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Scope for growth of *Mytilus galloprovincialis* and *Perna viridis* as a thermal stress index in the coastal waters of Japan: Field studies at the Uranouchi inlet and Yokohama

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ABSTRACT

In-situ physiological parameters of *Mytilus galloprovincialis* and *Perna viridis* were examined by conducting an underwater chamber experiments at three study sites in the western Japanese coastal waters along the Pacific Ocean side in summer and winter. Estimated growth energy balance derived by scope for growth (SFG) demonstrated a deficit of growth energy reserve for *M. galloprovincialis* in summer at temperatures beyond 28 °C. Similarly, insufficient energy reserve for *P. viridis* in winter temperature below 13 °C was exhibited. Decline of summer growth energy in *M. galloprovincialis* at 28–29 °C was deduced to be caused by the depletion of energy supply from food ingestion suggested by the reduction of clearance rate (CR). The observed depression of SFG confirmed that the warming stress on the metabolism of *M. galloprovincialis* could be a reason for the currently observed population decline of *M. galloprovincialis* in Japanese coastal waters. In winter condition, depression of growth energy in *P. viridis* below 13 °C could be attributed to the reduction in both the CR and the oxygen metabolism. The depleted winter SFG in *P. viridis* suggested that its current expansion in Japanese coastal water might be partly controlled by metabolic energy deficiency at winter temperature and the low food concentration environment. Assuming the increase in annual average coastal water temperature due to future climate change will be 2 °C, enhancement of *M. galloprovincialis* mortality is inevitable, as projected summer water temperatures will exceed the "pejus threshold" of 28 °C and warming lethal threshold of 29 °C. In contrast, *P. viridis* will have advantages in its population expansion in the future warming environment due to both decreasing cold-water stress on winter growth energy reserve and large growth energy in the summer if the food environment is sufficient to compensate for enhanced metabolic energy demand in this ectotherm.

1. Introduction

The blue mussel *Mytilus galloprovincialis* has been a major fouling organism in the intake tunnels of power plants and fishing gear, *etc.* in Japanese coastal waters in recent decades (Otani, 2004). It has been widely observed in Japanese coastal facilities due to coastal seawater temperatures ranging from 2 to 28 °C (Tateda et al., 2013). However, the abundance of *M. galloprovincialis* is decreasing, perhaps due to increased mortality associated with elevated summer water temperatures during the 2000s (Kurihara et al., 2010).

In contrast, the green mussel *Perna viridis*, originating and common in Asian tropical waters (Lee, 1986; Rajagopal et al., 1991, 2006) was found in Japan in the 1960s (Hanyu and Sekiguchi, 2000), and has increased its habituation area (Iwasaki et al., 2004; Otani, 2002; Umemori and Horikoshi, 1991). Its distribution in Japanese coastal waters is considered to be areas with a temperature range of 10–31 °C (Tateda et al., 2013). However, expansion of distribution is believed to be restricted, probably due to the reported winter mortality in seawater temperatures lower than 9–10 °C (Liu and Watanabe, 2002).

This does not fully explain the reported population changes for *M. galloprovincialis* and *P. viridis* in the recent decades. Japanese coastal seawater temperature has increased 1.3 °C during the past 100 years (JMA, 2011), however an equivalent rate of increase of 0.26 °C $20y^{-1}$ is likely to be insufficient to enhance summer mortality of *M. galloprovincialis* based on the observed lethal threshold for high water temperature: 29 °C for 8–12 days in Japanese coast (Yasuda and Hibino, 1986). The cause for the observed decline of *M. galloprovincialis* in Japanese coastal waters may be another factor such as the "pejus threshold" (meaning metabolically turning worse) for the temperature range of 24–29 °C (Anestis et al., 2007, 2010). Similarly for *P. viridis*, winter mortality of this green mussel was also elucidated as being caused by cold-water stress in temperatures ranging from 10 to 14 °C in the United States on the Florida coast (Urian, 2009).

To investigate metabolic thermal stress on *M. galloprovincialis* and *P. viridis* in summer and winter, we studied the scope for growth

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(SFG) (Widdows et al., 1997) as the growth energy reserve balance index for both species. To obtain the physiological parameters data required for calculation of SFG in the actual living environment, we measured and derived community oxygen consumption VO_2 and clearance rate CR by using underwater *in situ* experimental chamber equipment (Tateda, 2007) working with individual shellfish of each species, we calculated the energy absorption from ingested food originating from particulate organic matter in the inhabited seawater at the study sites, energy loss by *in-situ* respiration, and finally derived the SFG (Anestis et al., 2010; Li et al., 2002; Wong and Cheung, 2001; Wang et al., 2005, 2011; Widdows et al., 1997). Metabolic *in-situ* responses of *M. galloprovincialis* and *P. viridis* were evaluated at three study sites to elucidate physiological thermal stress "pejus thresholds" for each species in summer and winter.

2. Material and methods

2.1. Study sites

The Uranouchi Inlet, Kochi Prefecture (Fig. 1) situated along Pacific Ocean coast of Japan, was selected for an *in-situ* experimental study site for evaluation of summer and winter thermal stress on *M. galloprovincialis* and *P. viridis* under natural conditions. Due to its temperature variability despite the inlet's small size with the innermost area being located 8.8 km from the inlet mouth, the inlet is an appropriate compact study site to investigate the effect of temperature stress on the two mussel species. Habitation of the non-indigenous mussel *M. galloprovincialis* was recorded in the adjacent area of Susaki in 1994 (Asai et al., 1997) and it was observed on floating buoys in the inlet until 2005, while the population was reported to be declining during the 2000s (Yamada et al., 2010). Conversely, *P. viridis* was found after 2000 and has been reported from the mouth to the innermost area of this inlet (Yamada et al., 2010). As a reference, we also conducted experiments at a site in Yokohama in the inner part of the Tokyo Bay (Fig. 1), which has been reported to be the northern border of abundant habitation by *P. viridis* (Otani, 2002) on the Japanese Pacific Ocean coast.

2.2. Environmental measurements

Surface seawater temperature, salinity and current were measured by oceanographic observation instruments (COMPACT-CT, -AE: JFE Advantech Co. Ltd.) at the study sites of the Uranouchi Inlet mouth area (St. U1), Uranouchi Inlet innermost area (St. U2), and at the artificial seaside facility (St. Y) at the Port and Airport Yokohama Office (Fig. 1). Measurements were carried out for 3 days at low tide hours during the experimental period that included spring tides in January, April, June, and August 2011. Measurement of chlorophyll (chl-α) was additionally carried out in February, March and July to detect bloom

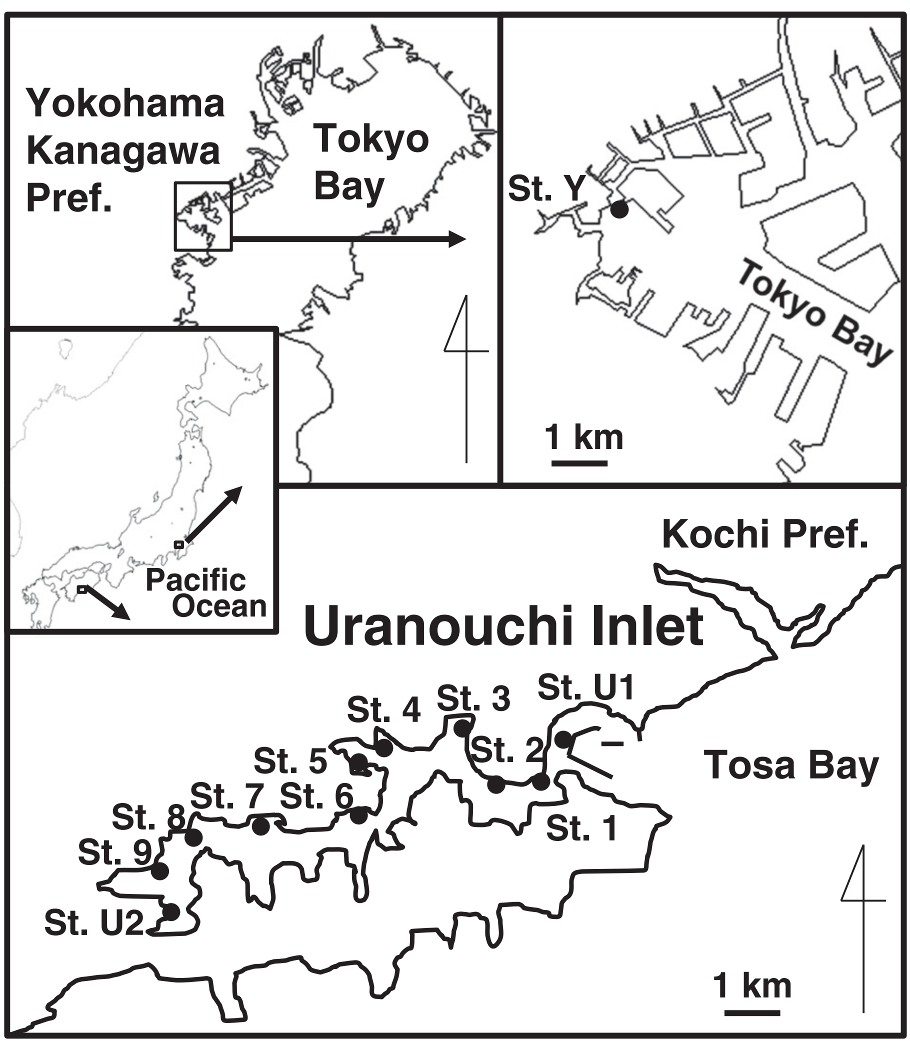

Fig. 1. Experimental sites (St. U1: Uranouchi Inlet mouth, St. U2: Innermost area of Uranouchi Inlet, St. Y: Artificial tidal flat, Port and Airport Yokohama Office) and environmental sample collection sites in the Uranouchi Inlet (St. 1–9).