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1       **Mass mortality event of White Sea sponges as the result of high temperature in**  
2 **summer 2018**

3  
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17  
18

19       **Abstract**

20       Although Arctic communities are very sensitive to global warming, direct evidence of the  
21 effects of high temperature on bottom communities is quite rare. A mass mortality event  
22 (MME) of sponges we observed by SCUBA diving in July and August 2018 along the coasts of  
23 Kandalaksha Bay, White Sea, sub-Arctic. This event severely affected sponges from hard-  
24 substratum communities in particular, the demosponges *Isodyctia palmata* and *Halichondria*  
25 *sitiens*. Constant and exceptionally high temperatures throughout the water column (average  
26 temperature differences of 6.5° C in July and 5.6° C in August 2018, relative to the average  
27 temperatures in previous years at a depth of 20 m) may have led to an environmental context  
28 favorable to the MME. As was observed for the thermal anomaly, mortality was limited at the  
29 depth below a thermocline. However, it is not possible to ascertain whether temperature had a  
30 direct effect on organisms or whether it acted in synergy with a latent and/or waterborne agent.  
31 However, viewed in the context of global warming, there is an urgent need to rapidly set up  
32 monitoring programs of physical-chemical parameters and vulnerable populations in benthic  
33 communities through the Arctic Basin.  
34

35           **Introduction**

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

44           One of the consequences of global warming is mass mortality events (MMEs) - the rapid,  
45 catastrophic die off of organisms. MMEs may have important ecological effects regulating  
46 population levels by impacting all size classes or developmental stages in a given population  
47 (Mangel and Tier 1994; Fey et al. 2015; Langangen et al. 2017). MMEs seem common in  
48 marine benthic ecosystems in the different regions of the world ocean (Eiane and Daase 2002;  
49 Stokstad 2014; Prada et al. 2017), but this phenomenon has been better investigated in the  
50 Mediterranean, where MMEs are associated with positive thermal anomalies (Cerrano et al.  
51 2000; Pérez et al. 2000; Romano et al. 2000; Rodolfo-Metalpa et al. 2005, 2006; Coma et al.  
52 2009; Cupido et al. 2009; Garrabou et al. 2009; Kruzic et al. 2016). The affected species are  
53 mostly long-lived sessile epibenthic invertebrates such as sponges, anthozoans, bivalves,  
54 bryozoans and ascidians. Accordingly, MMEs, occurring with the dominant species lead to  
55 significant changes in benthic communities.

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

59           It should be noted that the abnormally high water temperatures in the summer of 2018  
60 were recorded in different parts of the Kandalaksha Bay (data from the monitoring program  
61 "White Sea Hydrology and Zooplankton Time Series: Kartesh D1"). During the summer of  
62 2018 we detected for the first time in the sub-Arctic a mass mortality event affecting sponges  
63 from the White Sea. This event is the subject of this short communication.

64

65           **Material and Methods**

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

69 The observed area - Velikaya Salma, and precisely, the region of the transects – was the  
70 object of regular diving of the biologists and the divers of the WSBS. We monitored the  
71 abundance and health status of sponges and sea water temperature in summer 2018. The  
72 incidence of marine sponge mortality was surveyed by SCUBA diving in July and August  
73 2018. In general, each survey was carried out from 8.5 to 19 m of depth. The sponge's species  
74 affected were recorded, by the presence of necrosis and the temperature of the water. A total  
75 of 270 surveys were conducted, 120 by scientists and 150 by recreational divers. For the  
76 percentage of damage was calculated 125 individuals of *Isodictya palmata* and 273 ones of  
77 *Halichondria sitiens* from both transects.

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

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

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

96

## 97 **Results and Discussion**

98 The White Sea is a semi-enclosed sub-Arctic sea which occupies a long gulf south-east of  
99 the Kola Peninsula and which is joined to the Barents Sea by a strait. The White Sea covers  
100 approximately 95 000 km<sup>2</sup>. Surface waters are considerably fresher (salinity 24–26‰) than  
101 bottom waters (salinity 30–30.5 psu) (Howland et al. 1999; Pantyulin 2003). Seasonal variation  
102 of surface water temperature in the White Sea is about 20° C but bottom waters have a constant

103 temperature of about  $-1.5^{\circ}\text{C}$  (Pantyulin 2003). Average water temperatures in the top layer of  
104 water in Kandalaksha Bay measure about  $0^{\circ}\text{C}$  in winter,  $+6^{\circ}\text{C}$  by late spring, and rise to 13-  
105  $14^{\circ}\text{C}$  in early August, while remaining fairly constant (around  $0^{\circ}\text{C}$ ) at depths of over 50 m.

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

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

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

130 During June 2018, no signs of sponge disease were recorded. However, during July and  
131 August massive disease leading to necrosis and death of some sponges from the Velikaya  
132 Salma was observed. Visual observations and comparison of photographs taken in the area of  
133 transects in August of previous years and in 2018 indicate a significant decrease in the number  
134 of sponges in 2018. The majority of the affected sponges belonged to *Isodyctia palmata* (Ellis  
135 and Solander 1786) (87.2% of necrotic and dead sponges), and *Halichondria (Eumastia) sitiens*  
136 (Schmidt 1870) (34.5% of necrotic and dead sponges) (Fig. 1). Among others damaged sponges

137 we detected only demosponges *Haliclona (Gellius) fibulata* (Schmidt 1862) and *Haliclona*  
138 *gracilis* (Miklucho-Maclay 1870), but we find only some necrotic individuals.

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

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

145 Both damaged species are distributed throughout the North-Atlantic and Arctic regions  
146 (Ereskovsky 1994, 2010). In the White Sea, *Isodyctia palmata* lives at depths ranging from 8 to  
147 59 m, at the average temperature between -1.3°C to + 16.5°C, inhabits areas with strong  
148 current, and develops mainly on stones. *Halichondria sitiens* was recorded at depths ranging  
149 from 2.5 to 110 m, at the average temperature between - 1.7°C to + 15°C, and on all types of  
150 substrate. However, both species are found primarily in areas with high hydrodynamics.

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

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

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

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

169 Data on sponge diseases and mortality are available from various geographic regions.  
170 However, different populations of Mediterranean and Caribbean sponges were the most

171 susceptible to disease. Further publications report on sponge diseases from other regions such  
172 as Mexico, Papua New Guinea and the Great Barrier Reef (GBR) (Luter and Webster 2017).  
173 However, we show for the first time a mass mortality event of sponges from the sub-Arctic  
174 region.

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

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

189

### 190 **Conflicts of interest**

191 The authors declare that there are no conflicts of interest.

192

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198 the long-term monitoring of hydrology in the White Sea from program "White Sea Hydrology  
199 and Zooplankton Time Series: Kartesh D1".

200

201

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299

300

301 **Figure legends**

302

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

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

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

311

312

313 **Electronic Supplementary Material**

314

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

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

320

321