Fathers modify thermal reaction norms for hatching success in Atlantic cod, Gadus morhua

Climate-driven warming is altering marine ecosystems at an unprecedented rate and evolutionary adaptation may represent the last resort for many ectothermic organisms to avoid local extinction. The first step to elucidate the potential for adaptation to unfavorable thermal conditions is to assess the degree of genotype-based variation in thermal reaction norms of vital fitness traits. Marine broadcast spawning fishes experience extremely high rates of mortality during early life stages. Paternally derived (genetic) variation underlying offspring fitness in adverse environmental conditions may therefore hold important implications for resilience. This study examined how males differ in their ability to sire viable offspring and whether the paternal contribution modified thermal reaction norms for hatching success in two replicated trials with cod Gadus morhua from the Northwest Atlantic (trial 1) and Baltic Sea (trial 2). Each trial included five temperature treatments (2.0, 4.0, 6.0, 8.0, 10.0 °C in trial 1, and 6.5, 8.0, 9.5, 11.0, 12.5 °C in trial 2) encompassing optimum conditions as well as the amount of warming projected in various future pathways for the year 2100. In both trials, mean hatching success significantly decreased towards thermal extremes. However, half-sibling families varied in their response to different incubation temperatures as indicated by significant paternity × temperature interactions and crossing of reaction norms. The influence of paternity itself was highly significant and explained 56% and 44% of the observed variation in hatching success in trials 1 and 2, respectively. Early embryogenesis represented the most crucial developmental period in terms of thermal tolerance and paternally mediated variation in hatching success. High variation in daily embryo survival among half-sibling families and temperature treatments was observed during blastula and gastrulation stages (until 100% epiboly), while almost no mortality occurred during subsequent development and throughout the hatching period. The observed magnitude of genetic variation underlying thermal reaction norms for embryo viability represents a relevant resource for adaptive responses (favorable selection) of cod populations exposed to environmental variability and/or directional changes, such as ongoing ocean warming.