Assessing the viability of a socio-ecosystem subject to fisheries-predator conflicts: a bio-economic modelling approach

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et al. (**Félix Massiot-Granier, Paul Tixier**, H. Poupon, B. Le Gallic, S. Metz, C. Péron, N. Gasco, C. Guinet)

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25 January, 2023 – 3 days MESSH (Mathematics for bio-Economics and Sustainability of fiSHeries), Sète

Presentation outline

- General context
- Case study
- Bio-economic model
- Results
- Perspectives

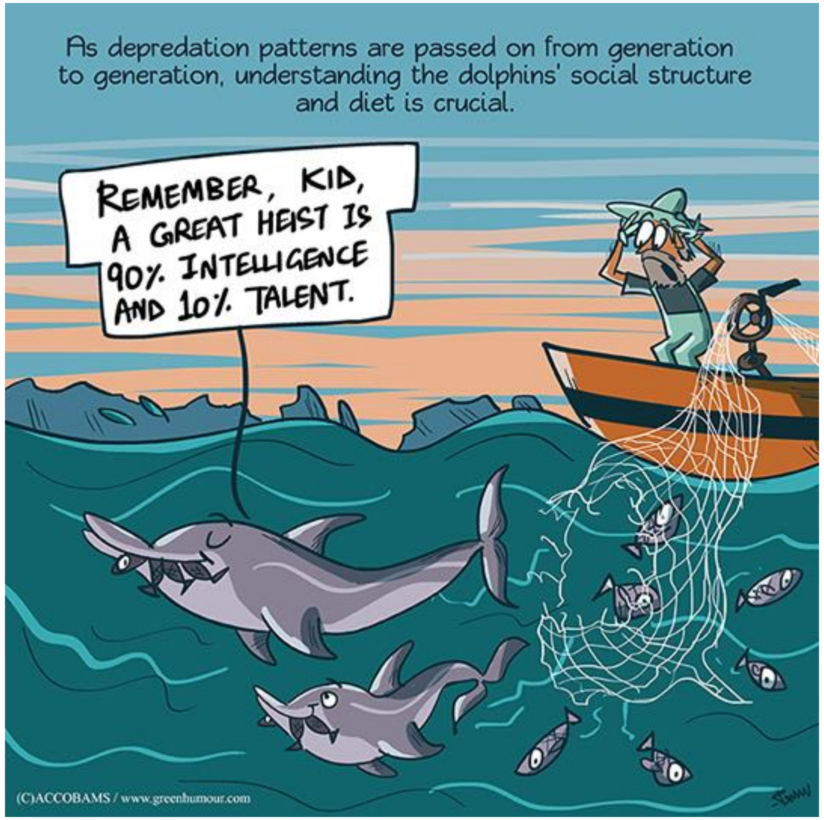
General context

Depredation

Conflicts between human activities and marine biodiversity have intensified

Depredation (marine predators – *e.g. cetaceans, pinnipeds, sharks, squids, birds* – feeding on fishing catch)

threatens both the socio-economic viability of fisheries and the conservation of species (target fish, but also depredator species)



Depredation

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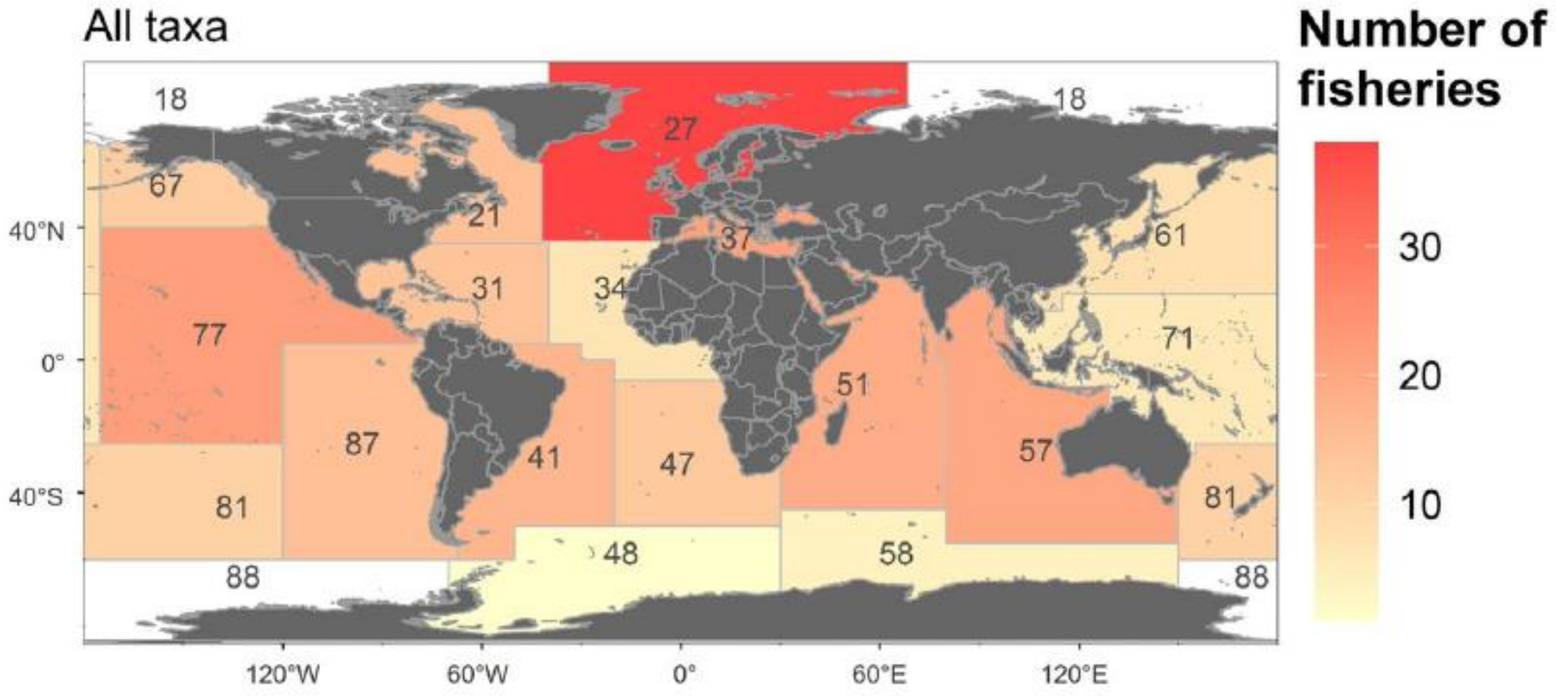

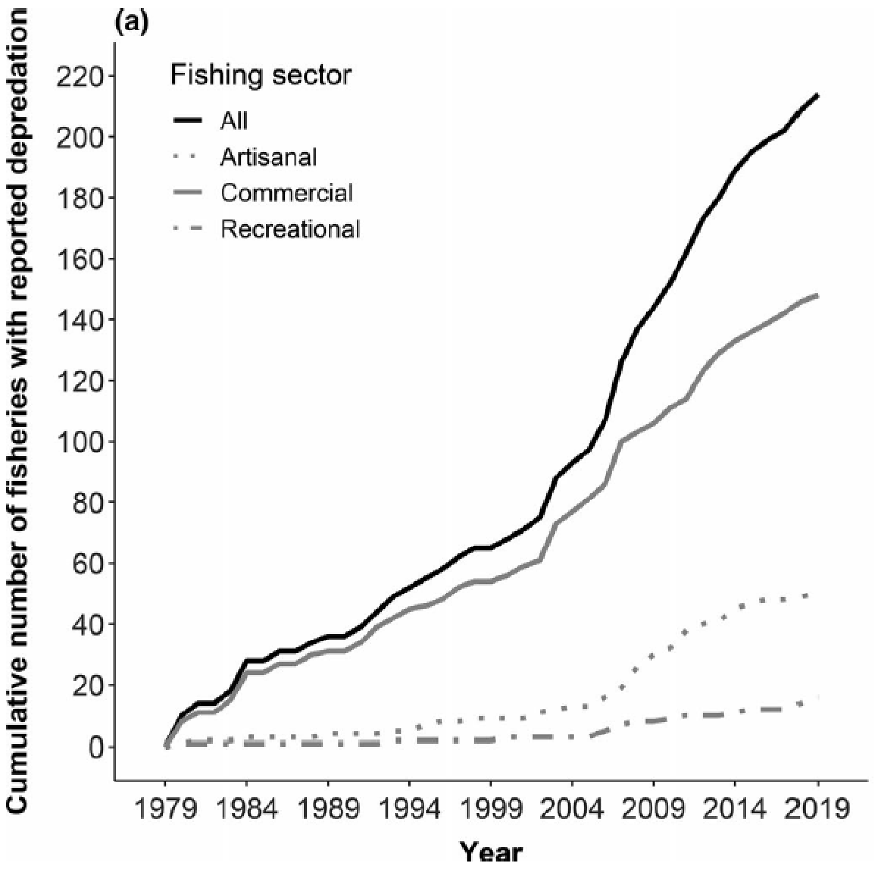

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. (2021). When large marine predators feed on fisheries catches: global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53

Case study

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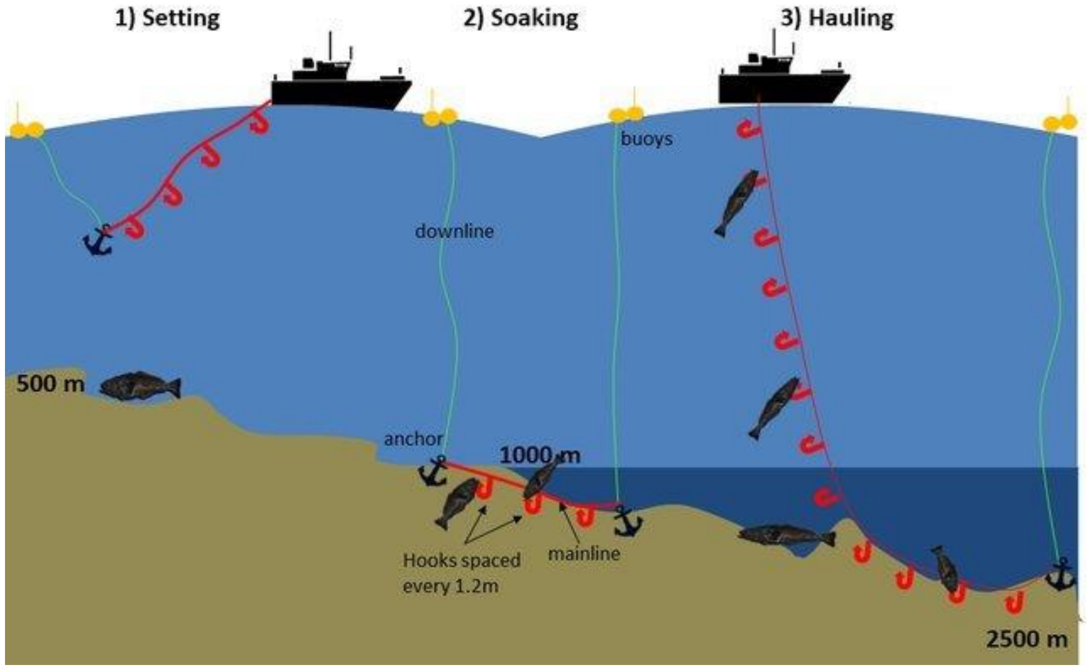
French Patagonian toothfish fisheries

French toothfish fishery

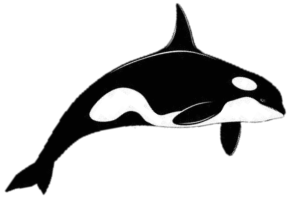
The French demersal longline fishery targeting Patagonian toothfish (*Dissostichus eleginoides*) around the Crozet and Kerguelen Islands



https://orcadepred.cnrs.fr/activite-de-peche/

Issue

Fishery with one of the highest **depredation rates** in the world, mainly due to interactions with killer whales and sperm whales (~580 tons / ~12millions € annually)



Orcinus orca

Physeter macrocephalus

Implementation of **mitigation measures** (operational, technological approaches)
=> more or less effective
=> socio-economic costs (e.g. investment in mitigation devices, increased fuel consumption, workload and time)

depredation rate =
biomass of depredated fish / total biomass of fish caught

Issue

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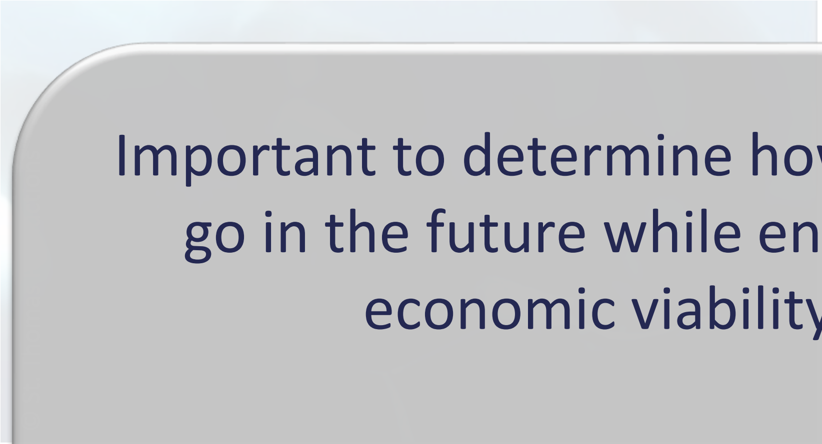
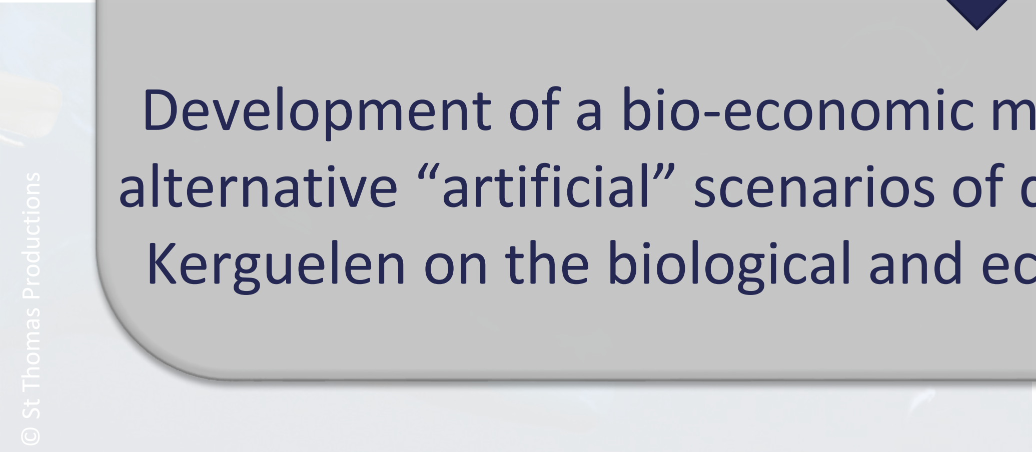
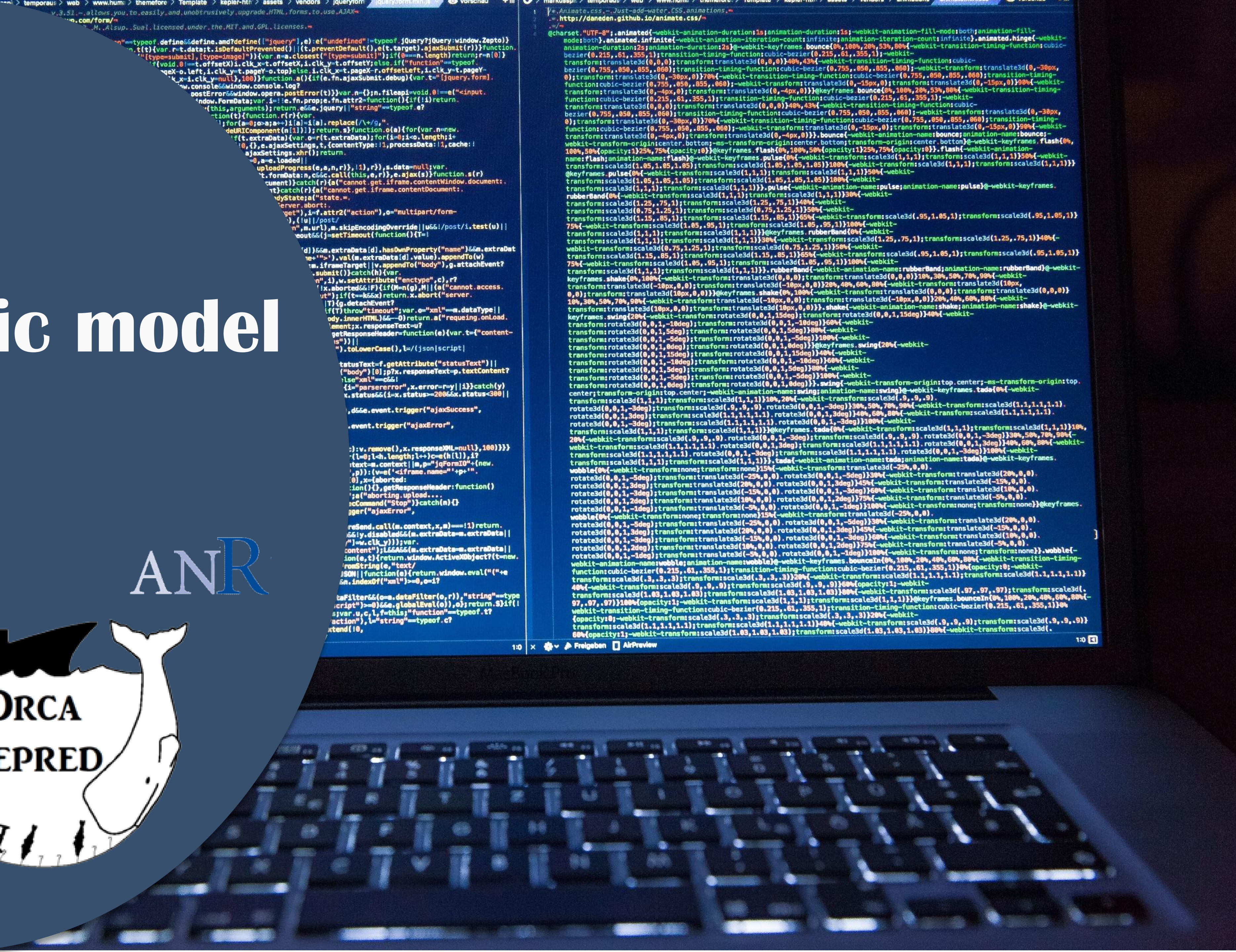




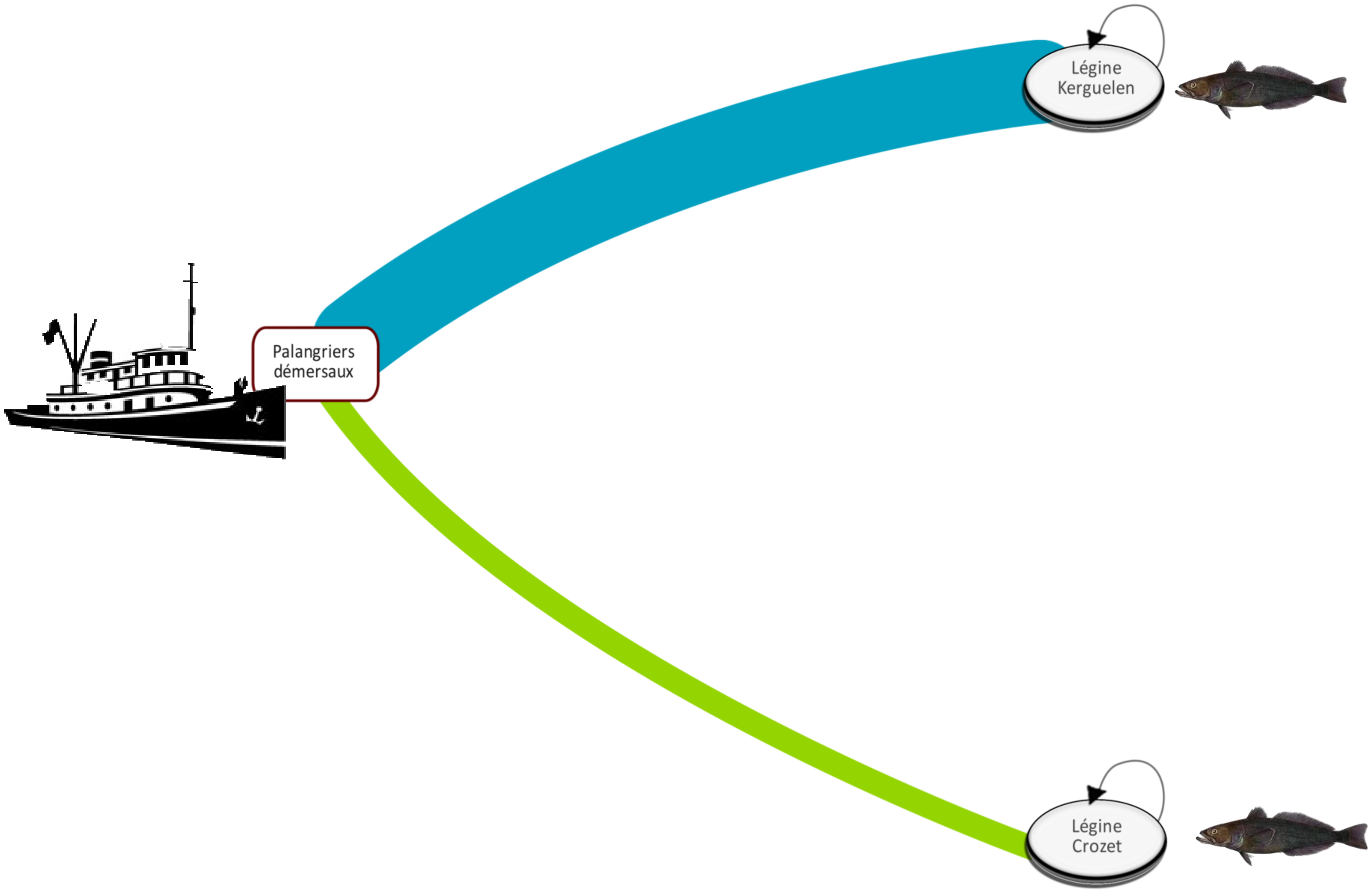
Important to determine how far the level of depredation can go in the future while ensuring the biological and socio-economic viability of the socio-ecosystem

Development of a bio-economic model to analyze the impacts of alternative "artificial" scenarios of depredation rates in Crozet and Kerguelen on the biological and economic viability of the system

Bio-economic model

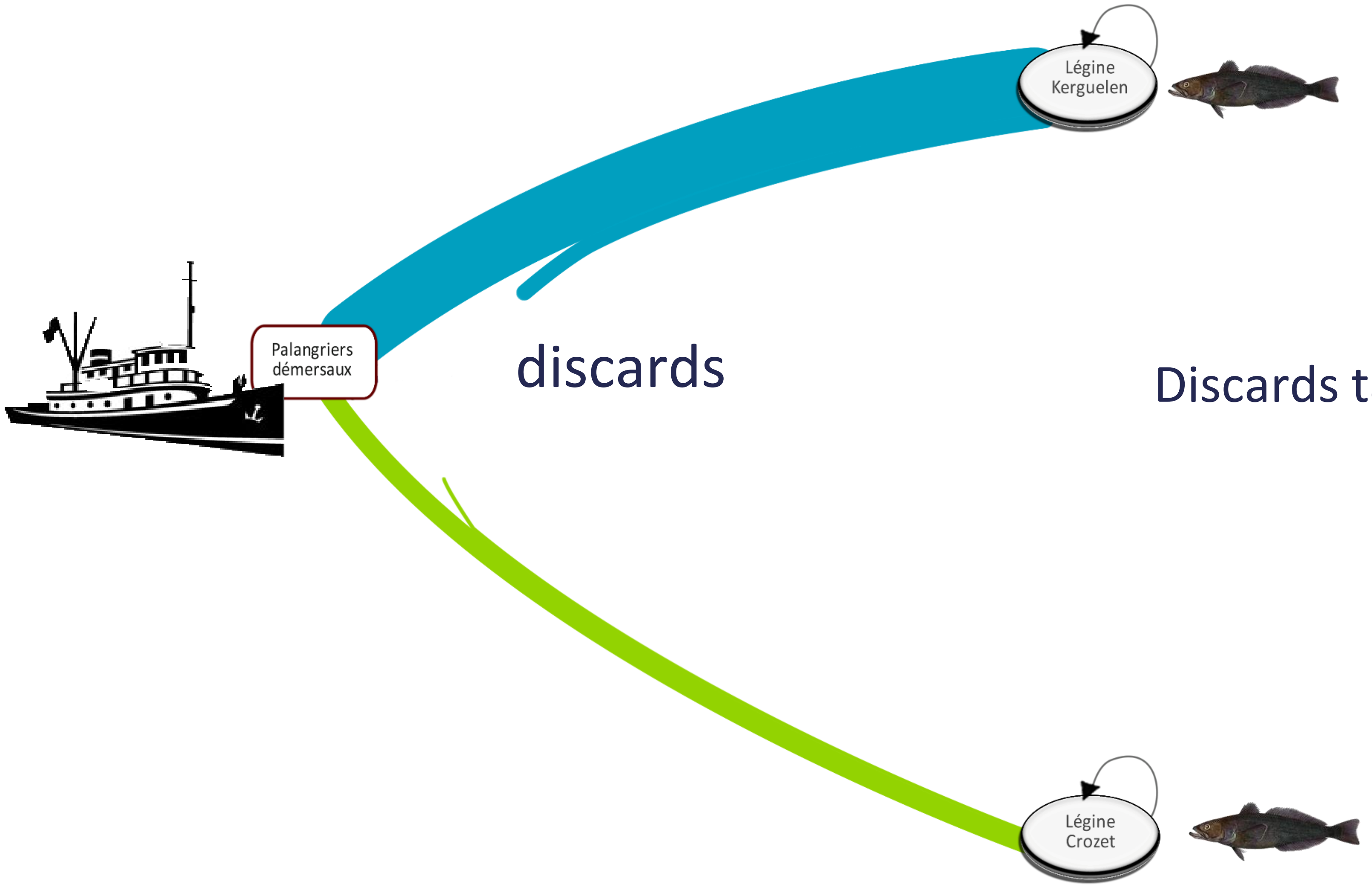


Integrated model



Arrow width: proportional to the quantity caught
MNHN PECHEKER data; Landings and discards / 2017-2018 season

Integrated model



Discards taken into account

Arrow width: proportional landed or discarded quantities
MNHN PECHEKER data; Landings and discards / 2017-2018 season

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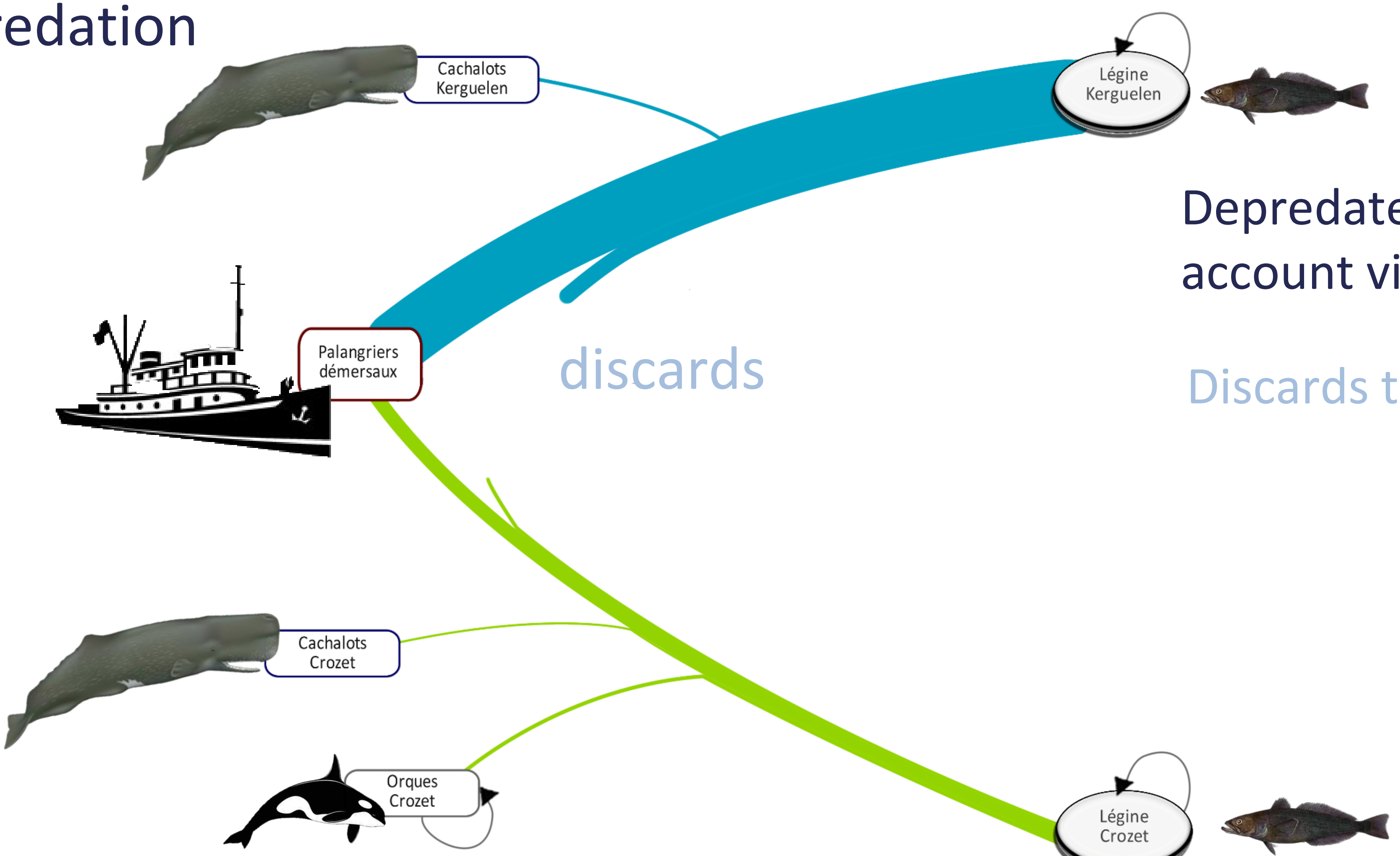
Integrated model

depredation



Depredated quantities taken into account via depredation rates

Discards taken into account

Arrow width: proportional landed, discarded, or depredated quantities
MNHN PECHEKER data; Landings and discards / 2017-2018 season

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Integrated model

Explicit dynamics of the 2 toothfish stocks
(age-structured population model based on the CASAL stock assessment used by MNHN)

Annual dynamics; structured in 35 age classes

Beverton-holt stock-recruitment relationship

$$Recruits_{area}(t+1) = R0_{area} YCS_{area}(t+1) \frac{SSB_{area}(t)}{B0_{area}} \frac{1}{1 - \frac{5h-1}{4h}\left(1 - \frac{SSB_{area}(t)}{B0_{area}}\right)}$$

Arrow width: proportional to the quantity caught
MNHN PECHEKER data; Landings and discards / 2017-2018 season

Integrated model

Explicit dynamics of the 2 toothfish stocks

(age-structured population model based on the CASAL stock assessment used by MNHN)

Annual dynamics; structured in 35 age classes

Beverton-holt stock-recruitment relationship

Environmental variability in toothfish recruitment

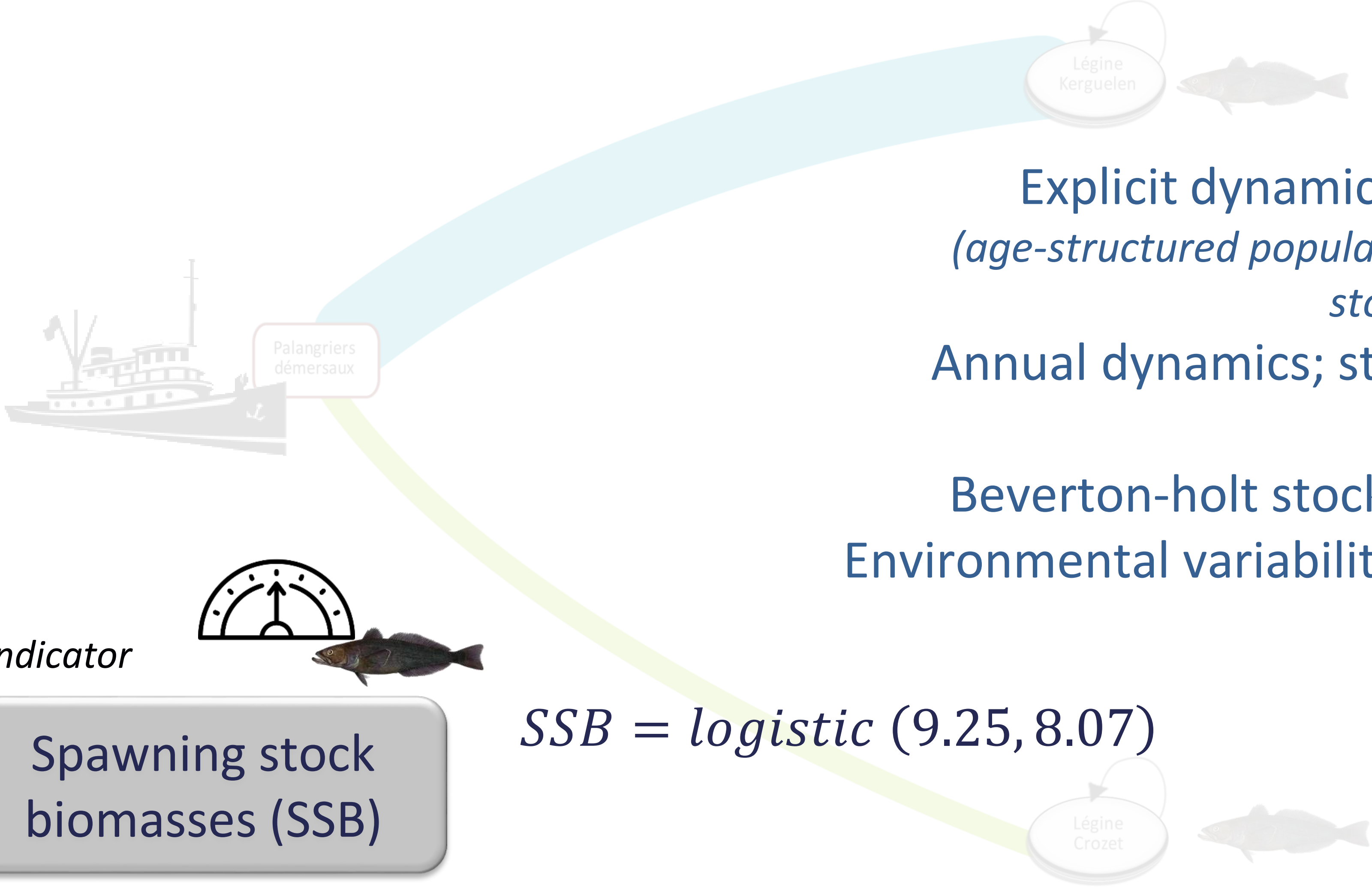
Variations on YCS (Yearly Class Strength multiplier)

$\Rightarrow$ same for Crozet and Kerguelen, but independent each year

$\Rightarrow$ normal law - for the moment - based on historical values

(work in progress to be refined)

$$Recruits_{area}(t+1) = R0_{area}\boldsymbol{YCS}_{area}(t+1)\,\frac{SSB_{area}(t)}{B0_{area}}\,\frac{1}{1-\frac{5h-1}{4h}\left(1-\frac{SSB_{area}(t)}{B0_{area}}\right)}$$



Explicit dynamics of the 2 toothfish stocks

(age-structured population model based on the CASAL stock assessment used by MNHN)

Annual dynamics; structured in 35 age classes

Beverton-holt stock-recruitment relationship

Environmental variability in toothfish recruitment

indicator

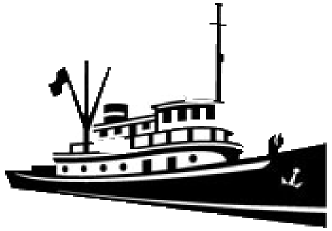
Spawning stock biomasses (SSB)

$$SSB = logistic\ (9.25, 8.07)$$

Arrow width: proportional to the quantity caught
MNHN PECHEKER data; Landings and discards / 2017-2018 season

Integrated model

Dynamic of the fishery:
7 "average" vessels



Effort unit: **number of longlines** *(average number of hooks per longline and catchabilities per hook; different for Crozet and Kerguelen)*

Fishing season from September to August with longlines set per month in Crozet and Kerguelen *(taking into account a maximum number of longlines per month)*
And stop in one area when annual quota of this area is reached

Total effort ($E_{crozet} + E_{Kerguelen}$)
in terms of number of longlines set

Integrated model

Catches and landings per longline per area for year *t*

$$C_{longline,area}(t) = q_{area} Nb\_hook_{area} B_{area}(\mathrm{t})$$

catchability per hook, per area

average hook number in a longline, per area

Patagonian toothfish biomass, per area

Catches

-

Depredated quantities

-

Discards

$$L_{longline,area}(t) = C_{longline,area}(t)(1 - \boldsymbol{Dep\_rate_{area}(t)}) * (1 - Discard\_rate_{area})$$

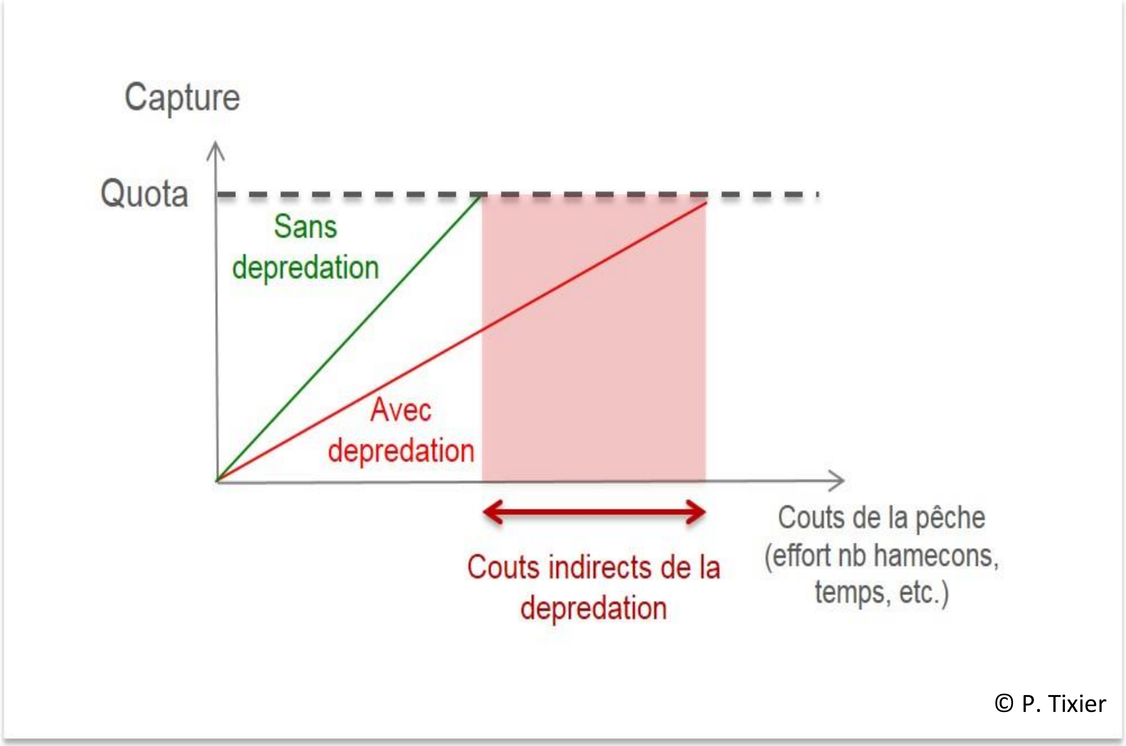
What we will change "artificially" in our scenarios

When $\sum_{longline} L_{longline,area}(t) \geq TAC_{area}(t)$ => stop fishing

With a maximal number of longlines per month, per area, based on historical data

Landed quantities to compare with quotas

Integrated model



Proxy for depredation costs

(in the absence of economic data)

=> estimation of the annual number of additional longlines due to depredation

We calculate landings (per longline) if there was no depredation, and when the sum of these landings exceeds the quota –per area - , we consider all subsequent longlines to be "supplementary " longlines

"supplementary " longlines per area

sup

Integrated model

Incomes

From landings : taking into account the processing coefficient for the calculation of revenues

$$Incomes(t) = \underbrace{\sum_{area} L_{area}(t)}_{\text{total annual landings in weight}} * Transf_{coef} * price(t)$$

transformation coefficient

Patagonian toothfish first sale price (€/kg)

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Results

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SQ scenario (constant TAC, constant depredation rates)

TRAJECTORIES WITH STATUS QUO SCENARIO:

Scenarios with constant depredation rates (same as current situation)

=> Depredation rates at Crozet = 0,378 / depredation rate at Kerguelen = 0,054

Tixier et al., 2020. *Rev. Fish. Biol. Fisheries*

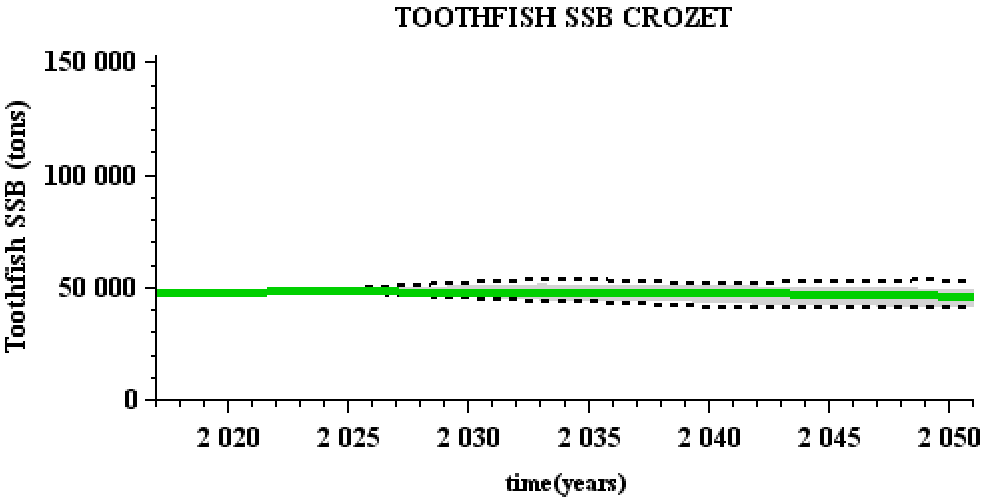
Constant TAC (800 tons at Crozet and 5200 tons at Kerguelen)

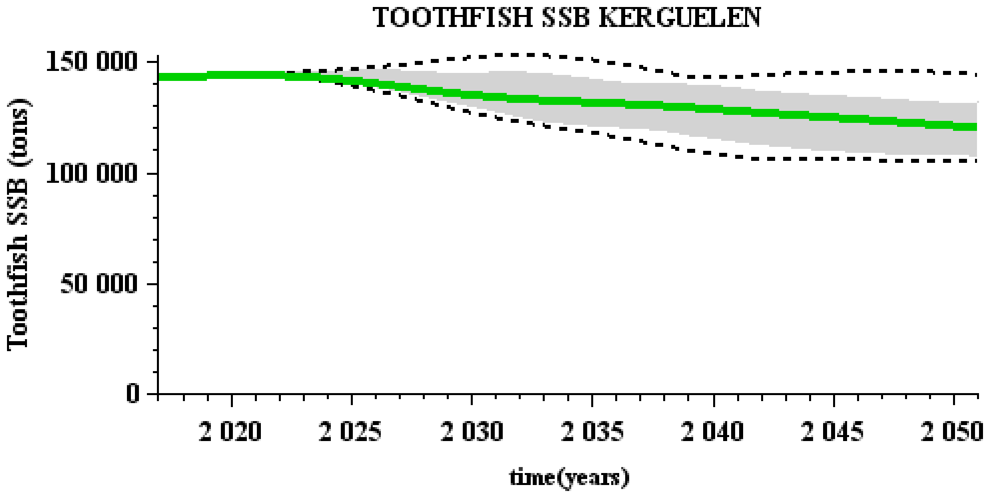
Simulation over 35 years

Number of simulations (environmental variability) =100

SQ scenario (constant TAC, constant depredation rates)

Depredation rates: 0,378 at Crozet and 0,054 at Kerguelen





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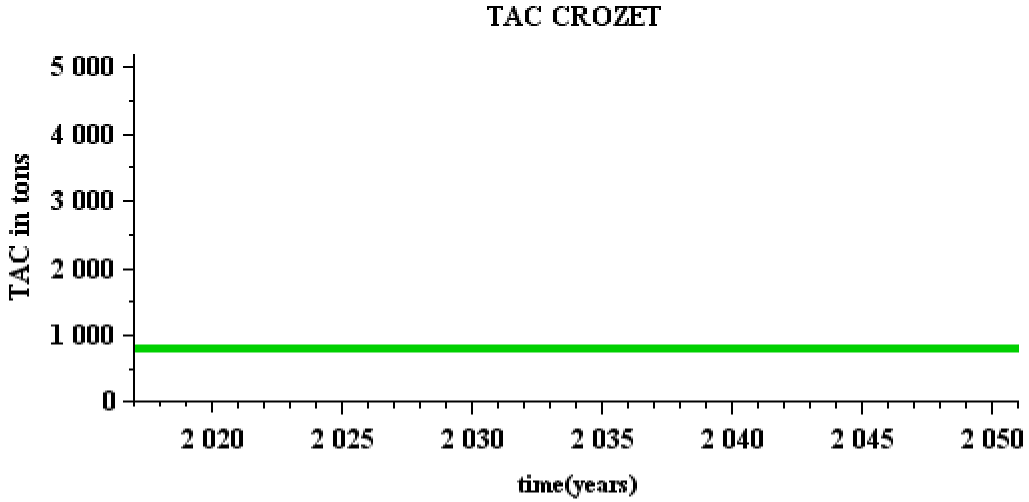

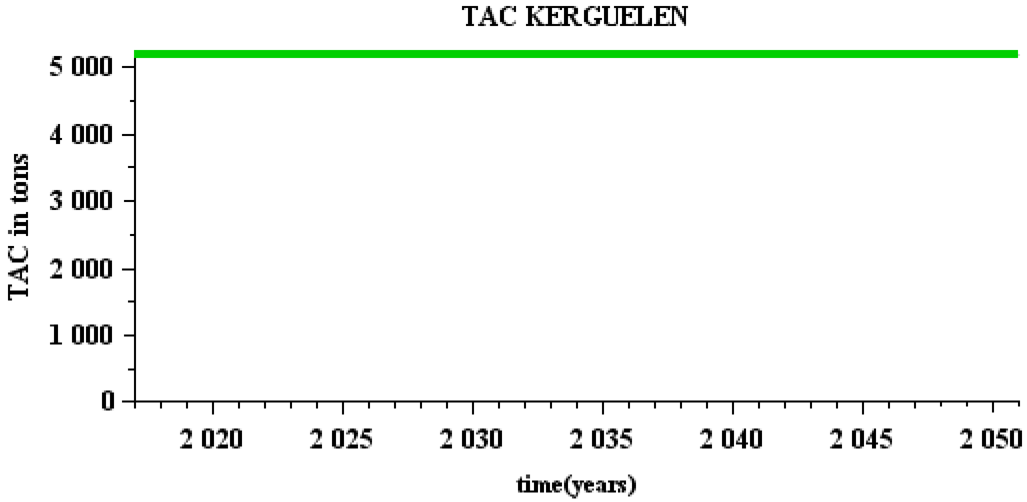

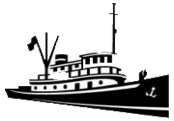

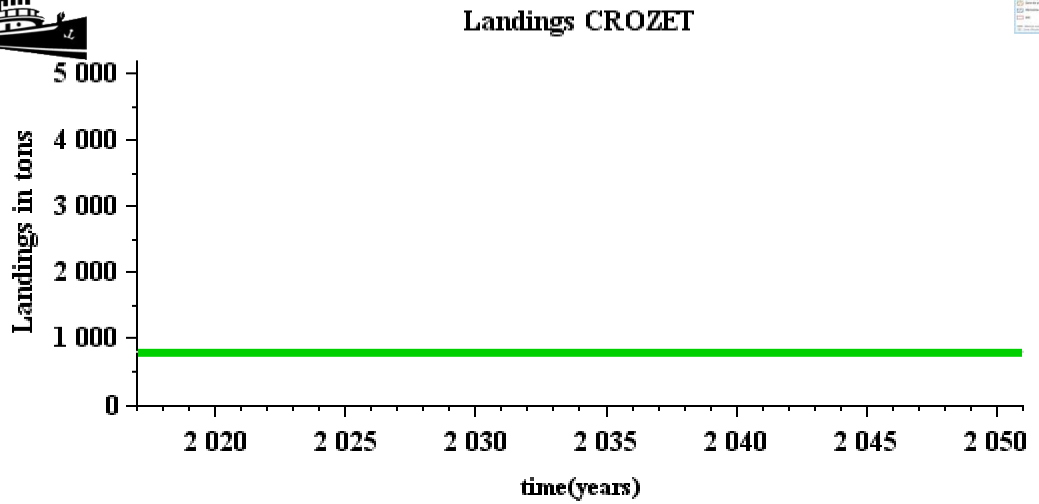

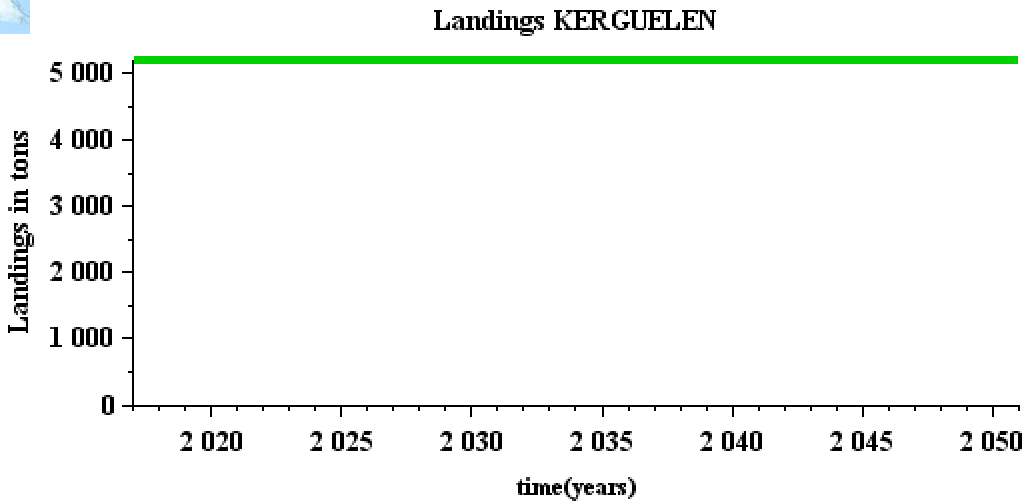

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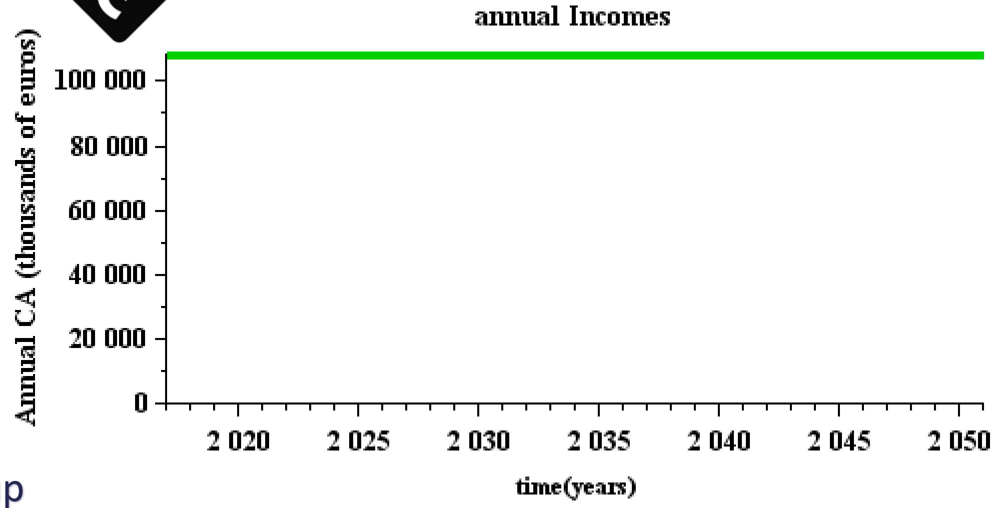

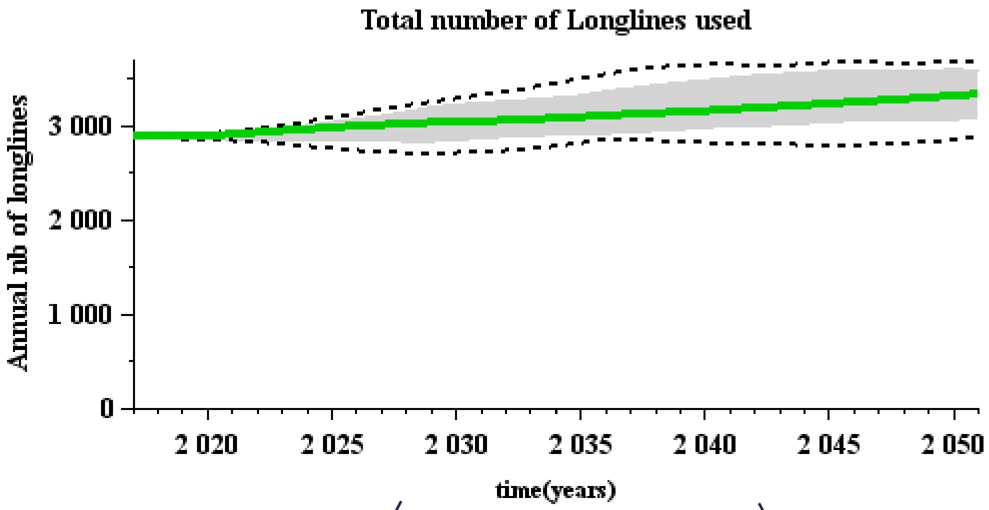

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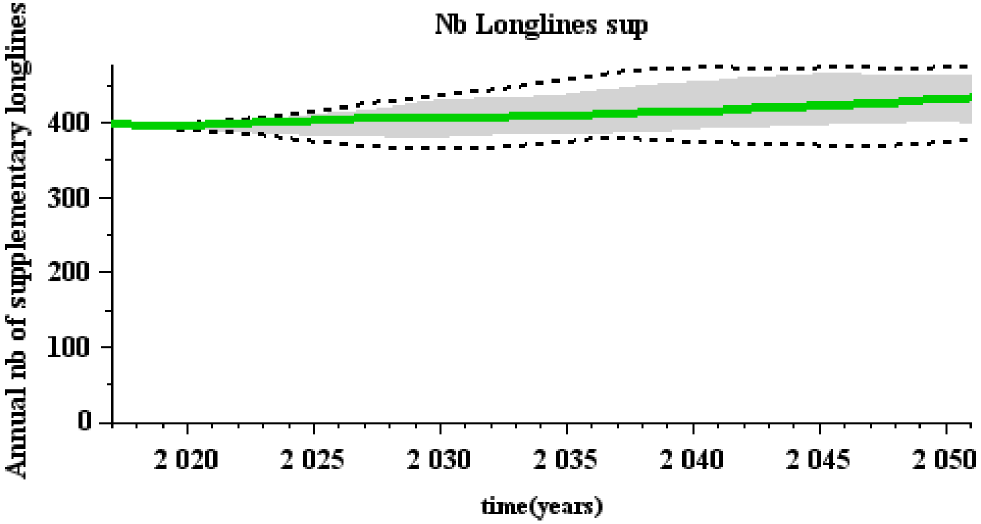
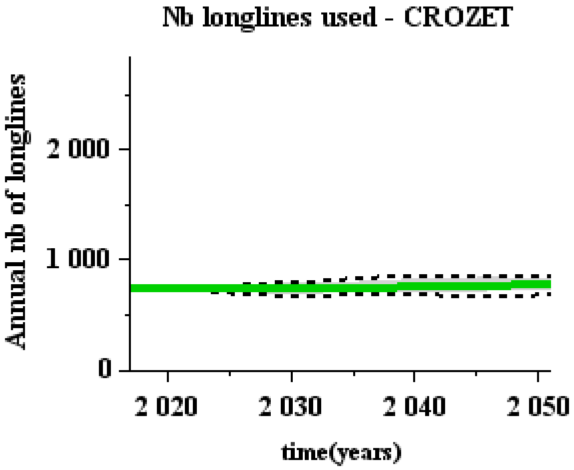
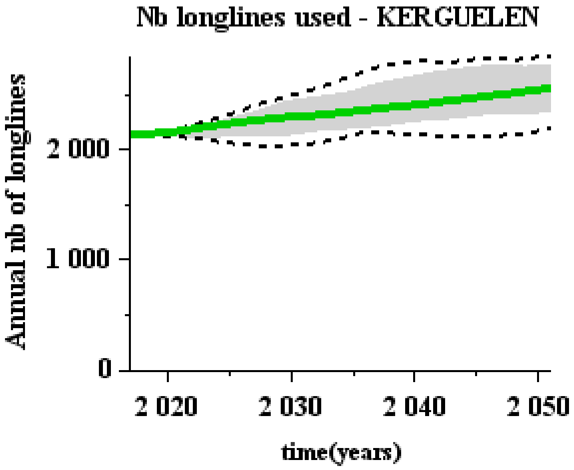






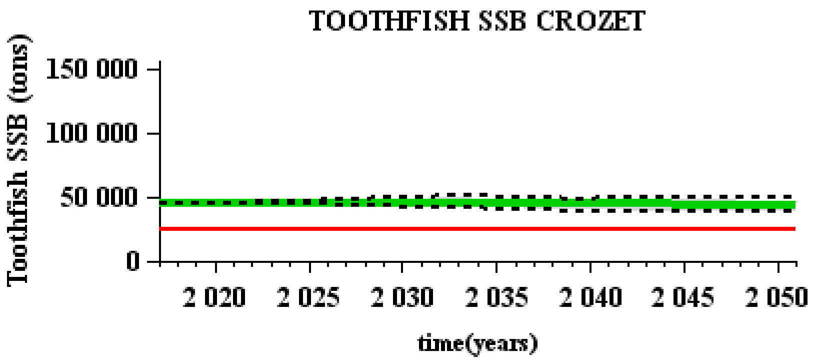
Ecoviability approach - application

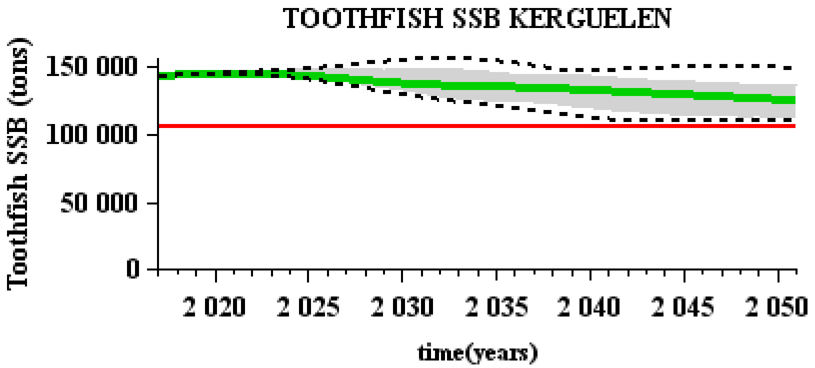
Ecoviability constraints:

Minimum acceptable threshold of toothfish spawning biomass (SSB)

45% virgin SSB for the 35 years of the simulation

SQ scenario





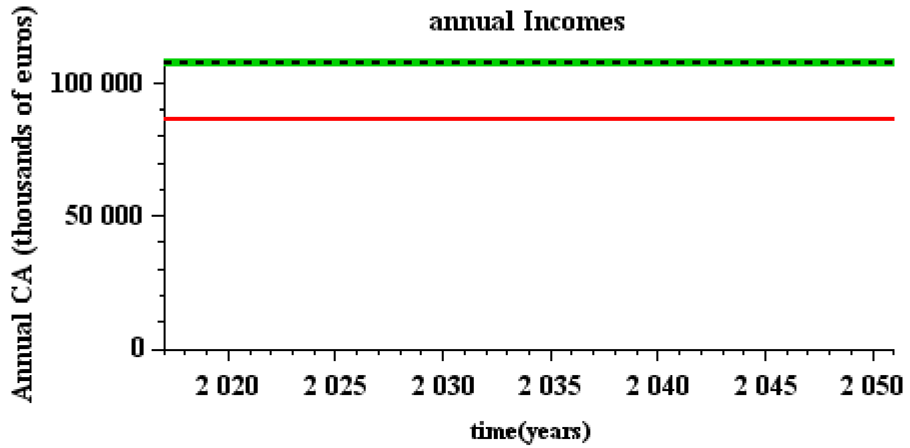
*virgin SSB = unfished stock SSB

Ecoviability constraints:

SQ scenario

Minimum acceptable threshold of toothfish SSB
(here 45% of virgin SSB)

Minimum acceptable income threshold
(here 80% of reference income)



Ecoviability constraints:

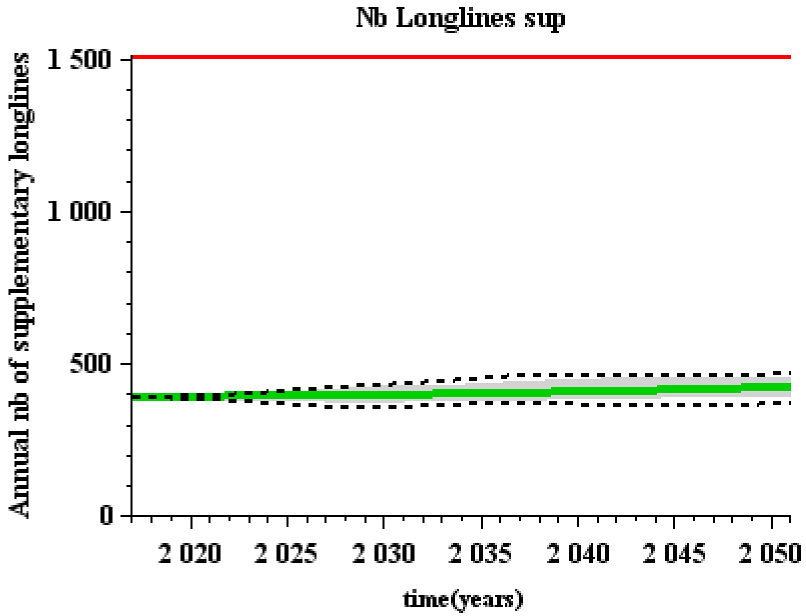
SQ scenario

sup

Minimum acceptable threshold of toothfish SSB
(here 45% of virgin SSB)

Minimum acceptable income threshold
(here 80% of reference income)

Maximum acceptable number of additional longlines - related to depredation
(here 1508 additional longlines)

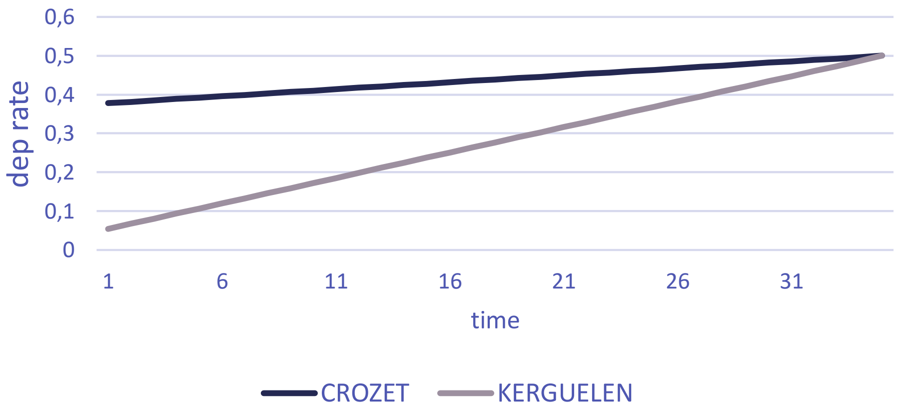


proxy for depredation costs (in absence of economic data)

Estimation of co-viability probabilities for **different scenarios of artificial depredation rates**

Starting year: current depredation rates
(0.378 at CRO and 0.054 at KER)
End of simulation: depredation rate fixed per area
With linear variation per year between the two points

example of depredation rate scenario with
0.5 in CRO and 0.5 in KER



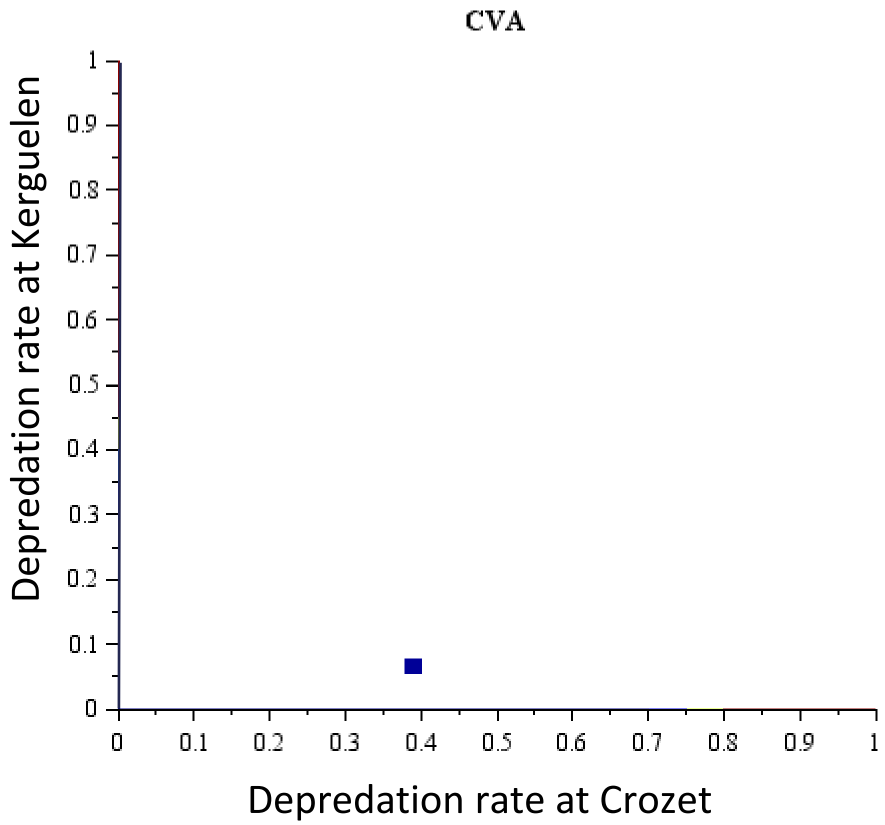
With TAC per area depending on depredation rates and environmental variability*
TAC defined by period of 3 years

Simulation over 35 years
Number of simulations (environmental variability) =100

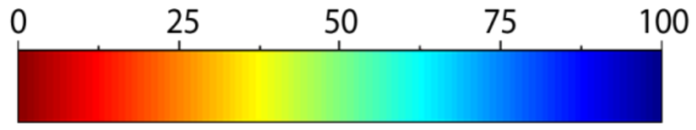
*different management options are possible (cst TAC, TAC dependent on depredation rate, and /or on environmental conditions)

Ecoviability - results

Artificial depredation rate scenarios: variations between 0 and 1, for Crozet and Kerguelen



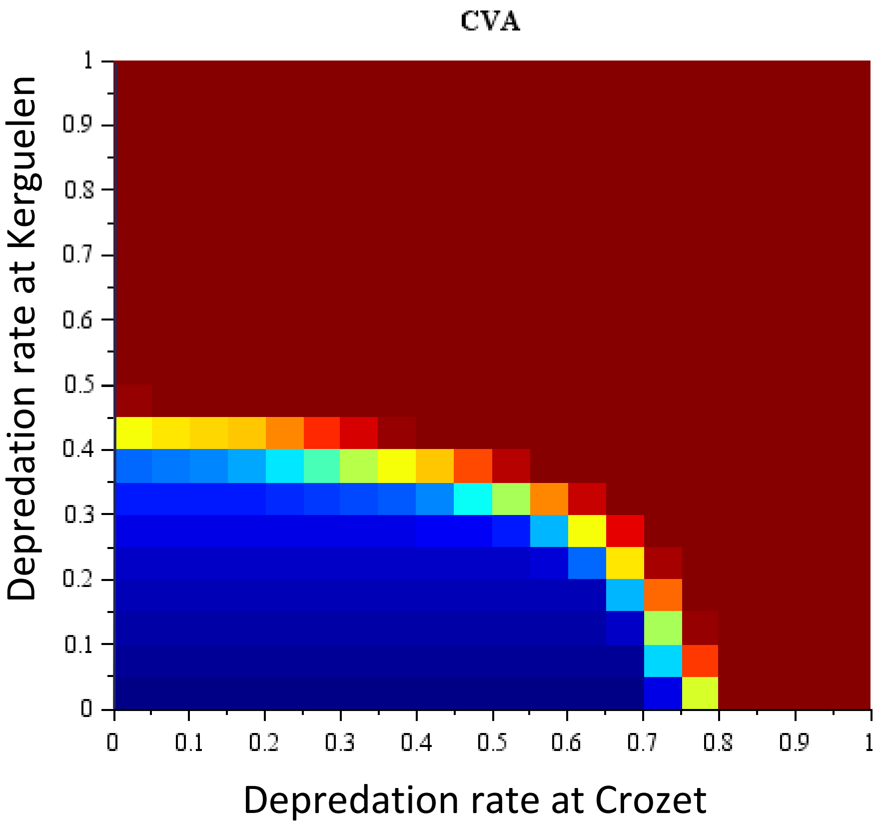
Ecoviability probability (probability of satisfying all defined constraints)



(in x and y axes : final depredation rates that are displayed)

Ecoviability - results

Artificial depredation rate scenarios: variations between 0 and 1, for Crozet and Kerguelen



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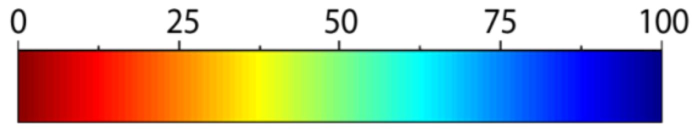

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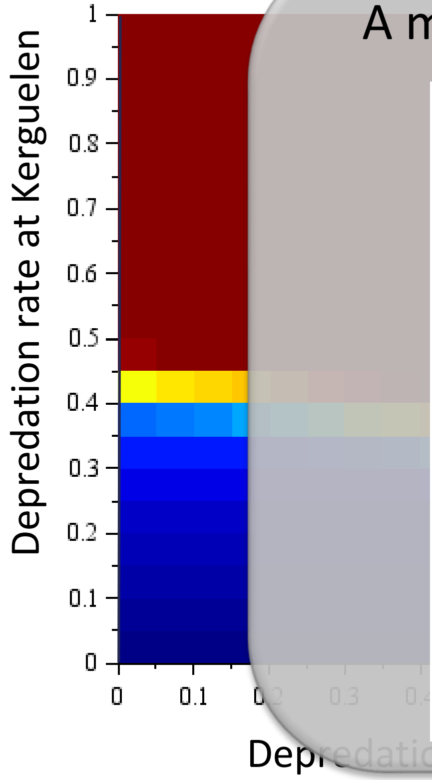
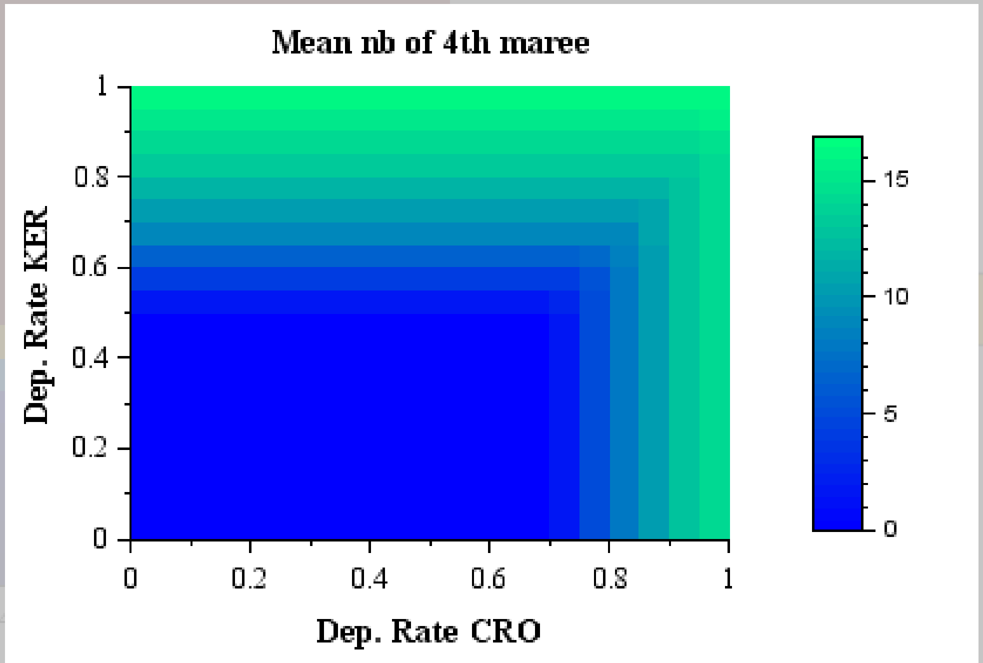


A more social indicator => “4th maree”



(in x and y axes : final depredation rates that are displayed)

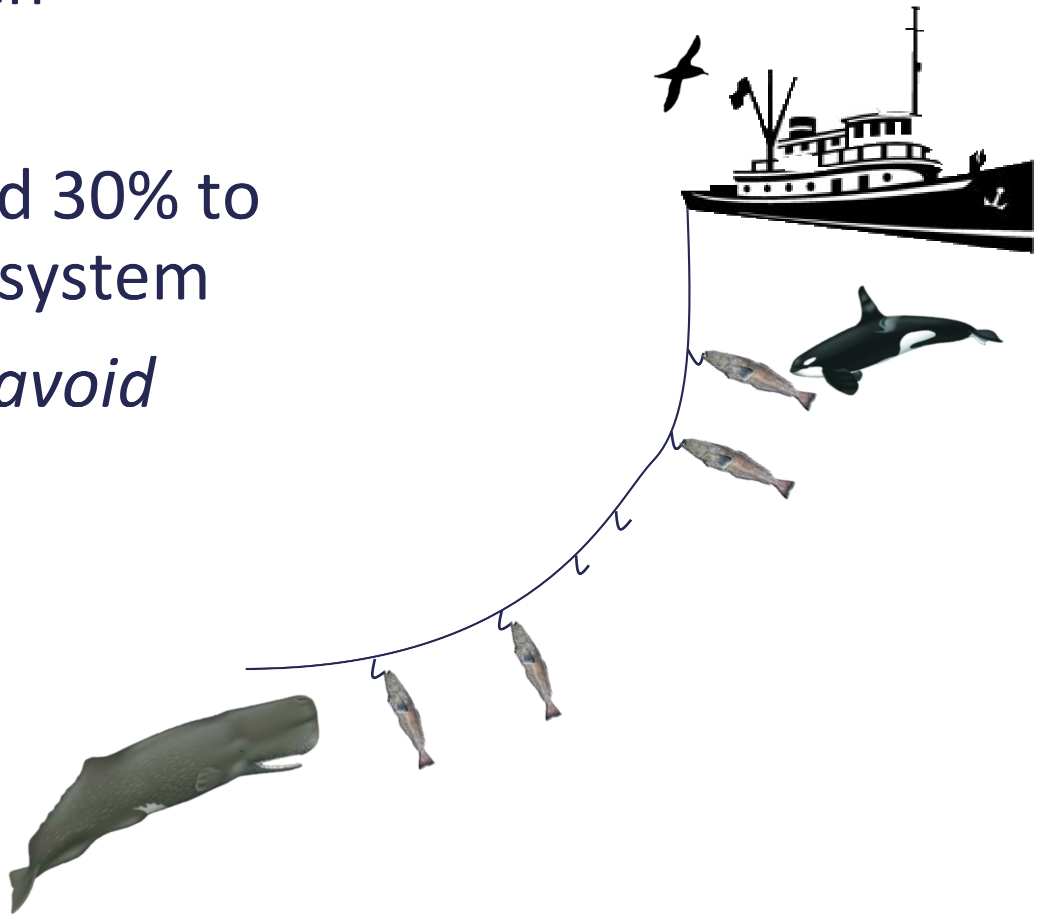
Discussion and Perspectives

Discussion

Significant decrease in income and important increase in costs (*here via number of longlines set*) when depredation rates increase - mainly in Kerguelen

Depredation rate in Kerguelen: must not exceed 30% to ensure biological and economic viability of the system

=> efforts by fishermen must be maintained to avoid depredation by killer whales in Kerguelen



Perspectives (1/2)

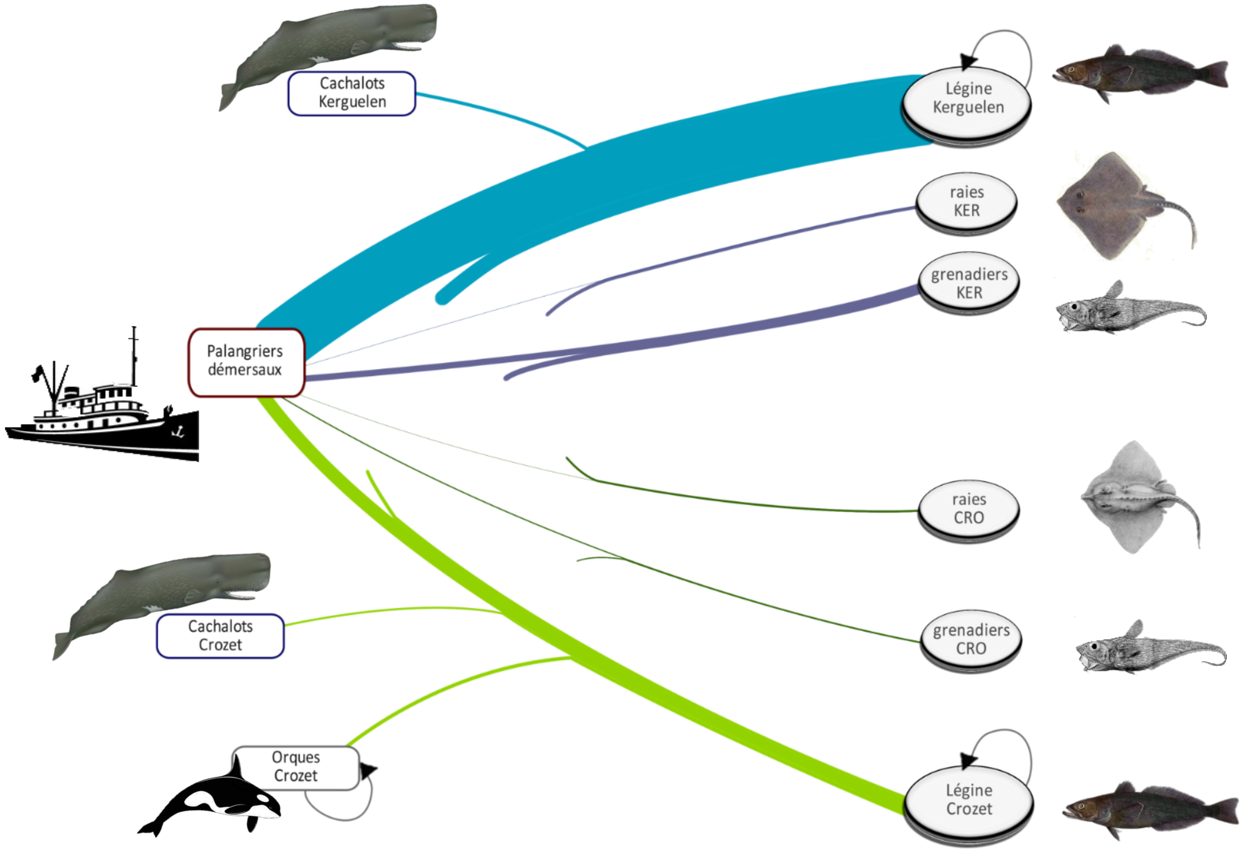
Short term:

Update of parameters - *ongoing*

Byproduct and bycatch landings (e.g. grenadier, rays) to take into account, especially in income estimations for by-products

Medium/long term:

Adding a sustainability constraint on catches of non-target species



Perspectives (2/2)

In the medium / long term :

Adding viability constraint on killer whale population

Estimation of economic cost related to the number of longlines set
Addition of operating costs => calculation of profits

Comparison of ecoviability results under various economic scenarios *(toothfish market prices, fuel prices, etc.)*

Other depredation scenarios (e.g. simulations of interactions between killer whales, sperm whales and vessels)

Adding fishing behaviour *(e.g. modelling of individual vessels with fishing behaviour that adapts to depredation and differentiated quota per vessel: agent-based modelling)*

Thank you for your attention

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