Cah. Biol. Mar. (2020) 61 : 415-421
DOI: 10.21411/CBM.A.F2973099

The Pacific serpulid tube worm *Hydroides ezoensis* Okuda, 1934 reaches the ports of Rotterdam and Vlissingen (Flushing), the Netherlands (North Sea)

Marcus A. FAASSE[1,2], Harry A. TEN HOVE[2] and Peter PAALVAST[3]
(1) *eCOAST Marine Research, Korringaweg 7, 4401 NT, Yerseke, the Netherlands*
(2) *Taxonomy and Systematics Group, Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands*
(2) *Ecoconsult, Esther Vergeerstraat 31, 3118 JK, Schiedam, the Netherlands*
Corresponding author: marco.faasse@naturalis.nl

Abstract: The serpulid tube worm *Hydroides ezoensis*, originating from the Pacific and introduced near the mouth of the Loire River, France in 1973 or earlier, did not spread widely. After it had been recorded in southern England in 1976 and northwest France in 1997 no newly colonised areas in Europe were reported. In the course of monitoring of hard substrata in North Sea ports in the Netherlands we found *H. ezoensis* at two locations, about 40 kilometres apart, Rotterdam and Vlissingen (Flushing), more than 40 years after its last significant range extension. We hypothesise that rising water temperatures during the last decades may have contributed to this northward spread. Although the number of worms we collected is very low, this first colonisation in the North Sea area enhances the chance of spread along its borders.

Résumé *: L'annélide serpulien du Pacifique* Hydroides enzoensis *Okuda, 1934 atteint les ports de Rotterdam et de Vlissingen (Flessingue) aux Pays-Bas (Mer du Nord).* L'annélide serpulien *Hydroides ezoensis*, d'origine Pacifique, a été introduite près de l'embouchure de la Loire (France) en 1973 ou quelques années auparavant et ne s'est pas dispersée de manière remarquable depuis ce point. Il n'y a pas eu de nouveaux signalements en Europe après son observation dans deux localités dans le sud d'Angleterre à partir de 1976 et au Havre en 1997. Nous avons observé *H. ezoensis* lors d'un échantillonnage des substrats durs des ports de Rotterdam et Vlissingen (Flessingue) (40 km plus vers le sud) au bord de la Mer du Nord aux Pays-Bas, plus de 40 ans après son introduction initiale en France. Une raison de cette dispersion retardée pourrait être l'augmentation de la température de l'eau pendant les dernières décennies. Malgré le petit nombre de vers récoltés, cette première colonisation de la Mer du Nord augmente les chances de dispersion additionnelle.

Keywords: Hydroides ezoensis • Introduction • North Sea • Temperature • Artificial substratum

Reçu le 10 mars 2020 ; accepté après révision le 18 mai 2020.
Received 10 March 2020; accepted in revised form 18 May 2020.

Introduction

The southwestern delta area of the Netherlands, between the large ports of Rotterdam and Antwerp, is a hotspot for marine traffic, shellfish trade and culture. A high number of marine and estuarine non-indigenous species has been recorded and in brackish water they constitute about 20% of the species number (Wolff, 2005). Other factors favouring the introduction of non-indigenous species are the prevalence of coastal defence works and the high number of marinas. Coastal defence works, and floating pontoons in sheltered areas provide habitats for non-indigenous species. Tube worms belonging to the family Serpulidae are commonly found within fouling communities in harbours and marinas. Serpulids cause particular concern because of additional fuel consumption after settlement on ship's hulls. Similarly, non-indigenous species require special attention since their sometimes massive aggregations may compete with oysters or cause severe fouling in supplies of cooling water to power stations, as is the case for *Hydroides elegans* (e.g. Arakawa (1971), respectively Behrens (1968), both as *H. norvegicus*).

We are involved in two monitoring programmes in sea ports along the coast of the southwest of the Netherlands and Belgium, which are both aimed at indigenous and non-indigenous macrobenthos on hard substrata. In this paper we will discuss the monitoring results with respect to serpulid tube worms.

The first monitoring programme is restricted to the port of Rotterdam. In 2018 experimental structures, both inter- and subtidally, of various kinds were applied in the port of Rotterdam to study their potential contribution to enhance marine life and biomass production. During monitoring of these structures on 27 August 2018 a non-indigenous serpulid tube worm species (Annelida, Serpulidae) was collected. During a subsequent monitoring on 17 and 18 June 2019, more attention was given to calcareous tubes on the experimental structures and several specimens of the same tube worm species were present on a concrete plate.

The second monitoring programme, in six seaports along the southern North Sea (Rotterdam, Vlissingen (Flushing), Terneuzen, Antwerp, Zeebrugge and Ostend), runs from 2014 till the present (Wijnhoven et al., 2017). During this monitoring the non-indigenous serpulid tube worm species was collected again, on 3 October 2019, this time from the port of Vlissingen, some 40 kilometres south of Rotterdam. It belongs to a non-indigenous species not previously recorded from the North Sea area.

Materials & Methods

Sampling locations

Samples were taken in the Calandkanaal, port of Rotterdam, which is part of the man-made Rhine-Meuse estuary (Paalvast, 2014). Experimental structures to enhance growth of sessile invertebrates and algae and the associated fauna were deployed between +1m NAP (Amsterdam Ordnance Datum) and -4 m NAP on support poles of the walkways of berths for ships. The mean tidal range is 1.8 m, from + 1.32 m NAP at MHWL (mean high water level) to -0.48 m NAP at MLWL (mean low water level). Water current varies between 0.15 $m.s^{-1}$ at neap tide and 0.25 $m.s^{-1}$ at spring tide (Port of Rotterdam, 2012), but the main water movement is caused by the propellers of ships passing by in the Calandkanaal, both vertically and horizontally. Salinity varies between 15 and 29 in relation to river discharge. On average, the water temperature varies according to the season between 5 and 21°C (Port of Rotterdam, 2012). Oxygen concentrations are relatively high in the Calandkanaal and may vary between 90% and over 100% saturation (Paalvast, 2014).

Samples from the port of Vlissingen were taken in the Van Cittershaven, which is open to the Westerschelde estuary and the North Sea. They were collected from a floating pontoon at a depth of approximately 0.5 m below the water surface. The pontoon is mainly used by inland cargo vessels from the Netherlands and Germany. In other parts of the port international shipping is important. Salinity in the Van Cittershaven was 25-34 during 2015-2018, based on one measurement in spring and one in autumn each year.

Sampling

Experimental structures in the port of Rotterdam were taken on-board with a crane and inspected visually on 27 August 2019 and 17-18 June 2019. Calcareous tubes visible with the naked eye were removed and transferred to the lab. Tube worms not known to belong to the local fauna were fixed in formalin for at least 24 hours and transferred to ethanol.

In order to determine if oxygen could be a limiting factor, samples of the surface water and water at a depth of -3.85 NAP were taken and oxygen concentrations were measured with a HQ20 Hach Portable LDOTM Dissolved Oxygen/pH Meter. Salinity and temperature were measured with a WTW-conductivity meter (Cond 3301) with a TetraCon®325 conductivity and temperature sensor. Water transparency was measured with a standard Secchi disc.

A pontoon in the port of Vlissingen was sampled on 3 October 2019 with a hand net provided with a scraping edge. The effectiveness of this method was good, even for organisms with calcareous housings such as barnacles, except for oysters. The catch was sorted visually on location. Organisms unidentifiable on location were transferred to the lab. Tube worms were fixed in formalin for at least 24 hours and transferred to ethanol.

Results

The results of physical measurements in the Calandkanaal in Rotterdam are presented in table 1.

Table 1. Physical measurements in the Calandkanaal, Port of Rotterdam on 26 August 2018 and 17 June 2019.

Date	26/08/2018	17/06/2019
time	11:35	11:18
Secchi depth (m)	2.9	3.2
Surface		
salinity	25.3	20.5
temperature (°C.)	19.1	18.6
oxygen saturation (%)	93.1	95.9
oxygen (mg.l^{-1})	7.5	7.5
3.5 m below surface		
salinity	25.7	21.6
temperature (°C.)	19.4	17.6
oxygen saturation (%)	96.9	95.6
oxygen (mg.l^{-1})	7.7	7.7

The sample from Rotterdam on 27 August 2018 contained one specimen of *Hydroides ezoensis* Okuda, 1934, without its calcareous tube. The samples taken on 17 and 18 June 2019 in Rotterdam contained 13 specimens in total, 3 from concrete blocks in so-called 'tidal cups' (Fig. 1 A-C) and 10 from a concrete plate that served as a reference for the

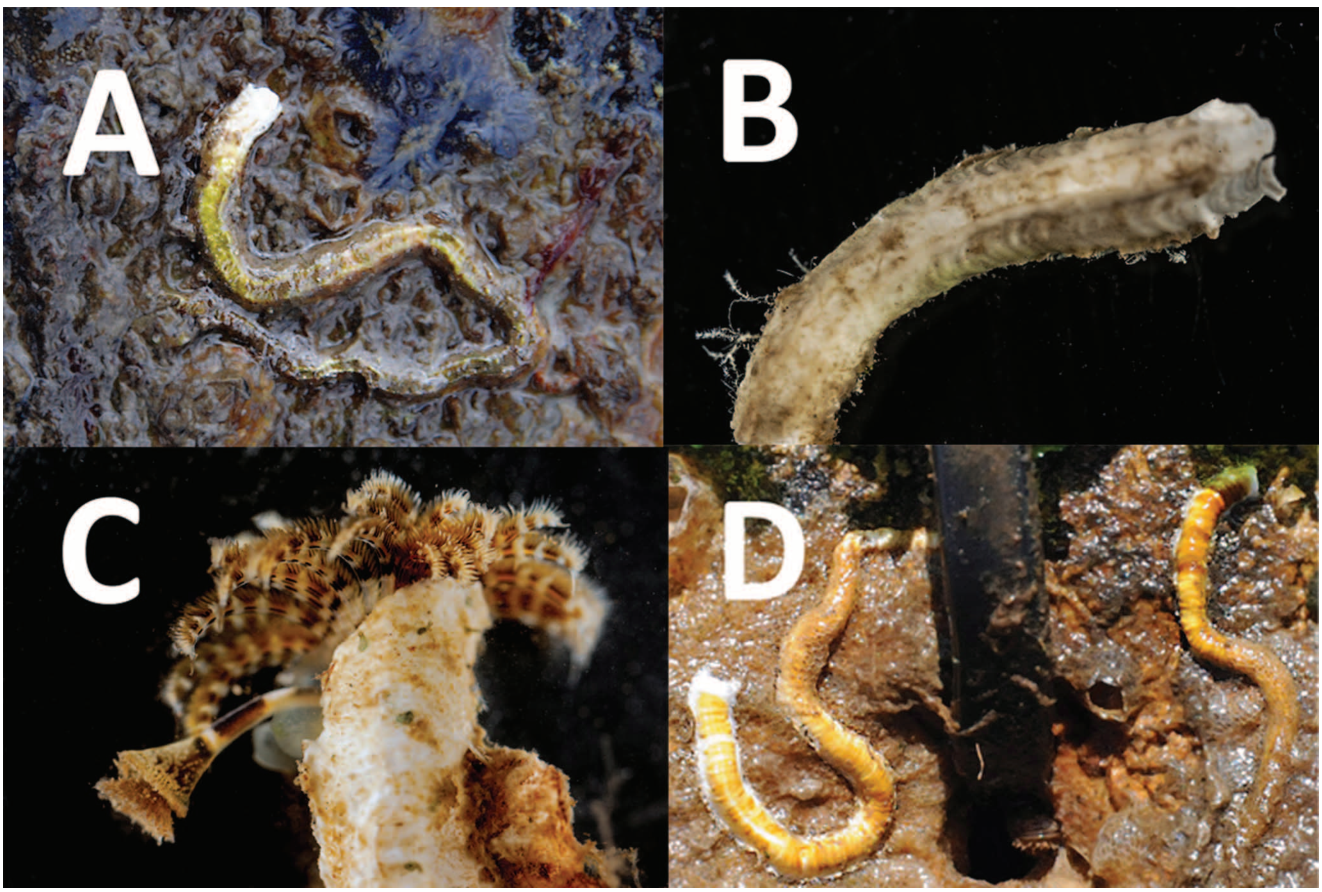

Figure 1. *Hydroides ezoensis* (**A, B, C**) and *Ficopomatus enigmaticus* (**D**) from Rotterdam, 17/18 June 2019.

Table 2. *Hydroides ezoensis*. Counts of opercular spines of three specimens from Rotterdam and two specimens from the United Kingdom in the collection of Naturalis Biodiversity Center. The funnel is smaller than the verticil and often (almost) hidden beneath it, which renders spine counts difficult.

Location	Coll.no.	specimen/ operculum	spines verticil	radii (spines) funnel
Rotterdam	RMNH. VER.19964	1	24	ca 55
Rotterdam	RMNH. VER.19964	2/old	22	40
Rotterdam	RMNH. VER.19964	2/new	31	50
Rotterdam	RMNH. VER.19964	3	24	hidden
Southampton	V.Pol.5411	1	23	ca 45
Portsmouth	V.Pol.3484	1	23	40

other underwater structures below the mean low water level (MLWL). Three voucher specimens from 17 and 18 June 2019 have been deposited in the collection of Naturalis Biodiversity Center (registration number RMNH. VER.19964) and the remainder of the specimens will be deposited in the same collection. Spine counts of the opercula of these three specimens have been compared with those from other European localities (Table 2). One of the specimens from Rotterdam had an old operculum, as well as a new replacement.

The samples from Vlissingen contained a Pacific oyster *Magallana gigas* (Thunberg, 1793) with two specimens of *Hydroides ezoensis* attached.

Identification

The genus *Hydroides* is characterized by a combination of characters: symmetrical body, opercular peduncle without distal wings, presence of pseudoperculum, collar chaetae simple and bayonet-type and operculum two-tiered (from key in Ten Hove & Kupriyanova, 2009). The two-tiered operculum consists of two superimposed funnels, the upper one, the verticil, consisting of a crown of chitinised spines (Fig. 1C). *Hydroides ezoensis* is the only species in the genus with the spines of the verticil all similar in size and shape, pale brown and not curved inward, provided with medial but not lateral teeth (Imajima, 1976, Fig. 2), though *H. fusicola* Mörch, 1863, is very similar, admittedly without medial teeth (Imajima, 1976, Fig. 1).

Distribution

Hydroides ezoensis was originally described from Akkeshi, Muroran and Oshoro, on Hokkaido Island, Japan (Okuda, 1934). The species is most probably native to the Northwest Pacific, i.e. Japan, where it can form large aggregations on intertidal rocky shores (Miura & Kajihara, 1984); it also is a well-known fouler from the eastern coast of Russia and China (e.g. Thorp et al., 1987; Cao et al., 2013, Zvyagintsev et al., 2004). It was introduced to the Baie de Bourgneuf and Le Croisic at the Atlantic coast of France (Gruet et al., 1976; Zibrowius, 1978)

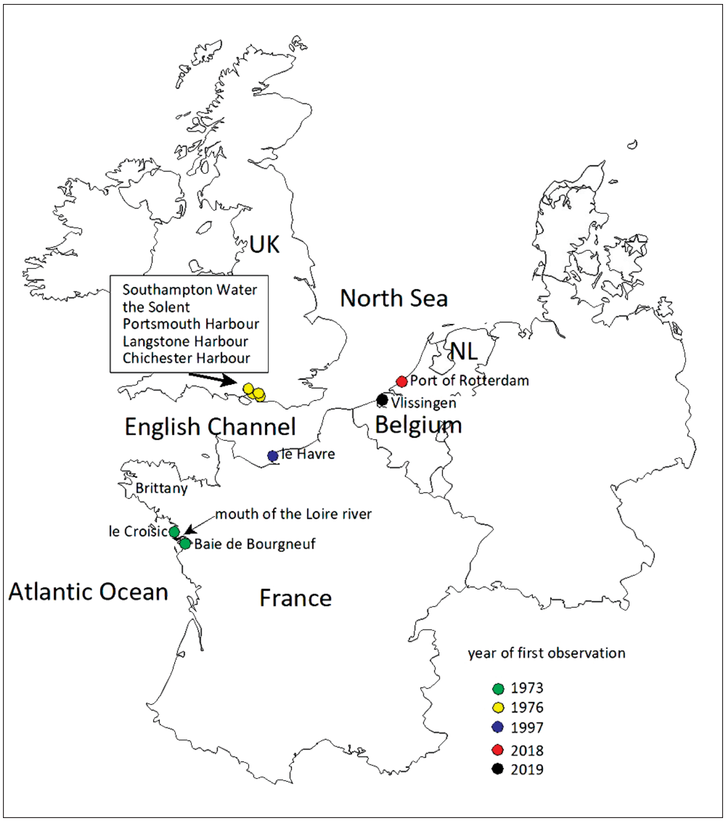

Figure 2. *Hydroides ezoensis*. Currently known distribution on the Atlantic coast of Europe. UK = United Kingdom, NL = the Netherlands. After Zibrowius (1978), Thorp et al. (1987) and Breton & Vincent (1999).

in 1973 or earlier and to southern England (Southampton Water and the Solent) in 1976 or earlier (Zibrowius & Thorp, 1989). In 1997 *Hydroides ezoensis* was recorded from Le Havre, much more north than the first French sites and at a similar latitude as Southampton Water (Breton & Vincent, 1999). In the same study the species was not recorded from Antifer, about 25 km north of Le Havre. More about the European occurrences, such as ecological and distributional data, can be found in Eno et al. (1997) and Breton (2014). Since 1997 it has become a fouling nuisance in Australia as well (e.g. Hewitt, 2002; Sun et al., 2015); it even reached New Zealand (Glasby et al., 2007). Figure 2 shows the currently known distribution on the Atlantic coast of Europe and the North Sea.

Discussion

Besides *Hydroides ezoensis*, one other species of serpulid tube worm was collected from the experimental structures in 2018 and 2019. *Ficopomatus enigmaticus* (Fauvel, 1923) was the most abundant species (Fig. 1D), although its density was much too low to form reef-like structures. In the nearby Dintelhaven, with a lower salinity than the Calandkanaal, it does build dense aggregations. In the field, the two species can be separated by the morphology of the tubes. *Ficopomatus enigmaticus* has a smooth tube with no longitudinal keels whatsoever (Fig. 1D), often with collar-shaped calcareous rings around the tube; *Hydroides ezoensis* has a corrugated tube with two rounded longitudinal keels and numerous wavy transverse growth lines (Fig. 1A & B).

Other species of the genus *Hydroides* recorded from the Netherlands are *H. elegans* (Haswell, 1883) and *H. norvegica* Gunnerus, 1768. Ten Hove (1974) recorded *H. elegans* from an inner harbour of Vlissingen which experienced artificial heating by a power station and is separated from the Westerschelde estuary and the North Sea by sluice docks. The artificial heating has been discontinued and *H. elegans* has not been observed since, whereas *Ficopomatus enigmaticus* has been present in the Netherlands for the last decades (van der Velde et al., 1993; Gittenberger et al., 2009). Gittenberger et al. (2009) recorded *H. norvegica* from marinas on the islands of Texel and Vlieland in the Wadden Sea area in the north of the Netherlands. Other representatives of the genus *Hydroides* than the three species mentioned have not been recorded in the Netherlands yet (ten Hove & Lucas, 1996).

Hydroides ezoensis and *H. elegans* exhibit a distinct substrate preference. Both species prefer sandstone over concrete and concrete over wood (Glasby, 2000). Glasby et al. (2007) suggest that artificial surfaces in estuarine habitats may facilitate the introduction of non-indigenous species. On the other hand, Miura & Kajihara (1984) noted a much higher density (2.3-8.4 ind.cm^{-2}) on natural rocks than on a vertical concrete wall of a jetty (0.8 ind.cm^{-2}). We found *H. ezoensis* on concrete and on the Pacific oyster *Magallana gigas*. As the Pacific oyster is widespread in estuarine areas as well as in brackish and marine harbour regions around the southern North Sea, the nature of the original substrate is probably not important once oysters have had time to settle. Cao et al. (2009) found in experiments an optimal temperature for reproduction of 24°C and a minimum temperature for reproduction of 18°C. In the Calandkanaal in Rotterdam where *H. ezoensis* was collected, water temperature reaches a value over 20°C almost every year (Port of Rotterdam, 2012). *Hydroides ezoensis* is able to survive much lower temperatures than required for reproduction: Ovsyannikova & Levenets (2003) recorded temperatures as low as 2.5°C in Amursky Bay, Sea of Japan, in April and May 1982-1994, suggesting even lower temperatures during winter, while in 1995 it was a subdominant species in the fouling, with the majority of specimens alive. Sea water surface temperatures in Akkeshi, the type locality, range yearly from -1 to 19° C (Uchida et al., 1963). Optimal salinity has been reported to be 25-35, but the species survived at 20-40 (Cao et al., 2013). Apparently, temperature and salinity in the port of Rotterdam (Table 1) are within the range of tolerance of *H. ezoensis*. Oxygen saturation is around 95%, unlikely to be a limiting factor. It has been suggested that high densities of this species may require a high phytoplankton concentration (Thorp et al., 1987). We have no measurements of phytoplankton concentrations in the Rotterdam and Vlissingen ports; the Secchi depth in Rotterdam was about 3 m. In any case, these ports are not situated at the open sea, just like Southampton Water, where *H. ezoensis* thrives (Thorp et al., 1987), favouring retention of phytoplankton and of *H. ezoensis* larvae, and the Sydney Harbour location, upstream of Sydney Harbour bridge, fully saline but protected (Sun et al., 2015).

Hydroides ezoensis was first reported from near the mouth of the Loire River (France) and from southern England in the 1970's. The latest range extension, to the northwest coast of France was in

1997 or earlier. Ships from the North West Pacific arrive in the port of Rotterdam on a daily basis. Notwithstanding these facts, the species only recently, with a lag time of more than 20 years, achieved a foothold in Rotterdam and Vlissingen. From our results it is impossible to conclude whether this lag phase might be related to increasing water temperatures, enhancing survival during winter and proliferation during summer, or just a random process, depending on ships picking up a species in donor areas, survival during transport, and insemination, survival and reproduction in recipient areas. Now that *H. ezoensis* has a population in the Netherlands, other harbour areas in North West Europe will experience a higher propagule pressure of this species and we expect a further spread.

Acknowledgements

The authors wish to thank the Port of Rotterdam Authority for financing, support and involvement in the monitoring and for their permission to publish the monitoring data. We thank three anonymous reviewers for their constructive comments.

References

Arakawa K.Y. 1971. Notes on a serious damage to cultured oyster crops in Hiroshima caused by a unique and unprecedented outbreak of a serpulid worm, *Hydroides norvegica* (Gunnerus) in 1969. *Venus,* 30: 75-82.

Behrens E.W. 1968. Cyclic and current structures in a serpulid reef. *Contributions to Marine Science,* 13: 21-27.

Breton G. 2014. Alien or invasive species in the ports of Le Havre, Antifer and Rouen (Normandy, France). *Hydroécologie Appliquée*, 18: 23-65.

Breton G. & Vincent T. 1999. Invasion du port du Havre (France, Manche) par *Hydroides ezoensis* (Polychaeta, Serpulidae), espèce d'origine japonaise. *Bulletin Trimestriel de la Société Géologique de Normandie et des Amis du Museum du Havre,* 86: 33-43.

Cao S.-M., Xu H., Liu P-L., Li J. & Sun W.-S. 2009. Effects of temperatures on growth, development and metamorphosis of *Hydroides ezoensis* larvae. *Journal of Dalian Fisheries University,* 24: 531-535.

Cao S.-M., Liu R.-C., Li X.-J., Hao S. & Xu H. 2013. Effects of salinity on fertility, hatching rate, survival and metamorphosis in *Hydroides ezoensis* larvae. *Journal of Dalian ocean university,* 28: 133-137.

Eno N.C., Clark R.A. & Sanderson W.G. (eds) 1997. *Non-native marine species in British waters: a review and directory.* Joint Nature Conservation Committee: Peterborough. 152 pp.

Gittenberger A., Rensing M., Stegenga H. & Hoeksema B.W. 2009. Inventarisatie van de aan hard substraat gerelateerde macroflora en macrofauna in de Nederlandse Waddenzee. GiMaRIS rapport 2009_11. i.o.v. Ministerie van Landbouw, Natuur en Voedselkwaliteit, Team Invasieve Exoten. 63 pp.

Glasby T.M. 2000. Surface composition and orientation interact to affect subtidal epibiota. *Journal of Experimental Marine Biology and Ecology*, 248: 177-190. Doi: 10.1016/S0022-0981(00)00169-6

Glasby T.M., Connell S.D., Holloway M.G. & Hewitt C.L. 2007. Non-indigenous biota on artificial structures: could habitat creation facilitate biological invasions? *Marine Biology,* 151: 887-895. Doi: 10.1007/s00227-006-0552-5

Gruet Y., Héral M. & Robert J.M. 1976. Premières observations sur l'introduction de la faune associée au naissain d'huîtres japonaises *Crassostrea gigas* (Thunberg), importé sur la côte atlantique française. *Cahiers de Biologie Marine,* 17: 173-184. Doi: 10.21411/CBM.A.541FADA5

Hewitt C.L. 2002. Distribution and biodiversity of Australian tropical marine bioinvasions. *Pacific Science*, 56: 213-222.

Hove H.A. ten 1974. Notes on *Hydroides elegans* (Haswell, I883) and *Mercierella enigmatica* Fauvel, 1923, alien serpulid polychaetes introduced into the Netherlands. *Bulletin of the Zoological Museum, Amsterdam,* 4: 45-51.

Hove H.A. ten & Kupriyanova E.K. 2009. Taxonomy of Serpulidae (Annelida, Polychaeta): The state of affairs. *Zootaxa,* 2036: 1-126.

Hove H.A. ten & Lukas J.A.W. 1996. Kalkkokerwormen in Nederland. *Het Zeepaard,* 56: 30-52.

Imajima M. 1976. Serpulinae (Annelida, Polychaeta) from Japan I. the genus *Hydroides*. *Bulletin of the National Science Museum, Tokyo, Ser. A (Zoology),* 2: 229-248.

Miura T. & Kajihara T. 1984. An ecological study of the life histories of two Japanese serpulid worms, *Hydroides ezoensis* and *Pomatoleios kraussii*. In: *Proceedings of the First International Polychaete Conference, Sydney,* (P.A. Hutchings ed.), pp. 338-354.

Okuda S. 1934. Some tubicolous annelids from Hokkaido. *Journal of the Faculty of Science Hokkaido Imperial University,* 3: 233-246.

Ovsyannikova I.I. & Levenets I.R. 2003. Macrofouling of the scallop *Mizuhopecten yessoensis* in the polluted area of Amursky Bay, Sea of Japan. *Russian Journal of Marine Biology,* 29: 395-402.

Paalvast P. 2014. Ecological studies in a man-made estuarine environment, the port of Rotterdam. PhD thesis, Radboud University, Nijmegen, the Netherlands. 206 pp.

Port of Rotterdam 2012. *HydroMeteoBundel,* nr 4: 1-93.

Sun Y., Wong E., ten Hove H.A., Hutchings P.A., Williamson J.E. & Kupriyanova E. 2015. Revision of the genus *Hydroides* (Annelida: Serpulidae) from Australia. *Zootaxa*, 4009: 1-99.

Thorp C.H., Pyne S. & West S.A. 1987. *Hydroides ezoensis* Okuda, a fouling serpulid new to British coastal waters. *Journal of Natural History,* 21: 863-877.

Uchida Y., Yamada M., Iwata F., Oguro C. & Nagao Z. 1963. The zoological environs of the Akkeshi Marine Biological Station. *Publications from the Akkeshi Marine Biological Station,* 13: 2-36.

Velde G. van der, Gaag M. van der & Hove H.A. ten 1993. De exotische trompetkalkkokerworm *Ficopomatus enigmaticus* (Fauvel), een nieuwe kolonisator in het Noordzeekanaal. *Het Zeepaard*, 53: 62-70.

Wijnhoven S., Gittenberger A., Faasse M. & Schellekens T. 2017. Overview alien species monitoring in the Western Scheldt: Current status of monitoring efforts and presence of alien

species among macrofauna and algae. Ecoauthor Report Series 2017 - 01: Heinkenszand, the Netherlands, 56 pp.
Wolff W.J. 2005. Non-indigenous marine and estuarine species in The Netherlands. *Zoölogische Mededelingen,* 79: 1-116.
Zibrowius H. 1978. Introduction du polychète Serpulidae japonais *Hydroides ezoensis* sur la côte atlantique française et remarques sur la répartition d'autres espèces de Serpulidae. *Téthys,* 8: 141-150 (volume for 1976, published 1978).
Zibrowius H. & Thorp C.H. 1989. A review of the alien serpulid and spirorbid polychaetes (Polychaeta, Annelida) in the British Isles. *Cahiers de Biologie Marine,* 30: 271-285. Doi: 10.21411/CBM.A.873EA88F
Zvyagintsev A.Yu., Korn O.M. & Kulikova V.A. 2004. Seasonal dynamics of pelagic larvae and settling of the fouling organisms in conditions of thermal pollution. *Russian Journal Marine Biology,* 30: 266-277.