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

Marine climate change is a syndrome of pervasive human meddling in our planet's affairs. Its three main symptoms are ocean warming, acidification and oxygen decline

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 modelling 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.

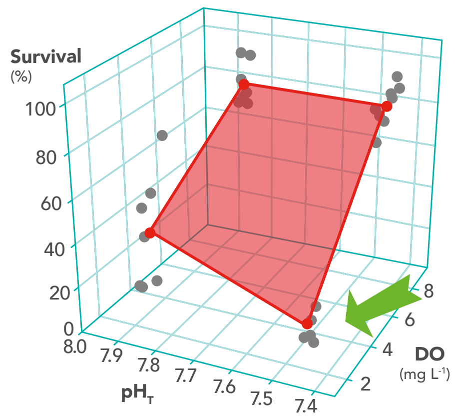
Coastal marine ecosystems represent the most diverse and productive parts of the world's oceans, providing a range of crucial ecosystem services such as food, protection, and recreation to humankind. Unfortunately, coastal ecosystems are threatened due to marine climate change, marked by three related and concomitant oceanic 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 (CO_2) levels in the atmosphere and in the ocean, with the latter absorbing almost half of all human CO_2 emissions to date. Atmospheric CO_2 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 CO_2 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 exasperating 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.



Above: On 12th September 2017, young-of-the-year Atlantic silversides (*Menidia menidia*) school in nearshore waters.

Left: This graph shows the individual and combined effects of low pH and low oxygen conditions on the survival of young silverside larvae. The green arrow points to the corner that appears drawn down, which is the visual representation of what is called a synergistic effect of the two variables. This means that low pH and oxygen together have a much more negative impact than what would be predicted from considering the sum of each factor alone (from Depasquale et al. MEPS 20115).

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, CO_2 and O_2. 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. Shorter-term experiments will measure embryonic and larval survival, growth, and metabolism, and will determine whether parents who experience stressful conditions produce more robust offspring. Novel, longer-term experiments will study the consequences of acidification over the species' entire lifespan by quantifying the effects of high CO_2 conditions on the ratio of males to females, lifetime growth, and reproductive investment. These studies will provide a more comprehensive insight into how multiple stressors may impact populations of Atlantic silversides and potentially other important forage fish species.

MONITORING CURRENT AND FUTURE CLIMATE SCENARIOS

The NSF-funded project employs a newly constructed, computer-controlled fish rearing system to allow individual and combined manipulation of dissolved oxygen (DO) content and seawater CO_2 pressure (pCO_2), where the latter serves as an indicator of acidification. The setup also allows the application of static and fluctuating pCO_2, DO and combined pCO_2 and DO (CO_2 × DO) levels that are chosen to represent contemporary and potential future scenarios in productive coastal habitats.

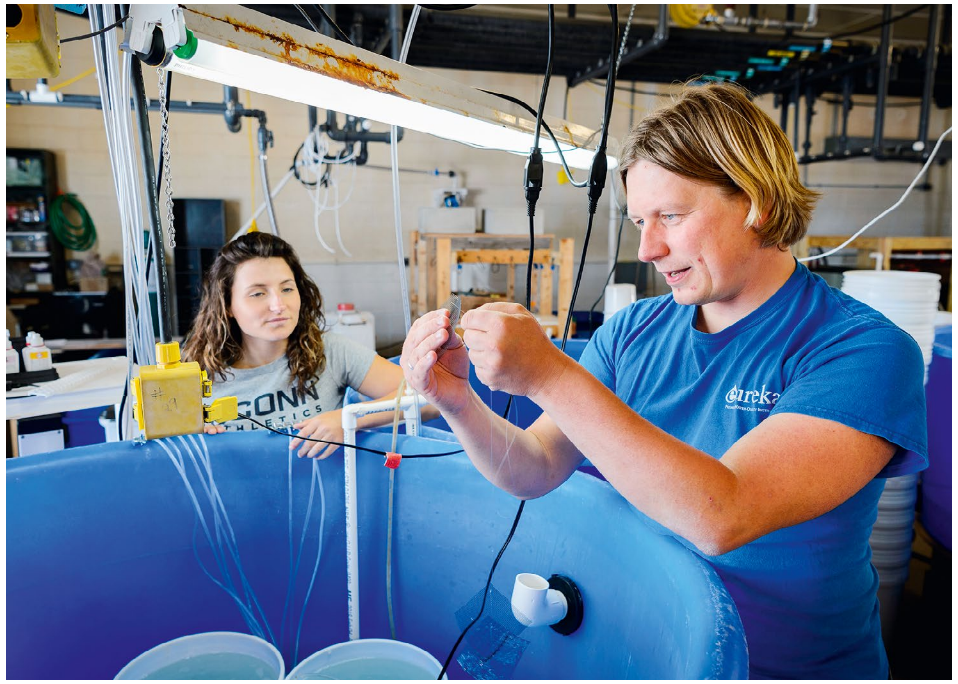
The initial phase of the project aims to quantify individual and combined CO_2 and DO dependent reaction norms for fitness-relevant early life history (ELH) traits. These traits, which provide reliable clues about the probability of successful reproduction later in life, include pre- and post-hatch survival, time to hatch and post-hatch growth. Traits will be measured in offspring obtained from wild adults and reared from fertilisation to 20 days post hatch (dph) using a statistically robust, factorial experimental design.

During the second phase of the project, the effects of daily CO_2 × DO fluctuations of different amplitudes on silverside ELH traits will be quantified. To address knowledge gaps regarding the CO_2-sensitivity in this species, laboratory manipulations of adult spawner environments and reciprocal offspring exposure experiments will elucidate the role of transgenerational plasticity (adaptations that span multiple generations) as a potential short-term mechanism to cope with changing environments.

To better understand the mechanisms underlying fish early life CO_2-sensitivity, the combined effects of temperature and CO_2 on pre- and post-hatch metabolism will be robustly quantified. The final objective is to rear silversides from fertilisation to maturity under different CO_2 levels and assess potential CO_2-effects on sex ratio and whole life growth and fecundity (reproductive rate).

TRAWLING THROUGH UNCHARTERED WATERS

Despite the documented widespread co-occurrence of acidification and hypoxia, and the likelihood that these conditions have a detrimental impact on marine-dwelling organisms, only a handful of studies have addressed the extent to which these stressors in combination exert additive, synergistic or antagonistic effects on marine life. The current project aims to explore these unanswered questions so that we can begin to understand the consequences of our actions to date and make predictions that can be implemented to improve the future for marine life in the face of continuous climate change.



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Above: In the Rankin Lab at the University of Connecticut, Hannes Baumann shows REU student Elle Parks how to distribute newly fertilised embryos of the Atlantic silverside among experimental containers.

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Left: On the beach of Mumford Cove, members of the Baumann work up the catch of the beach seine.

> We have yet to understand the full extent of the combined effects of marine climate change

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Above: In June 2017, the 100ft beach seine is being pulled onto the beach in Mumford Cove, CT, catching spawning ripe Atlantic silversides.

Below: A newly hatched Atlantic silverside larva of about 5 mm length tries gingerly to stalk and attack a brine shrimp nauplius.
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Q&A

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 North-American Atlantic coast, where they feed on small planktonic organisms before becoming food themselves for larger fish and seabirds. In addition, experimental research on this species has a long tradition, and many breakthrough studies in evolutionary ecology used 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 elude 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 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 often makes it challenging to detect 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.

Detail

RESEARCH OBJECTIVES

Dr Baumann's research 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 modelling 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.

FUNDING

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BIO

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