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The presence of *Melinna palmata* (Annelida: Polychaeta) and *Ensis directus* (Mollusca: Bivalvia) related to sedimentary changes in the Bay of Seine (English Channel, France)

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Abstract: Since late 1990s the annelid polychaete *Melinna palmata* and the mollusc bivalve *Ensis directus* have been collected in the eastern part of the Bay of Seine (English Channel), indicating changes in the benthic communities. *Melinna palmata* was never collected prior to 2002, whereas it was reported in the muddy fine sands of the western part of the Channel, along the French (e.g. Bay of Cherbourg) and southern UK (e.g. Southampton Waters) coasts. *Ensis directus* was first reported in 1998 and now appears to be well implanted, given the abundant population collected in 2006. The colonization of *Melina palmata* seems to be a consequence of recent increase of the fine sediment in the eastern part of the Bay, while that of the invasive *Ensis directus* seems more likely to be related to its southwest expansion, from the Scheldt estuary (Belgium and Netherlands) towards the Bay. Since both species have complex life cycles including planktonic larval phases, their colonisation may also be favoured either by an accidental introduction via ballast waters or by larval dissemination from neighbouring populations.

Résumé : *La présence de* Melinna palmata *(Annelida : Polychaeta) et de* Ensis directus *(Mollusca : Bivalvia) en relation avec les changements sédimentaires en Baie de Seine (Manche, France).* Plusieurs récoltes des deux espèces *Melinna palmata* (annélide polychète) et *Ensis directus* (mollusque bivalve) ont été effectuées dans la partie orientale de la Baie de Seine depuis la fin des années 1990, indiquant un changement récent de la faune benthique de cette région. *M. palmata* n'avait jamais été signalée en Baie de Seine, alors que des populations sont florissantes dans les vases sableuses des fonds de baies de la Manche occidentale le long des côtes françaises (par exemple la voisine Rade de Cherbourg), et dans toutes les baies côtières du sud de l'Angleterre (par exemple la Rade du Solent, Southampton). La récolte d'une population abondante d'*E. directus* en 2006 confirme son implantation qui avait été observée pour la première fois en 1998. L'introduction

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de *M. palmata* est probablement liée à un envasement récent de la partie orientale de la baie, alors que celle d'*E. directus* est liée à la progression vers le sud-ouest (de l'estuaire de l'Escaut à l'estuaire de la Seine) de cette espèce invasive. Pour ces deux espèces à cycle-bentho-pélagique, la colonisation de la Baie de Seine peut résulter d'un apport larvaire naturel depuis des populations voisines ou d'une introduction accidentelle due à l'homme (i.e. eaux de ballasts).

Keywords: *Melinna palmata* ● *Ensis directus* ● Bay of Seine ● English Channel ● Range expansion ● New records ● Environmental disturbances ● Invasive species

Introduction

Estuaries and coastal embayments exhibit a high biological diversity, which plays an important role in coastal ecosystem functions such as nutrient fluxes and primary and secondary productivity. However, many of these environments are also subject to increasing anthropogenic threats - including civil engineering works, fishing, pollution, and the introduction of alien species, in response to human development and urbanization - which can greatly affect marine habitats and biological communities. The Bay of Seine, the main coastal embayment along the French coast of the English Channel (Fig. 1), is highly representative of such recent alterations. Since the mid-19th century, the natural evolution of the Seine estuary has been drastically disrupted and has been completely fashioned by man through the building of embankments, jetties and dikes for the development of industrial and harbour activities (Lesourd et al., 2001). The most recent engineering works have been the construction of the 'Normandy Bridge' and the extension of the Havre Harbour (project 'Port 2000') (Dauvin et al., 2006 & 2007). These man-made modifications have mainly lead to changes in the morpho-sedimentary dynamics of the estuary, accompanied by an increase in fine-grained sedimentation in subtidal shallow waters. Furthermore, high levels of heavy metals and organic contaminants make the Seine estuary among the most polluted European estuaries, provoking major concern for the biological compartments (Dauvin, in press).

As the benthos is a good surrogate for measuring the consequences of natural and anthropogenic disturbances in coastal environments (Dauer et al., 2000), several research programs have been developed in the Bay of Seine, especially focusing on the benthos at a variety of spatial scales over the last few decades. The benthic communities were described through a large-scale dredging project carried out in the 1970s (Gentil & Cabioch, 1997), and a mesoscale quantitative study was conducted in 1998-1999 (Ghertsos, 2002). The presence of *Lanice conchilega* (Pallas, 1766) and the associated fine sand community was documented in the western Bay of Veys (Fig. 1) in March and October 1997 (Dauvin et al., 2004), while several benthic studies have been carried out in the eastern part of the bay (Thiébaut et al., 1997; Barnay, 2003; Dauvin et al., 2007) and in the Seine estuary (Dauvin et al., 2006) since the end of the 1980s.

Seven benthic surveys - conducted over two decades (1986-2006) prior to the recruitment period of the dominant species in February-March - have been used to define a spatio-temporal cartography of the macrofauna in the entire eastern part of the Bay of Seine (Thiébaut et al., 1997; Barnay, 2003; Dauvin, Gentil & Thiébaut, unpublished data). More recently, the database MABES2 (Macrobenthos of the Bay and Estuary of Seine), available from the data administrator of the GIP Seine Aval (nbacq@seine-aval.fr), has been set up to record all these benthic data (Dauvin et al., 2007). This allows a rapid extraction of all available information required to assess faunal changes in response to habitat modifications. MABES2 is a permanent database that will be updated as new observations are made.

The present paper describes the recent increase of the *Melina palmata* Grube, 1870 and *Ensis directus* (Conrad, 1843) populations in the eastern part of the Bay of Seine, which appears to indicate recent changes in the composition of the macrobenthic communities, likely related to both natural and anthropogenic environmental alterations.

Materials and methods

Table 1 summarizes the available data since 1998, the year in which the first live *Ensis directus* individual was recorded subtidaly. For the PECTOW campaigns, samples were collected using a Hamon grab (0.25 m^2, about 15 cm depth), with three grab samples collected at each station, two for biological analysis and one for sediment grain

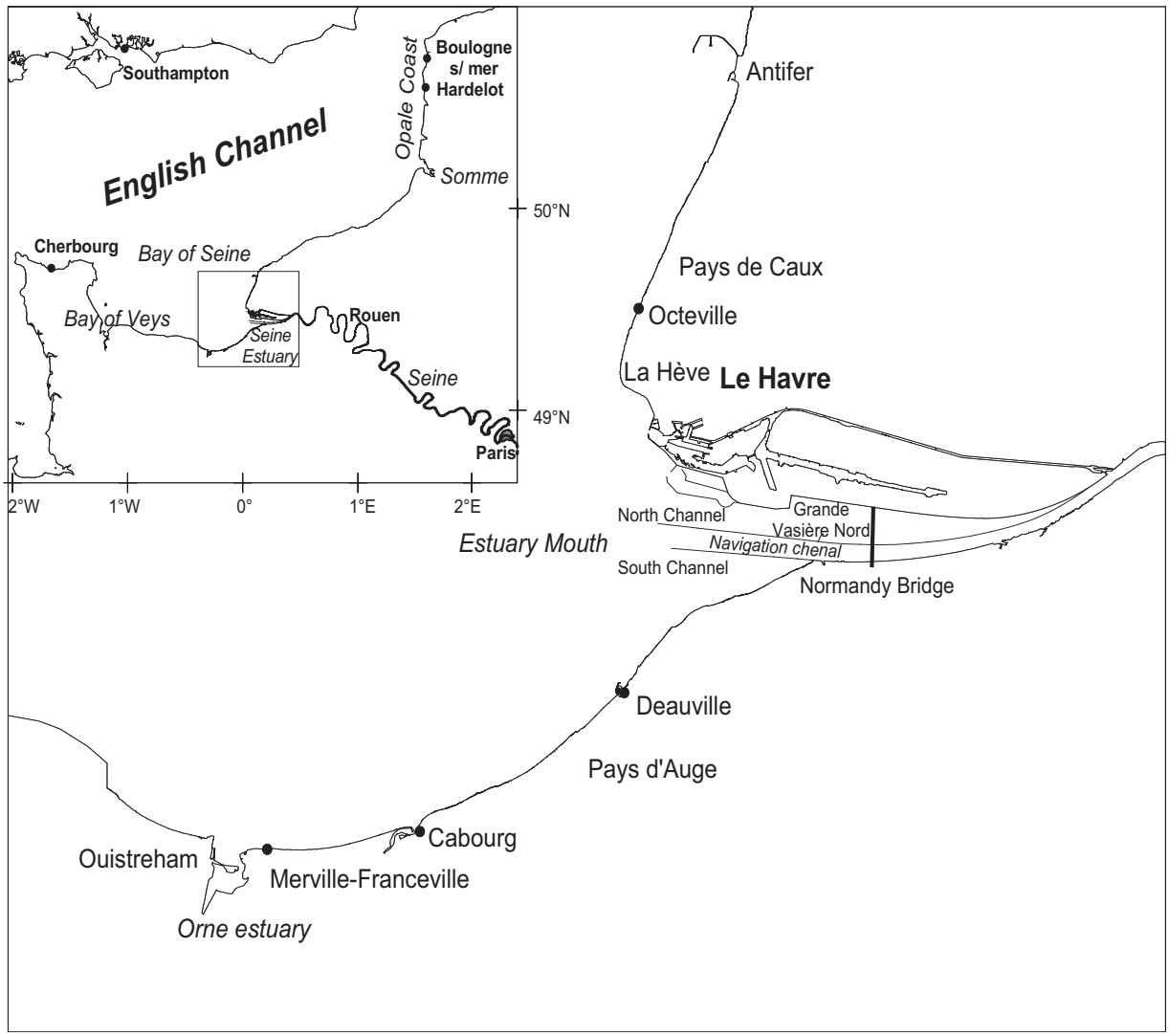

Figure 1. Location of the Bay of Seine and the Seine estuary in the eastern part of the English Channel
Figure 1. Localisation de la baie et de l'estuaire de Seine en Manche orientale.

analysis. Samples were sieved through a 2 mm mesh, and densities were expressed as the number of individuals m^{-2}. For the other benthic samplings, during different monitoring contracts and scientific programs, different types of sampling gears were used: Rallier du Baty dredge, Hamon grab, Smith McIntyre grab or Van Veen grab (Table 1); benthic samples were sieved either on a 1 mm or 2 mm mesh. Figure 2 shows where the 706 samples were collected in the study area from 1998 to 2006.

The relationships between organism densities and sediment grain size were calculated using the Spearman rank coefficient. Three sediment categories were considered: mud (< 63 µm), fine sand (63-250 µm) and medium sand (250-500 µm).

Results

Evolution of the sediment characteristics

From 1988 to 2001, most stations were predominantly composed of fine sand (i.e. < 5% of mud content) and muddy fine sand (i.e. 5-25% of mud content) (Fig. 3). Between 6.4 and 22.5% of the sampled stations, located off the Seine estuary and/or in Antifer harbour, were composed of sandy mud (i.e. 25-75% of silt-clay content). The sediment was unevenly distributed in 2001: although fine sand covered most of the sampled area, sandy mud was found only at the mouth of the Seine estuary. In 2006, sediments were muddier than in previous years: 31.1% of

Table 1. Main characteristics of the macrobenthos sampling campaigns from 1998 to 2006 (Data from the MABES2 database).
Tableau 1. Principales caractéristiques des campagnes d'échantillonnage du macrobenthos entre 1998 et 2006 (données extraites de la base de données MABES2).

Year	Campaign name	Gear	Sieving Size	Number of stations	Cumulated number of stations/year
1998	BENTHOSEINE	Hamon Grab	2 mm	19	
	Octeville	Van Veen Grab	2 mm	24	43
1999	BENTHOSEINE	Hamon Grab	2 mm	17	17
2000	Port 2000	Smith McIntyre Grab	1 mm	43	
		Rallier du Baty Dredge	1 mm	4	47
2001	Seine-Aval	Hamon Grab	1 mm	44	
			2 mm	11	
	PECTOW 01	Hamon Grab	2 mm	61	116
2002	Port 2000	Smith McIntyre Grab	1 mm	15	
	Seine-Aval	Hamon Grab	2 mm	69	
		Van Veen Grab	1 mm	47	131
2003	Octeville	Smith McIntyre Grab	1 mm	32	
	Port 2000	Smith McIntyre Grab	1 mm	36	
		Rallier du Baty Dredge	1 mm	4	72
2004	Octeville	Smith McIntyre Grab	1 mm	32	
	Port 2000	Smith McIntyre Grab	1 mm	42	
		Rallier du Baty Dredge	1 mm	4	78
2005	Octeville	Smith McIntyre Grab	1 mm	32	
	Port 2000	Smith McIntyre Grab	1 mm	40	
		Rallier du Baty Dredge	1 mm	6	78
2006	Rouen Harbour	Hamon Grab	1 mm	4	
	PECTOW	Hamon Grab	2 mm	74	
	Port 2000	Smith McIntyre Grab	1 mm	39	
		Rallier du Baty Dredge	1 mm	7	124

the sampled stations were characterized by sandy mud or mud (i.e. > 75% of silt-clay content) and were widely distributed around the bay, appearing opposite the Seine estuary, off the coast at Cabourg, and along the coasts between Le Havre and Antifer (Fig. 3).

Spatio-temporal distribution of Ensis directus

Ensis directus was first recorded subtidally in the eastern Bay of Seine in 1998, with 5 and 15 ind. m^{-2} at two stations in the deposit zone of the Le Havre harbour at Octeville (between Le Havre and Antifer) (Fig. 2). *E. directus* was not reported in 1999, but the low number of sampled stations may explain this absence (Table 1). There were a few more reports of the species in the same area between 1998 and 2006. Then, from 2000 to 2006, the species was regularly reported from stations opposite the Seine estuary and along the Pays d'Auge coastline. In 2001, *E. directus* was found at 9 stations (7 near Deauville), ranging from 2 to 96 ind.m^{-2} (PECTOW 01); five years later (PECTOW 06), 2 to 78 ind.m^{-2} were found at 14 stations along the Pays d'Auge coastline between Le Havre and Ouistreham (Fig. 2). Between 1998 and 2006, *E. directus* occurred in 81 stations out of the 706 sampled ones.

In 2006, the density of *E. directus* was non-significantly correlated at the 5% level to the sediment descriptors.

Spatio-temporal distribution of Melinna palmata

Melinna palmata was not reported in the PECTOW campaigns from 1986 to 2001. This species was first recorded (2 ind.m^{-2}) in 2002 at a station situated just

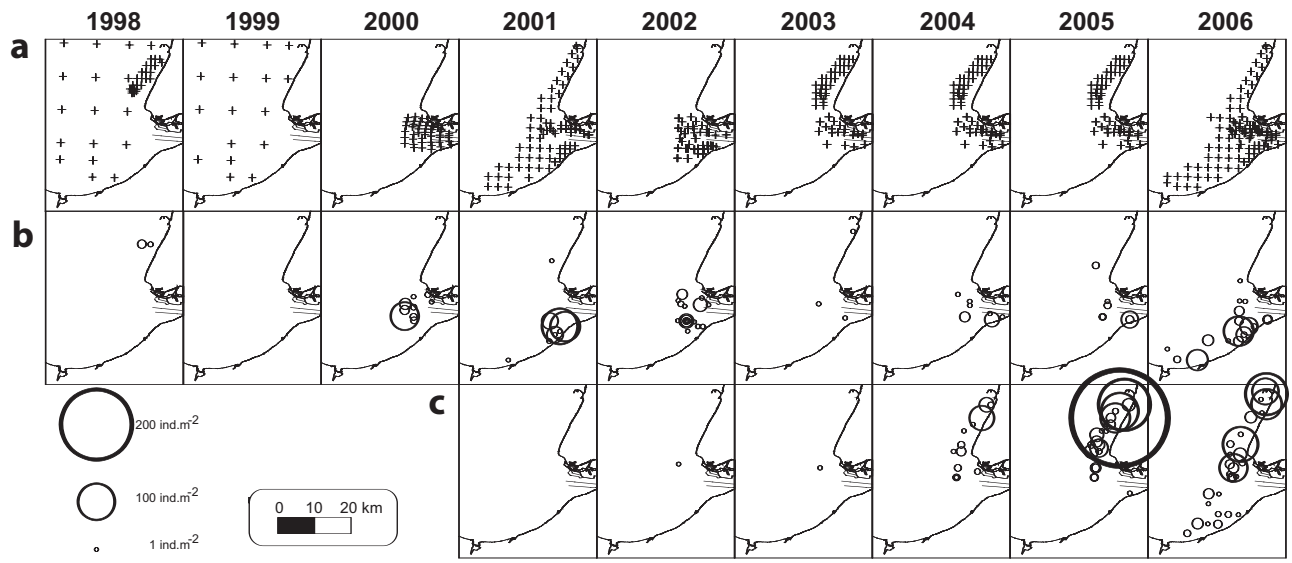

Figure 2. Benthic sites sampled between 1998 and 2006 (a) and abundance (ind.m^{-2}) of *Ensis directus* (b) and *Melinna palmata* (c).
Figure 2. Stations benthiques échantillonnées entre 1998 et 2006 (a) et abondance en (ind.m^{-2}) de *Ensis directus* (b) et *Melinna palmata* (c).

opposite the mouth of the Seine estuary (Fig. 2). Then, there was only one record in 2003 (3 ind.m^{-2}) in the same area. From 2004 to 2006, however, the species appears to have extended its population, being commonly reported in 2005 between Le Havre and Antifer (reaching up to 277 ind.m^{-2}). In 2006, *M. palmata* was observed at 24 stations; primarily between Le Havre and Antifer (11 stations) and along the Pays d'Auge coastline (10 stations) (Fig. 2). The species was widespread in the sampled area (except near the mouth of the Seine estuary, which had a freshwater influence), reaching from 2 ind.m^{-2} up to 114 ind.m^{-2}; three stations near the Antifer harbour and one off the coast of Le Havre had less than 50 ind.m^{-2} and along the Pays d'Auge coastline between Deauville and Ouistreham he density was even low (2 to 22 ind.m^{-2}). From 2002 to 2006, *M. palmata* occurred in 66 stations out of the 483 sampled ones.

In 2006, *Melina palmata* were mainly found at stations where silt-clay contents of the sediment exceeded 20% (Fig. 4), their densities being positively correlated with mud contents (r_S = 0.355, $p < 0.01$, n = 74) and negatively correlated with fine sand contents (r_S = -0.317, $p < 0.01$, n = 74). *M. palmata* was present in non-muddy sediments, particularly at the mouth of the Seine estuary (Fig 2), thus in less saline waters. Excluding these stations from the analysis reinforced the correlation between mud content and *Melinna* densities (r_S = 0.564, $p < 0.001$, n = 59).

Discussion

Ensis directus

Ensis directus closely resembles to other species of the genus (e.g. *Ensis arcuatus*). However, the *Ensis* species has been very carefully identified, ever since *E. directus* was introduced in 1991 along the French coast adjacent to the Dover Strait, to monitor its progression in the English Channel. A similar progression occurred in the North Sea, were it was introduced by tankers evacuating ballast water from North American Atlantic coasts (Severjins, 2001). Since the first specimens were found in 1979 near the mouth of the river Elbe in the German Bight (Severjins, 2001), *E. directus* has spread considerably along the western European coasts, from north (Oslo Fjord, Norway) to south (English Channel) (Luczak et al., 1993; Severijns, 2001; Dewarumez et al., 2003; Palmer, 2003). Along the English coasts, the species has been reported from the Humber Estuary (eastern coast) to Rye Bay in the English Channel (Palmer, 2003).

The first record of the species on the French coast was in 1991 at Gravelines in the southern part of the North Sea (Luczak et al., 1993) (Fig. 5). The species then expanded to the southwest in the eastern Channel: along the Opale Coast at Boulogne-sur-mer in 1992 and Hardelot in 1993, off the Bay of Somme (Picardy) in 1996 and the Bay of Seine in

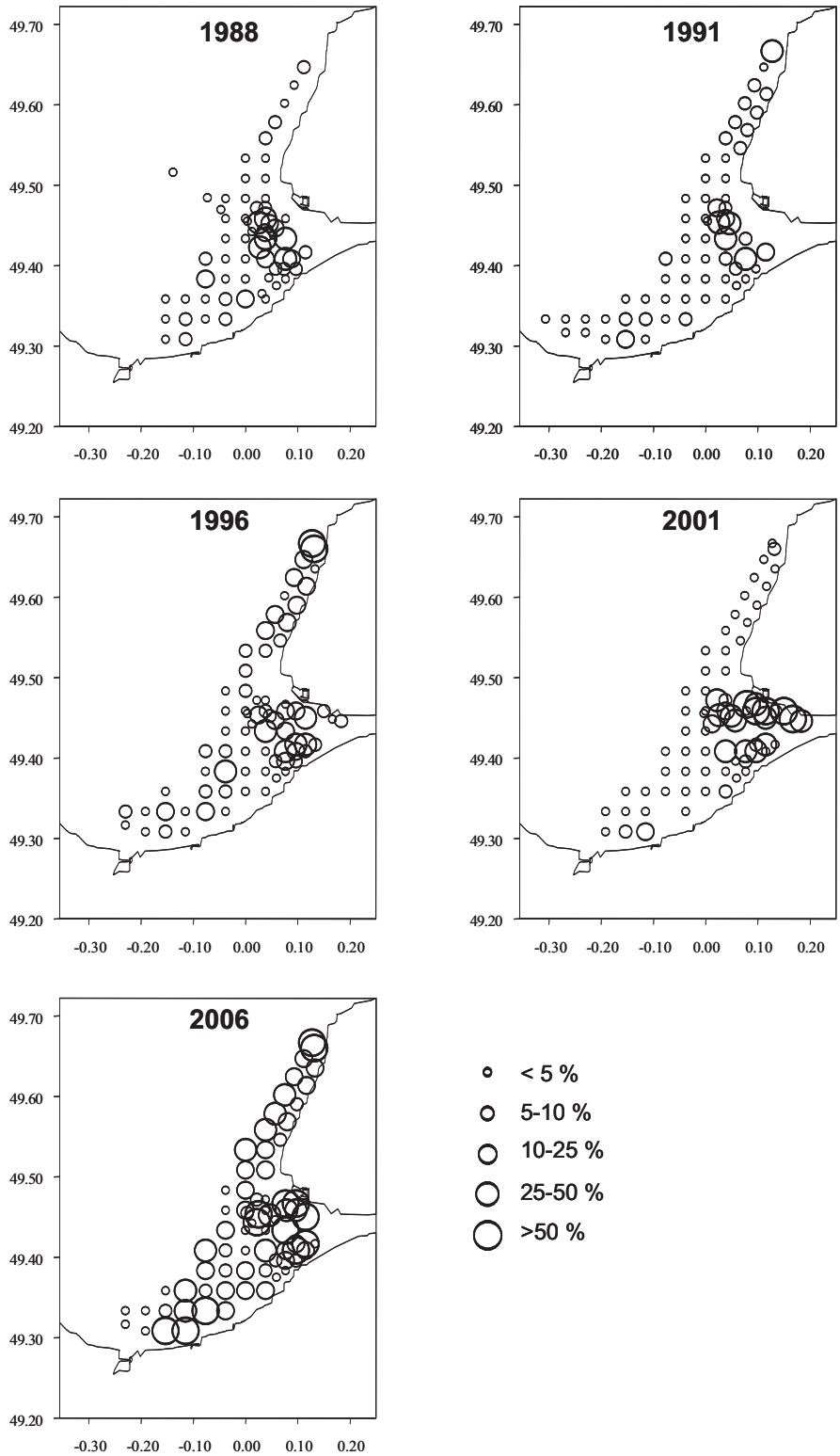

Figure 3. Percentage of fine particles (< 63 µm) in the sediment sampled during the five PECTOW campaigns from 1988 to 2006.

Figure 3. Pourcentage de particules fines (< 63 µm) dans les sédiments provenant des cinq campagnes PECTOW réalisées entre 1988 et 2006.

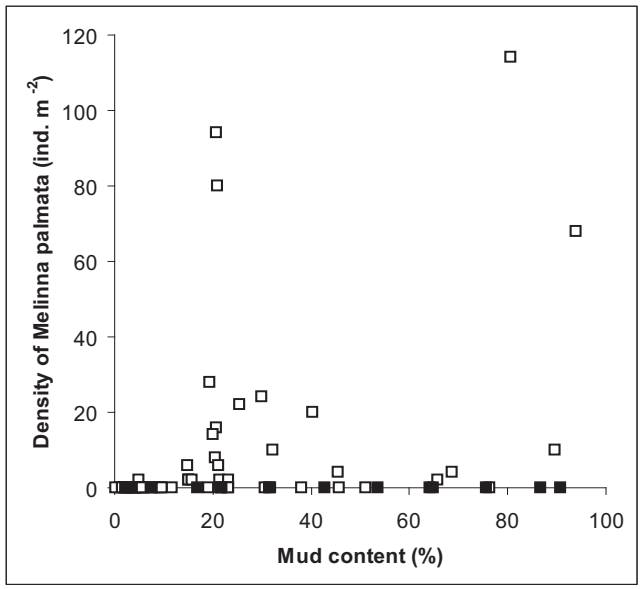

Figure 4. Relationships between the % of mud (% of fine particles < 63 µm) and the density of *Melinna palmata* (ind. m^{-2}) during the PECTOW 06 campaign. ■: stations located at the mouth of the Seine estuary (east of 0°4'E) in less saline waters; □: other stations.

Figure 4. Relation entre le pourcentage de vase (% de particules fines < 63 µm) et l'abondance de *Melinna palmata* (ind. m^{-2}) pendant la campagne PECTOW 06. ■ : stations localisées à l'embouchure de l'estuaire de la Seine à l'est de 0°4'E ; □ : autres stations.

1998 (Severijns & Gilles, 1993; Severijns & Vanhaelen, 1994; Severijns 2000a, b; Desroy et al., 2003; Dewarumez et al., 2003). Though the species had not yet expanded to the Bay of Veys in 1997 (Dauvin et al., 2004), its eastern location in the Bay of Seine was still the intertidal zone of the Orne estuary at Merville-Franceville near Ouistreham in August 2000 (Severijns, 2000b) (Fig. 5)

The progression of *Ensis directus* in the eastern Channel appears to move in the opposite direction of the residual tidal transport, and although it has been reported to prefer sandy bottoms, its distribution in the eastern Bay of Seine, mainly along the Pays d'Auge coastline, appears to be independent of sediment properties. Its populations can be very dense (> 30,000 ind.m^{-2}) just after benthic recruitment, with adult populations commonly reaching densities > 1,000 ind.m^{-2} in some areas, such as Gravelines and Wash Bay, where the species is exploited commercially (Dewarumez et al., 2003; Palmer, 2003). However, in the eastern Bay of Seine, the abundance values are moderate (< 100 ind.m^{-2}), perhaps because it's still recent colonisation.

Two possible hypotheses may explain the presence of *E. directus* in the eastern Bay of Seine at this time:

• An introduction through the intense maritime traffic of tankers, travelling from ports in Belgium or the Netherlands (e.g., Antwerp, Rotterdam, or Amsterdam) to Le Havre, transporting larvae from the North Sea in their ballast waters. If this is the case, the occurrence of *E. directus* in the Bay of Seine is a secondary introduction.

• A natural expansion through the larval dissemination by wind-induced currents. Long-term residual currents in the Channel are oriented towards the North Sea. However, wind-induced currents can greatly affect transport for periods ranging from a week to a few months (Salomon & Breton, 1993). The planktonic larval phase of *E. directus* extends from 10 to 29 days, depending on temperature (see Armonies, 2001). Thus, the dominance of NE winds in the Eastern Channel during the species' spring reproduction period (May-June) could favour the larval dissemination from the Opale Coast and the Bay of Somme to the Bay of Seine, as it has been previously reported for the isolated populations of *Owenia fusiformis* Delle Chiaje, 1841 (Barnay et al., 2003). *E. directus* also spreads rapidly along the continental shelf of the North Sea, presumably as pelagic larvae and byssus-drifting post-larvae (Armonies, 2001).

Melinna palmata

The tubicolous ampharetid *Melinna palmata* is highly distinctive, and thus difficult to be overlooked or misidentified in surveys previous to May 2002, when the first two specimens were collected in a single station in the Bay of Seine (Janson, 2007). However, the 2003-2006 campaigns confirmed its implantation, except near the mouth of the Seine estuary, influenced by freshwater inputs (Fig. 1). *Melinna palmata* has a boreo-Mediterranean distribution (Grehan, 1991). In the NE Atlantic, it is present from Norway to the Moroccan coast (Guillou & Hily, 1983; Grehan, 1991), being common around the Bristish Isles, Ireland, and the Brittany coast (France) (Fauvel, 1927; Cabioch et al., 1968; Retière, 1979; Guillou & Hily, 1983; Oyenekan, 1988; Grehan, 1991; Barnay 2003; Connor et al., 2004) and found previously among marine faunas at Plymouth (England) and Roscoff, Dinard and Wimereux (France) (Dauvin et al., 2003).

The current distribution of the species in the Channel (Fig. 5) extends along all the southern England bays and the French coasts (from the bay of Brest to the Antifer Cap). It has not been found in recent sampling (1998, 2000) of the shallow subtidal zone of the Eastern Channel (more than 200 stations from 0 to 10 m depth), from the Bay of Somme to the Belgium frontiers (Desroy et al., 2003), and its record off Wimereux remains uncertain.

The population density is variable according to the site: ≈ 100-4,000 ind.m^{-2} (Dauvin, 1982 & 2000; Guillou & Hily, 1983; Ibanez & Dauvin, 1988; Grehan, 1991; Connor et al., 2004). For the neighbouring English Channel

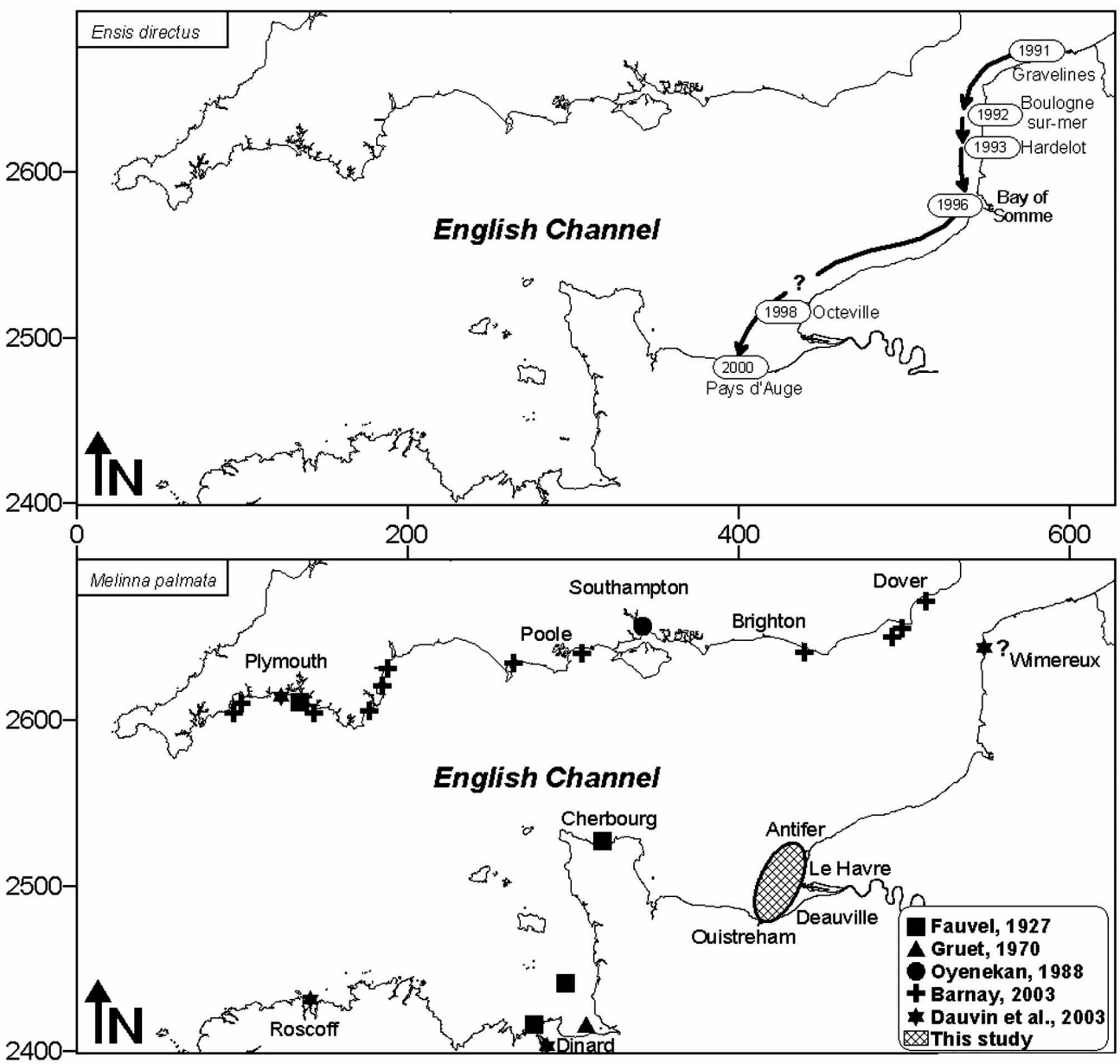

Figure 5. Locations of *Melinna palmata* (From Fauvel, 1927; Gruet, 1970; Oyenekan, 1988; Barnay, 2003; Dauvin et al., 2003, and this study) and *Ensis directus* (From Luczak et al., 1993; Severijns & Gilles, 1993; Severijns & Vanhaelen, 1994; Severijns 2000a,b; Desroy et al., 2003; Dewarumez et al., 2003, and this study) in the English Channel.

Figure 5. Localisation de *Melinna palmata* (D'après Fauvel, 1927 ; Gruet, 1970 ; Oyenekan, 1988 ; Barnay, 2003 ; Dauvin et al., 2003, et cette étude) et de Ensis directus (D'après Luczak et al., 1993 ; Severijns & Gilles, 1993 ; Severijns & Vanhaelen, 1994 ; Severijns 2000a,b ; Desroy et al., 2003 ; Dewarumez et al., 2003, et cette étude) en Manche.

population, a maximum of 468 ind.m^{-2} was reported in the Bay of Cherbourg (Kempf et al., 2002). Moderate abundances were observed in off Southampton in late 1980s (5-130 ind.m^{-2}) (Oyenekan, 1988) and in several bays along the southern England coasts in 2000: Plymouth Sound (344 ind.m^{-2}), Weymouth Bay (62 ind.m^{-2}) or Rye Bay (101 ind.m^{-2}) (Barnay, 2003). Despite the recent arrival to the Bay of Seine, *M. palmata* colonies are of the same order of magnitude (maximum: 277 ind.m^{-2}) as those in the Bay of Cherbourg, off Southampton, and in the other bays in the south of England, which suggests that the species has developed a viable population.

The cause of the colonization of *Melinna palmata* in the Bay of Seine remains unknown. Given its short planktonic larval phase (i.e. about one week) (Grehan et al., 1991), larval dissemination from neighbouring populations at least 110-170 km away (Bay of Cherbourg and the south of England) does not seem plausible. On the other hand, it could have been introduced via ballast water from the Le Havre - Portsmouth ferries.

Melinna palmata occurs in shallow mud, muddy sand and mixed-bottom deposits, as well as in *Zostera* beds (Cabioch et al., 1968; Retière, 1979). However, in the Bay of Cherbourg, the species was particularly abundant in the muddiest stations (> 15% of mud content) impacted by salmon farming (Kempf et al., 2002). The species has rapidly spread over the Rance Basin, probably from Dinard Bay just after the breach in the Rance dam, demonstrating its strong ability to colonize muddy fine sand sediment (Retière, 1979). Similarly, in the eastern Bay of Seine, *M. palmata* tends to be more abundant when mud content exceeds 20%. Its recent installation and extension in the muddy fine sand *Abra alba - Pectinaria koreni* community likely reflects the increase in fine particles reported between 2001 and 2006 in this part of the Bay.

Two anthropogenic phenomenons could have provoked the subtidal silting-up of the eastern Bay of Seine:

• Recent modifications in the Seine estuary have altered the morpho-sedimentary dynamics, leading to the expulsion of the Maximum Turbidity Zone outside the estuary during flood periods (Lesourd, 2000; Lesourd et al., 2001 & 2003). These modifications are the canalization of the Seine River from Rouen to the Bay of Seine, the construction of the Normandy Bridge, and the extension of the Havre Harbour, leading to the narrowing of the river channel and the strong reduction of the tidal flats, especially the 'Grande Vasière' in the northern part of the estuary (Dauvin et al., 2006 & 2007).

• The dredging deposit zone near Octeville receives about 3 million m^3 of sediment annually from the port at Le Havre, as well as an exceptional input — 45 million m^3 of gravel, sand and mud — when the navigation channel for the Port 2000 project was dredged from 2001-2003. This could explain the changes in sediment properties and, thus, the implantation of a dense *M. palmata* population along the Pays de Caux coastline (north the sampled area).

Recently, dredging deposits (mainly mud and sandy mud) have also been proposed to explain the presence and the extension of the muddy annelid polychaete *Sternaspis scutata* (Ranzani, 1817) along the southern coast of England, where the harbours must be dredged to allow ship navigation (Townsend et al., 2006). Since the first recorded sighting in the Channel off Portland Harbour (Hiscock & Hannam, 1986), the species has colonized a number of stations in South Devon, extending to Plymouth Sound in a westwards expansion of approximately 125 km. Townsend et al. (2006) suggested that the population first arrived in a ship's ballast water or on a piece of battleship equipment, since Portland Harbour is a major Royal Navy port and a training center for battleships from many countries.

The fact that two muddy polychaete species - *Sternaspis scutata* and *Melina palmata* - are currently extending their populations in the English Channel could be a result of the increase in mud habitats in the subtidal zone due to human disturbances. This increase being all the more spectacular, given that strong tidal currents in this macrotidal ecosystem naturally confine these sediment types to the inner parts of bays and estuaries.

Conclusion

Recent and regular surveys in the eastern part of the Bay of Seine (English Channel) over the last two decades has allowed to identify the colonization of two bentho-pelagic macrobenthic species, the bivalve *Ensis directus* and the polychaete *Melinna palmata*.

The colonisation of *E. directus* may be related to the southwest expansion of this invasive species from the Scheldt to the Seine estuary, while that of *M. palmata* may be a consequence of the recent increase of fine sediments caused by man-made modifications in the Seine estuary, their colonisation being either antropogenically mediated (e.g. via ballast waters) or favoured by natural larval dissemination from neighbouring populations.

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References

Armonies W. 2001. What an introduced species can tell us about the spatial extension of benthic populations. *Marine Ecology Progress Series*, **209**: 289-294.

Barnay A.S. 2003. Structure des peuplements de sables fins plus ou moins envasés en Manche : échelles spatiales et biodiversité. Thèse Université Pierre & Marie Curie (Paris VI), 250 pp.

Barnay A.S., Ellien C., Gentil F. & Thiébaut E. 2003. A model study on variations in larval supply: are populations of the polychaete *Owenia fusiformis* in the English Channel open or closed? *Helgolander Marine Research*, **56**: 229-237.

Cabioch L., l'Hardy J.P. & Rullier F. 1968. Inventaire de la Faune Marine de Roscoff. *Travaux de la Station Marine de Roscoff*, N.S., **17**: 1-95.

Connor D.W. Allen J.H., Golding N., Howell K.L., Lieberknecht L.M., Northen K.O. & Reker J.B. 2004. The Marine Habitat Classification for Britain and Ireland Version 04.05 JNCC, Peterborough.ISBN 1861075618 (www.jncc.gov.uk/MarineHabitatClassification).

Dauer D.M., Ranasinghe J.A. & Weisberg S.B. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. *Estuaries*, **23**: 80-96.

Dauvin J.C. 1982. Impact of Amoco Cadiz oil spill on the muddy fine sand *Abra alba* and *Melinna palmata* community from the Bay of Morlaix. *Estuarine Coastal Shelf Science,* **14**: 517-531.

Dauvin J.C. 2000. The muddy fine sand *Abra alba-Melinna palmata* community of the Bay of Morlaix twenty years after the Amoco Cadiz oil spill. *Marine Pollution Bull*etin, **40**: 528-536.

Dauvin J.C., Dewarumez J.M. & Gentil F. 2003. An up to date list of polychaetous annelids from the English Channel. *Cahiers de Biologie Marine*, **44**: 67-95.

Dauvin J.C., Gomez Gesteira J.L., Gentil F., Ghertsos K., Ropert M., Sylvand B. & Thiébaut E. 2004. Spatial structure of a subtidal macrobenthic community in the Bay of Veys (western Bay of Seine, English Channel). *Journal of Experimental Marine Biology and Ecology,* **307**: 217-235.

Dauvin J.C., Desroy N., Janson A.L., Vallet C. & Duhamel S. 2006. Recent changes in estuarine benthic and suprabenthic communities resulting from the development of harbour infrastructure. *Marine Pollution Bulletin*, **53**: 80-90.

Dauvin J.C., Ruellet T., Desroy N. & Janson A.L. 2007. The ecological quality status of the Bay of Seine and the Seine estuary: use of biotic indices. *Marine Pollution Bulletin,* **55**: 241-257.

Dauvin J.C. (in press). Effects of heavy metal contamination on the macrobenthic fauna in estuaries: the case of the Seine estuary. *Marine Pollution Bulletin.*

Desroy N., Warembourg C., Dewarumez J.M. & Dauvin J.C. 2003. Macrobenthic resources of the shallow soft-bottom sediments in the eastern English Channel and southern North Sea. *ICES Journal of Sea Research,* **60**: 120-131.

Dewarumez J.M, Desroy N., Luczak C., Desprez M., Gentil F. & Dauvin J.C. 2003. *Ensis directus* état de la population en Manche orientale et Mer du Nord, 12 années après son introduction. *IIIème Congrès International des Sociétés Européennes de Malacologie. Les Mollusques dans la recherche Actuelle, résumé p. 86.*

Fauvel P. 1927. Polychètes sédentaires. Addenda aux errantes, archiannélides, myzostomaires. *Faune de France*, **16**: 494 pp.

Gentil F. & Cabioch L. 1997. Carte des peuplements macrobenthiques de la Baie de Seine et Manche centrale sud. Carte et notice explicative de la carte. Editions de la Station Biologique de Roscoff.

Ghertsos K. 2002. Structure spatio-temporelle des peuplements macrobenthiques de la Baie de Seine à plusieurs échelles d'observation. Thèse de l'Université des Sciences et Technologies de Lille, 182 p.

Grehan A.J. 1991. Demography and reproductive biology of *Melinna palmata* (Ampharetidae: Polychaeta) in Inner Galway Bay on the west coast of Ireland. *Marine Biology*, **109**: 459-467.

Grehan A.J., Retière C. & Keegan B. 1991. Larval development in the Ampharetid *Melinna palmata* Grube (Polychaeta). *Ophelia* (Suppl.), **5**: 321-332.

Gruet Y., 1970. Faune associée des récifs édifiés par l'annélide *Sabellaria alveolata* (L.) en baie du Mont Saint-Michel : banc des hermelles. *Mémoires de la société des Sciences Naturelles et Mathématiques de Cherbourg*, **54**: 73-88.

Guillou M. & Hily C. 1983. Dynamics and biological cycle of *Melinna palmata* (Ampharetidae) population during the recolonisation of a dredged area in the cicinity of the Harbour of Brest (France). *Marine Biology,* **73**: 43-50.

Ibanez F. & Dauvin J.C. 1988. Long-term changes (1977 to 1987) in a muddy fine sand *Abra alba-Melinna palmata* community from the Western English Channel: multivariate time-series analysis. *Marine Ecology Progress Series*, **49**: 65-81.

Hiscock K. & Hannam M. 1986. Survey and Sampling in Portland Harbour. A report to British Petroleum Development Ltd from the Oil Pollution Research Unit, Field Study Council.

Janson A.L. 2007. Evolution de la biodiversité benthique des vasières de l'estuaire de la Seine en response à la dynamique sédimentaire. De l'approche descriptive à l'approche fonctionnelle. Thèse de l'Université de Rouen, 282 pp.

Kempf M., Merceron M., Cadour G., Jeanneret H., Méar Y & Miramand P. 2002. Environmental impact of a salmonid farm on a well-flushed marine site: II. Biosedimentology. *Journal of Applied Ichtyology*, **18**: 51-60.

Lesourd S. 2000. Processus d'envasement d'un estuaire macrotidal : zoom temporel du siècle à l'heure ; application à l'estuaire de la Seine. Thèse Université de Caen, 279 pp.

Lesourd S., Lesueur P., Brun-Cottan J.-C., Auffret J.-P., Poupinet N., Laignel B. 2001. Morphosedimentary evolution of the macrotidal Seine estuary subjected to human impact. *Estuaries,* **24**: 940-949.

Lesourd S., Lesueur P., Brun-Cottan J.C. Garnaud S. & Poupinet N. 2003. Seasonal variations in the characteristics of superficial sediments in a macrotidal estuary (the Seine inlet, France). *Estuarine Coastal and Shelf Science*, **58**: 3-16.

Luczak C., Dewarumez J.M. & Essink K. 1993. First record of the American jack knife clam *Ensis directus* on the French coast of the North Sea (short communication). *Journal of the Marine Biological Association of the United Kingdom*, **73**: 233-235.

Oyenekan J.A., 1986. Population dynamics and secondary

production in *Melinna palmata* (Polychaeta: Ampharetidae). *Marine Biology*, **98**: 247-251.

Palmer D. 2003. The introduced razor fish *Ensis directus* in the Wash and North Norfolk. *Shellfish new*, **16**: 13-15.

Retière C. 1979. Contribution à l'étude des peuplements benthiques du golfe normano-breton. Thèse Doctorat Etat, ès Sciences Naturelles, Université de Rennes, 370 pp.

Salomon J.C. & Breton M. 1993. An atlas of long-term currents in the Channel. *Oceanologica Acta,* **16**: 439-448.

Severijns N. & Gilles S. 1993. Records of *Ensis directus* (Conrad, 1843) between Boulogne-sur-Mer and Le Touquet. *De Strandvlo,* **13**: 56-67.

Severijns N. & Vanhaelen M.T. 1994. The distribution of *Ensis directus* (Conrad, 1843) in Northern France. *De Strandvlo,* **14**: 84-91

Severijns N. 2000a. Bijkomende waarnemingen van *Ensis directus* (Conrad, 1843) in Villers-sur-Mer (Normandië). *De Strandvlo,* **20**: 127-129.

Severijns N. 2000b. De Amerikaanse zwaadschelde *Ensis directus* (Conrad, 1843) nu ook in Normandië. *De Strandvlo,* **20**: 123-146.

Severijns N. 2001. De verspreiding van *Ensis directus* (Conrad, 1843) in Europa, 23 jaar na de introductie: de opmerkelijke opmars van een immigrant. *De Strandvlo,* **21**: 123-146.

Thiébaut E., Cabioch L., Dauvin J.C., Retière C. & Gentil F. 1997. Spatio-temporal persistence of the *Abra alba-Pectinaria koreni* muddy-fine sand community of the eastern Bay of Seine. *Journal of the Marine Biological Association of the United Kingdom*, **77**: 1165-1185.

Townsend M., Worsfold T.M., Smith P.R.J., Martina L.J., McNeill L. & Kendall M.A. 2006. Occurrence of *Sternaspis scutata* (Polychaeta: Sternaspidae) in the English Channel. *Cahiers de Biologie Marine*, **47**: 281-285.