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First record of the common sun star *Crossaster papposus* (L., 1767) in the Baltic Sea in over 100 years

by

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Abstract

The rare in the German North and Baltic Sea waters and strictly protected sea star *Crossaster papposus* was found in 2019 and 2021 during monitoring activities in a marine protected area. This unique observation was achieved by using towed camera platform imagery along a transect in the Fehmarn Belt, which allows monitoring of a much larger area of the seafloor compared to traditional invasive grab and dredge sampling. The last time *C. papposus* was documented in this area was in 1871, indicating the rarity of this species in the Baltic Sea. Possible explanations for such rare records of the occurrence of this presumably native species in the study region are briefly discussed, including uncommon survival due to salinity conditions caused by prior inflows of saline water from the North Sea.

Key words: *Crossaster papposus*, Fehmarn Belt, protected species, monitoring data, underwater imaging approach

GLOSSARY

IOW - Leibniz Institute for Baltic Sea Research Warnemünde

MPA - Marine Protected Area

1. Introduction

The common sun star *Crossaster papposus* (L. 1767) is a conspicuous and distinctive species. The generic designation of this species has historically alternated between *Solaster* and *Crossaster*, both belonging to the family Solasteridae (Ringvold & Moum 2020). *Crossaster papposus* shows a wide circumboreal distribution and is recorded mainly on the continental shelf in temperate waters (Ringvold & Moum 2020), but is also found at depths ranging from the low intertidal zone to 1200 m (Clark & Downey 1992). The species is widely distributed in the Pacific, the Atlantic Ocean and occurs all around the British Isles up to the southern North Sea (Djakonov 1950; Grainger 1966; Himmelman & Dutil 1991; Harms 1993; Carlson & Pfister 1999; Gaymer et al. 2004). In the German part of the North Sea, finds of *C. papposus* come from stone reefs in the eastern German Bight, but are mainly documented for the island of Helgoland (Rachor et al. 2013). Habitat preferences vary from coarse sand or gravel to rock bottom, mussel and oyster beds (and from the infralittoral fringe down to deep circalittoral habitats). A three-year study recording sublittoral communities around Helgoland proved the occurrence of *C. papposus* in one of the eight hard bottom communities, with a prevalence of 17% at the sampled locations (de Kluijver 1991). Moreover, the species occurs sporadically in the Great and Little Belt as well as in the Kattegat (Hayward & Ryland 1990; Clark & Downey 1992; Gonschior 2016), the transition areas connecting the North Sea with the Baltic Sea. Despite increasingly intensive mapping and monitoring efforts over the last decades, as well as yearly monitoring cruises by the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) since 2009, the last observations of *C. papposus* in the German Baltic waters date from before 1900 (Zettler et al. 2018; see additional file 1).

The common sun star is nationally protected under the German Federal Ordinance on the Conservation of Species (BArtSchV). Annex 1 to BArtSchV lists native protected species of fauna and flora whose populations are threatened by human interference, and *Crossaster papposus* is classified as a strictly protected species (§1 sentence 2; BArtSchV 2005). The occurrence of *C. papposus* has been better recorded in recent decades mainly due to the use of underwater video imaging. Therefore, the species has been moved from category 1 (threatened with extinction) to category 2 (highly endangered) on the national Red List (Rachor et al. 2013).

2. Materials and methods

The observations reported in the present study were collected on 21 April 2019 and 27 June 2021 during mapping and monitoring activities prescribed by the Habitats Directive and relevant to the implementation of the Marine Strategy Framework Directive. The common sun star *C. papposus* was found in both cases at the Natura 2000 site "Fehmarn Belt" (EU-Code: DE 1332-301) in the south-western Baltic Sea (54°34.41934'N; 10°50.06339'E and 54°35.48544'N; 10°54.82932'E; Fig. 1). The area is protected under national law since 2017. However, while management plans have recently been released, no actual management measures have yet been implemented at the time of drafting this paper. The Natura 2000 site is heavily impacted by vessel traffic, and intensive bottom trawling continues in its boundary areas (BfN (Ed.) 2020).

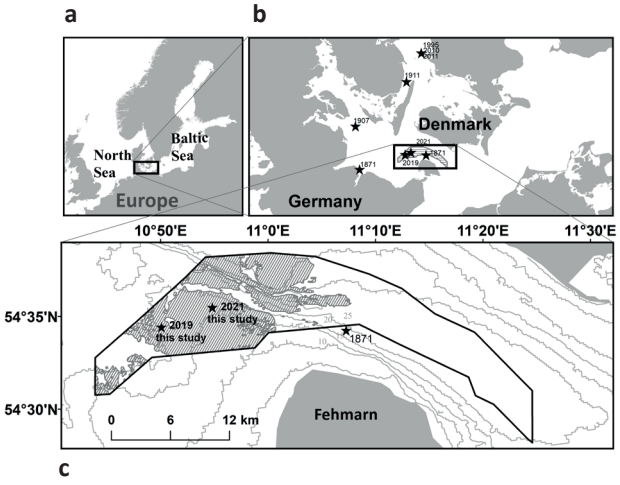

Figure 1

Location of the study area: (a) Map of Northern Europe showing the location of the "Fehmarn Belt" Marine Protected Area (MPA), (b) the MPA between Denmark and Germany, historical and recent records of *Crossaster papposus* in the area of interest, and (c) the records of *C. papposus* in the designated reef area.

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In the course of the expeditions "EMB211" and "EMB269" of the German research vessel "Elisabeth Mann Borgese", images of the seabed were recorded using a downward-facing towed camera system ("Baltic Seafloor Imaging System" as reported by Beisiegel et al. 2017). The camera system was vertically submerged over the ship's stern to its target altitude of ~1 m above the seafloor and was towed at a speed of ~0.5 knots along the transect. Four vertical parallel lasers produced laser points on the seafloor and allowed an exact image scaling. Identification of *C. papposus* was based on Southward & Campbell (2006).

3. Results

Crossaster papposus was observed twice in the area of the Fehmarn Belt through video imaging. On both occasions only one single individual was recorded. Since the specimens were not collected, taxonomic identification was based on photographs and video material. The two recorded specimens had 12 and 13 arms, a disc diameter of 6–7 cm and 3.5–4 cm, respectively, as well as the typical series of single dorsal marginals (Fig. 2). In our cases, the specimens had characteristic purplish coloration with one red and one whitish band along the arms.

Regarding abiotic factors, in 2019, one specimen was found at a depth of 16.3 m, with a near-bottom water oxygen level of 7.16 ml/l and salinity of 18.4. In 2021, the second specimen was observed at a depth of 10.9 m, with a near-bottom water oxygen level of 6.8 ml/l and salinity of 14.5. Both locations reported in this study are attributed to the so-called infaunal *Arctica* community, named after the ocean quahog (*Arctica islandica*) that dominates the biomass of the benthic macrofauna. Few shells of these bivalves are also visible in the images shown in Figure 2.

4. Discussion

The genus *Crossaster* typically features 8–15 (rarely 16) tapering arms (Lambert 1981; Clark & Downey 1992; Carlson & Pfister 1999; Southward & Campbell 2006), a moderate to large disc, and a single series of single conspicuous marginals visible in the dorsal view (Clark & Downey 1992; Ringvold & Moum 2020). Although the coloration may vary, the predominant aboral color of *Crossaster papposus* is purple-red, while arms sometimes show one or more whitish and/or dark red bands (Ringvold & Moum 2020). The appearance of the specimens from this study is fully consistent with those

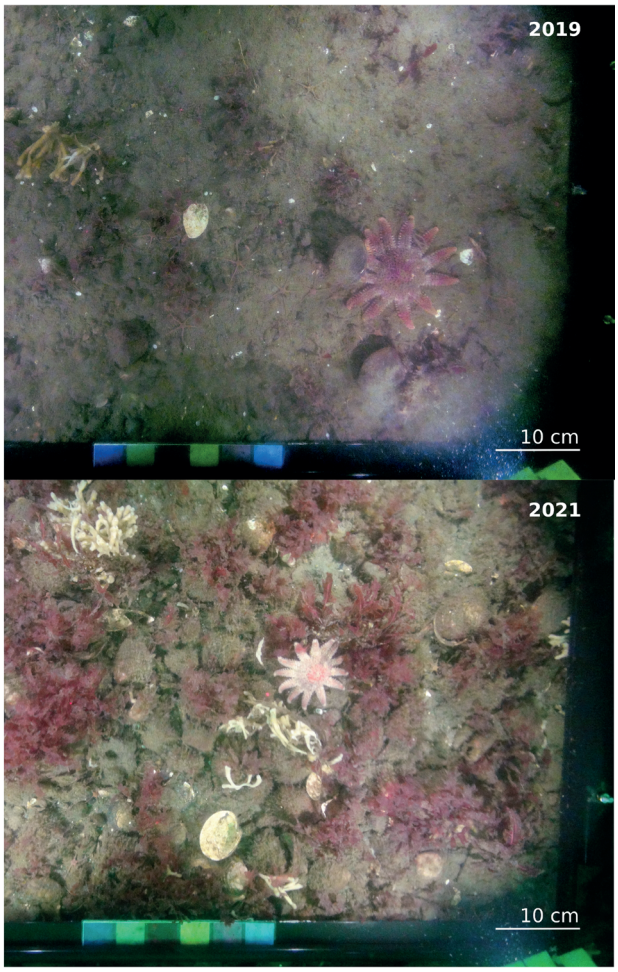

Figure 2

Top view on *Crossaster papposus* recorded with a drop camera system. The specimens were found in the "Fehmarn Belt" MPA (Baltic Sea).

descriptions, suggesting a taxonomic classification as *Crossaster papposus*. *Crossaster squamatus* is another closely related species of the genus. However, because of the purplish coloration with red and whitish bands along the arms, characteristic only of *C. papposus*, and not of *C. squamatus,* it is unlikely that the specimens found belong to the latter taxa. Furthermore, *C. squamatus* has never been recorded in the German parts of the North Sea or the Baltic Sea and results of several marine surveillance programs (MAREANO, BIOICE, BIOFAR) indicate that *C. squamatus* occurs at the shelf break in colder waters at a depth of 100 to 1600 m (Mortensen 1927; Ringvold & Moum 2020). In contrast, *C. papposus* occurs mainly at the shelf in temperate waters from a depth of 0 to 1200 m (Mortensen 1927; Clark & Downey 1992), which corresponds more closely to the prevailing conditions in the Baltic Sea and supports the taxonomic

identification of the specimens found and identified as *C. papposus*.

A seventeen-year study by Carlson and Pfister (1999) found that *Crossaster papposus* exhibits a relatively high longevity. Estimates based on growth and survival rates showed that some individuals live longer than 20 years and reach more than 20 cm in diameter (Carlson & Pfister 1999; up to 34 cm according to Wilson 2008). In our case, age estimation remains difficult due to the fact that the brackish environment of the Baltic Sea imposes stressful osmotic conditions on marine organisms, often resulting in a reduced growth rate and body size (Theede 1996).

In a suitable habitat, *C. papposus* is a highly mobile species known to be a dominant predator feeding on sea urchins, as well as on many other invertebrates, including echinoderms, bivalves, cnidarians, and tunicates (Himmelman & Dutil 1991). In the Fehmarn Belt, the substrate is dominated by patches of coarse and mixed sediments with rock outcrops, stones, cobbles and shell gravel, while fine-grained silt and mud prevail in deeper zones (Diesing & Schwarzer 2006). The area is known to be periodically and irregularly inhabited by marine species migrating actively or floating passively as adults or larvae from the Belt Sea. This pattern is triggered by aperiodic saline water inflows from the North Sea. The last extreme major Baltic inflow event occurred in 2014 (Mohrholz 2018). While, inter alia, the great spider crab *Hyas araneus* was observed in comparably high density in the year after the inflow event and is still present in the Fehmarn Belt (M.L. Zettler, IOW-benthos-database, unpublished), the occurrence of the sun star in this area is not directly linked to such an inflow event. However, in 2019, saline bottom water body with a maximum salinity over 20 was detected in the Fehmarn Belt in early February; weak barotropic inflows occurred in the Baltic Sea in March and April, also bringing saline waters from the North Sea (Naumann et al. 2020). The maximum bottom salinity of 19.3 was measured close to the study site during the EMB211 cruise farther east at a comparable depth.

The observation of *Crossaster papposus* in the Fehmarn Belt represents a very rare find in the Baltic Sea. It is the second easternmost observation ever, with only one documentation located less than 18.5 km farther east and dating back 150 years. The last known records of this species in the region were by Möbius (1873). His finds in 1871 were located close to the island of Fehmarn and in the south-western part of Kiel Bay (Bülk, Kiel Fjord). Since then, *C. papposus* was documented only from the Kattegat, and rarely from the Great and Little Belt. The most recent findings were made south of the Danish island of Anholt in 2016 (Gonschior 2016) and by the IOW in the Great Belt in 2010 and 2011 (M.L. Zettler, IOW-benthos-database, unpublished).

In addition to other factors, one major reason for the rare occurrence of *C. papposus* in the Baltic Sea may be the challenging osmotic conditions. The natural steep salinity gradient in the Baltic Sea, ranging from fully marine conditions near the narrow connection with the North Sea to almost freshwater values in the north-eastern parts (Schiewer 2008), strongly affects and limits the occurrence and distribution of species (Telesh et al. 2013; Zettler et al. 2014; Snoeijs-Leijonmalm & Andrén 2017). *Crossaster papposus* is regarded as native to the Baltic Sea (HELCOM 2020). The species has a larval stage and the potential for long-distance dispersal, but appears to favor full salinity conditions above 30 PSU, suggesting that physiological constraints are the most important factor affecting colonization in the region.

When species occur at their tolerance limits in very low densities, routine monitoring (based on point sampling once a year) cannot conclusively assess their distribution and status, therefore imaging has an obvious advantage of covering larger seafloor areas.

The amount of data collected in various sub-basins affects the number of species found, simply because the possibility of finding more species increases with the amount of data collected. Even trawling surveys that cover larger areas have not reported the occurrence of *C. papposus*, supporting the fact that the species is extremely rare. However, whether our detection of *C. papposus* in the Fehmarn Belt in 2019 and 2021 remain isolated findings needs to be proven by future monitoring efforts.

Acknowledgements

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