The spread goes on: the non-indigenous species *Grandidierella japonica* Stephensen, 1938 (Amphipoda: Aoridae) has reached Brittany (Gulf of Morbihan)

Gabin Droual[1], Vincent Le Garrec[1], Jérôme Cabelguen[2], Guillaume Gélinaud[3, 4] & Jacques Grall[1]

[1] Université de Brest, CNRS, UMS 3113, Observatoire marin, Suivis habitats benthiques, OSU-IUEM, Rue Dumont d'Urville, 29280 Plouzané, France
[2] Office Nationale de la Chasse et de la Faune Sauvage (ONCFS), 1 allée du Général Le Troadec, BP 520, 56019 Vannes, France
[3] Bretagne Vivante-SEPNB, Réserve Naturelle Nationale des Marais de Séné, route de Brouël, 56860 Séné, France
[4] EA 2119 Géoarchitecture, Territoires Urbanisation Biodiversité Environnement, Université de Bretagne Occidentale, UFR Sciences & Techniques, 6 avenue Le Gorgeu, 29200 Brest, France

Abstract

For the first time in Brittany, the aorid amphipod *Grandidierella japonica* Stephensen, 1938 is reported in the Noyalo River (Gulf of Morbihan). The finding of ovigerous females suggests a well-established, self-sustaining population. Similarly to other European localities, we hypothesise that the shellfish farming industry is the main vector of introduction.

Keywords: *Grandidierella japonica*; shellfish farming; non-indigenous species; Brittany

La propagation continue : l'espèce non-indigène *Grandidierella japonica* Stephensen, 1938 (Amphipoda : Aoridae) a atteint la Bretagne (golfe du Morbihan)

Résumé

Pour la première fois en Bretagne, l'amphipode *Grandidierella japonica* Stephensen, 1938 est signalé en rivière de Noyalo (golfe du Morbihan). La découverte de femelles ovigères suggère qu'une population viable y est bien établie. Tout comme dans d'autres régions européennes, nous faisons l'hypothèse que le vecteur principal d'introduction serait la conchyliculture.

Mots-clés : *Grandidierella japonica* ; conchyliculture ; espèce non-indigène ; Bretagne

Corresponding author:
Gabin Droual (e-mail : Gabin.Droual@univ-brest.fr)

Introduction

Grandidierella japonica Stephensen, 1938 is an amphipod originally described from Japan (Stephensen, 1938). It has firstly been reported outside its natural range in the San Francisco Bay by Chapman & Dorman (1975). Since, and due to various ways of transports (ballast water, oyster spat, leisure sailing) *G. japonica* has been found all around Europe, like in United Kingdom (Smith *et al.,* 1999; Ashelby, 2006), and more recently along the French (Jourde *et al.,* 2013; Lavesque *et al.,* 2014), Swedish (Berggren, 2015) and Italian coasts (Marchini *et al.,* 2016; Munari *et al.,* 2016). We present in this work a new locality for this species along the French coasts and the first one in Brittany. We discuss about the potential way of introduction, as well as a small review of morphological variations that may be useful for the benthologist community.

Material and methods

The Gulf of Morbihan is a sheltered shallow macrotidal bay of 115 km^2 protected from the swell by the Quiberon peninsula. The gulf receives an input of seawater from a channel at the south-west in Port Navalo (900 m wide) through the tide and three freshwater inputs from Vannes and Noyalo estuaries in the east and from Auray in the west (Figure 1) (Girard *et al.,* 1996).

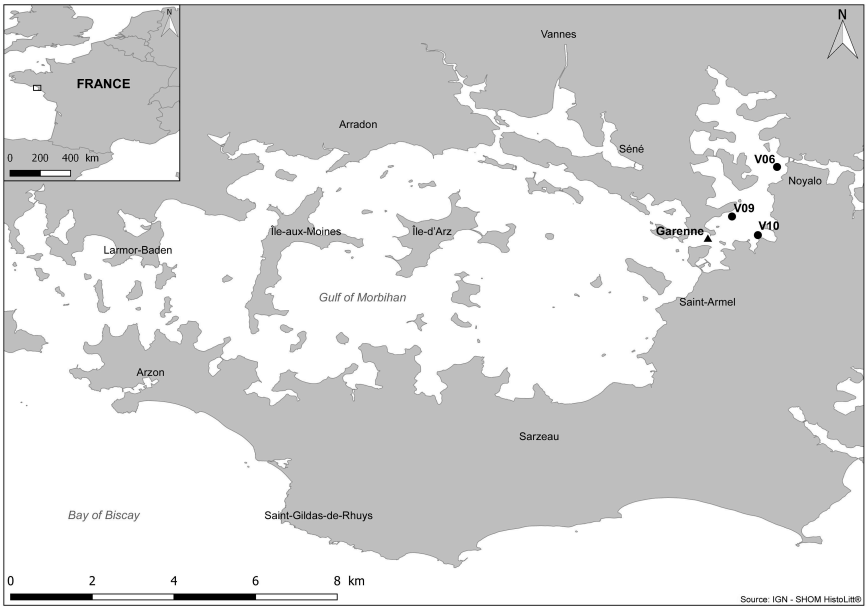

Figure 1: Map of the Gulf of Morbihan. Black dots indicate intertidal stations and the black triangle the subtidal station where *Grandidierella japonica* Stephensen, 1938 was found.

The samples, were collected in October 2015, at the eastern part of the bay close to Noyalo harbour (Figure 1) and are located in or bordering the Réserve Naturelle des marais de Séné.

Three intertidal stations (V06, V09, V10) were sampled using a hand-corer (0.008 17 m^2) and one subtidal station (Garenne) was sampled using a Van Veen grab (0.1 m^2) (Figure 1). All stations were characterised by muddy sediment and brackish waters conditions (Girard *et al.,* 1996; Allenou *et al.,* 2002). Once sieved on a mesh of 1 mm, samples were fixed in a 4% formaldehyde solution. Then, the macroinvertebrates were sorted and stored in 70% ethanol before identification in the laboratory. The specimens were identified using descriptions given by various authors of recent reports (Jourde *et al.,* 2013; Lavesque *et al.,* 2014). They all fit original description (Stephensen, 1938) and Chapman & Dorman (1975) redescription. Specimens were examined using a Zeiss Stemi 2000-C stereomicroscope and an Olympus BX-40 microscope. The pictures were made by a Retiga 2000R Q-Imaging camera installed on a Leica DM-IRB and with a Canon EOS 600D.

Length measurements were made from the rostrum to the telson.

Results

A total of 89 *Grandidierella japonica* specimens (Figure 2) were found including 32 males, 54 females (among which 13 ovigerous females and 24 with oostegites plates) and 3 undifferentiated juveniles. Over the 4 sampling stations the ovigerous females were present in 2 stations. The density was variable, ranging from a minimum of 20 ind m^{-2} at Garenne to up to 5018 ind m^{-2} at V10.

The maximum length observed was 8 mm for an ovigerous female and up to 7.5 mm for the larger male.

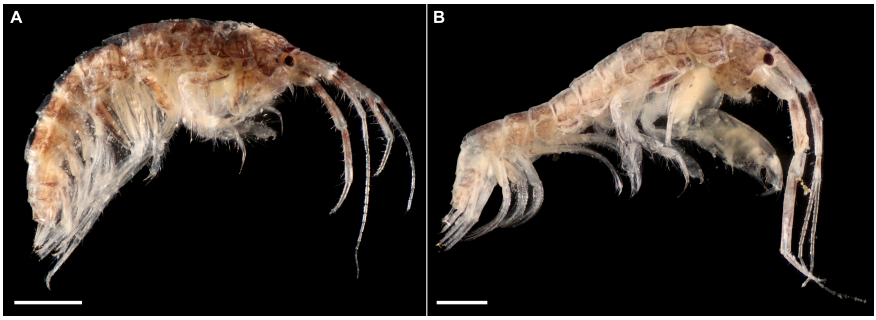

Figure 2: (A) female and (B) male of *Grandidierella japonica* Stephensen, 1938 from the Gulf of Morbihan (V10 and Garenne respectively). Scale bars: 1 mm.

Our specimens are all incomplete, they miss either antennae and/or pereopods. Even with carefulness the appendages are very deciduous but identification was feasible thanks to several diagnostic characters: 1) uniramous uropods 3; 2) ramus of uropods 3 longer than peduncle; 3) shape of gnathopod 1 carpochelate in mature males; 4) two accessory teeth on male gnathopod 1 carpus in addition to the antero-distal one; and 5) presence of stridulating organs on the gnathopods 1 in males.

The associated fauna found in stations V06, V09 and V10 was characterised by a large number of the gastropod *Peringia ulvae* (Pennant, 1777), the bivalve *Abra tenuis* (Mon-

tagu, 1803) and the oligochaete *Tubificoides* cf *benedii* (Udekem, 1855). Moreover, in samples from Garenne the polychaete *Micromaldane ornithochaeta* Mesnil, 1897, the gastropod *Crepidula fornicata* (Linnaeus, 1758), nematods, the amphipod *Monocorophium acherusicum* (Costa, 1853) and the bivalve *Nucula sulcata* Bronn, 1831 were abundant. In addition, another species of Aoridae, *Microdeutopus anomalus* (Rathke, 1843), was found. Together with *G. japonica*, three other non-natives species populations were present, the gastropods *Crepidula fornicata* and *Tritia neritea* (Linnaeus, 1758) and the bivalve *Ruditapes philippinarum* (Adams & Reeve, 1850).

Discussion

Along the French coasts, farming of the Japanese oyster *Crassostrea gigas* (Thunberg, 1793) has replaced the culture of *Ostrea edulis* Linnaeus, 1758 which was affected by two epizootics events in the seventies (Marteil, 1969; Goulletquer & Héral, 1997). Since then, *C. gigas* has been transplanted, immediately from Japan (Marteil, 1969) and from numerous other localities in the world (British Columbia), Europe (Ireland, Spain) or between the French basins of oyster production (Goulletquer, Bachelet, *et al.,* 2002; Lavesque *et al.,* 2014; Cecere *et al.,* 2016). All those transfers led to the introduction and spread of numerous non-native marine species in Europe (Gruet *et al.,* 1976; Goulletquer, Bachelet, *et al.,* 2002). Where no worldwide shipping harbour is in the vicinity, the shellfish farming industry is considered as the most likely way of introduction of *G. japonica* into Marennes-Oléron and Arcachon Bay (Jourde *et al.,* 2013; Lavesque *et al.,* 2014).

Similarly, the Gulf of Morbihan is a main important site for intertidal oyster farming in southern Brittany, with 4000 t per year produced (Allenou *et al.,* 2002; Dréano A., 2017, pers. comm.). As a species without planktonic larval stage and restricted to estuarine conditions (Chapman & Dorman, 1975), *G. japonica* has probably arrived in Brittany through a secondary way of introduction. In addition, the absence of shipping activities in the vicinity of the sampled area we consider the shellfish farming industry to be the most likely reason for the introduction of *G. japonica*. Another hypothesis for secondary introduction, less likely but not impossible, is the intense recreational sailing activities between the Gulf of Morbihan and other localities. As argued by Wasson *et al.* (2001), this activity may be an underestimated vector of introduction.

Shellfish culture (oysters mainly) is established all around Brittany in the same environmental water conditions (estuaries, rias) and we are thus expecting *G. japonica* to be present also in northern Brittany or in the eastern Channel (North of France). Under the current circumstances of continuous transfer of species from different areas, benthic ecologists are required to consult also taxonomic literature from different zoogeographical areas, especially when analysing benthos of high-risk sites of introduction, such as harbours, marinas and shellfish farms.

The presence of ovigerous females show that reproduction takes place in the Gulf of Morbihan. The probability to find this species also in other areas in the near future is thus high not only because of self-sustaining populations but also because of secondary ways of dispersion (e.g. oyster farming, sailing activities) from other localities that still occur (Bachelet *et al.,*

2009; Le Duff *et al.,* 2013; Cecere *et al.,* 2016).

Currently we do not know the geographical origin of our specimens from Brittany. They could either originate from Marennes-Oléron area and/or Arcachon Bay, from another French or European locality or even directly from Japan. Also, the area where the species was first introduced in Europe and its origin is currently unknown. Apart from Glémarec (1964) and Afli (1999) no study on the benthic macrofauna communities have been published. However, the intertidal area near the Noyalo river was sampled in 2004 and 2007, without sightings of *G. japonica* (Gélinaud & Le Roux, unpublished data). Unfortunately, as reported by various authors (Ashelby, 2006; Jourde *et al.,* 2013; Lavesque *et al.,* 2014) most commonly used European literature was inadequate to correctly identify the species (e.g. Lincoln, 1979) and likely led to many misidentifications, especially the female which looks like *Microdeutopus* spp. (found in sympatry in this study). The arrival of *G. japonica* has then been unnoticed and the species may have been present there for several years.

Regarding the morphology of *G. japonica*, Marchini *et al.* (2016) highlighted some variations across the various descriptions of the species in the literature. Firstly the size of the specimens following the studies showed considerable variations. Myers (1981), Greenstein & Tiefenthaler (1997), Smith *et al.* (1999) and Marchini *et al.* (2016) give a length below 9 mm, comparable to the animals found in this work. While Stephensen (1938), Nagata (1960), Chapman & Dorman (1975), Ariyama (1996), Munari *et al.* (2016) and Berggren (2015) reported lengths reaching 13 mm for the females and up to 22 mm for males. While most studies only mentioned the presence of spines, in accordance with the original description the great majority of our specimens have 4 spines (variations: 2 to 5 spines) on the first articles on the antenna 1. Regarding the small accessory tooth on the inner margin of the first pair of gnathopod on males Marchini *et al.* (2016) suggested that the variation found in the literature was due to different maturity stages. In this work our males below 5.5 mm length only show a median tooth near the middle of the carpus, while they lack a second one near the anterior margin as mentioned in Myers (1981) (Figure 3B). However, both teeth are obvious in our large males above 5.5 mm (Figure 3A) as mentioned in the original description by Stephensen (1938) and thus supporting Marchini *et al.* (2016) suggestion. Munari *et al.* (2016) noticed that their specimens have 3 spines on the antero-lateral margin of the first urosomite, while Chapman & Dorman (1975) give 2 spines in their diagnosis. Almost two-third of our specimens (N=53) showed clearly 3 spines, whereas the others showed two (N=27) or none (N=1). Finally, the number of stridulating organs is also highly variable, ranging from 18–20 (Stephensen, 1938), to less than 40 (Chapman & Dorman, 1975, Hirayama, 1984 and Lavesque *et al.,* 2014 after drawing and photo), to more than 40 (Ariyama, 1996, Munari *et al.,* 2016, present study).

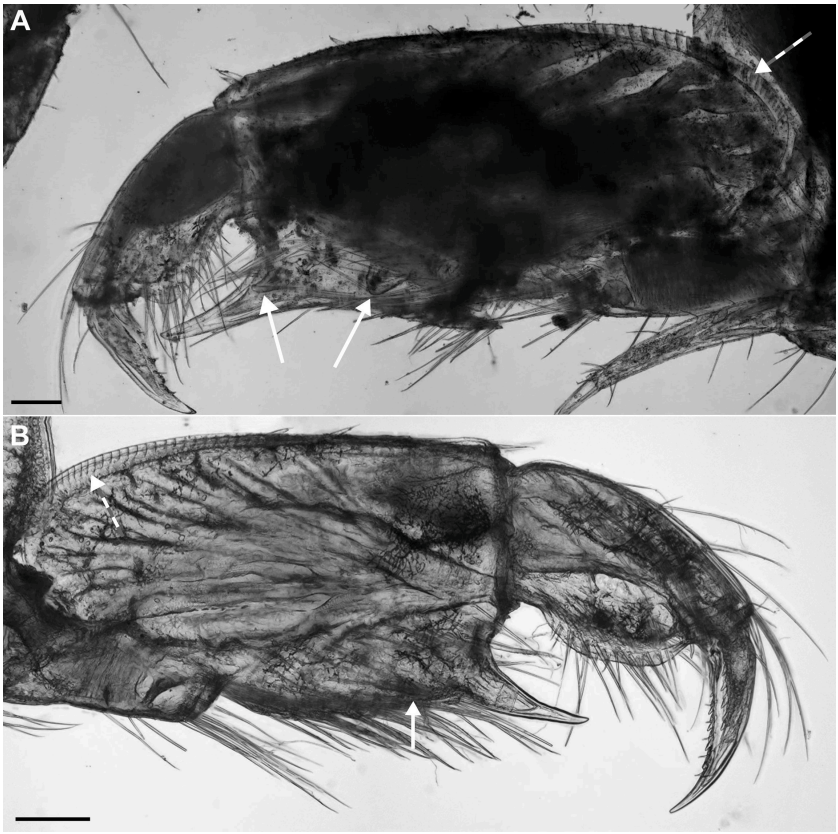

Figure 3: *Grandidierella japonica* Stephensen, 1938: male gnathopod 1 of (A) a large male from V10 and (B) a young male from Garenne 2, with white filled arrows showing the teeth on the carpus and dotted arrows showing the stridulating organs. Scale bars: 100 µm.

Conclusion

This study reports a new record for the Japanese amphipod *G. japonica* on the French Atlantic coasts and the first record of the species in Brittany. We assume that *G. japonica* is possibly much wider distributed than currently known. At present we cannot give a date of introduction to the Gulf of Morbihan area because of the scarce soft substrate macrofaunal benthic data since the beginning of the 21st century. We have hypothesised a scenario of recent introduction from other localities along the French Atlantic coast. A genetic study should focus on this species at a European scale in order to determine whether these amphipods originate from their type locality or whether they come from another area. It would also be interesting to determine whether European harbours show different clades as seen on the west coast of the United States (Pilgrim *et al.,* 2013) which could explain the morphological variation noticed by Marchini *et al.* (2016) and in this work.

Acknowledgements

The authors are grateful to the Réserve Naturelle Nationale des Marais de Séné and to the Réserve Nationale de Chasse et Faune Sauvage du golfe du Morbihan for their financial support to undertake this study. We would like to thank Jérôme Jourde, who provided specimens for comparison from Marennes-Oléron area during the Resomar workshop in 2015. We also would like to thank Ruth Barnich for revising English style and the reviewers of this paper for their constructive comments on the manuscript.

References

Afli, A., 1999. Variabilité temporelle des peuplements macrobenthiques de la partie orientale du golfe du Morbihan (Bretagne). Thèse de doctorat, Université de Bretagne Occidentale, Brest. 192 p.

Allenou, J.-P., Camus, P., Bouget, J.-F. & Joly, J.-P., 2002. Schéma de mise en valeur de la mer Golfe du Morbihan. Étude de l'état trophique du Golfe du Morbihan et croissance des huîtres creuses. Ifremer, station de La Trinité-sur-Mer. 69 p.

Ariyama, H., 1996. Four species of the genus *Grandidierella* (Crustacea: Amphipoda: Aoridae) from Osaka Bay and the northern part of the Kii Channel, central Japan. *Publications of the Seto Marine Biological Laboratory,* **37 (1–2),** pp. 167–191.

Ashelby, C., 2006. Records of the introduced amphipod *Grandidierella japonica* Stephensen 1938 (Crustacea: Amphipoda: Gammaridea: Aoridae) from the Orwell estuary, Suffolk. *Transactions of the Suffolk Natural History,* **42,** pp. 48–54.

Bachelet, G., Blanchet, H., Cottet, M., Dang, C., de Montaudouin, X., de Moura Queirós, A., Gouillieux, B. & Lavesque, N., 2009. A round-the-world tour almost completed: first records of the invasive mussel *Musculista senhousia* in the north-east Atlantic (southern Bay of Biscay). *Marine Biodiversity Records,* **2,** pp. e119. doi:10.1017/S1755267209001080.

Berggren, M. S., 2015. Nya kräftdjur påträffade i Sverige — *Grandidierella japonica* och *Rhithropanopeus harrisii*. *Fauna & Flora,* **110 (1),** pp. 20–23.

Cecere, E., Belmonte, M., Portacci, G., Rubino, F. & Pretrocelli, A., 2016. Live seafood importation as a potential vector for alien introduction in the Taranto seas (southern Italy, Mediterranean sea). *Rapport de la Commission internationale pour l'exploration scientifique de la mer Méditerranée,* **41,** pp. 428.

Chapman, J. W. & Dorman, J. A., 1975. Diagnosis, systematics, and notes on *Grandidierella japonica* (Amphipoda: Gammaridea) and its introduction to the Pacific coast of the United States. *Bulletin of the Southern California Academy of Sciences,* **74,** pp. 104–108.

Girard, A., L'Hardy-Halos, M.-T. & Castric-Fey, A., 1996. Inventaire de la faune et de la flore sur les fonds rocheux du Golfe du Morbihan et de la Ria d'Étel. Concarneau : Station marine du Muséum National d'Histoire Naturelle et du collège de France. 167 p.

Glémarec, M., 1964. Bionomie benthique de la partie orientale du Golfe du Morbihan. *Cahiers de Biologie Marine,* **5 (1),** pp. 33-96.

Goulletquer, P., Bachelet, G., Sauriau, P. G. & Noël, P., 2002. Open Atlantic coast of Europe — A century of introduced species into French waters. In *Invasive aquatic species of Europe: Distribution, impacts and management.* (Eds. Leppäkoski, E., Gollasch, S.

& Olenin, S.) Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 276–290. doi:10.1007/978-94-015-9956-6_30.

Goulletquer, P. & Héral, M., 1997. Marine molluscan production trends in France: from fisheries to aquaculture. In *The history, present condition, and future of the Molluscan fisheries of North America and Europe.* (Eds. MacKenzie, C. L., Burrell, V. G., Rosenfield, A. & Hobart, W. L.) **Volume 3, Europe.** NOAA Technical Report NMFS 129, Department of Commerce, Seattle, Washington, pp. 137–164. 240 p.

Greenstein, D. J. & Tiefenthaler, L. L., 1997. Reproduction and population dynamics of a population of *Grandidierella japonica* (Stephensen) (Crustacea: Amphipoda) in upper Newport Bay, California. *Bulletin of the Southern California Academy of Sciences,* **96,** pp. 34–42.

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,** pp. 173-184.

Hirayama, A., 1984. Taxonomic studies on the shallow water gammaridean Amphipoda of West Kyushu, Japan. II. Corophiidae. *Publication of the Seto Marine Biological Laboratory,* **29 (1/3),** pp. 1–92.

Jourde, J., Sauriau, P.-G., Guenneteau, S. & Caillot, E., 2013. First record of *Grandidierella japonica* Stephensen, 1938 (Amphipoda: Aoridae) from mainland Europe. *BioInvasions Records,* **2 (1),** pp. 51–55.
doi:10.3391/bir.2013.2.1.09.

Lavesque, N., Gouillieux, B., de Montaudouin, X., Bachelet, G., Bonifácio, P. & Simonet, E., 2014. Premier signalement de l'espèce introduite *Grandidierella japonica* Stephensen, 1938 (Crustacea : Amphipoda : Aoridae) dans le bassin d'Arcachon. *An aod - les cahiers naturalistes de l'Observatoire marin,* **III (1),** pp. 11-19.

Le Duff, M., Cadiou, S. & Grall, J., 2013. *Rapana venosa* (Valenciennes, 1846), une nouvelle trouvaille inquiétante. *An aod - les cahiers naturalistes de l'Observatoire marin,* **II (1),** pp. 27-30.

Lincoln, R. J. (1979). British Marine Amphipoda: Gammaridea. (Ed. British Museum (Natural History)) British Museum (Natural History), London. 658 p.

Marchini, A., Ferrario, J. & Nasi, E., 2016. Arrival of the invasive amphipod *Grandidierella japonica* to the Mediterranean sea. *Marine Biodiversity Records,* **9 (38),** pp. 1–7.
doi:10.1186/s41200-016-0049-y.

Marteil, L., 1969. La maladie des branchies des huîtres portugaises des côtes françaises de l'Atlantique : données générales sur la maladie des branchies. *Revue des Travaux de l'Institut des Pêches Maritimes,* **33 (2),** pp. 145-150.

Munari, C., Bocchi, N. & Mistri, M., 2016. *Grandidierella japonica* (Amphipoda: Aoridae): a non-indigenous species in a Po delta lagoon of the northern Adriatic (Mediterranean Sea). *Marine Biodiversity Records,* **9 (12),** pp. 1–8.
doi:10.1186/s41200-016-0018-5.

Myers, A. A., 1981. Taxonomic studies on the genus *Grandidierella* Coutière (Crustacea, Amphipoda). III. Fijian, Australian and Saudi Arabian species. *Bulletin du Muséum National d'Histoire Naturelle,* **4 (3),** pp. 213–226.

Nagata, K., 1960. Preliminary notes on benthic gammaridean Amphipoda from the *Zostera* region of Mihara Bay, Seto Inland Sea, Japan. *Publications of the Seto Marine Biological Laboratory,* **8 (1),** pp. 163–182.

Pilgrim, E. M., Blum, M. J., Reusser, D. A., Lee, H. & Darling, J. A., 2013. Geographic range and structure of cryptic genetic diversity among Pacific North American populations of the non-native amphipod *Grandidierella japonica*. *Biological Invasions,* **15 (11),** pp. 2415–2428.
doi:10.1007/s10530-013-0462-7.

Smith, P., Perret, J., Garwood, P. & Moore, G., 1999. Two additions to the UK marine fauna: *Desdemona ornata* Banse, 1957 (Polychaeta, Sabellidae) and *Grandidierella japonica* Stephensen, 1938 (Amphipoda, Gammaridea). *Newsletter of the Porcupine Marine Natural History Society,* **2,** pp. 8–11.

Stephensen, K., 1938. *Grandidierella japonica* n. sp., a new amphipod with stridulating (?) organs from brackish water in Japan. *Annotationes Zoologicae Japonenses,* **17,** pp. 179–184.

Wasson, K., Zabin, C. J., Bedinger, L., Diaz, M. C. & Pearse, J. S., 2001. Biological invasions of estuaries without international shipping: the importance of intraregional transport. *Biological Conservation,* **102 (2),** pp. 143–153.
doi:10.1016/S0006-3207(01)00098-2.