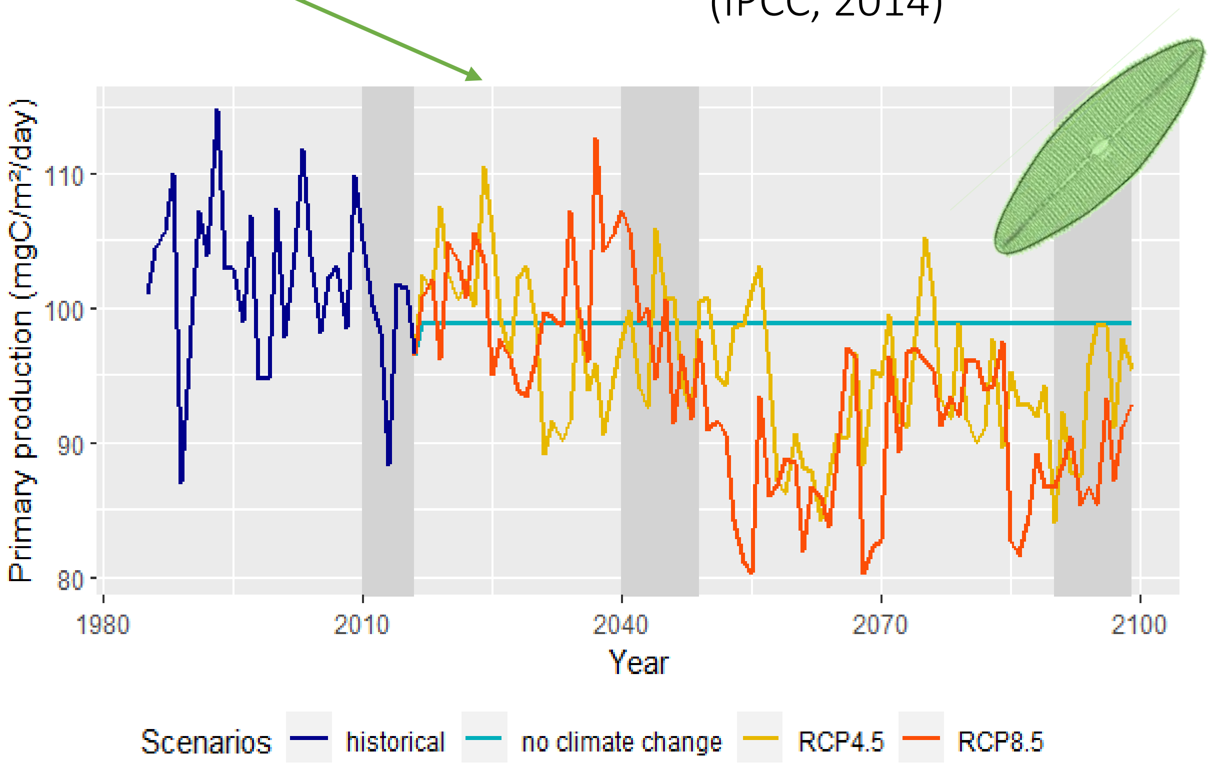
❸ Temporal simulation of climate change and fishery management scenarios

- Climate change scenarios

POLSCOM-ERSEM

(IPCC, 2014)





❶ Modifications of the 1985-2016 EwE model

❷ Assess the impact of fleets on the ecosystem in 2016

❸ Temporal simulation of climate change and fishery management scenarios

- Climate change scenarios
- Fishing management scenarios

Scenarios by species

In accordance with the current stock-based management

- Various usual management targets or strategies
- Multipliers
- Internal Fmsy

Scenarios by fleets

In accordance with a potential fleet-based management (ecosystem approach to fisheries)

- +/- fishing effort on some fleet's types
- +/- proportion of some gears targeting a species

❶ Modifications of the 1985-2016 EwE model

❷ Assess the impact of fleets on the ecosystem in 2016

❸ Temporal simulation of climate change and fishery management scenarios

- Climate change scenarios
- Fishing management scenarios
- Use of various indicators

Catch-based

- Catches
- Trophic level of catches

Ecosystem indicators

- Predator biomass (TL>3.25)
- Trophic level of predators
- Shannon diversity index (evenness)
- Biomass ratio chondrichtyans and demersal / Pelagics (equilibrium in the ecosystem)

❶ Modifications of the 1985-2016 EwE model

❷ Assess the impact of fleets on the ecosystem in 2016

❸ Temporal simulation of climate change and fishery management scenarios

- Climate change scenarios
- Fishing management scenarios
- Use of various indicators

Averaged over 2040s & 2090s

Catch-based	Ecosystem indicators
- Catches - Trophic level of catches	- Predator biomass (TL>3.25) - Trophic level of predators - Shannon diversity index (evenness) - Biomass ratio chondrichtyans and demersal / Pelagics (equilibrium in the ecosystem)

❶ Modifications of the 1985-2016 EwE model

❷ Assess the impact of fleets on the ecosystem in 2016

❸ Temporal simulation of climate change and fishery management scenarios

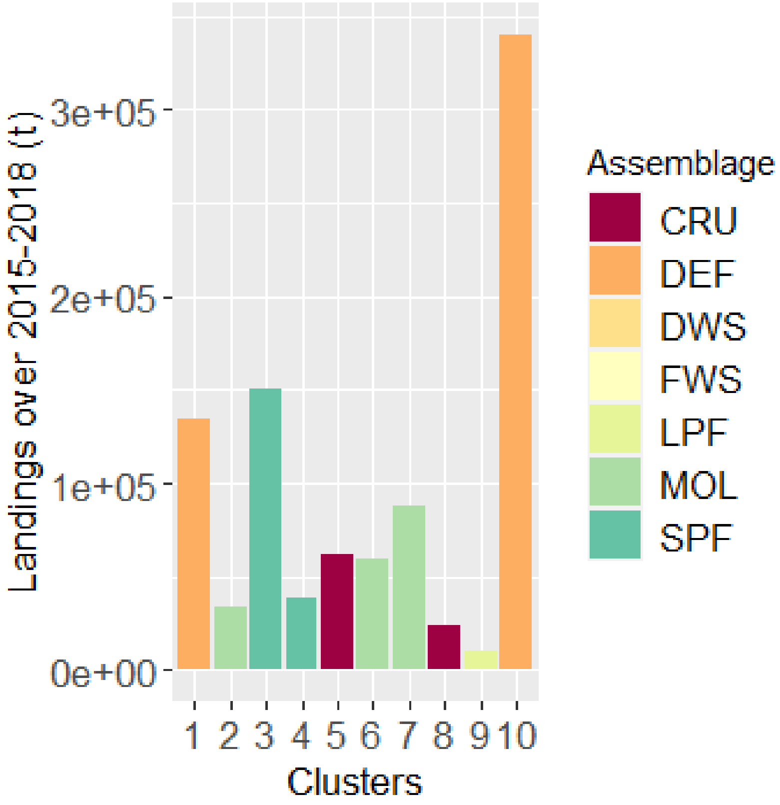
❹ Spatial simulation of climate change and fishery management scenarios

- Spatialisation of catches and predator biomass for 2090s

Ecospace= Spatial component of Ecopath

➢ *Result 1/7*: 34 fishing fleet defined for the Celtic Sea

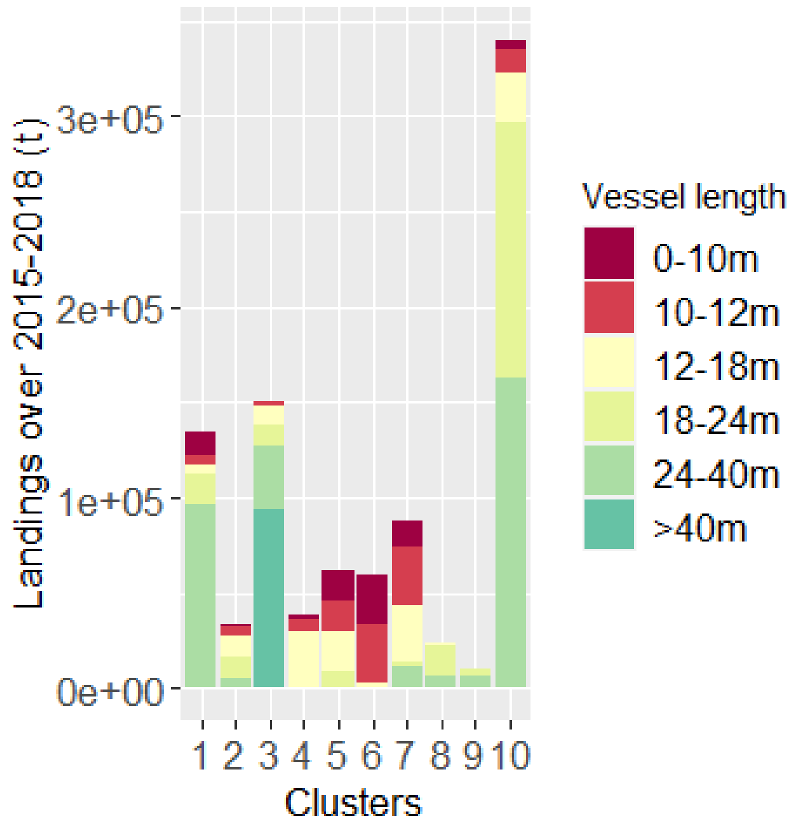
Stage	PCA and clustering	Empirical clustering	Separation by country
Number of clusters	7	10	34



- Clusters that have a main target functional group (ex: cluster 1 mainly targets hake)
- Quite structuring variables: target species assemblage and gear
- Less structuring variables: vessel size and country

➢ *Result 1/7*: 34 fishing fleet defined for the Celtic Sea

Stage	PCA and clustering	Empirical clustering	Separation by country
Number of clusters	7	10	34

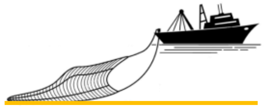
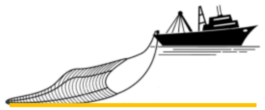
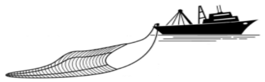
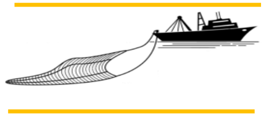


- Clusters that have a main target functional group (ex: cluster 1 mainly targets hake)
- Quite structuring variables: target species assemblage and gear
- Less structuring variables: vessel length and country

➢ *Result 2/7*: Fishing fleet impacts

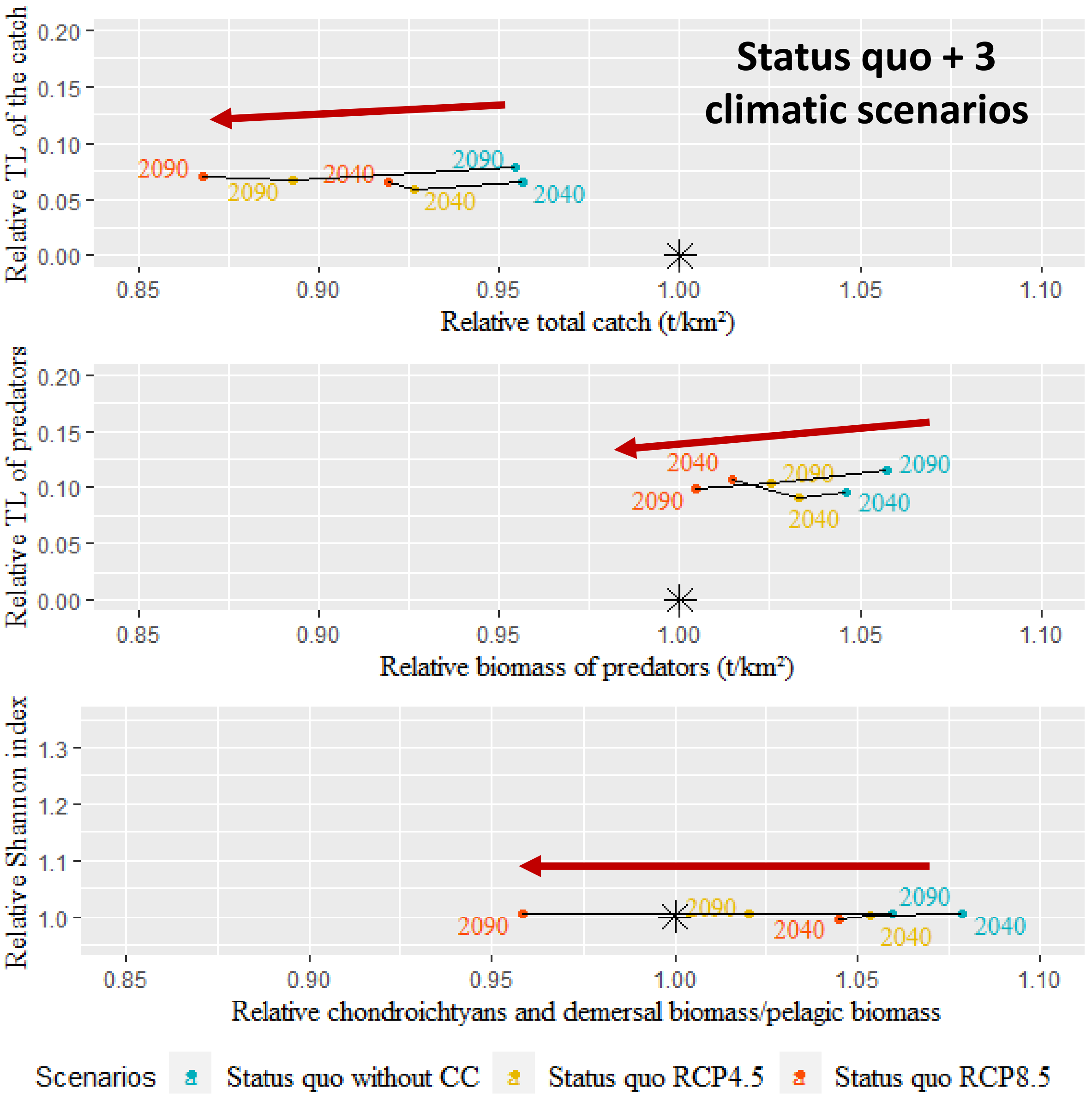
- Generally negative and direct impacts

- 5/34 fleets have high impacts on species

Fleets	Fishing mortality	Fishing losses	
FRA DEF tr	✓ cod, anglerfish, haddock	✓ megrim, cod, anglerfish	
UKM DEF tr	✓ cephalopods, plaice	✓ sole, plaice	
FRA MOL DRA	✓ Commercial bivalves		dredge
IRL SPF PTR/OTM		✓ herring	
OTH SPF OTM		✓ horse mackerel	

- Fleet interactions via the foodweb (mixed trophic impacts) -> Competition for the same species

➢ *Result 3/7*: Climate change impacts on the ecosystem



- Decrease in **total catches** (**4-8%** -> medium pelagic fish, cod, plaice, shrimps and endobenthivorous demersal fish)

- Impact on fleets targeting those species (demersal active gear fleets)

- Decrease in the **biomass of predators** (**3-5%;** plaice, cod, carnivorous demersal elasmobranch, sprat, large pelagic fish and endobenthivorous demersal fish)

= Decrease in the **biomass ratio** (3 -10%)

- No modification in the situation -> evolution of the indicators -> stabilisation effect

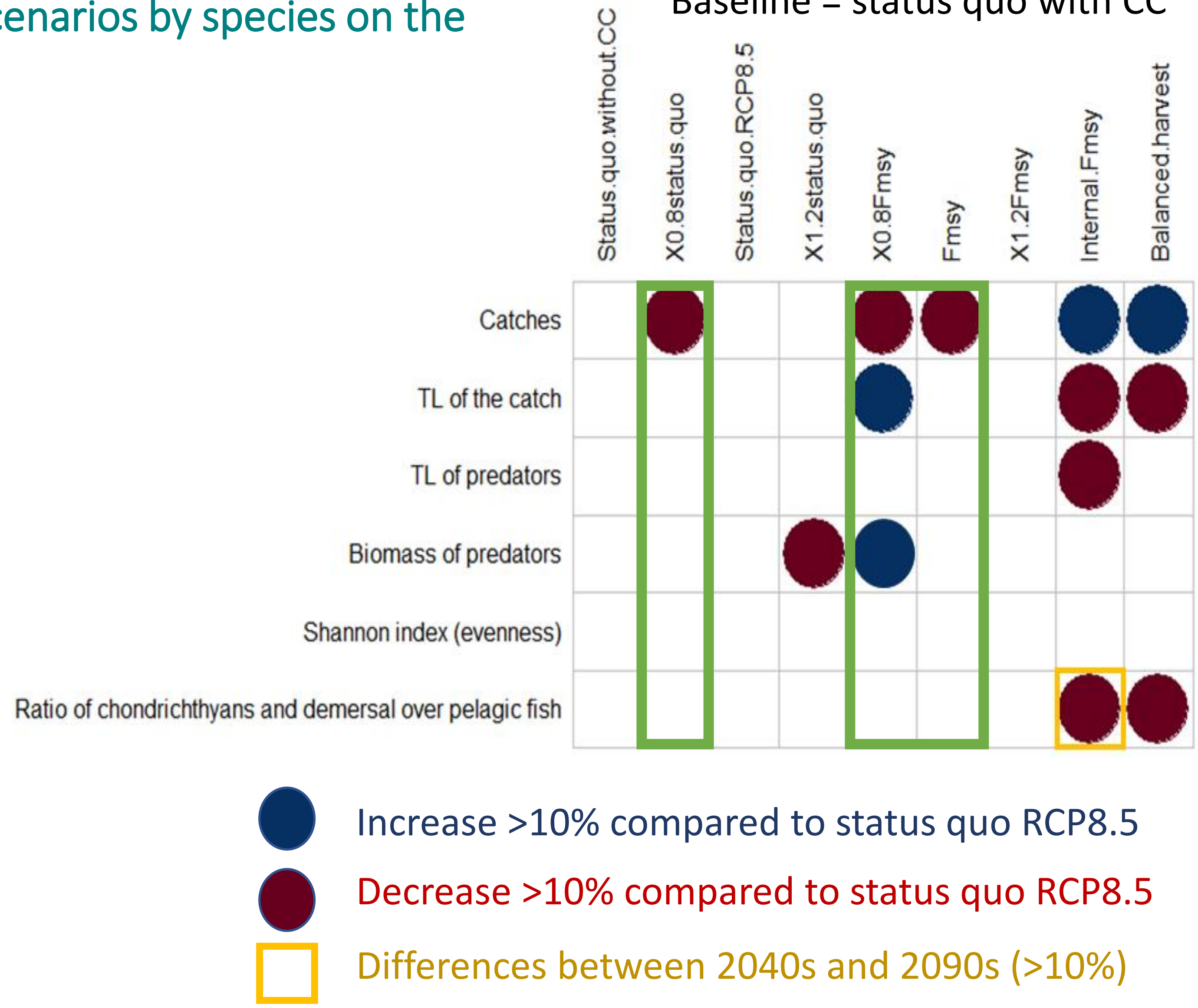
➢ *Result 4/7*: Impacts of fishing management scenarios by species on the ecosystem

- Positive impact scenarios that could compensate the loss of predator biomass

↘ 5% **predator biomass** with CC:
Fmsy = ↗ additional 2%
0.8Fmsy = ↗ additional 15%

↘ 8% **catches** with CC:
Fmsy = no additional ↘
0.8Fmsy = 10% additional ↘

Baseline = status quo with CC



➢ *Result 4/7*: Impacts of fishing management scenarios by species on the ecosystem

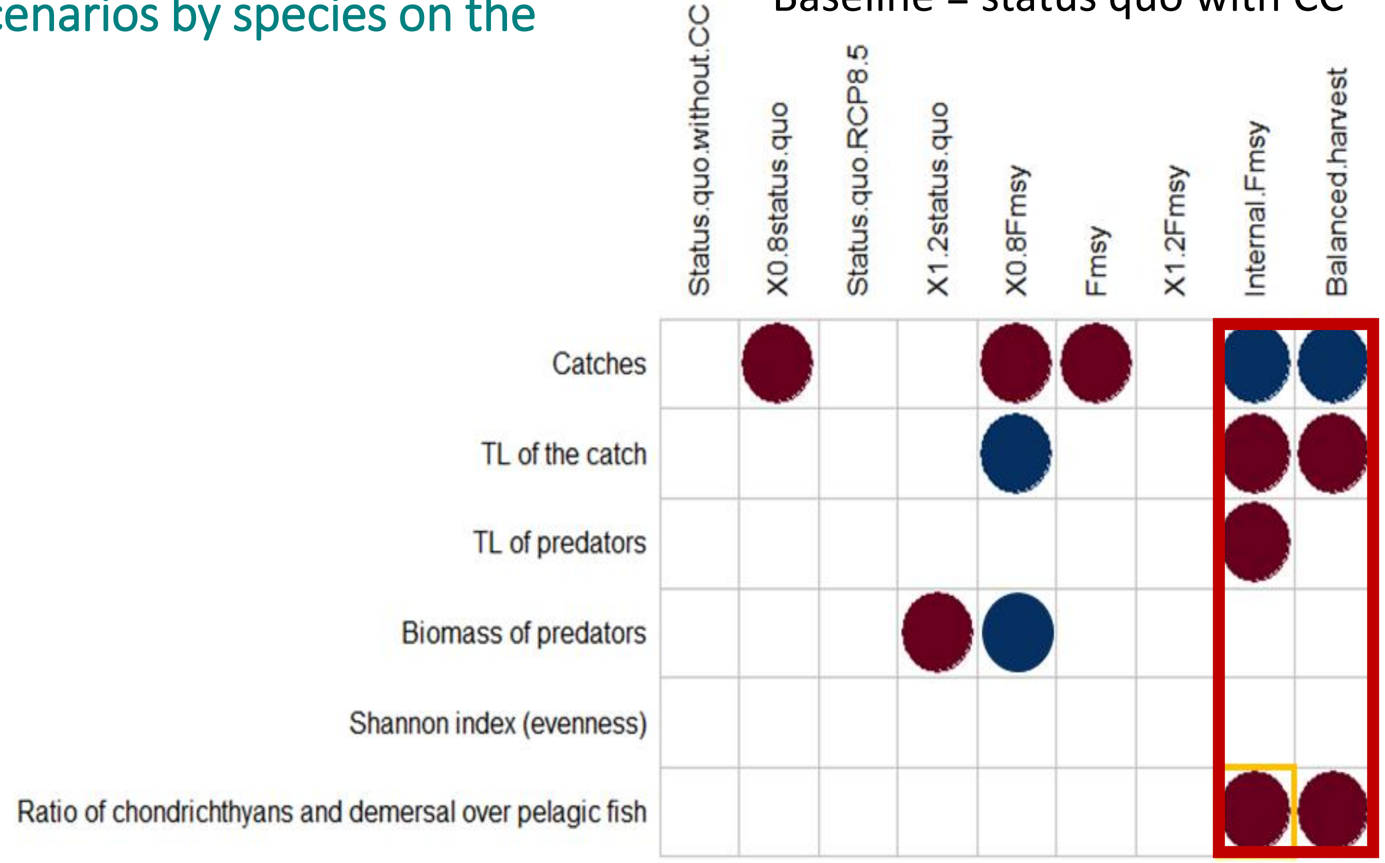
- Positive impact scenarios that could compensate the loss of predator biomass

↘ 5% **predator biomass** with CC:
Fmsy = ↗ additional 2%
0.8Fmsy = ↗ additional 15%

↘ 8% **catches** with CC:
Fmsy = no additional ↘
0.8Fmsy = 10% additional ↘

- Negative impact scenarios that could affect ecosystem health

Baseline = status quo with CC



Increase >10% compared to status quo RCP8.5

Decrease >10% compared to status quo RCP8.5

Differences between 2040s and 2090s (>10%)

➢ *Result 4/7*: Impacts of fishing management scenarios by species on the ecosystem

- Positive impact scenarios that could compensate the loss of predator biomass

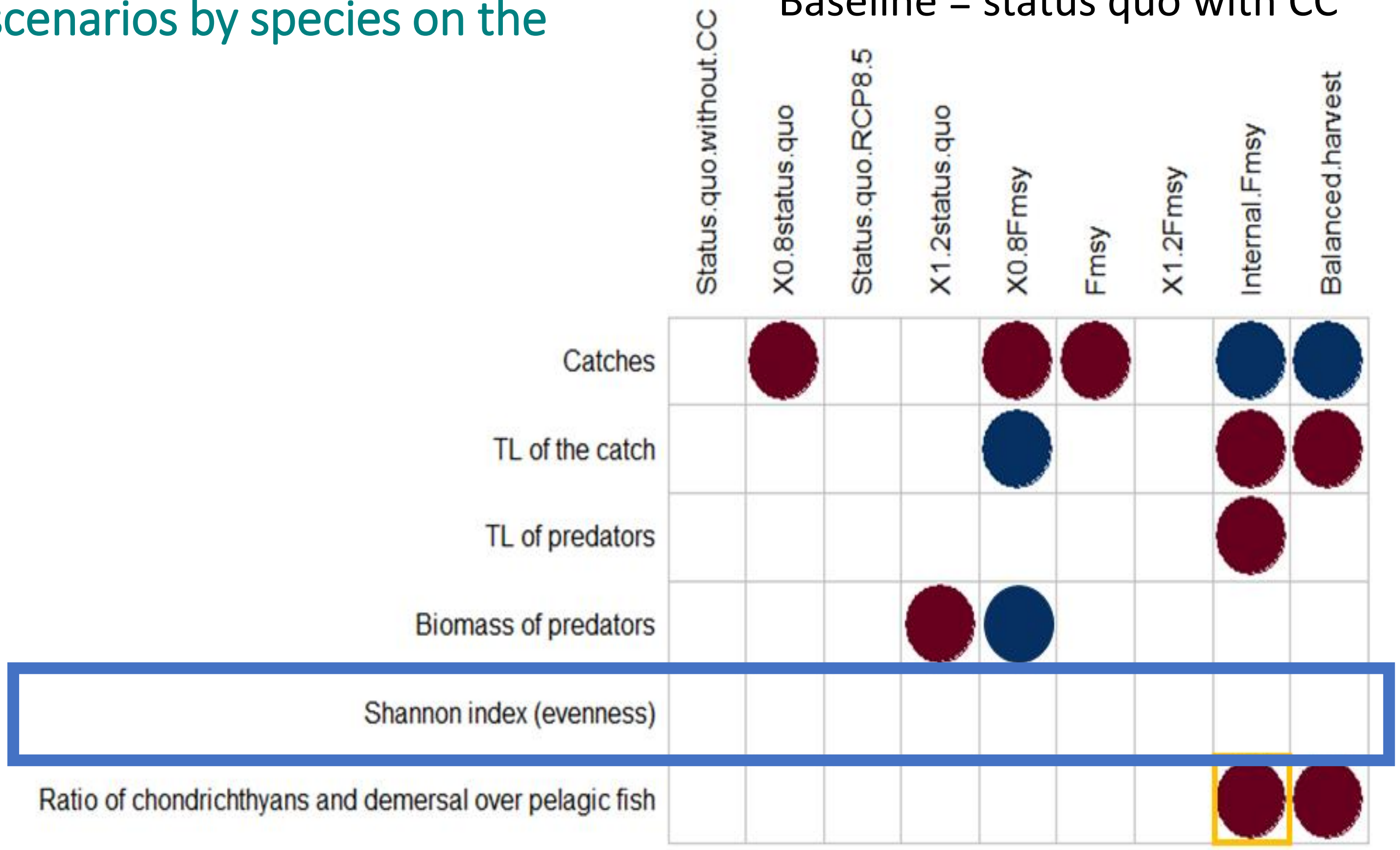
↘ 5% **predator biomass** with CC:
Fmsy = ↗ additional 2%
0.8Fmsy = ↗ additional 15%

↘ 8% **catches** with CC:
Fmsy = no additional ↘
0.8Fmsy = 10% additional ↘

- Negative impact scenarios that could affect ecosystem health

- Shannon: no sensible to fishing

Baseline = status quo with CC



Increase >10% compared to status quo RCP8.5

Decrease >10% compared to status quo RCP8.5

Differences between 2040s and 2090s (>10%)

➢ *Result 4/7*: Impacts of fishing management scenarios by species on the ecosystem

- Positive impact scenarios that could compensate the loss of predator biomass

  ↘ 5% **predator biomass** with CC:
  Fmsy = ↗ additional 2%
  0.8Fmsy = ↗ additional 15%

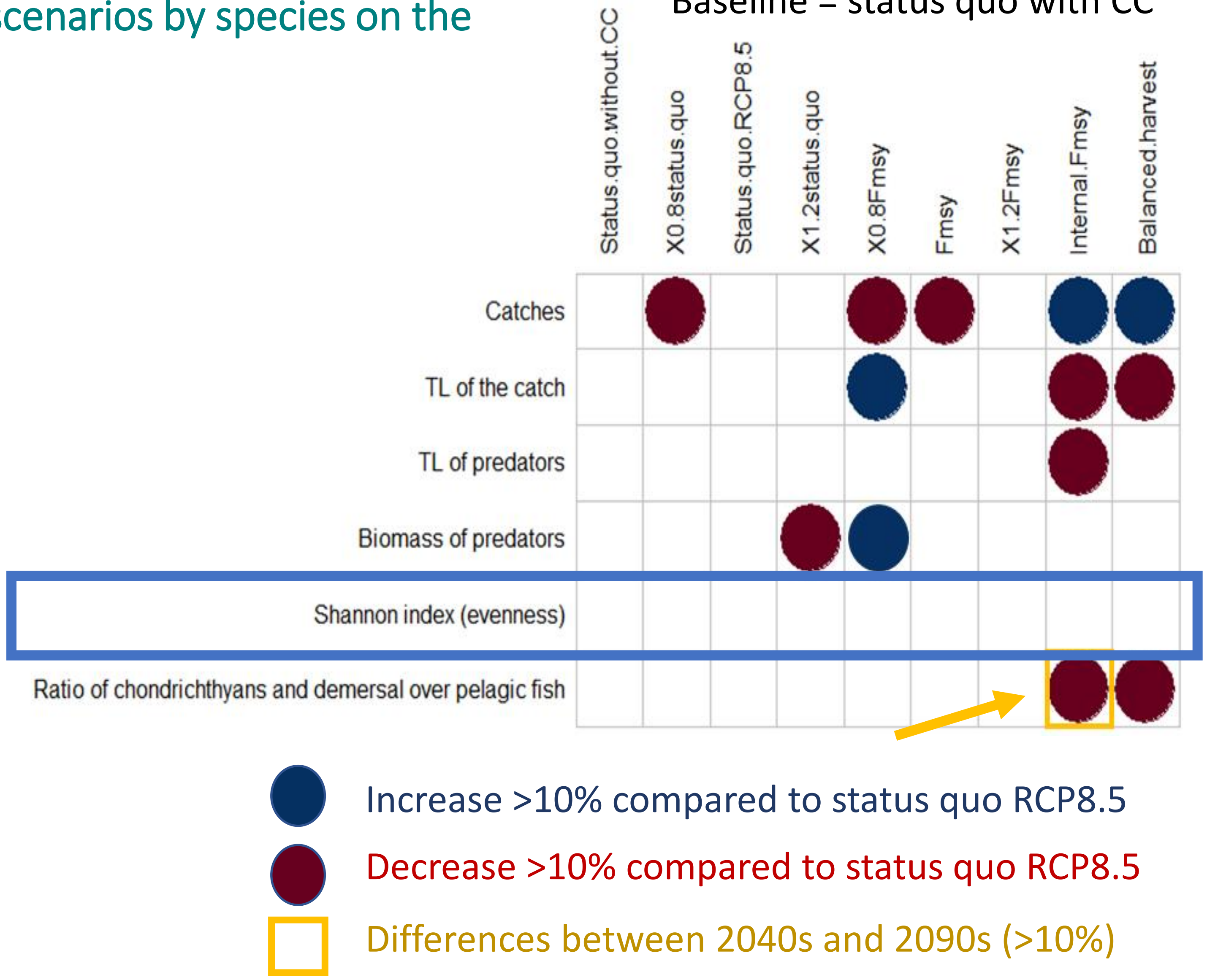
  ↘ 8% **catches** with CC:
  Fmsy = no additional ↘
  0.8Fmsy = 10% additional ↘

- Negative impact scenarios that could affect ecosystem health

- Shannon: no sensible to fishing

- Biomass ratio: high differences between 2040s and 2090s due to some species fluctuation

Baseline = status quo with CC



➢ *Result 5/7*: Impacts of fishing management scenarios by fleets on the ecosystem

Baseline = status quo with CC

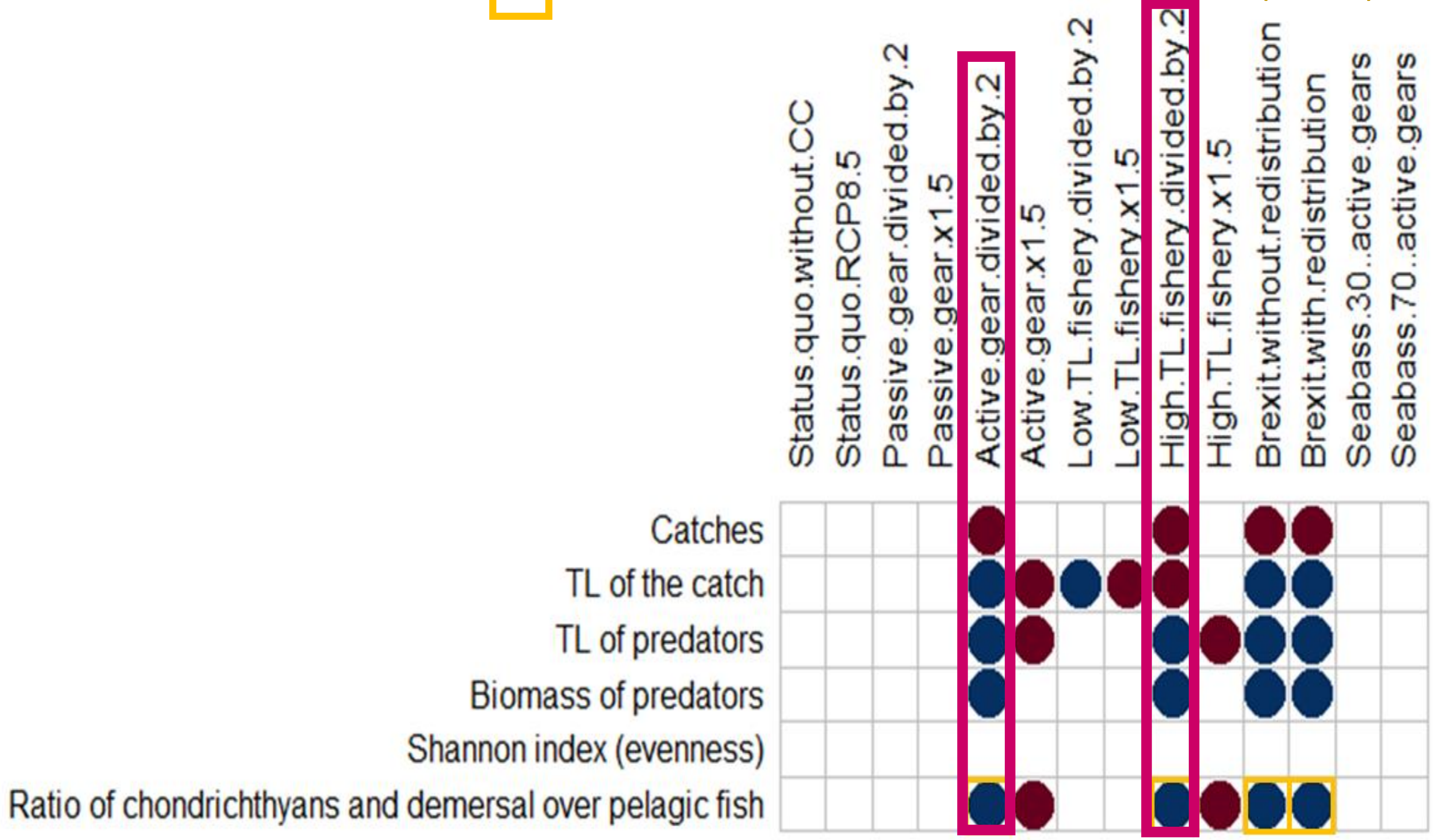
Increase >20% compared to status quo RCP8.5

Decrease >20% compared to status quo RCP8.5

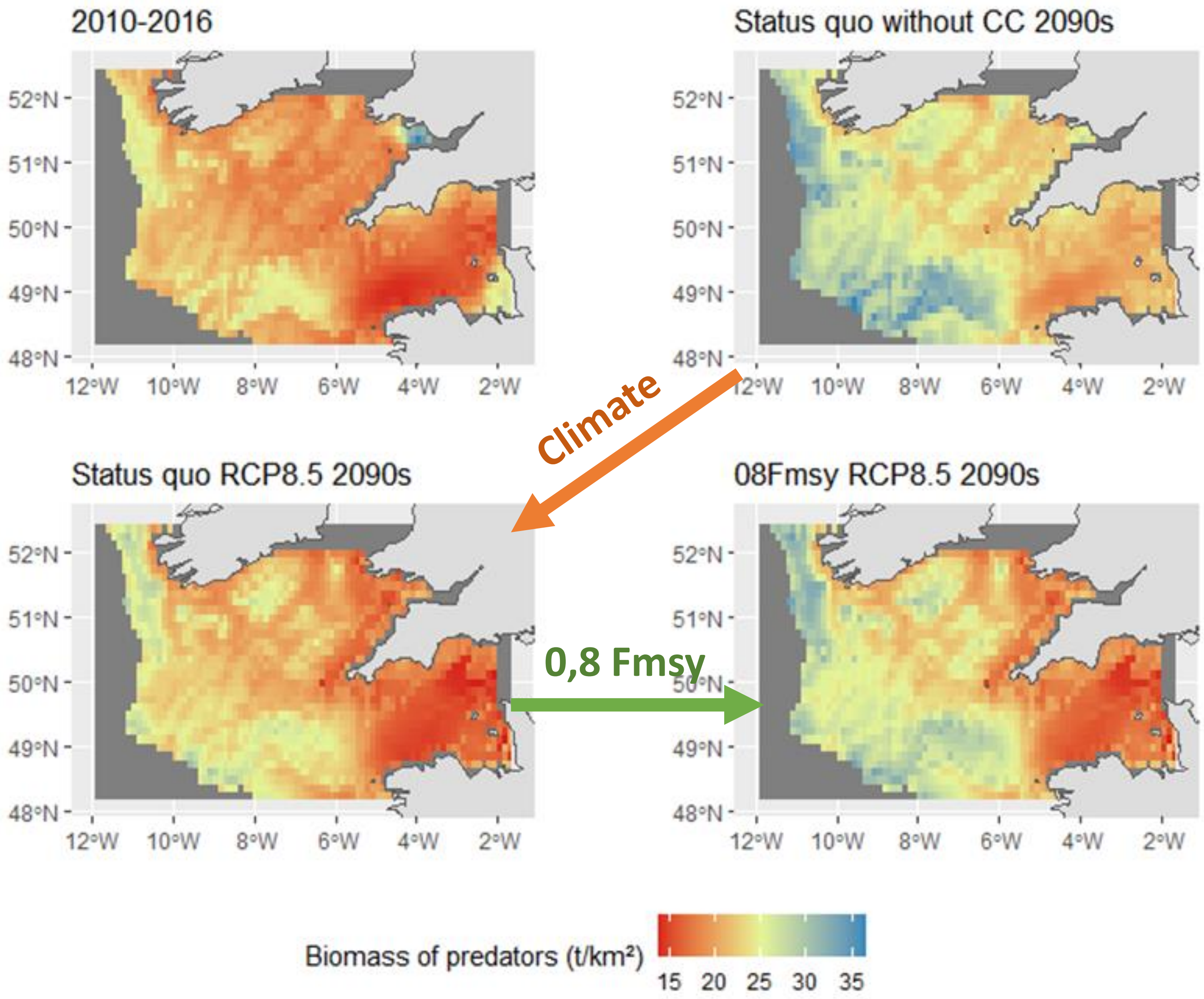
Differences between 2040s and 2090s (>10%)

- Levers to improve ecosystem health and biomass of predators:

  High TL fisheries
  Active gear fisheries



➢ *Result 6/7*: Spatial changes in predator biomass due to CC and fishing

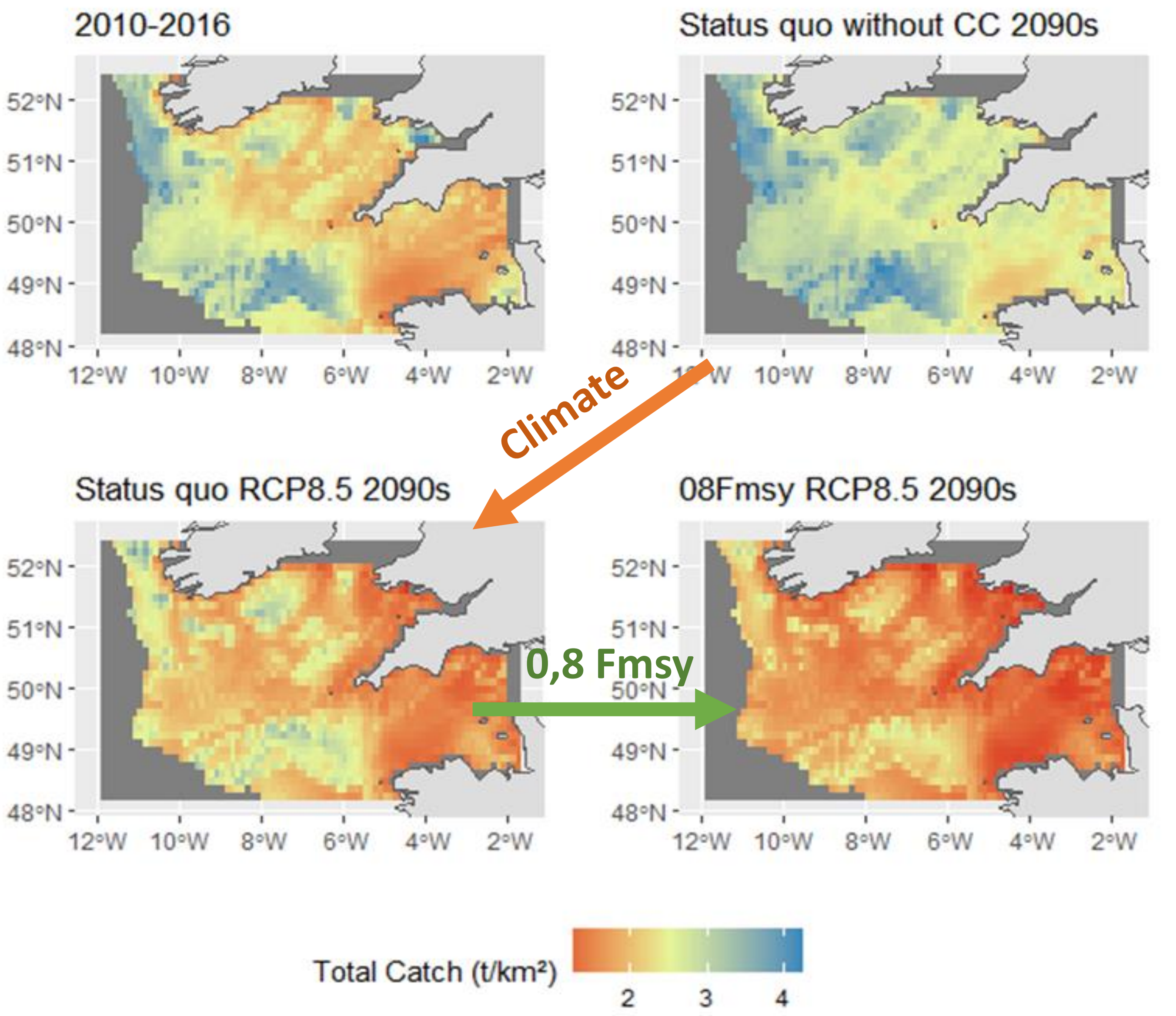


- Some areas contain high predator biomass
- CC effect: overall decrease (heterogeneous)
- 0.8Fmsy target effect: no compensation in every Celtic Sea area

1) More important increase in temperature near the coast -> ↘ some species near the coast (ex: epibenthivorous demersals)

2) ↗ some species near the slope (ex: ↗ boarfish due to food availability)

➢ *Result 7/7*: Spatial changes in catches due to CC and fishing



- Some areas contain high catches: pattern seems to follow predator biomass patterns
- CC effect: overall decrease (heterogeneous)
- 0.8Fmsy target effect: more important decrease due to loss of fishing pressure

Discussion 1/3: Celtic Sea fleets definition

New approach:

- Advantages: fleets with similar landings profile to take into account mixed fisheries' issues
- Disadvantage: clusters with high catches, data not enough disaggregated (lack of data) -> same vessel can be in two different fleets

Other works exist (Mateo et al. 2017; Moore et al. 2019) :

- Data coverage (restricted to one country, type of fishery …)
- Explains differences between fleets of the different studies

Discussion 2/3: Temporal simulations

Scenario definition

- Unrealistic scenarios and scenarios' limits

Fmsy of stock assessment

- Fmsy only for assessed species
- Other management rules for other species quite exploited

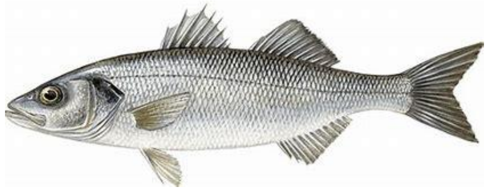
Scenarios' families

- By species: hypothesis of complete adaptation of fleets
- By fleet: fishing mortality time series do not allow for complete exploration

➢ Discussion 2/3: Temporal simulations

Seabass scenarios

= Variation of the proportion of active gears targeting seabass
1) 30% active gears
2) 70% active gears



- Ecosystem indicators -> no differences between scenarios

37

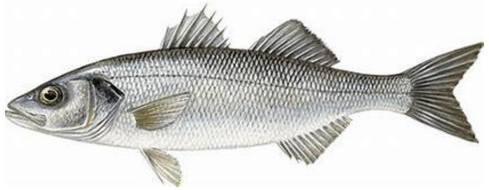
➢ Discussion 2/3: Temporal simulations

Seabass scenarios

= Variation of the proportion of active gears targeting seabass

1) 30% active gears

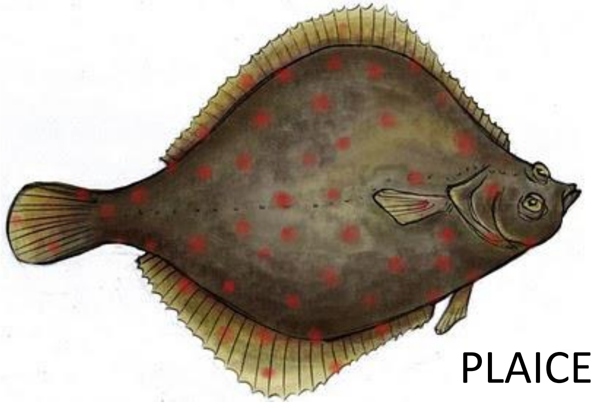
2) 70% active gears



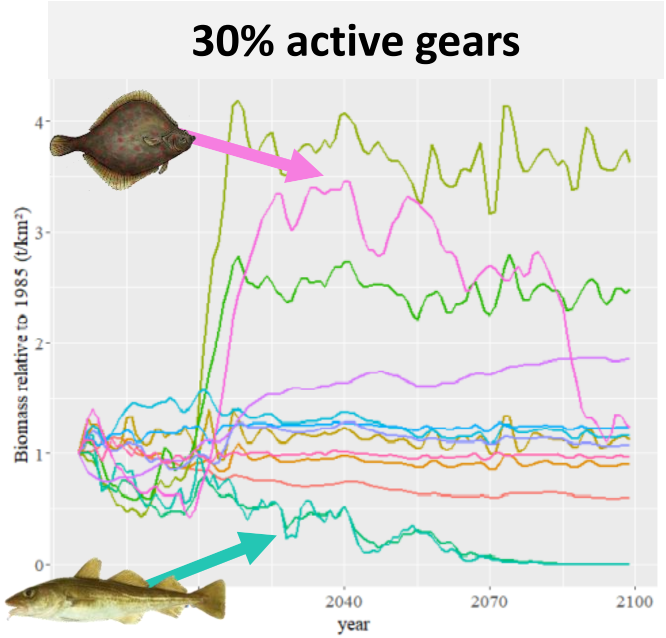
- Ecosystem indicators -> no differences between scenarios

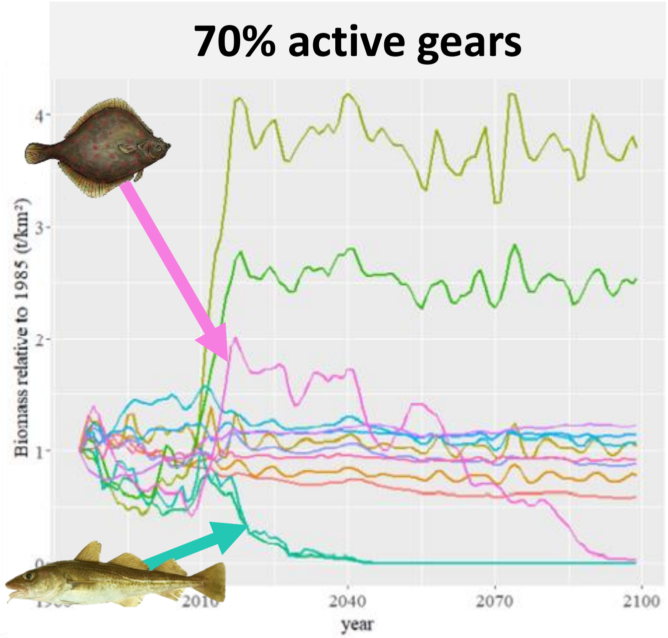
- Biomass and catches -> Huge impact on some stocks (e.g., plaice and cod)

COD



PLAICE





Discussion 2/3: Temporal simulations

Critical analysis of results

« Balanced Harvest » scenario

- Huge impact

- Quite discussed in the litterature:

Allow to keep size-structure and relative composition in the ecosystem (Garcia et al. 2012; Law et al. 2015)

Human will never fish as much zooplankton + lack of evidences of efficiency (Froese et al, 2016)

Discussion 2/3: Temporal simulations

Critical analysis of results

« Balanced Harvest » scenario

- Huge impact

- Quite discussed in the litterature:

Allow to keep size-structure and relative composition in the ecosystem (Garcia et al. 2012; Law et al. 2015)
Human will never fish as much zooplankton + lack of evidences of efficiency (Froese et al, 2016)

« Internal Fmsy » scenario

- Huge impact due to high Fmsy’s values given by the EwE routine -> structural issues

- To explore

➢ Discussion 2/3: Temporal simulations

Critical analysis of results

More impacting fleets: Active gears AND High trophic level fisheries

- Logical: high discards and catches in the model
- **Active gears** in the litterature: high impact because of **discards** (Davies et al. 2009, Zeller et al. 2018)
  impact on the **seabed** (Chuenpagdee et al. 2003, Collie et al. 2017)

- **Fishing predators in the litterature**: impact on stability (Allesia & Tang 2012; Nye et al. 2013)
  -> consistent

➢ Discussion 2/3: Temporal simulations

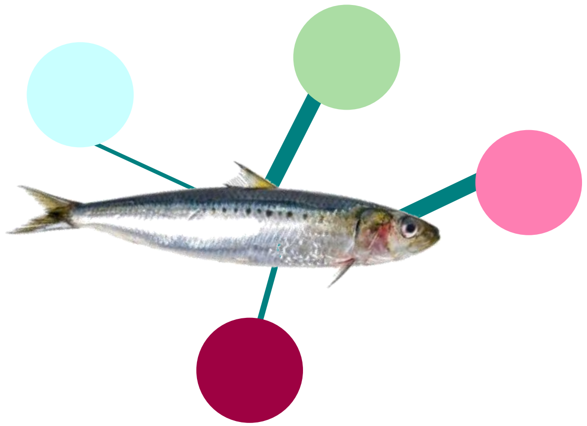
Critical analysis of results

RESULTS: ↘F high trophic levels = high ↘ catches

-> Not too much impact on catches + lever to improve ecosystem health = ↗ low trophic levels fisheries???

- « balanced harvest » not in accordance

- In the literature: ↗ fishing on small pelagics is not a good idea



Numerous connexions via the food web (e.g. Sardine)
-> stability (Smith et al 2011; Merillet et al. 2020)

Species depends on it (Pikitch *et al*. 2014; Wiley *et al*. 2013) -> seabirds

To see this effect -> redefinition of "predators" (limit ~ 3.6)

Discussion 2/3: Temporal simulations

Elected indicators

Indicators on predators are cited in other works:

- the European **Marine Strategy Framework Directive** (MSFD; 2008/56/EC)
- Indicators selected by **IndiSeas working group** (Shin & Shannon 2010, Coll et al. 2016)

Other indicators should be discussed:

- biomass ratio ->
  DISADVANTAGE: Difficulties to interprete

- Shannon ->
  DISADVANTAGE: not sensible to fishing

Discussion 3/3: Spatial simulations

Realism of effort distribution in Ecospace

Effort is not well distributed -> catches

Due to 2 modelling issues:

1) **Ecospace distribution of effort** does not take into account some parameters however important -> parameterization of Ecospace or implementation of spatialized effort maps (Walters 1999; Romagnoni et al. 2015)

2) **Habitat model** are sometimes lacking or are less performing (Hernvann et al. 2020)

➢ CONCLUSION

Study which allow:

- Assessing mixed fisheries' impacts and climate change on the ecosystem and on fleets

- Testing various temporal and spatial scenarios -> identifying some adaptation's scenarios to climate change

- Reflection on a potential fleet-based management (no management by a change in mesh size)

- Revealing structural issues in the model (e.g. Fmsy's routine ….) and possible improvements (e.g., effort time series for fleets …)

Thank you for your attention!

Mikaëla POTIER

25/11/2021
Amédée
Encadrants: Didier GASCUEL, Marianne ROBERT et Marie SAVINA-ROLLAND