Modelling effects of temperature and oxygen on the population dynamics of the European sturgeon using dynamic energy budget theory

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1) Introduction:

Context:

- *Acipenser sturio*: **Critically Endangered species** (IUCN [1])
- **Dramatic collapse of the population** (Fig 1.1): overfishing & loss of habitats [2]
- **Last** known wild **reproduction** in the Gironde-Garonne-Dordogne (GGD, Fig 1.2) basin: 1994 [3]

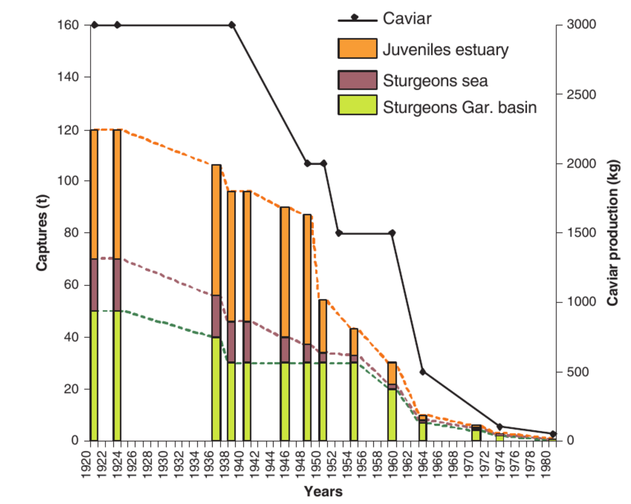

Fig 1.1: Sturgeon capture (t) and Caviar production (kg) in the GGD basin during the 20th century, from [4]

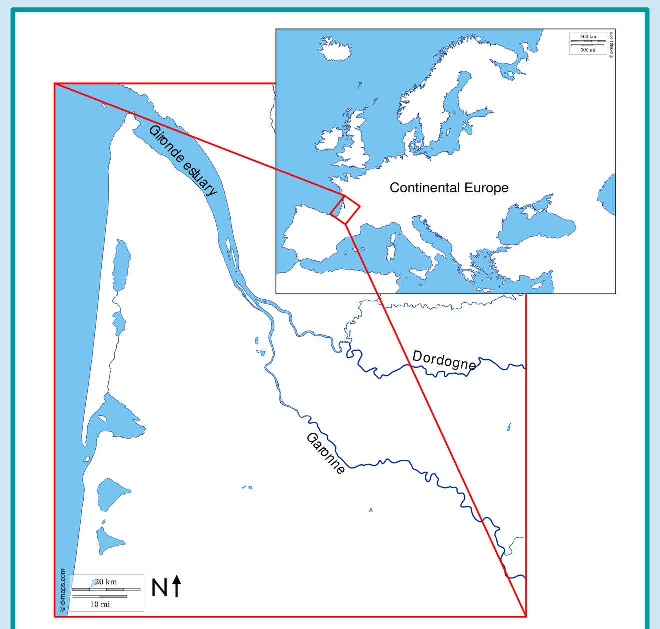

Fig 1.2: Map of the Gironde-Garonne-Dordogne basin, France

- **Reintroduction**: captive stock since 1994, first assisted reproduction & release in 1995, regularly since 2007
- **High anthropogenic pressure on first development stages** in the GGD basin: pollutants, hypoxic events, high temperature events

→ Survival of the first development stages is fundamental

Focusing on the juvenile stage: the SturTOP project

1) - Assessing **habitat quality for first development stages**

2) - Assessing **vulnerability of embryos and larvae** to pollution, hypoxia and temperature rise

3) - Studying **survival conditions of the juveniles** released into the wild

4) - Assessing relationships between habitat quality, contamination level and **juvenile health**

5) - Analysing **risks at population scale** in the GGD basin by modelling approach (Work began on January 2016)

A multi-scale approach:

→ Investigating effects of temperature & oxygen at **individual scale:** development of a standard DEB (Dynamic Energy Budget) model

→ Investigating effects of temperature & oxygen at **population scale:** implementation of the standard DEB model in a spatially explicit IBM of the GGD basin

2) Methods:

Dynamic Energy Budget Theory [5]:

- A **generic tool** to investigate metabolism at the individual scale: more than 300 species modelled
- A 10-hypotheses-based **general pattern** of energy acquisition & use: standard model (Fig 2.1)
- A "constrained" **modularity**: adding reserves and/or structures and/or toxicological modules

→ Increasing use in theoretical and applied research topics

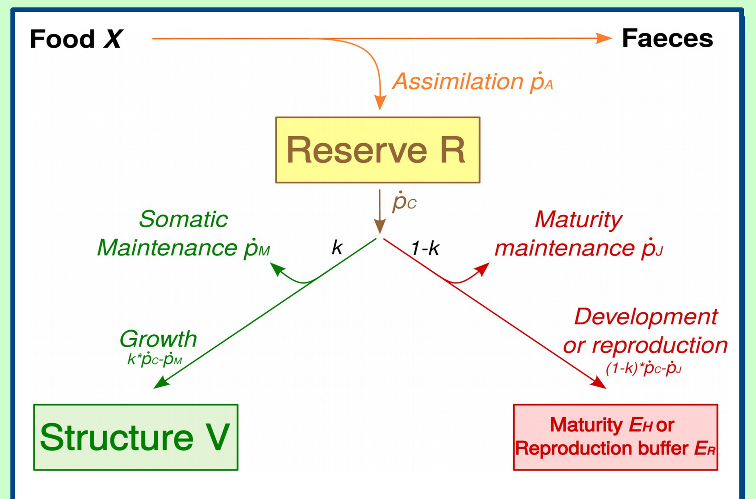

Fig 2.1: Conceptual representation of a standard DEB model, from [6]

Building the individual model:

- **Parametrisation** of a standard DEB model for *Acipenser sturio* with the covariation method [7]: minimisation of weighted sum of squared deviations between data sets and model predictions
- **Data sets:**
  1) **Observations** from literature: maximum reproduction rate ; age, length & weight **at specific moments of life-cycle** (birth, hatching, death) for different temperatures
  2) **Long-term observations** of length and weight of selected individuals **from a captive stock**: selection based on (i) availability of temperature history ; (ii) good health of individuals
- Implementing a module for hypoxia effects based on data from SturTOP project [8]

IBM approach:

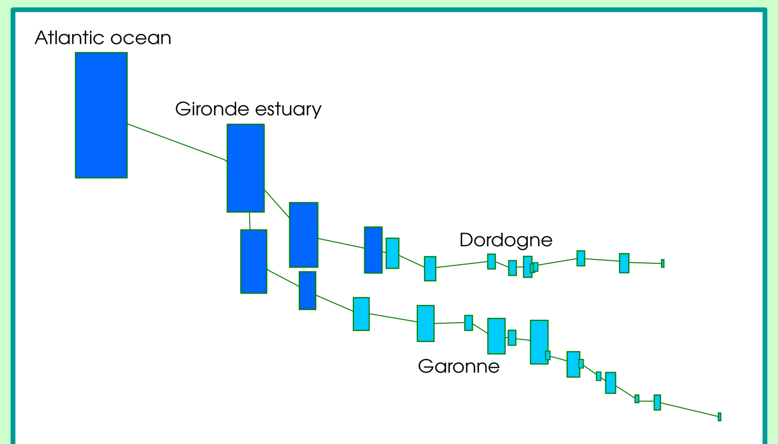

Fig 2.2: Conceptual representation of the StockedDiad model, composed of 24 spawning grounds, 2 river growing areas, 2 estuary growing areas and 1 ocean growing area

- **IBMs** are built on assumptions at individual scale, but highlight **emerging properties at population scale** [9]
- The StockedDiad Model (Fig 2.2) [10]: spatially explicit model of the GGD basin
- It integrates information collected during the SturTOP project on habitat quality

→ Testing different release strategies: age and location

3) Results:

Standard DEB model outputs:

- **Observations** at specific moments of life-cycle **are well reproduced** (Table 3.1)
- Modelled **length and weight** of individuals from the captive stock are **in accordance with data** (Fig 3.1)

Table 3.1: Literature and modelled observations at specific moments of the life-cycle. * data not used in parametrisation

Observations	Ref. Value	Modelled
Age at hatching (d) - 12°C	10.61	10.56
Age at hatching (d) - 16°C	7.31	8.52
Age at hatching (d) - 20°C	6.58	6.91
Age at hatching (d) - 23°C	5.84	5.92
Age at birth (d) - 18°C	16	10.36
Age at puberty* (y) – 18°C	11	8.1
Age at death (y) - 18°C	80	78.9
Length at hatching (cm) - 20°C	0.93	1.17
Length at birth (cm) - 18°C	1.65	1.46
Length at puberty* (cm) - 18°C	120	153
Maximum length (cm)	215	215.7
Weight at hatching (g) - 20°C	0.023	0.012
Weight at birth (g) - 18°C	0.031	0.023
Weight at puberty* (g) - 18°C	12960	25700
Maximum weight (g)	69569	71910
Max.reproduction rate (#/d) - 18°C	433.5	450.1

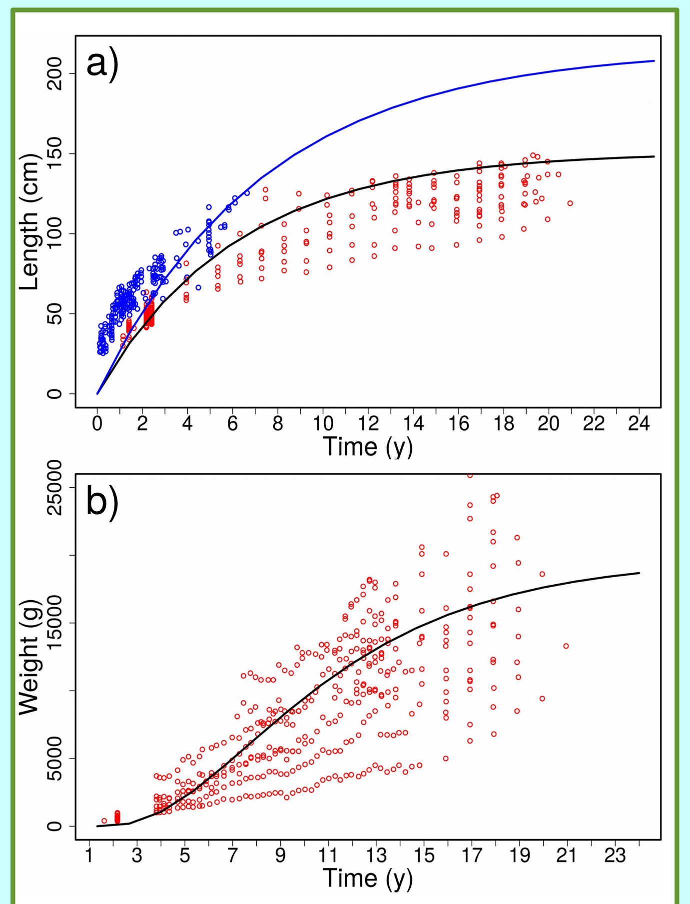

Fig 3.1: a) Modelled length (black line) versus data from the captive stock (red points) and wild stock (blue). b) Modelled weight (black line) versus data from the captive stock (red points)

- **Captive** individuals are **smaller than** individuals from the **wild**:
  (i) Food quality (blue curve on Fig 3.1) ?
  (ii) Stressor?
  (iii) Age estimation accuracy of wild individuals?

→ Individual model accurately reproduces the life-cycle of *Acipenser sturio*

Effect of temperature on reproduction:

- Reproduction occurs when energy invested in reproduction (E_R) reaches a density dependent threshold
- Simulated temperature is constant during the whole life-cycle

→ Reproduction interval is between 3 and 6 years depending on temperature (Fig. 3.2)

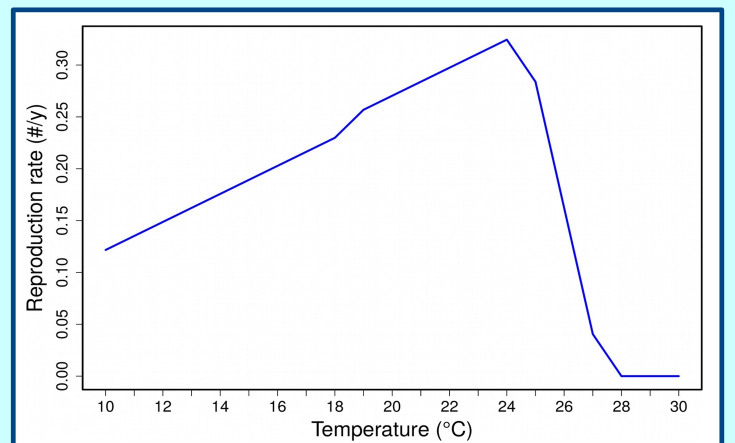

Fig 3.2: Reproduction rate as function of temperature

4) Next steps:

→ Integrating a module to model hypoxia effects (see Thomas *et al.* Oral presentation nb: O3.17)

→ Implementing the standard DEB model with the model of the GGD basin

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