First elements of exploration for the GR3D model (in development !)
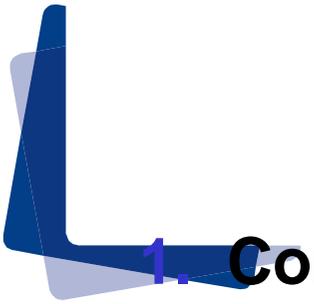# "Global Repositioning Dynamics for Diadromous fish Distribution"

T.Rougier (**thibaud.rougier@irstea.fr**), **P.Lambert, E. Rochard**

1. Context

2. The GR3D model

3. The next step: performing a sensitivity analysis !
→ HELP !!!

1. Context

1.1 Climate change and existing approaches

- **Beginning of my PhD in October 2010 :**

  « **Processes based approach of the repositioning of diadromous fish under the influence of climate change** »

- **Environnemental context of Climate Change**
  - *Threat for species and biodiversity → need to develop approaches to assess the potential impact of climate change*

- **Scientific context**
  - **Many studies using empirical and statistical models have forecasted the possible impact of climate change on species distribution for many taxa such as plants** *(Midgley et al., 2002 ; Thuiller, 2003, Zimmermann et al., 2009)*, **reptiles and amphibians** *(Segurado et Araujo, 2004 ; Araujo et al., 2006)*, **birds** *(Huntley et al., 2008)*, **mammals** *(Thuiller et al., 2006)*, **insects** *(Heikkinen et al., 2007, Barrows et al., 2008)*, **fish** *(Buisson, 2009)* **and diadromous fish** *(Lassalle, 2008)*

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1. Context
1.2 Call for new models

■ But…

REVIEWS AND SYNTHESES

Predicting species distribution: offering more than simple habitat models

Antoine Guisan[1][*] and Wilfried Thuiller[2,3]

Abstract
In the last two decades, interest in species distribution models (SDMs) of plants and animals has grown dramatically. Recent advances in SDMs allow us to potentially

Beyond bioclimatic envelopes: dynamic species' range and abundance modelling in the context of climatic change

Brian Huntley, Phoebe Barnard, Res Altwegg, Lynda Chambers, Bernard W. T. Coetzee, Lesley Gibson, Philip A. R. Hockey, David G. Hole, Guy F. Midgley, Les G. Underhill and

BIODIVERSITY VIEWPOINT

Moving beyond static species distribution models in support of conservation biogeography

Janet Franklin

Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models

David A Keith, H. Resit Akçakaya, Wilfried Thuiller, Guy F Midgley, Richard G Pearson, Steven J Phillips, Helen M Regan, Miguel B Araújo and Tony G Rebelo

ScienceDirect

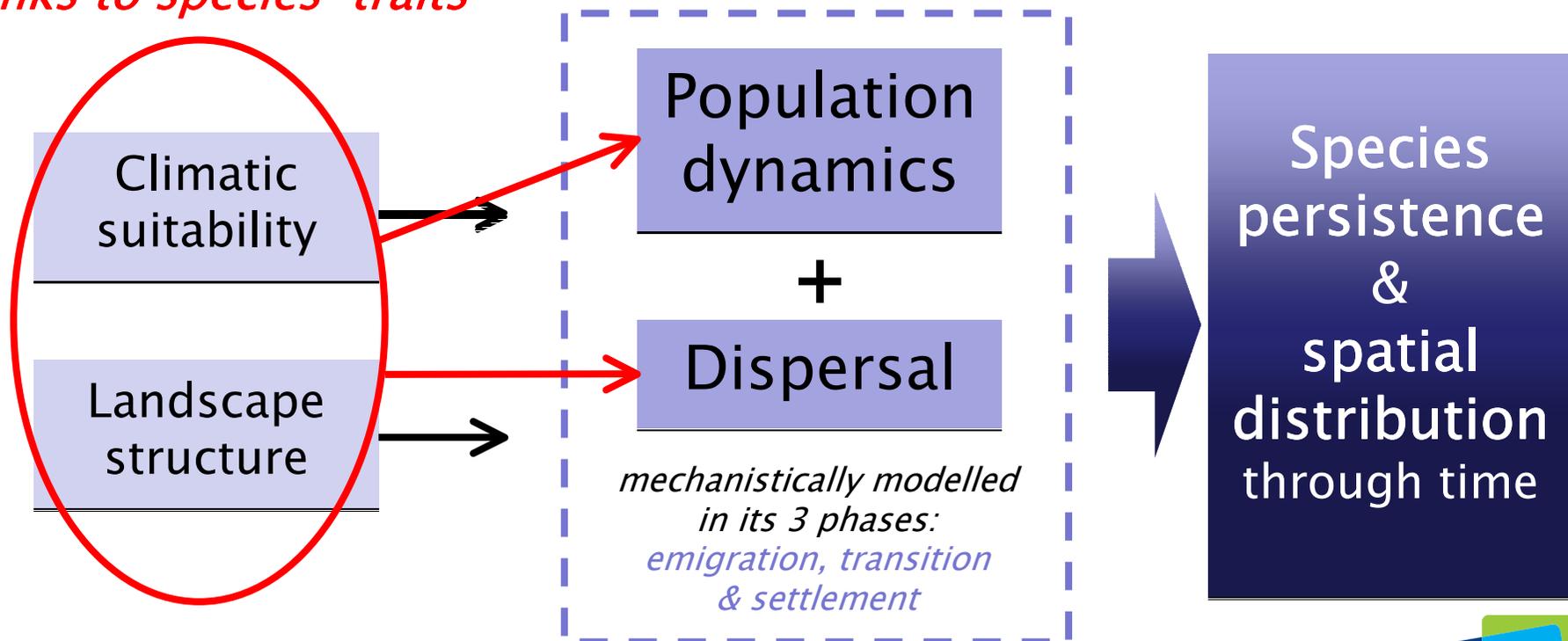## Predicting global change impacts on plant species' distributions: Future challenges

Wilfried Thuiller[a,*], Cécile Albert[a,1], Miguel B. Araújo[b,1], Pam M. Berry[c,1], Mar Cabeza[d,1], Antoine Guisan[e,1], Thomas Hickler[f,1], Guy F. Midgley[g,1], James Paterson[c,1], Frank M. Schurr[h,1], Martin T. Sykes[f,1], Niklaus E. Zimmermann[i,1]

Journées Mexico, 22&23/11/12

1.2 Call for new models

- **There is a call for a next generation of « fully integrated » dynamic models** *(Huntley et al. 2010)* **those could combine:**

Links to species' traits

```
Climatic
suitability          →          Population
                                  dynamics

                                      +

Landscape
structure            →            Dispersal

                     mechanistically modelled
                        in its 3 phases:
                     emigration, transition
                          & settlement
```

→ **Species persistence & spatial distribution through time**

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Test the effectiveness of alternative **management** strategies

Climate & Land use scenarios

Identify obstacles to persistence/range shift

Climatic suitability

Population dynamics

+

Dispersal

mechanistically modelled in its 3 phases: emigration, transition & settlement

Species persistence & spatial distribution through time

Landscape structure

Identify **data gaps** and guide further efforts in data collection

Gain a better understanding of species **spatial dynamics** and **processes**

6

... but also many CHALLENGES!!

- Details vs Generalisation

- What type of movement / dispersal model?

- Variability between individuals,

    populations & across the species' range

- Evolutionary response to environmental changes

- Spatio- temporal scales

- Data availability

Model parameterisation ???
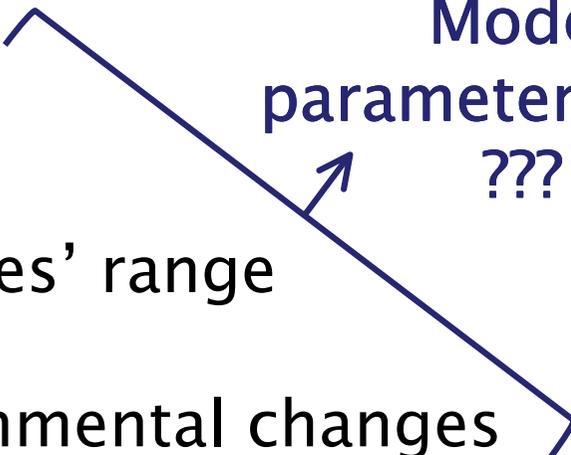
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2. The GR3D model
2.1 What it is

- **Under DEVELOPMENT**

- **Individual-based, spatially explicit and stochastic model**

- **Use of the SimAquaLife framework (Dumoulin, 2007)**

- **Designed to potentially work on several species (included virtual species) and switch easily from a species to another → exploitation of a life history traits database of European diadromous fish (TraitDiad 1.0)**
  - **First application with a shad-like species**

- **a <u>virtual environment</u>… Not definitive but at least in the first exploration phase…**

2. The GR3D model
2.2 Components of GR3D – Biological processes

■ **In each biological process, the <u>key inputs</u> are <u>life history traits</u>**

For example:
- *size at maturity*
- *age of first reproduction*
- *reproduction season*
- *duration of the marine phase*
- *duration of the continental phase*
- *…*

→ *If we have the information for each of the 29 diadromous species present at the European scale, it will be relatively easy to switch from a virtual species to another…*

A data base is in construction…

2. The GR3D model
2.1 The environment

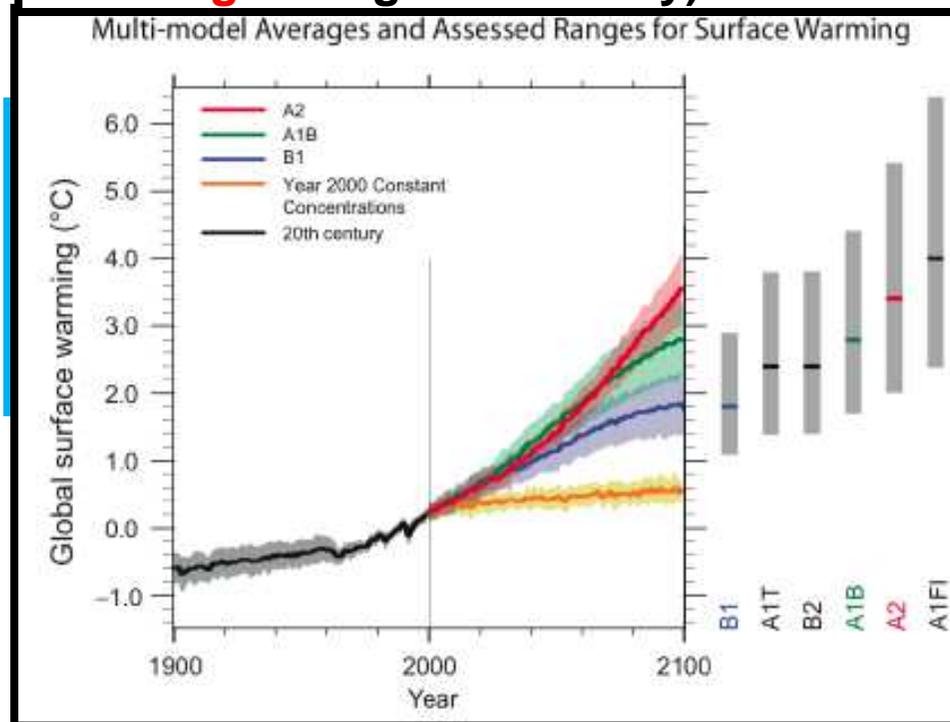■ A virtual environment with

An offshore basin   Sea basins   River basins

The Offshore b
- Temperature

We introduce a linear warwing (we just need to define **the intensity of the warming** during one century)

Multi-model Averages and Assessed Ranges for Surface Warming

River basin:
ition
mperature
face
vailable
ght of first dam

2. The GR3D model
2.1 What it is

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- **a <u>virtual environment</u>… Not definitive but at least in the first exploration phase…**

- **Aims to integrate <u>population dynamics</u>, <u>repositioning behaviours</u> and <u>habitat/climatic requirements</u> to investigate the diadromous fish-like responses to environmental changes**
    - **Which factors influence the repositioning ?**

2. The GR3D model
2.1 What it is NOT

- **GR3D <u>does not</u> incorporate evolutionary (genetic) response of individuals to climate change. We consider only a phenotic plasticity of individuals.**
  - **Very few elements in literature about evolutionary response of diadromous fish…**

- **Precipitations <u>are not</u> included in GR3D**
  - **Models linking Climate Change to river discharge do not exist everywhere**
  - **River flows are very sensitive to agriculture (irrigation), dams (mill pond)… link between Global Change and river discharge is also a challenge**
  - **How do the flow play on every species ?... Link between flow and biological processes.**

- **GR3D is not a pluri-specific model**

2. The GR3D model
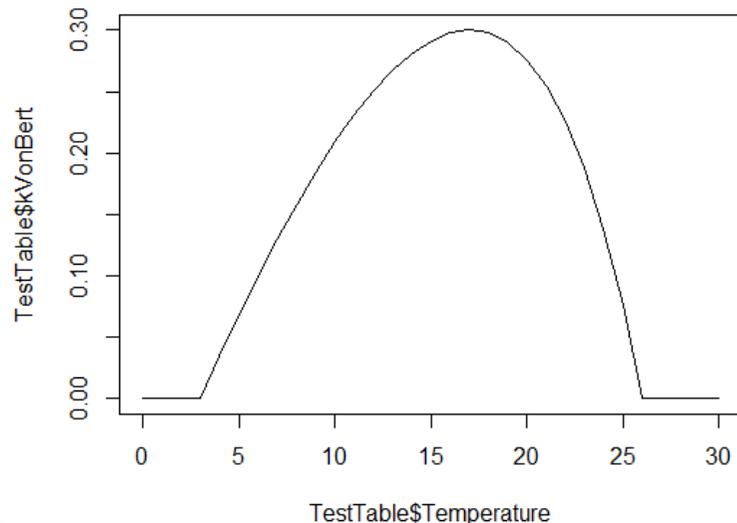## 2.2 Components of GR3D – Growth process

- **Growth process** (Fabens, 1965; Mallet et al., 1999; Dion & Hughes, 2004; Bal et al., 2011)

- **Von Bertalanffy growth function with a seasonal variability of the growth increment**

$$\Delta L = LogN\left(\mu_{\Delta L}, \sigma_{\Delta L}\right)$$

$$\mu_{\Delta L} = \log\left(\left(L_\infty - L_t\right) \times \left(1 - \exp^{-\kappa \Delta t}\right)\right) - \frac{\sigma_{\Delta L}^2}{2}$$

- **A growth rate parameter linked to the temperature**

Evolution of VBGF growth parameter for a shad like specie (Tmin=3, Tmax=26, Topt=17, Kopt=0.3, Lini=2, Linf=60)

$$\kappa = \kappa_{opt} \frac{\left(T - T_{min}\right)\left(T - T_{max}\right)}{\left(T - T_{min}\right)\left(T - T_{max}\right) - \left(T - T_{opt}\right)^2}$$

Parameters of the growth process:
- T_{min}, T_{max}, T_{opt}
- L_{ini}, L_{inf}
- K_{opt} (the same in river, sea and offshore)
- $\sigma_{\Delta L}$

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2. The GR3D model

2.2 Components of GR3D – Reproduction process

- **<u>Reproduction process</u> modelled with a stock recruitment relationship** (Beverton & Holt, 1957; Myers et al., 1995; Lierman & Hilborn 1997)

  - **A stock recruitment relationship follows the evolution of the initial recruitment (r_0) produced by a spawner stock (S) until a given stage of development (R)**

  - **We assumed that the initial recruitment (r_0) is directly proportional to the spawner stock level according to the fecundity of the species (parameter a):**

  - **Then we assumed 2 kinds of mortality of the initial recruitment:**
    - *a non density dependant mortality with temperature (parameter b)*
    - *a density dependant mortality according to the surface of the reproduction basin as it is a proxy of the available ressources (parameter c)*

$$S \quad \xrightarrow{\quad r_0 = aS \quad} \quad r_0 \quad \xrightarrow{\quad \frac{dr}{dt} = -(b+cr)\,r \quad} \quad R$$

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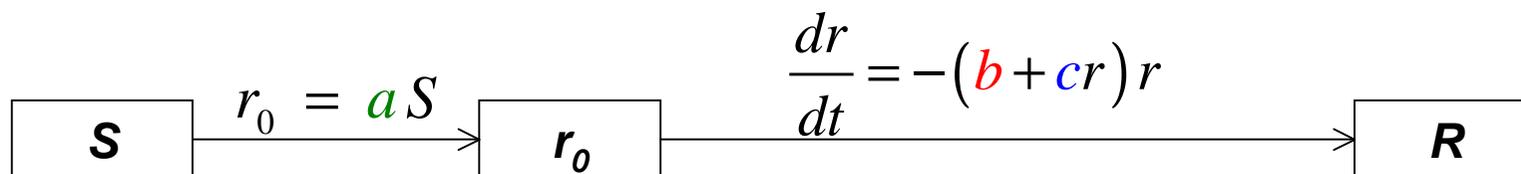
2.2 Components of GR3D – Reproduction process

- **Equation of the reproduction process:**

$$R = \frac{\dfrac{b\,e^{-b\Delta t}}{c\left(1-e^{-b\Delta t}\right)}S}{\left(\dfrac{b}{ac\left(1-e^{-b\Delta t}\right)}+S\right)}$$

$$with\ b = -\frac{1}{\Delta t}\ln\left[surv_{opt}\frac{\left(T-T_{min}\right)\left(T-T_{max}\right)}{\left(T-T_{min}\right)\left(T-T_{max}\right)-\left(T-T_{opt}\right)^2}\right]$$

$$and\ c = \frac{\lambda}{surf_{acc}}$$

Calibration:

- For shad like species, we use data about allis shad population dynamics in the Gironde basin (Rougier et al., 2012)

- For the other species, we will probably use assumptions

Parameters of the reproduction process:

- Reproduction Season

- T_{min}, T_{max}, T_{opt} for reproduction process

- number of female eggs per kg of female to compute a

- Delay between eggs and recruitment (Δt), optimal larvae survival rate ($surv_{opt}$), T_{min}, T_{max}, T_{opt} to compute b

- λ to compute c

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2. The GR3D model

2.2 Components of GR3D – Biological processes

- **Other simple processes**
  - **Age process**
  - **Survival process with survival equation**
  - **Migration processes: in sea, in offshore and in river**

> **Parameters of the other processes:**
>
> - **Optimal Survival rate (the same in River, Sea and offshore)**
>
> - T_{min}, T_{max}, T_{opt} **for survival (the same in River, Sea and offshore)**
>
> - **Migration Seasons**
>
> - **Age at migration, L_{mat} , Homing rate**

- **And the key process of GR3D:**

THE REPOSITIONNING PROCCESS

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2. The GR3D model
2.3 The repositionning process

- **What do we mean by repositioning of diadromous fish ?**
- → **The process by which the species will maybe explore new environment and change its distribution area (~ dispersal…)**

  - **For anadromous:**
    - → *The choice of the reproduction basin (Homing vs. Straying)*
  - **For Catadromous**
    - → *The choice of the "feeding" basin*

- → **For each species, it is about the choice of a basin… It is the modelling challenge! Because…**
  - **We know nothing…**
  - **Nothing relevant in literature…**
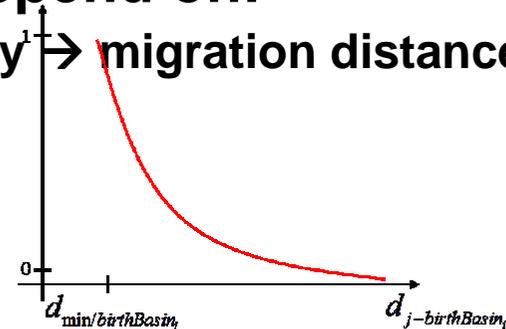
2. The GR3D model
2.3 The repositionning process
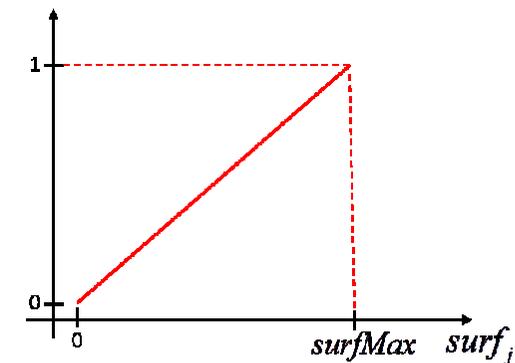
- **How do we model it ?**

→ **We designed a process allowing the test of different scenarios**

- **The choice of a basin might depend on:**
  - **The size of the fish (swim capacity → migration distance max)**
  - **The distance between the basin and the birth place of the fish**

  - **The surface of the basin (proxy of the flow)**
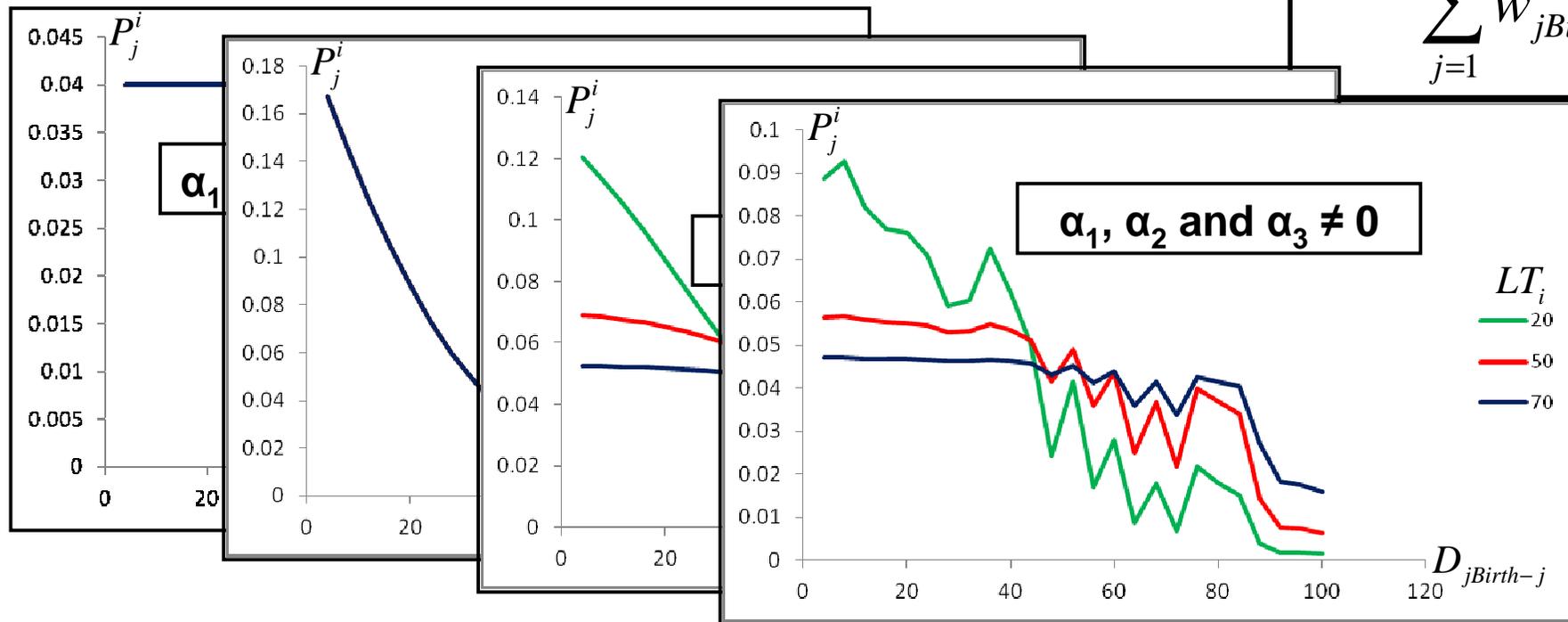
  - **The density of fish in the basin**

  - **…**

→ **We can test a multitude of scenarios**

2.3 The repositionning process

- **Equation of the repositioning process**

$$\text{logit}\left(w_{jBirth-j}\right) = \alpha_0 + \alpha_1 D_{jBirth-j} + \alpha_2 LT_i + \alpha_3 S_j \longrightarrow P_j^i = \frac{w_{jBirth-j}}{\displaystyle\sum_{j=1}^{n} w_{jBirth-j}}$$

α_1, α_2 and $\alpha_3 \neq 0$

LT_i
- 20
- 50
- 70

$D_{jBirth-j}$

Number of repositioning scenario:

- $2^3 = 8$ scenarios

2. The GR3D model
2.3 The repositionning process

What is the interest to test different scenarios ?

- **Each repositioning scenario can be relevant for one or more species**

- **Each repositioning scenario is in fact associated with life history traits**

- **We may identify the best repositioning scenarios and so the species with the most effective repositioning**

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3. The next step: performing a global sensitivity analysis
3.1 Definition of input factors (and their modalities)

- **Climate change:**
  - *warming' intensity*

- **Population dynamics**

  - **Reproduction:**
    - *a, b, c, T_{min}, T_{opt}, T_{max}*

  - **Growth:**
    - *Growth rate, Linf, T_{min}, T_{opt}, T_{max}*
  - **Survive:**
    - *Mortality rate Sea, River, offshore, T_{min}, T_{opt}, T_{max}*

  - **Migrations:**
    - *Ages at migration, $L_{mat...}$*
  - **Homing**
    - *Homing rate*

- **Repositioning process:**
  - *8 different scenarios*

About 20-30 parameters and 8 repositioning scenarios…

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3. The next step: performing a global sensitivity analysis
## 3.2 Choice of response variables to be considered

- **Questions:**

    - **Which repositioning scenario give the best results in terms of species persistence and repositioning efficiency ?**

    - **Which influence of the climate change on species persistence ?**

    - **Is there some species traits which have a great effect on the simulation results ?**

3. The next step: performing a global sensitivity analysis
3.2 Choice of response variables to be considered

- **Output candidates to estimate species persistence and repositioning efficiency**
  - **Abundance**
    - *Total number of individuals*
  - **Distribution area**
    - *Number of basins with a population (i.e. with reproduction)*
  - **Distribution area modifications**
    - *Localization of the most northern basin*
    - *Localization of the most southern basin*
    - *Distance between the most northern and southern basins*
    - *Number of basins with extinction between the start and the end of the simulation*
    - *Number of basins with colonization between the start and the end of the simulation*
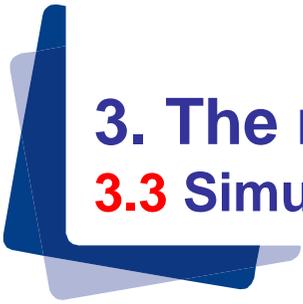
3. The next step: performing a sensitivity analysis
3.3 Simulation design and statistical model to applied ???

- **Actually, we start thinking about this step…**

- **Need to determine the modalities of the input factor**

- **Group screening and pls ? (Drouineau *et al.*, 2006; Lehuta *et al.*, 2010)**

Perspectives

- **Other questions:**

  - **Change the environment… A real landscape based on CCM ?!**

  - **Work with a grey mullet-like (case of a catadromous species)**

Thanks for your attention !...

Questions ?

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2. Le modèle G3D

2.3 les processus de G3D (Process overview and scheduling in Grimm et al., 2006)
→ le processus biologique de reproduction

- A stock recruitment relationship follows the evolution of the initial recruitment ($r0$) produced by a spawner stock (S) until a certain stage of development (R)

- We assumed that the initial recruitment ($r0$) is directly proportional to the spawner stock level according to the fecundity of the species (a):

$$r_0 = a\,S$$

- We assumed that the mortality of the initial recruitment ($r0$) depends on the temperature through a parameter b, and on the density of the recruitment (intraspecific competition) through a parameter c directly linked to r. So, the variation of the initial recruitment is

$$\frac{dr}{dt} = -(b + cr)\,r$$

- The solution integrating between $t = 0$ where $r = r0 = aS$, and $t = \Delta t$ where $r = R$ is

$$R = \cfrac{\dfrac{b\,e^{-b\Delta t}}{c\left(1 - e^{-b\Delta t}\right)}\,S}{\left(\dfrac{b}{ac\left(1 - e^{-b\Delta t}\right)} + S\right)}$$

2. Le modèle G3D

2.3 les processus de G3D (Process overview and scheduling in Grimm et al., 2006)

→ le processus biologique de reproduction

- **Assuming that**

$$\alpha = \frac{b\,e^{-b\Delta t}}{c\left(1-e^{-b\Delta t}\right)} \qquad\qquad \beta = \frac{b}{ac\left(1-e^{-b\Delta t}\right)}$$

- **we recognize the formulation of the Beverton & Holt SR relationship proposed by Lierman and Hilborn (1997)**
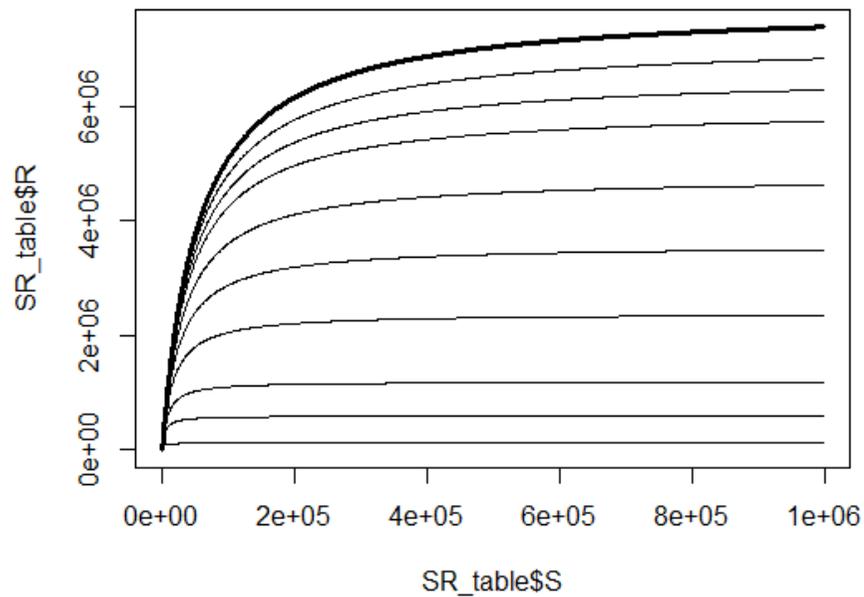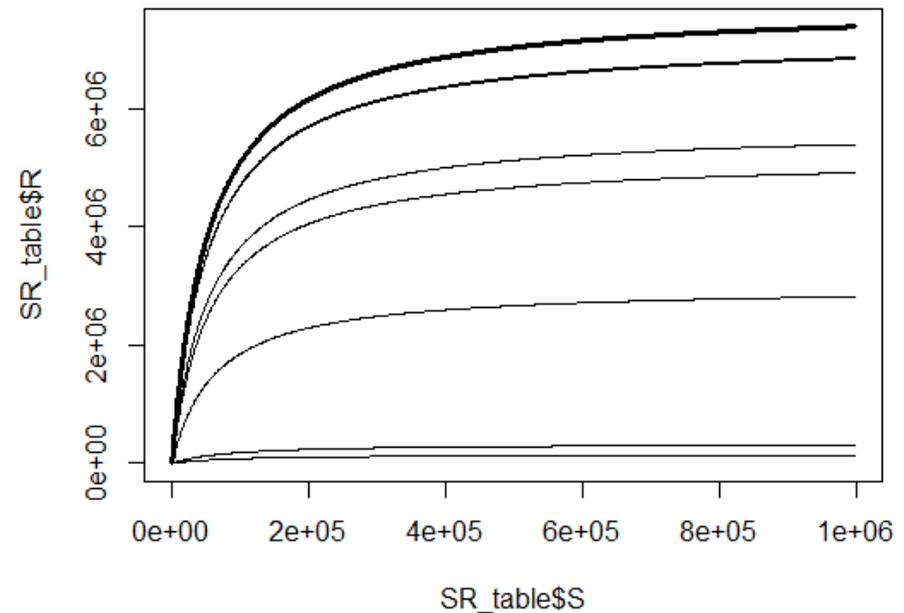
$$R = \frac{\alpha S}{\beta + S}$$

2. Le modèle G3D

2.3 les processus de G3D (Process overview and scheduling in Grimm et al., 2006)
→ **le processus biologique de reproduction**

- **Quelques courbes SR**

Topt mais surfaces accessibles différentes

Surfaces accessibles Max mais T°C différentes