A multistressor world: marine climate change and its effects on ocean life

Dr Hannes Baumann is Assistant Professor in the Department of Marine Sciences at the University of Connecticut. Here, he leads the Evolutionary Fish Ecology lab that investigates how fish populations adapt to natural variability in their environment, and how they respond to unfolding changes in acidity, oxygen levels and temperature in our oceans and coastal waters. The research involves experimental, field, and modeling approaches to study these effects with the ultimate goal of understanding the vulnerability and potential for adaptation of coastal fish to the combined consequences of marine climate change.

Coastal marine ecosystems represent the most diverse and productive parts of the world’s oceans, providing a range of crucial ecosystem services such as food, protection, and recreation to humankind. Unfortunately, coastal ecosystems are threatened due to marine climate change, marked by three related changes: warming, acidification (increased carbon dioxide levels), and declining oxygen levels.

**WHAT DRIVES MARINE CLIMATE CHANGE?**

Marine climate change is caused by combined global and regional forces. Globally, the burning of fossil fuels and deforestation increase carbon dioxide (CO₂) levels in the atmosphere and in the ocean, with the latter absorbing almost half of all human CO₂ emissions to date. Atmospheric CO₂ accumulation intensifies Earth’s greenhouse effect, which is the cause for global warming of both land and oceans. Warmer ocean waters also hold less oxygen, and the increasing CO₂ dissolution reduces ocean pH, a process known as ocean acidification. Furthermore, warmer oceans are often more stratified, i.e., water masses with different properties (e.g., different oxygen levels or temperatures) form distinct layers that may fail to mix, further exacerbating the problem of oxygen depletion. On a regional scale but all over the world, agriculture and dense coastal populations often pollute coastal waters with excessive nutrients (e.g., nitrogen, phosphorus), which in turn stimulate an overgrowth of algae blooms followed by markedly increased microbial respiration. These processes further deplete oxygen levels and exacerbate acidification of coastal waters. Therefore, in many marine ecosystems, man-made warming, acidification and declining oxygen levels occur simultaneously and may be more stressful to organisms than previously recognised.

**A NEW FRONTIER IN MARINE RESEARCH**

Unfortunately, most of the research carried out to date examined the impacts of single stressors (e.g., temperature or oxygen or acidification). This means that despite decades of research on temperature, acidification and hypoxia effects on marine life, the combined effects of these stressors remain largely unclear. This is because stressors in combination may not simply add their individual effects, often they act antagonistically (mitigating) or synergistically (re-enforcing) to produce outcomes that simply cannot be deduced from extrapolating previous single stressor research. For example, in a pioneering experiment testing the individual and combined effects of acidification and low oxygen on the survival of newly hatched fish larvae, mortality upon the combined treatments was disproportionally higher than under each individual scenario (Fig 1). Hence, understanding the true impact of human-mediated environmental change and the interactions between stressors urgently requires multi-stressor research.

This represents a new frontier in marine research and is the primary focus of Dr Baumann’s research group at the University of Connecticut, USA.

**ANSWERS FROM THE ATLANTIC SILVERSIDE**

In a newly-initiated National Science Foundation (NSF)-funded project to determine the combined effects of multiple stressors on marine organisms and their fitness traits (likelihood of reproductive success), Dr Baumann leads a collaborative research team in investigating how an ecologically important model fish species, the Atlantic silverside (Menidia menidia), responds to observed and predicted changes in temperature, CO₂ and O₂. The research combines environmental monitoring with advanced experimental approaches to characterise early and lifelong consequences of acidification and hypoxia in this species, an important forage fish that resides along most of the eastern coast of the United States. Short-term experiments will measure...
The initial phase of the project aims to study productive coastal habitats. Contemporary and potential future scenarios of dissolved oxygen (DO) levels that are chosen to represent effects of daily CO2 acidification. During the second phase of the project, the factorial experimental design will produce more robust offspring. Novel, longer-term experiments will study the consequences of transgenerational plasticity (adaptations that span multiple generations) as a potential forage fish species.

What makes the Atlantic silverside such an ideal model for your research? Atlantic silversides may look inconspicuous, but they are much more important and famous than most people realise. They are ubiquitous in nearshore coastal waters along the northwestern Atlantic coast, where they feed on small planktonic organisms before becoming food for larger fish and seabirds. In addition, experimental research on this species has a long tradition, and many breakthrough studies in evolutionary ecology and silversides as models. The species is easy to obtain from the wild, relatively easy to rear under laboratory conditions from embryo to mature adults, and their short 1-year lifespan enables multigenerational studies that elucidate other more long-lived species. Together, the species ecological importance, the large body of previous research, and the ease of experimental manipulation make it the ideal model for our research project. 

Do you expect that your findings can be widely extrapolated across fish species? Our results will be more representative of coastal marine fish than research on other model fish (e.g., zebra fish, freshwater) would be. In addition, our main focus is on the early life stages, which have a comparable ecology across marine species, makes our results valuable and potentially extrapolatable to other marine species. Caution is however warranted, particularly because silversides have a much shorter life expectancy than most commercial marine species (e.g., cod) and they also live in a much more fluctuating, nearshore environment than other important marine species. The latter means that silversides might be more robust than other, more oceanic species.

What technical challenges do you face in your research? One of the main challenges stems from the fact that we target the youngest life stages of this species. During this time, mortality is naturally very high and very variable, which makes it challenging to study specific effects of experimental manipulation.

Do you see any application for your research in conservation biology? Fully integrating the concept of multiple stressors, i.e., potentially larger negative effects of climate change than previously thought, is of fundamental importance to conservation biology. It teaches us to apply conservative thinking when setting thresholds, e.g., for hypoxia. In isolation, oxygen concentrations below 2 mg l-1 are commonly referred to as hypoxic and are known to have negative effects on marine life. However, hypoxia and acidification co-occur in nature, so perhaps the threshold should be more conservative, i.e., higher.

What implication, if any, will your findings have on international policies concerning climate change? Our research will lead to a more holistic view of the many related changes due to human activity on this planet. While it will reinforce the need for a global solution to greenhouse gas emissions, it will also highlight the need for regional mitigations, e.g., by reducing nutrient pollution of coastal waters.