Distribution of the alien species *Hydroides dianthus* (Verrill, 1873) (Polychaeta: Serpulidae) in Osaka Bay, Japan, with comments on the factors limiting its invasion

MICHIKO OTANI¹,* & RYOHEI YAMANISHI²

¹ Marine Ecology Institute Inc. 3–3–4 Harada Motomachi, Toyonaka, Osaka 561–0808, Japan
² Osaka Museum of Natural History. 1–23 Nagai Park, Higashi-sumiyoshi-ku, Osaka 546–0034, Japan

Received 14 February 2010; Accepted 25 March 2010

**Abstract:** During our survey of the subtidal macrobiota on wave dissipating concrete blocks along the coast of Osaka Bay in 1997, we recorded a species of serpulid polychaete that was not immediately identifiable. In 2007, we re-examined the specimens and discovered that they were identical to *Hydroides dianthus*, native to the East Coast of North America. The density of the worm in Osaka Bay varied remarkably between sites and depths. A Steel-Dwass multiple comparison analysis was used to evaluate the differences among sites, depths and seasons. Spearman’s rank correlation was used to examine the influence of physical factors of temperature, salinity and dissolved oxygen, and biological ones of the densities of coexisting organisms. The results suggest that salinity greater than 30 psu and biological interaction with macroalgae or mussel (*Xenostrobus securis*) are presently acting as limiting factors for the invasion of *H. dianthus*.

**Key words:** alien species, biological interactions, *Hydroides dianthus*, limiting factor, water quality

---

**Introduction**

On our survey of the subtidal macrobiota at five wave dissipating concrete block sites in Osaka Bay in 1997, several species of *Hydroides* (Polychaeta: Serpulidae) were recorded, including one that was unidentifiable (Otani et al. 2004). This was assigned the temporary operational taxonomic name of *Hydroides* sp. and stored without registration in the Osaka Museum of Natural History. Our re-examination of the specimens in 2007 revealed that they were nearly identical to *Hydroides dianthus* (Verrill), a species native to the East Coast of North America. The density of the worm in Osaka Bay varied remarkably between sites and depths. A Steel-Dwass multiple comparison analysis was used to evaluate the differences among sites, depths and seasons. Spearman’s rank correlation was used to examine the influence of physical factors of temperature, salinity and dissolved oxygen, and biological ones of the densities of coexisting organisms. The results suggest that salinity greater than 30 psu and biological interaction with macroalgae or mussel (*Xenostrobus securis*) are presently acting as limiting factors for the invasion of *H. dianthus*.

The first record of the species in the world as an alien was at Izmir in Turkey in 1865 under the name of *Serpula uncinata* (Philippi) (a synonym of *H. dianthus*) prior to the original description by Verrill in 1873. After that initial record from Turkey, *H. dianthus* was recorded in the 1960s along the coast of the Mediterranean, the Atlantic coast of France and Spain and Senegal of West Africa (Zibrowius 1971). The occurrence of *H. dianthus* at Southampton, England in 1970 (Zibrowius 1978) showed that it had also extended its distribution to the English Channel. While there are abundant records of *H. dianthus* as an alien in Europe for more than a century, there have never been records as such outside the Atlantic Ocean including the Pacific Ocean until our report in 2007. In Japan, ten years after our first record, *H. dianthus* was reported on a test panel placed in Tokyo Bay in 2006 (Link et al. 2009) and at Hamana Lake in 2008 (Aoki 2009). These records seem to imply that *H. dianthus* has already extended its distribution to various inland bays around Japan though we cannot confirm it on account of insufficient information. In order to predict future occurrence of *H. dianthus* in Japanese waters, it is essential for us to obtain data on its ecology and physiology.

In the present study, we noted the results of the subtidal macrobiota surveys in Osaka Bay conducted by the Osaka Natural History Museum in 1997, and discuss factors influencing the distribution pattern of *H. dianthus* statistically to make some predictions concerning its future distribution in

---

* Corresponding author: Michio Otani; E-mail, m-otani@marineco.co.jp
Materials and Methods

Study area

Samples of subtidal macrobiota were collected at five sites along the north and the east coast of Osaka Bay (Fig. 1). These sites were located around the Bay at Akashi (34°38′20″N, 134°59′56″E), Nishinomiya (34°41′17″N, 135°21′46″E), Maishima (34°39′45″N, 135°23′24″E), Kishiwada (34°30′06″N, 135°22′30″E) and Tannowa (34°20′05″N, 135°11′24″E), respectively. Nishinomiya and Maishima were located near the mouth of Yodo River. Tannowa and Akashi were located near the opening of the bay. Kishiwada was located between Maishima and Tannowa. Sampling was conducted uniformly on wave dissipating concrete blocks.

Sampling procedure and the sample treatment

Samples of subtidal macrobiota were collected four times a year (18–20 February, 16 and 28 May, 7 and 8 August and 13 and 14 November in 1997, at depths of 0 m (chart datum), −2 m and −4 m. Three replicate samples were taken at each depth by divers using a 25 cm×25 cm quadrat. These samples were fixed immediately in 10% formalin and transported back to the laboratory. After sorting in a 1 mm mesh sieve, we measured the wet weight of the macroalgae to an accuracy of 0.01 g using an electronic microbalance, and counted the number of animals by species under a binocular dissecting microscope. In the present study, we selected the examined specimens of Hydroides sp. from every sample including the species and measured their total length, thoracic length, thoracic width with the accuracy of 0.1 mm, the number of radii at the funnel and the number of spines at verticil in order to confirm them as to be Hydroides dianthus.

Data analysis

A Steel-Dwass multiple comparison analysis was used to evaluate the differences in density of H. dianthus among sites, depths and seasons. Several factors that are considered to affect the distribution of H. dianthus were also examined. They consist of the physical factors of temperature, salinity and dissolved oxygen, and the biological factors of the density of sedentary and sessile organisms which may compete with H. dianthus. Spearman’s rank correlation coefficient was determined for the density of H. dianthus compared with those factors. A two-way ANOVA was used to determine the interaction between the species and the depth. The data were used without any transformation. For the three physical variables, we used the data of water temperature, salinity and dissolved oxygen at sea surface for five years from 1993–1997 taken by the Osaka Prefectural Experimental Station for their seasonal water quality survey (Nakajima et al. 1995–1999). Among 20 sites set by the Station in Osaka Bay, we chose four sites situated near to our sampling sites for our analysis (Fig. 1).

Results

Taxonomic features

Hydroides dianthus (Verrill) (Fig. 2, 3a–g)

Body color and size: Both thorax and abdomen pale yellow in preserved specimens. Thorax orange and abdomen pale yellow in life according to recent observation on live material. Total length: 23.5±1.4 mm (mean±S.D., n=120, r (range of data): 4.1–62.8). Funnel with approximately 31 radii (30.6±4.0, n=108, r: 9–41) (Fig. 3a). Verticil with approximately 10 yellow spines (9.9±1.0, n=109, r=8–13),
all curving ventrally (Fig. 3a). Dorsal spines larger than ventral ones. Tip of spines pointed. Spines with one basal internal spinule, without external and lateral ones and/or wings (Fig. 3a, b). Collar chaetae bayonet-like with two blunt-rounded teeth, distal blade smooth (Fig. 3c). Length of thorax: $4.4/110061.4$ mm (n=118, r: 1.1–8.7), width $1.4/110060.3$ mm (n=118, r: 0.4–2.5). Thoracic membranes well developed. Chaetigers 2–7 with limbate chaeta on notopodia (Fig. 3d) and saw-shaped uncini with 7–8 teeth arranged in one row on their back at neuropodia (Fig. 3e). Anterior and middle abdominal chaetigers with flat-trumpet chaeta on notopodia (Fig. 3f). Anterior abdominal chaetigers with saw-shaped uncini with 6 teeth arranged in one row on their back on notopodia (Fig. 3g).

The measurements of the specimens described here agree well with those of Bastida-Zevala & ten-Hove (2002), with the exception of its rather larger body size compared with western Atlantic specimens which have a mean total length of 16.5 mm. However, the important diagnostic characters, such as the number of verticil spines and its morphology, exactly coincide with the western Atlantic specimens.

**Water quality around the sampling sites**

We calculated the means and the standard deviations of sea temperature, salinity and dissolved oxygen at sea surface for five years from the data of Nakajima et al. (1995–1999) (Table 1). Water temperature varied from $17.7/110066.2$°C to $19.1/110067.5$°C (mean $11006S.D.)$. High salinity over 30 psu was recorded at the sites around Akashi and Tannowa. It has a tendency to be lower around the head of the bay, with less than 30 psu around Nishinomiya, Maishima and Kishiwada. Dissolved oxygen varied from $7.8/110061.2$ mg L$^{-1}$ to $11.5/110063.1$ mg L$^{-1}$, showing a tendency to be higher around Nishinomiya, Maishima and Kishiwada than around Akashi and Tannowa.

**Horizontal and vertical distribution and seasonal variation**

The mean density of *H. dianthus* at each site was calculated from the data collected over four seasons at each depth. The mean density varied horizontally at every site. The worms occurred abundantly at Kishiwada and Nishinomiya, and scarcely at Maishima and Tannowa. Differences were significant between Nishinomiya and Maishima or Tannowa at the 5% level (Steel-Dwass multiple comparison analysis). Vertical bars indicate standard deviations.

---

**Table 1.** Water temperature, salinity and dissolved oxygen (mean±S.D.) at four sites surveyed for water quality in Osaka Bay from 1993 to 1997 (modified from Nakajima et al. 1995–1999).

| Site/item       | Water temperature (°C) | Salinity (psu) | Dissolved oxygen (mg L$^{-1}$) |
|-----------------|------------------------|----------------|------------------------------|
|                 | mean±S.D. | mean±S.D. | mean±S.D. |
| 1 (near to Tannowa) | $18.7/110066.7$ | $32.0/110061.1$ | $8.6/110061.5$ |
| 6 (near to Akashi) | $17.7/110066.2$ | $32.3/110060.6$ | $7.8/110061.2$ |
| 13 (near to Kishiwada) | $19.1/110067.5$ | $29.9/110062.3$ | $10.7/110063.4$ |
| 18 (near to Nishinomiya and Maishima) | $18.7/110067.6$ | $26.5/110064.2$ | $11.5/110063.1$ |

---

**Fig. 3.** *Hydroides dianthus* from Nishinomiya: a, Operculum, lateral view; b, Central part of operculum, apical view; c, Collar chaeta; d, Thoracic limbate chaeta; e, Thoracic uncini on neuropodium; f, Abdominal flat trumpet chaeta on notopodium; g, Abdominal uncini on neuropodium.

**Fig. 4.** Comparison of the density of *Hydroides dianthus* in Osaka Bay. For each site treatments sharing the same letters are not significantly different, $p>0.05$ (from a Steel-Dwass multiple comparison analysis). Vertical bars indicate standard deviations.
Vertically, *H. dianthus* was distributed mainly at the depth of 2 m and/or 4 m at Nishinomiya, Maishima and Kishiwada each with scarce density or absent (at Maishima) at 0 m. The difference between 2 m or 4 m and 0 m were significant at the 5% level. On the contrary, *H. dianthus* did not appear at 2 m and 4 m at all, and it was present only at 0 m at Tannowa (Fig. 5).

The mean density of *H. dianthus* at five sites by each season showed the tendency to increase from the winter through spring and summer to autumn (Fig. 6), though there was no significance among each season at 5% level.

**Distribution of other dominant sessile or sedentary organisms and grazers**

Dominant species of sessile, sedentary organisms and grazers are listed in Table 2. Macroalgae were abundant at Akashi and Tannowa, but were scarce at Nishinomiya, Maishima, and Kishiwada, especially least at Nishinomiya. All the other dominant species (except for *Hydroides ezoensis* (Okuda)) tended to be abundant at Nishinomiya and Maishima, while they were scarce at Kishiwada and...
The density of *H. dianthus* showed a significant negative correlation with salinity, but showed no significant correlation with water temperature and dissolved oxygen (Table 3). The density of *H. dianthus* also showed significant negative correlations with macroalgae and *Xenostrobus securis* (Lamarck) and showed significant positive correlations with other dominant sessile or sedentary animal species except for *Mytilus galloprovincialis* (Lamarck) (Table 3).

To examine the interaction between *H. dianthus* and macroalgae and/or *X. securis* with depth, a two-way ANOVA was used. Whereas the density of *H. dianthus* and macroalgae showed significant differences both between species and between depths, they did not show significant species × depth interaction (Table 4(a)). As is seen in Fig. 7(a), this implies that change of depth did not have an important effect on each other’s density. The density of *H. dianthus* and *X. securis* did not show significant difference between species, but showed significant difference between depths. There was also significant species × depth interaction, implying that density varied with depth with different pattern between these two species (Table 4(b), Fig. 7(b)). Though there is not always a significant difference in all combination of these two species with depth, as seen in Fig. 7(b), *X. securis* is abundant at 0 m but scarce at other depths. On the contrary, *H. dianthus* seems to become more abundant, while *X. securis* becomes less abundant, with depth.

**Discussion**

The density of *Hydroides dianthus* showed differences between sites and depths. These spatial differences are assumed to be caused by the interaction with environmental factors.
Factors potentially affecting the distribution of *H. dianthus* are examined in detail in this study. Among physical factors, water temperature and dissolved oxygen did not have any significant correlation with the density of *H. dianthus*. The data on the geographical distribution of *H. dianthus* (see Zibrowius 1971, Zibrowius & Thorp 1989, Bastida-Zavala & ten-Hove 2002) show it is widely distributed through the climatic zones from tropical to subarctic (definition of climate zones after Nishimura, 1981). Because of their eurythermy, the difference in water temperature among sites in Osaka bay, whose climate is mid-temperate, is not an obstacle to the distribution of *H. dianthus*. This may be the reason for the no significant correlation between them. Dissolved oxygen also had no significant correlation between *H. dianthus* because of the high dissolved oxygen condition at the sea surface at every site through the year. It is not an obstacle for the distribution of *H. dianthus*. On the other hand, *H. dianthus* is also known to have a high tolerance towards hypoxia (Sagasti et al. 2001). Though Zibrowis (1970) described the suitable range of salinity for the distribution of *H. dianthus* as 28–50 psu, Hill (1967), as *Hydroides uncinita*, stated that it was restricted to salinities above 20 psu and growth was poor between 30–33 psu, concluding that the most suitable level of salinity for the species was between 20–30 psu. Among the studied sites, salinity exceeded 30 psu at Akashi (where *H. dianthus* did not occur at all) and at Tannowa (where *H. dianthus* occurred only sparsely). These facts support Hill’s (1967) argument that high salinity over 30 psu does restrict the distribution of *H. dianthus*.

Among biological factors, with the lack or scarcity of *Xenostrobus securis* at Akashi and Tannowa, macroalgae are likely to be the limiting factor for the distribution of *H. dianthus* because they showed significant negative correlation with the species (Table 3). The abundance of macroalgae at Akashi and Tannowa may form a barrier for the settlement of the larvae of *H. dianthus* through inhibition of water-borne movement or whiplash action (Lewis 1964, Seed 1969, Russell et al. 2008). As Jenkins & Hawkins (2003) stated that grazing activity of limpet shells was also a disincentive for the settlement of barnacle larvae, chitons and limpets may have prevented the settlement of the larvae of the species through their grazing activity at these sites.

The density of *H. dianthus* is also scarce at Maishima as well as Akashi and Tannowa. Considering that the salinity at Maishima is similar to that of Nishinomiya where *H. dianthus* is abundant, it seems that salinity is not a limiting factor for the distribution of the species, but some biological factors act as limiting factors here. As is seen in Table 3, significant negative correlations between *H. dianthus* and macroalgae or *X. securis* suggest that there is a competition for substrata between them. The competition for the substrata between *H. dianthus* and *X. securis* is also shown with depth (Table 4, Fig. 7(b)). *X. securis*, with a longevity of 1–2 years similar to *H. dianthus* (Grave 1933, Kohama et al. 2001), also may have gained advantage in their competition over the latter, with only one recruit time in summer (Dean & Hurd 1980) by having two yearly recruit times in summer and autumn (Kohama et al. 2001). Chitons and limpets that prey on juvenile *H. dianthus* together with small macroalgae on the substrata are not a limiting factor for the distribution of *H. dianthus* at Maishima because they did not occur here at all (Table 2). As well as physical factors, the biological factors including sessile or sedentary organisms are considered to have restricted the distribution of the species.

Taking into account the factors potentially limiting the distribution of *H. dianthus* discussed in the present study, inland bays in Japan with no records of *H. dianthus* where the salinity is less than 30 psu seem to be vulnerable to its invasion in the future. However, even if salinity meets the condition for the invasion of *H. dianthus*, it does not always occur because other limiting factors may prevent their invasion. In the present study, it is estimated that abundance of macroalgae and *X. securis* acted as such a limiting factor. If we intend to predict the invasion of *H. dianthus* into inland bays here and there in Japan, we should pay attention not only to the environmental factors like salinity, but also to the presence of these competing species as the biological factors. It is estimated that *X. securis*, which may be one of the limiting factor for the distribution of *H. dianthus* in Osaka Bay, has already invaded into Japanese waters in the 1970s (Kimura 2001). It is also known that *X. securis* is already widely distributed at inland bays in Japan including Tokyo Bay and Hamana Lake (Otani 2002, Iwasaki et al. 2004) where *H. dianthus* also occurs. This means that there may be a similar competition between *X. securis* and *H. dianthus* as presently occurs in Osaka Bay. However, there are no studies about their competition other than Osaka Bay. We should clarify common limiting factors restricting the invasion of *H. dianthus* through studies at various bays in Japan because those studies always lead us to the breakthrough of the mechanisms of invasion and expansion of invading species when they enter new worlds.

**Acknowledgments**

We express sincere thanks to Dr. R. Willan of the Museum and Art Gallery of the Northern Territory who kindly helped us to improve the English text and made valuable comments. Thanks are also due to Dr. S. Ishida of the Osaka Museum Natural History for many helpful suggestions. We are deeply grateful to Dr. R. Bastida-Zavala of Ciudad Universitaria who identified the specimen, Dr. E. Nishi of Yokohama National University, Dr. S. Aoki of the Toyoohashi University of Technology and Dr. E. K. Kupriyanova of Flinders University who gave us useful papers and two research divers of Marine Ecology Institute for collecting many samples.
References

Aoki S (2009) Studies on the transfer character of the electric furnace slag by the wave action and the current and its applicability for practical use. Rep Coast Eng Lab Toyohashi Univ Tech, 46 pp. (in Japanese)

Bastida-Zavala JR, ten Hove HA (2002) Revision of Hydroides Gunnerus, 1768 (Polychaeta; Serpulidae) from the western Atlantic region. Beaufortia 52: 103–178.

Dean TA, Hurd LE (1980) Development in an estuarine fouling community: The influence of early colonists on later arrivals. Oecologia (Berl.) 46: 295–301.

Grave BH (1933) Rate of growth, age at sexual maturity, and duration of life of certain sessile organisms, at Woods Hole, Massachusetts. Biol Bull 65: 375–386.

Hill MB (1967) The life cycles and salinity tolerance of the serpulids Mercierella enigmatica Fauvel and Hydroides uncinita (Philippi) at Lagos, Nigeria. J Anim Ecol 36: 303–321.

Iwasaki K, Kimura T, Kinoshita K, Yamaguchi T, Nishikawa T, Nishi E, Yamanishi R, Hayashi I, Okoshi K, Kosuge T, Suzuki T, Hemmi Y, Furuta T, Mukai H (2004) Human-mediated introduction and dispersal of marine organisms in Japan: Results of a questionnaire survey by the committee for the preservation of the natural environment, the Japanese Association of Benthology. Jpn J Benthol 59: 22–44. (in Japanese with English abstract)

Jenkins SR, Hawkins SJ (2003) Barnacle larval supply to sheltered rocky shores: a limiting factor? Hydrobiologia 503: 143–151.

Kimura T (2001) Where did Xenostrobus securis come from? Its identity and the route. In: Aliens in black outfits: The current knowledge of alien sessile bivalves (ed The Sessile Organisms Society of Japan). Kosei-sha Kosei-kaku, Tokyo, pp. 47–69. (in Japanese)

Kohama T, Montani S, Kajiwara Y, Yamada M (2001) Population dynamics of sessile bivalves Mytilus galloprovincialis and Xenostrobus securis in a hyper eutrophicated bay, Japan. NSUGAF 67: 664–671. (in Japanese with English abstract)

Lewis JR (1964) The Ecology of Rocky Shores. English University Press, London, 323 pp.

Link H, Nishi E, Tanaka K, Bastida-Zavala R, Kupriyanova EK, Yamakita T (2009) Hydroides dianthus (Polychaeta: Serpulidae), an alien species introduced into Tokyo Bay, Japan. Mar Biodiversity Rec 2: 1–5.

Nakajima M, Yamamoto K, Tsujino K (1995–1999) Seasonal observation of water quality in Osaka Bay. Annu Rep Osaka Pref Fish Exp Stn.

Nishimura S (1981) The sea and life on the earth. Introductory for biogeography. Kaisei-sha, Tokyo, 284 pp. (in Japanese)

Otani M (2002) Appearance and latest trends of introduced marine sessile animals in Japanese waters. Sessile Org 19: 69–92. (in Japanese with English abstract)

Otani M (2004) Introduced marine organisms in Japanese coastal waters, and the processes involved in their entry. Jpn J Benthol 59: 45–57. (in Japanese with English abstract)

Otani M, Yamanishi R (2007) Two newly recorded alien species Rhithropanopeus harrisii (Crustacea; Panopeidae) and Hydroides dianthus (Polychaeta; Serpulidae). Sessile Org 24: 161. (in Japanese)

Russell LK, Hepburn CD, Hurd CL, Stuart MD (2008) The expanding range of Undaria pinnatifida in southern New Zealand: distribution, dispersal mechanisms and the invasion of wave-exposed environments. Biol Invas 10: 103–115.

Sagasti AL, Schaffner C, Duffy JE (2001) Effects of periodic hypoxia on mortality, feeding and predation in an estuarine epifaunal community. J Exp Mar Biol Ecol 258: 257–283.

Seed R (1969) The ecology of Mytilus edulis L. (Lamellibranchiata) on exposed rocky shores. I. Breeding and settlement. Oecologia (Berlin) 3: 277–316.

Zibrowius H (1971) Les espèces Méditerranéennes du genre Hydroides (Polychaeta Serpulidae). Remarques sur le prétendu polymorphisme de Hydroides uncinita. Téthys 2: 691–745.

Zibrowius H (1978) Introduction du polychète Serpulide japonais Hydroides ezonesis sur la côte atlantique française et remarques sur la répartition d’autres espèces de Serpulide. Téthys 8: 141–150.

Zibrowius H, Thorp CH (1989) A review of the alien serpulid and spirorbid Polychaetes in the British Isles. Cah Biol Mar 30: 271–285.