Ocean acidification affects early life stages of heavily exploited fish

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Ocean acidification (OA) and its effects on fish have recently come into focus. Early developmental stages, in particular, are sensitive to OA because they lack efficient osmoregulation. Our experiments indicate severe damages in major organs in Atlantic cod during the transition from the larval to the juvenile stage, and showed differences in sensitivities of different populations of Atlantic cod (Baltic vs. Northeast Atlantic). OA may constitute an additional bottleneck in the life cycle of fish potentially causing mortality and affecting the recruitment to fisheries.

Ocean acidification the "other CO_2 problem" is presently considered to be one of the most complex and critical anthropogenic threats to marine life. It is caused by the uptake of excess atmospheric CO_2 by the oceans, reducing not only the pH of surface seawater but also the mid and bottom waters due to CO_2-remineralization by decomposition of primary plankton production. Ocean acidification has been found to affect a wide array of organisms from single-celled algae to complex invertebrates. While calcifying organisms are particularly challenged by acidified waters, fish are considered less vulnerable as they have a well developed acid-base regulatory system in the gills. However, early life stages that hatch without functional gills may be more vulnerable to high CO_2 concentrations. Ocean acidification data on marine fish remain limited, negative effects so far have been identified in the behavior of coral reef fishes and in an estuarine fish species, the Atlantic silversides with reduced growth and increased mortality in the early larval stages (Baumann et al. 2012). In coral reef fish realistic CO_2 levels predicted by global climate models for the near future impaired their olfactory ability for homing, while predator and prey detection was also compromised. In contrast, no significant effects on embryonic duration, egg survival and size at hatch for these reef fish, but on the size of the otoliths, the earstones of the fish, were found (f.e. Munday et al., 2009).

Hence, we intended to address ocean acidification effects in Atlantic cod, a key fish species which is heavily exploited in the entire northern Atlantic. Experiments were performed in large land-based outdoor mesocosms (Fig. 1) under natural temperature, salinity and light conditions near Bergen, Norway using natural plankton from the nearby fjord as food for the larvae. The Atlantic cod is widely distributed along the entire North Atlantic coast. It matures at 3 – 5 years. Its reproduction is characterized by high fecundity with an average of 1 million eggs per female and fluctuations in recruitment (stage were fish enter the fisheries) are mainly caused by high mortality during the early life stages. Cod are external fertilizers and their sperm is activated by changes in ionic composition and osmolality as it is expelled into the open ocean during a spawning event. Therefore reduction in seawater pH has the potential to influence sperm behavior and fertilization success. By examining the effect of elevated CO_2 concentrations over the entire early life-history range from gametes to the juvenile stage, vulnerable stages could be defined. While gametes and yolk-sac larvae seem to be robust to very high levels of CO_2, (Frommel et al., 2010, 2012a) the transition from larvae to juveniles was heavily impacted by CO_2 (Frommel et al., 2012b). At this developmental stage, severe damage to internal organs (liver, pancreas, kidney and gut) in larvae raised under ocean acidification scenarios was found based on histological sectioning (Fig. 2). This transi-

Fig.1: Mesocosm set up at Espegrend, Norway.

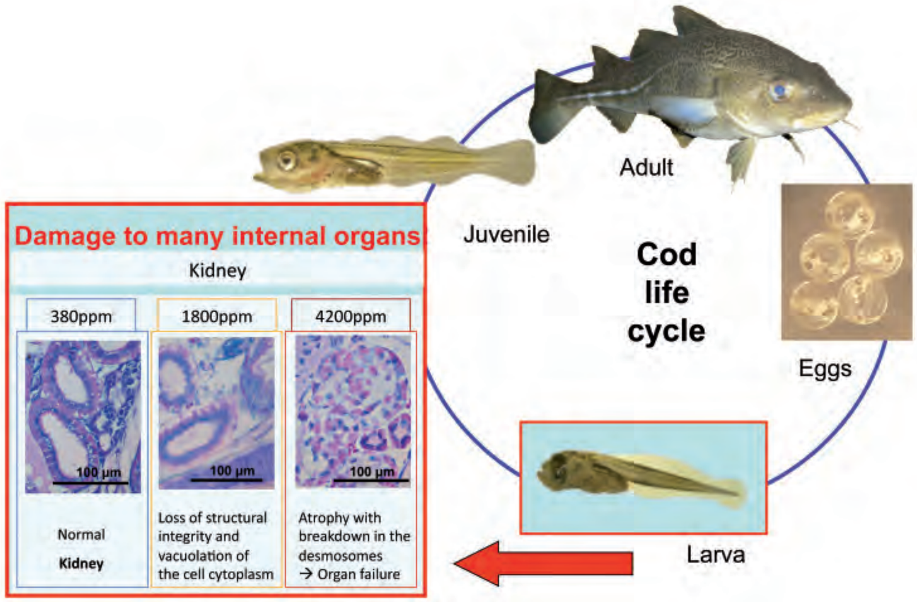

Fig. 2: The life cycle of cod showing an example of damage to one of the organs (kidney) occurring in the transition phase between larval and juvenile stage.

tion marks a particularly vulnerable phase in which structural reorganization like the development of functional gills takes place, lowering the chance of larval survival considerably. Additionally, changes in lipid metabolism were observed (Frommel et al., 2012b).

One has to be very careful when extrapolating results from our findings, measured in one population at one time point, to the species or even genus level. Different cod populations may experience very different environmental conditions rendering them more or less sensitive to climate change. Atlantic cod populations along the Norwegian coast live in full saline and well oxygenated water. In contrast, Baltic cod spawn in oxygen depleted water layers and naturally experience CO_2 levels predicted for the year 2100 in other areas (global, open ocean average). Therefore Baltic cod may be adapted to chronically elevated CO_2 levels, since the non-feeding stages of Baltic cod larvae were insensitive to elevated CO_2 levels (Frommel et al., 2012a). Similar results were obtained for herring larvae from the western Baltic Sea which showed no effect of ocean acidification on the embryonic development, hatch rate and size, and weight at hatch. The RNA concentration, as a proxy for protein biosynthesis, was reduced at higher CO_2 levels possibly indicating an energy deficiency (Franke & Clemmesen, 2011). An evolutionary ecology perspective is thus indispensible to understand biological effects of global warming and acidification on fish populations. Multiple hydrographical stressors in the Baltic Sea may also lead to a higher sensitivity in later stages, which so far have not been studied. Effects of ocean acidification on the survival of these stages, as indicated by the results from our working group, must be further analysed in combination with other relevant climate change variables to ensure a better projection of the effects of ocean acidification on fish populations. Furthermore, species that already experience strong pressure via fisheries exploitation have a reduced buffering capacity towards climate change aspects.

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