Acclimation Capacity Underlies Susceptibility to Climate Change

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Recent reports have presented meta-analyses of global biological impacts of climate change (*1*, *2*). However, there is debate as to the level of confidence ascribed to the certainty that global climate change has caused the observed biological changes (*3*). Two important considerations in the assessment of how climate change will impact organisms are (i) how close organisms are to their thermal limits in nature and (ii) an understanding of how organisms respond to increasing habitat temperatures, especially the degree to which organisms are able to adjust, or acclimatize, their thermal sensitivity.

Here, I report the effects of thermal acclimation on thermal limits of cardiac function in four congeneric species of marine invertebrates (Porcelain crabs, genus *Petrolisthes*) from different thermal habitats. Crabs in this genus are distributed throughout the eastern Pacific, from Alaska to Chile, and at all sites in this latitudinal range sympatric species have discrete patterns of vertical intertidal zonation (*4*). During low tide, these crabs remain under stones, where temperatures during hot, low tide periods have been shown to change over 20°C in 6 hours (*4*,*5*). Two of the species (*P. gracilis* and *P. hirtipes*) are endemic to the Northern Gulf of California, and the other two (*P. cinctipes* and *P. eriomerus*) are distributed in the cold- temperate zone of the northeastern Pacific (*4*). *P. gracilis* and *P. cinctipes* are upper intertidal zone species, *P. hirtipes* is a middle intertidal zone species, and *P. eriomerus* is found in and below the low intertidal zone (*4*). *P. gracilis* and *P. hirtipes* are in one phylogenetic clade that diverged ~6 million years ago (Ma), and *P. cinctipes* and *P. eriomerus* are in a different clade with a divergence time of ~13 Ma (*4*).

The upper and lower thermal limits of heart function (defined as CT_{max} and CT_{min}, respectively) (fig. S1) (*5*) were determined in specimens acclimated to 10°C temperature ranges (Fig. 1, A and B) (*5*). CT_{max} (Fig. 1A) and CT_{min} (Fig. 1B) values at either acclimation temperature were generally consistent with thermal microhabitat. CT_{max} values are at or near maximal habitat temperatures (Fig. 1, A and C) (*4*) in all species except for *P. eriomerus*. The striking result of this experiment is shown in Fig. 1C. The change in CT_{max} over the 10°C acclimation temperature range (ΔCT_{max}) decreased linearly among species in an inverse relation with maximal microhabitat temperature. In other words, the species that have evolved the greatest tolerance to high temperatures have done so at the expense of acclimation capacity of CT_{max}, and it is these species that will be the most susceptible to the smallest increases in microhabitat temperatures. The opposite effect was apparent for CT_{min}, where there was a positive correlation between ΔCT_{min} and maximal habitat temperature. These trends remained apparent after phylogenetic transformation of the data by independent contrasts analysis (*5*).

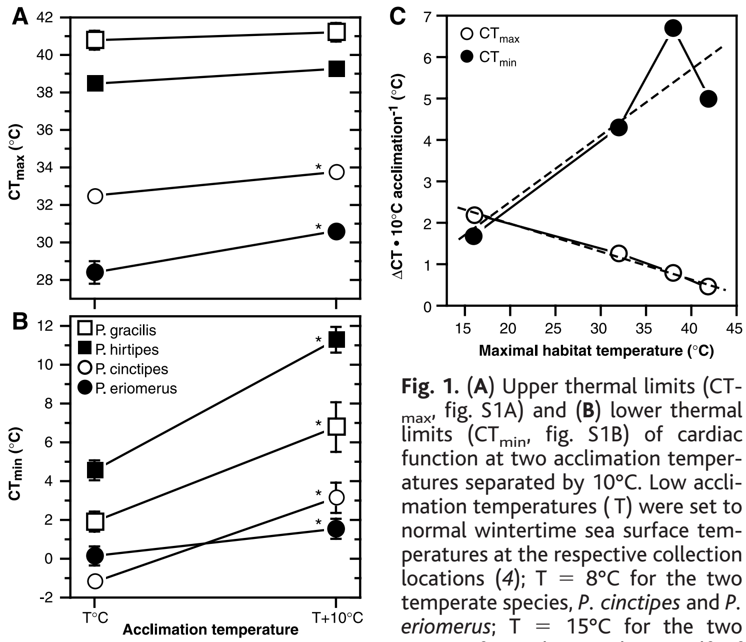

Fig. 1. (**A**) Upper thermal limits (CT_{max}, fig. S1A) and (**B**) lower thermal limits (CT_{min}, fig. S1B) of cardiac function at two acclimation temperatures separated by 10°C. Low acclimation temperatures (T) were set to normal wintertime sea surface temperatures at the respective collection locations (*4*); T = 8°C for the two temperate species, *P. cinctipes* and *P. eriomerus*; T = 15°C for the two species from the Northern Gulf of California, *P. gracilis* and *P. hirtipes*. Acclimations were ≥4 weeks in each case. Each data point is the mean ± 1 SE; n = 5 to 6 individuals. Asterisks indicate significant differences between T and T+10 values for each species (*t* test, $P < 0.05$). (**C**) The change in CT_{max} and CT_{min} over the 10°C acclimation range for each species, plotted as a function of maximal habitat temperatures (*4*). Each data point is the difference in means of CT_{max} or CT_{min} for one species. Linear regression (dashed lines) was significant ($P = 0.0044$) for CT_{max} but not for CT_{min} ($P = 0.11$).

The prediction generated from these results is that the *Petrolisthes* species that would be impacted the most with increased warming would be those from the Northern Gulf of California. The capacity for acclimation of CT_{max} in *P. gracilis* is less than the estimated average amount of global warming that has already occurred (*2*), and thus this species may have already been impacted by climate change. There is evidence that *P. cinctipes* has been affected by climate-related increases in thermal microhabitat. An analysis of long-term changes in species composition of the intertidal invertebrate community in Monterey, California, reported that the abundance of *P. cinctipes* has dramatically declined during a period of 60 years associated with increasing thermal stress levels (*6*). If a relatively long-term set of data existed for *P. gracilis* and *P. hirtipes* in the Gulf of California, similar changes in abundance would have likely been observed. Thus, by understanding the biological bases that underlie the responses of organisms to increasing habitat temperature, we can increase our certainty of the direct impacts that climate change has on life in nature.

References and Notes

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5. Materials and methods are available as supporting material on *Science* Online.
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Supporting Online Material
www.sciencemag.org/cgi/content/full/301/5629/65/DC1
Materials and Methods
Fig. S1
References

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Editor's Summary