Physiology, climate change and biological invasions: a case study of *Mytilus* mussels in the Northeast Pacific Ocean

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1. Introduction

Invasive species pose numerous threats to marine ecosystems. As climate change continues to alter marine habitats, an expected outcome is that species more tolerant of new conditions will expand biogeographic ranges and displace native species. Native and invasive species of blue mussel (genus *Mytilus*) along the west coast of North America exemplify this potential consequence of climate change. Historical records show that native *Mytilus trossulus* were once abundant within protected sites along much of the coastline, but current distributions are mostly limited to central California and northward. This biogeographical shift has been attributed to the introduction of the European blue mussel *Mytilus galloprovincialis*, a vigorous invader native to the Mediterranean Sea, where habitats are characterized by warmer water temperatures, lower magnitude tidal fluxes and less seasonal variation than is found in the Northeastern Pacific. As a reflection of this evolutionary history, *M. galloprovincialis* has evolved a warm-adapted physiology that allows it to competitively displace *M. trossulus* along its warmer southern range, an effect that may become exacerbated as oceans continue to warm.

2. Role of Physiology in responses to climate change

Evolution under different abiotic conditions has presented the opportunity for natural selection to differentially shape the physiologies of these two mussels. These physiological differences underlie their responses to ocean warming. All physiological and biochemical
comparisons of the native and invasive blue mussels published to date show *M.
galloprovincialis* to be more warm adapted than *M. trossulus* and therefore more likely to
persist in a warmer climate. In the following section, four physiological differences are
described that contribute to the success of the invasive mussel *M. galloprovincialis* in a warmer
ocean. First, heart function in *M. galloprovincialis* can be sustained at higher temperatures than
in the native species *M. trossulus* (Braby and Somero, 2006). For intertidal species, heart
function is considered a weak link in physiology and loss of cardiac function is tightly correlated
with death. Second, the induction of heat shock proteins is more pronounced in the more warm
adapted mussel *M. galloprovincialis*. A near universal aspect of responses to elevated
temperatures is the induction of heat shock proteins (Hsp’s). Hsp’s act as molecular chaperones
that bind to proteins unfolded by temperature and work to re-fold these damaged proteins and
return their function. The ability to produce more Hsp’s suggests that *M. galloprovincialis* is
capable of maintaining protein function at relatively higher temperatures than *M. trossulus*
(Hofmann and Somero, 1996). Third, *M. trossulus* increases the abundance of proteasome
proteins at relatively lower temperatures than *M. galloprovincialis*. The proteasome is the cell’s
recycle bin and terminally damaged proteins are transported to the proteasome so that cells
can reuse amino acids in the proteins. Increases in proteasome expression indicate that
proteins in *M. trossulus* are becoming damaged at lower temperatures than in *M.
galloprovincialis* (Lockwood and Somero 2010). Fourth, important metabolic enzymes are able
to function at higher temperatures in *M. galloprovincialis*. Enzymes exhibit reduced ability to
bind substrates at rising temperatures due to changes in the shape of the enzyme. Several
metabolic enzymes in *M. galloprovincialis* can bind substrates at temperatures where substrate
binding fails in M. trossulus. One such enzyme is malate dehydrogenase (MDH), which is part of the citric acid cycle. The protein for MDH differs by only a single amino-acid between M. galloprovincialis and M. trossulus, which illustrates the ability of minor changes in protein sequence to shift the enzyme performance during heat stress and thereby influence a species’ optimal temperature range (Lockwood and Somero 2011).

3. Summary

As the Northeast Pacific Ocean warms, the warm-adapted and invasive mussel M. galloprovincialis will continue to displace the native mussel M. trossulus along the southern (i.e. warmer) portions of its range. Evolved physiological differences appear to be driving this response to climate change. M. galloprovincialis can maintain cardiac function and enzyme activity at higher temperatures, produce more Hsp’s and has more thermally stable proteins. While the further spread of M. galloprovincialis (one of the world’s 100 worst invasive species) seems inevitable, an important question to address in the future is what effect(s) this species will have on invaded ecosystems.

References

