Title

Thermal tolerance and physiological adaptation of the oyster in a changing environment

Acronym :

BODY

Reasearch unit

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Abstract

Climatological studies over the last few decades have shown a rise in the temperatures usually measured in water and air, and by a rise in sea level. In this context, it appears crucial to assess the acclimatization capacities of intertidal species to local climatic conditions, and in particular to the large amplitude thermal variations they encounter between periods of immersion and exoneration. Indeed, the nature of the habitat and the foreshore height of intertidal species will determine the amplitude of the temperatures they experience when they emerge. However, populations living at their maximum thermal tolerance limit may be more vulnerable to climate change.

The main objective of this thesis project is to study the life traits and acclimatization capacities of an intertidal bivalve mollusc as a function of altitude and latitude. This study focuses on the cupped oyster *Crassostrea gigas*. More specifically, the objectives are i) to analyze *in situ* with endogenous electronic sensors how the body temperature of this species varies according to the habitat, the origin of the individuals (wild vs. farmed animals), the shoreline exposure and the hydro-climatic conditions, ii) to characterize the physiological mechanisms of acclimatization (synthesis of heat shock proteins, homeoviscous adaptation of cell membranes, metabolic depression for example) in this species in relation to temporal variations in body temperature, iii) to use mechanistic modelling, from the endogenous data collected, to investigate the allocation to the different physiological functions during emergence conditions, according to bathymetric gradients.

This work will be usefull to analyze the mechanisms of thermal tolerance of this bivalve mollusc during the phases of shoreline exposure, and the consequences of endogenous temperature change on its physiological and anatomical characteristics. The evaluation of the plasticity of individuals under these conditions will be a fundamental prerequisite for making predictions on the oyster's distribution ranges in the context of climate change, and on its ability to colonize the northern European coasts.

Scientific background, objectives and interests

Scientific and technological context

Marine coastal areas are particularly exposed to the increasing impact of global change with many episodes during which several biotic and abiotic parameters change suddenly and strongly (IPCC, 2014). Organisms living in these coastal areas need to acclimatize to these changing environments while optimizing their physiological performance in terms of fitness and energy metabolism (Parker et al., 2017). Understanding individual adaptive responses in terms of physiological (reproduction, growth, survival, i.e. Hamdoun et al., 2003) or anatomical (shell size, colour or thickness; Zardi et al., 2016) traits and integrating their consequences at the population scale is necessary to try to predict the evolution of these species in response to global changes (Denny et al., 2011; Tomanek 2012, Chui et al., 2017).

In this context, we propose to study the dynamics and amplitude of variations in body temperature of an intertidal organism, the cupped oyster *Crassostrea gigas*, subjected to strong thermal variations in relation to its exoneration time defined by its position on the foreshore and its mode of rearing (in bags or naturally fixed on the rock), and according to a latitudinal gradient. This bivalve mollusc develops exclusively on the foreshore, a tidal zone, and is therefore regularly subjected to strong variations in temperature, salinity, solar irradiation and oxygen (Chapman et al., 2011). Its distribution on the foreshore can vary: oysters are either fixed on rocks for wild banks or reared on longlines, pearl nets, on the ground or in bags on the foreshore or in deep water. Depending on its position on the foreshore, the oyster (farmed or natural) will be exposed to very different water or air temperatures in its immediate environment, and to very different periods of exposure. The temperature experienced by the oyster's organs will therefore vary considerably depending on the animal's microenvironment. When oysters are immersed, it is already well known that the temperature of the seawater will directly influence the metabolism of the hollow oyster, blocking viral infection processes (Delisle et al.,2018) and increase survival rates in the face of deaths related to OsHV-1 virus (Pernet et al. 2012, Petton et al. 2013, Pernet et al., 2015, Renault et al., 2014) or bacteria of the genus Vibrio (Le Roux et al., 2016, Petton et al., 2015). However, during exoneration, there is very little data on temperatures directly measured in live oysters and their influence on energy metabolism and survival against pathogens. Recent studies have shown, through the use of "robots" recording environmental conditions close to the mussels during a complete tidal cycle, that laboratory experiments had largely underestimated the thermal tolerance and heart rates reached by these individuals in situ in response to variations in water temperature (Tagliarolo & McQuaid, 2016). Similarly, temperature measurements recorded within empty shells of Crassostrea virginica oysters deployed in the field during tidal cycles provided initial information on temperatures naturally encountered in the animal (Malek, J. C., 2010). However, these measurements are not real and do not take into account the internal regulations implemented by the living animal, such as valve spacings, which would influence the dynamics of its endogenous temperature (Fitzhenry et al., 2003). The interest of our thesis project is to follow, for the first time, the dynamics of the real endogenous temperature directly in the living animal in situ (bio-logging) as a function of altitude and latitude, in order to model the impact of endogenous temperature changes on the physiological performances of animals as a function of its bathymetric level.

Indeed, the relationships between endogenous temperature variations in the hollow oyster during exoneration and its physiological performance (survival, reproduction and growth) are still largely unknown today. More precisely, the oyster's thermal tolerance thresholds, its acclimatization capacities to local temperatures varying with the rhythm of the tides, and the direct impacts of these variations on physiological performance and on morpho-anatomical characteristics need to be studied in greater depth. Increasing our knowledge of the oyster's thermal tolerance thresholds and its capacity to adapt to the actual maximum temperature encountered during exoneration remains fundamental in order to make long-term predictions on oyster distribution ranges according to the different proposed climate change scenarios (Susarellu et al., 2013, Thomas et al., 2015). This knowledge will also make it possible to estimate the oyster's ability to survive in a context of global warming, knowing that populations living at their maximum thermal tolerance limit could be more vulnerable to climate change (Scanes et al., 2017).

This thesis topic is based on the technological development of endogenous (miniaturized and autonomous) electronic temperature sensors, the BODY sensors, developed for the first time for a sessile intertidal species (bio-logging). The BODY project, funded by LabexMER in 2018 on the "Emergence" theme, has enabled the development of BODY sensors that can be integrated into the oyster *in situ*. These sensors will make it possible to acquire data on the body temperature of the oyster in its natural environment during the seasons and over several years (one data per minute or in mesocosms simulating natural tides). This technological breakthrough will make it possible to acquire a unique set of data on variations in the internal temperature of the hollow oyster, according to different growth modes (cultivated versus wild) and positioning on the coastal strip, or according to different factors controlled in mesocosms. Professor Brian Helmuth of the Marine Science Center (Northeastern University), co-leader of the BODY LabexMER project, will be the subject of a dossier for visiting professor in 2021 as an international expert on this topic. We have also obtained his agreement for the future student to be hosted in his laboratory within the framework of international exchanges.

Originality and innovation

The originality of the subject is to characterize the link between the thermal adaptation of the oyster to *in situ* shoreline exposure in terms of physiological mechanisms (reproduction, growth, survival) and "original" morpho-anatomical characteristics of the oyster, such as shell thickness and colour, or the size of the palps, which varies according to the turbidity of the environment (Dutertre et al., 2009). To date, there are few studies that have coupled approaches to variations in physiological and anatomical characteristics. This thesis topic is based on the mastery and integration of a wide range of methodological approaches (endogenous temperature monitoring, eco-physiological and behavioral performances, morpho-anatomical characteristics, modelling) through in situ and controlled environment studies.

The innovative nature of the subject also results from the use of autonomous and miniaturised endogenous BODY sensors developed at Ifremer which will make it possible to obtain unique data sets on the real endogenous thermal variations of the oyster during exoneration in its natural environment over time (according to the seasons), in space (according to the bathymetric position), and according to a latitudinal gradient. Today, there are no data on the endogenous temperature of the oyster, and there is currently very little physiological data on the cupped oyster *Crassostrea gigas* in relation to heat stress events during emergence (respiration, heart rate, metabolism) (Scanes et al., 2017). The role of microclimatic acclimatization in defining thermal tolerance limits has recently been studied on other species of major ecological and economic interest, such as the mussel *Mytilus californianus* (Helmuth, 1998; Helmuth and Hofmann, 2001; Helmuth et al. 2002, 2016; Denny et al, 2011), the *Perna perna* mussel (Tagliarolo & McQuaid, 2016), the limpet *Patella vulgata* (Chapperon et al., 2016) or more recently the Australian oyster *Saccostrea glomerata* (Parker et al., 2017). Professor Helmuth's work indicates that today, intertidal species appear to be distributed around the world at their extreme limit of thermal tolerance (Helmuth et al., 2016). He thus demonstrates that climate change could induce strong impacts in certain parts of the globe where intertidal species would exceed their thermal tolerance. It will therefore be interesting to study where the hollow oyster is located in this climate change context.

Methodological approaches

In this scientific and technological context, the first objective of the thesis will be to analyse how the oyster's body temperature varies in the natural environment according to altitude and latitude. The aim will be to measure the internal temperature variations reached by oysters according to a bathymetric gradient (upper, middle, lower foreshore), which will vary the times of exondation and immersion, as well as on different sites scattered along the Atlantic coast. Variations in the body temperature of the animals will be measured *in situ*, using endogenous BODY sensors, in parallel with meteorological conditions close to the animals likely to influence these variations, such as air temperature (exondation), water temperature (immersion), sunshine, humidity, wind, rainfall or tidal rhythm (day and night). The analysis of these data will make it possible to estimate the extent to which altitude and latitude influence the internal temperature of the animal and will give the high and low limits of the endogenous temperatures naturally encountered by the animal in its environment, according to its lifestyle.
Most of this data will be acquired within the framework of the ECOSCOPA project. The thesis will indeed be able to rely on the different workshop sites of this national observatory. Foreshore experiments could thus be conducted on 4 contrasting sites: in Normandy, in the Brest bay, in Pays de Loire and in the Arcachon basin, in order to study 4 contrasting ecosystems of the Atlantic coast.

The second objective of the thesis will be to evaluate, with samples taken simultaneously from the animals during *in situ* monitoring, the physiological mechanisms of acclimatization in this species in relation to temporal variations in body temperature. To this end, different physiological descriptors such as growth rate, gonadal development, and survival rate will be measured in parallel with physiological measurements (i.e. heat shock protein synthesis, homeoviscous adaptation of cell membranes, metabolic depression) and certain morpho-anatomical characteristics (i.e. colour, shell thickness, size of palps).

The third objective will be to participate, using the internal and external temperature data collected, in the development of eco-physiological DEB models with the laboratory's modellers researchers. The allocation to different physiological functions according to altitude and latitude will be analyzed. This work will make it possible to determine the conditions (position on the foreshore, tidal range, weather) conducive to obtaining the best physiological performance of the oyster in its environment, and more specifically the optimal position on the foreshore for the best growth/survival/reproduction ratio. Finally, in the long term, this modelling work should make it possible to test, according to the different scenarios of global warming, whether the distribution of wild beds is likely to change, and to estimate the adaptation capacities required by the oyster to compensate for the effects of climate change.

Expected results and valorisation

i) Development of a methodology to measure the extent of the thermal variations of the cupped oyster *in situ* ;
ii) Obtaining a unique data set on the internal temperature variations of the cupped oyster, according to different growth modes (cultivated versus wild) and positioning on the coastal strip;
iii) Examine the variation of inter-individual variability by altitude, latitude and habitat;
iv) Develop a single set of data on the internal temperature variations of the cupped oyster, according to different rearing modes (cultured versus wild) and positioning on the coastal strip;
v) Examine the extent of inter-individual variability linked to altitude, latitude and habitat.
iv) To characterize the physiological mechanisms of acclimatization in this species in relation to temporal variations in body temperature,
(v) Participate in the modelling, based on the endogenous data collected, of the allocation to the different physiological functions according to the factors studied.

Partnerships

External collaborations:
- Pr. Brian Helmuth, Department of Marine and Environmental Sciences and School of Public Policy and Urban Affairs, Northeastern University, Boston, USA.

Internal collaborations:
LEMAR IRD
ODE/UL
DYNECO/LEBCO
REM/RDT

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