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Marine biology

The first records of sea star wasting disease in *Crossaster papposus* in Europe

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Sea star wasting disease (SSWD) refers to a suite of gross pathological signs observed in Asteroidea species. It presents to varying degrees as abnormal posture, epidermal ulceration, arm autotomy and eversion of viscera. We report observations of SSWD in the sunstar *Crossaster papposus*, the first observations of its kind in Europe. While the exact cause of SSWD remains unknown, studies have proposed pathogenic and environmental-stress pathways for disease outbreaks. Although the present observations do not support a precise aetiology, the presence of SSWD in a keystone predator may have wide reaching ecological and management implications.

1. Introduction

Sea star wasting disease (SSWD) is a poorly defined suite of gross observations afflicting sea stars (Echinodermata, Asteroidea) first reported in coastal seas around North America [1–4]. The condition manifests to varying degrees as abnormal posture, epidermal ulceration, arm autotomy and the eversion of viscera through the body wall that have coincided with mass mortality events in over 20 species of sea stars [4–6].

The precise aetiology of SSWD is unknown, and previously asserted pathogenic associations with a densovirus are questionable [7–10]. Furthermore, given the widespread distribution of wasting-like syndromes across multiple species of Asteroidea, it is unlikely to have a single aetiology and could refer to several conditions that may or may not be pathognomic [11–14]. However, despite the lack of precise aetiology, there is a linkage with environmental conditions which may exacerbate the progression of tissue degradation [15].

Studies have indicated a correlation of SSWD with environmental conditions such temperature and dissolved oxygen concentrations [15,16]. Some species may exhibit symptoms with exceptionally elevated temperatures (e.g. *Heliaster* kubinijI: [2]) or reduced temperatures (e.g. *Pisaster ochraceus:* [17]). SSWD symptoms have even been observed with unremarkable seasonally induced temperature fluxes [18]. There is some evidence that decreases in dissolved oxygen associated with elevated temperatures may stress the sea star and exacerbate SSWD symptoms [7]. Increases in dissolved organic matter (DOM), associated with enrichment events, may promote heterotrophic microbial growth at the asteroid–water boundary which may reduce the availability of dissolved oxygen [15]. This thesis is further supported by the susceptibility of larger more rugose species to SSWD; a bauplan that results in a lower surface area to volume ratio that restricts hydrodynamic flow and, by extension, diffusive respiratory potential, respectively [7,15]. Whatever the environmental trigger, SSWD symptoms appear to progress faster during periods of environmental instability [4,7,11,15].

While SSWD outbreaks in the northeast Pacific have attracted significant attention, the presence of asteroid wasting has been reported worldwide [11]. Menge [5] and Dungan *et al.* [2] both report on cases that predate the 2013 northeast Pacific outbreaks, with the former concerning *Asterias* spp. in the

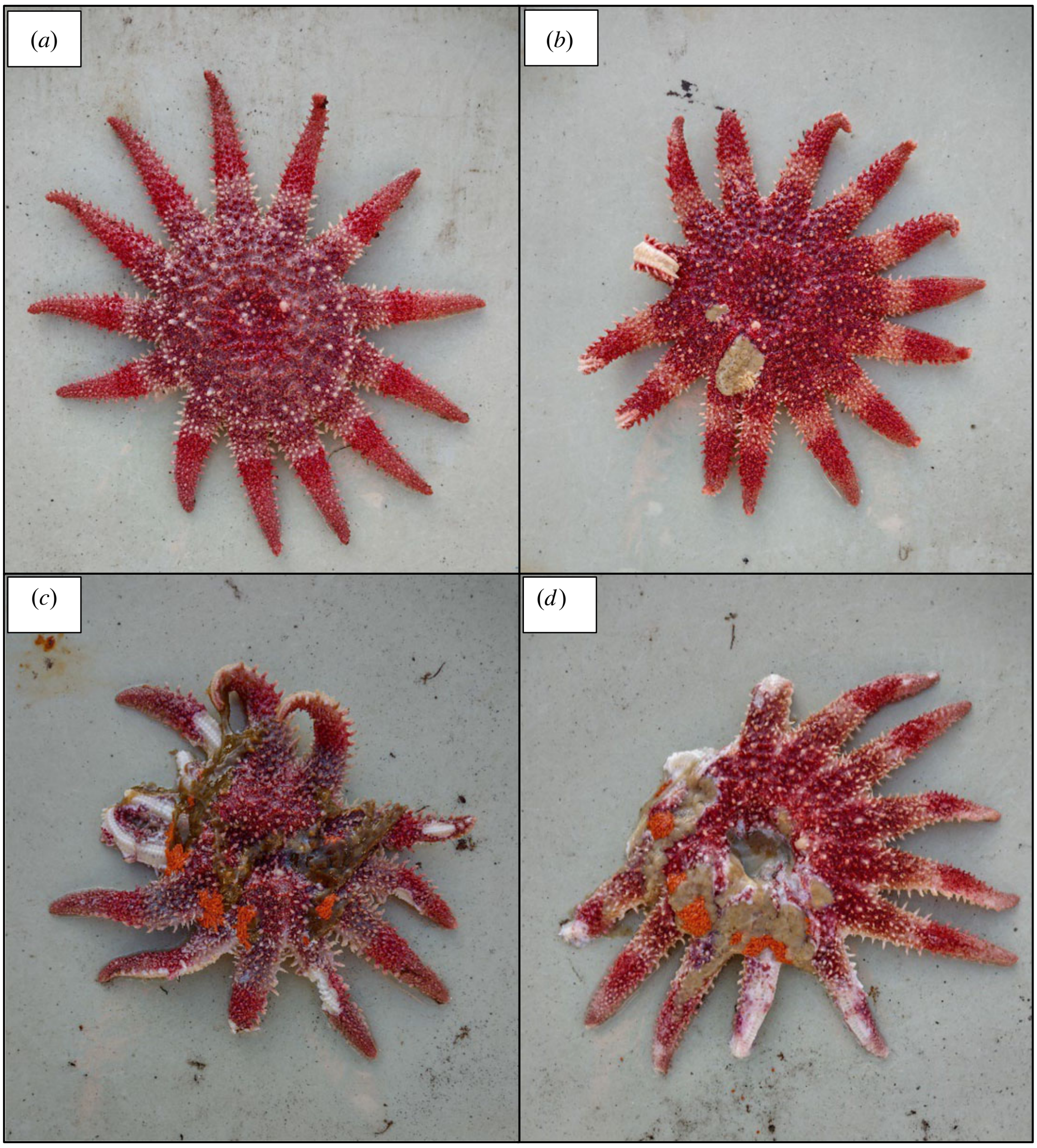

Figure 1. *Crossaster papposus* specimens displaying gross signs of SSWD. Healthy/asymptomatic individual displaying no gross signs of SSWD (*a*). Individual displaying viscera protruding from epidermis (*b*). Individual displaying viscera protruding from epidermis at multiple sites, limb degradation and contorted limbs (*c*). Individual displaying white lesions on limbs, limb degradation, viscera protruding from epidermis and gross tissue disintegration around the aboral surface of the body cavity (*d*).

North Atlantic. Further, similar signs of wasting have been reported for *Patirella vivipara* in Tasmania [12], for *Astropecten johnstoni* in Sardinia [13], and for *Acanthaster planci* on the Great Barrier Reef [19].

Reporting new cases is therefore important for understanding the geographical extent of SSWD, as well as the diversity of species that are susceptible. Here we present the first confirmed records of SSWD in a native European rugose sea star, *Crossaster papposus* (Solasteridae). We discuss these observations in relation to proposed SSWD aetiologies, and discuss the implications for European shelf sea management.

2. Material and methods

Specimens of *C. papposus* ($n = 12$) were collected on an *ad hoc* basis from crab creels from around 20–25 m depth in the Irish Sea and returned to holding tanks at Queen's University Belfast Marine Laboratory, Portaferry in March 2022. Specimens were collected for behavioural studies. All specimens presented a normal, healthy appearance and were housed individually in netted containers (L56 cm × W36 cm × H23 cm) within a covered flow through system. The entire system was supplied with UV and sand filtered seawater from the adjacent fully marine Strangford Lough. The containers included rocks to provide additional cover, and algal growth was permitted on the system's surfaces. While containers prevented contact between sunstars, water was able to flow freely between containers.

Gross signs associated with SSWD were confirmed by I. Hewson (2022, personal communication). Observations were conducted each day until day 31 after capture. Mortality resulting from disease progression was recorded, with a Kaplan–Meier survival curve produced for the month-long observation period based on time-to-death.

3. Results

Gross observations consistent with SSWD became notable in previously healthy/asymptomatic individuals (figure 1*a*) 5 days following resettlement in holding tanks. Initial gross signs displayed included white lesions appearing on the epidermis, body contortion, loss of body turgor giving the animal a 'limp' appearance when handled, however these

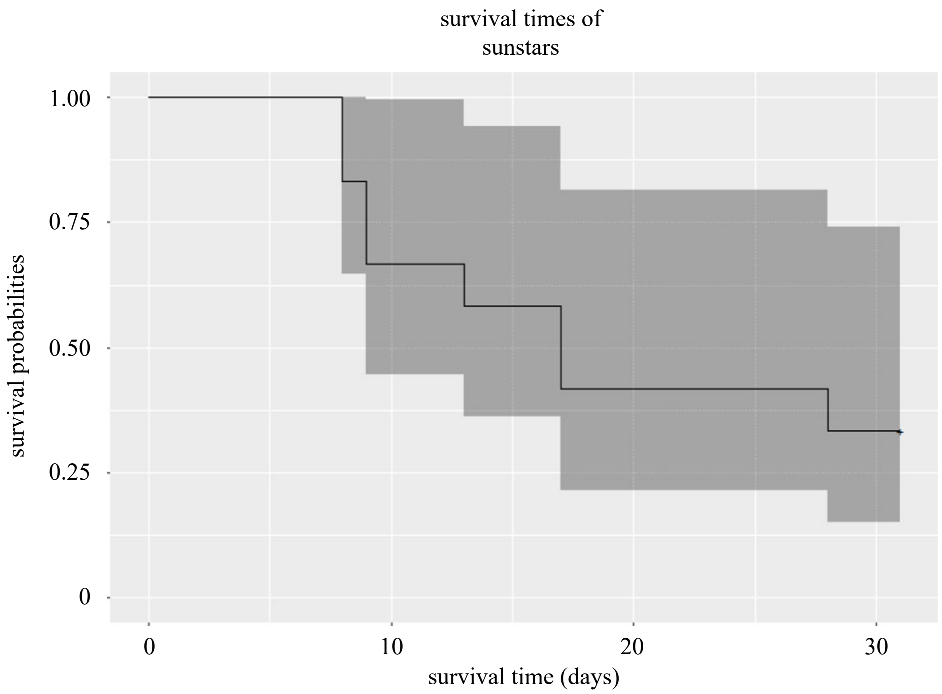

Figure 2. Kaplan–Meier survival curve for 12 *C. papposus* over a 31-day observation period since capture. Shaded area represents 95% confidence intervals.

were not consistent in all animals. Progression of the disease resulted in viscera (including pyloric caeca and gonads) protruding from epidermis (figure 1*b–d*), progressive limb degradation (figure 1*c*,*d*), and gross disintegration of the body cavity (figure 1*d*). Hydrostatic pressure in the water vascular system is seemingly maintained and tube feet may still be mobile at this point. Gross disintegration of the central disc epidermis leads to a disintegration of the stomach, resulting in an unrestricted cavity from the mouth to the aboral surface (figure 1*d*).

The survival probability of animals after 31 days was 0.333 (s.d. = 0.136; 95% CI 0.150–0.742). Four animals remained after 31 days of observation with the remaining eight having died (figure 2). In all cases of mortality, disease progression led to gross body disintegration.

4. Discussion

We report observations of the common sunstar, *C. papposus*, presenting gross signs consistent with SSWD. Previous studies have observed SSWD in *C. papposus* in the northeast Pacific (I. Hewson 2022, personal communication) with the larger size and more rugose epidermis suggesting susceptibility (*sensu* [7]). These findings represent the first case of SSWD in any asteroid in Europe. However, previous recordings of mass die-offs of asteroids in European waters (e.g. *Astropecten jonstoni*; [13]) may suggest that SSWD is underreported. Indeed, Staehli's [13] experimental work and anecdotal observations highlight symptoms mirroring SSWD related to elevated temperatures. In these cases, gross observations reported white lesions appearing on the epidermis, followed by a loss of turgor and large blisters forming on the aboral side, eversion of pyloric glands and rapid full body disintegration, all of which are symptoms for SSWD (*sensu* [1–4]).

With previous observations of wasting-like disease being associated with elevated temperatures, and the present observations mirroring their appearance and progression [13], it may be that the cases reported here are also linked to temperature fluctuation. While this would further associate SSWD with environmental fluxes, and highlights a thermally induced condition [13,16,17], a pathogenic aetiology cannot be ruled out. Disentangling environmental stressors from a pathogenic aetiology remains challenging. It is additionally possible that SSWD associated with thermal fluxes may push epidermal pathogens towards their thermal optima within host individuals and decrease immune responses [2,11,13,18,20].

Asteroids appear to present a limited suite of disease signs, and thus gross observations may never be consistent with a single aetiology [15]. Wasting signs may present following periods of stress, i.e. capture and transportation, and as such this cause cannot be ruled out. Field observations would therefore be necessary to confirm the wider prevalence of SSWD.

Supporting the pathogenic aetiology of SSWD, Fuess *et al.* [21] report on signs presented in the sunflower sea star *Pycnopodia helianthoides*. Following homogenate inoculation from symptomatic individuals, wasting signs in previously healthy individuals appeared in all subjects, suggesting disease transmissibility. Further RNA-sequence analysis highlighted differential immune system gene expression in control versus inoculated animals. As *C. papposus* was housed in netted containers that did not restrict waterflow between individuals, the potential for transmissibility was not prevented in the present study.

Corresponding with the period of capture, provisional UK Met Office statistics reported an elevated temperature anomaly of 1.7°C for late March 2022, along with a 90% increase in sunshine hours in Northern Ireland [22]. High atmospheric pressure led to unseasonably warm weather [23]; however, targeted research would be needed to demonstrate whether environmental fluxes are correlated to SSWD prevalence in European *C. papposus*.

Nevertheless, the possibility of thermal association of SSWD in European waters is concerning given projected climate change scenarios with more extreme weather events [24]. An increase in seabed temperature fluxes, and the compounding effects of increased primary production and higher DOM concentrations [7,15], may lead to large SSWD outbreaks in larger more rugose asteroids. As a subtidal sea star [25–27], mass mortality events in *C. papposus* may have gone undetected.

Many sea stars act as keystone predators responsible for regulating benthic invertebrate communities [28–31]. *Crossaster papposus* itself is an important predator of other echinoderms, including the swarm-forming asteroid *Asterias rubens* [32–34]. An increase in conditions supporting SSWD outbreaks may have management implications for benthic communities [11,17], the consequences of which will impact ecosystem service provisioning [35].

The observations reported in this article provide the first gross observations consistent with SSWD in the sunstar *C. papposus* in Europe. While the exact aetiology of SSWD is unknown, its prevalence is thought to be linked to rapid environmental fluxes. These findings demonstrate the susceptibility of *C. papposus* to SSWD and suggest that SSWD is more geographically widespread than initially thought. Further research is needed to fully quantify the extent of SSWD in this region; subtidal surveys and observations of actively wasting asteroids would further support the presence of SSWD in European Waters. This finding would be highly significant as many sea stars act as keystone species in their respective communities. With increasing frequency of temperature anomalies, targeted research into the mechanisms of SSWD outbreak and disease progression will be needed to outline its full extent and wider implications.

Ethics. The observations presented in this article follow the ethical guidelines of Queen's University Belfast.

Data accessibility. Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.zgmsbccf7 [36].

Authors' contributions. S.S.: conceptualization, data curation, investigation, methodology, project administration, writing—original draft, writing—review and editing; I.H.: visualization, writing—review and editing; P.C.: project administration, resources, supervision, writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

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