Thesis for the Degree of Doctor of Philosophy

Climate Change and the Norway Lobster

Effects of Multiple Stressors on Early Development

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Akademisk avhandling för filosofie doktorsexamen i marin zoologi, som med tillstånd från Naturvetenskapliga fakulteten kommer att offentligt försvaras fredagen den 28 november 2014 kl. 10.00, Hörsalen, Sven Lovén centrum för marina vetenskaper, Kristineberg, Fiskebäckskil.

Examinator: Professor Kristina Sundbäck, Institutionen för biologi och miljövetenskap, Göteborgs universitet.

Fakultetsopponent: Professor John Spicer, School of Marine Science and Engineering, Plymouth University, UK.

Abstract

Climate change together with anthropogenic eutrophication have led to, and will lead to, shifts in a number of abiotic factors in the oceans, such as temperature, pH, carbon dioxide [CO_2], oxygen saturation and salinity. These stressors will act simultaneously on marine organisms and may have synergistic, additive or even antagonistic effects on physiological performance and tolerance. As such, multiple stressor experiments are crucial to gain a better understanding of future vulnerability of species, populations and ecosystems.

Early life stages of invertebrates are generally considered most vulnerable to environmental stress, but only a few studies have concerned brooding species such as the Norway lobster (*Nephrops norvegicus*), which is a benthic species, of great ecological and commercial importance. The benthic stages (adults, juveniles and embryos) spend most of their time in soft sediment burrows where they may be afflicted by low pH, hypoxia and an increased Mn^{2+} concentration while the subsequent pelagial stages (Zoea I-III) are exposed to elevated seawater temperature and fluctuations in salinity. This poses the question: Is the Norway lobster already at it tolerance limit or can it tolerate additional climate change related stress?

This thesis comprises four studies primarily on embryonic development but also on larval, juveniles and egg-bearing female Norway lobsters. In **Paper I**, a potential combined effect of long-term (4 months) exposure to OA and elevated temperature on embryonic physiology was investigated. Although the Norway lobster embryos rarely encounter the highest temperature tested (18°C) naturally, they were found to be tolerant to the treatment with no combined effects on development rate, metabolic rate or the level of oxidative stress. In **Paper II** an easy-to-use quantitative tool for the development staging of the Norway lobster embryos was described. Qualitative variables was fitted to the quantitative scale of amount yolk and tested against elevated temperature and OA. There was an insignificant trend of the morphological characters appearing at a lower amount yolk in the OA and 18°C combination. In **Paper III**, climate change impacts of salinity and OA tolerance in zoea larvae were studied. Tolerance to hyposalinity treatment decreased quickly with age as newly hatched zoea I larvae were more tolerant than older. However, when allowed to acclimate, tolerance and thus survival to low salinity increased. The surviving larvae of the lowest longer-term salinity treatment (17 PSU) were 20% lighter than those exposed to higher salinities >21 PSU. Exposure to OA affected survival in some broods of zoea larvae negatively but not others, indicating genetic variation in OA tolerance. When larvae were starved, the mortality was also greater in OA indicating differences in energy usage. In **Paper IV** a higher level of OA was tested for 2 months, together with 1 week of exposure to hypoxia or manganese, on different life stages. Hypoxia drastically reduced oxygen consumption rate in all life-stages tested. Hypoxia in combination with OA also reduced metabolic rate further in embryos. Heart rate was however higher in embryos exposed to hypoxia, independent of OA but exhibited a more regular rhythm when exposed to the combination of hypoxia and OA. Females exposed to OA had a slightly increased oxygen consumption rate, but this effect was only significant in the combination with Mn^{2+}. Conversely, the combinations of OA and Mn^{2+} reduced metabolic rate of embryos. Despite the decreased metabolic rate, we found no significant effect on embryonic development rate in the combinational treatments. However, development rate was significantly lower in the control than in hypoxia and Mn^{2+}. This contradiction need to be further investigated.

In conclusion, all life stages tested seemed relatively resilient to OA alone but life-stage dependent effects were seen when treatments were combined, such as the opposite response to OA and Mn^{2+} in embryo and female metabolic rate. Previous research has shown brooding females to sense and adjust ventilation of their eggs in unfavorable conditions. If the responses seen in **Paper IV** was a result of an elevated fanning was not in the scope of this thesis but should be investigated. The synergistic effects seen in this thesis would have been overlooked in a single stressor experimental set-up, which emphasise the great need for additional multiple-stressor studies. Finally, the highest increase in pCO_2 (600 µatm) tested (**Paper IV**) still represents a moderate scenario for the end of this century, since different models predict an increase of between 500-1000 µatm pCO_2 (IPCC, 2013). Thus, the effects observed could be an underestimation of the future impact of OA. In many places the Norway lobster currently lives close to the tolerance limit of the early life stages. As such, the geographic area of suitable abiotic habitat for the Norway lobster may be severely affected in a near future.

KEYWORDS: *Nephrops norvegicus*, climate change, ocean acidification, hypoxia, salinity, temperature, manganese, oxidative stress, metabolic rate, cardiac performance, survival, embryo, zoea