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Measuring the effects of temperature rise on Mediterranean shellfish aquaculture

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ABSTRACT

Shellfish aquaculture represents a worldwide valuable segment of the aquaculture market, spreading along the Mediterranean coasts, and is sensitive to the still unforeseen, poorly-known effects of climate change. Threats due to temperature rise can threaten the deployment and development of this sector, up until now recognised as the best candidate to mitigate the effects of fishery overexploitation. Here, we investigate the effects of temperature increase on the model species, *Mytilus galloprovincialis*, measuring outcomes from valve fragility (thickness) and condition index. Evidence of a reduction in the thickness of valves and the modulation condition of the mussels along with temperature increase have been gathered from simulations of a natural temperature gradient changing along latitude (the Italian Peninsula) and temperature risen (mesocosm trial). The obtained results offer a baseline to help the next generation of managers and stakeholders when assessing the reliability and feasibility of shellfish culture in a changing sea that can generate undetected and underestimated impacts on the sector.

1. Introduction

Environmental change, including increasing temperature due to global warming, has direct effects on quality and quantity of cultivated bivalves by affecting their morphometric characteristics, growth rates and condition index (Mackenzie et al., 2014). Since bivalves represent an important segment of the aquaculture market worldwide, environmental change will risk reducing the role of this sector as the recognised best candidate of mitigating the effects of fishery overexploitation (FAO, 2016). Thus, the need for an accurate and proactive mechanistic understanding of "how", "where" and "when" the effects of global warming will manifest is becoming both pressing and compelling in a context of multiple stressors (Helmuth et al., 2014; Connell et al., 2017; Sarà et al., 2017). Temperature can affect the metabolism of cultivated molluscs according to specific rules following mechanistic relationships (e.g. Arrhenius temperature, Kooijman, 2010), with tested effects on both shell calcium fixation processes and the energy allocation to somatic and gonadic structures (Hiebenthal et al., 2012, 2013). A potential expression of this effect could be a reduction of thickness with a consequent increase in shell fragility (Olson et al., 2012; Briones et al., 2014). Valves play several primary ecological roles, such as reducing successful predation by crushers, protection from intense wave action and providing mechanical support from the effects of density and aggregation in beds, ropes or matrices (Elner, 1978; Briones et al., 2014 and references therein). Thus, any possible reduction in thickness and mechanical strength could have a profound effect on survival, not only by reducing protection of the soft tissues from predators and anthropogenic activity, but also by influencing the ability of bivalves to respond to environmental change (MacKenzie et al., 2014). The relationship between environmental temperature (Sea Surface Temperature, SST) and thickness in bivalves has had a new and recent impetus due to the results obtained by studies focusing on the expected increasing temperature effects on organismal performances (*sensu* McBryan et al., 2013; Helmuth et al., 2014). Overall, the experimental outcomes obtained by testing the relationship between temperature, latitude and thickness have shown contrasting trends (*sensu* MacKenzie et al., 2014), highlighting differences among cold and warm waters (Vermeij, 1993) in several invertebrates (Trussell, 2000; Trussell and Smith, 2000; Trussell and Etter, 2001; Sepúlveda and Ibáñez, 2012; Watson et al., 2012). Therefore, a general trend seems to be most commonly observed in that under higher temperature and at lower latitude, valves should be thinner (Briones et al., 2014). Considering the

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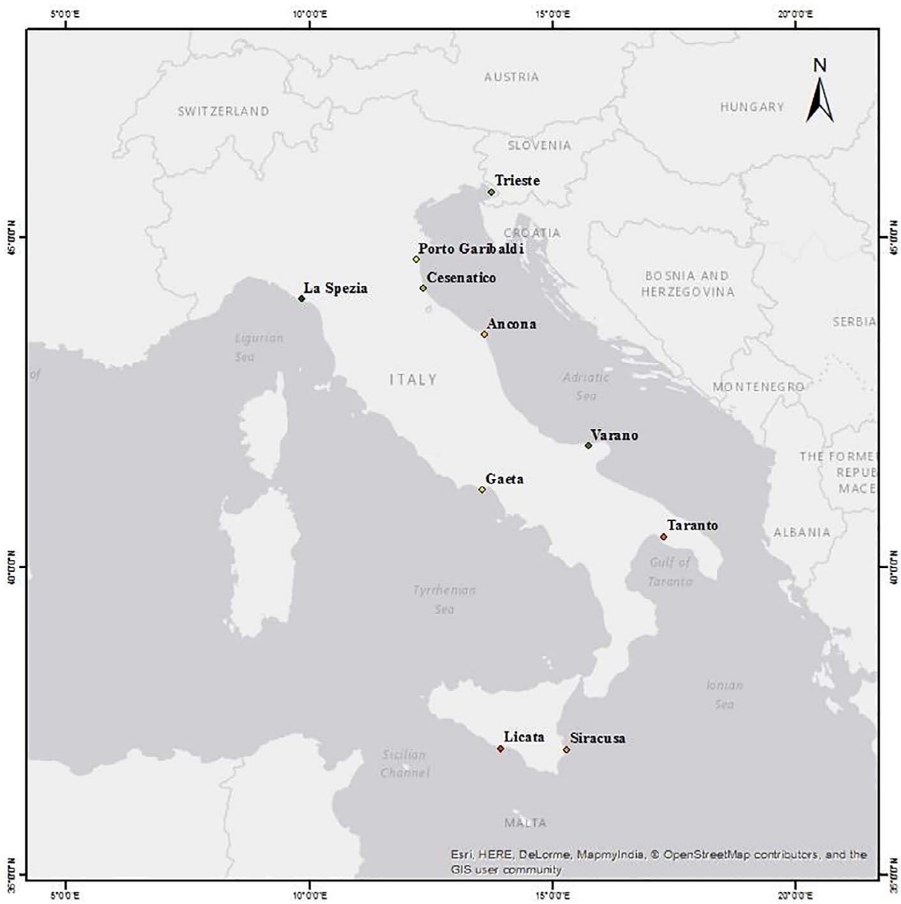

Fig. 1. Sampling sites along the Italian Peninsula. The red star bullet indicates the locality (Messina) where the mussels were collected to carry out the mesocosm experiment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

assumption that thickness correlates with valve strength (fragility), here we hypothesise that the expected increasing temperature under climate change may generate direct consequences on the amount of lost bivalves due to shell breakage caused during aquaculture facility operations, with direct implications on the amount of saleable product. Nowadays, the amount of lost product in aquaculture, due to breakage, is not usually recorded or taken into account by farmers, and it is neglected by shellfish managers, although anecdotal data reveal that it could depress the whole annual production by about 5–15% (G. Sarà pers. com).

Contextually, according to bioenergetics extrapolations (*sensu* Kooijman, 2010; Sarà et al., 2014), animals living under higher temperature regimes could have a larger amount of organic structures (i.e. somatic and gonadic tissues; Matzelle et al., 2014). This can be mirrored in a more positive condition index (i.e. individual length-weight; Matzelle et al., 2014) with direct consequences on the quality of saleable product. The term 'condition index' is usually loosely used to describe the general performance of cultivated animals (Filgueira et al., 2013; Briones et al., 2014). It should decrease under oligotrophic conditions (Raubenheimer and Cook, 1990) and reach higher values under a richer food environment (Mackenzie et al., 2014).

The relationships determining the organismal response to temperature increase, in terms of both valves fragility and individual condition, are usually neglected by managers when assessing the reliability and feasibility of shellfish culture in a changing sea. The relationship between the thickness of valves (as a potential proxy of fragility affecting product lost rate; *sensu*; Branch et al., 2013) and the condition of organisms (as a potential proxy of product quality; Watanabe and Katayama, 2010) is implicitly accounted in the product value and market price. Nevertheless, this information should be accounted in reliable metrics to seek economic trade-offs in order to manage aquaculture activities. In fact, the relationships among increasing temperature, local trophic conditions, morphometric traits and condition index in calcified shelled cultivable animals (e.g. mussels, oysters, cockles and clams) play a crucial role in our understanding of how global environmental change will affect productive systems, thus impairing the sustainability of commercial activities at sea.

This is much more crucial in the Mediterranean Sea where shellfish aquaculture spreads along the coast and where sea surface temperature is forecasted to increase at the northern sites (Lejeusne et al., 2010; Shaltout and Omstedt, 2014) and, as a possible secondary effect, to generate a trophic impoverishment (i.e. oligotrophication; *sensu* Nixon, 2009; Briones et al., 2014). Thus, northern sites are expected to become potentially warmer and food-poorer, weakening their productive potential with unpredictable socio-economic repercussions (IPCC, 2014). Here, we used the Mediterranean Mussel (*Mytilus galloprovincialis*) (Lamark, 1819), one among the most cultivated bivalve worldwide (FAO, 2016), as a model species to study whether the relationships between temperature, thickness, fragility (expressed as breaking load) and condition index were tested in the wild on a large spatial scale, under a sea surface temperature and trophic Mediterranean latitudinal gradient (9° degree). The adoption of the latitudinal gradient of temperature – to test the potential future expected effects of increasing temperature on organismal responses generated by climate change – is a common approach well-accepted across the current literature and it allows to increase the realism of climate change predictions (*sensu* Watson et al., 2012).

However, conscious that in designing an uncontrolled survey on a large spatial scale, the interpretation of organismal response can be biased by other factors (e.g. the local amount of food, the density of mussels in a bed, rope or matrix; Briones et al., 2014), here, to increase the realism of our predictions and the generalisation ability, we