The Role of Adaptive Physiology in a Changing Climate

By Roz Pidcock

Current projections indicate that human-induced climate change will be at least partly responsible for a major and rapid decline in biodiversity in coming decades. Much recent coverage has been given to the suggestion that fish and other ectotherms (cold-blooded animals) are likely to be at the forefront of this decline, due to an inability to adapt to one of the most well-documented impacts of climate change, increasing atmospheric temperature[1,2,3].

However, the existence of long-term data of species in their natural settings are still relatively lacking and recent developments in conservational physiology have demonstrated that the physiological response of animals to changes in their environment may be considerably more complex than previously thought and should therefore be a crucial component of future conservation efforts.

This year's SEB Conference in Prague featured the first Conservation Physiology session, chaired by Prof. Craig Franklin, Prof. Frank Seebacher, Dr Michael Kearney and Prof Michael Romero.

Twenty-one presentations and several more posters showcased a broad range of novel results offering significant insight into how the physiological responses of individual species will affect their likelihood of survival, given future warming scenarios.

Not All Bad News

The good news with respect to organisms' physiological responses to climate change is that it may not all be bad news.

Phenotypic plasticity describes the ability of some animals to change a specific phenotype reversibly and repeatedly during their lifetime in response to a change in the environment, far quicker than they could evolve by genetic adaptation. This means many animal species may in fact be able to adapt to changing conditions better than previously thought.

A basic premise exists that all animals have a specific temperature range over which they can function, due principally to the rigid requirements of basic molecular and cellular processes. Ectotherms are animals that control their body temperature through external means and as such, are vulnerable to changes in environmental heat sources. Human-induced climate warming has been attributed to potentially harmful consequences in many ectotherm species, by pushing the working temperature of these basic cellular processes to the upper limits of their thermal range. The proposed consequences for the animal are an increase in resting oxygen demand coupled with a decrease in efficiency of the heart, leading to body tissues being starved of oxygen[3,4], which in turn affects almost all higher-level functions.

Observations over the last 25 years of warming sea temperature in the North Sea have shown that nearly two-thirds of fish populations have already shifted further north or to deeper water, or both[1], in search of cooler temperatures. If extrapolated to other fish species, this spells disaster for worldwide marine ecosystems and commercial fisheries.

Tagged Atlantic Cod being released at sea. Courtesy of Dr Julian Metcalfe.

A growing knowledge of physiology, however, is demonstrating unequivocally that the story is by no means that simple. Specifically, the physiological response of one species cannot, and should not, be extrapolated to another.

Thermal Niches: Polar Fish and the Cane Toad

Results from recent tagging studies of Atlantic Cod (Gadus morhua), presented at this year's SEB meeting, suggest that individuals in a wild population are much less sensitive to temperature than previously thought. The CODYSSEY study, led by Dr David Righton from the centre for Environment, Fisheries and Aquaculture Science (CEFAS), analysed over 16 million temperature recordings from tagged individuals and showed that the total thermal niche of Atlantic Cod ranged from -1.5 °C in northern waters to 19 °C at the southern limit of their distribution, far above the 11-15 °C that was previously thought to be their optimal temperature range, based on laboratory experiments.

"We have found that Cod in the northeast Atlantic repeatedly experience abrupt temperature changes of up to 8ºC, suggesting that temperature may not be so crucial in constraining the movements and distribution of adult cod," explained Dr Metcalfe, a senior researcher on the study.

In the same vein, other research has suggested that the Antarctic fish species Pagaothenia

Cane toad courtesy of Ed Meyer

borchgrevinki currently lives on the cold side of its thermal niche[5,6]. It has the capacity for thermally-induced plasticity in cellular metabolism, its cardiovascular system and its overall swimming performance, allowing it to tolerate temperature increases of 6 °C higher than at present, far above the highest temperature rise predicted by future climate warming scenarios[7].

Similar thermal acclimation responses have been observed in temperate and tropical ectotherms[8,9]. At this years SEB meeting in Prague, Prof. Frank Seebacher presented the case study of the Australian Cane Toad. When given sufficient time to acclimate, the resting oxygen use of Cane Toads (which is a reflection on the basic metabolic requirement) remained constant between 20-30 °C, thus exhibiting no oxygen limiting effect. Furthermore, the cardiovascular system of the Cane Toads actually performed more efficiently with increasing temperature.

Thermally induced plasticity can particularly benefit animals that move actively to colonise new habitats, as may conceivably be the case due to human-induced environmental change. Unfortunately, populations of the Cane Toad, originally introduced due to its voracious appetite for the Cane Beetle, have now escalated out of control and they are considered a threat to native Australian predators, as their skin is highly toxic and deadly when ingested.

Whether or not other, less problematic, Anurans (the class of amphibians that includes frogs and toads) will benefit from rising temperatures in the same way is not yet established. "More research is needed to find out and each species must be judged on a case-by-case basis", explained Prof. Craig Franklin, co-author of the research.

Tropical Drosophila species (D. Birchii) Courtesy of Andrew Weeks.

Conservation Effort

So what does this mean for conservation efforts?

It is important to note that the existence of phenotypic plasticity does not alter the fact that climate change is a very clear and present danger. Although Atlantic Cod have the potential to tolerate a changing climate, their survival is likely to be constrained by other factors, such as interactions with prey and predators or finding a habitat at the right temperature during spawning season, when their thermal tolerance is narrower (1 - 8 °C) (J. Metcalfe).

Furthermore, any species without the capacity for thermally induced plasticity will remain vulnerable to the effects of increasing temperature. For example, it is thought that thermal acclimation is likely to be rare among Antarctic fish species, due to the decrease in haemoglobin associated with past adaptation to the cold, high-oxygen Antarctic waters[10].

Similarly, a study on 5 tropical and 5 temperate species of Drosophila, presented at this year's meeting by Dr. Johannes Overgaard from Aarhus University in Denmark, indicated very little capacity for heat acclimation, leading to the conclusion that it would be inadequate to compensate in any significant way for the impacts of global warming.

An understanding of the nature and extent of thermally-induced plasticity will help us to identify which species are likely to adapt sufficiently to the effects of climate change and which ones need a concentrated and sustained effort, leading not to a reduced conservation effort but a more efficient and effective one.

A Complex Environment

Of course the natural environment is unremittingly complicated. An added level of complexity arises from the fact that differences in cardiovascular, aerobic and temperature tolerance may exist within a particular species i.e. within two spatially separated populations, exposed to different environmental pressures[11].

Increased temperature can cause stress and reduced population replenishment in damsel fish P. amboinensis. Courtesy of Dr Mark McCormick http://www.reeffishecology.com

There are also a number of potential knock-on effects attributed to the effects of climate change, in the form of the stress such environmental changes cause to an individual or a population.

A study by Dr Mark McCormick of James Cook University, Australia (also presented at the SEB conference) found that Damselfish under stressful conditions during breeding (such as through habitat degradation) produced smaller, poorer quality offspring, which had lower survival rates and contributed less to population replenishment[12].

Another study led by Lesley Alton from the University of Queensland highlighted the effects of increased UV-B radiation on amphibian metabolism, indicating that it can act synergistically with temperature change and/or biological pressures such as predation, causing the direct mortality of tadpoles and potentially accelerating the decline of many amphibian species.

The Future

Physiology in the context of a warming climate is something of a double-edged sword. Knowledge of thermal sensitivity and thermal limits may be invaluable to understand adaptations to the present environment and to help predict the effects of projected climate change, leading to a targeted and efficient conservation effort. Furthermore, phenotypic plasticity is an undeniable illustration of the wonder, resilience and enduring power of the natural world to fight and survive. It cannot be overstated, however, that thermally induced plasticity is not, and should not be considered as, a silver bullet for mitigating the effects of climate change. Where some animals may compensate to changing conditions, for others those same conditions may be potentially devastating and may result in complex, unexpected feedback mechanisms.

It is clear, however, that a continued commitment to understanding this extraordinarily complex, interactive system through adaptive and responsive physiological research is critically important and may provide the necessary insight to help predict future ecological trends in the ever-changing world our own species has created, which under no circumstances should be taken lightly.

References

1 A. L. Perry, P. J. Low, J. R. Ellis, J. D. Reynolds, Science 308, 912 (2005).
2 G. R. Waither et al., Nature 416, 389 (2002)
3 H. O. Portner & R. Knust, Science 315, 41 (2007)
4 H. O. Portner, Comp. Biochem. Physiol. A 132, 739 (2002)
5 F. Seebacher et al., Biol. Lett. 1, 151 (2005)
6 C. E. Franklin, W. Davison, F. Seebacher, J. Exp. Biol. 210, 3068 (2007).
7 S. D. Solomon et al., Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007)
8 H. Guderley, Biol. Rev. 79, 409 (2004)
9 E. J. Glanville, F. Seebacher, J. Exp. Biol. 209, 4869 (2006).
10 H. O. Portner et al., Science 323, 877 (2009)
11 A. P. Farrell et al., Physiol. Biochem. Zool. 81, 697 (2008).
12 M. Gagliano & M. I. McCormick, Oecologia, 160, 657 (2009)