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Environmental stress decreases survival, growth, and reproduction in New Zealand mussels

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Abstract

To test the effects of environmental stress on mussel growth and reproduction, reciprocal transplants of two New Zealand mussel species, *Mytilus galloprovincialis* and *Perna canaliculus*, were performed between the high (high-stress) and low (low-stress) elevation edges of an intertidal mussel bed in New Zealand. Mussels transplanted to the high edge of the mussel bed exhibited slower growth, lower mass of reproductive tissue, and stress-induced spawning, indicating that stress impairs the ability of these organisms to grow and reproduce. *P. canaliculus* grew more quickly than *M. galloprovincialis* but allocated less relative energy towards reproduction. An anomalous high aerial temperature event led to differential mortality of the two mussel species in the field, indicating that *P. canaliculus* is less thermotolerant than *M. galloprovincialis*. These results suggest that the abundance of *P. canaliculus*, the competitive dominant on New Zealand rocky shores, may decrease in the face of increasing aerial temperatures predicted under global climate change scenarios, drastically altering intertidal community structure.

Keywords: Environmental stress; Mussels; *Mytilus galloprovincialis*; *Perna canaliculus*; Rocky intertidal

1. Introduction

Global temperatures have risen 0.6 °C during the past century and are predicted to continue rising by 1.4–5.8 °C over the next century (Houghton et al., 2001). Expected alterations to the physical environment under climate change scenarios include potential sea level rise, warming of both air and water temperatures, alterations to oceanic circulation, and increasing frequency and severity of storms (e.g. Lubchenco et al., 1993; Houghton et al., 2001). Climate change may also lead to numerous biological consequences for organisms, including phenological shifts and alterations to species ranges (Parmesan and Yohe, 2003). Marine systems such as coral reefs (Hoegh-Guldberg, 1999), kelp forests (Schiel et al., 2004), and the rocky intertidal zone (Sagarin et al., 1999) have already exhibited shifts in community structure as a result of warming water and air temperatures. It is likely that environmental stress will increase under scenarios of climate change, as increasing frequency and severity of aerial temperature events are predicted to occur (Houghton et al., 2001).

The rocky intertidal zone is an ideal model system for examining the effects of environmental stress, as the

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physical environment is inherently stressful to the biota that live in this habitat. Intertidal organisms are exposed to both terrestrial and marine conditions on a daily basis, and timing of aerial exposure varies with the tidal cycle (Denny and Paine, 1998; Helmuth, 1999; Helmuth et al., 2002). Upper distributional limits in the intertidal zone are thought to be determined primarily by desiccation and temperature stress, whereas lower limits are typically established by species interactions (e.g. Connell, 1961; Paine, 1966; Paine, 1974; Lubchenco, 1980). While environmental stress in the upper limit of the rocky intertidal zone is driven by a synergistic combination of temperature, desiccation, and decreased food supply that potentially result from exposure at low tide, high aerial temperatures appear to cause the most dramatic sublethal (e.g. Helmuth and Hofmann, 2001) and lethal (Tsuchiya, 1983) physiological consequences for intertidal organisms.

Mytilid mussels are dominant space-occupiers on temperate rocky shores throughout the world (e.g. Seed and Suchanek, 1992) and span the entire vertical area between the low zone, an area of relatively low temperature and desiccation stress, and the high zone, a potentially high-stress environment. High aerial temperatures during low tide can lead to protein damage (e.g. Helmuth and Hofmann, 2001; Halpin et al., 2004), reduced growth (e.g. Menge et al., 2002), and mass mortality (Tsuchiya, 1983) in mussels at the upper edge of the mussel bed. However, very little is known about the effects of environmental stress on intertidal mussel reproduction.

Reproduction can be inhibited by sublethal environmental stress, because animals reallocate energy away from gamete production and towards defense and repair mechanisms (e.g. Michalek-Wagner and Willis, 2001). Timing of reproduction can be modulated under an altered thermal regime, potentially having consequences of asynchrony and overall decreased fertilization and recruitment success (Walther et al., 2002; Philippart et al., 2003). All of these factors can lead to a decreased number of propagules that supply adult populations and communities.

On the east coast of the South Island of New Zealand, rocky shores are dominated by mussels in the mid-zone of the rocky intertidal zone (Knox, 1953; Menge et al., 1999). The two dominant species are *Perna canaliculus* Gmelin and *Mytilus galloprovincialis* Lamarck (Knox, 1953; Menge et al., 1999). Both species undergo gametogenesis throughout the year and exhibit both late winter and late summer spawning events (Kennedy, 1977; Buchanan, 2001). Both mussel species span the vertical gradient between the low zone and the high zone, and *P. canaliculus* appears to be the competitive dominant, growing large (~15 cm) at the lower edge of its distribution. However, in the very extreme upper edge of the mussel bed, this species is found only in crevices, suggesting that it is less thermotolerant than *M. galloprovincialis* (Kennedy, 1976).

The purpose of this study was to determine the effects of environmental stress on two intertidal mussel species. We predicted that under conditions of high stress, mussels would exhibit decreased growth and energy allocation towards reproduction. We also predicted that *P. canaliculus* would show the greatest responses to sublethal stress. Species-specific responses to stress could provide insight into future alterations to intertidal community structure under warming aerial temperatures predicted from global climate change scenarios.

2. Materials and methods

This study was conducted on the east coast of the South Island of New Zealand, specifically at "Box Thumb" (43°34′ S, 172°48′ E) on Godley Head of the Banks Peninsula near Christchurch. Box Thumb is a small peninsula with a basaltic substrate. Macroalgae and *P. canaliculus* dominate the low zone, *M. galloprovincialis* and *P. canaliculus* dominate the mid-zone, and barnacles dominate the high zone (Menge et al., 1999; Menge et al., in press). Tides are semidiurnal, and low tides often occur during the daytime throughout the summer season, providing the potential for high thermal and desiccation stress.

2.1. Temperature recording

Two TidbiT temperature loggers (Onset Computer Corp., Pocahassett, MA, USA) were deployed in the intertidal zone: one logger was placed above the high edge of the mussel bed ("high-zone logger") and the other was placed in the middle of the mussel bed ("mid-zone logger") on October 26, 2001; these loggers recorded hourly temperatures (air or water depending on tidal cycle) during the summers (October–February) from 2001 to 2005.

2.2. Surveys of mussel reproduction

Surveys of reproduction in natural mussel populations were conducted monthly during the experiment (Dec. 2004–Feb. 2005). Mussels of both species (*M. galloprovincialis* and *P. canaliculus*) were haphazardly collected from the lower edge (~+1.0 m above MLLW; "low edge") and upper edge (~+2.0 m above MLLW; "high edge") of the mussel bed ($n=50$ of both species, both edges; total mussels per month=200). All