Will ongoing climate change threaten the sustainability of Black Sea sprat (*Sprattus sprattus*) fisheries?

Giacomo Gardella [1] and Christoffer Koch[1]

Technical University of Denmark, National Institute of Aquatic Resources (DTU Aqua), DK-9850 Hirtshals

Correspondence: s223165@dtu.dk, s191185@dtu.dk

DTU

1. Background

Climate change is leading to a global redistribution of species. The sprat (*Sprattus sprattus*) is an ecologically and economically important clupeid fish. The Black Sea is situated at the southern end of the sprat's geographical range, and closely resembles the maximum temperatures that the sprat can withstand. We investigated how **+1.5°C** (Paris Agreement) and **+5°C** (worst IPCC projection) **end-of-century warming scenarios** will **affect** the **maximum sustainable yield (MSY)** of **Black Sea sprat**. We expect that climate change will cause a decrease in MSY, which will lead economic losses in the region.

$$
\begin{array}{cccccc}
0^+ & 1 & 2 & 3 & 4 & 5^+ \\
\end{array}
$$

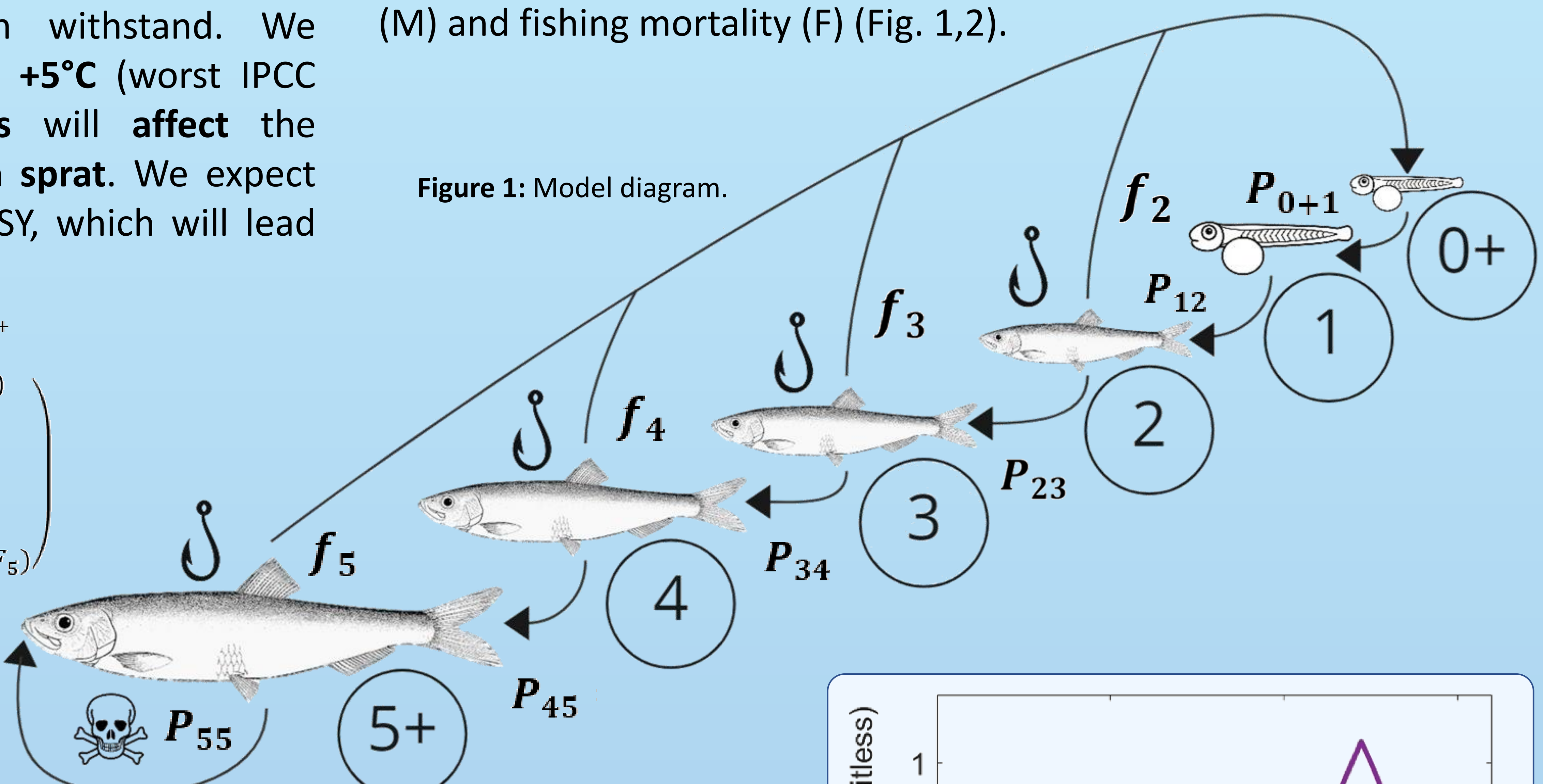
$$
\begin{pmatrix}
0 & 0 & f_2(S,T) & f_3(S,T) & f_4(S,T) & f_5(S,T) \\
P_{0^+1} & 0 & 0 & 0 & 0 & 0 \\
0 & P_{12} & 0 & 0 & 0 & 0 \\
0 & 0 & P_{23}(M_2,F_2) & 0 & 0 & 0 \\
0 & 0 & 0 & P_{34}(M_3,F_3) & 0 & 0 \\
0 & 0 & 0 & 0 & P_{45}(M_4,F_4) & P_{55}(M_5,F_5)
\end{pmatrix}
$$

Figure 2: Leslie matrix.

2. Model

We used an **age-structured Leslie matrix** to model the sprat population over **100 years**. Fecundities (f) are affected by the number of spawning adults (S) and temperature (T). The probabilities of surviving to the next age class are functions of natural mortality (M) and fishing mortality (F) (Fig. 1,2).

Figure 1: Model diagram.



3. Parameters

Fecundities (e=#0+, s=#spawners):

$$f_2 = Teff_{(T(i))} \cdot 6000 \frac{\#e}{\#s} e^{\frac{-3\cdot 10^{-10}}{\#s} S_{(i)}}$$

$$f_3 = Teff_{(T(i))} \cdot 8000 \frac{\#e}{\#s} e^{\frac{-3\cdot 10^{-10}}{\#s} S_{(i)}}$$

$$f_4 = Teff_{(T(i))} \cdot 10000 \frac{\#e}{\#s} e^{\frac{-3\cdot 10^{-10}}{\#s} S_{(i)}}$$

$$f_5 = Teff_{(T(i))} \cdot 12000 \frac{\#e}{\#s} e^{\frac{-3\cdot 10^{-10}}{\#s} S_{(i)}}$$

Warming scenarios:

$$+5°C: \quad T(i) = 15°C + \frac{1°C}{20\,y} i$$

$$+1.5°C: \; T(i) = 15°C + \frac{1.5°C}{100\,y} i$$

Fishing pressure:

$$\bar{F} = \frac{F_{23} + F_{34} + F_{45} + F_{55}}{4}$$

Survival $P_{ij} = e^{-M_{ij}-F_{ij}}$:

$$P_{0+1} = 0.001; \; P_{12} = 0.1$$

$$P_{23} = e^{-0.6-0.0003z}$$

$$P_{34} = e^{-0.3-0.000325z}$$

$$P_{45} = e^{-0.4-0.00035z}$$

$$P_{55} = e^{-0.8-0.000375z}$$

$$Teff_{(T(i))} = max\left\{0, \frac{1}{5} H(17.2°C - T)\left(e^{\frac{0.2}{°C}(T-8°C)} - 1\right) + \frac{4}{5} H(T - 17.2°C)\ln\left(\frac{1}{°C}(21°C - T)\right)\right\}$$

(Fig. 3)

$$Catch_{100} = \sum_{age=0^+}^{5^+} N_{100(age)} \cdot (1 - P_{ij}) \frac{F_{ij}}{F_{ij} + M_{ij}}$$

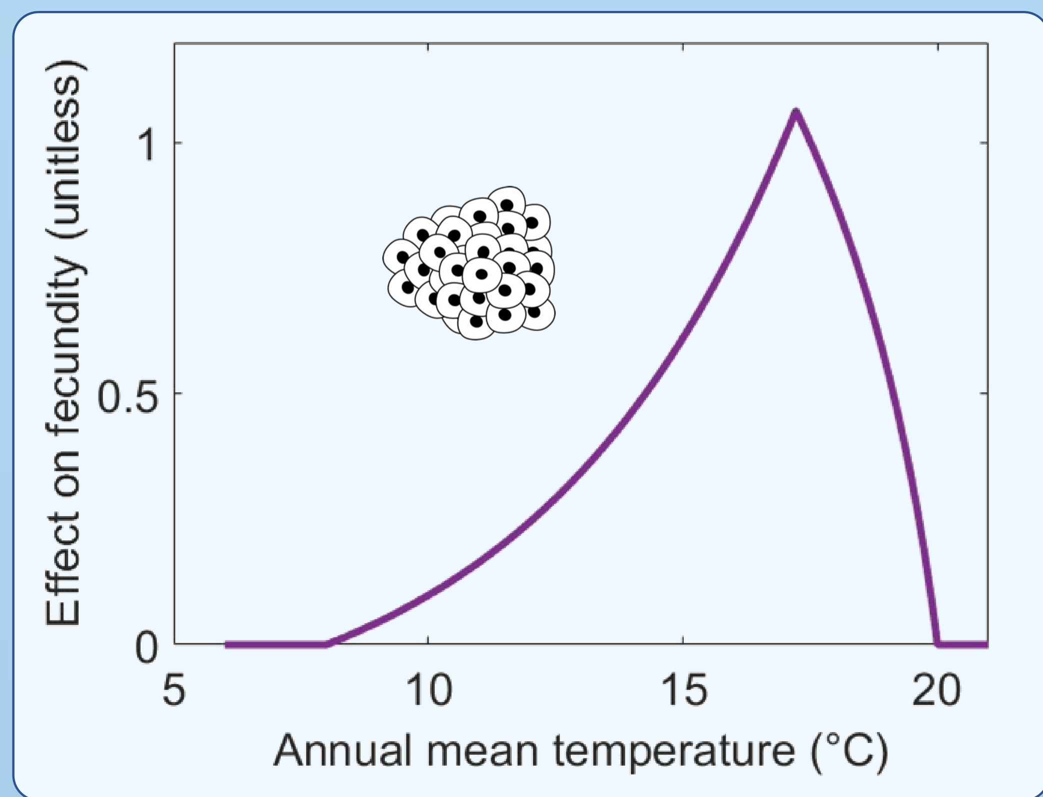
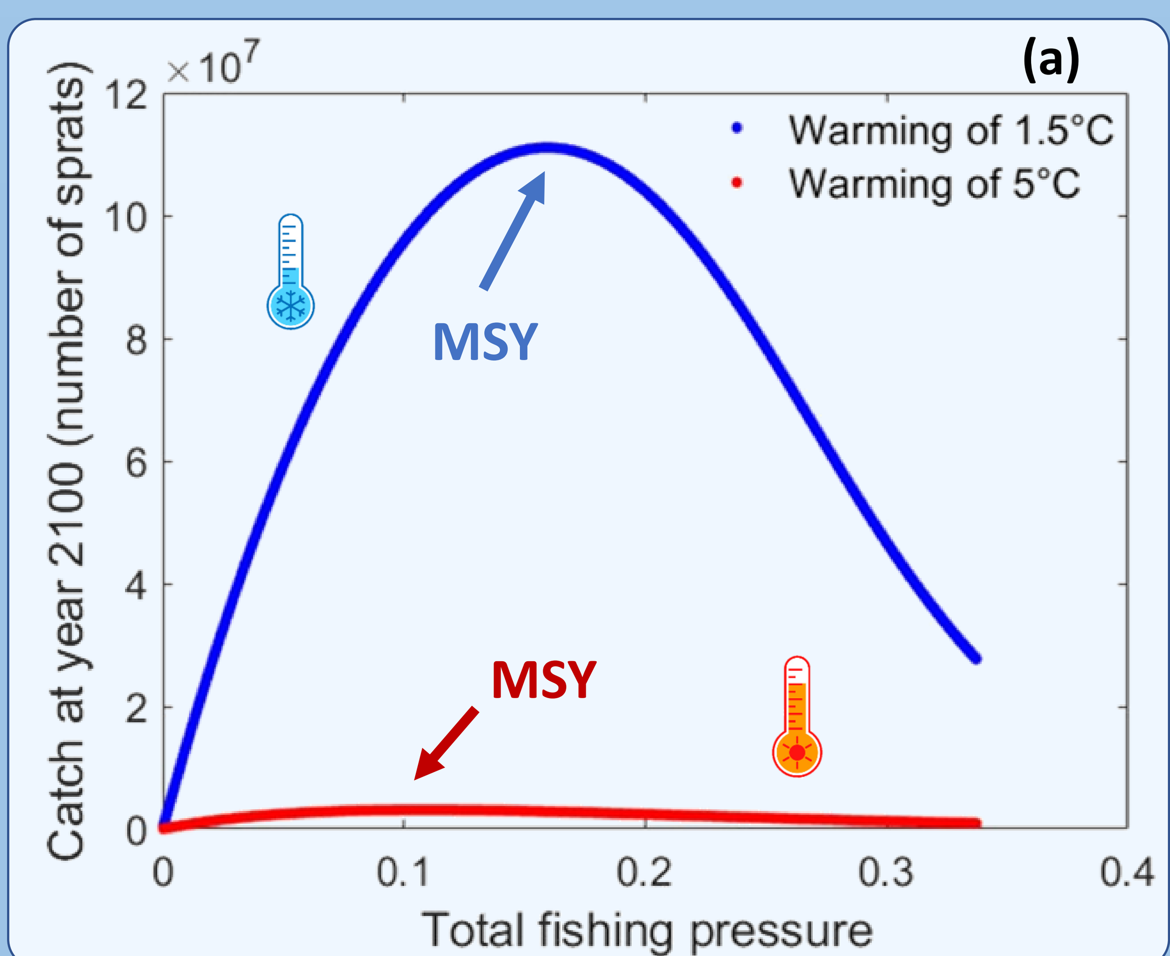


Figure 3: Plot of the effect of temperature on fecundity (equation shown below).

4. Results

Warming of **+5°C** caused a **decline** in the **sprat population** and **MSY**, while **+1.5°C** warming **did not** (Fig. 4). The MSY for +5°C warming is $3.1 \cdot 10^6$ sprat (~46.5 t), while for +1.5°C warming it is $1.1 \cdot 10^8$ sprat (~1666 t). **Yield** under **+5°C warming is <3%** of that under **+1.5°C warming**.



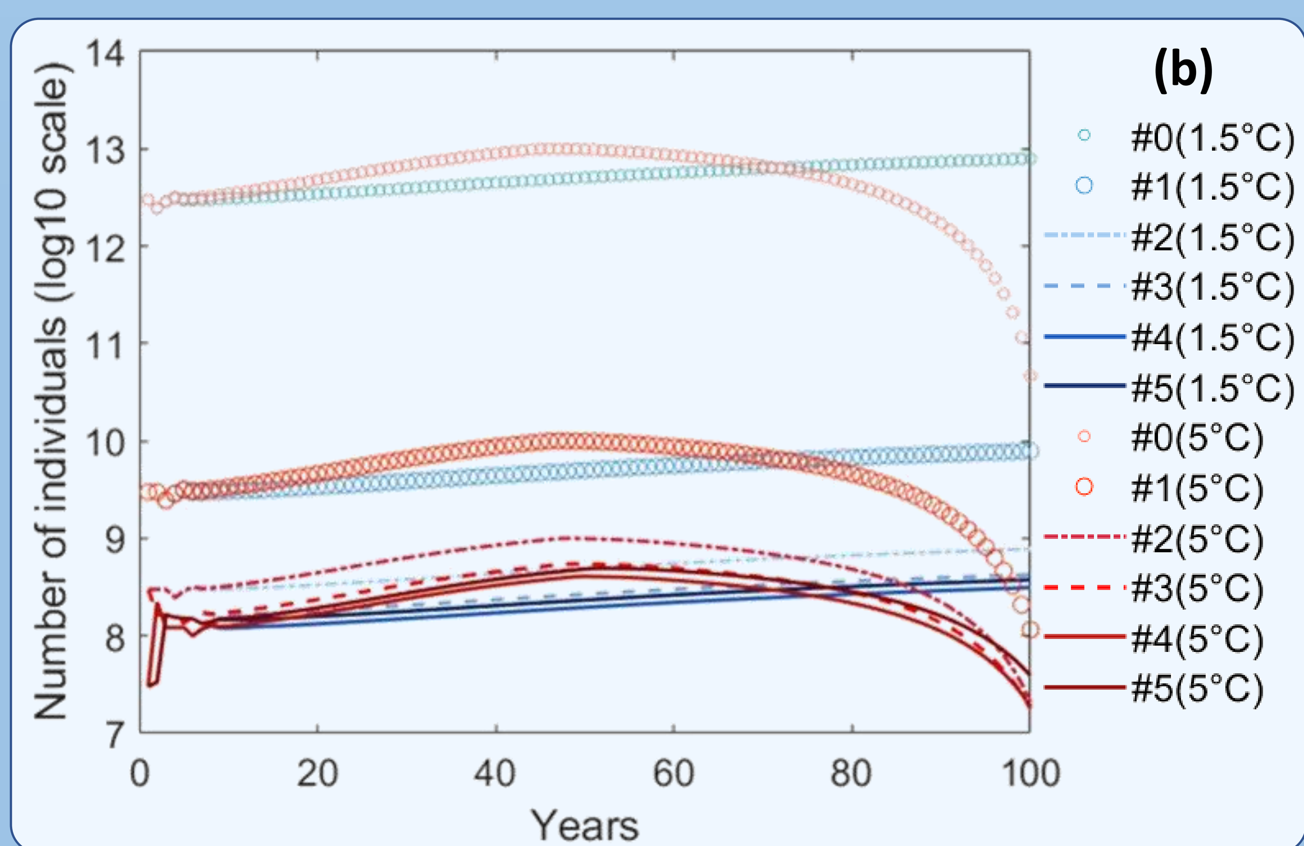


Figure 4: **(a)** Yield vs fishing mortality curves for 1.5°C and 5°C warming. **(b)** Evolution of the population under the warming scenarios without exploitation.

5. Conclusions

Climate change is expected to lead to a **decline** of **Black sea sprat**, and of the associated **MSY**. **Cascading trophic effects** in the Black sea may follow, as sprat is a major prey species. The decline in MSY will likely cause **economic losses. Fulfilling** the conditions of the **Paris Agreement** would thus benefit the Black sea sprat and its fisheries.

Giacomo Gardella

Christoffer Koch