Virtual experimentation as a complement to observation. Application to the assessment of the future and potential for adaptation of Atlantic salmon facing climate change in Southern Europe

Etienne Prévost, Mathieu Buoro, Cyril Piou, Julien Papaix

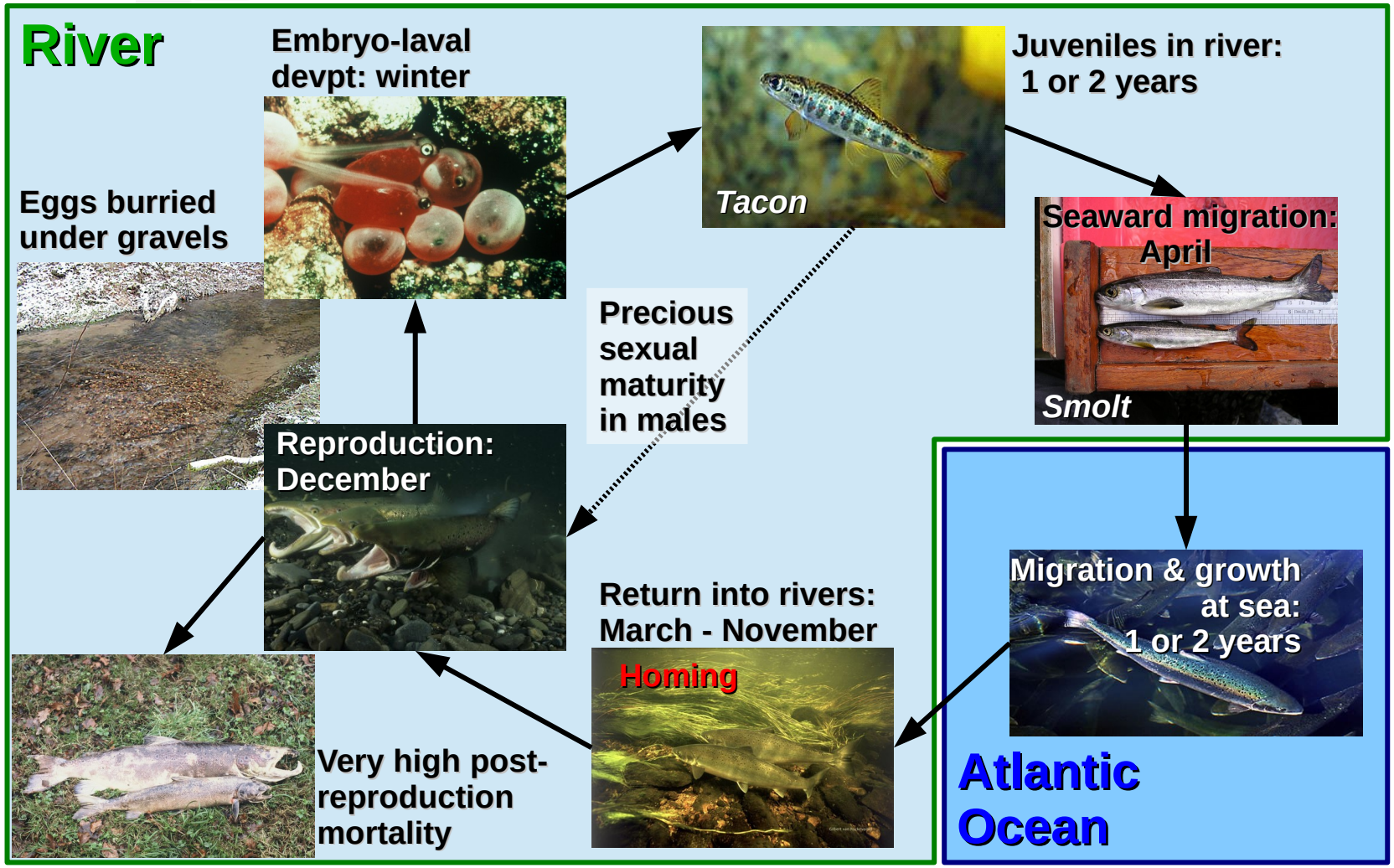
VIRTUAL EXPERIMENTATION AS A COMPLEMENT TO OBSERVATION

APPLICATION TO THE ASSESSMENT OF THE FUTURE AND POTENTIAL FOR ADAPTATION OF ATLANTIC SALMON FACING CLIMATE CHANGE IN SOUTHERN EUROPE

Etienne Prévost[1,2], *Mathieu Buoro*[1,2], *Cyril Piou & Julien Papaïx*

[1]UMR INRA/UPPA Ecobiop, Saint-Pée-sur-Nivelle, France
[2]Pôle Gest'Aqua, INRA/ONEMA, France

Atlantic salmon life cycle



Climate Change : an additional stress in Southern Europe

- Salmon: a poikilotherm and cold water species
- France (& Spain): southern edge of species distribution

  → *Salmon could be strongly impacted by CC in Southern Europe*

- Salmon is an emblematic and threatened species

  → *Strong demand from society and management bodies for assessing the future and potential adaptation of salmon to CC*

Original pic from http://www.wiseass.org/

How to assess *future CC effects* on A. salmon at the population scale ?

- Real world experiment: impossible
- In silico experiments with virtual population: an alternative option
  - Test diverse CC scenarios
  - Replication of experiments under a given CC scenario
  - Complementary to broad-scale approaches such as niche modelling that ignore behavioural and evolutionary processes
- INRA has developed a salmon population simulator for virtual experimentation of CC: IBASAM (Individual Based Atlantic Salmon Model)

  Piou & Prévost, 2012. Ecological Modelling, 231: 37-52

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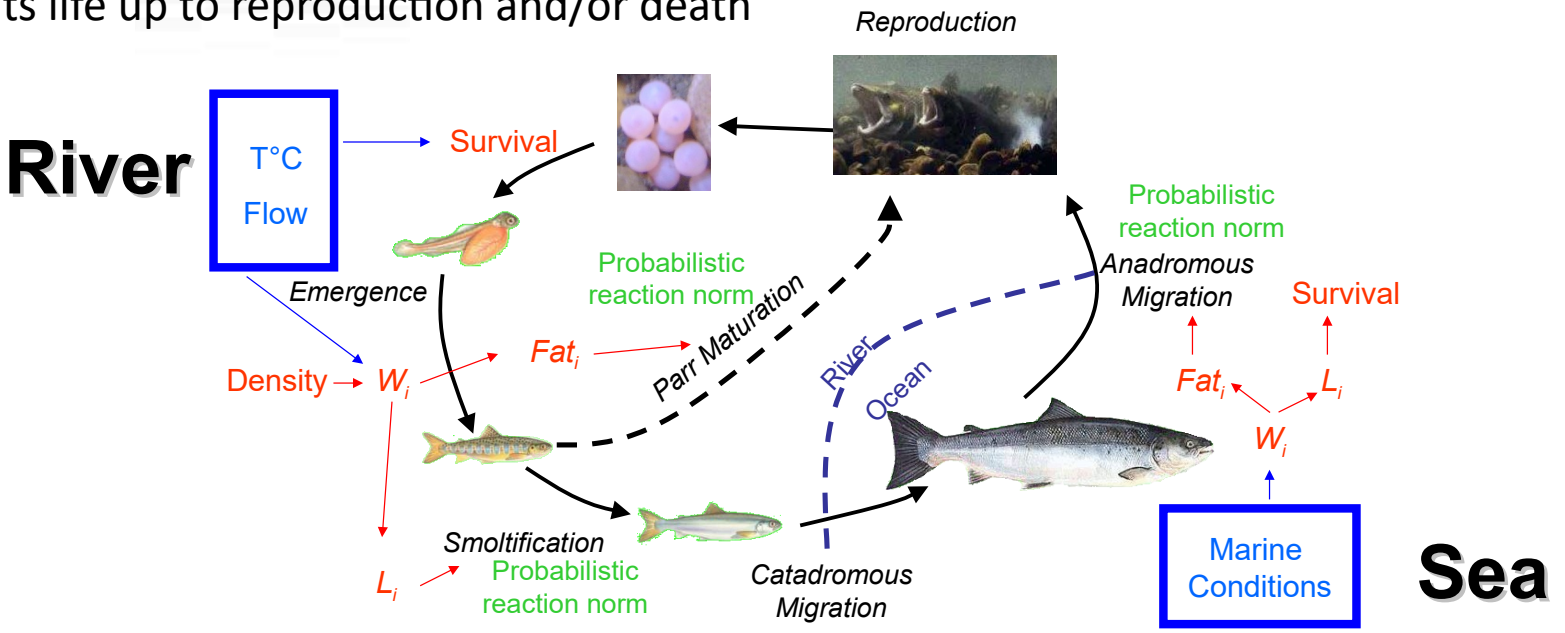
IBASAM : population simulator for the study of CC effects on Atlantic salmon

- Mimics a small population typical of french coastal streams
- CC is multiform
  - In rivers:
    - ↗ water T°
    - ↗ variability of flow
    - …
  - At sea:
    - ↘ conditions for growth
    - …

- Connect demo-genetic dynamics with riverine (T°, flow) and marine factors (conditions for growth)

IBASAM

- Every individual of a population is explicitly represented and followed through its life up to reproduction and/or death



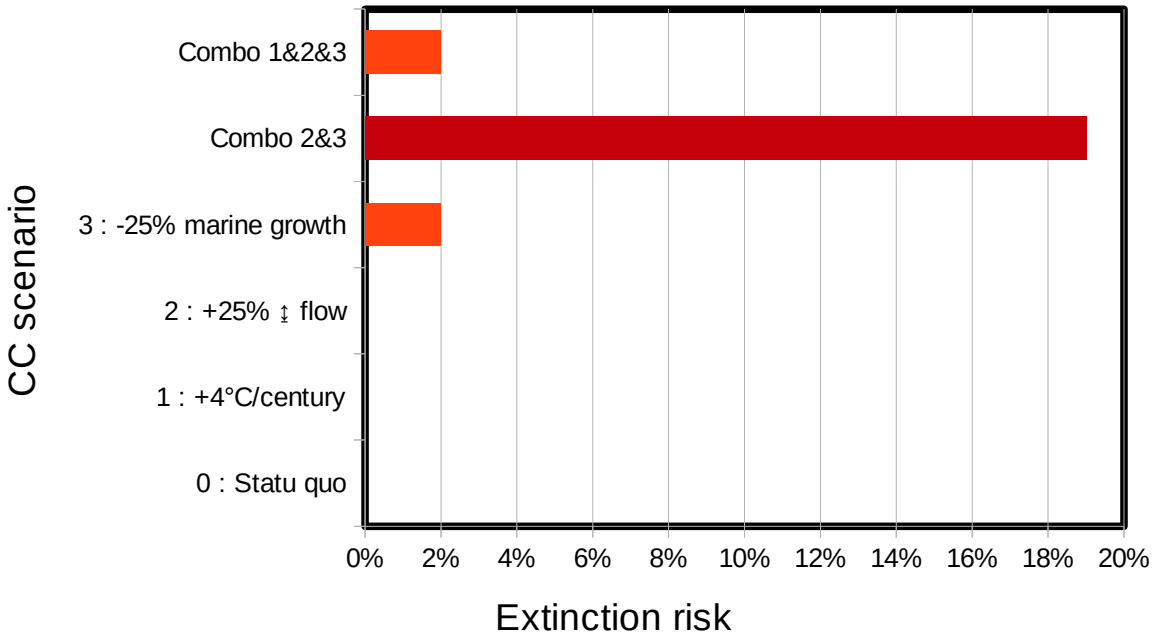
- Summarizes and articulates available knowledge on demo-evolutionary processes in A. salmon
  - Emphasis on the plasticity of the species: individuals adjust phenotype to yearly environmental variations
  - Explicitly represents individual genetic variability which control plasticity mechanisms
  - Accounts for environmental and demographic stochasticity in population dynamics
  - Explicitly represents the link between climate related forcing factors and individuals
- Calibrated against 15 years series of real population databases (Scorff river, Brittany, France)

First virtual experiments of CC with IBASAM
Combining riverine and marine changes

- 27 CC scenarios tested
  - ↗ river water T° (3 modalities)
  - ↗ river flow variability (3 modalities)
  - ↘ conditions for growth (3 modalities)

- Time horizon: 3 decades (~2045)
- 300 replicates per scenario
  - Initial size ~215 adults returning from the sea
    → small population

Potential CC effect on salmon population persistence



- Apart from worst case scenario, extinction risk is low at the 2045 horizon
- From the scenarios tested:
  - Marine conditions have the strongest effect
  - Synergetic effect of flow variability with marine conditions
  - ↗ river water T° mitigates the effect of the other 2 factors

First virtual experiments with IBASAM
CC & selective exploitation

- Selective exploitation is commonplace in salmon
  - Larger adults (maturing after 2 years at sea) are selectively harvested compared to smaller ones (maturing after 1 year at sea)
- CC and selective exploitation occur simultaneously → How to compare their respective effects while assessing their interactions?
- A virtual experimentation plan:
  5 CC scenarios X 5 exploitation scenarios
  - CC → only ↘ conditions for growth (main driver of CC effects)
  - Time horizon: 3 decades (~2045)
  - 30 replicates per scenario

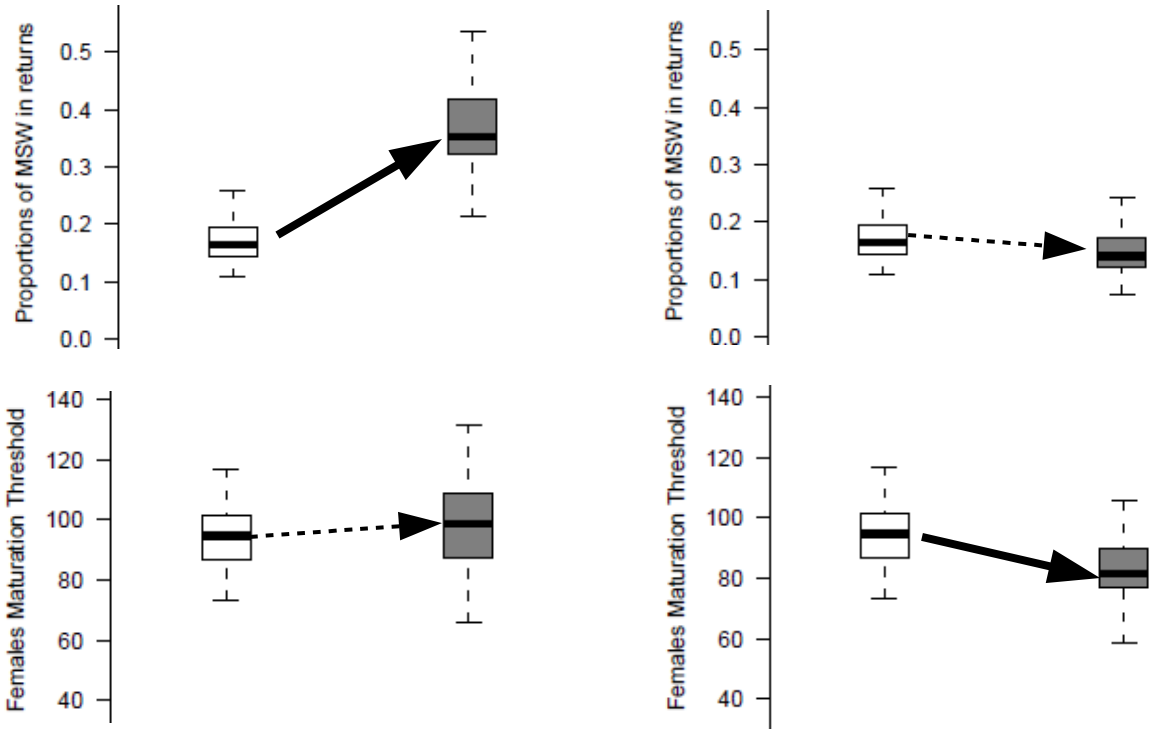
CC vs selective exploitation
Phenotypic plasticity vs genetic evolution

CC only
↘ 25% growth at sea

Selective fishing only
15% expl. rate 1 year at sea
↗ expl. rate 2 years at sea 15→75%

Phenotype
Prop. 2 years at sea

Genotype
Genetic threshold triggering sexual maturation in females



Mostly plastic response
Little genetic evolution

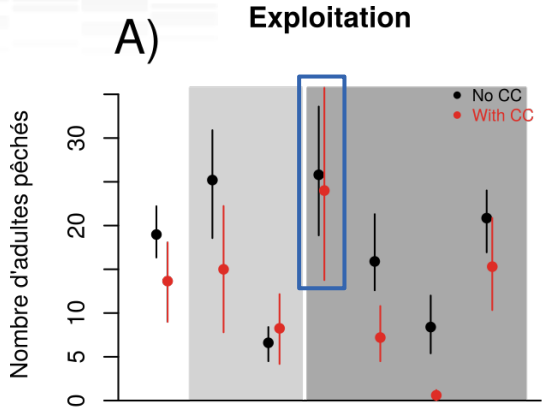
Stronger genetic evolution

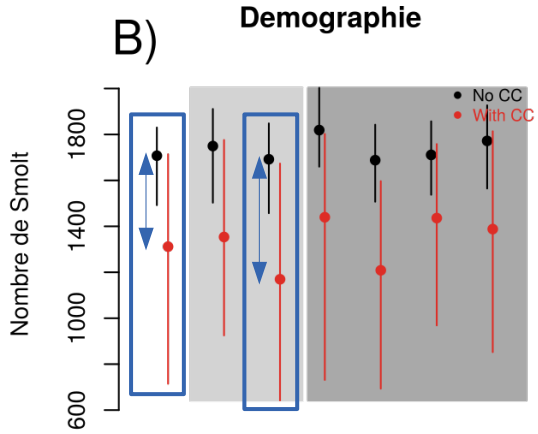
Selective exploitation *for* adaptation to CC

- Exploitation is an evolutionary force: could it be used on purpose to foster adaptation ?
  - SALMOCLIM Project (INRA funded)
- Virtual experimental design:
  1 CC scenario X 6 selective exploitation scenarios
  - CC at sea and in river (strong)
  - Time horizon: 3 décades (~2045)
  - 100 replicates par scenario
- New version of IBASAM: includes genetic heritability of growth and a survival/growth trade-off

Selective exploitation *for* adaptation to CC

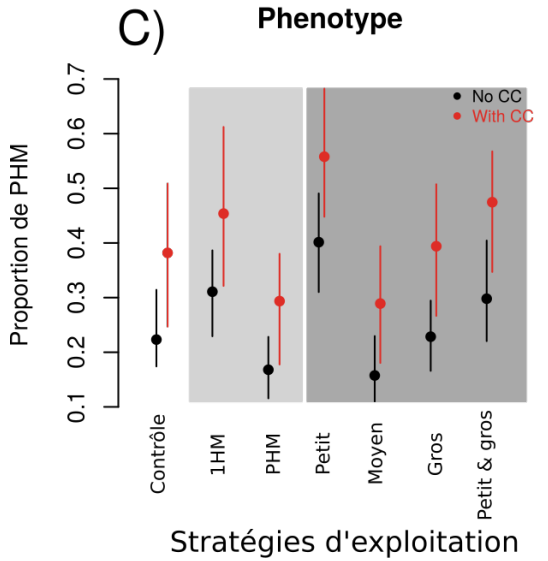
CC → ↓ catch
Selective expl.:
Catch maintained
if fishing targets
small fish

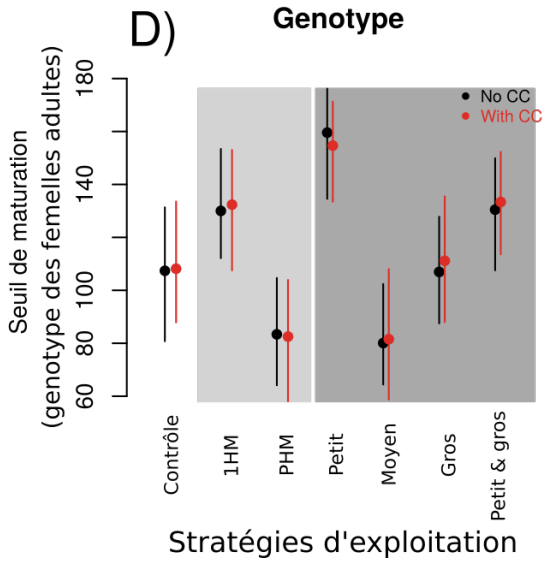




CC → ↓ pop size
→ ↑ variability
Selective expl.:
No gain
↑ increased gap
if fishing targets
MSW fish

CC → ↑ % MSW

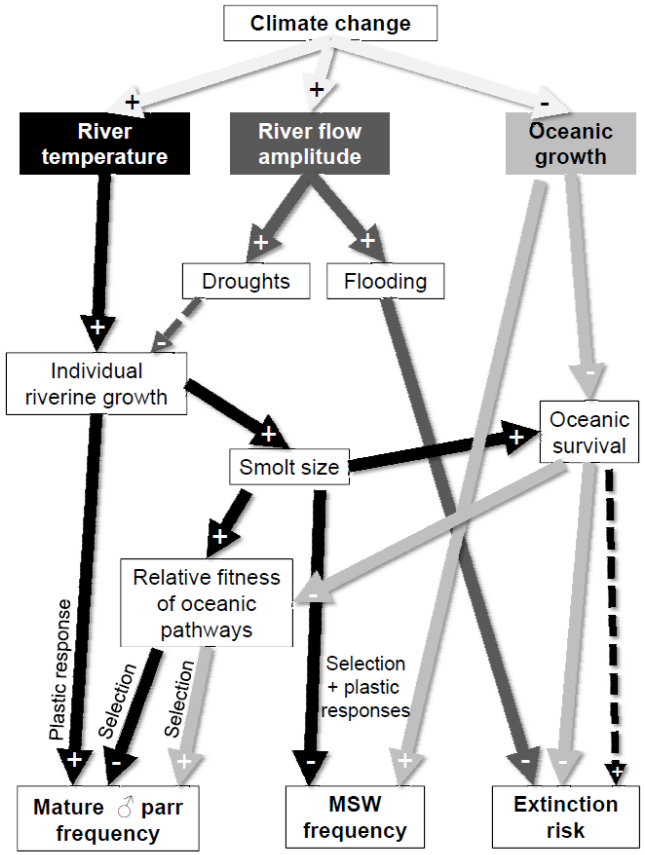




No genetic
evolution

Demo-genetic simulation: a tool for making scientific progress

- Demo-genetic simulation: a powerful approach to explore CC consequences on A. salmon populations
  - No substitute for assessing the outcome of an unprecedented climatic future at scales which prevent real world experimentation
- CC consequences cannot be appraised by mere intuition
  - The effects of CC are mediated by a complex array of interacting biological traits which outcome is the resultant of contradictory forces
- IBASAM:
  - a tool for better understanding of these interactions
  - A tool for management advice ? → Be patient and very cautious



Demo-genetic simulation for assessing adaption of A. salmon to CC Where are we? Where to go?

- It is just the beginning → field of active research but still scientifically immature
- Lack of understanding → any prediction is currently surrounded by (too) broad uncertainty (to be useful)
  - Acknowledge Science has still little to say to advise managers
    → despite strong demand for answers science must be cautious not to oversell preliminary results
- Not at the edge of population extinctions even in Southern Europe → must take advantage of the next two decades to improve :
  - Understanding of CC effects on A. salmon with IBASAM: considerable room for improvement
    - Improving realism of genetics of plastic traits → age at maturity reaction norm
    - Interacting populations → metapopulations
  - Scientific advice to A. salmon population management
    - Conceive management options that are robust to uncertainties
      - Exploring consequences of portfolio effects

First virtual experiments with IBASAM
What have we learned ?

- Some qualitative (not quantitive) results :
  - Complexity of interactions network → unexpected and non-intuitive outcomes
    - e.g. first results on population viability
  - CC may have strong/rapid demographic and phenotypic effects with (too?) little/slow genetic evolution
  - Selective exploitation :
    - might not be a way to foster adaptation
    - may well worthen CC effects


Thanks for your attention