A bayesian hierarchical modelling approach to unravel large scale patterns of decline in the marine productivity of A. salmon in the North Atlantic Ocean

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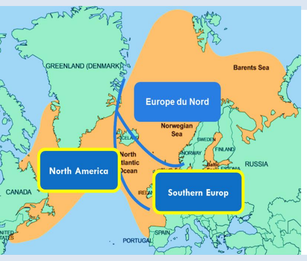
CONTEXT & OBJECTIVES



✓ **Context**

- A decline of Atlantic salmon (*Salmo salar*) population worldwide.

✓ **Questions**

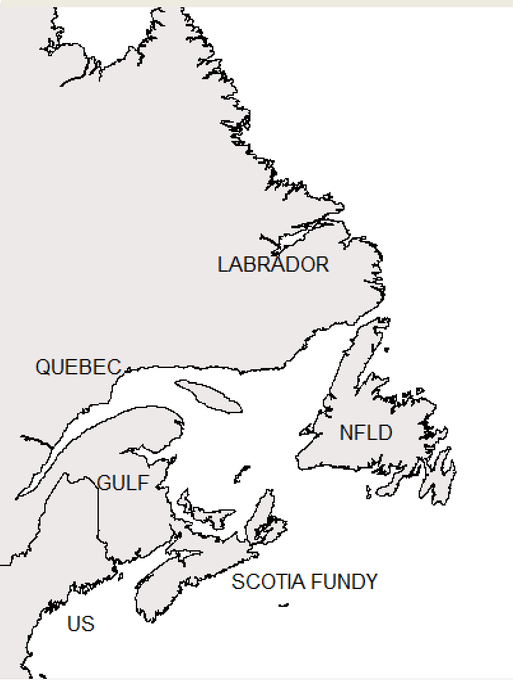
- Demographic and ecological mechanisms are unknown ?
- A response to global changes ?

✓ **Objectives & Approaches**

- A life cycle model that captures the population dynamics of all stock units (SU) of the European (7 SU) and the North American coast (6 SU) of the Atlantic Ocean.
- Separating out the effects of fishing and environmental variations in a hierarchy of scales (local and global).
- Unraveling the fingerprints of global changes on key life history traits of the marine phase: marine survival and probability to mature after the first year at sea .

MATERIAL & METHODS

North American Complex
6 stock units

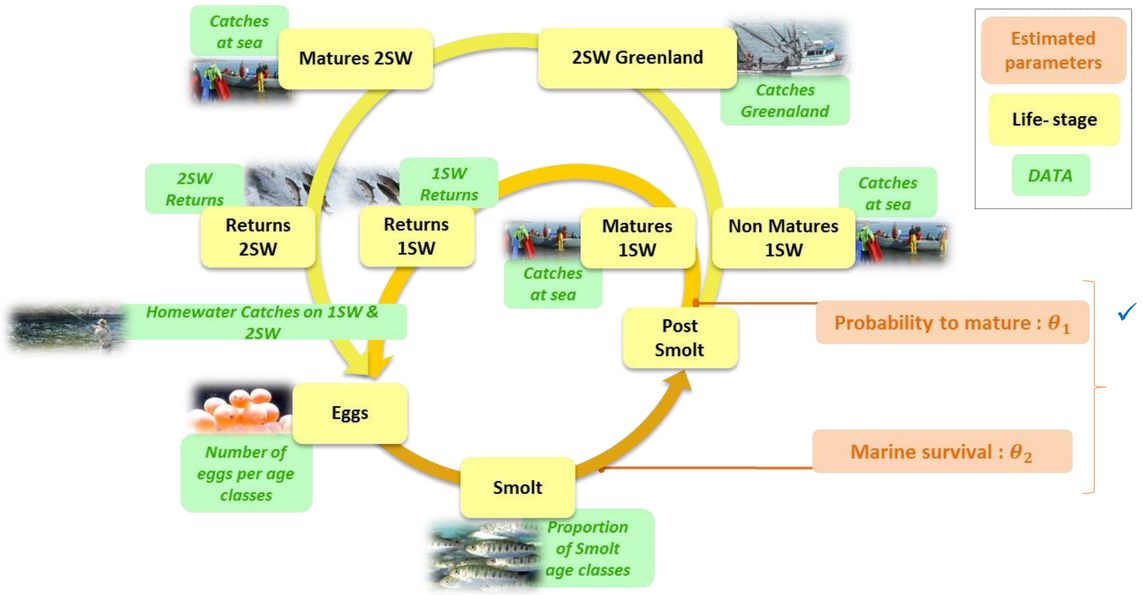


✓ A Bayesian Hierarchical Modelling framework to assimilate a 43-years time series of data (1970-2012) compiled by ICES WGNAS

✓ Age and stage-based life cycle model

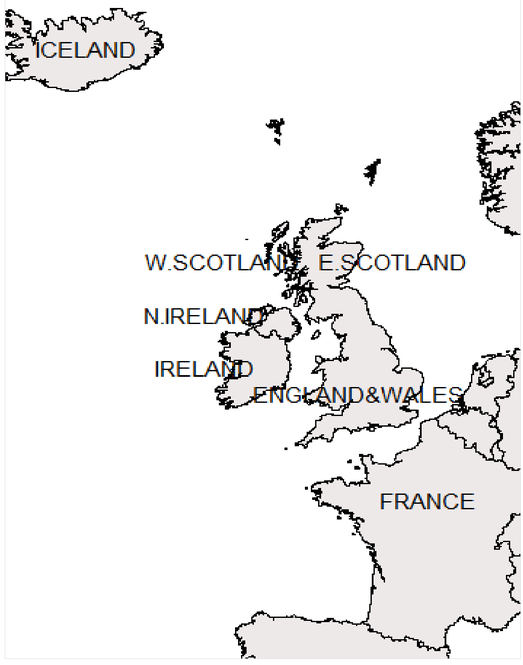
- Variability of life histories : Smolt ages (1 to 6 years) and Sea ages (1 Sea winter (1SW) or 2 Sea winters (2SW))
- Marine phase includes Natural Mortality and Fishery Mortality

✓ Common structure for each of the 13 stock units, but with specific parameters and data



✓ M1, M2 : Alternative models to quantify the spatial coherence in the dynamics of marine survival and maturing probability among stock units

Southern European Complex
7 stock units

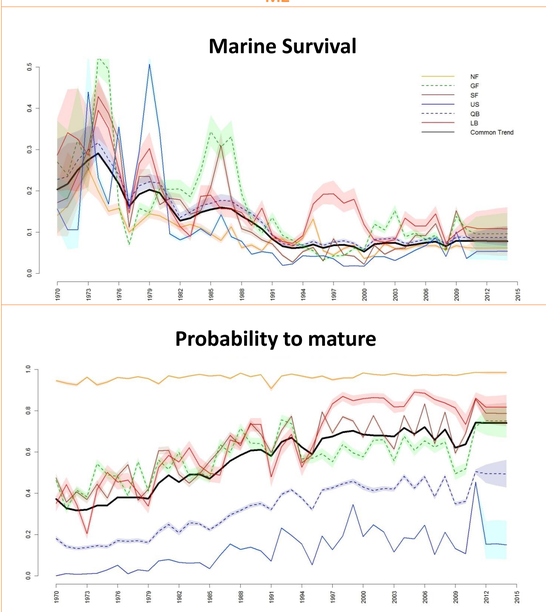


GENERAL STRUCTURE	*For t = 1: 43 r = 1:N with N=6 for North American complex and N=7 for Southern European complex*
M1 : Random walk with covariations among stock units	$logit(\theta_{t,r}) = logit(\theta_{t-1,r}) + \varepsilon_{t,r}$ $\quad \varepsilon_{t,r=1:N} \sim N\left(0, \sum s\right)$ $\quad \sum s = \begin{pmatrix} \sigma^2{}_{1,1} & \cdots & \sigma^2{}_{N,1} \\ \vdots & \ddots & \vdots \\ \sigma^2{}_{1,N} & \cdots & \sigma^2{}_{N,N} \end{pmatrix}$
M2 : Year variation partitionned into a common and a region-specifc component	$logit(\theta_{t,r}) = \gamma_t + \delta_r + \varepsilon_{t,r}$ $\quad \gamma_t = \gamma_{t-1} + \omega_t$ $\quad \omega_t \sim N(0, \sigma^2{}_\gamma)$ $\quad \varepsilon_{t,r=1:N} \sim N(0, \sum s)$ $\quad \sum s = diag(\sigma^2{}_1, \ldots, \sigma^2{}_N)$

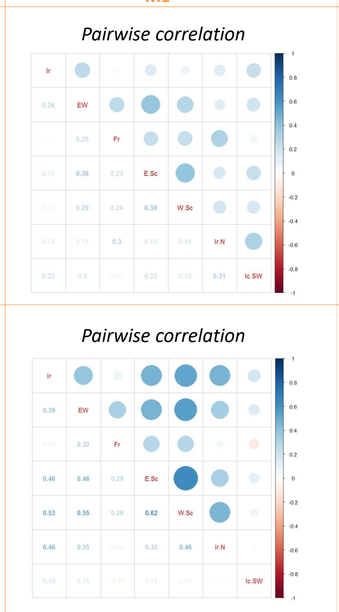
RESULTS

North American complex

M2

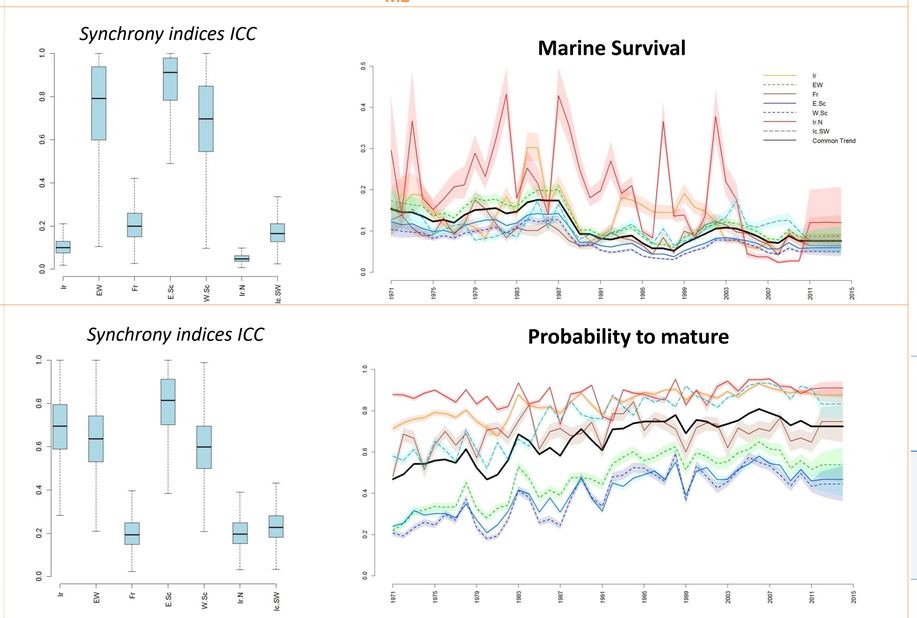


M1

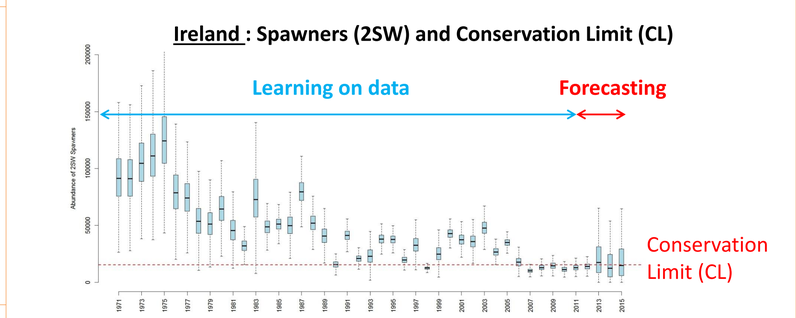


Southern European complex

M2



Predictions and Probability to reach the conservation limits



Stock Units	NF	GF	SF	US	QB	LB	Ir	E&W	Fr	Sc	N Ir	Ic
Probabilty to reach the CL (number of spawners) in 2013	0.25	0.15	0.0	0.0	0.12	0.47	0.56	0.82	0.02	0.18	1.0	0.85

✓ Models with covariations outperform models with independent time series among stock units (not shown), both in terms of quality of fit and predictive performance

✓ M1 slightly outperforms M2 in term of DIC and predictive performance (cross validation)

✓ Most of the pairwise correlations between time series of marine survival and probability to mature are positive (M1). Overall, pairwise correlations are stronger between closer stock units

✓ Generally, models provide evidence for a decline in the marine survival and for an increase in the maturing probability, common to all stock units in North America and Southern Europe

✓ Partition into a shared and specific component (model M2) shows contrasted patterns of relations between the common trends and each stock unit, with synchrony indices ranging from 0.8 (marine survival, Scotland East) to 0.1 (marine survival, Northern Ireland)

✓ Both models provides the posterior predictive probability of the abundance of spawners for all forecasted years (3 years) that can be compared to Conservation Limits (CLs) as defined by ICES WGNAS

CONCLUSIONS

✓ **A hierarchical model that quantifies the spatial coherence in the temporal variation of key demographic parameters**

- **Covariance among stock units is high and provides evidence for a common response of distant populations**
- **Trends suggest that marine survival and maturing probability are not independent: a decline in marine survival being associated with an increase in maturing probability**

✓ **Results support the hypothesis of a response of populations to environmental factors susceptible to impact distant populations**

✓ **A response of salmon populations to changes in the marine ecosystem observed in the North Atlantic in the early 1990s, that may have induced changes in the availability and quality of salmon preys** *(Beaugrand et al., 2003, 2013 ; Mills et al., 2013)*

PERSPECTIVES

Improve ecological and demographic mechanisms → Hypothesis of a plastic response to environmental changes (link between Environmental conditions/Growth/Probability to mature/Survival)

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