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Sexually-manifested variations in pigmentation of *Boeckella poppei* (Copepoda, Calanoida) from Livingston Island (Maritime Antarctica)

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Abstract

Antarctic environments are exposed to high levels of ultraviolet radiation (UVR) that are often detrimental to their biota. Recent studies suggest that the genus *Boeckella* (Copepoda, Calanoida) has a high level of plasticity in terms of its reaction to UVR, which enables its wide distribution in various water bodies in Antarctica. *Boeckella poppei* is common in freshwater habitats of all three main biogeographic regions in Antarctica: sub-Antarctic islands, maritime and continental. We present for the first time a specific photoprotective response in populations of *B. poppei* from Livingston Island, Maritime Antarctica. In non-ovigerous females and in males, we observed uniform distribution of carotenoids in the body, while these pigments were almost entirely concentrated in the ovisacs of mature females. We consider this as a means of progeny protection from the teratogenic influence of the high level of UVR in Antarctic environments. Unequivocally, such adaptation would facilitate the expansion of *B. poppei* on the continent through colonisation and survival in shallow freshwater habitats. Given that the Antarctic environment is dynamically changing over the past decades and the accelerated retreat of permanent ice cover is a premise for the formation of shallow ponds, *B. poppei* could be a suitable indicator for reflecting the ongoing global environmental changes in Antarctica.

Keywords

Bulgarian Antarctic Base, copepod pigmentation, freshwater, ovigerous females, progeny photoprotection

Introduction

Solar radiation is an essential modulator of the functioning of natural ecosystems (Wetzel 2003). Ambient levels of biologically-damaging ultraviolet radiation (UVR) have been rising in aquatic systems in Polar Regions (Karentz and Bosch 2001; Perin and Lean 2004). During the 20th century, the release of anthropogenic contaminants increased the potential for photoactivated toxicity in these aquatic systems, triggering the organisms to develop mechanisms to minimise phototoxic damage (Diamond 2003).

The calanoid copepod *Boeckella poppei* (Mrázek, 1901) is widely distributed in freshwater habitats in the three main biogeographic regions in Antarctica: sub-Antarctic islands, maritime and continental Antarctica (Maturana et al. 2019). On Livingston Island, the species has been reported from the Hurd Peninsula (Pandourski and Apostolov 2004) and in most of the 15 studied lakes on the Byers Peninsula (Toro et al. 2007). During the last 25 years, owing to the environmental changes and the climate change-driven expansion of permanent ice-free habitats, *B. poppei* colonised many newly-formed temporary shallow water bodies in the north-west part of the Hurd Peninsula (Evtimova et al. 2021).

Boeckella poppei is known to have a wide plasticity to the specific polar environmental conditions, a result of various adaptations, including carotenoid pigmentation (Byron 1982) and photoprotection through the use of "sunscreen" compounds, for example, mycosporine-like amino acids (Rocco et al. 2002). Nevertheless, the population of *B. poppei* from Livingston Island demonstrates relatively high morphological variability and teratology (Pandourski and Chipev 1999; Pandourski and Evtimova 2009).

Here, we describe for the first time a sexually-manifested variation of pigmentation in *B. poppei*, inhabiting shallow temporary freshwater ponds on permafrost sediments.

Material and methods

We sampled two adjacent temporary turbid freshwater shallow ponds (with coordinates 62.63622°S, 60.35117°W and an altitude of 23 m a.s.l.) on 07.02.2020. The ponds were situated on permafrost sediments; dense and thick flocculation of microalgae and diatoms covered the ponds' bottom and edges (Fig. 1). The water transparency was very low due to colloidal inorganic particles, originating from glacier activity. Their depths did not exceed 10–12 cm, allowing solar radiation to penetrate to the bottom of the ponds. The bottom of the ponds was covered with a layer of fine inorganic particles and cobbles a few cm deep.

Basic physical and chemical characteristics of the water (Table1) were measured using hand-held oximeter Oxi 300i with DurOx 325 electrode and conductometer Cond 330i with KLE 325 electrode (WTW, Germany).

The specimens of *B. poppei* were collected with a hand-held net (50 µm mesh size) after intensive mixing of the water. They were transported alive to the laboratory of the Bulgarian Antarctic Base, immobilised in highly diluted ethanol and photographed.

Figure 1. General view of pond 1 (**a**) and flocculation of microalgae and diatoms in pond 2 (**b**). Photo: I. Pandourski.

Table 1. Basic characteristics of the two ponds.

Pond	Area (m^2)	Water temperature (°C)	Salinity (‰)	Oxygen (mg.dm^{-3})	Oxygen (%)	Conductivity (µS.cm^{-1})
1	10–12	7.6	0.00	8.4	74	82
2	5–6	9.1	0.00	9.5	81	131

Males, copepodites and females (ovigerous and non-ovigerous) were separated, based on the level of their morphological development and the morphological features typical for the species following published descriptions of the species (e.g. Bayly 1992). Body pigmentation was assessed visually in circa 100 individuals (males and females) from each pond. The basic morphometric characteristics of males and females in a population from Livingston Island are presented in Pandourski and Chipev (1999).

Results

We observed clearly manifested differences in body pigmentation of ovigerous females vs. adult males, non-ovigerous females and copepodites of *B. poppei*. The body of ovigerous females was depigmented, almost transparent, while their egg sacs were from red to dark orange. Ingested algae with a high concentration of pigments were clearly visible in their gut content (Fig. 2). Of the studied specimens, all mature females exhibited the described colouration. The body of males and non-ovigerous females was dark orange or red-coloured due to the even distribution of pigments (Fig. 3).

Discussion

We describe for the first time sexually-manifested pigmentation of *B. poppei*. Pigments were evenly distributed throughout the body of all specimens, except for mature ovigerous females, where they were concentrated in the egg sacs. Reddish colouration in copepods is caused by different carotenoids synthesised from the β-carotene

Figure 2. Depigmented, almost transparent body of mature females of *Boeckella poppei* with intensely pigmented ovisacs (above) and males with evenly pigmented bodies (below). Photo: L. Kenderov.

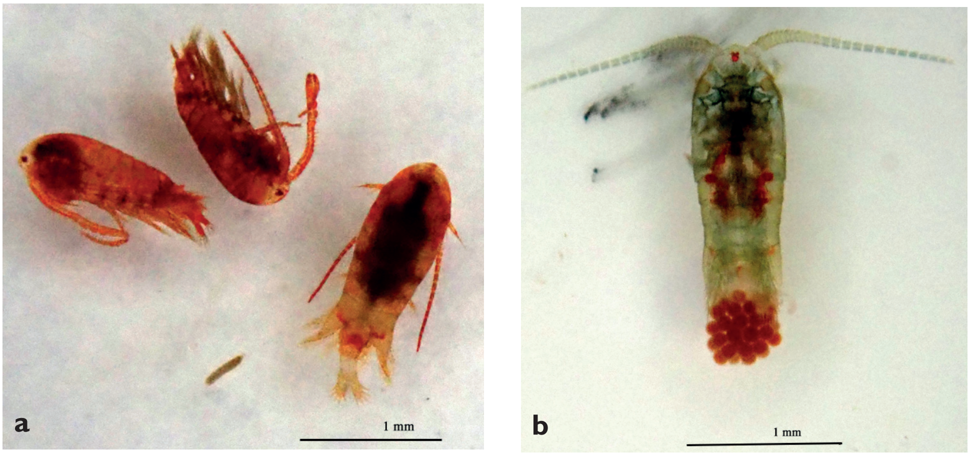

Figure 3. *Boeckella poppei*: two evenly pigmented males and one non-ovigerous female (**a**) and a mature female with almost transparent body and intensely pigmented ovisacs (**b**). Photo: L. Kenderov.

present in the algae used as a food source (Ringelberg 1980). One of the functions of this pigmentation is photoprotection. The synthesis of photoprotective compounds in the body of copepods is amongst the most important strategies to avoid the damaging effect of UVR in the Antarctic (Rocco et al. 2002) and high- latitude environments (Hansson 2004), as well as in alpine lakes (Tartarotti et al. 1999; Tartarotti et al. 2017). Sommaruga (2010) established very high carotenoid concentrations (free astaxanthin) in calanoid copepods from clear fishless Himalayan alpine lakes. The concentrations of carotenoids in these copepods were inversely related to the lake depth refuge, while the lowest concentrations were found in copepods from a turbid glacier-fed lake.

The studied populations of *B. poppei* from Livingston Island inhabit small shallow turbid ponds. There the photoprotective strategy of migration to the deeper water layers was not possible as the depth of the ponds was only 5–12 cm and, despite the high turbidity of the water, the calanoids were likely exposed to the action of the UVR. In shallow ponds and lakes, the carotenoid pigments are known to play an important photoprotective role. According to Rocco et al. (2002), only the presence of photoprotection could be demonstrated in populations of *B. poppei* from the studied lakes on the Antarctic Peninsula, while the limited efficiency of enzymatic DNA repair mechanisms could be related to the low temperatures prevailing in Antarctic lakes.

In Antarctica, the life cycle of copepods in temporary ponds is controlled by the alteration between liquid water and ice and only few species can survive in these harsh conditions (Pociecha and Dumont 2008). Ovogenesis is one of the most sensitive stages in their life cycles as the damaging and teratogenic effect of UVR could cause morphological abnormalities incompatible with the survival of the individual. We consider the concentration of practically the whole amount of the accumulated pigments (as implied by the intensity of the colouration) into the ovisacs of females of *B. poppei* a specific strategy to protect progeny from the damaging UVR in the dynamically changing Antarctic environmental conditions over the past decades, enhancing the survival of individuals and expanding the range of this species.

Conclusions

The observed phenomenon of concentrating of carotenoid pigments in eggs of ovigerous females demonstrates the plasticity of *B. poppei* to survive in habitats exposed to high UVR. Further studies are needed to establish the type of the pigments and the mechanisms of their accumulation in the ovisacs. We suggest this pigmentation is a strategy for avoiding the teratogenic effects of UVR and for progeny protection. This, in turn, is facilitating the expansion of *B. poppei* in Antarctica through colonisation and survival in freshwater habitats, newly formed after the retreat of permanent ice cover. Thus, *B. poppei* could be a suitable indicator for reflecting the ongoing global environmental changes in Antarctica.

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