Combined effects of temperature and hydrostatic pressure on the early ontogeny of the common whelk *Buccinum undatum* (Linnaeus, 1758); is low temperature the key to successful deep sea invasion?

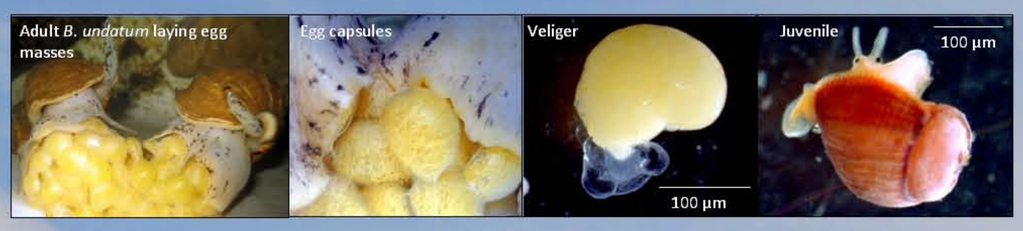
Kathryn Smith[1] and Sven Thatje[1]

[1] University of Southampton, National Oceanography Centre, Southampton, European Way, Southampton, UK, SO14 3ZH

Email: Kathryn.Smith@noc.soton.ac.uk

Abstract

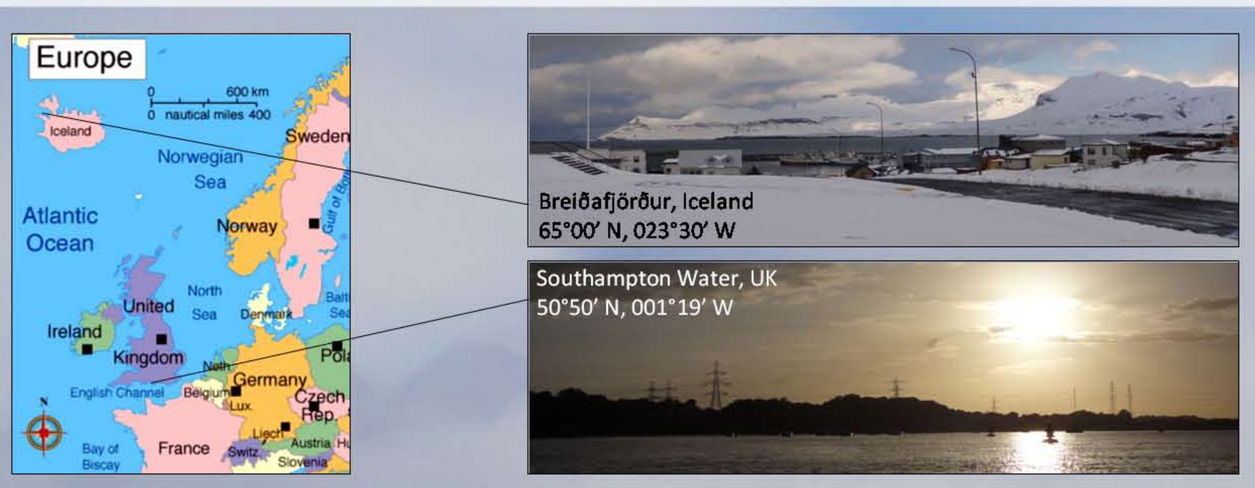
The dispersal and migration of marine fauna are affected by many factors; two of which to be considered significant are temperature and hydrostatic pressure. To understand the necessary evolutionary adaptations for colonisation of different thermal and hyperbaric environments it is important to understand how these factors affect not only adults, but also early life stages. Here we examine how these variables impact veligers and juveniles of the neogastropod *Buccinum undatum.* Development in this species is intracapsular. Egg masses were maintained at temperatures ranging from 3 to 18°C. In veligers, temperature affected respiration rates but no effect of pressure up to 400 atm was seen. In juveniles, respiration rates were affected by temperature, pressure and the interaction of the two factors. The greatest tolerance to high pressure was seen at the lowest experimental temperature (3°C). The temperature and pressure tolerances observed are outside the bathymetric and latitudinal range of *B. undatum's* current distribution, which may suggest this species is capable of further expanding its distribution range. The increased pressure tolerance seen with decreased temperature in juveniles may be linked to the deep-sea origin of neogastropods. This study highlights the importance of understanding the full effects of temperature and pressure across all ontogenetic stages. Without this knowledge it is impossible to understand better how changes in climate envelopes affect the distribution and radiation of species, with regard to both latitude and depth.



Introduction

Temperature and hydrostatic pressure are capable of causing major physiological disruptions, and both independently and collectively create substantial evolutionary challenges for marine fauna. To understand how these factors affect different life stages will give insight into both past radiations and help predict future migrations in light of potential threats like climate change.

Gastropods from the Buccinidae family are found widely distributed throughout the oceans (Martell et al., 2002). The shallow-water species *Buccinum undatum* (the Common Whelk) is found on both sides of the Atlantic, from Iceland to the southern coast of England (Hancock, 1967). Here, using samples collected from both ends of the species distribution range, the physiological effects of temperature and pressure during early ontogeny were investigated.



Method

Buccinum undatum egg masses were collected from Southampton Water and the Solent, UK (12 masses; Jan-Feb 2010 and 2011) and from Breiðafjörður, Iceland (6 masses; Apr-May 2011). Egg masses from the UK were incubated at 6, 10, 14 or 18°C. Egg masses from Iceland were incubated at 3 or 6°C. Three egg masses were maintained under each condition.

Investigations into oxygen consumption rates were carried out on veligers and hatching juveniles from all conditions. Pressurisation took place in 2.8ml vials (3 individuals per vial; 9 vials per condition). Vials were pressurised to 1, 100, 200, 300 or 400 atm for 4h at each developmental temperature. After depressurisation, vial oxygen content was measured to determine oxygen consumption (analysed according to Benson & Krause, 1984).

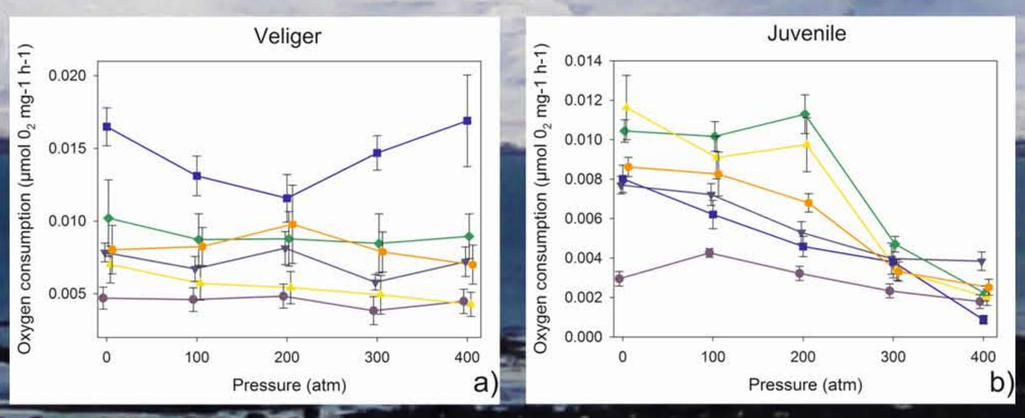


Figure 1: Effects of temperature and pressure on oxygen consumption in a) veliger and b) juvenile *B. undatum*. For each point n=9. Error bars display standard error.

Results

Analysis indicated a pattern of decreasing oxygen consumption with increasing pressure in juveniles ($p \leq 0.001$). A difference in oxygen consumption between temperatures was observed in both veligers and juveniles ($p \leq 0.001$). A significant interaction was determined which implied the effects of increasing pressure on oxygen consumption were reduced with decreasing temperature (Tables 1 and 2).

Table 1: *Post-hoc* analysis of the effects of temperature, pressure and temperature/pressure interactions on oxygen consumption in veliger and juvenile in *B. undatum*. Significant values are in **bold.**

	Veliger O_2 cons.	Juvenile O_2 cons.
Temperature	**0.000*****	**0.000*****
Pressure	0.440	**0.000*****
Temperature * Pressure	0.934	**0.000*****

Table 2: *Post-hoc* analysis of pressure effects on oxygen consumption (when compared to 1 atm) at different developmental temperatures in a) veliger and b) juvenile *B. undatum*. Significance **level indicated by asterisks,* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.**

a)

Temperature (°C)			Pressure (atm)			
			100	200	300	400
Southampton Water, UK		18	1.0000	1.0000	1.0000	1.0000
		14	1.0000	1.0000	1.0000	1.0000
		10	1.0000	1.0000	1.0000	1.0000
		6	1.0000	1.0000	1.0000	1.0000
Breiðafjörður, Iceland		6	1.0000	1.0000	1.0000	1.0000
		3	1.0000	1.0000	1.0000	1.0000

b)

Temperature (°C)			Pressure (atm)			
			100	200	300	400
Southampton Water, UK		18	1.0000	1.0000	**0.0001*****	**0.0001*****
		14	1.0000	1.0000	**0.0000*****	**0.0000*****
		10	1.0000	1.0000	**0.0002*****	**0.0000*****
		6	1.0000	0.2690	**0.0019****	**0.0000*****
Breiðafjörður, Iceland		6	1.0000	0.9997	**0.0263***	**0.0268***
		3	1.0000	1.0000	1.0000	1.0000

Discussion and summary

Results suggest that during its early ontogeny this species is able to tolerate deep-sea conditions. Impacts of high pressure also appear to be partially compensated for by decreased temperature. This is contrary to previous investigations (e.g. Tyler et al. 2000; Oliphant et al. 2011) and is likely linked to the deep sea and cold water origin of neogastropods. These results indicate tolerance levels vary as individuals develop and highlight the importance of studying the effects of variables such as temperature and pressure on all life stages. They also give insight into the potential for future radiations with regard to latitude and depth in response to future environmental change and global warming.

Acknowledgements

The authors would like to express their thanks to the team at Vör Marine Research Centre in Breiðafjörður, Iceland, skipper and crew of RV Callista (Southampton, UK) for their help with collection of samples. This project was supported by grants from The Malacological Society.to KS and the Total Foundation (Abyss2100) to ST.

References

- Benson, B.B., Krause, D.Jr., 1984. The concentration and isotopic fractionation of oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere. Limnol. Oceanogr. 29, 620-632.
- Hancock, D., 1967. Whelks. Laboratory leaflet (new series) no. 15. M.A.F.F. 1-14.
- Martell, K.A., Tunnicliffe, T., Macdonald, I.R., 2002. Biological features of a buccinid whelk (Gastropoda, Neogastropoda)at the Endeavour ventfields of Juan de Fuca ridge, northeast Pacific. J. Moll. Stud. 68, 45-53.
- Oliphant, A., Thatje, S., Brown, A., Morini, M., Ravaux, J., Shillito, B., 2011. Pressure tolerance of the shallow-water caridean shrimp *Palaemonetes varians* across its thermal tolerance window. J. Exp. Biol. 214, 1109-1117.
- Tyler, P.A., Young, C.M., Clarke, A., 2000. Temperature and pressure tolerances of embryos and larvae of the Antarctic sea urchin *Sterechinus neumayeri* (Echinodermata: Echinoidea): potential for deep-sea invasion from high latitudes. Mar. Ecol. Prog. Ser. 192, 173-180.

University of Southampton

National Oceanography Centre, Southampton
University of Southampton and Natural Environment Research Council

ABYSS2100 Supported by Total Foundation

The Malacological Society of London
http://www.Malacsoc.org.uk