***Manuscript***

**Larger but younger fish when growth compensates for higher mortality in warmed ecosystem**

Max Lindmarka,b,1, Malin  Karlssona, Anna Gårdmarkc

a Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Coastal Research, Skolgatan 6, 742 42 Öregrund, Sweden

b Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Marine Research, Turistgatan 5, 453 30 Lysekil , Sweden

c Swedish University of Agricultural Sciences, Department of Aquatic Resources, Skolgatan 6, SE-742 42 Öregrund, Sweden

1 Author to whom correspondence should be addressed. Current address:

Max Lindmark, Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Marine Research, Turistgatan 5, 453 30 Lysekil , Sweden, Tel.: +46(0)104784137, email: max.lindmark@slu.se

**Keywords**: body growth, size-structure, size-spectrum, mortality, climate change

Abstract

Ectotherms are often predicted to “shrink” with global warming, in line with the temperature-size rule (TSR), which states warming leads to smaller adult body sizes. But the TSR also predicts faster growth rates. As such, whether the average size of a population declines with warming depends on the mortality rates. We used data from an artificially heated (+8C) lagoon to analyze how warming has affected body growth, mortality rates and population size-structure of Eurasian perch (*Perca fluviatilis*). Compared to a reference area, we found that the size was larger for all ages and growth was faster for all sizes, to the extent that the size-spectrum slope was larger (indicating a higher proportion of large fish in) – despite the increased mortality rates. General size-temperature rules derived from experimental studies may not always translate to natural populations, and thus predictions of climate change impacts should incorporate a wider range of demographic parameters.

Introduction

Introduction

Results

Results

Discussion

Discussion

Materials and Methods

*Study system*

The Biotest basin is a 1 km2 artificial enclosure of Swedish Baltic Sea archipelago, built in conjunction with the construction of the nuclear power plant in Forsmark in 1977. Since 1980, the lake has received cooling water from the plant, after which the water temperature has been approximately 8 higher than in surrounding reference area (Adill *et al.* 2013; Huss *et al.* 2019). All types of fishing (apart from the regular surveys) have been banned since the construction (Huss et al., 2019). The Biotest Lake was also provided with a grid at its outlet which, together with the strong current, prevented fish larger than 10 cm from migrating in and out of the area (Adill et al., 2013; Huss et al., 2019). Genetic studies confirm the reproductive isolation between the two populations (Björklund et al., 2015) between 1980-2003 (the grid was removed in the spring 2004 and the Biotest Lake has since then been an open system (Adill et al., 2013); hence all analyses in this report are based on data collected before 2004).

The Biotest basin and the reference bay outside (henceforth the warm and cool area) have been scientifically sampled using survey-gillnets since the construction of the enclosure. We use data from 1987 and onwards,

during the same period as the back-calculated length-at-age data (1987-2003) in the heated Biotest lake and in the reference area. Fishing took place during one night each year in October in the Biotest lake and in August in the reference area when temperatures are most comparable between the two areas (Huss et al., 2019). Fish were classified into 2.5 cm length groups during 1987-2001, and into 1 cm length groups during 2001-2003. To express lengths in a common length standard, 1 cm intervals were converted into 2.5 cm intervals (full description of length group standardisation see Appendix). All data from fishing events with disturbance affecting the catch (e.g. seal damage, strong algal growth on the gears, clogging by drifting algae, boat traffic or other human inference) were removed. All length-frequency data from the Biotest Lake in 1999 and 2000 were removed as a consequence of disturbance on the fishing gear due to strong algal growth.

*Data*

*Statistical Analysis*

Code and Data Availability

All data and R code (lists of studies in literature search, data preparation, analyses and figures) can be downloaded from a GitHub repository (<https://github.com/maxlindmark/warm_life_history> ) and will be archived on Zenodo upon publication.

References

Acknowledgements

Acknowledgements

Author Contributions

Author Contributions

Additional Information

Additional Information