Climate change may add significantly to the impacts of pollution and habitat loss on fish populations

Climate change is seen globally as a major environmental risk, along with pollution and the loss of natural habitats. Many regions of the world are predicted to experience increasing climatic fluctuations and extremes, including either drought or flooding, but in general most are likely to undergo warming throughout this century. As a consequence species with temperature-dependent sex determination may be especially susceptible to climate change. Warmer temperatures during egg incubation have been shown to induce female-biased populations in many reptiles, including tortoises, turtles and crocodilians. Conversely, in lizards, fish and some amphibians, temperature elevation tends to induce male development, and male-biased sex ratios may be far more problematic for wildlife populations, as the numbers of egg-laying females are reduced. Other environmental stressors predicted to accompany climate change (reduced nutrition, overcrowding, inbreeding and, in aquatic environments, increasing chemical residues, acidification and reduced dissolved oxygen) may also generate male-skewed sex ratios (Fig. 1), and some of these stressors have been shown to have additive effects.

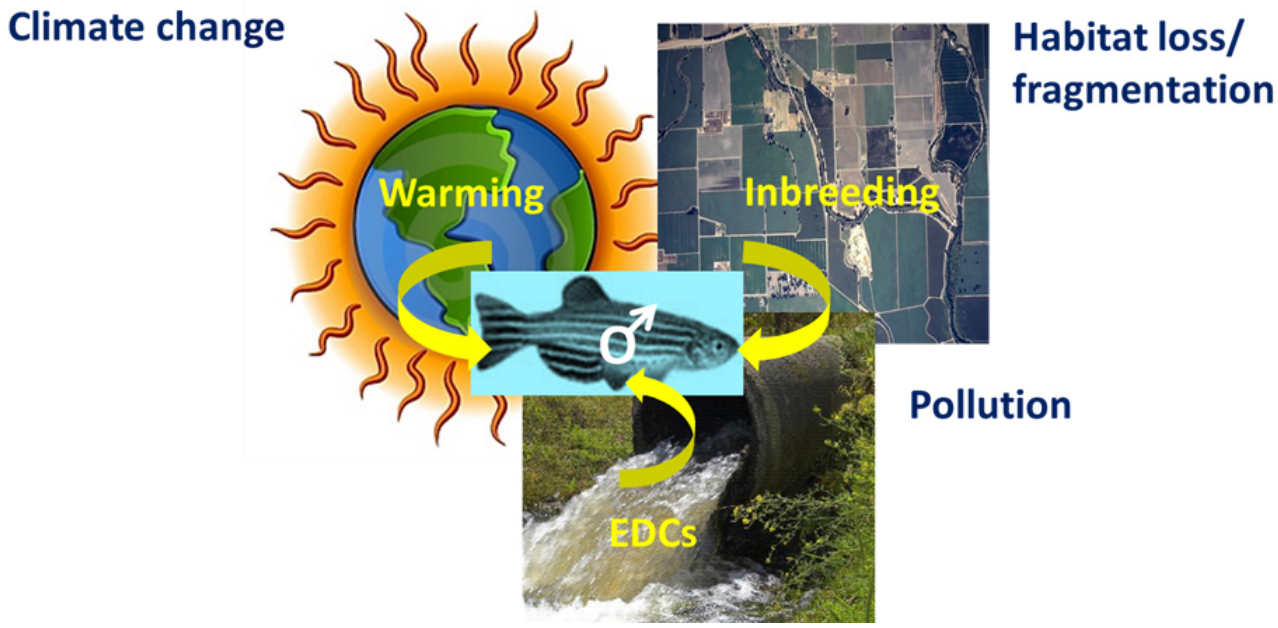

Fig. 1. Additive effects of environmental stress factors inducing male sex (?) in fish

In order to examine the individual and interactive effects of climate change (warming), habitat loss (causing inbreeding) and pollution (from endocrine disrupting chemicals (EDCs)), collaborating scientists from AstraZeneca, the University of Exeter and Bangladesh Agricultural University conducted a series of laboratory and computer simulations on the zebrafish (Fig. 2). The zebrafish

is a widely used model species and was selected for this research because it shows environmental/ temperature-dependent sexual differentiation and rapid maturation, enabling sex to be confirmed in 2 to 3 month old fish. Zebrafish are native to the Indian sub-continent and reproduce and develop during the monsoon season in flooded rice paddy fields, where they may be exposed to various agrochemicals.

The study chemical clotrimazole is one of many azole fungicides and the selected upper exposure concentration represented total combined azole concentration measured in the field. The laboratory results showed that clotrimazole exposure skewed sex-ratios significantly towards males, and the skew was amplified at warmer water temperatures predicted for the year 2100. Male-skews were also greater in inbred populations (those with reduced genetic variation) compared to outbred (genetically more diverse) populations. The combined effects of all three environmental treatments were shown to be additive, generating almost completely (97%) male populations in inbred zebrafish, maintained at elevated temperature (33°C), together with elevated clotrimazole (8 micrograms per litre) exposure. In contrast, outbred zebrafish maintained at the lower baseline temperature (28°C) with no clotrimazole showed a balanced sex ratio (48% males).

Fig. 2. Laboratory studies on wild caught zebrafish from Bangladesh

Laboratory results were then input to a computer-based population viability analysis (PVA) model to simulate the population-level effects of male-skewed sex ratios in zebrafish, and to predict population growth rate and probability of extinction for the various exposure scenarios. After running over 100 exposure scenarios, each one represented by 100 repeat simulations of 100 years of exposure, inbred zebrafish populations exposed to elevated water temperature and clotrimazole were shown to be more likely to decline (56-100% probability) compared with outbred zebrafish populations (0-19% probability). Male-skewed sex ratios of >82% in inbred zebrafish resulted in a three-fold reduction in population growth rate, whereas in outbred fish, larger (>90%)

skews were required to induce smaller population declines, amounting to two-fold reductions in population growth rate.

Overall, the study showed that interactions between elevated temperature and chemicals, which skew sex ratios toward males, can have profound impacts on populations of species with environmental sex determination and/or differentiation. Furthermore, in combination with habitat loss, these impacts are likely to be greater for isolated, inbred and endangered populations.

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