Peter Thor // Norwegian Polar Institute
Howard Browman // Institute of Marine Research
Claudia Halsband // Akvaplan-niva

Ocean acidification – CO_2 effects in Northern waters

At present we are emitting CO_2 at alarming rates. We all know the result is global warming, but what is probably less well-known is what marine chemists have termed "the other CO_2 problem".

ONE THIRD of the CO_2 emitted is absorbed by the world's oceans, where it is transformed into carbonic acid, making the pH of the oceans lower. There are growing concerns that this ocean acidification (OA) will disturb affected marine wildlife in ways we cannot yet predict. The Arctic is an area of particular concern. Colder water absorbs more CO_2 and the acidification is more severe in polar regions, where natural pH and carbonate ion concentrations have always been higher than elsewhere. At the same time, polar regions are blank areas in our knowledge of how OA affects marine life. For example, we do not know much about the seasonal changes of pH and associated ocean chemistry, or how it varies from year to year.

In 2011 the Fram Centre flagship "Ocean acidification and ecosystem effects in northern waters" was established to serve as a platform for research on acidification in the Arctic Ocean. As part of the flagship we initiated studies of OA effects on pelagic copepods in 2012. Marine pelagic copepods constitute the most numerous animal group on earth. These crustaceans comprise 80% of the global zooplankton biomass, and they are the most important food for larvae of many fish species. Also commercial fish stocks depend on copepods, and survival and growth of cod and herring larvae depend strongly on the copepod biomass in their feeding grounds. Consequently, if copepods suffer from OA and their numbers decline during the next decades, this will carry over to fish populations and ultimately to fisheries.

We started our studies of OA effects by looking at populations from the North Sea. Here we found very different effects among species – even closely related ones. Metabolism and egg production rates remain unchanged in *Calanus finmarchicus*, a relatively large copepod (2-4 mm), when subjected to pH levels predicted for the year 2100. This species, which dominates in the North Atlantic, normally produces many eggs (>20 eggs per individual per day) that are spawned freely into the water.

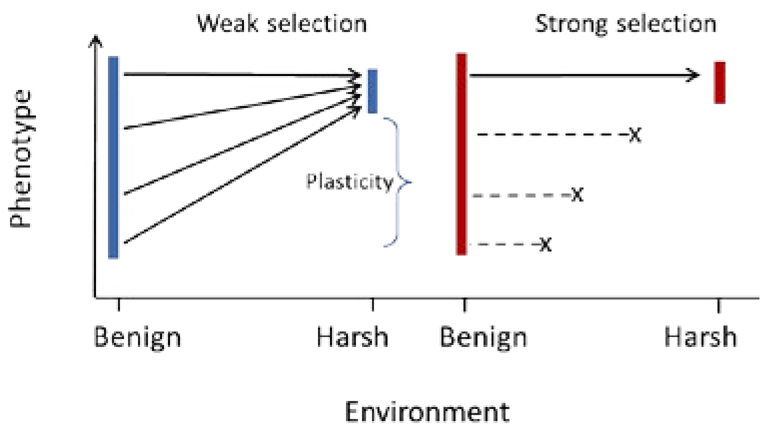
A smaller species, *Pseudocalanus acuspes* (1-2 mm), is apparently more severely affected by OA. This species is found in large numbers in North Atlantic and Arctic waters. We observed a significant decrease in both metabolism and egg production under conditions of OA. The results suggest that egg production will decrease by 30% by the year 2100, and this may have harmful consequences for the populations. *Pseudocalanus acuspes* carries its eggs in a brood sac until they hatch. This is an evolutionary strategy to avoid the fierce predation on eggs in the plankton. It allows

P. acuspes to invest less energy into egg production (<3 eggs per individual per day) and nonetheless attain the same number of surviving larvae as free-spawners such as *C. finmarchicus*. A 30% reduction in egg production may not reduce the number of surviving larvae of free-spawners like *C. finmarchicus* because it could be counteracted by decreased density-dependent predation on eggs. But the effects would be more pronounced in populations of egg-carrying copepods. Egg production rates are low and the supply of new larvae is all the more dependent on constant production of new eggs. So the risk that OA will affect future population sizes of *P. acuspes* negatively is very real.

Previous studies have shown that such effects influence animals higher up in the food chain. In the Baltic Sea, the abundance of a sibling species, *P. elongatus*, has declined due to climate change. This species is the preferred prey for Baltic herring, and due to this decline, the herring have been forced to revert to less favourable copepod species for prey, which has limited herring growth in these waters.

OA is a recent and dramatic environmental change. Nevertheless, it progresses at rates that may be sufficiently slow to allow populations to adapt to the new conditions through selection of the more fit individuals over the course of many generations. Our experiments have shown that copepod populations can respond very quickly to changes in their environment. They can, for example, change their body size by 15% per generation when this trait is manipulated towards larger or smaller individuals. Moreover, individual organisms may be able to acclimatise to the changed environment if their physiology allows. This acclimatisation would lessen the natural selection, because the genetic effects of OA would be alleviated.

The question here is then: Does OA induce adaptation (genetic change) or are the animals able to compensate the physiological stress by acclimatisation (phenotypic change)? We are directing part of our work to address these questions. Our studies on North Sea *P. acuspes* suggest that populations may develop some resilience against OA through selection. Populations



This graph shows the effects of acclimatisation and selection on a given phenotype (for example egg production rate). In a benign environment, the populations contain a diverse range of genotypes giving rise to many different phenotypes (individuals with different egg production rates) under these circumstances. When the environment changes, certain phenotypes prevail because these individuals perform better, either because they can already cope with the new conditions, or because they are able to change their phenotype – a process called "plasticity". In the blue population, selection is weak because all genotypes survive. Every individual can plastically change their phenotype (acclimatisation) and genetic diversity is maintained. In the red population there is no phenotypic plasticity and most individuals disappear. Here the genetic diversity decreases.

that had been subjected to year 2100 levels of OA for two generations did experience the 30% decrease in egg production rate described above, but the effect of OA was twice as severe in control populations kept at present-day pH until the second generation and then transferred to the year 2100 level 3 weeks before measurements. Egg production rates would have plummeted by more than 60% had the population not adapted to OA. This would have had severe consequences for the populations in the North Sea.

The studies will continue and we are now (January 2014) starting a study on arctic *Calanus glacialis* (a sibling species to *C. finmarchicus*) at a cold-water OA laboratory we have established at the research station in Austevoll, run by the Institute of Marine Research. We hope to extend these studies into the second generation of the animals, to be able to address similar evolutionary questions as for *P. acuspes*. In 2015 we will initiate further studies on arctic species at the Marine Lab, Ny-Ålesund, Svalbard.

Note: The oceans are basic (pH between 7.9 and 8.1) and the term ocean acidification is slightly misleading. The anthropogenic emission of CO_2 has not made the oceans acidic (pH under 7), only less basic.

Helge M. Markusson // Fram Centre

New report on ocean acidification

A new report on Arctic Ocean acidification was presented 6 May 2013, during the International Conference on Arctic Ocean Acidification organised by the Arctic Monitoring and Assessment Programme (AMAP) in Bergen.

The Arctic Ocean is absorbing carbon dioxide (CO_2). This leads to acidification – a permanent decline in the pH of the ocean. This change is impacting on marine ecosystems in the Arctic, ecosystems that are already compromised by rising temperatures and melting sea ice.

The report presented in Bergen is the result of a three-year study initiated by AMAP, an Arctic Council working group, and is the first large-scale study of acidification of the Arctic Ocean. The members of the international working group included several researchers affiliated with the Fram Centre's research programme on ocean acidification. In connection with the conference, the Fram Centre also held a reception and presented the Centre's flagship research programme.

IMPORTANT FINDINGS

- The world's oceans are becoming more acidic. Acidification is taking place as a result of the oceans' uptake of large amounts of CO_2 emitted through human activity.
- In the past 200 years, the average acidity of ocean surface waters has increased by about 30 per cent globally.
- The Arctic Ocean is particularly vulnerable. CO_2 is absorbed more quickly in cold water, and the increasing quantities of freshwater entering the Arctic from rivers and melting ice are reducing the ocean's capacity to neutralise the acidification.
- Acidification is particularly prominent in central areas of the Arctic Ocean. Monitoring stations in the region show that, in particular, surface waters are growing more acidic.
- Since arctic marine food chains are relatively simple, the ecosystems are vulnerable to change when key species are affected by external factors.