Evolvability in the face of climate change: understanding developmental effects on bone and its ecological consequences

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Background: Evolutionary biology has focused on the processes determining ecological divergence where different forms ('ecomorphs') within a species specialise on particular habitats. Fish have been important models for demonstrating how ecological specialisation can be associated with phenotypic, and genetic changes. While these studies focus on dietary differences, there are many environmental factors that can contribute to ecological divergence. For example, temperature differences exist between the benthic and limnetic habitats where ecological divergence usually occurs with near shore benthic habitats being warmer on average. Temperature is already known to affect rates of growth and life history, and also to influence patterns of skeletal development (e.g. the number of vertebrae that fish develop, and the extent to which cartilage is converted to bone). Since benthic and limnetic ecomorphs often differ in skull size and bone density, differences in temperature regimes between habitats could be having important influences. However, the mechanisms by which temperature influences ecological divergence in bone have not been investigated. Given recent predictions that global temperatures will increase an average of 4°C, or even 8°C in Arctic regions, it is vital that we understand the influence that temperature can have on evolution.

This project will use three-spine sticklebacks (*Gasterosteus aculeatus*) as a study animal due to its propensity for ecological divergence, broad distribution, and amenability to laboratory conditions. Through laboratory experiments and fieldwork this project will examine how temperature affects developmental processes involved in ecological divergence. We predict that increases in temperature will cause increased levels of bone ossification. Increased ossification may make the skeleton stronger but in turn make bone a less 'evolvable' tissue, as it is less able to respond to mechanical stresses via phenotypic plasticity (the ability of a genotype to alter its phenotype dependent upon environmental cues). Plastic responses to diet have been shown to have important adaptive consequences in fishes so it is possible that higher temperatures could limit adaptation, and the effects of natural selection.

Objectives:

This project will initially address four main questions:

1) Do increases in temperature increase bone ossification rates in sticklebacks?

2) Do increases in temperature reduce the amount of morphological plasticity in response to diets that mimic benthic and limnetic prey?

3) Is morphological shape, both overall and with regard to specific bones, changed by temperature and its effects on ossification?

4) Do changes in ossification and bone shape in relation to temperature have adaptive functional consequences?

Training Opportunities: The questions addressed in this project are at the interface between ecology, evolution, development, and genetics, which will provide the student with exciting opportunities to integrate approaches. Field work will include research in Iceland, where adjacent natural populations of stickleback fish inhabit very contrasting thermal regimes including volcanic hot pools where the long-term evolutionary effects of increased temperature can be examined. More specifically, the student will gain an understanding of bone biology, shape analysis, experimental design, and statistics. There is also scope for an interested student to further explore the genetic processes underlying responses of bone to temperature.

Relevant Publications by the Supervisory Team:

Lee, W., **Monaghan, P.**, and **Metcalfe, N.B.** 2012. The pattern of early growth trajectories affects adult breeding performance. *Ecology* 93:902-912.

Parsons, K.J., Sheets, D., Skulason, S., and Ferguson, M.M. 2011. Phenotypic plasticity, heterochrony, and ontogenetic repatterning contribute to adaptive divergence during early juvenile development in Arctic charr. *The Journal of Evolutionary Biology* 24:1640-1652

Parsons, K., Y.H. Son, and Albertson, R.C. 2011. Hybridization promotes evolvability in African cichlids: connections between transgressive segregation and phenotypic integration. *Evolutionary Biology* 38:306-315.

Parsons, K.J., Skulason, S., and Ferguson, M.M. 2010. Morphological variation over ontogeny and environments in resource polymorphic arctic charr (*Salvelinus alpinus*). *Evolution and Development* 12: 246-257

Parsons, K.J., and Albertson, R.C. 2009. Bmp4 and calmodulin in jaw and beak development: Evo-Devo and Beyond. *Annual Review of Genetics* 43: 369-388.

Robinson, B.W., and **Parsons, K.J.** 2002. Changing times, spaces, and faces: tests and implications of adaptive morphological plasticity in the fishes of northern postglacial lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 59:1819-1833.