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► To cite this version:

Alexander Ereskovsky, Dmitry Ozerov, Anatoly Pantyulin, Alexander Tzetlin. Mass mortality event of White Sea sponges as the result of high temperature in summer 2018. *Polar Biology*, 2019, 42 (12), pp.2313-2318. 10.1007/s00300-019-02606-0 . hal-02379769

HAL Id: hal-02379769

<https://hal.science/hal-02379769>

Submitted on 13 Jan 2020

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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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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 km². 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°C (Pantyulin 2003). Average water temperatures in the top layer of
104 water in Kandalaksha Bay measure about 0°C in winter, $+6^{\circ}\text{C}$ by late spring, and rise to 13-
105 14°C in early August, while remaining fairly constant (around 0°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°C in July and 5.6°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 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

193 **Acknowledgements**

194 This work was supported by grants of A*MIDEX, Grant/Award Number:
195 ANR- 11- LABX- 0061; Excellence Initiative of Aix- Marseille University - A*MIDEX,
196 grant RFBR 18-05-60158, and grant PRC CNRS/RFBR n° 1077. We thank the White Sea
197 Biological Station of the Russian Academy of Sciences «Kartesh» for providing materials on
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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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