

SHORT COMMUNICATION

First record of the calanoid copepod *Acartia omorii* (Copepoda: Calanoida: Acartiidae) in the southern bight of the North Sea

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The occurrence of the calanoid copepod, Acartia omorii, is reported for the first time in the coastal waters of the Southern bight of the North Sea, off Calais harbour. Acartia omorii males and females were consistently found in four plankton samples. The collected specimens were compared with A. omorii individuals collected from the type locality (Tokyo Bay, Japan). The capture of A. omorii, a species native to Japanese coastal waters, is in agreement with the recent observation of the Japanese macroalgae Undaria pinnatifida within Calais harbor and the hypothesis of passive transport in ship's ballast water.

INTRODUCTION

Copepods of the family Acartiidae are common inhabitants of coastal and estuarine environment in all oceans of the world. They are thought to be mainly adapted to high food concentrations, which are encountered in estuaries and upwelling regions. Paffenhöfer and Stearns (Paffenhöfer and Stearns, 1988) demonstrated that *Acartia tonsa* have to be restricted to coastal waters, because they cannot obtain enough food for reproduction offshore where food concentration is low. However, alternative factors which could contribute to the nearshore affinity of *A. tonsa* include limited salinity tolerances (Tester and Turner, 1991; Cervetto *et al.*, 1999), a proper combination of warm water and low salinity favourable to naupliar survival (Tester and Turner, 1991) and omnivorous feeding characteristics (Johnsson and Tiselius, 1990). Their space–time distribution may owe a lot to the fact that a number of *Acartia* species produce diapause eggs which

allow them to lie dormant in the sediment and to appear suddenly in the plankton when conditions are favourable (e.g. Viitasalo and Katajisto, 1994). Diapause eggs may also have played a role in the dispersion of *Acartia omorii* by transportation in ship's ballast water to other parts of the world (Hirakawa, 1988).

While large copepods (mainly *Calanus* spp.) are abundant in the Northern North Sea and the western English Channel, small species such as *Acartia clausi*, *Centropages hamatus* and *Temora longicornis* dominate in the eastern English Channel and the southern bight of the North Sea (e.g. Franz *et al.*, 1991; Williams *et al.*, 1993). To our knowledge, the only copepods of the family Acartiidae reported in the coastal waters of the eastern English Channel and the southern bight of the North Sea are *A. clausi*, *A. tonsa*, *Acartia discaudata* and *Acartia bifilosa*, the last three being mainly restricted to the waters of Dunkirk harbour (Brylinski, 1981, 1984;

Bradford-Grieve, 1999). *Acartia clausi* Giesbrecht has long been considered as an abundant and widespread plankton calanoid copepod in Japanese inlet waters and as a good indicator species of these waters (Yamazi, 1956). Bradford (Bradford, 1976), however, making a revision of Acartiidae species, distinguished the Japanese *A. clausi* from Giesbrecht's *A. clausi* s. str. and described the new species *A. omorii* from Tokyo Bay.

Some copepods formerly attributed to *A. clausi* in the Northwest Pacific have thus been showed to consist of at least two species, i.e., *A. omorii* and *Acartia hudsonica* (Ueda, 1986). While extensively studied in terms of vertical distribution (Tanaka *et al.*, 1987a,b; Kimoto, 1988), physiology (Laguna and Uye, 2001), feeding (Ishii, 1990; Uye and Takamatsu, 1990), egg production (Ayukai, 1987), population dynamics (Liang and Uye, 1996) and taxonomy (Yoo *et al.*, 1991), *A. omorii* have only been observed once outside Japanese waters, in the coastal waters of southern Chile (Hirakawa, 1988; Bradford-Grieve, 1999; Bollens *et al.*, 2002). To date, *A. omorii* have never been recorded in the coastal waters of the eastern English Channel and the southern bight of the North Sea, although many zooplankton surveys have been carried in this area (e.g. Brylinski, 1981, 1984; Brylinski *et al.*, 1988; Seuront, 1999; Breton, 2000; Cotonnec, 2001).

In this article, *A. omorii* collected in the coastal waters of the southern bight of the North Sea are described. Their relative abundance is compared to indigenous zooplankton taxa, and their body proportions compared to those of the indigenous *A. clausi*, *A. omorii* specimens from the type locality and to previous taxonomic studies. A mechanism for their introduction in the study area is proposed with regard to a recent evidence for the presence of another non-indigenous marine species. The potential consequences of their successful establishment and dispersal are briefly discussed.

METHOD

Zooplankton were collected by vertical hauls of a WP2 net (200- μ m mesh size), on 10 May 2004, during a routine survey cruise. The net was hauled vertically at 50 cm s⁻¹, and filtered volume was estimated from the flowmeter reading and the net diameter. The specimens were netted in three different hauls, taken at four stations with coordinates 50°58'788 N/1°51'230 E, 50°58'855 N/1°52'194 E, 51°59'438 N/1°53'901 E, and 51°59'594 N/1°54'334 E. Immediately after sampling, zooplankton were fixed and preserved in 5% paraformaldehyde (final concentration).

Calanoida and Harpacticoida species were identified according to Farran (Farran, 1948a,b, 1951a,b) and Wells (Wells, 1970). The Acartiidae species were identified following Bradford (Bradford, 1976), Chihara and

Murano (Chihara and Murano, 1997) and Bradford-Grieve (Bradford-Grieve, 1999). *Acartia omorii* is closely related to *A. hudsonica* and *A. clausi* (e.g. Barthélémey, 1999; Bradford-Grieve, 1999) and has sometimes been confused with *A. hudsonica* and *A. omorii* (Ueda, 1986). *Acartia omorii* was mainly distinguished from *A. clausi* by the absence of posterodorsal spines and posterior hairs on the posterior prosome of *A. omorii* for females and for males (i) the absence of posterodorsal spines and posterior stiff hairs on the posterior prosome of *A. omorii* and (ii) the posteroventral hairs on the posterior prosome of *A. omorii* (Table I). The criteria used to distinguished *A. omorii* from *A. hudsonica* were the proportion of length to width of the genital double somite for females and the shape of the inner lobe of the third exopodal segment of the right fifth leg for the males. In *A. hudsonica*, the genital segment of the female is long (i.e. ratio of genital segment length/width is bounded between 1.20 and 1.34; Chihara and Murano, 1997; Bradford-Grieve, 1999) and the inner projection on the right segment of the right fifth leg of the male has a rounded distal end (Ueda, 1986; Table I). In contrast, in *A. omorii*, the genital segment of the female is relatively short (i.e. ratio of genital segment length/width is bounded between 0.99 and 1.10; Chihara and Murano, 1997; Bradford-Grieve, 1999) and the inner projection of the right fifth leg of the male has two unequal distal processes (Ueda, 1986; Table I). We finally ensure the relevance and the generality of our determination by comparing *A. omorii* specimens observed in the present work with specimens of *A. omorii* sampled from the type locality (i.e. Tokyo Bay, Japan; Bradford, 1976) at an anchor station (35°23'55 N, 139°46'45 W) on October 24, 2000. The sampling strategy employed was identical to the one described above. Copepods were identified under a dissecting microscope (Olympus SZX12), and for *A. clausi* and *A. omorii* the sex of individuals and body proportions were measured using an ocular micrometer.

RESULTS AND DISCUSSION

Seven copepod species were identified: the calanoid copepods *A. clausi*, *A. omorii*, *Centropages typicus*, *Paracalanus parvus*, *Pseudocalanus minutus* and *T. longicornis*, and the harpacticoid copepod *Euterpina acutifrons*. No significant differences in copepod absolute or relative abundance were found between the four sampling stations. The zooplankton assemblage was strongly dominated by *T. longicornis* (1430 \pm 112 individuals m⁻³; 42.8 \pm 1.1%) and *A. clausi* (1028 \pm 102 individuals m⁻³; 31.7 \pm 1.4%). The abundance of *P. parvus* and *P. minutus* was fairly similar (420 \pm 41 individuals m⁻³ and 12.6 \pm 1.4%, and 365 \pm 32 individuals m⁻³ and 10.9 \pm 1.3%, respec-

Table I: Comparisons of distinctive characters of *Acartia* species closely related to each other

	<i>Acartia omorii</i>	<i>Acartia clausi</i>	<i>Acartia hudsonica</i>
Female			
Last pedigerous somite posterodorsally with spines	No	No	No
Posterior prosome	Ventral hairs	Posterodorsal spines and posterior stiff hairs	Ventral hairs
Proportion of length to width of genital double somite	0.99–1.10 ^{abc}	1.10–1.20	1.20–1.34
Posterodorsal margin of genital somite	Naked	Bordered posterodorsally with conspicuous spines	Naked
Male			
Posterior prosome	Posteroventral hairs	Dorsal spines and posterior stiff hairs	Two rows of lateral hairs
First exopodal segment of right fifth leg	With a long setae	With a long hairy setae	With a long setae
Inner lobe of third exopodal segment of right fifth leg	With two unequal distal processes	With a rounded distal end	With a rounded distal end

^aReferred from Ueda (1986).

^bReferred from Chihara and Murano (1997).

^cReferred from Bradford-Grieve (1999).

tively), and significantly higher than the abundance of *C. typicus* (50 ± 6 individuals m^{-3} ; $1.5 \pm 0.4\%$), *A. omorii* (12 ± 3 individuals m^{-3} ; $0.3 \pm 0.1\%$) and *E. acutifrons* (7 ± 2 individuals m^{-3} ; $0.2 \pm 0.1\%$). Apart from the newly observed *A. omorii*, the abundances of all other reported species are congruent with previous studies conducted in the same area (e.g. Brylinski, 1986; Breton, 2000; Cotonnec, 2001). The abundance of *A. omorii*, observed here for the very first time in the southern bight of the North Sea, is 88 times smaller than the one of *A. clausi*, the only other Acartiidae species identified here. The sex ratio of *A. clausi* (0.51 ± 0.05) is significantly higher ($P < 0.05$) than the one of *A. omorii* (0.30 ± 0.02), potentially suggesting different mating strategies as it would be more difficult for a *A. omorii* male to find a female than for a *A. clausi* male.

Measurements of body proportions of *A. omorii* and *A. clausi* males and females are shown and compared in Table II. The prosome lengths (PL) of both *A. omorii* males and females are significantly higher (Wilcoxon–Mann–Whitney U-test, $P < 0.05$) than those of *A. clausi* and similar to previous measurements found in the literature (Bradford, 1976; Ueda, 1986; Chihara and Murano, 1997; Bradford-Grieve, 1999; Soh and Suh, 2000; Table II; see also www.copepodes.obs-banyuls.fr). For both species, males are significantly smaller than females (U-test, $P < 0.05$; Table II), and there is a significant negative correlation (Spearman test, $P < 0.01$) between the female prosome length/width ratio (PL/PW) and PL length size. The male PL/PW, however,

is independent of body size ($P > 0.05$). The mean ratio does not significantly differ between male and female within a same species (U-test, $P > 0.05$) and is significantly higher for *A. omorii* than *A. clausi* ($P < 0.01$; Table II). The length/width ratio of the genital segment (GL/GW) is positively correlated with body size for both species ($P < 0.05$). Finally, the caudal ramus length/width ratio (RL/RW) varies greatly and within the same species, it is significantly higher ($P < 0.05$) for females than males. This ratio is not significantly different for male *A. omorii* and *A. clausi* but is significantly higher ($P < 0.05$) for female *A. clausi* (Table II).

The previous results are specified by the comparison of the body proportions of males and females of *A. omorii* sampled in the southern bight of the North Sea and in the type locality (Tokyo Bay, Japan). No significant differences are observed between the specimens sampled in the North Sea and Tokyo Bay, both in terms of specific morphologic characters (Table I) and body proportions (Table II). The allometric relationships observed between (i) males and females prosome length and prosome length/width ratio, (ii) female prosome length and the length/width ratio of the genital segment, and (iii) males and females prosome length and the caudal ramus length/width ratio are not distinguishable for the specimens from the North Sea and Tokyo Bay (t -test, $P > 0.05$; Table III), providing sufficient evidence to support the identification of collected specimens as the exotic Japanese species, *A. omorii*, and suggesting that the European and Japanese cannot be distinguished morphologically.

Table II: Prosome length and body proportions of Acartia omorii males and females sampled in the Southern bight of the North Sea and the type locality (Tokyo Bay, Japan) and Acartia clausi males and females sampled in the southern bight of the North Sea (France)

	Species											
	<i>Acartia omorii</i> (North Sea)				<i>Acartia omorii</i> (Tokyo Bay)				<i>A. clausi</i>			
	Male	<i>n</i>	Female	<i>n</i>	Male	<i>n</i>	Female	<i>n</i>	Male	<i>n</i>	Female	<i>n</i>
PL	1.03 (0.01)	10	1.12 (0.02)	10	1.10 (0.02)	25	1.15 (0.02)	30	0.80 (0.01)	15	1.01 (0.02)	15
	<i>1.00–1.19</i>		<i>0.94–1.22</i>		<i>1.00–1.19</i>		<i>0.94–1.22</i>		<i>0.71–1.31</i>		<i>0.81–1.47</i>	
PL/PW	2.45 (0.04)	10	2.48 (0.04)	10	2.41 (0.05)	25	2.50 (0.04)	30	2.32 (0.02)	15	2.36 (0.03)	15
GL/GW	–		1.02 (0.02)		–		1.00 (0.02)		–		1.15 (0.02)	
	–		<i>0.99–1.07</i>		–		<i>0.99–1.07</i>		–		<i>1.10–1.20</i>	
RL/RW	1.14 (0.04)	10	1.45 (0.05)	10	1.17 (0.04)	25	1.48 (0.06)	30	1.13 (0.04)	15	1.94 (0.05)	15
	<i>1.10–1.25</i>		<i>1.05–1.84</i>		<i>1.10–1.25</i>		<i>1.05–1.84</i>		<i>1.02–1.24</i>		<i>1.83–2.08</i>	

GL and GW, genital segment length and width; *n*, number of individuals considered; PL and PW, prosome length and width; RL and RW, right caudal ramus length and width. The numbers in parentheses and in italic are the standard deviations obtained in the present work and the range of values reported in Bradford-Grieve (1999), respectively.

Table III: Allometric relationships obtained between prosome length and different morphometric ratios for Acartia omorii adult males and females sampled in the southern bight of the North Sea (France) and in the type locality (Tokyo Bay, Japan)

	<i>Acartia omorii</i> (North Sea)		<i>Acartia omorii</i> (Tokyo Bay)	
	PL _{male}	PL _{female}	PL _{male}	PL _{female}
PL/PW	NS	PL/PW = 4.2 – 1.1PL ($\rho = 0.76$; $P < 0.01$; $n = 10$)	Ns	PL/PW = 3.9 – 1.2PL ($\rho = 0.41$; $P < 0.05$; $n = 30$)
GL/GW	–	GL/GW = 1.1 + 0.6PL ($\rho = 0.79$; $P < 0.01$; $n = 10$)	–	GL/GW = 1.2 + 0.7PL ($\rho = 0.32$; $P < 0.05$; $n = 30$)
RL/RW	NS	NS	NS	NS

GL/GW, genital segment length/width ratio; *n*, the number of individual considered; NS, not significant; PL/PW, prosome length/width ratio; RL/RW, right caudal ramus length/width ratio; ρ , Spearman’s rank correlation coefficient.

To our knowledge, this is the first record of the calanoid copepod *A. omorii* in the coastal waters of the southern bight of the North Sea. It is even the first report of a non-indigenous zooplankton species in this area and the second record of *A. omorii* outside Japanese waters (Hirakawa, 1988; Bradford-Grieve, 1999; Bollens *et al.*, 2002). *Acartia omorii* has already been demonstrated to be able to be transported in ship’s ballast water from Japan to southern Chile (Hirakawa, 1988). In the present case, the observation of *A. omorii* in the coastal waters of the southern bight of the North Sea off Calais harbour is congruent with the first identification in 1998 and the subsequent proliferation of the Japanese macroalgae *Undaria pinnatifida* within one of the harbour basins (Leliaert *et al.*, 2000). It is notable that a similar sampling strategy, conducted over the same period in the coastal

waters of the Eastern English Channel, never identified *A. omorii* but only *A. clausi* (Flamme, 2004). Assuming that *A. omorii* has been introduced in Calais harbour, the absence of *A. omorii* in the eastern English Channel could be related to the tidally driven residual circulation parallel to the coast with nearshore coastal waters drifting toward the North Sea (Brylinski *et al.*, 1991). The observed non-indigenous *A. omorii* cannot spread southward in the eastern English Channel but are likely instead to disperse northward into the North Sea as suggested by the first record of *U. pinnatifida* in Zeebrugge harbour (Belgium) in 2001 (Dumoulin and De Blauwe, 1999; De Blauwe, 2000).

The introduction and successful establishment of non-indigenous species (NIS) in marine and estuarine habitats has become a major global concern (see Bollens *et al.*, 2002 for a review), as the number of aquatic NIS

taxa is now suspected to total in the hundreds (e.g. Carlton and Geller, 1991, 1993). The vector of transport of *A. omorii* and *U. pinnatifida* is likely to be the release of ballast water of ships (Ruiz *et al.*, 2000) rather than accidental or intentional release by aquaculture, fisheries or pet industries (Ruiz *et al.*, 1997). Yet the consequences, or ecological impacts, of NIS are not always understood (Parker *et al.*, 1999), especially in planktonic systems. Despite a large number of NIS taxa being identified from marine and estuarine habitats, little is still known on the potential consequences of their dispersal, physiology, feeding and community interactions in their new habitats. Even at the low relative abundance described here, the identification of *A. omorii* in the southern bight of the North Sea raises several critical issues such as the possibility and consequences of interbreeding with the native *A. clausi* species, its trophic impact on other zooplankton species or more generally the resilience and resistance of the North Sea coastal ecosystems, already heavily threatened by anthropogenic and climatic changes (e.g. Beaugrand *et al.*, 2003; Seuront and Prinzivalli, 2005), to invasions.

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