Can ocean 'cold spots' enhance resilience to climate change?

Rapidly rising global temperatures threaten coastal ecosystems. One management strategy aimed at enhancing the resilience of these ecosystems, or their ability to maintain functioning, involves siting marine reserves in ocean 'cold spots'. These 'cold spots', cooled naturally by factors such as fog or upwelling, create thermal refuges that may sustain pockets of higher survival in a warming ocean[1]. Protecting these thermal refuges is thought to enhance resilience in the face of warming by capitalizing on naturally climate-resistant populations with steady sources of larval production, which can then replenish surrounding areas. However, most of the evidence to support this hypothesis is based on observations from coral reefs. We know little about the mechanisms underlying the connection between thermal refuges and resilience, especially at higher latitudes where warming effects are expected to be strongest. I propose to evaluate the potential of temperate rocky shore thermal refuges to maintain survival and fecundity of the foundation species, *Semibalanus balanoides*, when subjected to warming. Rocky shores are considered 'sentinel ecosystems' for exploring climate effects because they encompass extreme environmental gradients from land to sea, and many rocky shore species live at the edge of their thermal tolerances[2]. I will also address the effects of thermal refuges on community-level diversity and productivity, two ecological properties known to enhance resilience. Species richness increases response diversity and functional redundancy, while productivity facilitates recovery following disturbance[3].

Questions and Approach

Q1) Do thermal refuges increase survival and fecundity of* S. balanoides *in response to experimental warming? In Northwest Atlantic estuaries characterized by cobble beaches and hot summers, extensive rocky benches are thermal refuges for intertidal species because their massive size buffers them from high temperatures at low tide[4]. To simulate the effects of climate warming, I will secure small plastic greenhouses to rock surfaces in the mid intertidal zone. I will compare warmed plots to greenhouse-control and unmanipulated plots (n=10 plots/treatment) in thermal refuge (bench habitats) and non-refuge sites (cobble beach habitats) (n=4 sites/habitat). I will scrape all plots clear in December preceding the summer experiment, to capture annual barnacle recruitment and the successional process equally at all sites. To assess the importance of thermal refuges across the biogeographic range of *S. balanoides*, I will replicate the experiment at four latitudes between Nova Scotia, CA and Connecticut, USA. Throughout the summer, I will monitor rock surface temperatures, barnacle survivorship as percent cover of live barnacles, and fecundity by subsampling individuals to assay reproductive status.
Q2) Are thermal refuge communities more diverse and productive? At the beginning and end of the summer, I will quantify community-level metrics of diversity and productivity such as species richness, evenness, percent cover of invertebrates and biomass of algae in the experimental plots described above.

Anticipated results and significance

Q1) In the southern portion of the study range, where summer heat stress causes substantial barnacle mortality even in the absence of warming[4, 5], thermal refuges should enhance summer survival. These effects may be reduced in the northern part of the study range where heat stress is less severe. Since reproduction in *S. balanoides* occurs in the fall, after summer heat has affected barnacle populations, I expect population-level fecundity to be highest in thermal refuge areas. **Q2)** Many rocky shore species are particularly vulnerable to warming[2], so increased temperatures may cause reduced productivity, or even local extinctions of some species. However, more heat-tolerant species may compensate for reduced productivity and local extinctions by establishing in non-refuge sites. Results from this study will provide much-needed empirical evidence to inform our limited understanding of resilience dynamics in coastal ecosystems. Since rocky bench habitats occur at spatial scales relevant to marine reserve design (10-100kms), understanding the potential for these 'cold spots' to enhance resilience to climate warming will help inform effective marine conservation planning for a changing climate.

References: 1. West JM, Salm RV. 2003. *Cons. Biol.*17(4):956-967 2. Somero, G. N. 2002. *Int and Comp Biol* 42:780-789. 3. Gunderson LH. 2000. *Annu. Rev. Ecol. Syst.* 31(1):425-439 3. 4. Gedan, K., J. Bernhardt, M. Bertness, H. Leslie. *In press. Ecology*. 5. Wethey, D. S. 1983. *Biol Bull.* 165:330-341.