Project proposal 6: A temperature-dependent model for intraguild predation between a native and invasive estuarine crab species

Introduction and Background

To understand and forecast the impacts of climate change on ecological communities, it is important to understand the effects of temperature change not only on individual species, but also on the strength and stability of species interactions. If the relationship between temperature and species interactions is known mechanistically via its effects on ecological rates, models can be developed to predict coexistence and interaction strength across a temperature gradient. Such models, if they are an accurate depiction of observed species distributions, can not only provide insight into the factors influencing species distributions, but also be used predict responses to climate change. Although theoretical models have been developed for the temperature dependence of consumer-resource[1] and competitive interactions,[2] no models to date have examined the effect of temperature change on intraguild predation (IGP), a combined predation-competition module that is ubiquitous and important in ecological food webs.[3]

IGP occurs where two predators consume a common resource, and one of the predators (the IG predator) also consumes the other (the IG prey). Theory predicts that stable coexistence of both predators is only possible if the IG prey is the superior competitor for the shared resource, and the IG predator benefits substantially from its consumption of the IG prey.[4] Under certain conditions, IGP can also lead to alternative stable states and unstable dynamics. Given that all parameters in an IGP model – predator attack rates and conversion efficiencies (for both the resource and IG prey), predator mortality rates, and resource input (growth rate and carrying capacity) – may all vary as a function of temperature, the dynamics of an IGP system will also vary with temperature. Of particular interest for climate change is under what circumstances temperature increase will allow for coexistence or exclusion, or will stabilize or destabilize a system. This may have important implications particularly at the range boundaries of the predators, if such boundaries occur at critical temperatures which delimit regional alternate stable states determined by IGP interactions.

I am interested in developing a temperature-dependent IGP model for two particular species: the native blue crab (IG predator) and invasive green crab (IG prey), which co-occur in estuaries across a temperature gradient between Chesapeake Bay and Cape Cod along the Atlantic coast of North America. The green crab is not found south of Chesapeake Bay, and the blue crab is not found north of Cape Cod. My preliminary work suggests that as predicted, the green crab is a superior competitor, but also that competitive interactions and the frequency of IGP are size and temperature dependent. Only when blue crabs are sufficiently large and when temperature is sufficiently warm does IGP appear to occur. Both crabs are important predators in estuarine communities and provide a case study for testing how IGP will be affected by temperature, and how well it explains observed distribution patterns.

Questions and Goals

How will the equilibrium behavior of an IGP model for blue crab – green crab interactions differ across a range of temperatures, given the known (or hypothesized) responses of competition, IGP, and resource availability to temperature? How well do model predictions match the observed distributions of the crabs?

Methodological Approach

I will generate an IGP model to represent the activity of adult crabs in estuaries during the summer months, which is the period of active feeding, growth, and reproduction. I will assume no interactions or differential mortality during the winter months, when the crabs hibernate, and will ignore larval life history stages, which are subject to very different dynamics. Based on existing research, will then determine the likely functional response of the following parameters to temperature change: (1) Relative competitive ability for the shared resource (as measured by relative attack rates on resource); (2) Rate of IGP (as measured by attack rate of IG predator on IG prey); (3) Resource productivity (as measured by resource carrying capacity or input). I will then test how the equilibrium behavior of the model differs across a range of temperatures as different temperature dependencies are incorporated into the model, singly and in combination.

I assume that growth rate of the blue crab to larger size classes (which are the only ones that can exhibit IGP) is also correlated with temperature, so that this size-dependency can be subsumed into the effect of temperature on IG attack rate. However, I will also modify the model so that the blue crab has 2 age classes, only the larger of which can consume green crabs, and then test how the model behavior changes if the recruitment of blue crabs into the larger size class is temperature dependent (singly and in combination with other temperature dependencies). This model could also be used to account for differences in the competitiveness of small and large blue crabs relative to green crabs.

Using values from the literature and from laboratory studies I will conduct during the summer on competitive and predatory interactions between crab species at different temperatures and relative sizes, I plan to parameterize the models more accurately to predict the temperatures at which coexistence and exclusion should occur. I will see how well these predictions match the observed distributions of the crabs, using mean summer water temperature within an estuary as a geographic indicator of thermal conditions. If there is a discrepancy, I can make hypotheses about what other factors may be important (e.g. larval processes, niche partitioning).

Expected Results and Implications

My preliminary work suggests that blue crab activity is more negatively affected by cold temperature than green crab activity, so IGP should increase with temperature, and the relative competitive ability of the green crab should decrease with temperature. Across a temperature gradient, I would expect to see exclusion of the green crab at high temperatures due to predatory interactions, which would be consistent with field observations,[5] and exclusion of the blue crab at low temperature due to competitive interactions. Alternatively, I might see this same pattern result from changes in resource availability, which is expected to increase with temperature. At low resource abundance, blue crabs (the weaker competitor) may be unable to persist, whereas at high resource availability, blue crabs may exclude green crabs through apparent competition.

Although developed specifically for a crab system, this model and approach is also valuable and applicable to other IGP (and non-IGP) systems. It provides a general framework for understanding how local species interactions are modified by environmental context. One can test whether the distribution and range boundaries of species can be explained by temperature-dependent species interactions, and explore how changes to the environment might affect these distributions. For blue crabs and green crabs, the results will have implications for crab range expansions and/or contractions, interactions between native and invasive species, and top-down vs. bottom-up effects in estuarine communities. Blue crabs are an economically valuable fishery species, green crabs are a destructive invasive species, and the coastal estuaries they inhabit provide numerous important ecosystem services to society, so this research will contribute to our understanding and managing of these systems, and preparing for the effects on climate change.

[1] Gilbert et al. 2014 *Ecol Letters*; [2] Urban et al. 2012 *Proc R Soc B*; [3] Polis et al. 1989 *Ann Rev Ecol Syst*; [4] Holt and Polis 1997 *Am Nat*; [5] de Rivera et al. 2005 *Ecology*