

Rapid Communication

Spread of the non-indigenous serpulid *Hydroides sanctaecrucis* Krøyer in Mörch, 1863 in the Pacific Ocean: a new record from Taiwan

Jasmine Ferrario^{1,*} and Dan Minchin^{2,3}¹Department of Earth and Environmental Sciences, University of Pavia, Via S. Epifanio 14, 27100 Pavia, Italy²Marine Science and Technology Centre, Klaipeda University, 84 Manto, Klaipeda, Lithuania³Marine Organism Investigation, Marina Village, Ballina, Killaloe, Co Clare, IrelandE-mail addresses: jasmine.ferrario@unipv.it (JF), moireland@yahoo.ie (DM)

*Corresponding author

Received: 10 October 2016 / Accepted: 6 December 2016 / Published online: 9 January 2017

Handling editor: Kestutis Arbaciauskas

Abstract

The serpulid polychaete *Hydroides sanctaecrucis* Krøyer in Mörch, 1863, native to the Caribbean, was found in the Port of Kaohsiung, Taiwan, and this currently represents the most northern record within the western Pacific Ocean. It was found associated with the invasive dreissenid bivalve *Mytilopsis sallei* (Récluz, 1849), also native to the Caribbean. It is likely that the spread of this serpulid within the Pacific Ocean has been due to vessel hull fouling, and the extensive shell surfaces of *M. sallei* in the estuarine regions of the port have provided suitable surfaces for its settlement. Here we review the occurrence of *H. sanctaecrucis* within the Pacific Ocean. It is expected to spread to other ports in the western Pacific Ocean.

Key words: fouling, introduced species, serpulid, shipping, South China Sea, hull

Introduction

Calcareous tubeworms (Serpulidae, Annelida) are important colonizers of hard substrates in marine benthic environments and they also foul anthropogenic structures. The genus *Hydroides* Gunnerus, 1768 is widely distributed world-wide, mostly occurring within tropical and sub-tropical environments (Zibrowius 1971; Kupriyanova and Badyaev 1998). *Hydroides* is the largest serpulid genus with over 100 species (ten Hove and Kupriyanova 2009; Pillai 2009; Sun et al. 2015, 2016; Tovar-Hernández et al. 2016). Some species within the *Hydroides* genus are capable of fouling ship hulls (Visscher 1927; Zibrowius 1971; Bastida-Zavala and ten Hove 2003; Lewis et al. 2006) and other artificial substrates (Sun et al. 2012a, 2015). Within the Indo-Pacific regions, *Hydroides dirampha* Mörch, 1863, *Hydroides elegans* (Haswell, 1883) and *Hydroides sanctaecrucis* Krøyer in Mörch, 1863 are examples of aggressive fouler serpulids that have rapidly spread to many areas (Sun et al. 2015). *Hydroides dirampha* and *H. elegans* are common fouling species found in harbours and

on ship's hulls, with *H. elegans* being dominant in tropical-subtropical harbours and in artificially heated waters (ten Hove 1974). The invasion history of *H. dirampha* and *H. elegans* dates back to the twentieth century (Zibrowius 1971, 1973), whereas *H. sanctaecrucis* has only recently been recognised as having invasive characteristics (Lewis et al. 2006; Sun et al. 2015). *Hydroides sanctaecrucis* is native to the Caribbean, occurring within coastal lagoons and estuarine regions from the southern coasts of Florida to Brazil. It is known to have arrived in the Pacific Ocean since the early nineteen-seventies (Bastida-Zavala and ten Hove 2002), most likely having been carried there via the Panama Canal following an increase in shipping transits in this direction (Ruiz et al. 2006). There are fifty-one possible species carried in this direction from the North-West Atlantic, including *H. sanctaecrucis* (Cohen 2006); however, since this time there have been further new records within the Pacific Ocean. We review the Pacific occurrence of *H. sanctaecrucis* and report a new record from the semi-tropical Port of Kaohsiung, in the South China Sea.

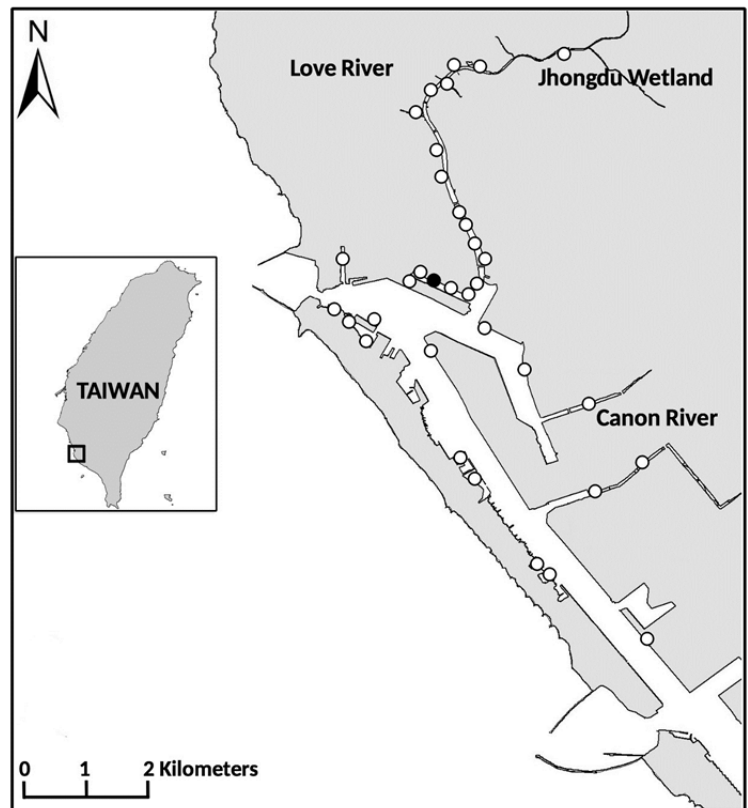


Figure 1. Study area of the targeted bivalve monitoring programme, with open circles indicating the thirty-four stations investigated. The black dot indicates the station where serpulids and bryozoans were collected.

Methods

The Port of Kaohsiung, Taiwan, extends over a coastline length of ca. 11 km. It has two entrances and is protected by a modified and linear sand bar, now also part of the port (Figure 1). This study is part of a wider targeted bivalve monitoring programme carried out in thirty-four stations throughout the Port of Kaohsiung and within the three canalised rivers draining into the port (Minchin et al. 2016a). The study took place over a three-day period in November of 2015. Sampling was restricted to quaysides with public access. We examined immersed ropes with fouled sections below the lowest water level. Serpulids were common at most of the stations surveyed and a small sample was collected at a single station close to the Love River entrance.

The sample, preserved in ethanol, was examined in the laboratory under a stereoscope and specimens were photographed with an AXIO CAM 55 ERc5s camera. The taxonomic revisions of Sun et al. (2012a, 2015) were followed for serpulid identification, using the ornament of the operculum as the main diagnostic feature.

Results

Both *Hydroides elegans* and *Hydroides sanctaecrucis* were associated with the abundant non-indigenous black striped mussel: *Mytilopsis sallei* (Récluz, 1849; Figure 2A, B). *Hydroides sanctaecrucis* was distinguished from the congeneric species through the ornament of the operculum. The opercular verticil has elongated spines of similar height with pointed tips curving ventrally; midway along each spine length there is a single small external spinule curved downwards (Figure 2C). *Hydroides sanctaecrucis* was easily distinguished from *H. elegans* which has fused spines of the verticil to half-way along its length, with lateral and internal spines. *Hydroides sanctaecrucis* was also distinguished from *Hydroides dianthus* (Verrill, 1873), another invasive species recently found in Japan (Link et al. 2009; Otani and Yamanishi 2010) and China (Sun and Yang 2000), on account of the presence of the external spinule.

Hydroides sanctaecrucis was found associated with other species attached to artificial surfaces, consistent with most other findings of the species in the Pacific Ocean (Supplementary material Table S1; Figure 3).

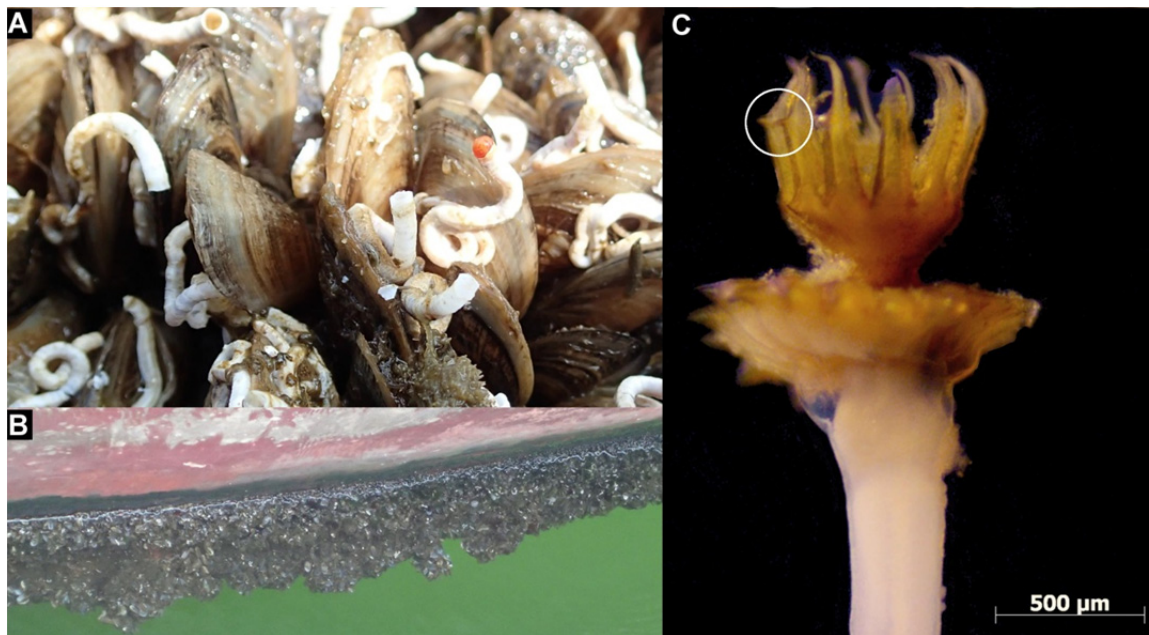


Figure 2. (A) Reef of *Mytilopsis sallei* colonized by *Hydroides* spp. in Kaohsiung Port; (B) serpulids attached to *Mytilopsis sallei* on the hull of a ship moored in Kaohsiung Port; (C) *Hydroides sanctaecrucis* operculum. The circle indicates the external spinule. Photographs A and B by Dan Minchin; photograph C by Jasmine Ferrario.

In addition to serpulids, the epifaunal organisms associated with *M. sallei* were also analysed. The most commonly observed species were: *Amathia* cf. *gracilis* (Leidy, 1855), *Amathia verticillata* (delle Chiaje, 1822) (Minchin et al. 2016b), *Amphibalanus reticulatus* (Utinomi, 1967), *Brachidontes variabilis* (Krauss, 1848), *Bugula neritina* (Linnaeus, 1758), *Hiatella arctica* (Linnaeus, 1767), and *Savignyella lafontii* (Audouin, 1826).

Discussion

Two *Hydroides* species were found associated with the black striped mussel *Mytilopsis sallei* in the Port of Kaoshiung. Both *Hydroides sanctaecrucis* and *Hydroides elegans* have been confused with each other in the past (Lewis et al. 2006), but with microscopic examination of the verticil of the operculum, they can be easily distinguished. In the field, these *Hydroides* species look alike, and it was only when voucher specimens were examined that *H. sanctaecrucis* was revealed. While there were many stations with *Hydroides* species present within the Port of Kaoshiung, the specimen of *H. sanctaecrucis* was found amongst a selection of *Hydroides* spp. collected where the Love River discharges into the port. On account of the single sample, we have no indication as to the relative abundance or extent

of either species in the port. In this region, *Hydroides* species were common and locally abundant attached to ropes, quay walls, and vessel hulls (Figure 2B). The finding of *H. sanctaecrucis* in Kaohsiung Port represents the first record of this serpulid from Taiwanese waters. Furthermore, Taiwan represents the northernmost record of *H. sanctaecrucis* in the western Pacific Ocean.

The fouling species assemblage observed with *M. sallei* was made up of cosmopolitan and widespread species (e.g., *Amphibalanus reticulatus*, *Bugula neritina*, *Hiatella arctica*), as well as non-indigenous species (e.g., *Amathia verticillata* and *H. elegans*). *Mytilopsis sallei* is an opportunistic species able to change the macrofaunal community and can facilitate the introduction of its associated fauna by providing a new habitat (Cai et al. 2014), this could be the case of *H. sanctaecrucis* in Kaohsiung Port.

Mytilopsis sallei and *H. sanctaecrucis* have the same Caribbean origin and are likely to have entered the Pacific Ocean via the Panama Canal, with *M. sallei* having been found in the drained locks at either end of this canal (Cohen 2006). In Asia, *M. sallei* may be locally dominant in sheltered and estuarine environments. The first record of *M. sallei* within Taiwan was from a lagoon just south of the Port of Kaoshiung, recorded in 1977 (Chang 1985). All indications are that both species would have been

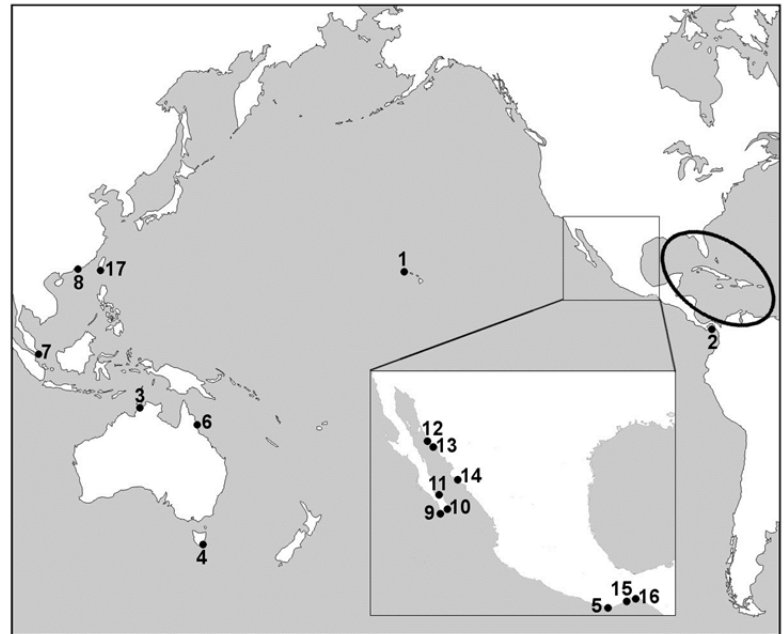


Figure 3. Invaded Pacific range of *Hydroides sanctaerucis*. Numbers correspond to first introduction records listed in Supplementary material Table S1; the circle approximately indicates the native range.

distributed either by hull fouling (Willan et al. 2000; Pettengill et al. 2007) or perhaps ballast water (Chu et al. 1997). The most likely mode of transmission for many of the *Hydroides* species is by hull fouling as they are able to tolerate common copper-based antifouling paints used on ship hulls (Lewis and Smith 1991)

Taking into account the year of first record of *H. sanctaerucis* in its distributional range, it seems to have become established in the eastern Pacific before appearing in the western Pacific. In Australia there are records of *H. sanctaerucis* from Hobart and Cairns on naval vessel hulls: on a Japanese ship and an Indonesian tall-ship, respectively (Lewis et al. 2006). This serpulid has been spread over a wide region in Australia, but the only confirmed established population are from Cairns and Darwin (Lewis et al. 2006; Sun et al. 2015); while the harbour of Hobart, in Tasmania, may not permit reproduction due to lower water temperatures. In Singapore, the population of *H. sanctaerucis* is established (Lewis et al. 2006). In China, *H. sanctaerucis* has been found only in Hong Kong and then only recently (Sun et al. 2012a); it was not known previously (e.g., Fiege and Sun 1999; Sun and Yang 2000). In Hong Kong, *H. sanctaerucis* was observed in low densities, while the dominant fouling species was *H. elegans* (Sun et al. 2012a), this may be similar to the situation observed in the Port of Kaoshiung, since more specimens of *H. elegans* were found.

The Port of Kaoshiung is one of the world's largest ports involved in the transport of both general cargo and containers (Liu and Tsai 2011) and, in 2015, >34,000 ships visited this port (Taiwan International Ports Corporation 2016). As a result, there is a large volume of global ship traffic, and so the port may act as a receptor area for non-indigenous species from many world regions (Liu et al. 2014). Additionally, the high shipping connectivity among Indo-Pacific countries may favour the further spread of non-indigenous species. In particular, *H. sanctaerucis* may already have a broader distribution than is currently known due to the small number of serpulid specialists and the limited monitoring effort in marine environments.

Acknowledgements

The authors thank Dr. Jian-Wen Qiu (Hong Kong Baptist University) and Yanan Sun (Macquarie University, Sydney) for their help in confirming the taxonomic identification. We also thank Professors T-K Liu and Sergej Olenin for assistance during the port survey. The manuscript greatly benefited from the comments of Professor José Rolando Bastida-Zavala and another anonymous reviewer. This work was supported by the Taiwan–Latvia–Lithuania Cooperation Project BALMAN “Development of the ships' ballast water management system to reduce biological invasions”, project # TAPLLT-14-013 (for DM).

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Supplementary material

The following supplementary material is available for this article:

Table S1. Invasive Pacific range of *Hydroides sanctaecrucis*.

This material is available as part of online article from:

http://www.reabic.net/journals/bir/2017/Supplements/BIR_2017_Ferrario_Minchin_Supplement.xls