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ON THE SWARMING OF *CRESEIS ACICULA* (RANG 1828) (MOLLUSCA, GASTROPODA) IN THE WESTERN ARABIAN GULF

SUMMARY

An incidental swarming event of a zooplankton species took place in the anchorage area of Ras Tanura (Western Arabian Gulf), between June 10th and 13th 2020, causing serious problems to the anchored vessels. Examination of the samples collected from the clogged water pump of a vessel showed that the swarming was caused by the gastropod species *Creseis acicula*. Incidentally, it happens to be the first documented report on planktonic Gastropoda swarming in the Saudi waters of the Arabian Gulf. The swarming lasted only 2-3 days. Examination of the satellite images before, during, and after the swarming event indicated some changes in the color patterns of Ras Tanura surface waters, which could be linked to the swarm event. Due to bad weather conditions during and after the swarm period, it was not possible to collect seawater samples from the anchorage area and hence it was not possible to confirm whether this event could be linked with an algal or cyanobacterial bloom, as previously reported in another area of the Indian Ocean. Although most of the studies that reported *C. acicula* swarming indicated that this phenomenon is a natural one rather than being caused by external factors, some general precautionary/mitigation measures were proposed. Further studies and field observations are needed to better understand the causes of sea slug swarming and to avoid the issues it can cause to vessels, as it happened in the Western Arabian Gulf.

INTRODUCTION

Worldwide oceans have recognized, along the past decades, numerous and various blooms of many plankton species, with serious environmental and economic consequences (Dai *et al*., 2020). For instance, most of the blooms reported in the literature were caused by Cyanobacteria, Dinophyta, and Crustacea (Glibert *et al*., 2008, 2009; Smetacek and Zingone 2013; Sun *et al*., 2015; Huisman *et al*., 2018; Wang *et al*., 2019; Zeng *et al*., 2019). While the blooms of some marine species are quite known to be induced by certain environmental conditions such as eutrophication and other anthropogenic factors (Anderson *et al*., 2002; Edwards *et al*., 2006; Heisler *et al*., 2008), many other blooms remain unexplainable, as the biology and ecology of the species causing them are still not yet recognized. This is for example the case of the Pteropoda whose swarms are among the less studied.

Like many other groups of zooplankton, Pteropoda play a crucial role in the marine trophic chains. These animals are known to often form dense aggregations and represent preys for many marine fish species, sea birds and cetaceans (Conover and Lalli, 1972; Larson and Harbison, 1989; Kacprzak *et al*., 2017). While the highest number of Pteropoda species was reported in tropical regions, their highest abundances were recorded in cooler regions (van der Spoel, 1976; Lalli and Gilmer 1989; Comeau *et al*. 2009; Howard *et al*. 2011). Compared to the other groups of Mollusca, Pteropoda have received so far scant attention from marine scientists, and the studies on the biology and ecology of this taxon remain very limited and even inexistent (Kacprzak *et al*., 2017). To our knowledge, most of the studies conducted on Pteropoda were conducted on species belonging to the sub-orders of Thecosomata and Gymnosomata (Kacprzak *et al*., 2017). These two clades have a variety of food preferences and play different roles in the marine ecosystems (Gilmer and Harbison 1986, 1991; Lalli and Gilmer 1989; Bernard *et al*., 2009).

Some of the Pteropoda are known to swarm and form very dense aggregations in the coastal areas, but the factors enhancing these swarming events are not yet well defined and recognized. This is mainly because the swarms do not often last for long times and also because no comprehensive field investigations can be conducted at the time of detecting them. This is for example the case of the species *Creseis acicula* (Rang 1828), which has a worldwide distribution, across the temperate, tropical, and subtropical regions. Its blooms were reported so far in the Mediterranean Sea (Burgi and Devos, 1962; Albergoni, 1975; Kokelj *et al*., 1994), Indian Ocean (Krishnamurthy, 1967; Sakthivel and Haridas, 1974; Peter and Paulinose, 1978; Pillai and Rodrigo, 1984; Naomi, 1988), Japan Sea (Nishimura, 1965; Morioka, 1980), and Gulf of Mexico (Hutton, 1960). To our knowledge, the most recent swarms of *C. acicula* were reported in November 2016, in the Red Sea (Lindemann *et* *al.*, 2019) and in mid-June 2020 in South China Sea (Dai *et al.*, 2020). In the same period of this last swarming event (mid-June 2020), another *C. acicula* swarm was recorded close to the port of Ras Tanura, along the Saudi coast in the Arabian Gulf, causing serious problems for the anchored ships. This paper describes this first Pteropoda swarming reported in the Arabian Gulf and aims to identify the potential factors behind it. The information given in this manuscript may serve as a baseline for future studies on *C. acicula* swarming.

MATERIAL AND METHODS

An incidental swarming event of an unknown marine species was reported on June 14th, 2020. The swarming event took place in the coastal anchorage area of Ras Tanura Terminal (N26°38′66.03″ E50°10′57.79″; Fig. 1), during 11 - 13 June 2020, causing serious problems to the anchored vessels (clogging strainers and accumulating in piping; see Fig. 2). The swarming was noticed in the above location (Fig. 1) over an area of 2 NM radius off Ras

Fig. 1. Location of the swarming area of *Creseis acicula* in the coastal anchorage area of Ras Tanura (Saudi Arabia, Western Arabian Gulf).

Tanura. Based on the photos of the clogged filters of vessels' water pumps, it was deduced that the density of this marine species in the seawater was very high, and the bloom caused a greyish yellow color (Fig. 2). On June 15th, 2020, a sample of the swarming species was collected from the clogged filter of one of the anchored vessels in Ras Tanura. In the laboratory, the sample was examined in order to identify the species, investigate its biology/ecology, and try to define the potential causes behind its extensive reproduction in this area. In parallel, we examined the satellite images covering the period before, during, and after the swarming event, in order to check if there were any changes in the color patterns of the coastal surface waters of Ras Tanura that may be linked to this event. The satellite images from Sentinel-2 (the optical fine spatial resolution free access satellite of the European Space Agency (ESA), which can provide systematic global acquisitions of fine spatial resolution multispectral images with a fine revisit frequency) were used to validate the presence or absence of the swarming event during the reported period. The free access images of Sentinel-2 due to their high resolution for regional water bodies' mapping, gave admirable support to the findings.

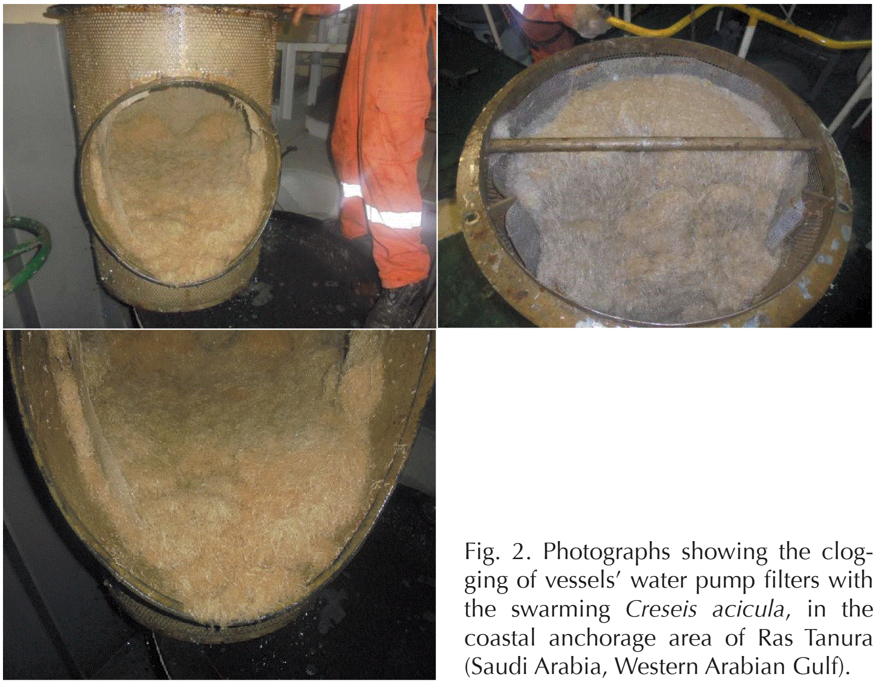

Fig. 2. Photographs showing the clogging of vessels' water pump filters with the swarming *Creseis acicula*, in the coastal anchorage area of Ras Tanura (Saudi Arabia, Western Arabian Gulf).

RESULTS

Based on the microscopic observations of the sample and the literature survey we conducted, the collected specimens were found to correspond to the species *Creseis acicula* (Rang, 1828). This mollusc species belongs to the class Gastropoda and order Pteropoda. Fig. 3 (a-d) shows the ocular and microscopic views of the specimens. The specimens are long, slender, conical and have needle-like shells. Their shells, having a smooth surface with round cross section, measured 2-3 mm. The visceral mass in almost all the examined specimens were absent, although parts of the soft tissues were barely apparent through the transparent shells (Fig. 3c). This is most likely due to the fact that the sample we received was not fresh and was not appropriately preserved after sampling. In addition, the sample was not taken directly from the water column, but from the clogged filter of a vessel water pump, and it might be possible that the filtered sea slugs were damaged during the filtration process. This could be confirmed with the cracks observed in the shells of most of the specimens examined.

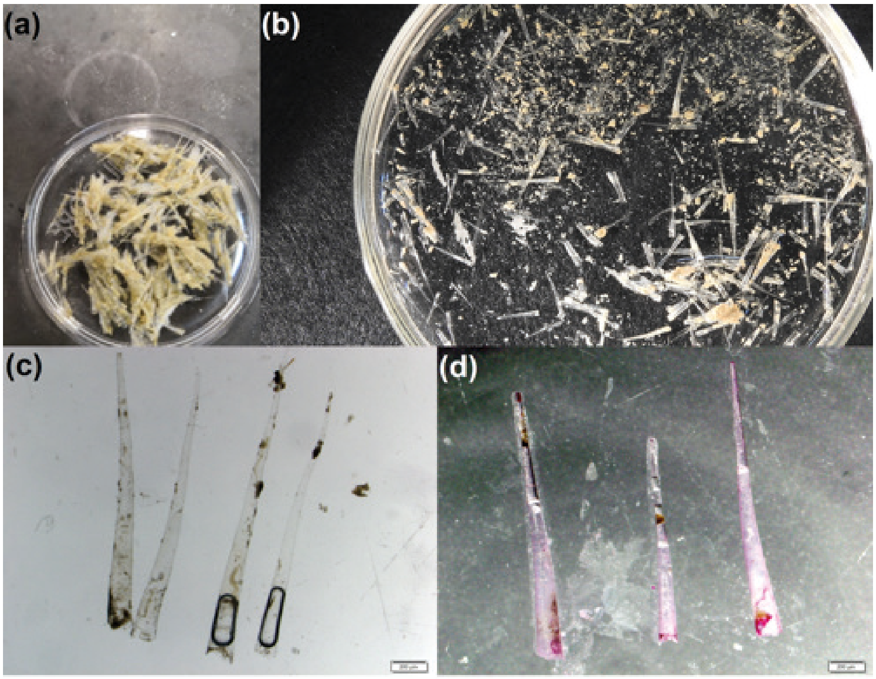

Fig. 3. Photographs of *Creseis acicula*. Nacked eye (a) and microscopic (b) observations of a sample patch of Pteropoda. Microscopic observations of few *Creseis acicula* specimens (c) without staining and (d) after staining with Rose Bengal.

The nature and extent of the Pteropoda swarming in Ras Tanura were assessed using the images of Sentinel-2 satellite, from European Space Agency (ESA). NDWI (Normalize difference Water Index) and false color satellite images were compared in order to detect the swarm effects. Normalized Difference Water Index (NDWI) may refer to one of at least two remote sensingderived indexes, related to liquid water used to monitor changes in water content of leaves, using near-infrared (NIR) and short-wave infrared (SWIR) wave lengths. Being one of the most common datasets in Sentinel-2, the latter index was used to calculate the bands in relation to the region. False color images are a representation of a multispectral image produced using any bands other than visible red, green, and blue as the red, green and blue components of the display. False color composites allow to visualize wavelengths that the human eye cannot see (i.e., near-infrared and beyond). Using bands such as near infrared highlights the spectral differences and often increases the interpretability of the data. The false color composite of the Sentinel-2 images is based on combination of 8, 4, and 3 bands, at 10 m resolution. False Color band combination and NDWI for the different days of observation are shown in Figs 4 and 5. It can be seen in Fig. 4 that there was no occurrence of swarming events (blooms) on May 24th, 2020, and June 3rd, 2020. A type of bloom (ex: swarm or others) can be observed on June 11th, 2020 (Fig. 4).

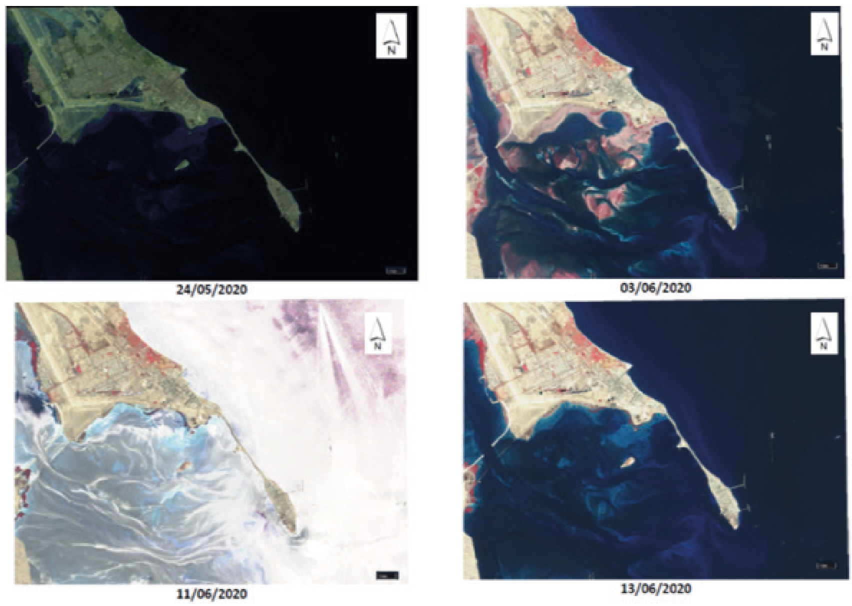

Fig. 4. False color composite of the Sentinel-2 images, based on 8, 4, and 3 bands, at 10 m resolution, taken at four different dates (May 24th, June 3rd, June 11th, and June 13th, 2020).

Fig. 5 shows the satellite images produced using Normalize Difference Water Index, which uses the original green and NIR bands, and we could observe clear offshore seawater as blue which indicated the absence of swarming on May 24th, June 3rd, and June 13th, 2020. In contrast, a bloom was suspected to have appeared on June 11th, 2020. This white color could represent the bloom reflection. On the other hand, seawater color was observed as dark after two days, on June 13th, 2020, which indicated the normal seawater color. All these analyses could be detailed using other indexes and comparing with other satellite images in order to have more accurate assessment of the bloom.

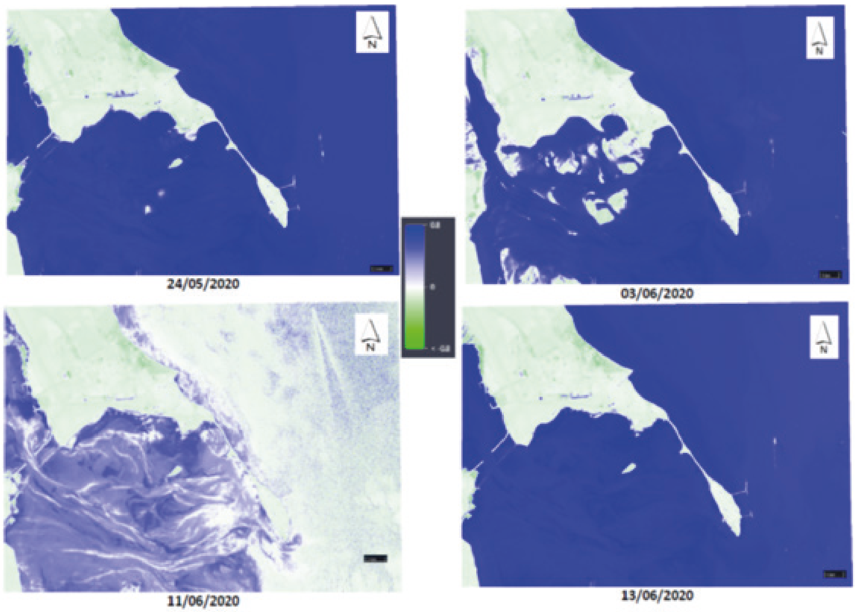

Fig. 5. Normalize Difference Water Index for Sentinel -2 images, taken at four different dates (May 24th, June 3rd, June 11th, and June 13th, 2020).

DISCUSSION AND CONCLUSIONS

Pteropoda are widely distributed and abundant in all the tropical and subtropical oceans. *Creseis acicula* is a holoplanktonic species occurring in the Indo-Pacific Ocean, Western Atlantic Ocean, and Mediterranean Sea. The species has a continuous distribution in the warm waters, and is abundantly found in the Arabian Sea, Bay of Bengal, Red Sea, and Mediterranean Sea (Peter and Paulinose, 1978; Reiss *et al.*, 1980; Goswami, 1983). *Creseis acicula* has a very broad environmental tolerance and can be abundant in different marine areas with temperatures and salinities ranging between 26 and 33 °C, and 35.5 and 45 PSU, respectively (Rottman, 1980; Goswami, 1983; Pillai and Rodrigo, 1984). Pteropoda are proterandric hermaphrodites which feed on phytoplankton and Protozoa available in the water column (Pillai and Rodrigo, 1984).

Most on the reports on *C. acicula* swarming have not indicated potential factors for the swarm (Nishimura, 1965; Peter and Paulinose, 1978; Lindmann *et al*., 2019). It was believed that the *C. acicula* swarming happens due to the natural process occasionally or seasonally depending on the prevailing physicochemical conditions. Tab. 1 summarizes the swarming events of *Creseis acicula* which have been reported from different regions around the globe.

Tab. 1. List of swarming events of *Creseis acicula* reported in different regions around the globe, and their potential causes.

Year	**Region (Country)**	**Potential Cause**	**Reference**
1936	Madras coast (India)	Unknown	Aiyar (1936)
1940	Krusadai Island (India)	Unknown	Chacko (1950)
1945	Trivandrum coast (India)	Unknown	Menon (1945)
1959	Niigata coast (Japan)	Unknown	Nishimura (1965)
1959	St. Petersburg, Florida (USA)	Unknown	Hutton (1960)
1964	Hamasaka coast (Japan)	Unknown	Nishimura (1965)
1968	Inshore waters off Bombay (India)	Unknown	Pillai (1968)
1973	Inshore waters off Cochin (India)	*Trichodesmium erythraeum* bloom	Sakthivel and Haridas (1974)
1977	Bay of Bengal (India)	Unknown	Peter and Paulinose (1978)
1980	Palk Bay (India)	Unknown	Pillai and Rodrigo (1984)
2016	Coral reefs of Eilat (Red Sea, Israel)	Unknown	Lindmann *et al*. (2019)
2020	Daya Bay (South China Sea, China)	Sharp increase of temperature and chlorophyll a and an abrupt decrease of salinity attributed to heavy rainfall that lasted for more than 20 days	Dai et al. (2020)
2020	Ras Tanura (Arabian Gulf, Saudi Arabia)	Unknown	Present work

However, few works have indicated that the swarm was possibly correlated with phytoplankton blooms. For example, the swarming event documented by Sakthivel and Haridas (1974) along the inshore waters off Cochin (India) was synchronized with *Trichodesmium erythraeum* bloom. The authors reported that the sampling net was entirely clogged with *C. acicula*, and their removal from the net meshes was very difficult. In the Bay of Bengal, the swarming of *C. acicula* was reported to be seasonal and associated with high zooplankton production (Peter and Paulinose, 1978). In the same sense, Mileykovsky (1970) reported that juvenile Gymnosomata feed on phytoplankton and very small suspensions, which results in their aggregations in more fertile coastal waters. In Vellar estuary (India), Krishnamurthy (1967) reported the highest abundance of Pteropoda during the rainy season, a period characterized with deceased water temperature and salinity. Similar observations were also reported by Dai *et al*. (2020) who linked the 2020 *C. acicula* swarm event to a sharp increase of temperature and chlorophyll *a* and an abrupt decrease of salinity attributed to heavy rainfall that lasted for more than 20 days.

Creseis acicula swarming events are not yet well understood. In fact, the knowledge gap about the biology and ecology of this species makes it unclear why and when it swarms. In the case of the swarming event, reported recently in western Arabian Gulf, it was not possible to collect samples from the swarming area and during the swarming event. Thus, it was not possible to identify the potential reasons for sea slug swarming in this area. The satellite images showed that there were some changes in the color patterns of the seawater surface in Ras Tanura during the swarming event, leading to hypothesize that an algal bloom might have induced *Creseis acicula* swarming. The limited information we got from our examination of the incidental swarm event of Pteropoda in Ras Tanura do not allow us to propose specific measures to mitigate the effects of this phenomenon.

Sudden changes in water quality due to coastal or offshore discharges may lead to phytoplankton and zooplankton blooms. As reported in some cases shown in Tab. 1, plankton blooms may lead to *Creseis acicula* swarming events. Therefore, as a precautionary action, the following general mitigation measures should be implemented to avoid the blooming of marine organisms such as *Creseis acicula:*

- While in port, discharges from the vessels should adhere to the nationally and internationally adopted Standards.
- All offshore discharges should be conducted according to the discharge permit requirements and maintain the Marine Sanitary Device in operating conditions.
- Seawater quality monitoring should be conducted at regular intervals inside the ports and terminals to assess the compliance status.

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