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Rapid Communication

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

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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.

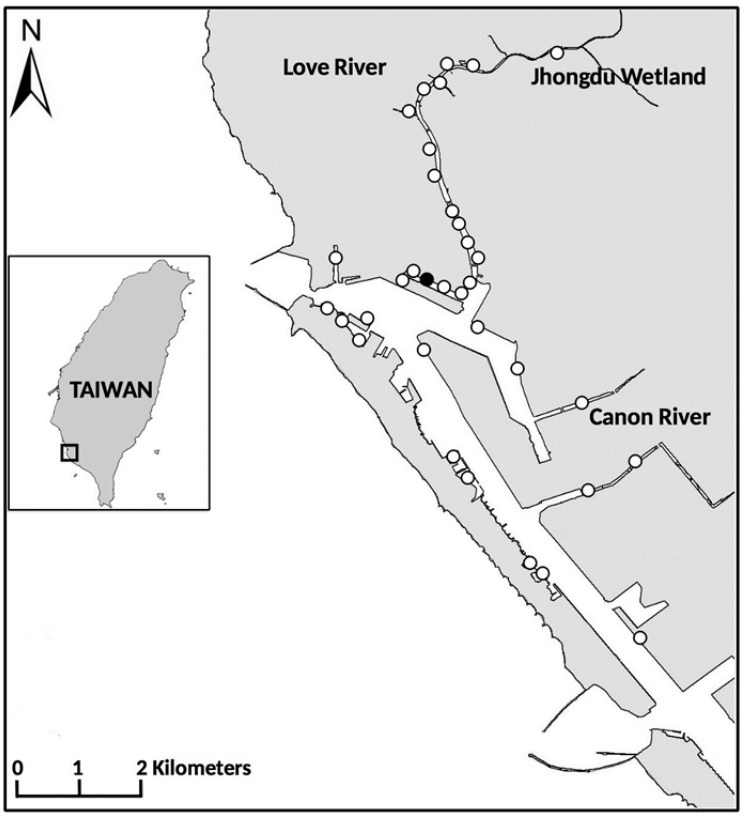

Figure 1. Study area of the targeted bivalve monitoring programme, with open circles indicating the thirty-four stations investigated. The black dot indicates the station where serpulids and bryozoans were collected.

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 vertical 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).

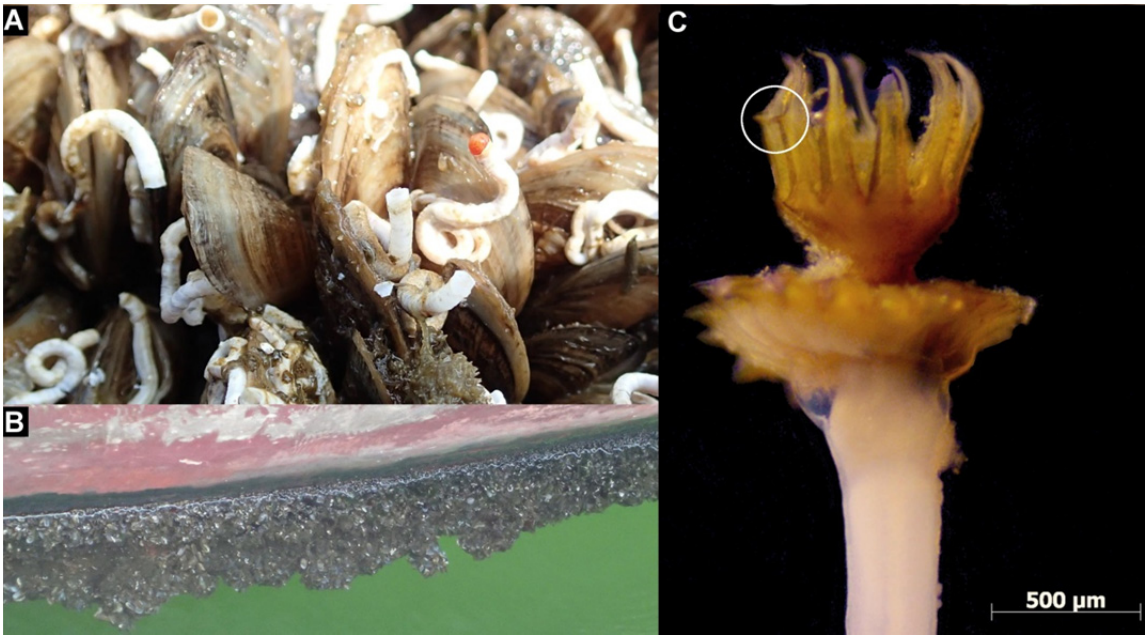

Figure 2. (**A**) Reef of *Mytilopsis sallei* colonized by *Hydroides* spp. in Kaohsiung Port; (**B**) serpulids attached to *Mytilopsis sallei* on the hull of a ship moored in Kaohsiung Port; (**C**) *Hydroides sanctaecrucis* operculum. The circle indicates the external spinule. Photographs **A** and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

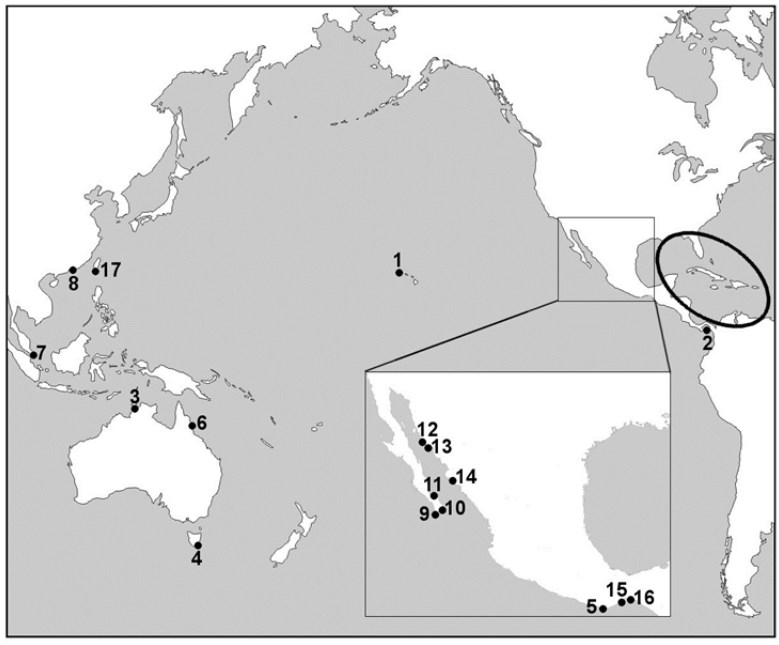

Figure 3. Invaded Pacific range of *Hydroides sanctaecrucis*. Numbers correspond to first introduction records listed in Supplementary material Table S1; the circle approximately indicates the native range.

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. sanctaecrucis* 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. sanctaecrucis* 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. sanctaecrucis* is established (Lewis et al. 2006). In China, *H. sanctaecrucis* 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. sanctaecrucis* 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 Kaohsiung 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. sanctaecrucis* 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.

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References

Audouin JV (1826) Explication sommaire des planches de polypes de l'Égypte et de la Syrie, publiées par Jules-César Savigny. In Description de l'Égypte, ou recueil des observations et des recherches qui ont été faites en Égypte pendant l'Expedition de Armée française, publié par les ordres de Sa Majesté l'Empereur Napoléon le Grand. Histoire Naturelle. Tome 1, 4° partie. Imprimerie Impériale, Paris, pp 225–244

Bastida-Zavala JR (2008) Serpulids (Annelida: Polychaeta) from the Eastern Pacific, including a brief mention of Hawaiian serpulids. *Zootaxa* 1722: 1–61

Bastida-Zavala JR, ten Hove HA (2002) Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the western Atlantic region. *Beaufortia* 52(9): 103–179

Bastida-Zavala JR, ten Hove HA (2003) Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the eastern Pacific region and Hawaii. *Beaufortia* 53: 67–110

Bastida-Zavala JR, Rodríguez Buelna AS, de León-González JA, Camacho-Cruz KA, Carmona I (2016) New records of sabellids and serpulids (Polychaeta: Sabellidae, Serpulidae) from the Tropical Eastern Pacific. *Zootaxa* 4184: 401–457, https://doi.org/10.11646/zootaxa.4184.3.1

Cai L-Z, Hwang J-S, Dahms H-U, Fu S-J, Zhuo Y, Guo T (2014) Effect of the invasive bivalve *Mytilopsis sallei* on the macrofaunal fouling community and the environment of Yundang Lagoon, Xiamen, China. *Hydrobiologia* 741: 101–111, https://doi.org/10.1007/s10750-014-2012-4

Chang KM (1985) Newly introduced false mussel to Taiwan (Bivalvia: Dreissenidae). *Bulletin of Malacology ROC* 11: 61–67

Chu KH, Tam PF, Fung CH, Chen QC (1997) A biological survey of ballast water in container ships entering Hong Kong. *Hydrobiologia* 352: 201–206, https://doi.org/10.1023/A:1003067105577

Cohen AN (2006) Species introductions and the Panama Canal. In: Cohen AN, Gollasch S, Galil BS (eds), Bridging divides: maritime canals as invasion corridors, Springer Netherlands, Dordrecht, pp 127–200, https://doi.org/10.1007/978-1-4020-5047-3_5

delle Chiaje S (1822) Memorie sulla storia e notomia degli animali senza vertebre del Regno di Napoli. Vol. 1. dalla stamperia de "Fratelli Fernandes"

Fiege D, Sun R (1999) Polychaeta from Hainan Island, South China Sea. Part I: Serpulidae (Annelida, Polychaeta, Serpulidae). *Senckenbergiana Biologica* 79(2): 109–141

Gunnerus JE (1768) Om Nogle Norske Coraller. *Det Kongelige Norske Videnskabers Selskabs Skrifter* 4: 38–73

Haswell WA (1883) On some new Australian tubicolous annelids. *Proceedings of the Linnean Society of New South Wales* 7(4): 633–638

ten Hove HA (1974) Notes on *Hydroides elegans* (Haswell, 1883) and *Mercierella enigmatica* Fauvel, 1923, alien serpulid polychaetes introduced into the Netherlands. *Bulletin Zoologisch Museum* 4(6): 45–51

ten Hove HA, Kupriyanova EK (2009) Taxonomy of Serpulidae (Annelida, Polychaeta): the state of affairs. *Zootaxa* 2036: 1–126

Krauss F (1848) Die Südafrikanischen Mollusken. Ein Beitrag zur Kenntniss der Mollusken des Kap- und Natallandes und zur Geographischen Verbreitung derselben mit Beschreibung und Abbildung der neuen Arten. Ebner and Seubert, Stuttgart, 140 pp, https://doi.org/10.5962/bhl.title.13936

Kupriyanova EK, Badyaev AV (1998) Ecological correlates of Arctic Serpulidae (Annelida, Polychaeta) distributions. *Ophelia* 49: 181–193, https://doi.org/10.1080/00785326.1998.10409381

Leidy J (1855) Contributions towards a knowledge of the marine Invertebrate fauna of the coasts of Rhode Island and New Jersey. *Journal of the Academy of Natural Sciences of Philadelphia* 3(2) no.11: 135–152

Lewis JA, Smith BS (1991) *Hydroides* settlement in Sydney Harbour (Australia) and its control in sea-water cooling systems. In: Rossmoore HW (ed), Biodeterioration and Biodegradation. London, New York, pp 464–466

Lewis JA, Watson C, Hove HA (2006) Establishment of the Caribbean serpulid tubeworm *Hydroides sanctaecrucis* Krøyer [in] Mörch, 1863, in northern Australia. *Biological Invasions* 8: 665–671, https://doi.org/10.1007/s10530-005-2062-7

Link H, Nishi E, Tanaka K, Bastida-Zavala R, Kupriyanova EK, Yamakita T (2009) *Hydroides dianthus* (Polychaeta: Serpulidae), and alien species introduced into Tokyo Bay, Japan. *Marine Biodiversity Records* 2: 1–5, https://doi.org/10.1017/S1755267209000931

Linnaeus C (1758) Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Editio decima, reformata. Laurentius Salvius: Holmiae ii, 824 pp

Linnaeus C (1767). Caroli Linnaei. Equitis De Stella Polari, Archiatri Regii, Med. & Botan. Profess. Upsal. Acad. Upsal. Holmens. Petropol. Berol. Imper. Lond. Monspel. Tolos. Florent. Soc. Systema Naturae per Regna Tria Naturae: Secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis. Editio duodecima. 1. Regnum Animale. 1 & 2 Holmiae, Laurentii Salvii, Stockholm, pp 533–1327

Liu T-K, Tsai TK (2011) Vessel traffic patterns in the Port of Kaohsiung and the management implication for preventing the introduction of non-indigenous aquatic species. *Marine Pollution Bulletin* 62: 602–608, https://doi.org/10.1016/j.marpolbul.2010.11.016

Liu T-K, Chang C-H, Chou M-L (2014) Management strategies to prevent the introduction of non-indigenous aquatic species in response to the Ballast Water Convention in Taiwan. *Marine Policy* 44: 187–195, https://doi.org/10.1016/j.marpol.2013.08.023

Long ER (1974) Marine fouling studies off Oahu, Hawaii. *The Veliger* 17(1): 23–36

Minchin D, Olenin S, Liu T-K, Cheng M, Huang S-C (2016a) Rapid assessment of target species: byssate bivalves in a large tropical port. *Marine Pollution Bulletin* 111: 177–182, https://doi.org/10.1016/j.marpolbul.2016.08.023

Minchin D, Liu T-K, Cheng M (2016b) First record of the bryozoan *Amathia* (=*Zoobotryon*) *verticillata* (Bryozoa: Vesiculariidae) from Taiwan. *Pacific Science* 70: 509–518, https://doi.org/10.2984/70.4.9

Mörch OAL (1863) Revisio critica Serpulidarum. Et Bidrag til Rørormenes Naturhistorie. *Naturhistorisk Tidsskrift. København*, Ser. 3, 1: 347–470

Otani M, Yamanishi R (2010) Distribution of the alien species *Hydroides dianthus* (Verrill, 1873) (Polychaeta: Serpulidae) in Osaka Bay, Japan, with comments on the factors limiting its invasion. *Plankton & Benthos Research* 5: 62–68, https://doi.org/10.3800/pbr.5.62

Pettengill JB, Wendt DE, Schug MD, Hadfield MG (2007) Biofouling likely serves as a major mode of dispersal for the polychaete tubeworm *Hydroides elegans* as inferred from Microsatellite loci. *Biofouling* 23: 161–169, https://doi.org/10.1080/08927010701218952

Pillai TG (2009) Descriptions of new serpulid polychaetes from the Kimberleys of Australia and discussion of Australian and Indo-West Pacific species of *Spirobranchus* and superficially similar taxa. *Records of the Australian Museum* 61: 93–199, https://doi.org/10.3853/j.0067-1975.61.2009.1489

Récluz C (1849) Description de quelques nouvelles espèces de coquilles. *Revue et Magasin de Zoologie Pure et Appliquée* (2) 1: 64–71

Ruiz GM, Lorda J, Arnwine A, Lion K (2006) Shipping patterns associated with the Panama Canal: effects on biotic exchange. In: Cohen AN, Gollasch S, Galil BS (eds), Bridging divides: maritime canals as invasion corridors, pp 113–125, https://doi.org/10.1007/978-1-4020-5047-3_4

Sun R, Yang D (2000) Study on *Hydroides* (Polychaeta: Serpulidae) from waters off China I. *Studia Marina Sinica* 42: 116−135

Sun Y, ten Hove HA, Qiu J-W (2012a) Serpulidae (Annelida: Polychaeta) from Hong Kong. *Zootaxa* 3424: 1−42

Sun Y, Kupriyanova EK, Qiu JW (2012b) COI barcoding of *Hydroides*: a road from impossible to difficult. *Invertebrate Systematics* 26: 539−547, https://doi.org/10.1071/IS12024

Sun Y, Wong E, ten Hove HA, Hutchings PA, Williamson JE, Kupriyanova EK (2015) Revision of the genus *Hydroides* (Annelida: Serpulidae) from Australia. *Zootaxa* 4009: 1−99, https://doi.org/10.11646/zootaxa.4009.1.1

Sun Y, Wong E, Tovar-Hernández MA, Williamson JE, Kupriyanova EK (2016) Is *Hydroides brachyacantha* (Serpulidae: Annelida) a widespread species? *Invertebrate Systematics* 30: 41−59, https://doi.org/10.1071/IS15015

Taiwan International Ports Corporation (2016) Annual statistical report 2015. Statistics Section of Accounting Department (eds), Taiwan, April 2016, 117 pp

Tovar-Hernández MA, Yáñez-Rivera B, Villalobos-Guerrero TF, Aquilar-Camacho JM, Ramírez-Santana ID (2012) Invertebrados marinos exóticos en el Golfo de California, pp 381–409, http://www2.inecc.gob.mx/publicaciones/libros/713/invertebrados.pdf

Tovar-Hernández MA, Villalobos-Guerrero TF, Kupriyanova EK, Sun Y (2016), A new fouling *Hydroides* (Annelida, Sabellida, Serpulidae) from southern Gulf of California. *Journal of the Marine Biological Association of the United Kingdom* 96(3): 693−705

Utinomi H (1967) Comments on some new and already known cirripeds with emended taxa with special reference to the parietal structure. *Publications of the Seto Marine Biological Laboratory* 15: 199−237

Verrill AE (1873) Report upon the invertebrate animals of Vineyard Sound and the adjacent waters, with an account of the physical characters of the region. *Reports of the United States Commissioner of Fisheries* 1: 1−778

Visscher JP (1927) Nature and extent of fouling of ships' bottoms. *Bulletin of the Bureau of Fisheries* 43(2): 193−252

Willan RC, Russell BC, Nicolas B, Moore KL, McEnnulty FR, Horner SK, Hewitt CL, Dally GM, Campbell ML, Bourke ST (2000) Outbreak of *Mytilopsis sallei* (Récluz, 1849) (Bivalvia: Dreissenidae) in Australia. *Molluscan Research* 20: 25−30, https://doi.org/10.1080/13235818.2000.10673730

Zibrowius H (1971) Les espèces Méditerranéennes du genre *Hydroides* (Polychaeta Serpulidae). Remarques sur le prétendu polymorphisme de *Hydroides uncinata*. *Téthys* 2: 691−746

Zibrowius H (1973) Remarques sur trois espèces de Serpulidae acclimatées en Méditerranée: *Hydroides dianthus* (Verrill, 1873), *Hydroides dirampha* Mörch, 1863, et *Hydroides elegans* (Haswell, 1883). *Rapport de la Commission International pour la Mer Méditerranée* 21(9): 683−686

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