Climate vulnerability of fish populations: Integrating lifecycle bottlenecks and emission scenarios

Flemming Dahlke, Daniela Storch and Hans-Otto Pörtner, Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research

Background

Estimating the climate vulnerability of species requires knowledge of the most sensitive life stages and how stage-specific thermal tolerance varies across geographic regions. Here, we present a global meta-analysis investigating the hypothesis that fish embryos and reproductive adults (spawners) have smaller thermal tolerance ranges than larval stages and non-reproductive adults (Figure 1). Climate impact risks are assessed by linking estimated warming tolerance margins (explained in Figure 1) with projected warming scenarios. In addition, potential benefits of limiting global warming to 1.5°C above preindustrial are demonstrated for an Arctic keystone species (Polar cod, *Boreogadus saida*). In this case study (Figure 5), we considered the combined effects of ocean warming and ocean acidification on highly sensitive embryos to estimate changes in spawning habitat suitability under different emission scenarios.

Conclusions

- Upper tolerance limits increase from the poles to the equator, and from spawning adults to embryos, larvae and non-reproductive adults (Figure 2).
- Spawners and embryos of polar and tropical species are more vulnerable to warming than temperate ones (Figure 3).
- Globally, the fraction of potentially affected species could be reduced from more than 50% to less than 10% if global warming is limited to 1.5 °C above preindustrial (Figure 4).
- Physiology-based habitat models (Figure 5) represent an important tool not only for climate risk assessments, but also for identifying potential refuge habitats that should be prioritized in conservation.

Hypothesis

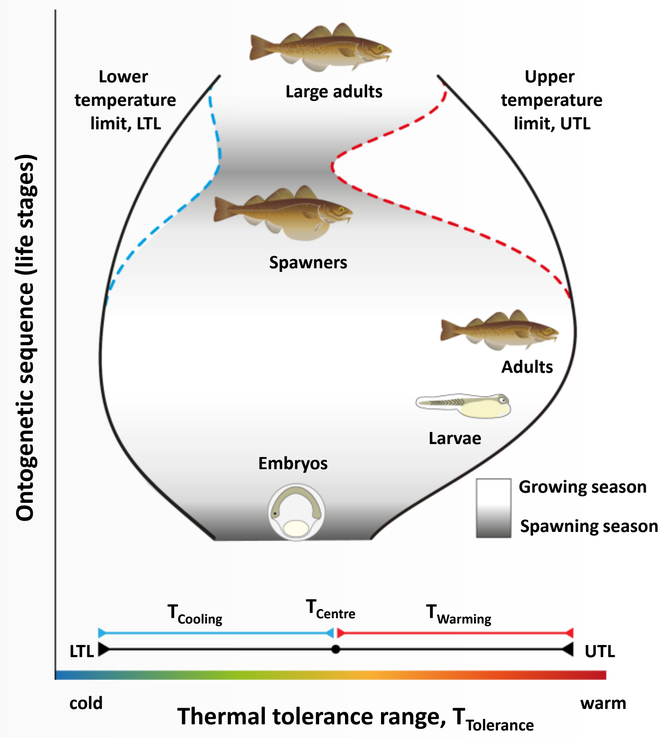


Figure 1. Thermal tolerance is expected to increase from embryos to adults according to the development of cardio-respiratory systems and associated capacities for homeostatic regulation and oxygen supply. In large-bodied individuals and especially spawning stages with advanced gonads, tolerance ranges may narrow due to allometric constraints on oxygen supply-demand relationships.

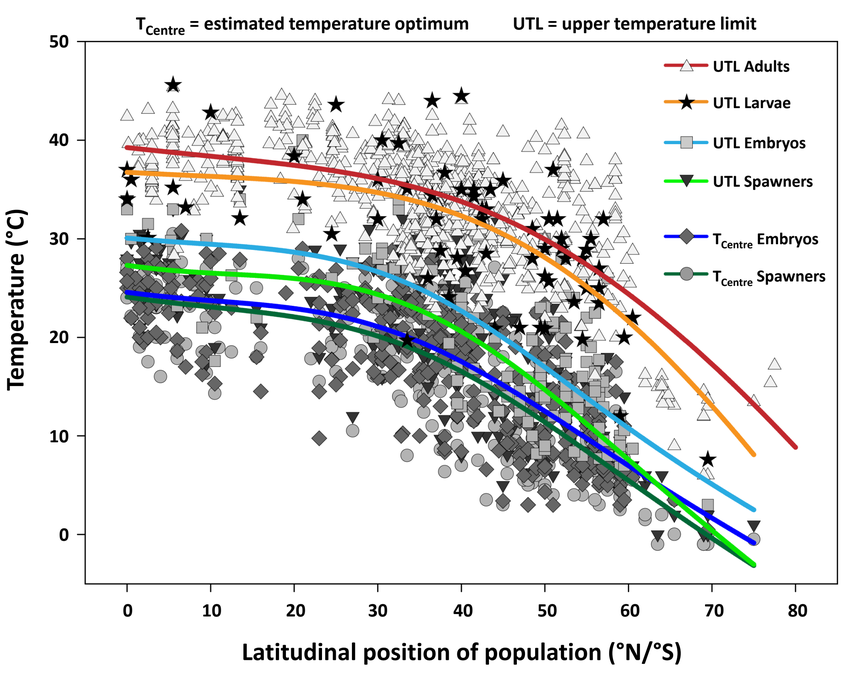


Figure 2. Ontogenetic and geographic variation in thermal tolerance.
(**A**) Different symbols indicate stage-specific thermal threshold categories (TTCs), including estimated optimum temperatures (T_{Centre}) of spawners and embryos and upper temperature limits of spawners, embryos, larvae and non-reproductive adults. Individual values are displayed in relation to the latitudinal position of the respective population (latitudinal range midpoint or sample location). Regression fits (colored lines) indicate a consistent relationship between stage-specific TTCs (spawners < embryos < larvae < adults) and latitude.

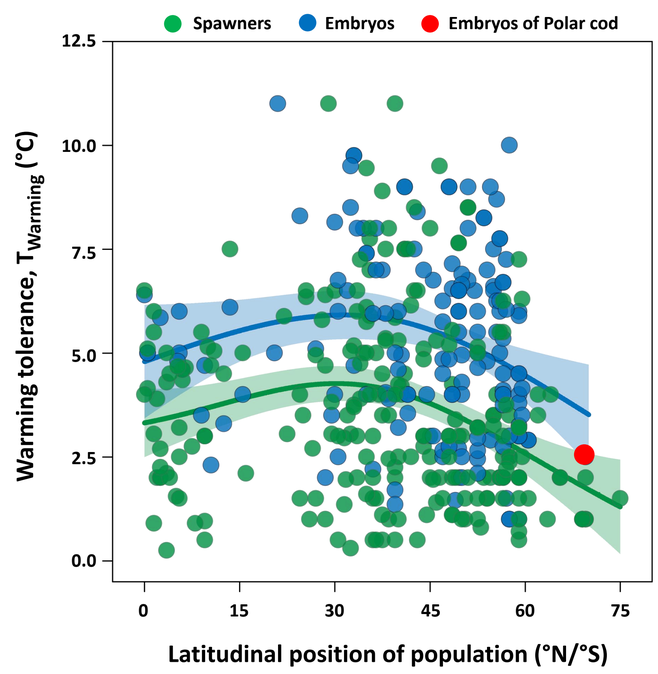


Figure 3. Warming tolerance margins of spawners and embryos across latitudes.
Warming tolerance margins ($T_{Warming}$) of spawning adults (green symbols) and embryos (blue symbols) were calculated as UTL – T_{Centre} (see Fig. 1). Regression fits (colored lines, shadings are 95% confidence intervals) indicate that tropical and polar species have smaller tolerance margins and are thus more vulnerable to global warming than temperate (mid-latitude) species.

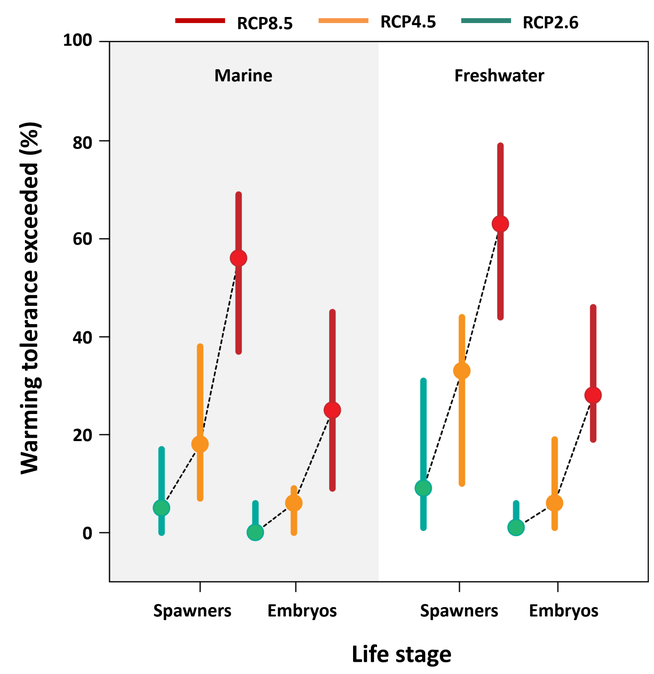
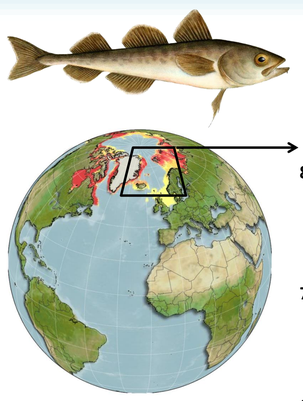


Figure 4. Marine and freshwater fishes at risk from global warming.
Circular symbols indicate the percentage of species (represented in Fig. 3) with $T_{Warming}$ smaller than the projected level of warming (global annual mean for 2081-2100) under different representative emission scenarios (RCPs). Color-coded vertical lines denote 95% confidence intervals of the climate model ensemble projection as reported in the 5th IPCC Report.

Case Study: Climate change effects on spawning habitat suitability of Polar cod



Distribution of Polar cod, *Boreogadus saida*
Red color indicates high probability of occurrence

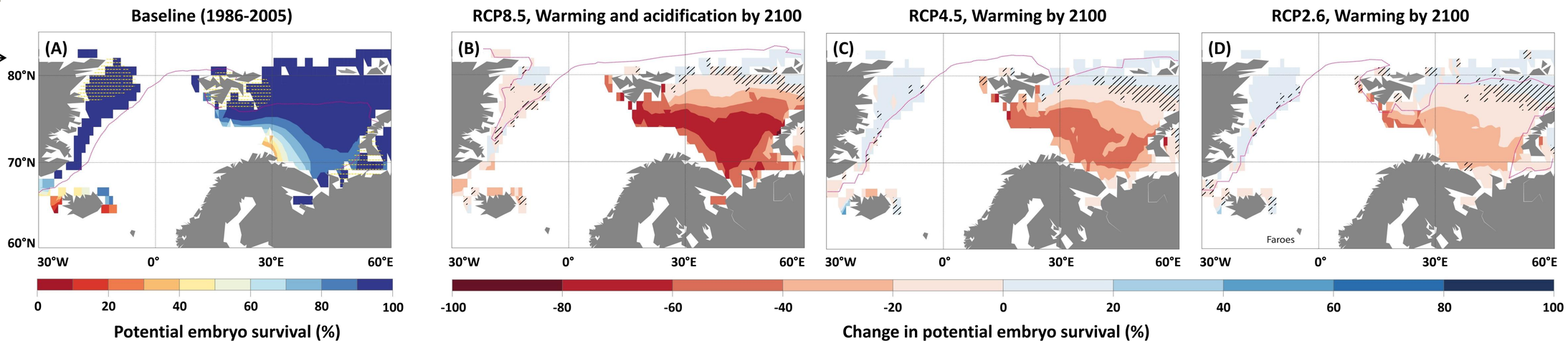


Figure 5. Current and future spawning habitat suitability of Polar cod in the Nordic Seas
(**A**) Baseline (current) spawning habitat suitability is quantified as potential embryo survival by linking experimental data (not shown) with World Ocean Atlas (WOA13) temperature fields (1981-2006). Main (known) spawning regions are indicated by yellow dashed areas. (**B-D**) Maps show the shift in potential egg survival between the baseline (A) and the median of CMIP5 multimodel-based projections (monthly sea surface temperature, 0-50m) for this century's end (2081–2100) under different Representative Concentration Pathways (B: RCP8.5, C: RCP4.5, D: RCP2.6). Black shading indicates areas with high uncertainty . Dotted magenta lines represent the sea-ice edge position. From Dahlke et al. 2018, Science Advances.

Acknowledgements: Funding for projects BIOACID and METAFISCH was received from the German Federal Ministry of Education and Research (BMBF).