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Simulations of phenotype-environment associations and their application to forecasting the adaptability of populations to environmental change

In response to environmental change, a population may: 1) disperse to new areas containing suitable habitat conditions, 2) adapt to the new environment, or 3) suffer population declines and risk local extirpation. While many models have been introduced that examine the new habitat conditions to which a species could disperse in the face of environmental change (e.g., species distribution models), fewer models consider the ability of population to adapt to these changing conditions. Such models are especially critical for species that are dispersal limited.

Species distribution models examine the relationship between species occupancy and environmental variables and then use this relationship to determine areas which contain suitable environmental conditions to which species can disperse. We extend this framework to predict the ability of populations to adapt to environmental change by examining the relationship between phenotype and environment. These phenotype-environment associations are then used to determine the phenotypes the population must attain in order to persist within a habitat with altered environmental conditions.

First, we conduct simulations using a quantitative genetics model of linear reaction norms to examine the effects of natural selection, phenotypic plasticity, and temporal autocorrelation in the environment on the strength of phenotype-environment associations. Our results demonstrate that phenotype-environment associations are promoted by strong natural selection, high magnitudes of plasticity, and greater degrees of positive temporal autocorrelation (i.e., when the environment in the current generation is similar to the environment in the previous generation).

Second, we apply this framework to examine the adaptability of stream fish populations to future changes in flow rates caused by global climate change. Our analysis indicates that fish body shape was significantly associated with contemporary flow, as individuals found in high-flow habitats have a more streamlined body shape than individuals from low-flow habitats. Hydrologic models based on future temperature and precipitation data from regional climate models predict subbasin-level declines in flow rate in the years 2051 – 2060 relative to current flow rates. Thus, stream fish would require less-streamlined body shapes in the future. Using the same simulation models as above, we determine the combinations of selection intensity and phenotypic plasticity necessary for each population to reach the expected body shape. Our analysis reveals that the adaptability of some populations to future changes in flow rate requires strong and potentially unrealistic levels of selection and plasticity. Consequently, species may incur substantial demographic costs across populations.