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PROJECT IDENTIFICATION

Acronym : ORMALG

Title : Abalone responses to global change and potential role of macroalgae in mitigating the effects

University in charge of the project

Université Bretagne Occidentale

Ecole Doctorale : EDSML ☒ SP ou MATHSTIC pour les projets ISblue ☐

SUPERVISORS

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- **5 recent references :**

- Kavousi, **Roussel**, Martin…& Auzoux-Bordenave, (in press).Ocean warming and acidification have complex adverse effects on the larval stages of the European abalone *Haliotis tuberculata*. *Marine Pollution Bulletin*.
- Chauvaud, Day & **Roussel,** 2021. No evident effect of domestication on the anti-predator behaviour of European abalone (*Haliotis tuberculata*): Implications for stock enhancement programs. *Applied Animal Behaviour Science*, 244, 105470.
- **Roussel** et al., 2020. *Haliotis tuberculata*, a generalist marine herbivore that prefers a mixed diet, but with consistent individual foraging activity. *Ethology*, 126, 716-726.
- Avignon, Auzoux-Bordenave…. & **Roussel**, 2020. Ocean acidification impacts growth and shell strength in adult abalone (*Haliotis tuberculata*). *Ices Journal of Marine Science*, 77, 726-756.
- **Roussel** et al. 2019. Anti-predator response of *Haliotis tuberculata* is modified after only one generation of domestication. *Aquaculture Environment Interactions* 11, 129-142.

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ABSTRACT

Ocean warming and acidification are major threats to marine organisms. Experts predict that surface temperatures could rise by 1 to 3°C and oceanic pH could fall by 0.2 to 0.4 unit by 2100. Molluscs, which

develop a CaCO3 shell, are particularly vulnerable to these changes. The European abalone, Haliotis tuberculata, is a mollusc of ecological and economic interest, naturally present on the Breton coast, and its farming is developing. Our recent work has highlighted the negative effects of acidification on the growth, physiology and biomineralisation of H. tuberculata. In natural environment, the effects of acidification are combined with other factors, in particular warming, which can lead to an exacerbation or an attenuation of the effects of pH. The combined effects of acidification and warming on H. tuberculata are still poorly understood and could compromise population renewal and the economical value of the resource. Macroalgae, naturally present in the abalone environment, could however mitigate the effects of global change by raising the seawater pH and offering abalone the possibility to adapt to it.

The objective of the ORMALG project is to better understand the adaptation/acclimatisation processes of abalone to their environment in a context of global change. It will take into consideration the abiotic (pH/temperature) and biotic (interaction with macroalgae) environmental factors to which abalone are subjected in both natural (boulder fields and seaweed fields) and aquaculture (sea farming structures) environments. In a broader context, this project could identify innovative bio-remediation solutions that could be implemented to protect calcifying mollusc species that show a high vulnerability to global change.

The ORMALG thesis project will be conducted in two phases :
Phase 1: Characterisation of the variability of physico-chemical parameters of the abalone environment. Continuous measurements will be carried out during the first year of the thesis in the living/rearing environments of the abalone, i.e. their natural habitat (boulder fields and kelp forests) and in situ aquaculture structures (open sea abalone grow-out cages and seaweed cultures). Monitoring of fluctuations in these parameters on a daily and seasonal scale will form the basis for laboratory experiments in a controlled environment in order to incorporate natural variability in temperature and pH into the experiments.
Phase 2: Analysis of the combined effects of seawater warming and acidification in H. tuberculata and assessment of the potential role of macroalgae in bioremediating these effects. Juvenile abalone will be exposed for 6 months to different ambient (current) and future temperature/pH conditions (SSP5-8.5). Macroalgae will be used in the experimental system to study their ability to mitigate the effects of acidification on molluscs.

An integrative multidisciplinary approach combining zootechnical (growth and survival), physiological (metabolism, biomineralisation, reproduction) and behavioural measurements will be implemented thanks to the complementary expertise of the scientific partners as well as the national and international collaborations. The PhD student will use several tools available in the laboratories: marine chemistry, electronic microscopy, biomechanics, ecophysiology and behavioural analysis in order to characterise the biological responses of abalone to variations in pH and temperature.

STATE OF THE ART, HYPOTHESIS AND SCIENTIFIC BOTTLENECK

Team's references are in blue

State of the art

Ocean warming and acidification are major threats to marine ecosystems: the average surface temperature of the oceans could increase by 3°C by 2100, while the pH could decrease by 0.4 unit (doubling the acidity of seawater) according to the IPCC's most pessimistic scenario (SSP5-8.5). In coastal areas, environmental changes are often more pronounced and can have disastrous consequences for fisheries and aquaculture [1]. Ocean warming and acidification will act in concert in the coming decades. Their synergistic effects could be more damaging than the sum of their individual effects, so it is essential to study the combined pressures of these two stressors.
The European abalone *Haliotis tuberculata* is the only species of abalone present in Europe with a commercial resource for fishing and aquaculture. In Brittany, abalone populations have suffered severe declines due to a combination of factors such as overexploitation, disease and climate change [2, 3]. Recent

work by our team has shown a high sensitivity of European abalone larvae to decreasing pH **[4]** as well as negative effects on growth, physiology and biomineralisation at different stages of its life cycle **[5-8]**. The combined effects of warming and acidification of seawater are not yet well understood, but they could compromise the renewal of wild populations and jeopardise aquaculture production of this species.

Hypotheses

In coastal areas, the effects of climate change may be more pronounced due to daily and seasonal fluctuations in temperature and pH **[9-10]**. As abalone are present in shallow intertidal and subtidal zones, it seems important to monitor these cyclical fluctuations (tides, day/night alternation, season) locally in order to finely characterize the variability of their environment and to be able to adjust the experimental conditions. In the natural environment of abalone, one of the potential sources of pH variability is the presence of macroalgae which, due to their ability to fix CO_2, can modify the chemical parameters of seawater and increase the pH [11]. Environments rich in macroalgae could thus provide a refuge against acidification for species with a calcareous skeleton, especially during the summer period (high light levels) when temperatures rise [12]. It therefore seems essential to study the role of macroalgae in controlling carbonate chemistry parameters and to test their effects on the response of abalone to global change. In a broader context, this project could help identify bio-remediation solutions that could be implemented to protect calcifying mollusc species.

Scientific bottleneck

One of the current challenges of experiments on the effects of global change is to set up experimental protocols that are as close as possible to the local biotic and abiotic conditions of the environment to which the organisms are subjected. The objective is therefore to characterize this environment in detail and to reproduce it experimentally by integrating the variability (daily and seasonal) of abiotic factors (temperature and pH) and, on the other hand, biotic interactions with macroalgae. The second challenge in assessing the effects of climate change is to understand the consequences on a time scale long enough to take into account the animal's development cycle, while studying the effects on the various biological functions.

METHODOLOGY

The interdisciplinary thesis project will combine field measurements and controlled laboratory experiments, with two complementary phases.

Phase 1: Monitoring the variability of environmental factors (year 1)

Environmental variability will be monitored at different spatial and temporal scales. Physico-chemical parameters (temperature, irradiance, pH, salinity, total alkalinity and concentrations of nutrient salts and dissolved oxygen) will be measured in natural environments (with and without algal fields) and aquaculture (sea cages) in order to characterize the environment of wild and farmed abalone. In the natural environment, the methodology will be based on recent work evaluating the effects of macroalgae on seawater chemistry [13]: two stations will be identified, one within a kelp forest in North Finistère and the other, nearby, on a boulder field without large algae. Continuous measurements of the pH and temperature of the sea water in situ will be carried out using autonomous submersible probes (SeaFet and CTD).

Phase 2: Experimental study of the response of abalone to global change (years 2 and 3)

The complementary expertise of the partners will enable the construction of a robust experimental system. Abalone will be subjected to two conditions: (i) current ambient and (ii) future (SSP5-8.5 scenario) which will incorporate local fluctuations in temperature and pH, with a shift of +3°C and -0.4 pH unit for the future scenario. It will involve 18-month-old juvenile abalone in order to observe biological, physiological and

behavioural responses on a time scale representative of the abalone's physiological cycle (8 months from January to August 2024, covering two contrasted seasons for the abalone physiology). The setting up of the experimental system, the adjustment and monitoring of the physico-chemical parameters will be based on the methodologies already developed by the project partners [5-8]. The potential role of macroalgae in mitigating the effects of global change will be tested with an additional treatment using green algal cultures (*Ulva* sp., Chlorophyta) as a bio-remediation tool. These algae are well suited to ex-situ experimental conditions and will thus enable upstream treatment of the seawater. In total, the experimental system will be composed of 20 entities divided into 4 treatments (Current conditions/Future scenario × presence/absence of macroalgae, n = 5). The response of abalone to the experimental treatments will be assessed through an integrated approach combining measurements of survival, growth, physiology (acid-base balance, respiration, excretion, immune status, calcification), reproduction and behaviour (activity rate, response to predators). The experimentation will be carried out at the Concarneau marine station (MNHN).

The project will rely on the complementary and multidisciplinary expertise of the participating teams. These teams already have good experience of field monitoring and conducting experiments on the effects of ocean acidification. The PhD student will benefit from access to different platforms for analyses: Pachiderm (LEMAR/IUEM) for nutrient salts, AD2M for chemical parameters, the Concarneau station for shell microstructure, and the SBR (Roscoff) and LEMAR/IUEM sea service for field measurements. He/she will also have access to the partners' instrumentation facilities (ULB, LEMAR and AD2M). The involvement in the project of the France-Haliotis hatchery, which masters the complete cycle of abalone development and algae culture in ponds will strengthen the technical background of the project.

REGIONAL AND INTERNATIONAL CONTEXT

Regional and international context of the project

Abalone (*Haliotis* sp.) are marine gastropods found on most continents, with more than 56 species described worldwide. They have been eaten for centuries as a traditional food in Asia and in Brittany. Poaching, disease outbreaks and habitat destruction have contributed to the decline of abalone in many countries. At the same time, there has been a huge increase in aquaculture production with over 160,000 tons produced worldwide. In Europe, only one species, *Haliotis tuberculata*, occurs naturally. Most of the fishing (about 40 T) and aquaculture production (10-15 T) takes place in Brittany. Abalone is an emblematic species of Brittany, mainly sold to high quality restaurants, and is also characterised by a significant recreational fishery. North Brittany, where the measurements will be carried out, is a maritime area characterised by large abalone populations and numerous seaweed fields. A significant research dynamic exists at the international level with several teams working on themes ranging from aquaculture to ecology. This network will benefit the thesis student.

Partnership at regional level

The thesis will be carried out in three research laboratories located in Brittany (main site: Plouzané; secondary sites: Roscoff, Concarneau). The three co-supervisors have been carrying out collaborative research work for five years **[4-8]**. The student will also be required to work and/or interact with two partners from the socio-professional world, allowing for a facilitated transfer of the knowledge acquired:
- The company France Haliotis, the main abalone hatchery, will be involved in several aspects of the project: provision of its rearing systems (on land and at sea) for in situ measurements of the physico-chemical parameters of the water, and participation in the experiments based on its technical skills in abalone rearing and ulve cultivation.
- The Comité Régional des Pêches Maritimes et des Elevages Marins (CRMEM), a partner in the OURMEL project led by S. Roussel, will be involved in disseminating the results of the thesis to the socio-professional community, with a communication of the results to abalone fishermen.

Partnership at international level

This thesis project will strengthen existing collaborations with several international laboratories. In addition to the international network developed by the partners in the framework of other collaborative projects (Spain, South Africa and Mexico), two researchers will be strongly involved:
- Philippe Dubois is a professor at the Université Libre de Bruxelles (Belgium). He is an expert in acid-base physiology and skeletal biomechanics. In addition to the loan of autonomous probes for field monitoring, he will host the PhD student for 3 months to acquire compression and nano-indentation techniques in order to study the mechanical and strength properties of abalone shells exposed to different experimental conditions of temperature and pH. He has already collaborated and co-authored several papers with the partners **[5-8]**.
- Rob Day is a Professor at the University of Melbourne (Department of Biosciences, Australia). He is an ecologist and biostatistician and has been conducting research on abalone for over 40 years. He will be involved in experimental design and statistical analysis. He also collaborated on several articles in the past **[14-17]**.

REFERENCES

[1] Cochrane K et al, FAO Fisheries and Aquaculture Technical Paper, No. 530. FAO, Rome (2009) [2] Cook PA, Modern Economy 5: 1181-1186. (2014) [3] Travers et al., Glob Change Biol. 15: 1365–1376 (2009) **[4]** Kavousi et al., Mar. Pol. Bull (in press) **[5]** Wessel et al., J. Exp. Mar. Biol. Ecol. 508: 52-63 (2018) **[6]** Auzoux-Bordenave et al., Mar Biol. 167, 11 (2020**) [7]** Avignon et al., ICES J Mar. Sc. 77: 757-772 (2020) **[8]** Auzoux-Bordenave et al., Comp. Biochem. Physiol. A, 259: 110996 (2021) **[9]** Legrand et al., Regional Studies in Marine Science 17: 1-10 (2018) **[10]** Gac et al., Front. Mar. Sci. 7:712 (2020 [11] Pfister et al., Ecology 100 (10): e02798 (2019) [12] Ling et al., PLoS ONE 15(10): e0239136(2020) [13] Pfister et al., Ecology 100 (10): e02798 (2019) [14] Chauvaud et al, Appl Anim Behav Sc. 244 : 105470 (2021) [15] Roussel et al., Ethology. 126, 716-726 (2020) [16] Roussel et al., Aquaculture, 734385 [17] Lachambre et al. 2017. Aquaculture. 467 : 190-197 (2017)

PROFILE OF THE CANDIDATE

The candidate should have a strong background in marine biology/ecology and/or marine chemistry.
He/she will be motivated by a multidisciplinary research including physico-chemical measurements in the field, experiments in mesocosms and the combination of various methodologies (electronic microscopy, biomechanics, physiological measurements, behavioural tests) in the host laboratories.