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Summary
Temperature increase associated with global climate change can be expected to directly influence the spawning success of fish species. We investigated and compared responses of development time and survival of fish eggs from 32 species and populations in the North Atlantic to different temperatures in order to assess and compare potential consequences of global warming for these species. The response of development time to temperature increase exhibited a decreasing trend. The similar slopes of regression lines relating development time and temperature indicate similar sensitivity to temperature changes. Across-species differences were mainly driven by intercept values, indicating up to 8-fold differences in development time at given temperature. Moreover, the sensitivity of survival of eggs from different species to temperature increase differed among species, indicating different vulnerabilities. The results quantify physiological effects of temperature on the eggs and show that such effects are major factors leading to a close correspondence between the physiological optimal temperature for survival and observed temperature at spawning sites. Temperature during egg development appears to be a key evolutionary force affecting spawning time and location.

Introduction
One of the most important effects of temperature on fish physiology is its influence on reproductive processes, including the development and survival rates of fish eggs (e.g., Geffen and Nash 2012). The early life stages of fish and other marine biota have relatively narrow thermal tolerance ranges compared to the adult stages (e.g., Pörtner and Peck 2010), making them more sensitive to temperature changes. Given that climate change is likely to increase ocean temperatures in the coming decades (IPCC 2014), knowledge of how fish will respond to these changes will be needed to understand and predict climate change consequences for fish ecology. Among pelagic fish species currently inhabiting, or those which could inhabit, the North Atlantic under future climate change, it is unclear which ones produce eggs which could benefit from, or be harmed most by expected rises in temperature. The present study is a comparative analysis of the early life history traits for a range of fish species of the North Atlantic. We anticipate that new analyses of interactions between temperature, development and survival rate will generate new insights to the thermal ecology of reproduction in North Atlantic fish species and the role of temperature on the evolution of their spawning strategies.

Materials and Methods
We compiled development time and survival data from laboratory egg incubation experiments at different temperatures (T_i). Linear regression analysis was applied to investigate temperature effects on developmental time (D_T; ln-transformed) of populations and species. The slopes represent the sensitivity of development time to temperature differences; for species or populations having similar slopes, intercepts represent differences in development rate after having accounted for temperature differences. We ranked the slopes and intercepts from lowest to highest and compared the values among species and populations.

Survival and temperature relationship was described by a Gaussian equation, the parameters of which can give estimates of the optimal temperature and the temperature range within which survival is highest. We estimated the impact of a 2 °C warming of spawning areas on expected egg survival using the Gaussian fitted parameters for each species and calculated the difference in survival rate under present and future climates.
Temperatures during spawning season for each population/species were retrieved from the literature and plotted against the optimal temperatures at which survival was maximized.

Results and Discussion

We have found that development rate responses to temperature (i.e., slopes of regressions of ln development time vs. temperature) are relatively similar, indicating similar sensitivity to temperature changes. Across-species differences were mainly driven by intercept values, indicating up to 8-fold differences in development time at given temperature. Given these general patterns, it is expected that climate change will accelerate development times for eggs, but will have comparatively little impact on the relative differences in development time among the different species and populations. Faster egg development times would result in earlier hatching (Greve *et al.* 2005) and earlier food requirements for developing larvae. The consequences of such changes in phenology on early life survival are presently difficult to assess because of uncertainties in how phyto- and zooplankton production will change under climate change. New field, laboratory and modelling investigations are needed to address these effects.

We found substantial variability in the sensitivity of survival to temperature difference among species (difference in survival rate under present and future climates.). Some species were relatively more sensitive to temperature changes than others. It is therefore evident that egg survival in some of the species analysed here will be more vulnerable to global warming than others.

Finally, we demonstrated that the physiological optimal temperature ranges for egg survival corresponded closely to the mean of spawning temperature ranges (Figure 1; here considered to represent conditions prevailing during final gonadal maturation and spawning). Therefore, optimal temperatures for egg survival appears to be an important constraint for the time and location of spawning.

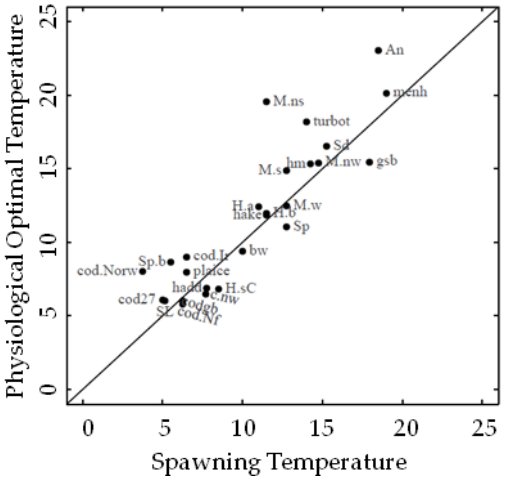

Figure 1 Average temperature during spawning (x-axis) and physiological optimal temperature (y-axis) at highest survival.

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