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The role of freshwater and marine productivity in defining the overall outcome for Atlantic salmon populations

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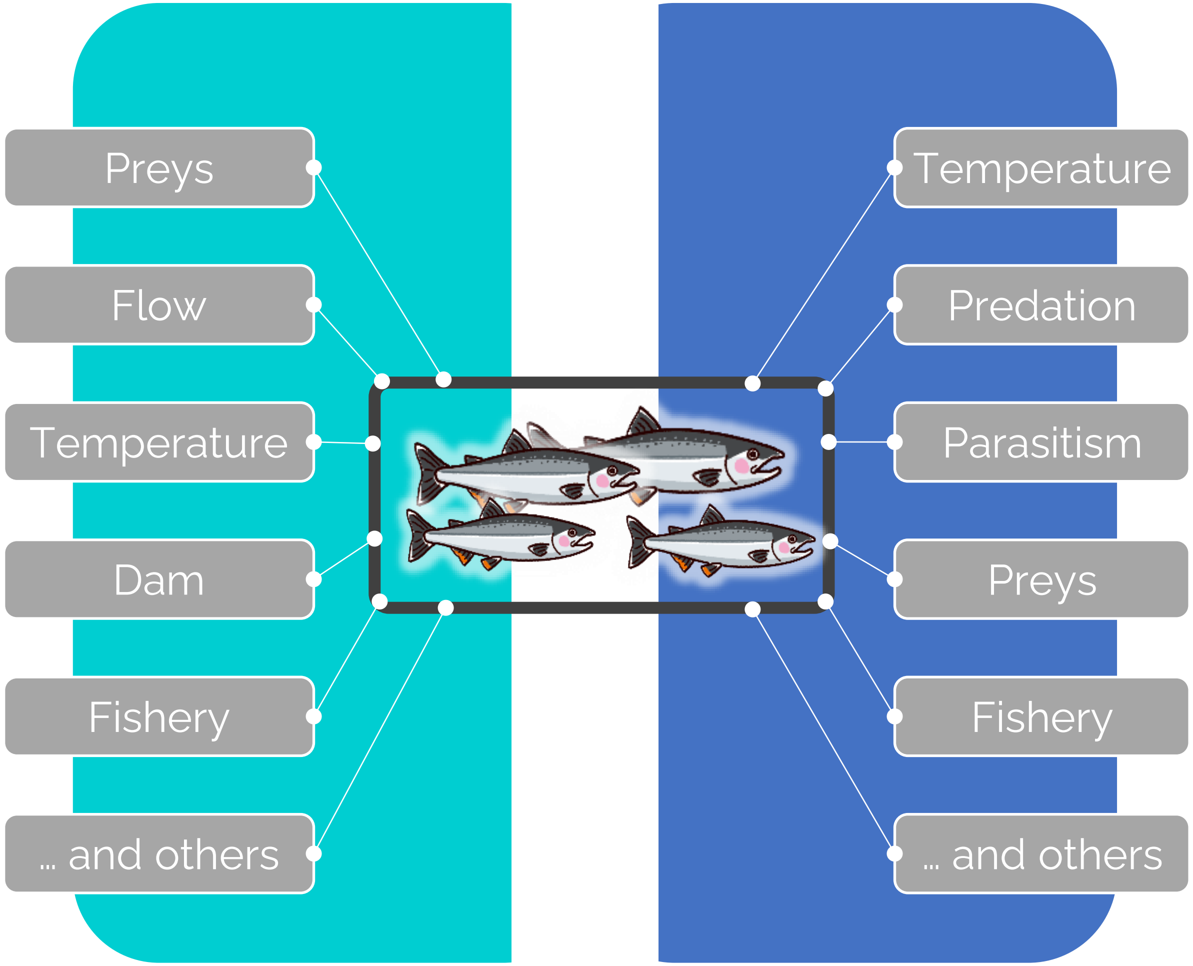
6 June 2023/ NASCO Theme Based Special Session/ Informing a strategic approach to address the impacts of climate change on wild Atlantic salmon

Multiple impacts of climate change on wild Atlantic salmon

Salmon life cycle takes place across different environments, and multiple stressors act in each environment.



Multiple impacts of climate change on wild Atlantic salmon

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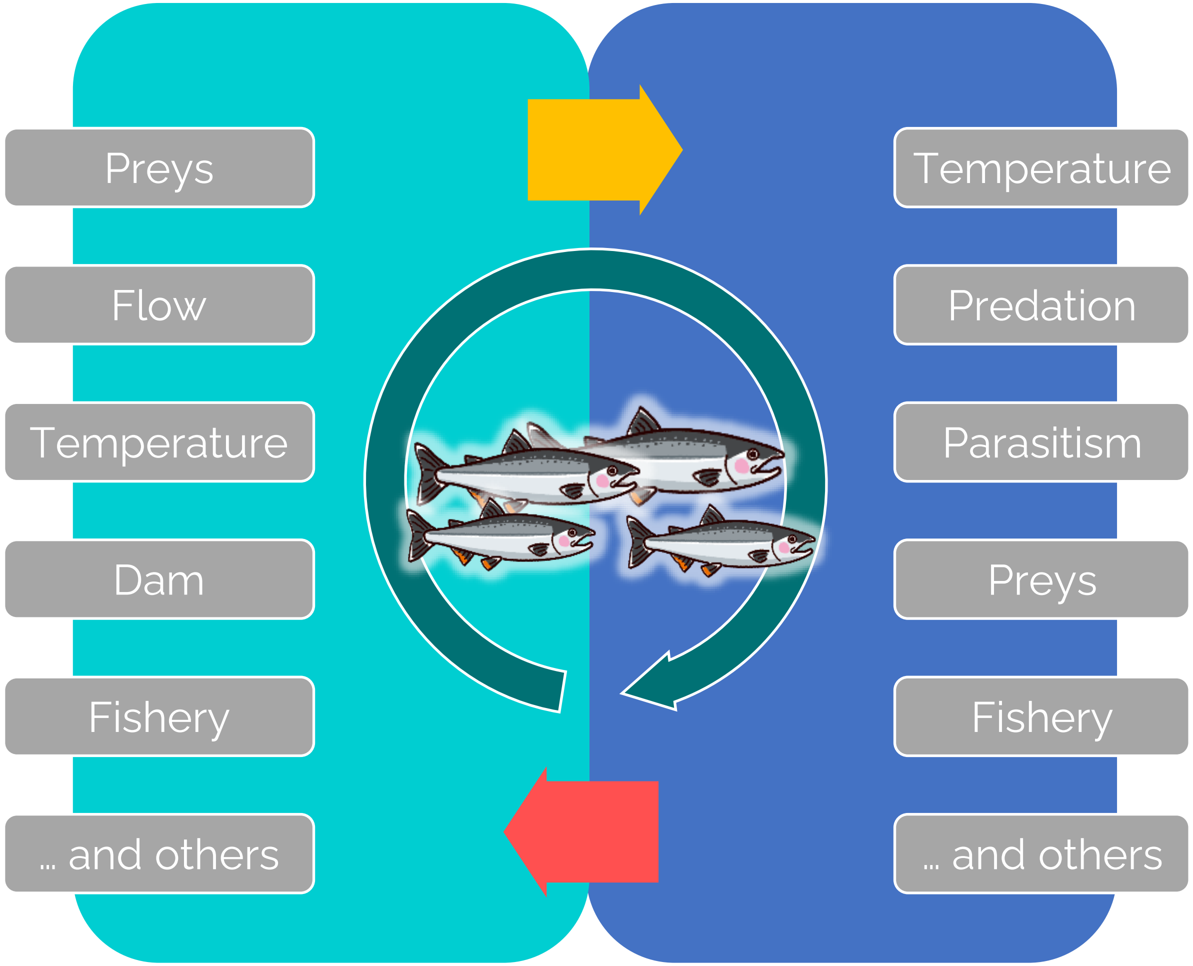
The anadromous migration links the different environments, and the impacts of stressors.

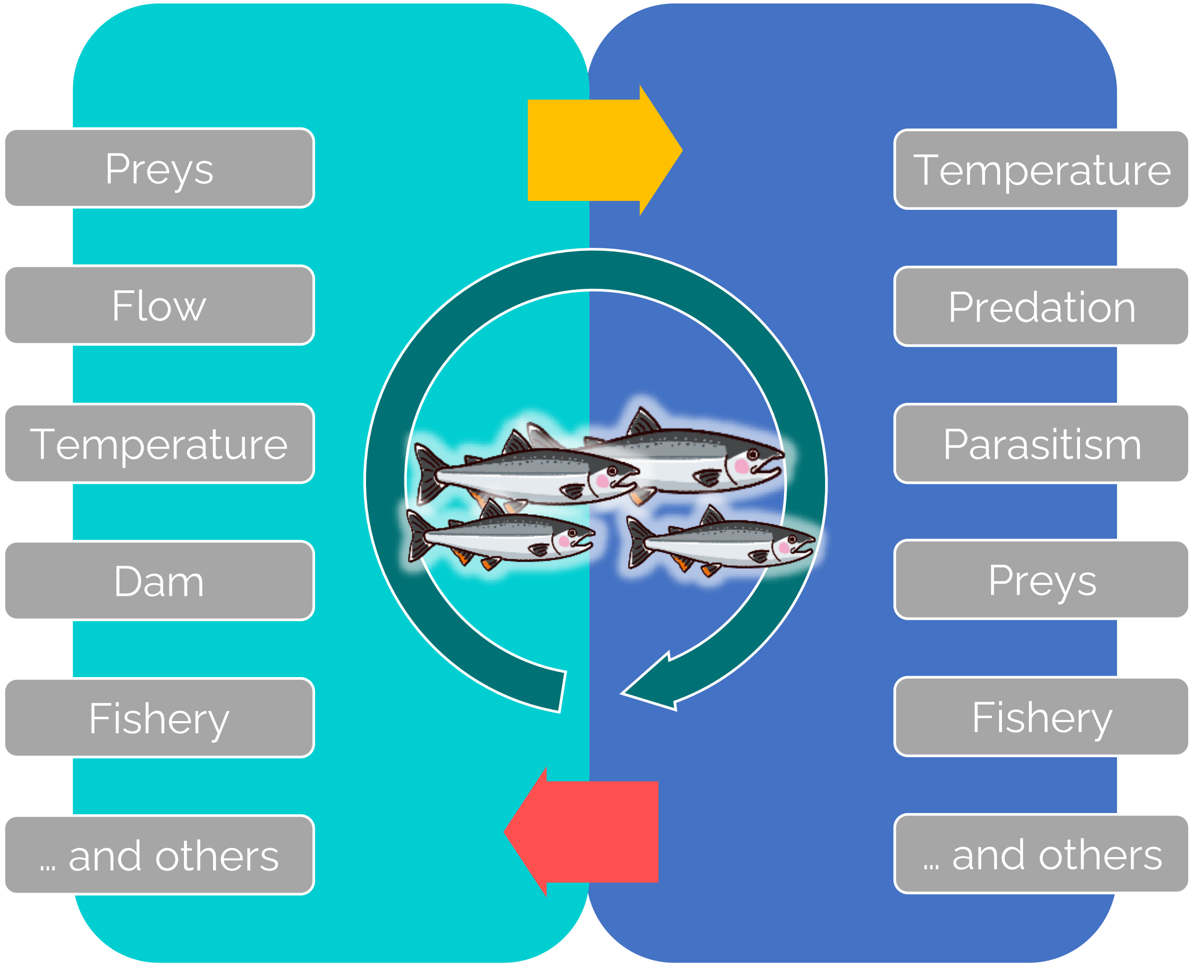


Multiple impacts of climate change on wild Atlantic salmon

Salmon life cycle takes place across different environments, and multiple stressors act in each environment.

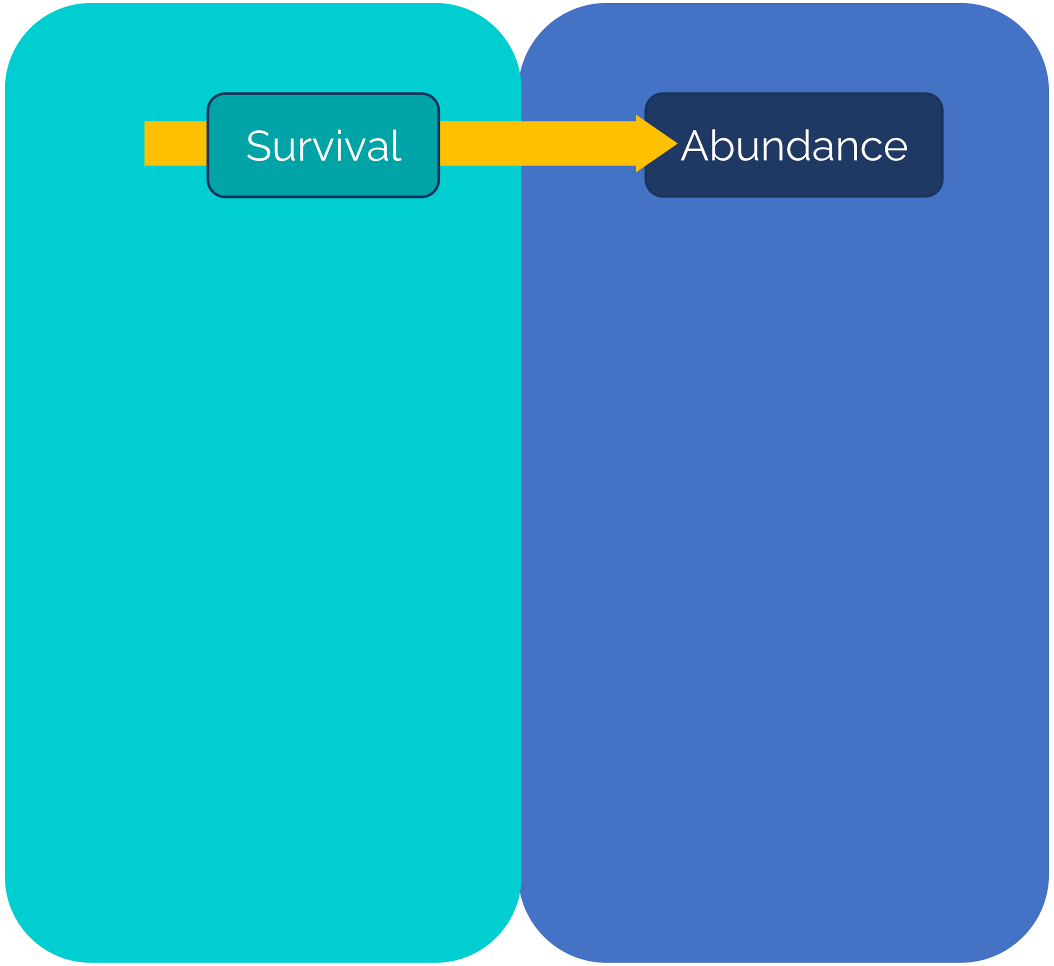
The anadromous migration links the different environments, and the impacts of stressors.

Impacts of climate change accumulate over the life cycle and may have long lasting consequences.



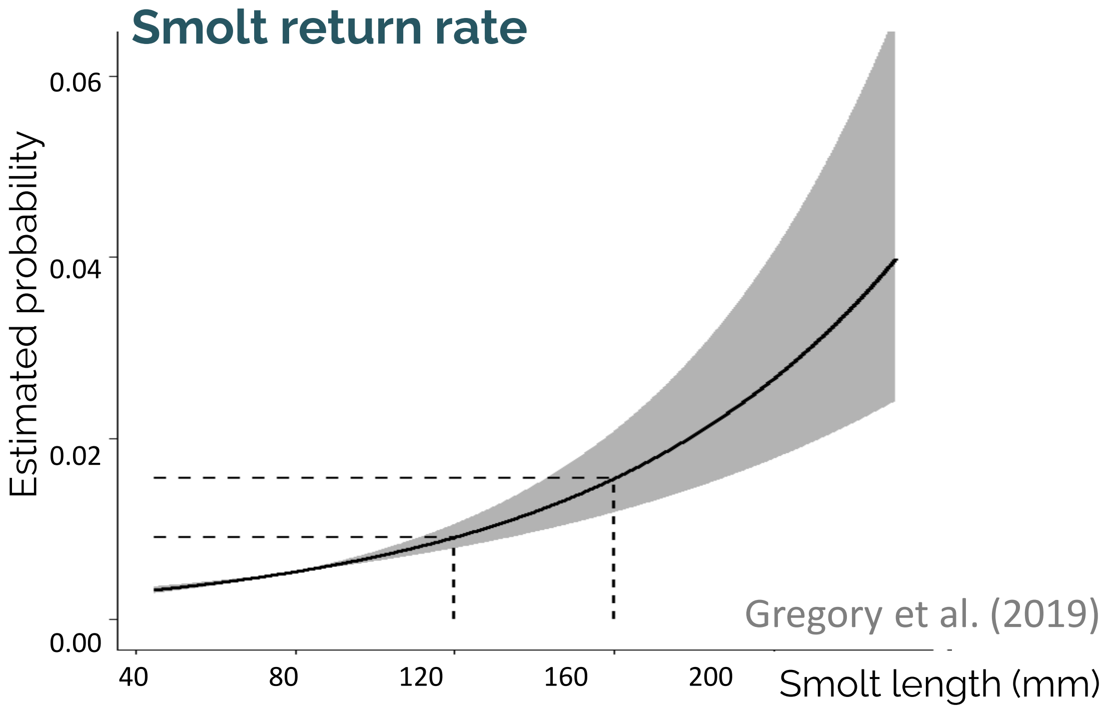
The freshwater environment influences salmon at sea

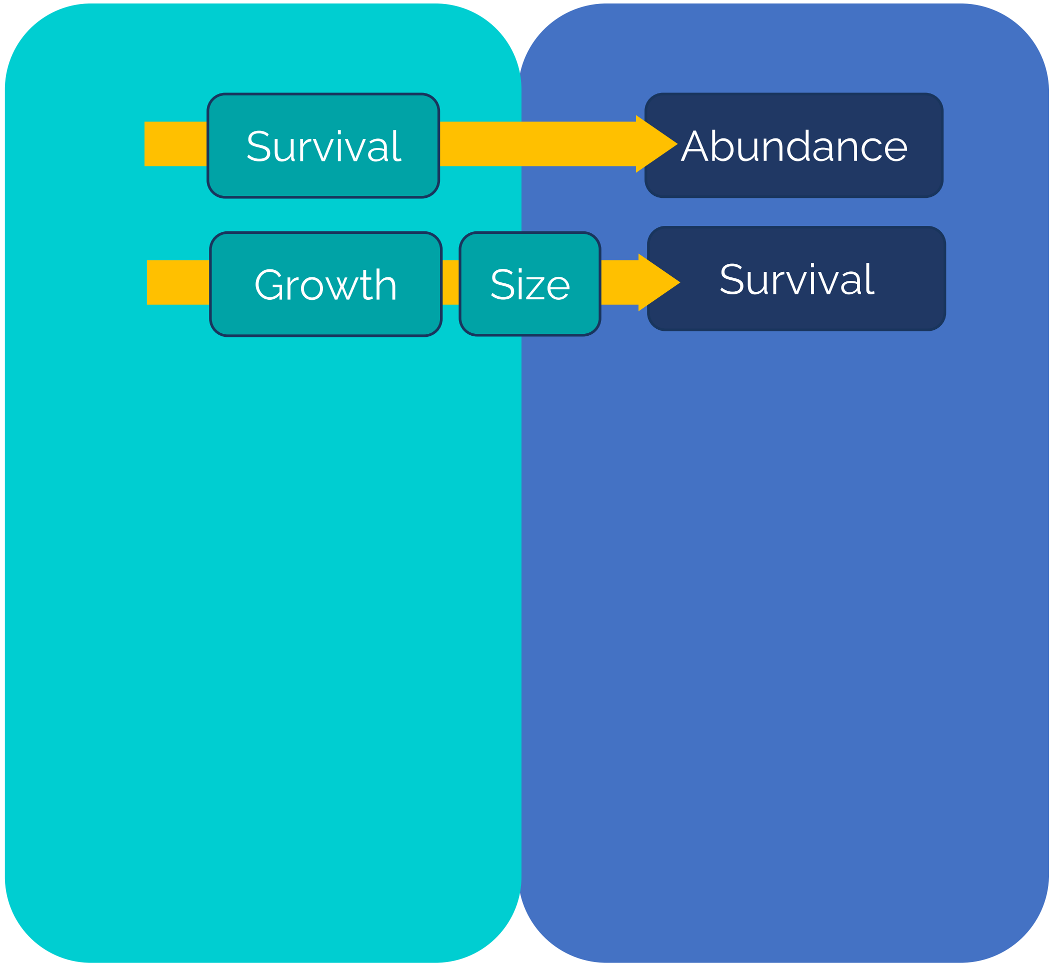
- Survival in freshwater impacts the number of smolts



The freshwater environment influences salmon at sea

- Survival in freshwater impacts the number of smolts
- Growth influences the quality of smolts (size, age)

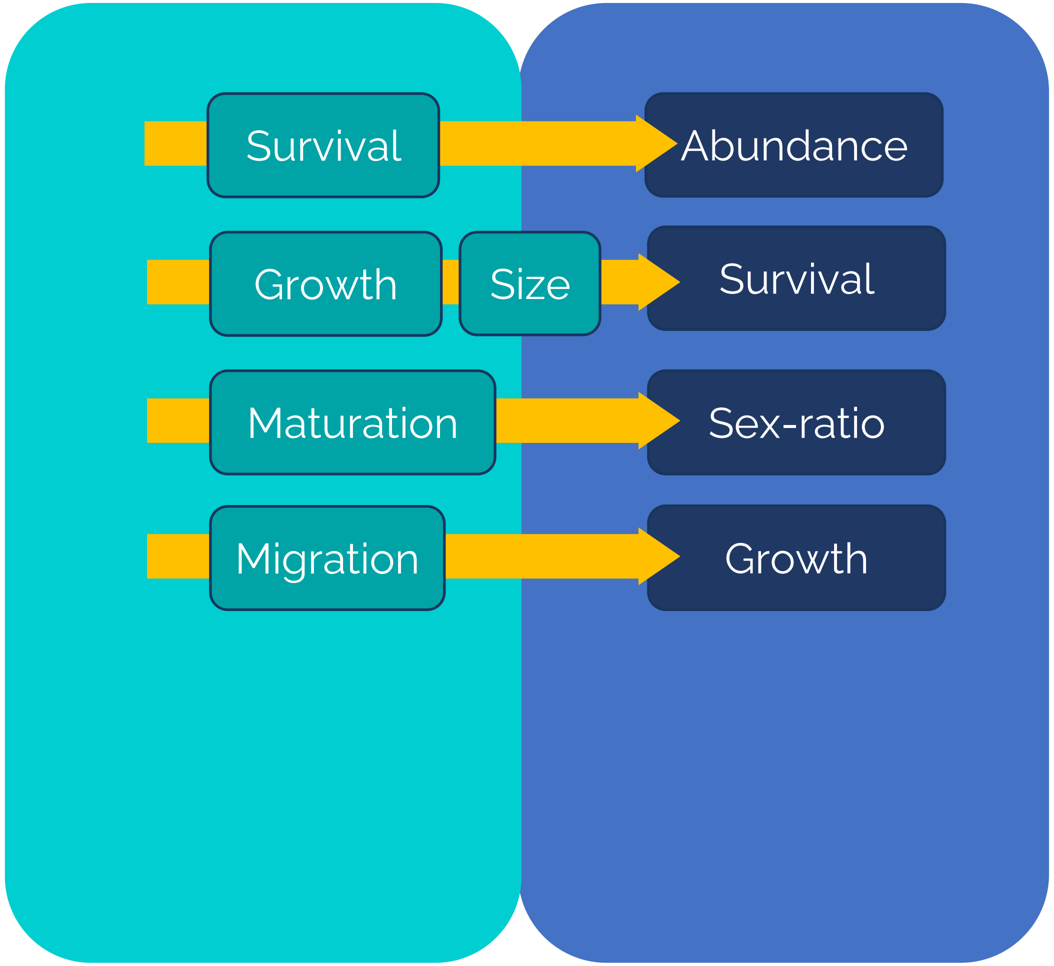




The freshwater environment influences salmon at sea

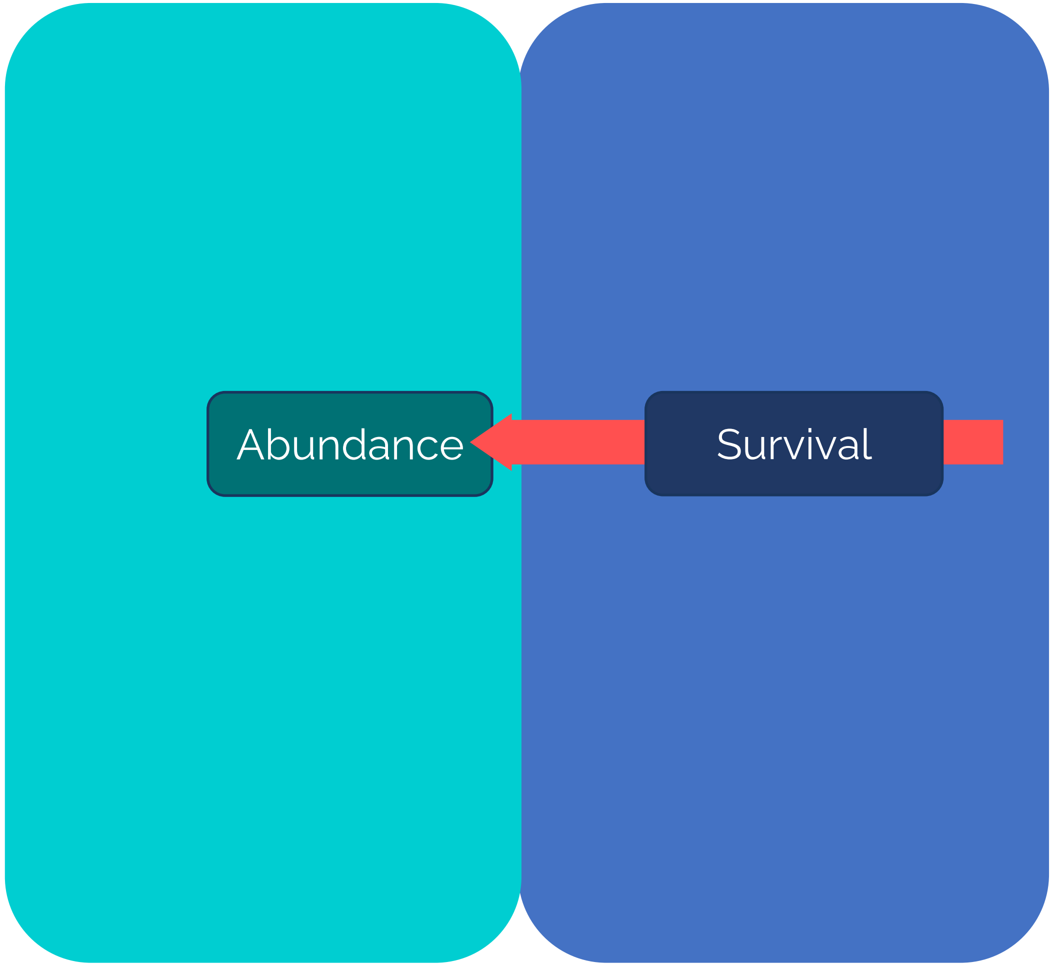
- Survival in freshwater impacts the number of smolts
- Growth influences the quality of smolts (size, age)
- Precocious maturation in males affects sex-ratio
- Migration timing influences prey availability at sea

The freshwater environment influences the quantity, the quality and the phenology of the salmon at sea.



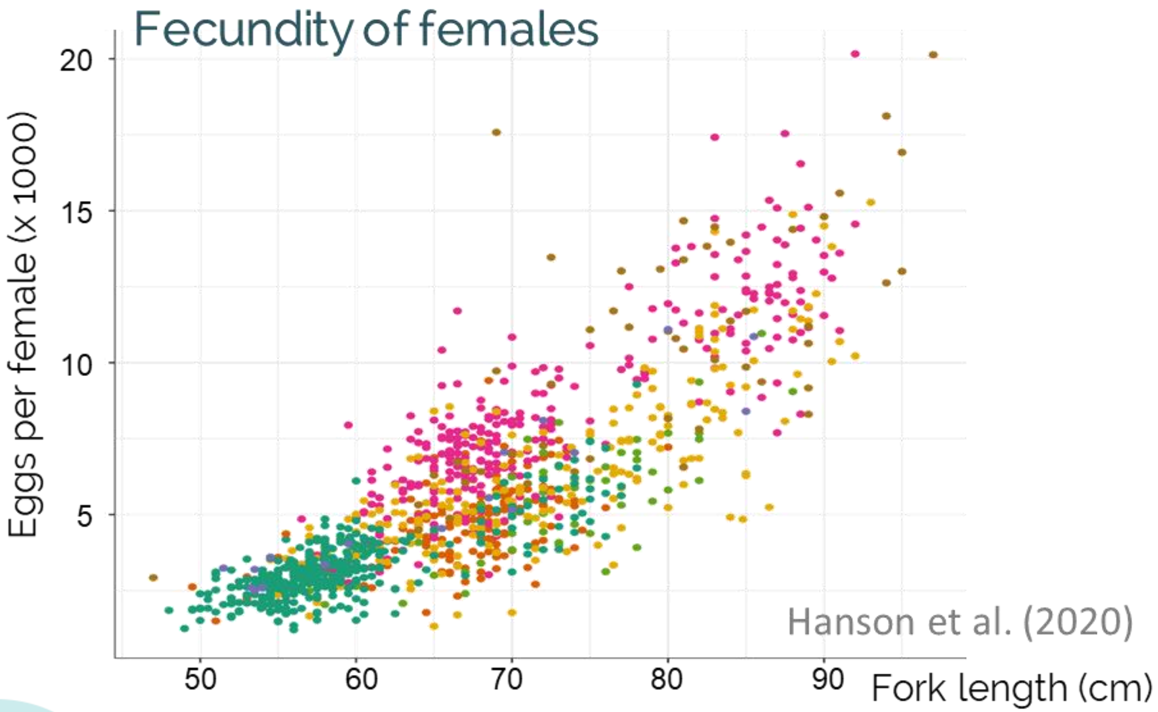
The marine environment influences salmon back in freshwater

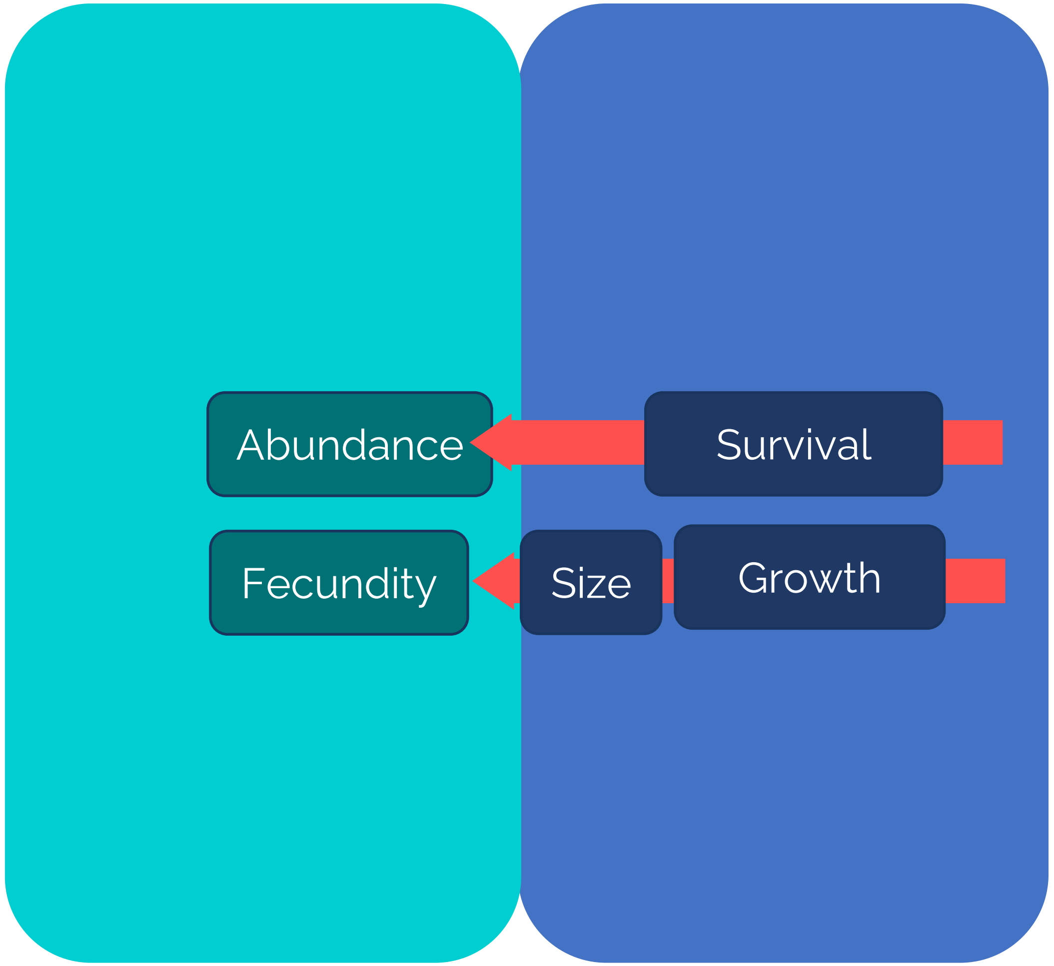
- Survival at sea impacts the number of returns



The marine environment influences salmon back in freshwater

- Survival at sea impacts the number of returns
- Growth influences maturation and fecundity

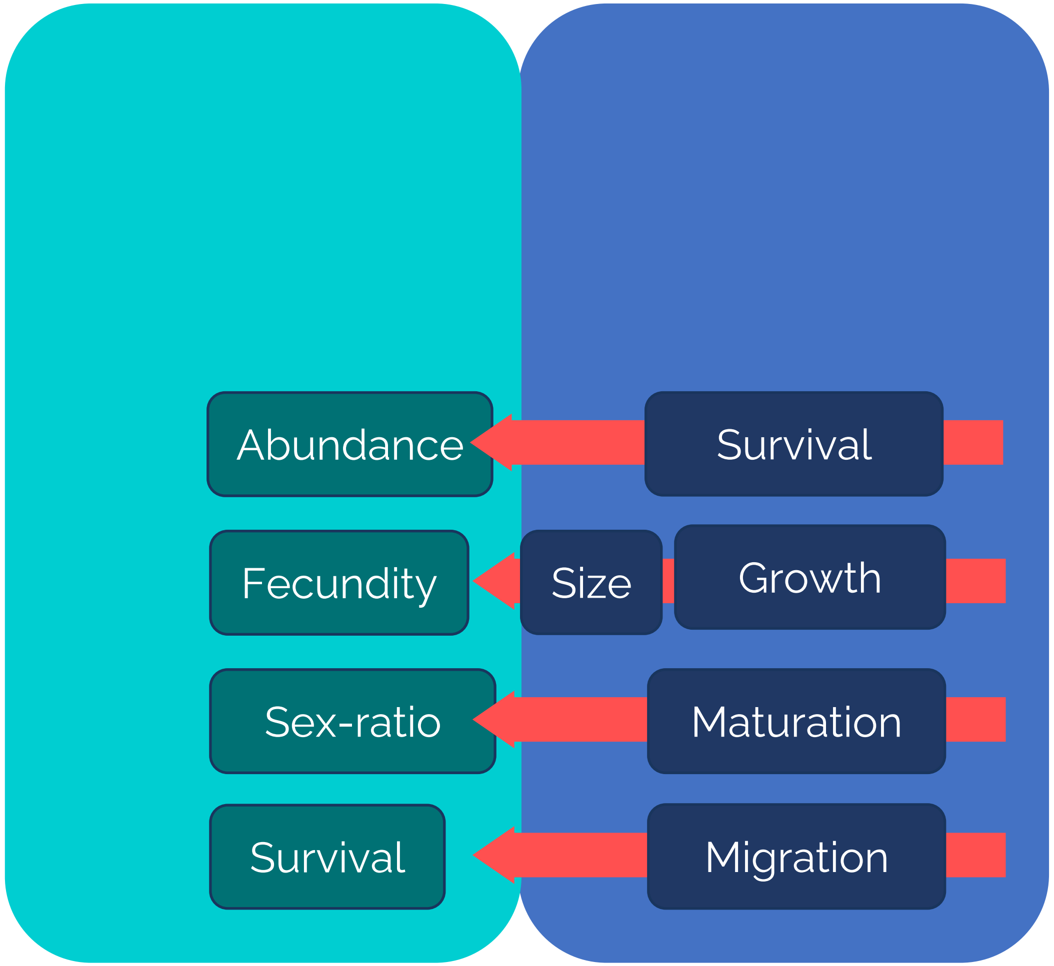




The marine environment influences salmon back in freshwater

- Survival at sea impacts the number of returns
- Growth influences maturation and fecundity
- Sex-specific age at maturation affects sex-ratio
- Migration timing may influence the conditions faced in freshwater and survival until spawning

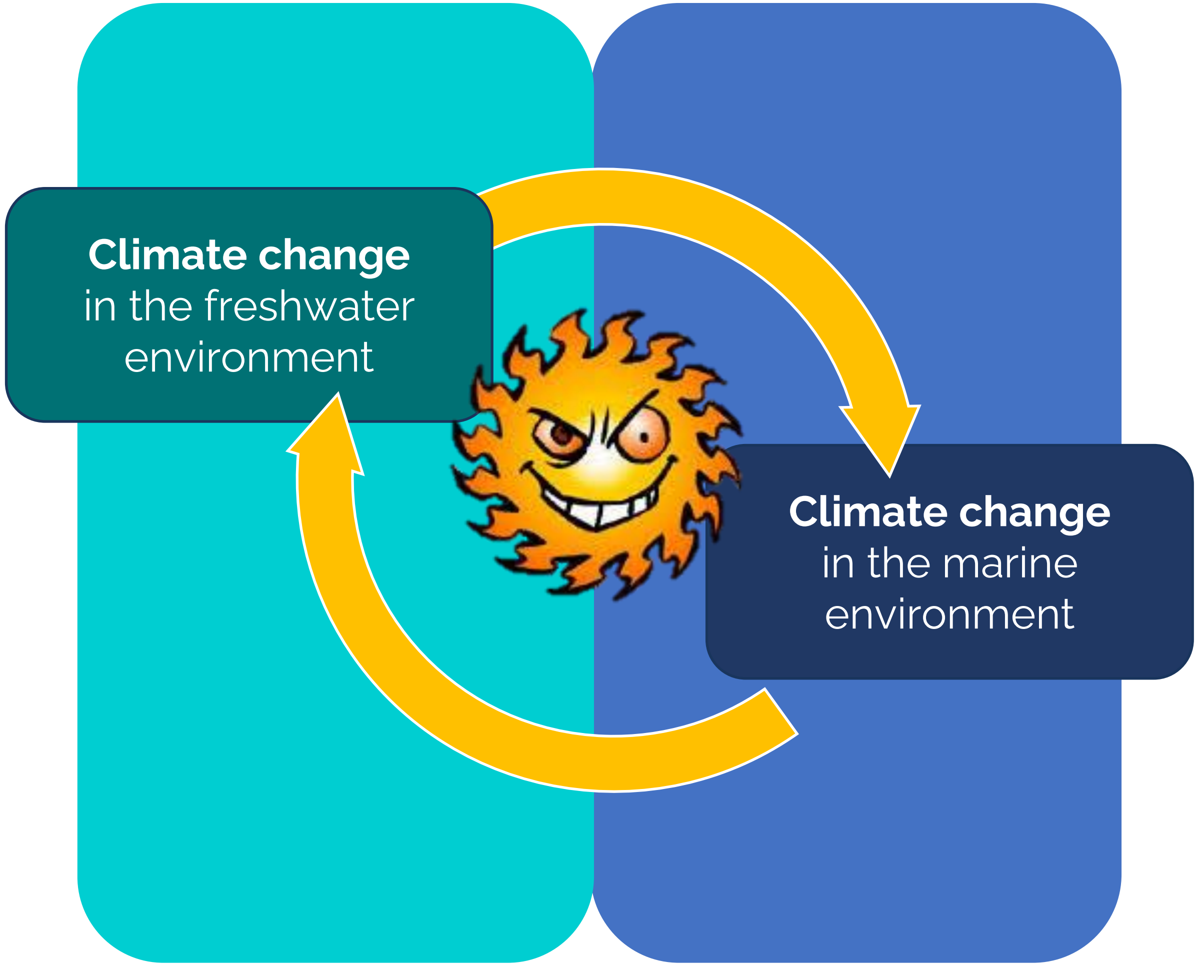
The marine environment influences the quantity, the quality and the fecundity of the spawners in freshwater.



What is the impact of climate change on salmon productivity?

We need an integrative approach to track changes in salmon abundance and phenotype across the life cycle, the spatial and temporal scales.

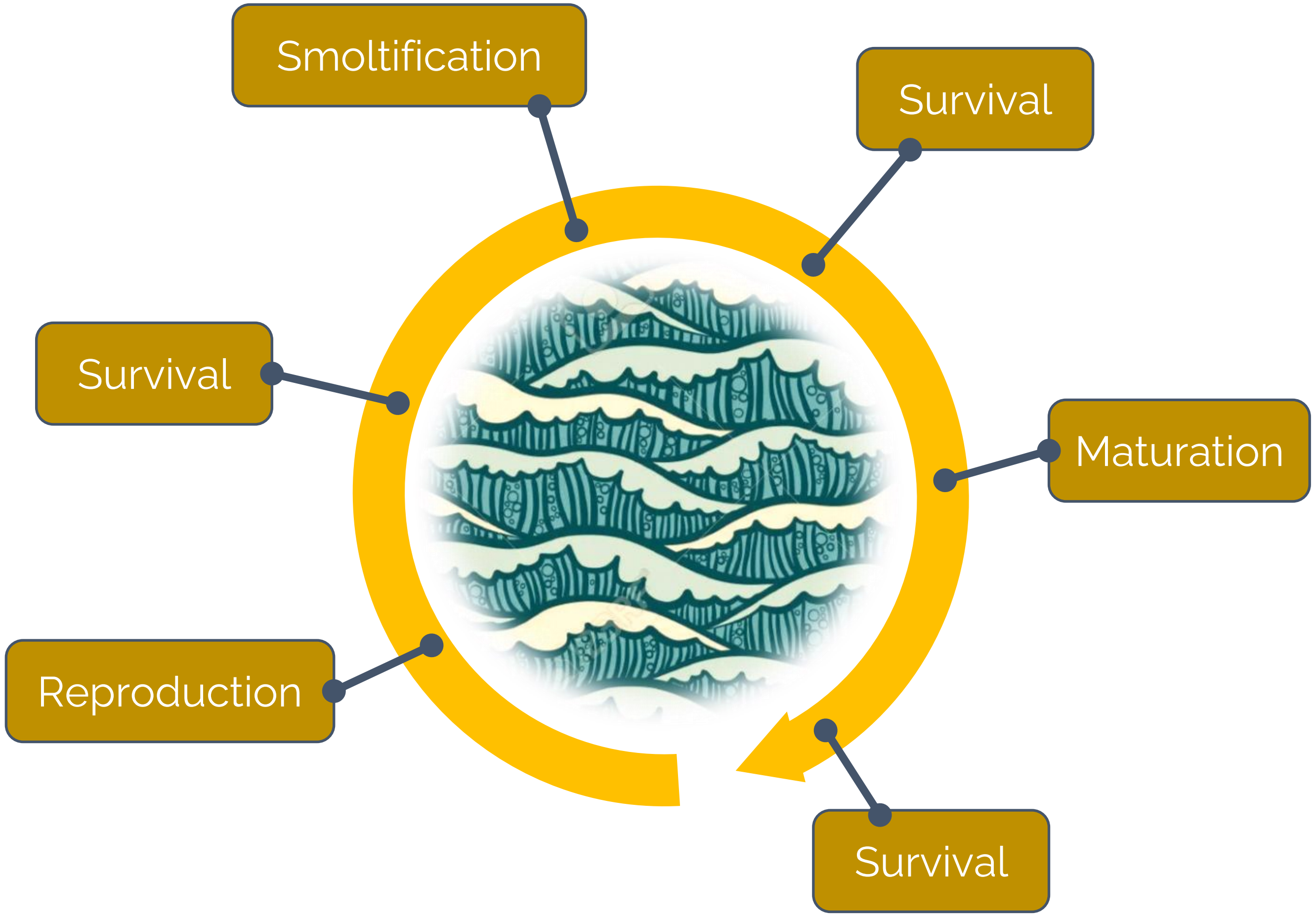
Life cycle models



Life cycle models of salmon population dynamics

Abundance = Gains - Losses

Key demographic processes are explicitly represented across the life cycle.

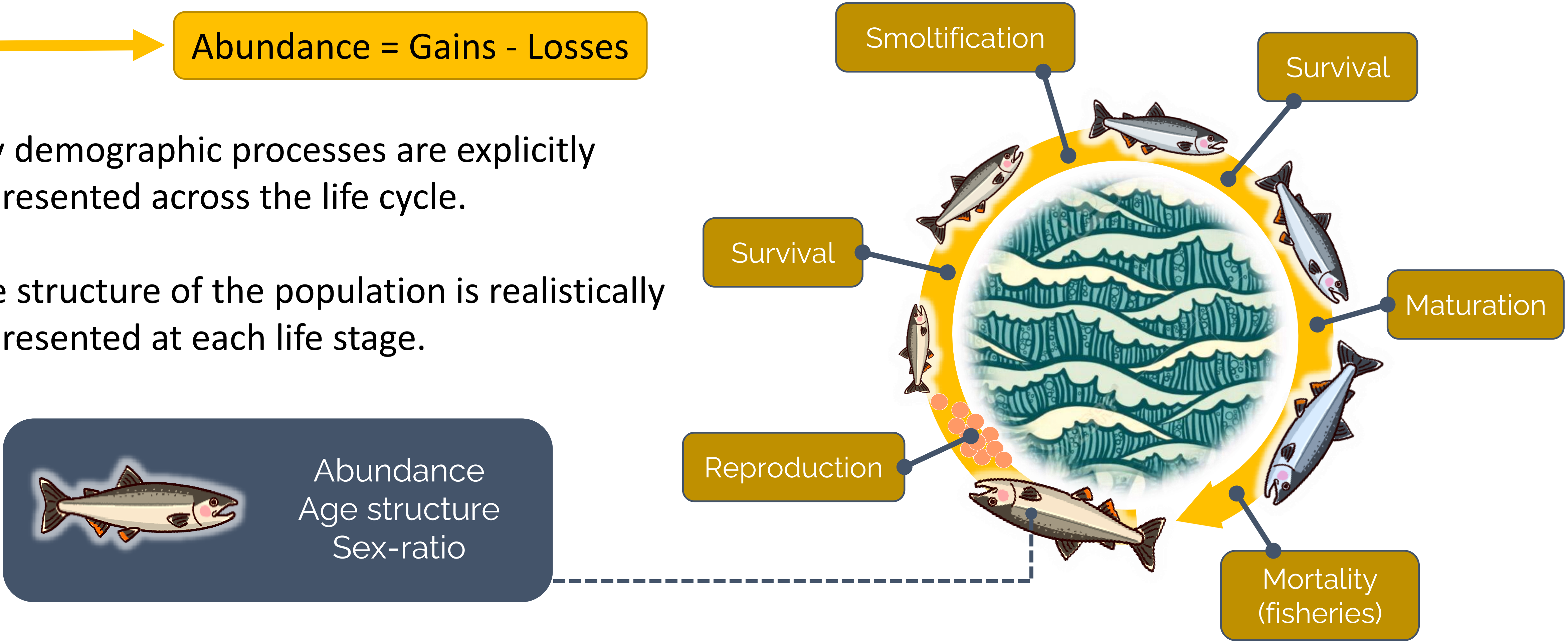


Life cycle models of salmon population dynamics

Abundance = Gains - Losses

Key demographic processes are explicitly represented across the life cycle.

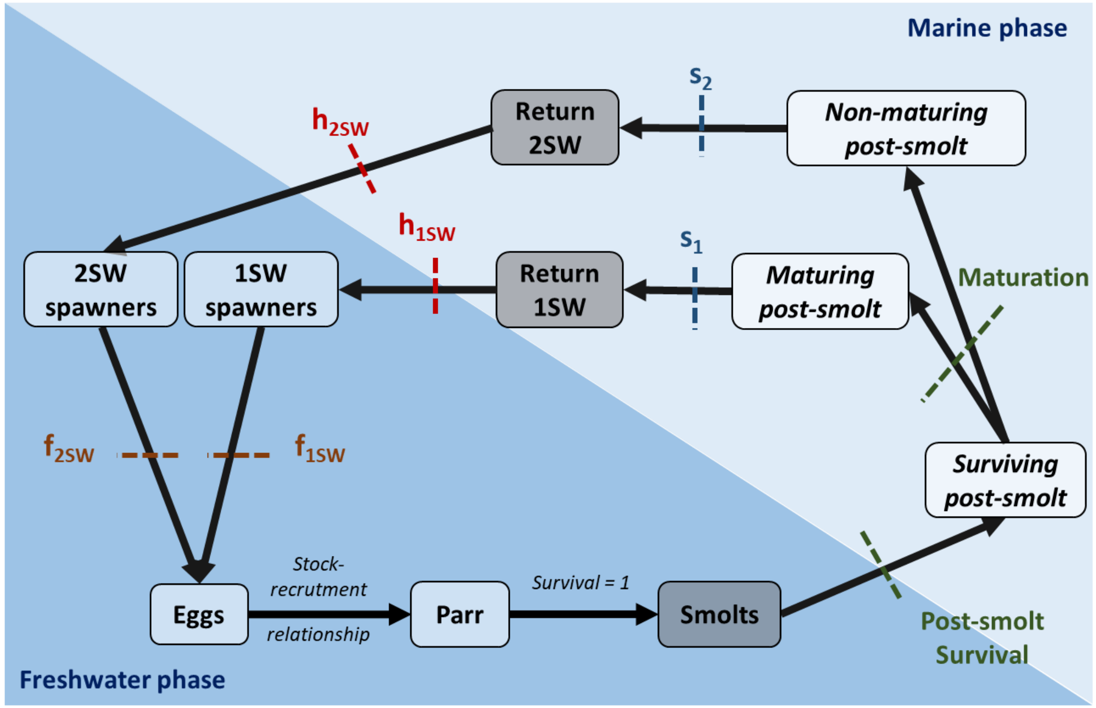
The structure of the population is realistically represented at each life stage.



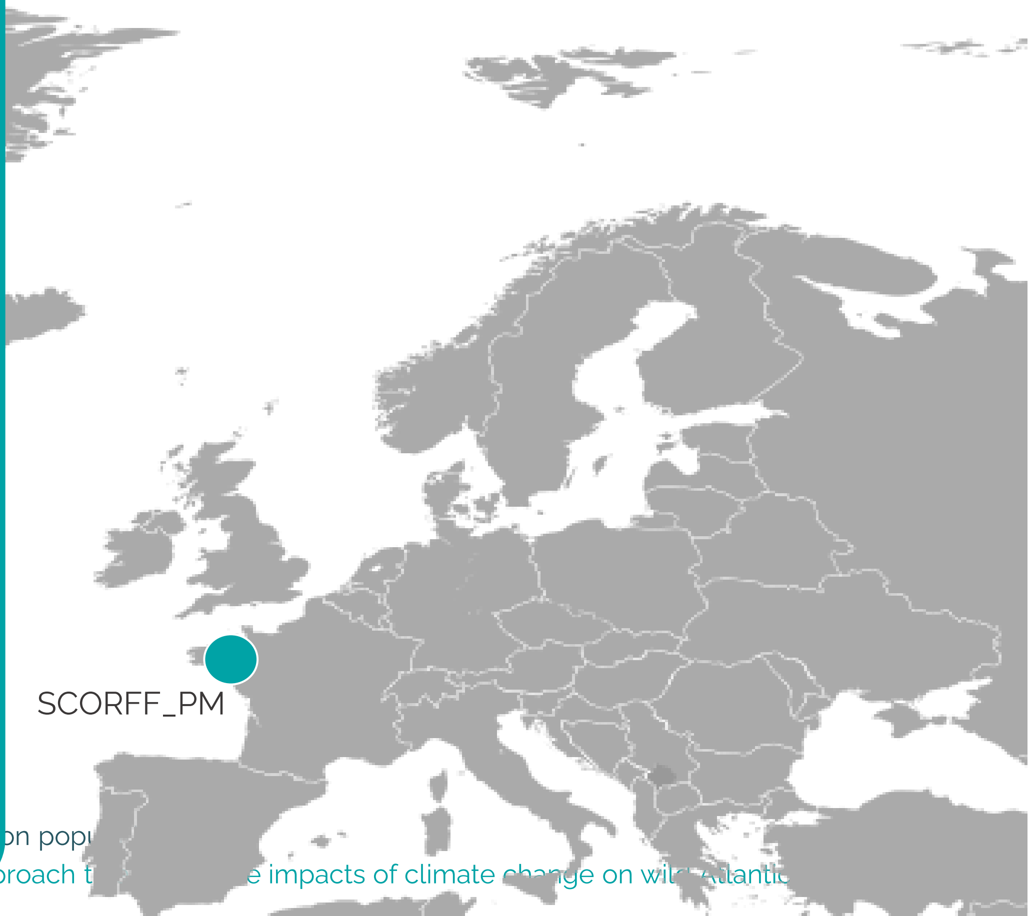
Life cycle models of salmon population dynamics

Life cycle models provide a unified framework applied on a variety of spatial scales.

SCORFF_PM: 1 index river



Rivot et al. (In prep)



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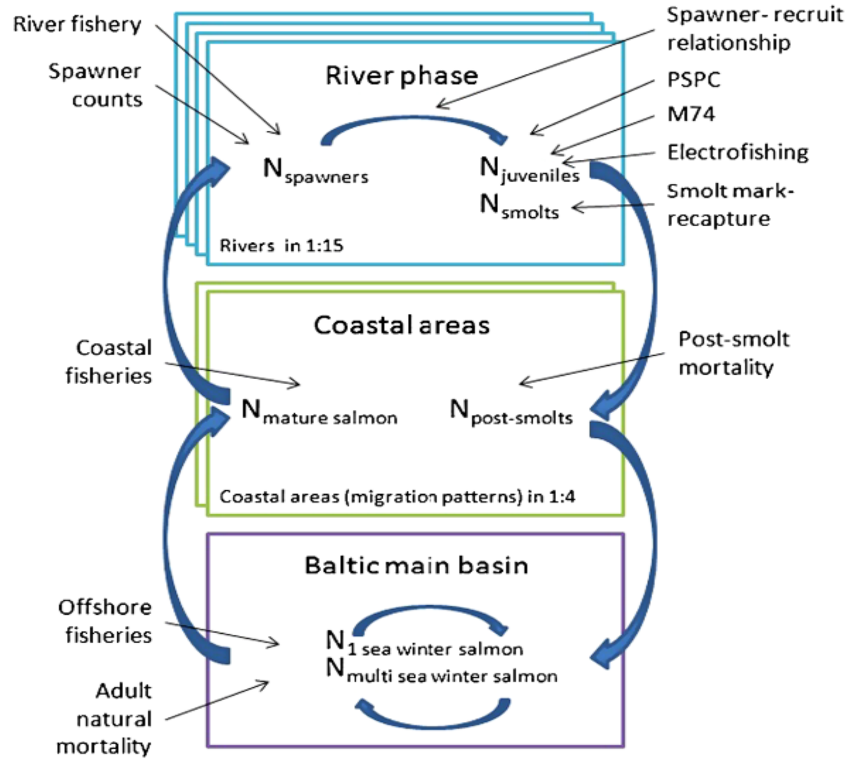
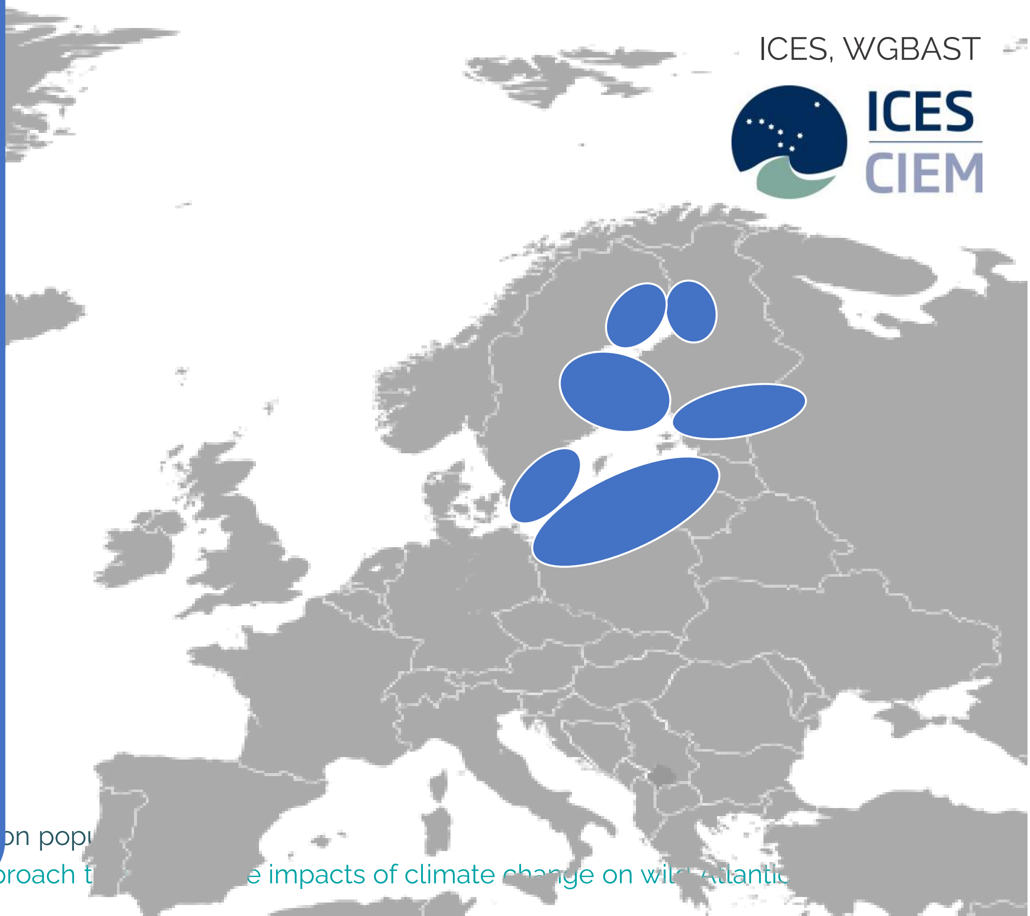
WGBAST: 15 rivers feeding 6 assessment units



Kuikka et al. (2014)

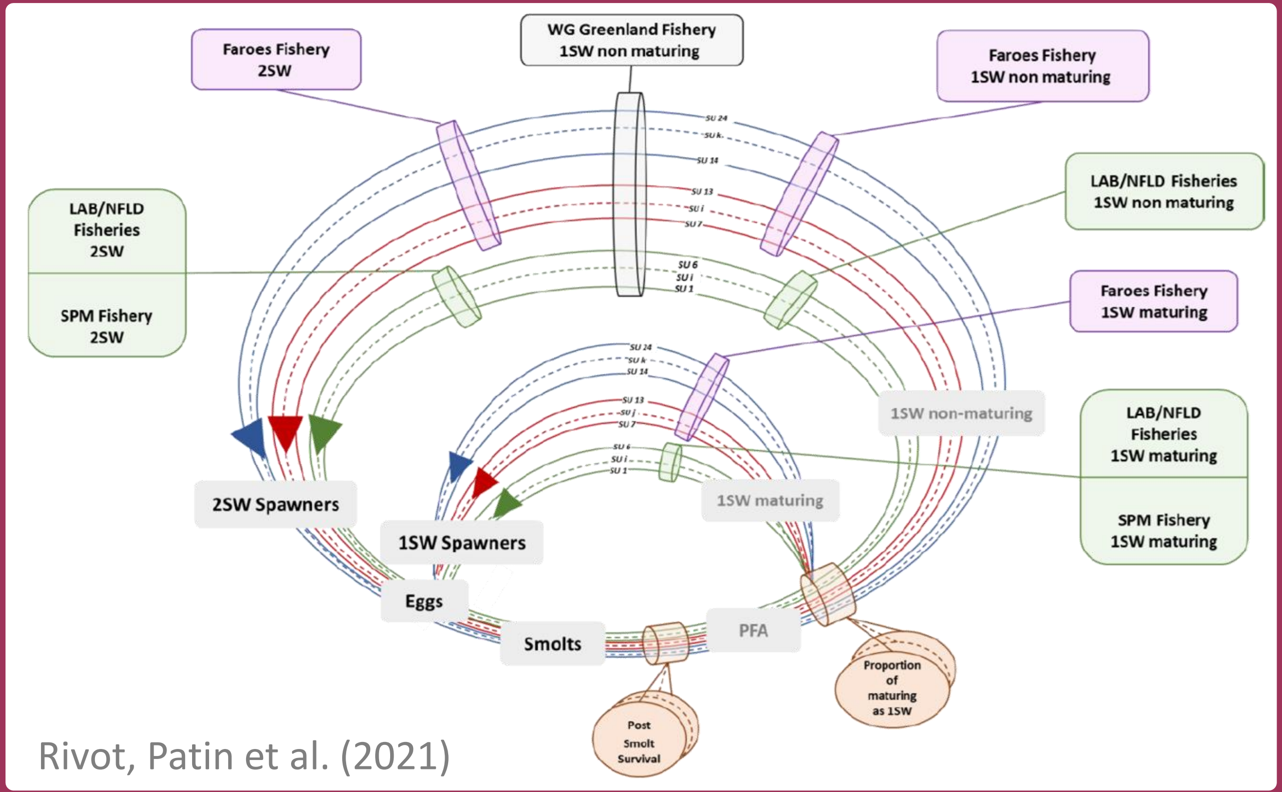


ICES, WGBAST

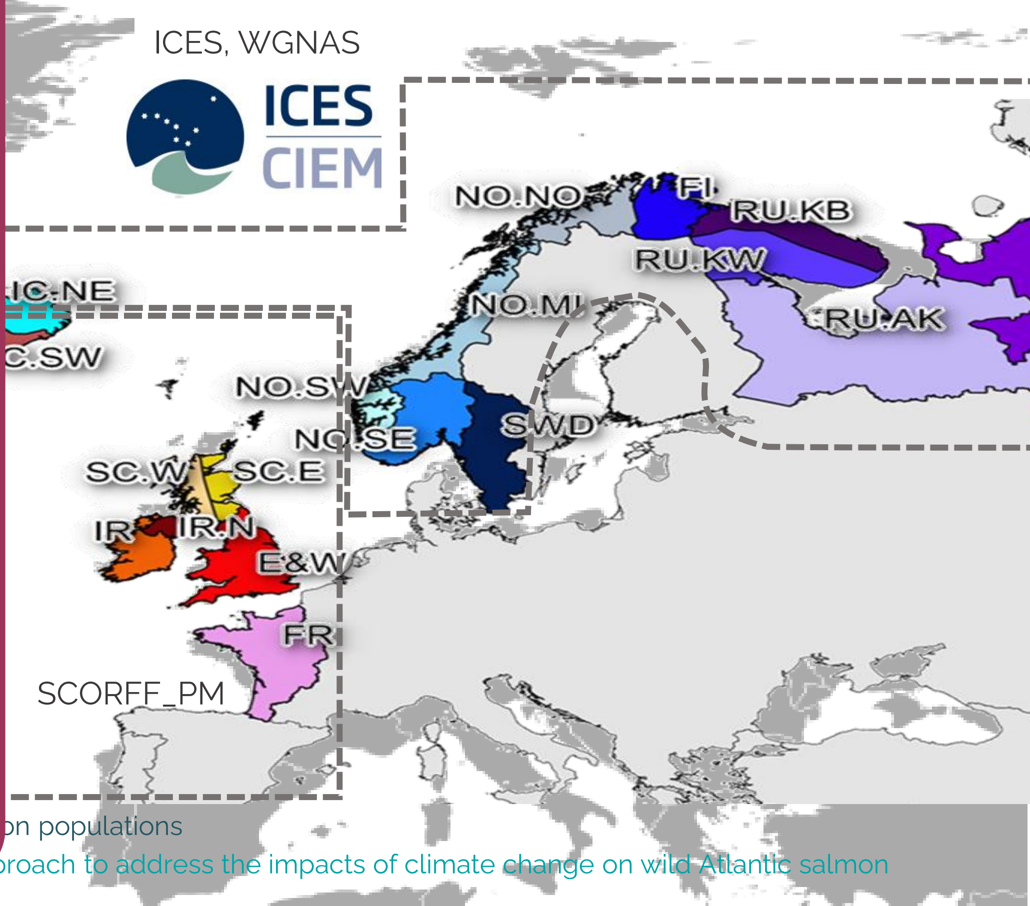
Life cycle models of salmon population dynamics

Life cycle models provide a unified framework applied on a variety of spatial scales.

WGNAS: 25 stock units in 3 complexes



Rivot, Patin et al. (2021)



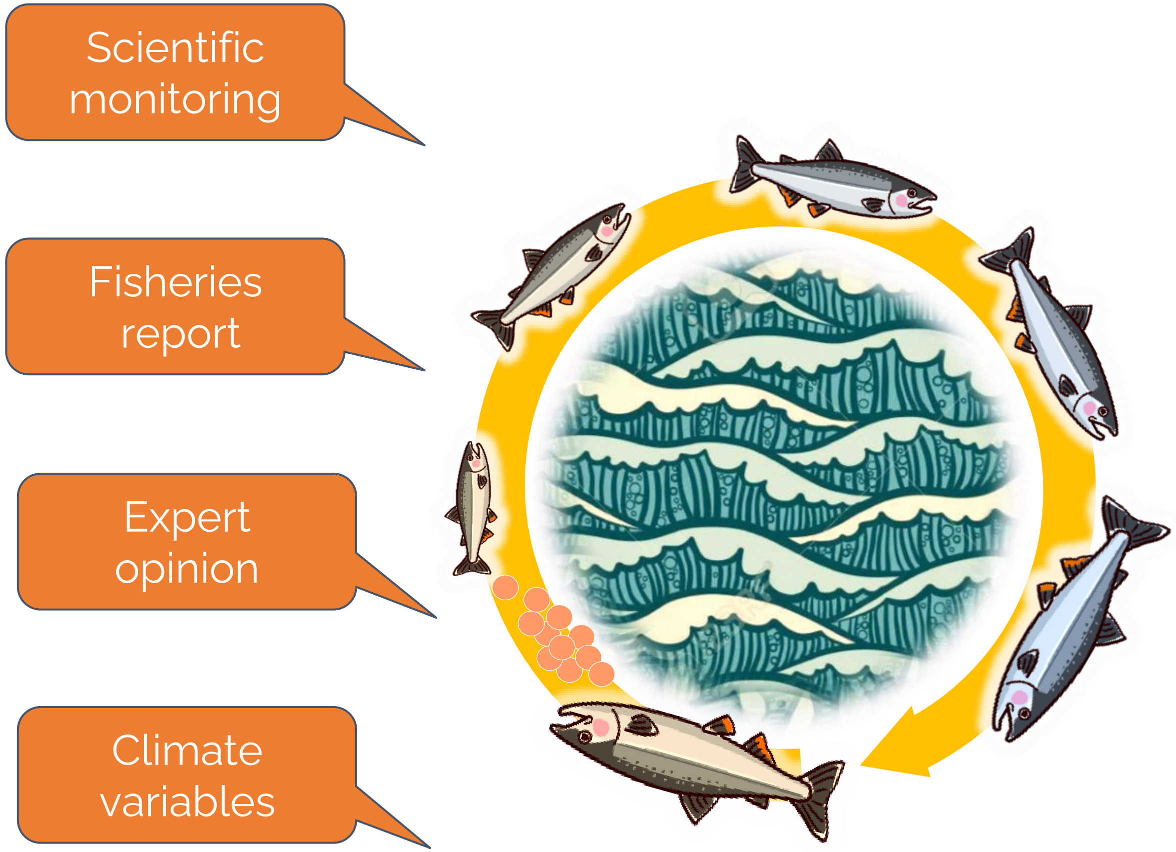
on populations

proach to address the impacts of climate change on wild Atlantic salmon

Life cycle models of salmon population dynamics

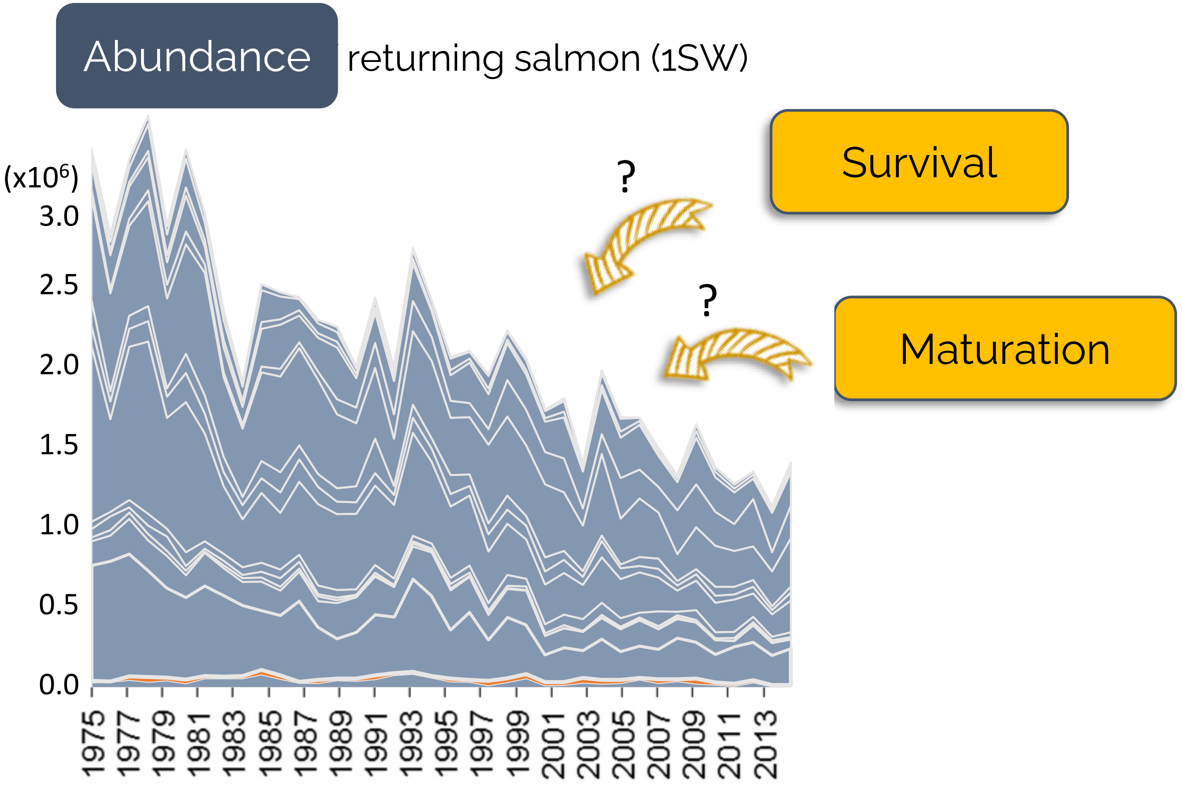
Statistical models are based on data to produce estimates of past and present population dynamics (hindcast).

The statistical models integrate different sources of information and can make the most of available data and knowledge.



Hindcast of past salmon population dynamics

Statistical models can describe the unobserved demographic processes underlying the observed changes in past population abundance (given some hypotheses).



ICES, WGNAS (2021)

Hindcast of past salmon population dynamics

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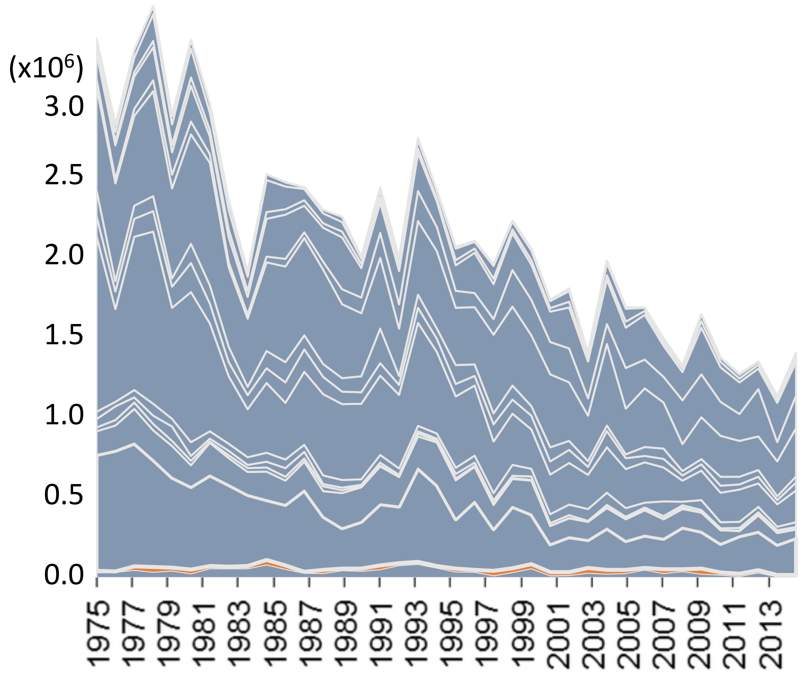
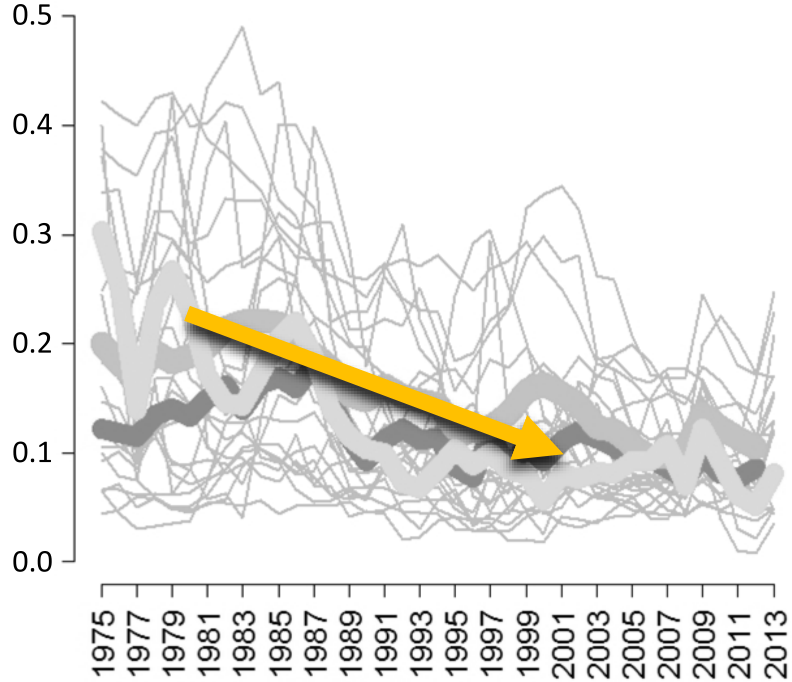
Abundance returning salmon (1SW)

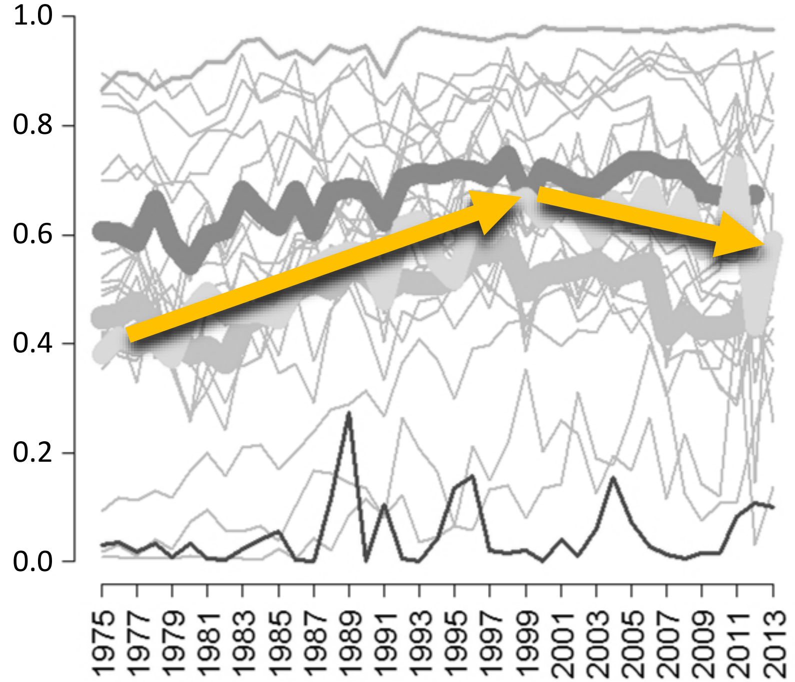


ICES, WGNAS (2021)

Post-smolt survival



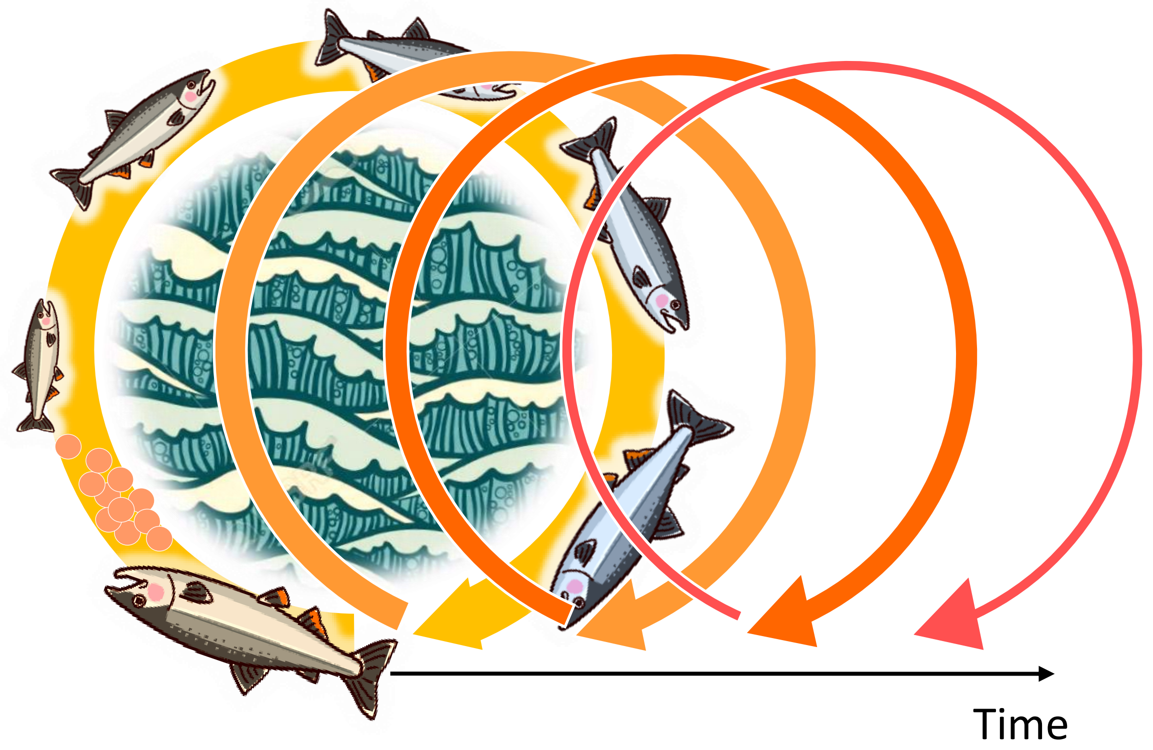
Maturation after 1SW



Rivot et al. (2021)

Short-term forecast of future salmon population dynamics

Statistical models can produce short-term projections of salmon populations.
In the absence of new data, the model propagates uncertainties in forecasts very quickly.



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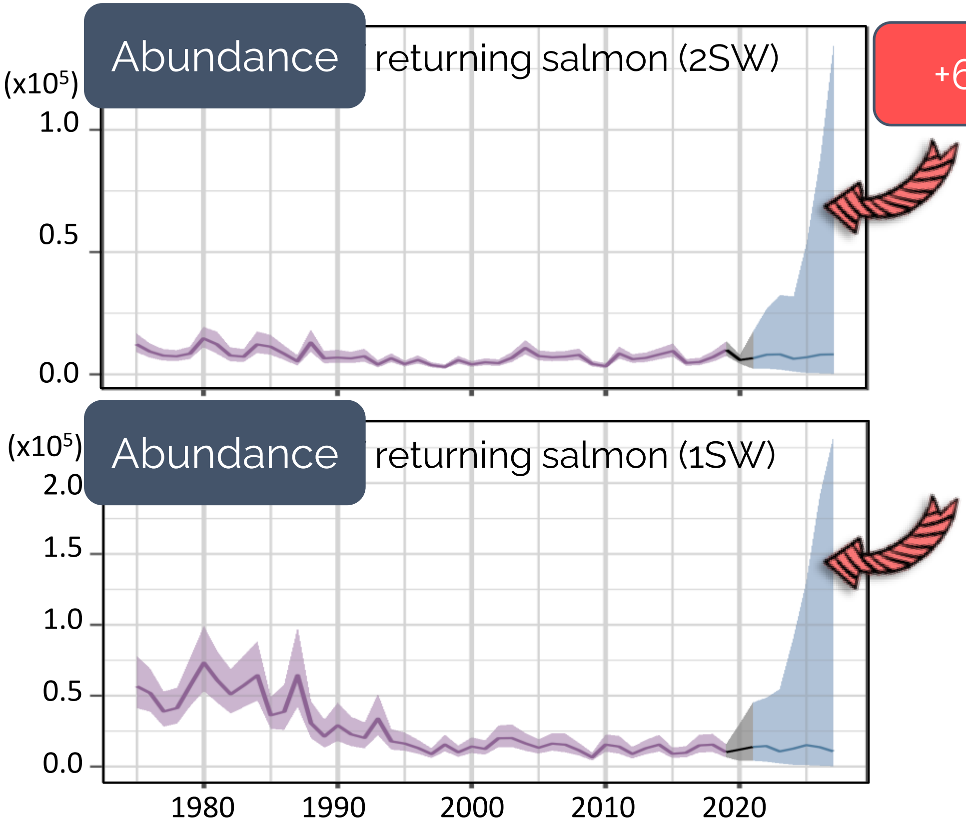
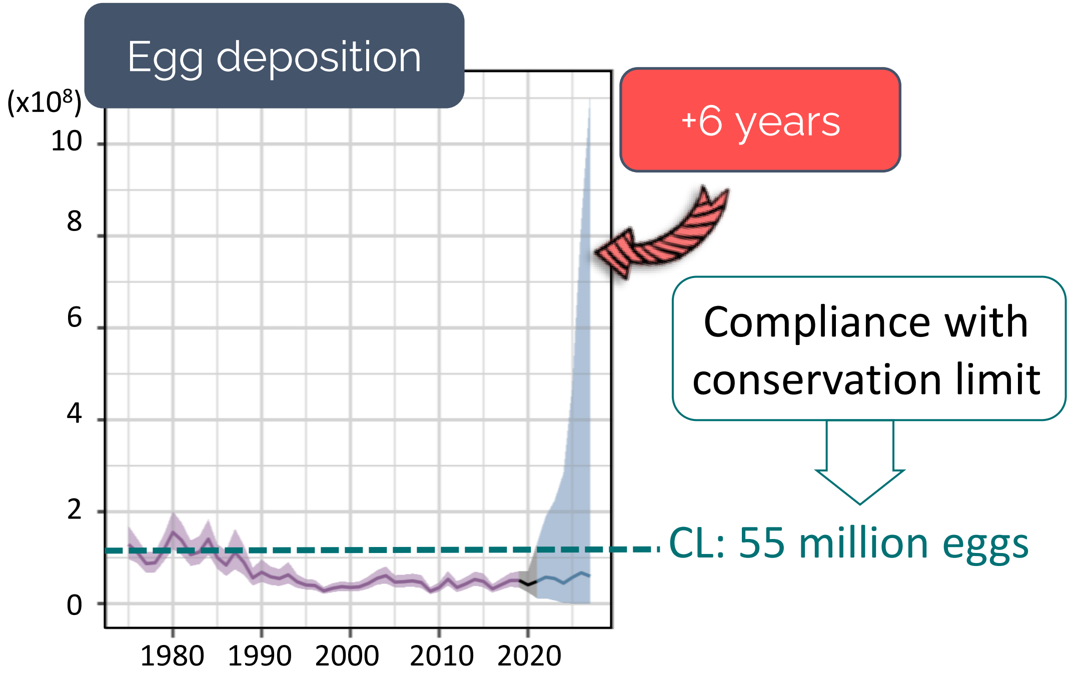
France

Rivot et al. (2021)



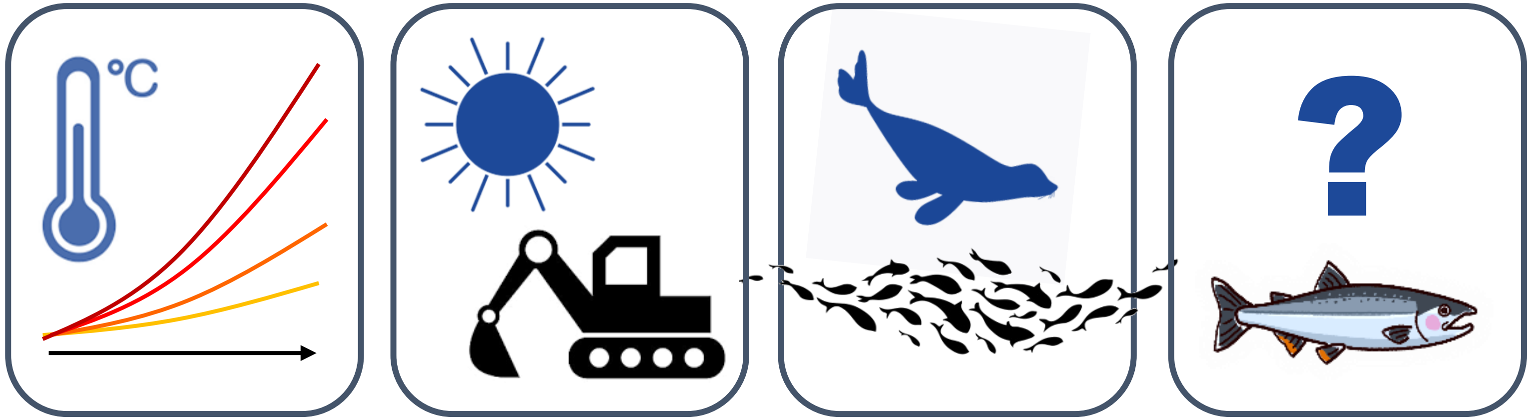


Long-term forecast of salmon population dynamics

Life cycle models cannot predict the future far ahead.

Responses to climate change cannot be forecasted because:

- models of future climatic conditions are uncertain,
- climate change interacts with anthropogenic activities,
- salmon interact with other species within an ecosystem,
- salmon will face conditions never experienced before.



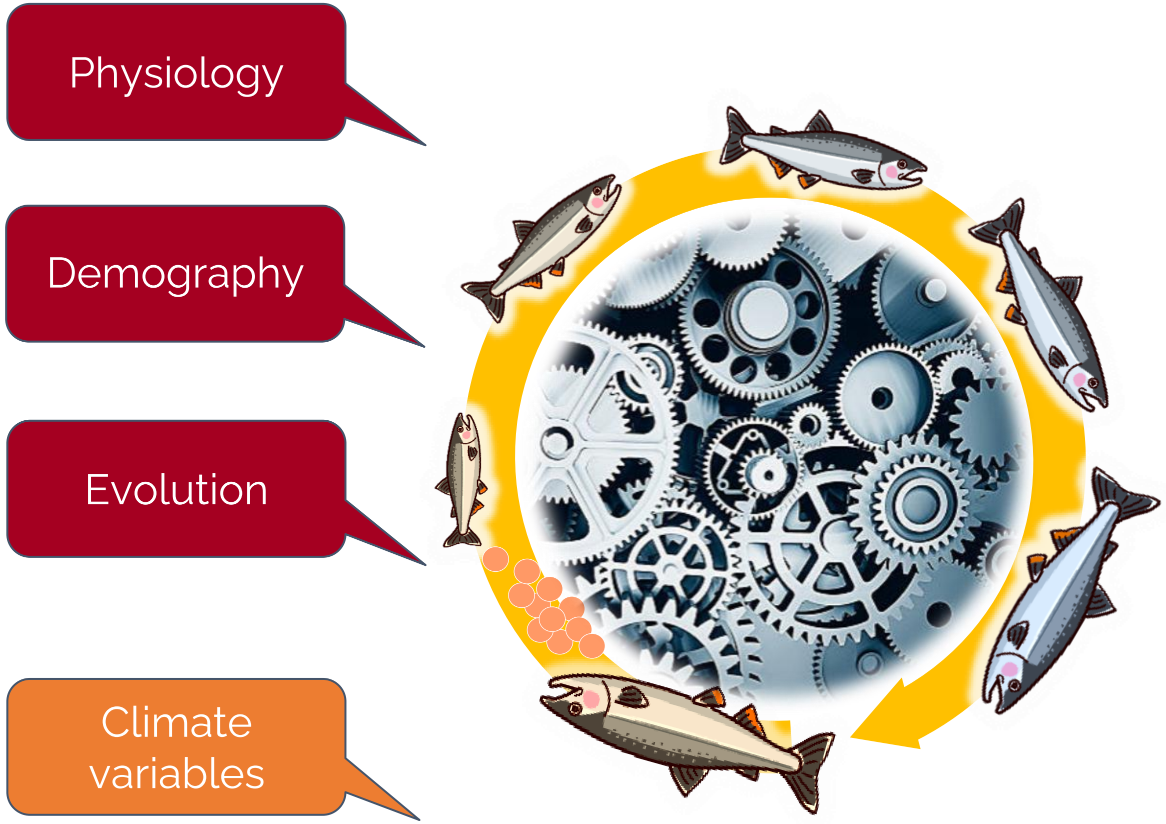
Prediction

Exploration of scenarios

Long-term forecast of salmon population dynamics

Simulation models are based on a more detailed representation of biological mechanisms and their interactions (physiology, demography, evolution).

The simulation models rely on information provided by statistical models and can be used for prospective studies.



Long-term forecast of salmon population dynamics

Life cycle models can simulate the response of salmon populations to different scenarios.
In this computer-based experiment, model outputs depend on the selected set of hypotheses.

Long-term forecast of salmon population dynamics

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In this computer-based experiment, model outputs depend on the selected set of hypotheses.

A case study from model IBASAM:

Climate change
in the freshwater environment

Evolution

Homewater fishery
High selectivity on MSW

Piou et al. (2015)

Climate change
Poor marine growth conditions

Plasticity

Management
in the marine environment

Management
In transition zone

Long-term forecast of salmon population dynamics

Life cycle models can simulate the response of salmon populations to different scenarios.
In this computer-based experiment, model outputs depend on the selected set of hypotheses.

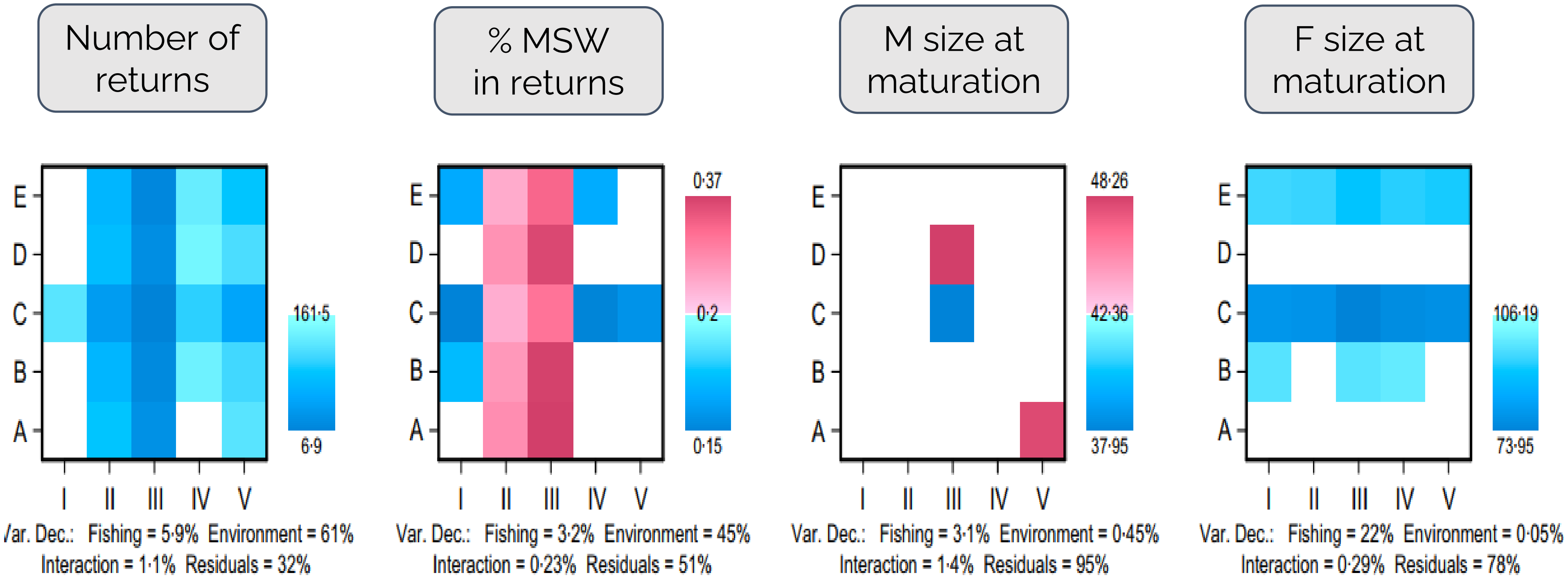
5 scenarios

Climate change
Poor marine growth conditions

x 5 scenarios

Homewater fishery
High selectivity on MSW

After 50 years



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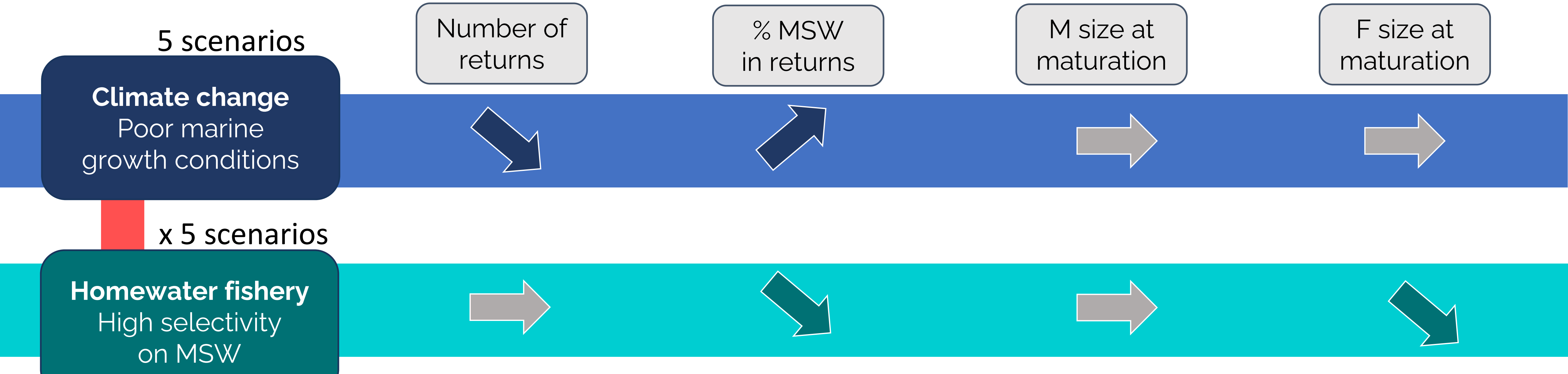

After 50 years

In this virtual experiment, high fishing pressure on MSW worsen the effect of climat change at sea on salmon population dynamics and resilience.

Piou et al. (2015)

Conclusion

Simulation is not prediction, but simulations can be useful to prepare the future.

Future will always be uncertain, but we can aim at managing the risks induced by these uncertainties.

Life-cycle models are key tools to help policy making, but scientists and managers should keep a critical eye on model output, their potentialities and their limits.

Thank you for your attention.

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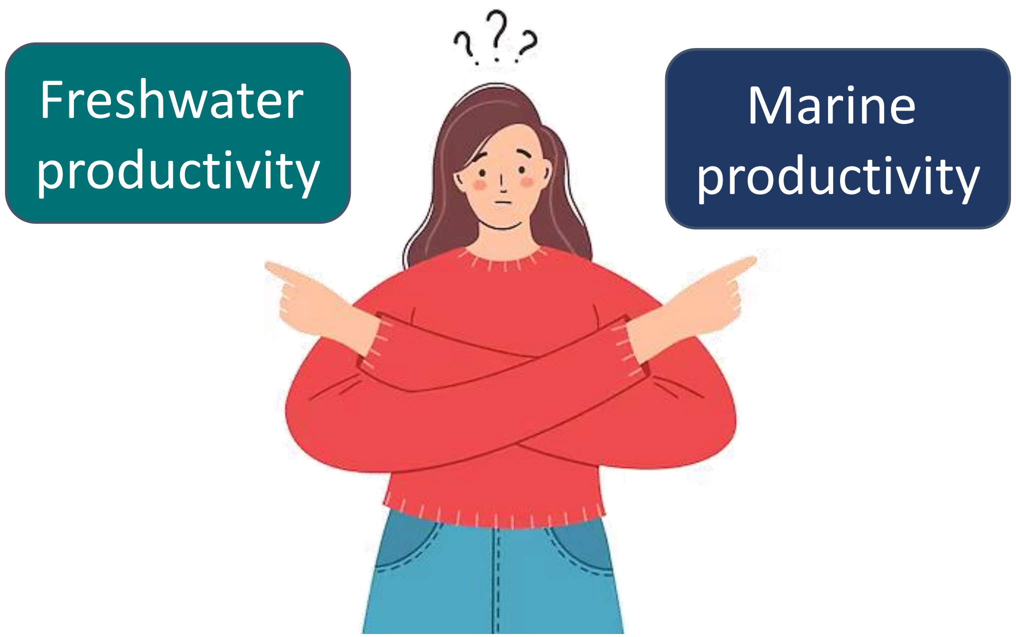
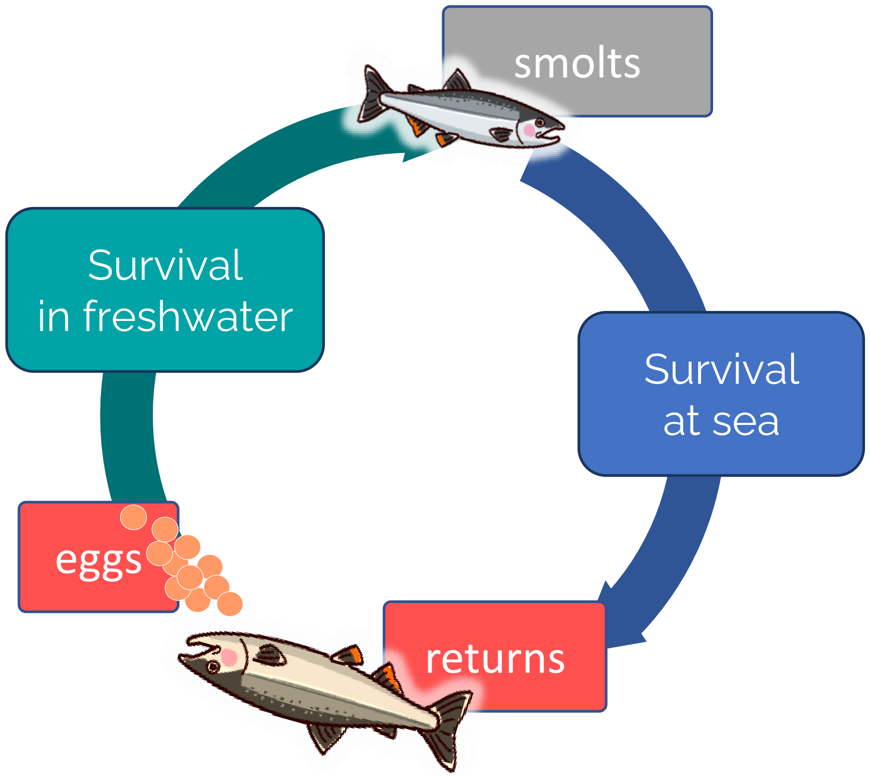
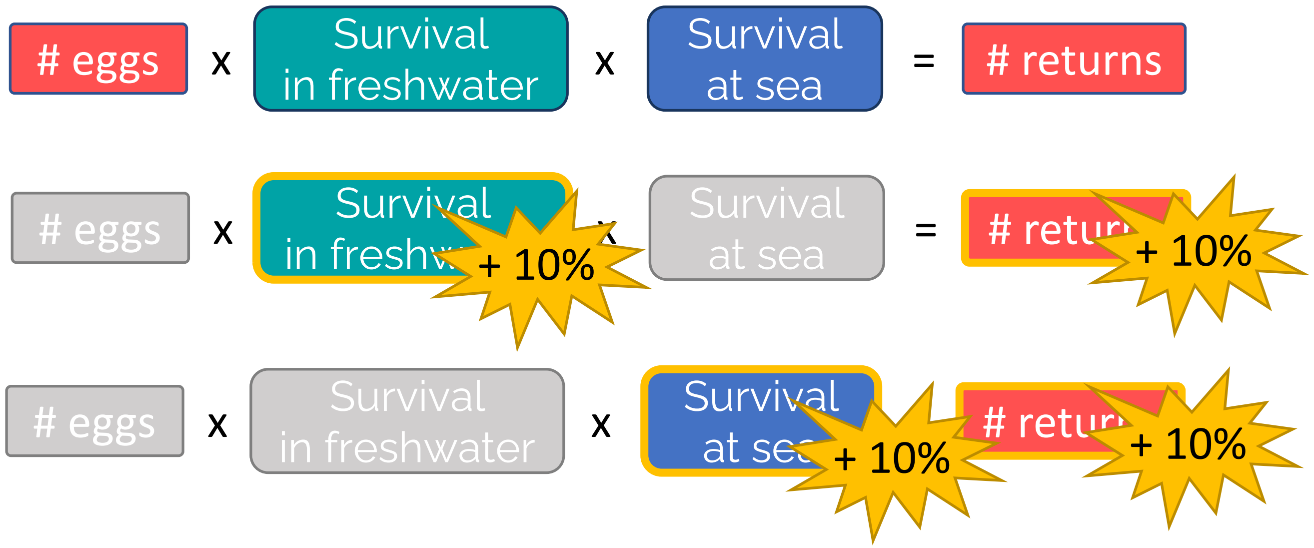
From forecast to foresight of salmon population dynamics

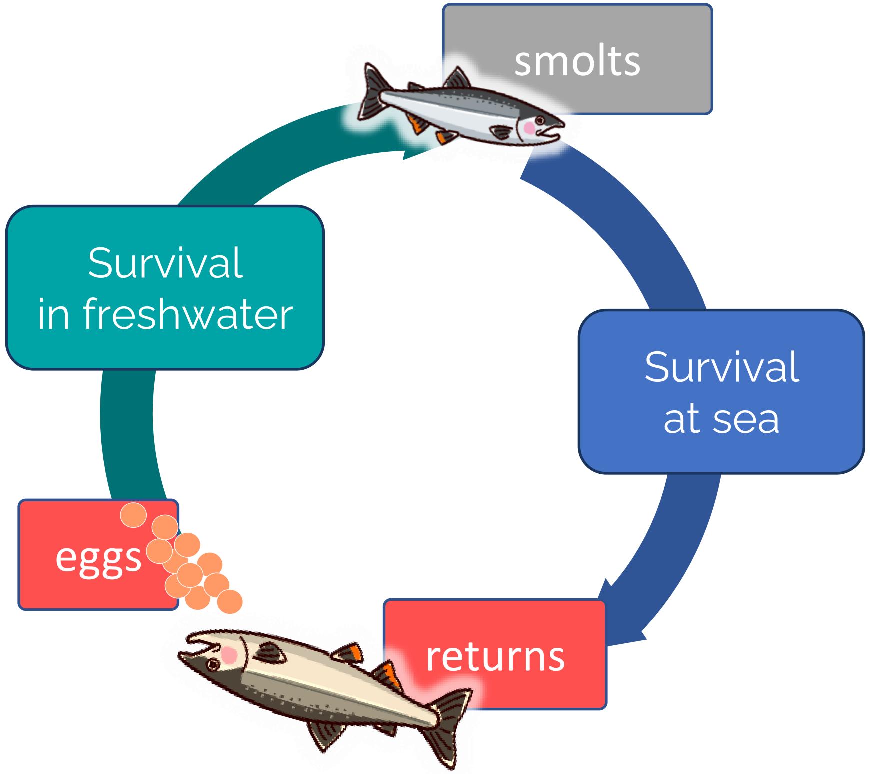




From forecast to foresight of salmon population dynamics

- Multiplicative effect of demographic rates.
- Any given increase of a rate would have the same effect on productivity, whatever the rate.

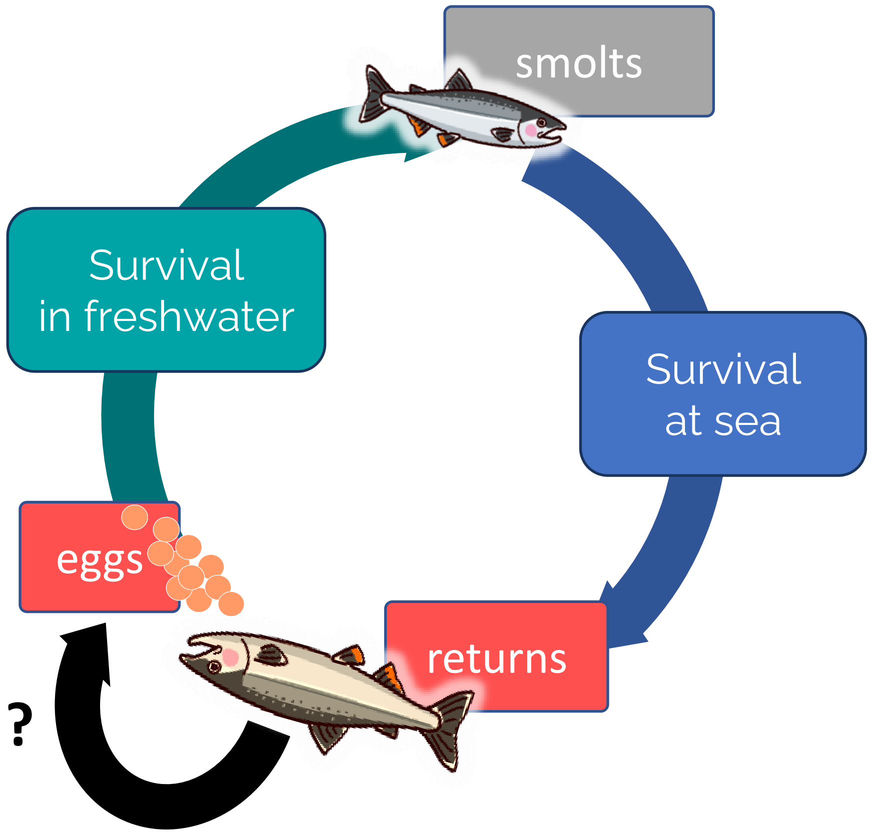




From forecast to foresight of salmon population dynamics

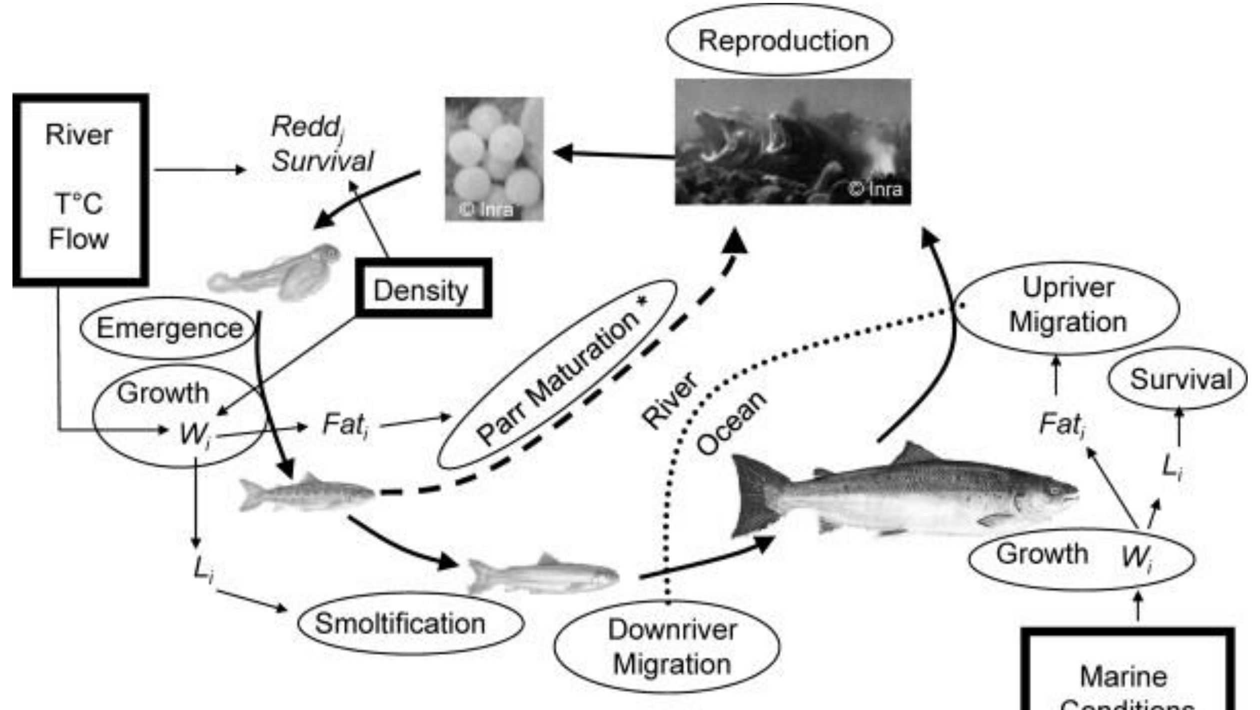
- Multiplicative effect of demographic rates.
- Any given increase of a rate would have the same effect on productivity, whatever the rate.

- Demographic rates are not independent.
- Any given increase of a rate would potentially have an effect on the other subsequent rates.
- How to estimate survival, and other rates?



From forecast to foresight of salmon population dynamics

IBASAM: a model for 1 index river + neaby rivers



Piou & Prévost (2012, 2013)

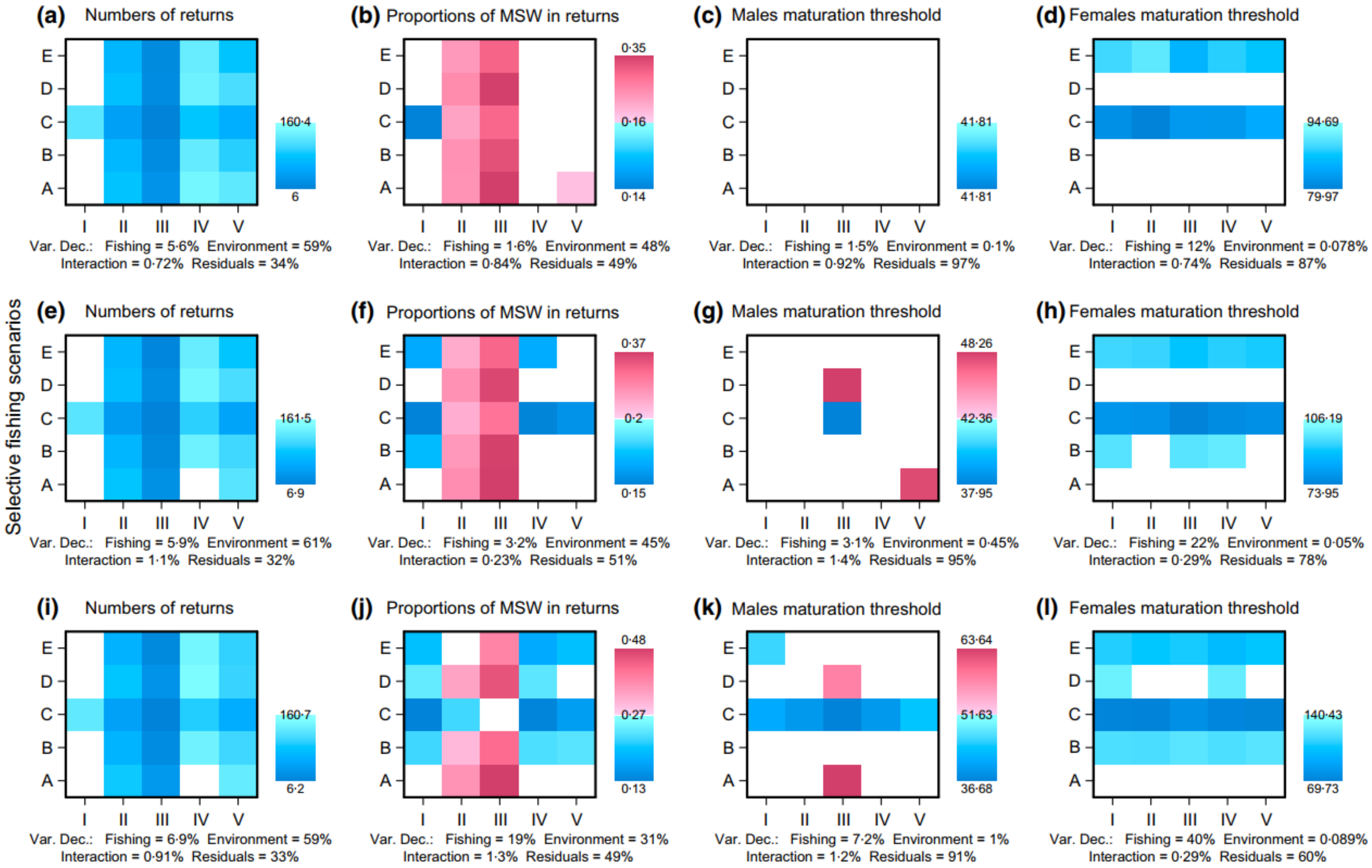


Fig. 4. Influence of oceanic growth conditions (I–V scenarios) and selective fishing on multiple-sea-winter (MSW) (A–E scenarios) at final simulation time (50 years) and for different heritability values (a–d: $h^2 = 0{\cdot}2$; e–h: $h^2 = 0{\cdot}4$; i–l: $h^2 = 0{\cdot}99$) on numbers of returning individuals to the river (a, e & i), proportions of MSW in these returns (b, f & j), genetically coded maturation thresholds of anadromous males (c, g & k in grams) and females (d, h & l in grams). For each graph, a white colour indicate that the simulation results are not different (pairwise *t*-tests with Bonferroni correction, $P = 0{\cdot}002$) from the base scenario (I–A) at the given heritability. Note that *t*-tests are used here only as a mean to identify the most prominent effects and must not be interpreted in the usual context of statistical significance since we control the number of replicates in our experimental setting. Blue intensities indicate the strength of decrease and red intensities indicate increase. Colour scales on the right of each graph indicate the ranges of significantly different mean values resulting from the last 5 years of the 100 replicates of the scenarios. The variance decomposition (Var. Dec.) indications for each graph help in the interpretation of the respective effects of the treatments (selective fishing and environmental growth conditions), their interactions and the replicate variations (residuals) into the variance of the given measures.

Piou et al. 2015