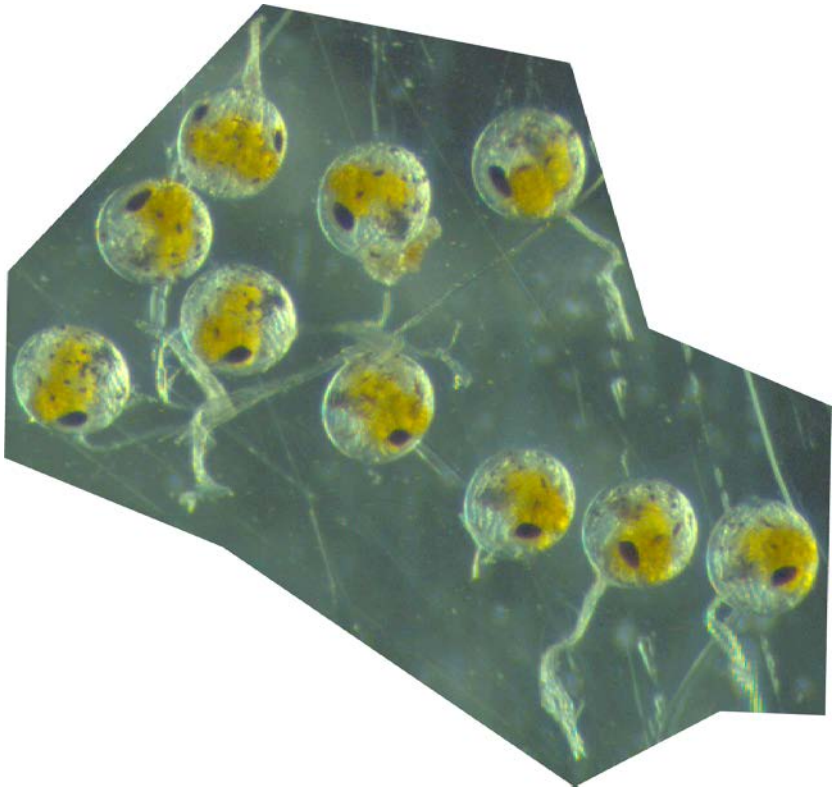
The effects of climate change on vulnerable life traits of aquatic ectotherms: towards an integrated approach



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Summary

During the four days of the Workshop, 34 early career and senior scientists met at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany. Most of the participants, who ranged from post graduate students, at the very beginning of their PhD studies, to post doctoral students, came from various laboratories in several European countries (e.g. UK, Italy, Germany, Poland, France, Portugal, Croatia, Sweden, Denmark, Switzerland and the Netherlands), but we could also attract students from South Africa and the United States. The group proved to be a perfect mix in terms of size and composition and, together with the invited speakers, we had lively discussions about facts and ideas of the impact of Global Warming and Ocean Acidification on the life stages of aquatic biota. Our hopes were that informal discussions between all participants would be made possible and even be supported by that relatively small group of people. And indeed, they comprised a very central part of this workshop, often spilling over into the coffee breaks and continuing during lunch and dinner at the workshop venue.

All participants gave presentations about their research, and each thematic session was framed by introductory and/or summarizing presentations by the invited speakers. Individual contributions diversely varied from ecological approaches to physiological analyses of the effects of various stressors on susceptible life stages of aquatic animals, such as increased CO_2 concentrations in the atmosphere and oceans, rising air and water temperatures and the increasing occurrence of hypoxia events. Due to the different scientific backgrounds and research focus of the participants, presentations also covered a wide range of habitats from tropical mangroves to mudflats in the North Sea and Polar ecosystems on both hemispheres.

The scientific diversity granted a wide exchange of opinions between senior and young scientists and many fruitful discussions tried to integrate the many different aspects of the presentations to develop the following ‘take home messages’.

It was generally agreed that there was a need to further interlink ecological and physiological approaches to be able to quantify and qualify the nature and consequences of the effects of climate change in order to come up with realistic conclusions and predictions. To this end, we will have to integrate different approaches and use multiple stressor scenarios to predict synergistic stressor effects on individual performance. We will further need to include community approaches to extend the knowledge from single species to communities and to include community interactions such as competition and predator-prey relationships. To precisely predict ecological interactions, it is therefore necessary to compare field and laboratory data from various study sites. Ideally, this should include both hemispheres and several climatic zones to take habitat peculiarities into account.

Judging from the participants’ feedback and the concentrated, scientifically demanding yet always joyful atmosphere of workshop, we, the organizers, feel that this workshop was a full success and made an important contribution to promoting integrated research approaches in modern biological research. We would like to thank the participants and the European Science Foundation for making this possible and hope for much fruitful future collaboration between the participants.

Description of the scientific content of and discussion at the event

Our main objective, as the Workshop organizers, was to underline the need of a deeply integrated approach for the understanding of the effects and consequences of climate change on aquatic ectotherms. From the very beginning of the workshop planning we tried to embrace a range of research lines as large as possible and to put forward the benefits of the merging of these lines. Thus, we proposed to adopt a fully ontogenetic approach, ranging from early embryos to larvae, juveniles and adults until spawning individuals, in order to point out the variability of animal susceptibility to environmental solicitations during the various life stages. Besides, we promoted the discussion within different ecological levels, from the single individual approach to the population and community levels to show how specific and punctuated response can affect scenarios at larger scale. Furthermore, we high lightened the need to consider change in space and in time when forecasting the consequences of climate change, analyzing both shift of phenologies and variations of biogeographyc patterns. Regarding the selection of applicants, we choose since the beginning participants coming from both ecological and physiological research fields in order to increase the interdisciplinary approach and to balance the discussions among different points of view. Finally to realize a successfully interactive and scientific provocative event, we invited six keynote speakers capable to cover the previously mentioned research fields and to increase exchanges between participants raising discussion points throughout the whole workshop

In details the scientific contents of the workshop are efficiently represented by the topic covered by the keynote speakers.

Prof **Gray A. Williams** of the Swire Institute of Marine Science in Hong Kong, opened the workshop underlining the importance of the life history impacts of environmental stressors. His message was: ecologists strive to measure the distribution and abundance of species, to understand the factors that control these patterns, and how these interact to determine community structure. Such information can help to predict how species may respond to environmental changes and how this will impact community structure and functions. The rocky intertidal zone is an extremely harsh physical environment where many species are living close to their physiological limits. Whilst organisms spend part of their lives immersed in stable and benign seawater, emersion periods are highly stressful, when individuals are exposed to hot and desiccating aerial conditions. This is especially true in tropical areas where rock temperatures during emersion can exceed 50°C. Such conditions are often extreme enough to cause mass mortalities, and can be exacerbated by seasonal and tidal cycles, or stochastic events such as hot and/or calm weather. The success of different species is determined by a suite of factors, including their phylogeographic history and genetic or phenotypic ability to acclimate or tolerate physical stresses. Within populations, survival of individuals also varies with life-history stages or due to simple factors such as at which shore level an individual recruited (settlement processes) or it comes to rest after moving (behavioural selection). Small scale variability in these factors can result in great differences in individual performance having both short term, acute effects (mortality) and also longer term chronic effects on individual fitness. Variation in the relative susceptibility of different species can result in changes in community structure. Unlike in temperate areas, where intertidal species have long-life histories and dominate communities, on tropical shores species tend to be short lived, with fast turnover rates. Consequently, free space resulting from mass mortalities or other disturbance events, such as typhoons, is quickly colonized and communities are very resilient. Although few quantitative or long-term data sets are available for these regions, more frequent disturbance or harsh environmental

conditions may, however, push such systems beyond their resilience boundaries, and may make tropical communities more vulnerable to climate change than temperate communities.

Dr. **Frank Melzner**, of the Leibniz-Institute of Marine Sciences (IFM-GEOMAR) in Kiel and Dr. **Sam Dupont**, of the Department of Marine Ecology at the University of Goteborg highlighted the need to adopt a comprehensive approach to the study of climate change which should ranges from the causal and mechanistic level of species sensitivity and response to the eco-physiological and evolutionary consequences.

Dr. Melzner, in his presentation, provided a brief overview on the magnitude of ocean acidification to be expected within the next 100 years in oceanic and coastal habitats, with particular reference to stressful microhabitats, such as seasonally hypoxic regions, boundary layers and ontogenetic habitats (egg masses). Then, he illustrated, how elevated seawater pCO_2 impacts animal physiology through alterations in body fluid acid-base chemistry and how calcification can suffer in a secondary fashion. Finally, he pointed out similarities in physiological response to ocean acidification in different marine phyla. A special emphasis has been placed on early life stages. He concluded with the exploration about why some, but not all, calcifying communities in naturally CO_2 - rich ocean regions might be vulnerable to future acidification.

Following, Dr. Dupont underlined that ocean acidification (OA) is believed to be a major threat for near-future ecosystems and that amongst the most sensitive taxa will be calcifying organisms and the free-living larval stages produced by many benthic marine species. However, it is of primary importance to take life-history strategy into account when assessing the impact of this stressor. For example, the impact of OA on planktotrophic larvae is globally negative while lecithotrophic larvae appear to benefit from OA. Within a species, egg size and spawning time are also of tremendous importance; for example, in northern hemisphere, late spawners appear to be more at risk than early spawners. Other “rescue” strategies such as larval cloning can also play a major role and life-history strategies should be included in any large scale predictions of the impact of OA and climate change and that some of the original paradigms (e.g. OA will negatively impact marine calcifiers) should be reconsidered. With these premises he finally discussed the role of acclimation, phenotypic plasticity and selection.

Prof. **Hans-Otto Pörtner**, of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, presented a more theoretical and provocative talk, dealing with the need of disclose unifying physiological principles in the field of climate change biology. He argued that emerging insight into effects of climate warming, ocean acidification and progressive hypoxia on marine ecosystems emphasize the need for a common understanding of underlying principles by physiologists and ecologists. The whole organism responses to these challenges link to ecosystem response and build on a suite of tissue, cellular, molecular and genomic events, in a systemic to molecular hierarchy of limitation. All of these mechanisms are involved in setting limits to tolerance, shaping a species-specific, limited budget of tolerance over time. The limiting mechanisms are also the targets of processes shaping acclimatisation and evolutionary adaptation. The concept of oxygen and capacity limitation of thermal tolerance (OCLTT) was proposed as a matrix integrating the levels of biological organisation and the synergistic effects of environmental stressors including ocean acidification. Adaptation to various climate regimes becomes visible in the positioning and width of thermal windows on the temperature scale. Ocean acidification causes a narrowing of thermal tolerance and current research addresses how thermal, CO_2 and hypoxia effects are intertwined at whole organism level.

Prof. **Henrique Queiroga**, of the Centre for Environmental and Marine Studies, University of Aveiro, presented, with a more ecological and modeling approach, the issue of larval dispersal and population connectivity and their susceptibility to environmental and climatic change. He said that most extant marine invertebrates and fishes have a planktonic larva in their life cycles, which is dispersed by ocean currents and is considered to be the main means of dispersal. Larval dispersal and supply is basic for the local occurrence, abundance and connectivity of populations. His arguments were that i) because mortality rates of larvae are typically very high, small changes in the mortality factors during the planktonic phase result in large changes in the number of competent larvae that are supplied to adult habitats and ii) because larvae are transported by currents in a relatively unbounded medium, many marine species form metapopulations. In his presentation Prof. Queiroga first addressed the larval ecology of a widespread coastal invertebrate, the shore crab *Carcinus maenas*, highlighting the interactions between larval biology and marine currents affecting dispersal mechanisms, and the consequences of dispersal for population connectivity and phylogeography, in order to provide a background aiding in identifying the potential impacts of climate change on the larval phase. He further provided a review of the main effects of acidification and temperature rising on development, growth and survival of several model invertebrates. Finally, he explored the potential impacts of changing circulation patterns on larval dispersal pathways with the use of bio-physical numerical models.

Finally, Dr. **Nia M. Whiteley** of the School of Biological Sciences, Bangor University, presented an extended overview on crustaceans as model organisms for ecological and physiological studies related to climate change effects and responses. At present, climate changes are occurring at rates that make it difficult for marine species to adapt, thus, the future survival of animal populations will depend to some extent on the ability of individuals to compensate for perturbations in their physical environment. The ability to compensate for change is constrained by the plasticity available within the existing genotypes, and can vary considerably between and within species. Such variation is shown by crustaceans which inhabit a range of aquatic habitats and they show remarkable diversity in their ability to compensate for change. Physiological studies on crustaceans were used to illustrate the progression from single-factor, short but acute exposure experiments aimed at disentangling the mechanisms responsible for physiological adjustments, to multi-factor experiments which are more relevant to the simultaneous changes taking place during climate change. Considerations were given to the effects of hypoxia, seawater dilution, acidification and temperature on crustacean species experiencing different degrees of change in their natural environment. Furthermore, Dr Whiteley focused on sexually mature adult crustaceans and the way in which they alter respiratory gas exchange, blood-gas transport and acid-base homeostasis in order to survive and reproduce. Finally, she related the physiological information to performance indicators and used to characterise those species or groups most at risk from climate change.

Assessment of the results and impact of the event on the future direction of the field

As organizers of the Workshop, we strongly agree that the event in itself was a true success and that the original aims of the project were entirely met. In fact, for what concern the aim of providing “students and post-docs with challenging points of view and ideas on the effects of climate change on aquatic ectotherms species and communities”, we indeed succeeded. Young researchers could profit of a very informal and relaxed atmosphere which helped a free and constant discussion. The whole Workshop resulted in a melting-pot of ideas and scientific approaches, which usually is very difficult to create in Congresses and Meetings involving large numbers of researchers.

Our warmest thanks are due to the Invited Speakers, which were always disposed to share ideas, give good pieces of advice and explain their latest results to the younger participants. Their contributions in providing new ideas and challenging points to PhD and Post-Doc students were fundamental, and the young researchers involved in the Workshop were clearly delighted to have the possibility to share their research protocols and ideas with such experienced and eminent colleagues. Young researchers left the Workshop with clearer ideas about their research fields, with respect to their arrival, and with new perspectives to be developed in their PhD Thesis and/or in their academic carriers.

Another important result was the merging of different techniques and approaches among students coming from different theoretical schools. The most ecologically oriented among the participant were able to share their ideas with senior scientists coming from physiological disciplines, while students specialized in physiological approaches and in studies conducted at organismal level, could profit from a discussion with experts in ecological approaches and in community-level studies.

As a matter of fact, our second aim, to "gather a multidisciplinary and heterogeneous cohort of scientist to merge the various approaches in an integrated discussion about future studies of vulnerable life stages", was entirely met as well. All participants agreed that the Workshop clearly stressed a gap in our knowledge on the effect of climate change on natural systems: we are still missing the impact on the vulnerable life-stages. Thus, all participants could get the take home message that a critical point to develop, for future research directions, will be to focus on the overall life cycle of aquatic ectotherms, stressing the importance of their weakest links and phases. We all agreed that a new ontogenetic approach, as stated since the beginning of the preparation of the present Workshop, is of outmost importance to enhance our capabilities of model and predict future climate change scenarios.

Another impact of our workshop on the multi-faced new scientific discipline named climate change biology, was to clarify that all experimental fields, from physiology to evolutionary ecology, from behavioral biology to ecological modeling, should be integrated into a new approach to the study of ecosystem responses and species resilience to climate change. All participants could understand, for instance, how the studies on the effects of climate change on the metabolism of single organisms should be merged with the study of the consequence of global warming on marine currents and their effects on connectivity of large populations. To link these datasets in an holistic view is probably the most important challenge we have to face to understand what is next in climate change biology.

Last but not least, the Workshop speakers and participants set up a "critical mass" for the building of a future research network on the issues of global warming and ocean acidification. In fact, about twenty Universities and Research Institutions were represented in the Workshop, ranging from United States to Europe, South Africa and China, constituting in itself a true Network of Excellence in ecological, as well as physiological and natural community studies. Our purpose now, as organizers, is to keep in contact with all the participants, also by constantly updating with scientific papers and events the website created for the Workshop (http://www.dbe.unifi.it/climateandectotherms), thus to give birth to the already mentioned critical mass of laboratories capable to enhance the European Research Capacities and successfully apply for research funding to various Agencies.

Final Programme of the meeting

Sunday 18th		
16.00	*Registration*	
17.00	*Welcome and Icebreaking*	
18.00	Invited contribution – **Gray Williams**	*From the cradle to the grave: life history impacts of environmental stressors*
19.00	*Dinner*	
Monday 19th		
9.00	Invited contribution – **Frank Melzner**	*Causal relationships between ocean acidification, pH regulation and calcification in marine animals*
10.00	**Rachel Hale**	*Predicted levels of future ocean acidification and temperature rise could alter community structure and biodiversity in marine benthic communities*
10.20	**Fabrizio Bartolini**	*Climate change reduces offspring fitness in littoral spawners*
10.50	Welcome to the AWI – **Prof. Dr. Karin Lochte**	Director of the Alfred Wegener Institute
11.00	*Coffee break*	
11.30	**Daniel Small**	*Investigating the synergistic impacts of climate change on the European lobster,* Homarus gammarus
11.50	Invited contribution – **Sam Dupont**	*Species-sensitivity and life-history strategies, from eco-physiology to evolution*
12.50	*Lunch*	
14.00	**Maria Inês Seabra**	*Ecological and physiological perspectives on the relationships between rocky intertidal keystone species and microhabitats: the case-study of Patellid limpets and tidepools versus emersed rock environments in SW Portugal*
14.30	**Ivana Prusina**	*The heat shock protein (Hsp70) expression and haemolymph osmolality in two congeneric Mediterranean limpets – how much is too much stress?*
15.00	**Anneli Strobel**	*Acclimatory response to temperature and hypercapnia of Antarctic fish energy metabolism*

15.30	**Samuel Rastrick**	*The effect of ocean acidification and temperature on the physiological responses of ecologically important benthic invertebrates: possible affects on growth, reproduction and organism health.*
16.00	*Coffee break*	
16.30	**Tommy Andersen Norin**	*Effects of temperature on metabolic performance across metamorphosis in the common frog,* Rana temporaria
17.00	**Alisha Shah**	*Determining vulnerability as a factor of oxygen-limited thermal tolerance in macro-invertebrates in temperate and tropical stream habitats.*
17.30	**Rasmus Ern**	*Effects of temperature on aerobic scope and critical oxygen tension in the giant freshwater shrimp (*Macrobrachium rosenbergii*)*
17.50	*Round table*	
18.30	Invited contribution – **Hans-Otto Pörtner**	*Climate change physiology: searching principles in on-going and evolutionary change*
19.30	*Dinner*	
Tuesday 20th		
9.00	Invited contribution – **Henrique Queiroga**	*Potential effects of climate change on marine invertebrate larvae: acidification, temperature and dispersal pathways*
10.00	**Gabriela Torres**	*Maternal and embryonic effects on mRNA expression of proteins involved in osmoregulation in larvae of the shore crab* Carcinus maenas
10.30	*Coffee break*	
11.00	**Melanie Schiffer**	*Physiological and behavioural response in Arctic* Hyas araneus *larvae to elevated seawater* PCO_2
11.20	**Katja Leicht**	*You or your offspring - Immune defense and reproduction under high temperature*
11.50	Invited contribution – **Nia M. Whiteley**	*Surviving climate change: Role of physiological studies on adult crustaceans*
12.50	*Lunch*	
14.00	**Rym Zakhama-Sraieb**	*How many alien species in the Gulf of Gabès coasts (South of Tunisia)?*
14.30	**Amy Fowler**	*Temperature and salinity tolerances of stage 1 zoeae predict possible range expansion of an introduced crab*

15.00	**Joao Canning Clode**	*Invasive Species and Climate Change: Are Cold Spells Part of the Change?*
15.20	*Coffee break*	
15.50	**Marco Fusi**	*An ontogenetic approach to the thermal response of mangrove macro-benthos: explaining processes in endangered coastal systems under global change*
16.20	**Francesca Porri**	*Larval connectivity along the Agulhas Bank of South Africa: biology, physics and variability*
16.50	**Abigail Cahill**	*Response of* Crepidula *larvae to temperature as a function of geography and developmental mode: existence of local adaptation*
17.20	*Round table*	
19.30	*Dinner at the STRANDHALLE*	
Wednesday 21st		
9.00	**Astrid Wittmann**	*Acute vs. chronic effects of temperature in various life stages of the stone crab* Paralomis granulosa
9.30	**Aurelia Chaalali**	*Some evidences for long-term climate-driven changes in the Gironde estuary*
10.00	**Rafael Ortiz-Rodríguez**	*Effects of the cyanobacterial toxin MC-LR on* Daphnia magna *neonates and adults: Searching for transgenerational effects*
10.30	*Coffee break*	
11.00	**Wilco Verberk**	*Revisiting oxygen supply and demand to better understand thermal limits in aquatic ectotherms*
11.30	**Anna Bednarska**	*Effect of forecasted global warming on reproduction traits of* Daphnia *fed with cyanobacteria*
12.00	**Anneke Van den Brink**	*The effect of temperature on brood duration in three* Halicarcinus *species (Crustacea: Brachyura: Hymenosomatidae)*
12.30	*Concluding remarks*	
13.00	*Lunch*	