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Abstract

Although Arctic communities are very sensitive to global warming, direct evidence of the effects of high temperature on bottom communities is quite rare. A mass mortality event (MME) of sponges we observed by SCUBA diving in July and August 2018 along the coasts of Kandalaksha Bay, White Sea, sub-Arctic. This event severely affected sponges from hard-substratum communities in particular, the demosponges *Isodyctia palmata* and *Halichondria sitiens*. Constant and exceptionally high temperatures throughout the water column (average temperature differences of 6.5° C in July and 5.6° C in August 2018, relative to the average temperatures in previous years at a depth of 20 m) may have led to an environmental context favorable to the MME. As was observed for the thermal anomaly, mortality was limited at the depth below a thermocline. However, it is not possible to ascertain whether temperature had a direct effect on organisms or whether it acted in synergy with a latent and/or waterborne agent. However, viewed in the context of global warming, there is an urgent need to rapidly set up monitoring programs of physical-chemical parameters and vulnerable populations in benthic communities through the Arctic Basin.

Introduction

Present warming has amplified worldwide during the past few decades, including air and sea temperature rise in the Arctic (Harley et al. 2006; Smedsrud et al. 2013). At these high latitudes, warming has particularly significant impacts on cold- and ice-adapted species because suitable habitats contract toward the poles. Wassmann et al. (2011) found a total of 51 reports of documented changes in Arctic marine biota in response to climate change up to and including 2009. These reports indicate that climate warming is inducing structural change over large spatial scales at high latitudes leading, for example, to the borealization of fish communities in the Arctic (Fossheim et al. 2015).

One of the consequences of global warming is mass mortality events (MMEs) - the rapid, catastrophic die off of organisms. MMEs may have important ecological effects regulating population levels by impacting all size classes or developmental stages in a given population (Mangel and Tier 1994; Fey et al. 2015; Langangen et al. 2017). MMEs seem common in marine benthic ecosystems in the different regions of the world ocean (Eiane and Daase 2002; Stokstad 2014; Prada et al. 2017), but this phenomenon has been better investigated in the Mediterranean, where MMEs are associated with positive thermal anomalies (Cerrano et al. 2000; Pérez et al. 2000; Romano et al. 2000; Rodolfo-Metalpa et al. 2005, 2006; Coma et al. 2009; Cupido et al. 2009; Garrabou et al. 2009; Kruzic et al. 2016). The affected species are mostly long-lived sessile epibenthic invertebrates such as sponges, anthozoans, bivalves, bryozoans and ascidians. Accordingly, MMEs, occurring with the dominant species lead to significant changes in benthic communities.

However, the biological consequences of extremes in Arctic temperatures remain poorly resolved owing to their unpredictable nature and to the difficulty in quantifying their mechanisms and impacts.

It should be noted that the abnormally high water temperatures in the summer of 2018 were recorded in different parts of the Kandalaksha Bay (data from the monitoring program "White Sea Hydrology and Zooplankton Time Series: Kartesh D1"). During the summer of 2018 we detected for the first time in the sub-Arctic a mass mortality event affecting sponges from the White Sea. This event is the subject of this short communication.

Material and Methods

The study sites are located in Velikaya Salma Strait between Velikij Island and Moscow State University's White Sea Biological Station (WSBS) (66^{o} 34' N, 33^{o} 08' E), covering a distance of about 2 km (Online Resource 1).

The observed area - Velikaya Salma, and precisely, the region of the transects – was the object of regular diving of the biologists and the divers of the WSBS. We monitored the abundance and health status of sponges and sea water temperature in summer 2018. The incidence of marine sponge mortality was surveyed by SCUBA diving in July and August 2018. In general, each survey was carried out from 8.5 to 19 m of depth. The sponge's species affected were recorded, by the presence of necrosis and the temperature of the water. A total of 270 surveys were conducted, 120 by scientists and 150 by recreational divers. For the percentage of damage was calculated 125 individuals of *Isodictya palmata* and 273 ones of *Halichondria sitiens* from both transects.

Photomonitoring was carried out along two transects measuring 97 m and 190 m at the depths from 10 to 15 m, using a Panasonic Lumix GH5 camera fitted with a Panasonic Lumix G Fisheye 1:3.5/8 lens in a Subal scuba box. The coordinates of the transects were determined using the Garmin GPSmap 78 GPS navigator. The bottom was filmed while moving along the entire length of the transect. Individuals of *I. palmata* and *H. sitiens* found along the way transferred to a close-up plan to further assess the degree of necrosis and description, after which diver continued to move in a straight line along the transect above the bottom. The state of the sponges was analyzed by video recording in the laboratory. Photos are freeze frames from the video. Affected sponges were grouped in three categories according with the percentage of affected surface: <10%; 10–70%; >70%.

Temperature recording during sponge mass mortality events was made using an underwater electronic thermometer (Suunto Zoop dive computer, Vaanta, Finland). These data were compared with average temperatures for the 9 to 25 m depth range spanning 36 summer seasons taken on site of WSBS (http://wsbs-msu.ru/doc/view.php?ID=23) and from Pantyulin unpubl.

Field study permissions. No specific permissions were required for these locations because the study was conducted outside national parks, private lands, or protected areas. We declare that the field studies did not involve endangered or protected species.

Results and Discussion

The White Sea is a semi-enclosed sub-Arctic sea which occupies a long gulf south-east of the Kola Peninsula and which is joined to the Barents Sea by a strait. The White Sea covers approximately 95 000 km^2. Surface waters are considerably fresher (salinity 24–26%) than bottom waters (salinity 30–30.5 psu) (Howland et al. 1999; Pantyulin 2003). Seasonal variation of surface water temperature in the White Sea is about 20° C but bottom waters have a constant temperature of about – 1.5° C (Pantyulin 2003). Average water temperatures in the top layer of water in Kandalaksha Bay measure about 0□ C in winter, +6□ C by late spring, and rise to 13-14□ C in early August, while remaining fairly constant (around 0□ C) at depths of over 50 m.

During summer 2018, an anomalous increase in water temperature was recorded in Kandalaksha Bay, White Sea. Recordings made at our observation sites showed that mean temperatures recorded at 9 and 19 m depths between the beginning of July and the end of August 2018 were exceptionally high (Online Resource 2b). Averaged temperature differences were found to be 6.5° C in July and 5.6° C in August (Online Resource 2). This high thermal phenomenon observed at the July and the end of August of 2018 contrasts spectacularly with the region's normally occurring mean temperatures at the same depths and the same months (Online Resource 2a).

Velikaya Salma is a two-kilometer long strait with an average width of about 500 meters. The Strait connects Kandalaksha Bay with two large shallow-water inlets, Rugozerskaya Guba and Babye More. Under the influence of the tides, large volumes of water move through the Strait four times a day. The maximum flow velocity reaches 1.7 m s^{-1}. Due to the high turbulence of these tidal currents, the Strait is an active mixing zone, meaning that vertical stratification of the waters by temperature and salinity is much weaker here than in the open part of Kandalaksha Bay (Naumov et al. 2016). The water in the shallow inlets (Rugozerskaya Guba and Babye More) warms up on hot days. This warm water from the shallow inlets flows through the Strait, creating abnormally high temperature conditions for bottom animals. It should be noted that sponges can be monitored by divers during standing water only, when the flow is minimal, meaning that the unusually elevated bottom temperatures recorded by divers at slack tide may not even be as high as those actually occurring at the peak of low tide, when rushing tidal flow prevents diving.

An anomalous increase in water temperature is periodically recorded in the White Sea, for example, in 1990, 1994, 1998, 2000 (Bobkov et al. 2005), but the effect of such high temperatures on benthic hydrobionts has not yet been studied.

During June 2018, no signs of sponge disease were recorded. However, during July and August massive disease leading to necrosis and death of some sponges from the Velikaya Salma was observed. Visual observations and comparison of photographs taken in the area of transects in August of previous years and in 2018 indicate a significant decrease in the number of sponges in 2018. The majority of the affected sponges belonged to *Isodyctia palmata* (Ellis and Solander 1786) (87.2% of necrotic and dead sponges), and *Halichondria* (*Eumastia*) *sitiens* (Schmidt 1870) (34.5% of necrotic and dead sponges) (Fig. 1). Among others damaged sponges we detected only demosponges *Haliclona* (*Gellius*) *fibulata* (Schmidt 1862) and *Haliclona gracilis* (Miklucho-Maclay 1870), but we find only some necrotic individuals.

We did not find any traces of disease in sponges from the same habitat *Amphilectus lobata* (Montagu 1814), *Halichondria panicea* (Pallas 1766), *Haliclona aquaeductus* (Schmidt 1862), *Leucosolenia* cf. *variabilis* and *Sycon* sp.

It is difficult to talk about the disease of the other sponge's species from the area of transects as other sponges, except *H. panicea* and *H. aquaeductus* are small forms with a weak skeleton. It is possible that in the event of disease they quickly decompose.

Both damaged species are distributed throughout the North-Atlantic and Arctic regions (Ereskovsky 1994, 2010). In the White Sea, *Isodyctia palmata* lives at depths ranging from 8 to 59 m, at the average temperature between -1.3°C to + 16.5°C, inhabits areas with strong current, and develops mainly on stones. *Halichondria sitiens* was recorded at depths ranging from 2.5 to 110 m, at the average temperature between - 1.7°C to + 15°C, and on all types of substrate. However, both species are found primarily in areas with high hydrodynamics.

The body of *I. palmata* is elongated, lobate, fan-shaped, often with finger-shaped outgrowths, and always has a foot. These sponges can reach heights of up to 35 cm and are light gray, yellow, or yellow-orange in color (Fig. 2).

In *I. palmata*, the first observable signs of illness were small pink-orange necrotic areas, contrasting with the surrounding healthy yellow-orange ectosome. In the next stage of the disease, necrosis resulted in reductions in living tissue volume, where the tissue contracted to central skeletal fibers, leaving subdermal gaps between the skeletal fibers. The dead sponge was a naked skeleton.

The body of *H. sitiens* is cushion-shaped, lumpy, and sometimes cylindrical. The presence of numerous flattened papillae on the apical surface is characteristic. Sponge dimensions vary depending on the nature of the substrate, but can range from 2 cm in height and 1 cm in diameter to 5 cm in height and up to 15 cm in diameter. The color of the sponge is usually gray or gray-yellow (Fig. 3). The papillae are semi - transparent.

Regarding *H. sitiens*, disease and necrosis were more dramatic than in *I. palmata*: the papillae lost their transparency, the dermal membrane of the papillae ceased to be expressed, and the papillae contracted in size, giving the appearance of oval bulges on the surface of the sponge. Diseased sponges gradually became covered with mucus, lost their natural color, and acquired a gelatinous consistency (Fig. 3).

Data on sponge diseases and mortality are available from various geographic regions. However, different populations of Mediterranean and Caribbean sponges were the most susceptible to disease. Further publications report on sponge diseases from other regions such as Mexico, Papua New Guinea and the Great Barrier Reef (GBR) (Luter and Webster 2017). However, we show for the first time a mass mortality event of sponges from the sub-Arctic region.

There is evidence of a high correlation between sponge diseases and environmental factors such as rising temperature and increasing agricultural/urban runoff (Luter and Webster 2017). In the Mediterranean for example, sponge mass mortality occurs during periods of abnormally high seawater temperature (Vacelet 1994; Cebrian et al. 2011; Di Camillo et al. 2013).

Our observations indicate the relationship between sea temperature anomalies and mortality events of benthic sessile invertebrates using the example of sponges occurring in the White Sea. Arctic marine ecosystems are increasingly exposed to rapid environmental change driven by accelerated warming (Hoegh-Guldberg and Bruno 2010; Overland and Wang 2013; Denisenko et al. 2019; Jørgensen et al. 2019). The benthic communities, the most diverse and the very important part of Arctic biota, are highly vulnerable and at risk of being greatly impacted by climate anomalies that reach this geographic zone (Kortsch et al. 2012). As we show, key structuring species such as the sponges of the White Sea benthic community may be undergoing exposure to thermal conditions beyond their upper thresholds, and may thus prove to be very sensitive to extreme sea temperatures.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Figure legends

Fig. 1. The percentage of sponges affected by the 2018 mass mortality events in Kandalaksha Bay of the White Sea. Axis X - the categories of damaged sponges according with the percentage of their affected surface; axis Y - percentage of affected sponges.

Fig. 2. *Isodictya palmata in situ*: (a) - healthy, (b, c, d) – different stages of necrosis, (e) - almost dead sponge with small islands of living tissue (arrowhead), (f) - dead sponge. Arrows show necrotic tissues.

Fig. 3. *Halichondria sitiens in situ*: (a) – healthy (inset – papillae), (b, c) – different stages of necrosis, (d) - almost dead sponge. Arrows show necrotic tissues.

Electronic Supplementary Material

EMS 1. Map of the investigated site in Kandalaksha Bay of the White Sea. In red: the transects.

EMS 2. Temperature in the Velikaya Salma Strait: (a) –monthly averages temperature of the period from 2005 to 2016 (http://wsbs-msu.ru/doc/view.php?ID=23); (b) – temperature in the summer of 2018.