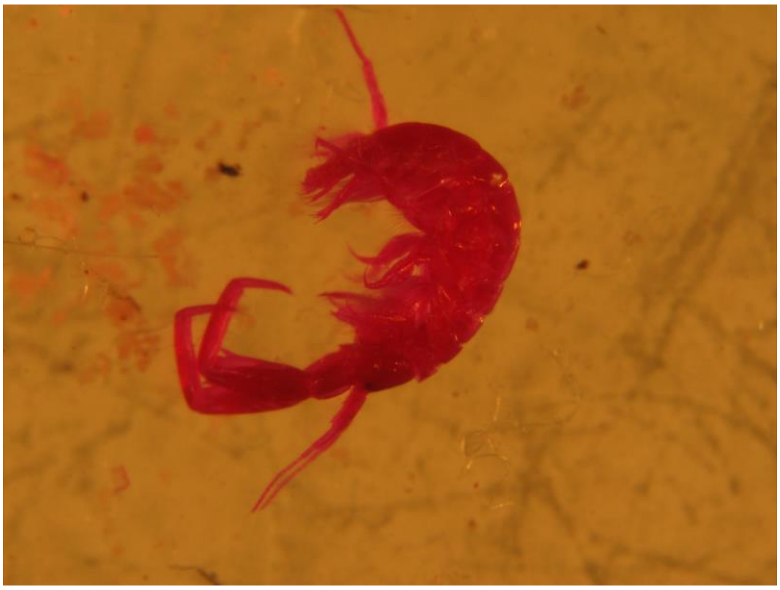
Recent range extensions of *Corophium multisetosum* (Crustacea: Amphipoda) in the Netherlands?



Sander Wijnhoven, Wil C. H. Sistermans, Maartje A. Bergmeijer, Lianne A. Dek, Herman Hummel

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Cover: Specimen of *Corophium multisetosum* from the MT-collection, collected in the western part of the Haringvliet.

RECENT RANGE EXTENSIONS OF *COROPHIUM MULTISETOSUM* (CRUSTACEA: AMPHIPODA) IN THE NETHERLANDS?, *Sander Wijnhoven, Wil C. H. Sistermans, Maartje A. Bergmeijer, Lianne A. Dek en Herman Hummel, 20 pp with figures and tables in the appendices.*

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Keywords: *Corophium multisetosum*, distribution, ecological niche, community, SW-Netherlands

Abstract

Corophium multisetosum was first discovered in the Netherlands in the 1950s, and after that found in several estuaries and water bodies in Western Europe ranging from freshwater to brackish and salt. The observations of the species in the Netherlands however remained restricted to a canal with a salinity gradient and a few smaller waters, whereas plenty potentially suitable waters are present. Recently, several specimens of *C. multisetosum* were observed in samples from various locations of the Rhine-Meuse delta (viz. from the Haringvliet, Westerschelde and Oosterschelde), where the species was observed under very different environmental conditions and in completely different communities. Where no viable population seems to be present in the Oosterschelde, it is expected that the settlement of *C. multisetosum* in the Haringvliet and Westerschelde has a permanent character, and that further range extension might be expected in the future. In the Haringvliet *C. multisetosum* is found at depths below 0 m up to 3 meters in stagnant freshwater with salinity around 0.5 ‰, in the Westerschelde on intertidal flats with salinity ranging between 6 and 21 ‰, on both locations at fine sandy substrates and under more muddy conditions. Whereas in the Haringvliet, *C. multisetosum* is associated with *Dreissena polymorpha*, *Valvata piscinalis* and *Bithynia tentaculata*, in the Westerschelde the species is associated with *Nereis diversicolor* and *Corophium volutator*. Moreover, the samples with *C. multisetosum* of the two areas do not have any other species in common. Comparing the observations in the Rhine-Meuse delta with communities containing *C. multisetosum* in other parts of Europe, leads to the conclusion that we are not dealing with two different types of *C. multisetosum*, but that competition in intervening habitats in the Rhine-Meuse delta might be too severe, so far. Possible reasons and routes for the recent appearance of *C. multisetosum* in the Rhine-Meuse delta and possible developments in the future are discussed.

Introduction

The amphipod *Corophium multisetosum* (Stock, 1952), considered an endemic species to the north-east Atlantic region (Buckley et al., 2004), was first discovered in the Netherlands and described for the North Sea Canal; a canal between the port of Amsterdam and the North Sea with a brackish water gradient. There, and in some smaller waters near the Eem, where it appeared to be found already in the 1920s, and near Wieringen (observed in the 1950s), it occurred in the less saline waters with salinities below 4 ‰ and at depths between 1 and 8 meters on sand and clay bottoms where it builds mud burrows or occasionally builds free tubes upon substratum (Stock, 1952; Mulder & Stock, 1954; Lincoln, 1979). *C. multisetosum* was found frequently together with *Corophium lacustre* (Vanhoffen, 1911), and only once with the close related *Corophium volutator* (Pallas, 1766). Later, it was found in other parts of Europe that the salinity tolerance of *C. multisetosum* is much larger, and that the species occurs at salinity values up to 22.5 ‰ (Janta, 1995) or even above 30 ‰ in the Canal de Mira in Portugal (Queiroga, 1990). The species is besides the Netherlands, now known from England (several upper reaches of estuaries), Poland and Germany (a few canals and bays near the Baltic Sea), France (fish culture ponds), Portugal and Spain (several canals and estuaries along the Atlantic coast) (Janta, 1995).

However, until recently new recordings of *C. multisetosum* from the Netherlands are absent despite of the presence of several fresh to brackish water bodies and estuaries with salinity gradients in the Rhine-Meuse delta in the south-western part of the Netherlands (Fig. 1) which might hold potential niches for the species.

Recently, several specimens of *C. multisetosum* were observed in samples from various locations of the Rhine-Meuse delta. The present study describes the locations of the new observations. Local conditions and community structures at the sites of observation are compared with each other and with areas containing *C. multisetosum* populations in other parts of Europe. The status of the recent range extensions of *C. multisetosum* in the Netherlands will be discussed.

Materials & Methods

The macrofauna communities of the large water bodies of the Rhine-Meuse delta in the south-western part of the Netherlands (Fig. 1) are monitored and sampled during various projects. However, the sampling intensity (times, numbers and densities) differs a lot between the areas/waters and years (Table 1). Figure 1 (A, B and C) shows the locations of the sample sites since 1990 in the vicinity of where *C. multisetosum* is observed in the three large water bodies Haringvliet, Westerschelde and Oosterschelde. All macrobenthos monitoring data of the Centre for Estuarine and Marine Ecology of the Netherlands Institute of Ecology (NIOO-CEME) are stored in the Benthos Information System (BIS v1.22.0) database at the institute. Corophiids were determined to species level using the key of Lincoln (1979).

To characterize the sample sites where *C. multisetosum* is observed, the average salinity and water temperature ± standard deviations are calculated for the Westerschelde from the monthly averages of the two years before the observation date, at the stations Waarde, Perkpolder, Baalhoek and Bath, globally surrounding the sites of observation. The data are extracted from LIMS v3.8.1, the database containing the abiotic (monitoring) data of the NIOO-CEME. For the Oosterschelde the values are calculated from the data of monitoring station Krabbenkreek – Keeten, situated in the vicinity of the site of observation of *C. multisetosum*. The temperature values for the Haringvliet are calculated in a similar way from data extracted from the Waterbase (Waterbase, 2007), and salinity indications for this region are extracted from Bavelaar & Ligtenberg (2004).

The communities of samples with and without *C. multisetosum* in the different areas are compared on the presence and absence of the other species separately, using multiple t-tests (after F-testing) taking Bonferroni corrections for multiple tests on the significance levels ($p=0.05/(n*(n-1)/2)$ with n = number of tested species) into account (Sokal & Rohlf, 1995). Only samples of the same series in which *C. multisetosum* was observed (same dates and regions) are taken into account (e.g. only the Haringvliet samples at the eastern side of the dam Haringvliet; in the eastern part of the Westerschelde only samples from the Waarde and Walsoorden tidal flats area).

Results

The densities of *C. multisetosum* differ with the site of observation. In the Haringvliet and the Oosterschelde low densities were found, whereas in the Westerschelde much higher densities were regularly found (Table 2).

Comparing the communities in which *C. multisetosum* was observed, those are in the Haringvliet largely Tubificidae, *Bithynia tentaculata* (Linnaeus, 1758), and *Corbicula sp* (Mergele von Mühlfeld, 1811) dominated. At Waarde they are *Corophium* (Latreille, 1806) dominated, especially *C. volutator* and *C. multisetosum*, and regarding biomass also *Nereis diversicolor* (Müller, 1776). For the specimens indicated with *Corophium sp*, it is uncertain whether these belong to *C. volutator*, *C. multisetosum* or *Corophium arenarium* (Crawford, 1937), the third species of the Corophiidae observed in the area, as they were juveniles or incomplete specimens (Lincoln, 1979). At Walsoorden *Pygospio elegans* (Claparède, 1863), *Hydrobia ulvae* (Pennant, 1777), *Macoma balthica* (Linnaeus, 1758) and the Oligochaeta are always present in high numbers or biomasses. Further also *Heteromastus filiformis* (Claparède, 1864) is common in the Westerschelde samples containing *C. multisetosum*.

The number of species is in the same range for the Haringvliet and Westerschelde samples (i.e. no significant differences between the Haringvliet and Walsoorden samples). The total macrofauna densities and biomass are however much higher for the Westerschelde samples than for the Haringvliet samples.

In general, the samples from the Waarde, Walsoorden and Biomon projects (intra-Westerschelde comparison) show large similarities, whereas there are large differences between the regions Haringvliet, Westerschelde and Oosterschelde. Although the observations in the Westerschelde differ more than 4 years in time, *C. multisetosum* was found in the three studies in co-occurrence with *C. volutator*, *M. balthica*, *N. diversicolor* and *P. elegans* (Table 3). These observations are originating from a small geographical area, within less than 5 km of reciprocal distance. The observations in the Haringvliet are however always in co-occurrence of *B. tentaculata*, *Corbicula sp*, *Dreissena polymorpha* (Pallas, 1771), *Valvata piscinalis* (Müller, 1774) and Tubificidae. Thus, there is no overlap at all in co-occurring species between the Haringvliet and Westerschelde samples. The single observation in the Oosterschelde was found in another very different community which only had a few species in common with the Westerschelde samples.

Another difference between the three regions for the samples with *C. multisetosum* is the sample depth. In the tidal Westerschelde, *C. multisetosum* was always found on the tidal flats (0 m), whereas in the stagnant Haringvliet it was observed around 2 m depth and in the Oosterschelde at 6.6 m (Table 3). Whereas the differences in water temperature between the three regions are small, though significant, with higher temperatures in the Haringvliet than in the Westerschelde ($p=0.02$), and again higher in the Westerschelde than in the Oosterschelde ($p<0.001$), the differences in salinity are huge. Highest salinity occurred in the Oosterschelde, intermediate in the Westerschelde, and lowest (freshwater, always < 1 ‰) in the Haringvliet (Bavelaar & Ligtenberg, 2004) (significant differences between regions, $p<0.001$). As far as sediment characteristics are available from the sampling sites where *C. multisetosum* was found, these are generally described as fine sandy sediments, but *C. multisetosum* was also found on other fine sediment types, as mud with clay, in the Westerschelde and the Haringvliet.

Comparing the communities of the samples with *C. multisetosum*, with those without *C. multisetosum* within the same region, it is found that in the Haringvliet *C. multisetosum* is negatively related to *Corbicula fluminea* (Müller, 1774), *Gammarus zaddachi* (Sexton, 1912) and the Nematoda for all sample sites in the Haringvliet research area (Table 2). In the Westerschelde negative relations are found with *Haustorius arenarius* (Slabber, 1769).

Discussion

According to our sampling results, *C. multisetosum* appeared in the south-western part of the Netherlands in 2001 in the Haringvliet for the first time. In the Westerschelde the first observation was made in 2002 and in 2006 for the second time, and in the Oosterschelde in 2006.

For the entire northern part of the Rhine-Meuse delta, consisting of the Haringvliet, Hollands Diep and Biesbosch, several other macrobenthos monitoring surveys are available. *C. multisetosum* was, however, not found during those other studies, including a specific Amphipod survey in the whole Rhine-Meuse estuary in 1992/93, generally focusing on hard substrates (Platvoet & Pinkster, 1995), a general study on the sublittoral macrozoobenthic assemblages in the northern Dutch delta in 1988 (Smit et al., 1995), and a study focusing on creeks in the Biesbosch in 2001 (De Lange et al., 2004). The last study yields indications that *C. multisetosum* is not present in the Biesbosch, as the associated species found by us in the Haringvliet in 2001, D. *polymorpha*, *B. tentaculata* and *V. piscinalis*, were found but never together in the Biesbosch study (Lange et al. (2004).

The environmental conditions of this northern area historically changed a lot, during the transition from an estuary with a salinity gradient to a series of freshwater basins in the 1970’s and the concurrently improvement of the water quality (Wijnhoven et al., 2007). Yet, the last decade the environmental conditions are relatively stable. *C. multisetosum* might thus be related to this more stable phase in the Haringvliet, although it then remains uncertain why it was not found more to the east in the Biesbosch, since in the Hollands Diep and the Biesbosch similar shallow waters are available (extracted from MapSend BlueNav, Europe v.1.01g, Thales Navigation 2003) and salinity levels are not very different although a bit lower to the east (Smit et al., 1995). The salinity in large parts of the Biesbosch thus might just be too low for *C. multisetosum*, although more fine grained sediments towards the east may be a reason too (see below). That *C. multisetosum* is present in the Hollands Diep and/or the Volkerak in 2006, might be indicated by our singular observation of *C. multisetosum* in the Oosterschelde. On the other hand, *C. multisetosum* is also found to maintain at higher salinities of above 30 ‰ in other parts of Europe (Queiroga, 1990). Where salinity and species composition in the Mondego River are comparable with the Westerschelde, *C. multisetosum* is in the Mondego River observed between depths of 0.8 and 6 m, indicating that at salinities between 2 and 31.6 ‰, *C. multisetosum* is not necessarily found on tidal flats alone (Chainho et al., 2006). Salinities reaching higher than 31.6 ‰, up to 40.2 ‰ appear to be too high for *C. multisetosum* (Chainho et al., 2006). An average salinity of 30.6 ‰, together with the 6.6 m depth at which the specimen is found, would be the extreme tolerance limit for *C. multisetosum*. This tolerance limit would make it also more likely that the single specimen found in the Oosterschelde entered with water (or boats) from the northern Delta area (i.e. Volkerak, Hollands Diep, Haringvliet) through the sluices and that no viable population is present in the Oosterschelde.

In the Westerschelde, *C. multisetosum* was first observed in 2002 in a corner of the tidal flat of Waarde. *C. multisetosum* was later also observed in a sample in 2006 in the same corner of the tidal flat of Waarde, showing that the population maintained there. Moreover, *C. multisetosum* also established on the tidal flat of Walsoorden in 2006, where it was absent in previous samples. In the Westerschelde *C. multisetosum* is probably only found on tidal flats, as deeper parts are even more intensively monitored since 1990 in the Biomon project, and in other studies (e.g. Mees & Hamerlynck, 1992; Mees et al., 1995). Other potentially suitable locations for *C. multisetosum*, are therefore the tidal flats up- and downstream and south of the Waarde and Walsoorden tidal flats. Upstream of the Waarde and Walsoorden tidal flats, potential locations like the tidal flats of Buitenschoor, Galgenschoor en Paardenschoor (situated in Belgium) are investigated in 1996 and 1997 (Ysebaert et al., 2000 & 2005). From these studies we know that at salinities lower than in the Waarde and Walsoorden area, ranging between <5 and 13.4 ‰, and at water temperatures that might be slightly higher (on average 14.3 °C in April and 21.3 °C in September), of the two species found to be associated with *C. multisetosum* in the Waarde and Walsoorden area, only *C. volutator* was frequently found. *H. arenarius*, the species negatively related to *C. multisetosum*, which means that it was found in the same region but specifically at sites where *C. multisetosum* was not found, was completely absent. Looking for sites where since 2000 the with *C. multisetosum* associated species *N. diversicolor* and *C. volutator* are found together and where *H. arenarius* is in the vicinity, it seems that certain parts of the Schor van Baalhoek (close to and southwest of the Walsoorden tidal flat), the East side of the Platen van Ossenisse tidal flats, parts of the Platen van Hulst tidal flats, and an occasional site at the Middel Plaat and the Hooge Platen tidal flats (all downstream to far downstream from the Waarde and Walsoorden area) might be suitable for *C. multisetosum*. These for *C. multisetosum* potential locations cover the yearly average salinity range from approximately 12 to 28 ‰ (Ysebaert et al., 1998), known as suitable for *C. multisetosum* in other parts of Europe (Chainho et al., 2006). It is therefore possible that *C. multisetosum* will extend its range in the Westerschelde to these areas in the future, or that the species is already present there, but missed so far. For conditions meeting more or less those found at the Haringvliet locations with *C. multisetosum* present (around 0.5 ‰ salinity, and water depths between 0 and 3 m) in the Schelde estuary, one has to go upstream as far as 90 to 100 kilometer from the mouth, called the Zeeschelde (Ysebaert et al., 1998; Breine et al., 2007). However, compared to the Haringvliet, this part of the Zeeschelde has a large tidal range of 5.1 m, and the oxygen levels are very low (1-38 % saturation), which leads to highly Oligochaeta dominated communities, with almost no other taxa (Seys et al., 1999). It is therefore very unlikely that *C. multisetosum* is present in the freshwater and near-freshwater part of the Schelde estuary.

Queiroga (1990) shows that *C. multisetosum* prefers sediments rich in particles between 125 and 1000 µm, and that the occurrence of *C. multisetosum* is negatively correlated with sediments rich in particles below 125 µm. The observations in the Rhine-Meuse delta which are predominantly on sediments described as fine sand are in line with that, however also observations on finer sediments described as mud with clay are made. Also Stock (1952) records that the burrows of *C. multisetosum* in the North Sea Canal and near the Eem are in clay and sand which is underlined by *C. multisetosum* present in the Stour estuary with benthic substratum mostly made up of fine sediments (<120 µm) (Buckley et al., 2004). However, sediment type can limit the distribution of *C. multisetosum* also in the Rhine-Meuse delta, where in both the Westerschelde and the Haringvliet upstream of the areas where *C. multisetosum* is found now (e.g. Hollands Diep, Biesbosch and Zeeschelde), fine sediment types are more common (Smit et al., 1995; Ysebaert et al., 1998).

The distances, including potential physical barriers, between the waters where *C. multisetosum* is known to occur and the new observations in the Rhine-Meuse delta, and the fact that *C. multisetosum* is never observed in areas in between (e.g. Platvoet & Pinkster, 1995; Smit et al., 1995), makes it unlikely that the species traveled trough the connected waters on its own. The North-Sea Canal near Amsterdam is connected to the Delta by the Amsterdam-Rhine Canal and the Rhine arms, the rivers Lek and Waal, or via the coastal waters of the North Sea. However, in the first case a long stretch of freshwater and in the second case, seawater should be crossed, which both might hold salinity problems for the species. It is therefore more likely that *C. multisetosum* came to the Delta attached to boats or in ballast water, especially in a region as the Rhine-Meuse delta with heavy shipping. It is therefore also possible that the newly settled populations are originating from estuaries from other parts of Europe.

At first sight, it almost seems like we are dealing with two types of *C. multisetosum*. Another possibility is that the species finds a niche in two different habitats where it seems to be a good competitor with other species and Amphipods in particular, whereas competition in the intermediate habitats is more severe. Although *C. volutator* is a close relative of *C. multisetosum*, which might compete for the same niche, the species are often found together. A difference between the species, is that *C. multisetosum* generally makes burrows, although the building of mud tubes on fixed substrata has been found, whereas *C. volutator* constructs tubes (Lincoln, 1979). It has been observed that *C. volutator*, replaces *C. multisetosum* at the more saline side of the spectrum (Jażdżewski, 1976; Buckley et al., 2004). Probably *C. arenarium*, a burrowing species, is more a competitor for *C. multisetosum*, although also this species might be more tolerarant towards full salinity. *C. lacustre* is often described as being in association with *C. multisetosum* (Stock, 1952; Lincoln, 1979). *C. lacustre* and *Chelicorophium curvispinum* (Sars, 1895), both tube building species, might replace *C. multisetosum* at the freshwater side of the spectrum (Jażdżewski, 1976; Buckley et al., 2004), although while occupying different substrata than *C. multisetosum*, they will generally not compete for space.

Cunha et al. (2000b) more or less recorded the same phenomenon as we observe in the Rhine-Meuse delta. *C. multisetosum* was in the Ria de Aveiro and other channels of the Ria (Portugal) especially found in shallow low-salinity areas, yet also in higher-salinity areas where it occurred mainly on intertidal sandy sediments near mean high water level.

In Poland *C. multisetosum* is found at salinities between 3 and 7 ‰ in a basin and a canal with a slow current at shallow depths (Jażdżewski, 1976). Although salinities are higher, the Polish situation might look more like the situation of *C. multisetosum* in the Haringvliet. In the Polish canal environment, *C. multisetosum* was accompanied by *C. volutator*, *Bathyporeia pilosa* (Lindstrom, 1855), *Gammarus duebeni* (Lilljeborg, 1852) and *G. zaddachi*. Whereas *G. zaddachi* was negatively associated with *C. multisetosum* in the Haringvliet, which means that it was frequently present in the surroundings but usually not in the same samples as *C. multisetosum*, *C. multisetosum* was positively associated with *C. volutator* in the Westerschelde. The same as accounts for *G. zaddachi* in the Haringvliet, accounts for *B. pilosa* in the Westerschelde, although the negative association was not significant. These are indications that the two new habitats found in the Netherlands might be extremes, but that there are similarities with the Polish situation. The recordings by Stock (1952) and Mulder & Stock (1954) near Amsterdam are more comparable to the Polish situation.

In the tidal Canal de Mira (Portugal) where *C. multisetosum* was highly dominant, the species was found in a salinity range with average values between 0.1 and 28.7 ‰, but with salinity peaks above 30 ‰ (Queiroga, 1990). But the species appeared to be more abundant there where salinities range between 0 and 20 ‰, and much more abundant where salinities range between 0 and 13 ‰ (Queiroga, 1990). It was also shown that the species breeds at salinities between 0 and 15 ‰ (Cunha et al., 2000a). In Canal de Mira, the abundance of *C. multisetosum* was amongst others positively correlated with those of *Cyathura carinata* (Kröyer, 1848) (Cunha et al., 2000b), a species which co-exists with *C. multisetosum* in the Westerschelde and was relatively abundant. Two species who were negatively correlated with the abundance of *C. multisetosum* in Portugal, but which co-existed, were *N. diversicolor* and *V. piscinalis*, of which we found that they were positively associated with *C. multisetosum* in the Westerschelde and the Haringvliet respectively. In the case of the Rhine-Meuse delta the two associated species were abundant where in Portugal the numbers of these species appeared to be low at a high abundance of *C. multisetosum*, indicating that they might be competitors of *C. multisetosum* in the same niches, or in the case of *N. diversicolor*, that they might influence the substrate such that this is negative to *C. multisetosum* (Cunha et al., 2000b).

Densities and especially the distribution of *C. multisetosum* in the Rhine-Meuse delta, but also for instance in Poland and England, (Jażdżewski, 1976; Buckley et al., 2004), might be limited by competition for food or space with the other Corophiidae. *C. volutator, C. arenarium* and/or possibly *C. lacustre, C. insidiosum* and *C. curvispinum* might compete for resources in areas where *C. multisetosum* in potential can be abundant. These species are not present in Canal de Mira (Cunha et al., 2000b). In the Mondego River (Portugal), *C. multisetosum* is also found to be abundant, where as the only other Corophiid, *Corophium acherusicum* (Costa, 1857) is found in low densities (Chainho et al., 2006). The species co-existing here with *C. multisetosum* in relatively high abundances (*Streblospio shrubsollii* (Buchanan, 1890), Oligochaeta, *H. ulvae*, *C. carinata*, and *Spio martinensis* (Eliason, 1962) and *Capitella capitata* (Fabricius, 1780)) do also co-exist with *C. multisetosum* in the Westerschelde, but *S. shrubsollii* not as a dominant species, and *S. martinensis* and *C. capitata* are negatively associated and therefore not found at exactly the same spots. Only *C. fluminea* is not found in the Waarde and Walsoorden area, but is however found in the Haringvliet, where it is negatively associated with *C. multisetosum*.

Wijnhoven et al. (2007) showed that the average temperature in the Haringvliet has gradually increased with approximately two degrees since 1959, probably as a result of the increased use of river water for cooling by industries. Regression analyses of the daily surface water temperature measurements at Bath between 1908 and 1996 (Waterbase, 2007), completed with monthly measurements by the NIOO-CEME between 1995 and 2007 (LIMS v3.8.1), showed a similar pattern in the Westerschelde. A significant gradual temperature increase of 2.8 °C during the last century was found, at which the last 20 years the increase was even steeper (0.035 °C per year). The water temperature increase might have made settlement of *C. multisetosum* possible, as slightly higher temperatures might have been more favorable to *C. multisetosum* than to its competitors. In the Haringvliet the average annual temperature is nowadays well above 13 °C, and in the Westerschelde the 13 °C is being approached. For a species breeding at temperatures between 8 and 25 °C (Cunha et al., 2000a), the temperature increase can make a huge difference.

The current status of *C. multisetosum* outside the Rhine-Meuse delta and the North Sea Canal is uncertain. *C. multisetosum* might still be present near Wieringen, but it is very uncertain whether *C. multisetosum* is still present in the waters surrounding the Eem, as observations date back to the time that lake IJsselmeer was in open connection with the sea (before 1933), and was brackish water. Nowadays the Eem and the surrounding waters will all contain freshwater.

The current study shows that *C. multisetosum* has settled permanently in the Rhine-Meuse delta. When and how the species arrived is not totally clear. It is very likely that *C. multisetosum* settled in the Westerschelde on the tidal flat of Waarde in or just before 2002, and extended its range to the tidal flat of Walsoorden a few years later, in or just before 2006. It is expected in the near future that *C. multisetosum* will also be present at tidal flats in the vicinity of Waarde and Walsoorden, or at tidal flats up- and downstream. When the species arrived in the Haringvliet is more uncertain. *C. multisetosum* was observed in 2001, but might already be present there already some years before, since the other surveys in the northern Delta stem from the late 1980s and early 1990s. It is most likely that *C. multisetosum* reached the new locations via boats and/or ballast water.

C. multisetosum can be found in two clearly separated niches in the Rhine-Meuse delta holding a completely different community; 1) at depths below 0 m up to 3 meters in stagnant freshwater with salinity around 0.5 ‰ or even lower, dominated by *B. tentaculata*, juvenile

Corbicula sp. and Tubificidae, in association with *D. polymorpha*, *V. piscinalis*, *B. tentaculata*, and negatively related to Nematoda, *C. fluminea* and *G. zaddachi* living in the vicinity, and 2) on intertidal flats with salinity ranging between 6 and 21 ‰, in *C. volutator* and Oligochaeta dominated communities, in association with *N. diversicolor* and *C. volutator*. It is most likely that *C. multisetosum*, elsewhere in Europe also observed in intervening environments, is only present in these two extreme environments (jet), due to a more severe competition in the environments in between. Further changing conditions (e.g. increasing water temperature) might favor *C. multisetosum* more than its competitors (e.g. other Corophiidae) and lead to range extensions or a more dominant position within the Rhine-Meuse delta in the future.

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Figure captions

Fig. 1: Positioning of the Rhine-Meuse delta in the south-western part of the Netherlands. Areas where *C. multisetosum* was observed before, i.e. North Sea Canal, river Eem and near Wieringen are indicated. New observations are from the Rhine-Meuse delta.

Fig. 1.A: The monitoring sites in the Haringvliet and the eastern part of the Haringvliet Voordelta (North Sea) sampled in 2001. The plusses (✚) indicate the sites where *C. multisetosum* was found.

Fig. 1.B: The monitoring sites in the Oosterschelde near the 'Krammer' sluices sampled in 2006. The plus (✚) indicates the site where *C. multisetosum* was found.

Fig. 1.C: The monitoring sites in the central and eastern part of the Westerschelde separated in the years 2000-2001; 2002; 2003-2005; 2006, indicated with circles (○). Plusses (✚) indicate the sample sites where *C. multisetosum* is found in 2002 and 2006.

Figures

Fig. 1:

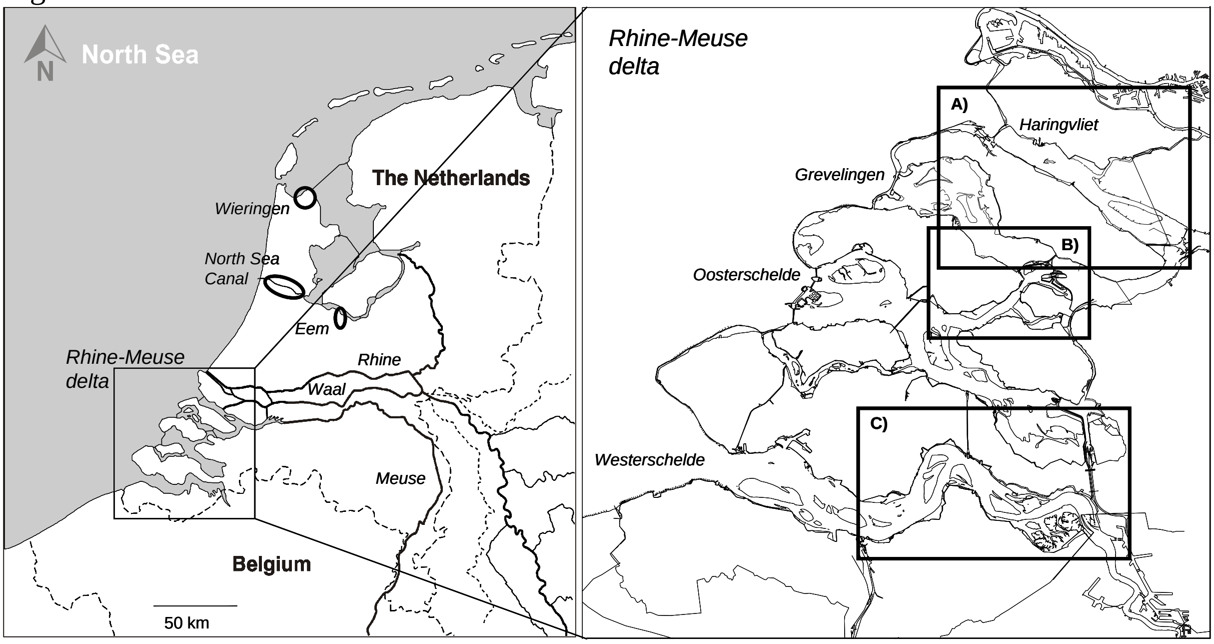
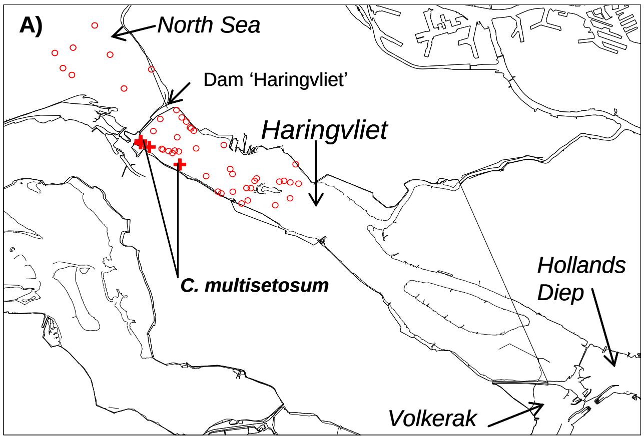


Fig. 1A:



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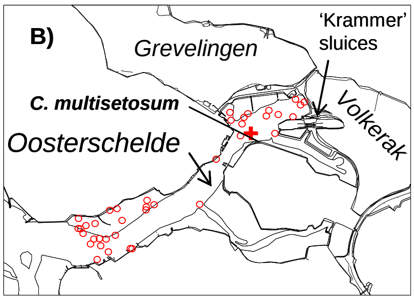

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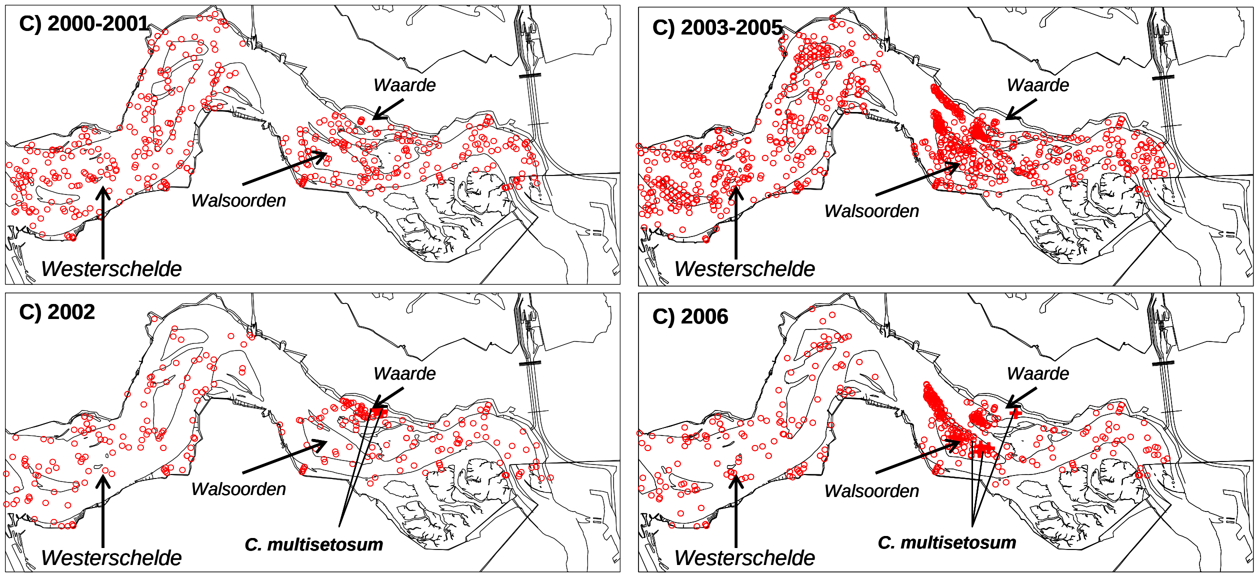

C) 2000-2001
Waarde
Walsoorden
Westerschelde
C) 2003-2005
Waarde
Walsoorden
Westerschelde
C) 2002
Waarde
Walsoorden
Westerschelde
C. multisetosum
C) 2006
Waarde
Walsoorden
Westerschelde
C. multisetosum

Tables

Table 1: Monitoring programmes with their samples and sampling characteristics as executed during the years 1990-2006 in the large water bodies Haringvliet, Westerschelde and Oosterschelde.

Table 2: Characteristics of the samples from the Rhine-Meuse delta including *Corophium multisetosum*.

Table 3: Characteristics of the areas where *Corophium multisetosum* is found and possible associations of *C. multisetosum* with other species.

Table 1:

Project	Region	Depth	Season	Year	Methodology	Number of samples
Haringvliet monitoring	Haringvliet (western part)	0 – 2 m	Autumn	2001 at random sampling	3 x 8 cm diameter corers directly in sediment or from Reineck boxcorers	10
		>2 m				10
	Haringvliet (central-western part	0 – 2 m				10
		>2 m				10
Waarde	Waarde tidal flat	Intertidal*	Spring	2002 (also sampled between 1987-1991)	3 x 8 cm diameter corers directly in sediment	30
Walsoorden	Walsoorden tidal flat	Intertidal*	Twice a year in spring and autumn	2004-2006 fixed sample sites	3 x 8 cm diameter corers directly in sediment	120[1]
Biomon WS	Westerschelde (WS; eastern part of Dutch WS)	Intertidal*	Twice a year in spring and autumn	1990-2006 at random sampling	3 x 8 cm diameter corers directly in sediment or from Reineck boxcorers	10
		2 – 5 m				10
		5 – 8 m				10
		>8 m				10
	WS (central part)	idem	idem	idem		idem
	WS (western part)	idem	idem	idem		idem
Move	WS (intertidal areas)	Intertidal*	Twice a year in spring and autumn	1994-2006 fixed sample sites	15 x 4.5 cm and 5 x 15 cm diameter corers directly in sediment	40
	WS (central-western part)	Intertidal*	Twice a year in spring and autumn	1994-2006 at random sampling	3 x 8 cm diameter corers directly in sediment or from Reineck boxcorers	5
		2 – 5 m				5
		5 – 8 m				5
		>8 m				5
Biomon OS	Oosterschelde (OS; near Krammer sluices)	Intertidal*	Twice a year in spring and autumn	1990 – 1994 at random sampling; 1994 – 2006 fixed sample sites	3 x 8 cm diameter corers directly in sediment or from Reineck boxcorers	10
		2 – 5 m				10
		5 – 8 m				10
		>8 m				10
	OS (eastern part)	idem	idem	idem		idem
	OS (western part)	idem	idem	idem		idem

*Intertidal samples are taken within the depth range of +1 to -2 meter relative to the mean tide level (MTL)

[1]In 2004, only 40 and 60 samples were taken in spring and autumn respectively

Table 2:

Code	Region	Project	Sample date	Sampled area (m2)	Depth (m)	*Corophium multisetosum* (n/m2)	Dominant species (in numbers)	Dominant species (in weight)	Number of species	Density of total macro-fauna (n/m2)	Biomass of total macro-fauna (mg/m2)	Sediment characteristics	Remarks
1	Haringvliet	Haringvliet monitoring	02/10/01	0.015	1.5	66.7	TUBI, BITE, CORB, STIC, LIAR	BITE, POAN, TUBI, VAPI, DIPT	12	3800	573	fine sand	
2					2.7	66.7	BITE, CORB, TUBI, PIHE, PICA	BITE, CORB, TUBI, COMU, PISU	13	3533	807	mud with clay	
3					2.1	133.3	TUBI, STIC, HYIN, CORB, BITE	HYIN, CORB, COMU, STIC, TUBI	19	9267	2238	fine sand with little mud	also CORO 133.3/m^2
4					2.5	66.7	TUBI, HYIN, BITE, PIHE, VAPI	VAPI, CORB, TUBI, HYIN, BITE	16	5600	1267	fine sand with mud	
5	Westerschelde	Waarde	05/05/02	0.005	0	2000	OLIG, COVO, PYEL, COMU, NEDI	NEDI, COVO, OLIG, HEFI, COMU	7	18600	8508		
6					0	1000	COVO, CORO, PYEL, MABA, OLIG	MABA, COVO, NEDI, COMU, HEFI	8	20000	14444		
7					0	400	COVO, MABA, COMU, CYCA, OLIG	CYCA, COVO, COMU, MABA, NEDI	6	3200	1481		
8					0	200	COVO, MABA, CORO, PYEL, HEFI	COVO, NEDI, HEFI, MABA, CORO	8	11200	4494		
9					0	400	COVO, NEDI, HEFI, COMU, OLIG	NEDI, COVO, HEFI, COMU, CYCA	7	8200	11418		
10		Walsoorden	29/08/06	0.015	0	200	PYEL, HEFI, CORO, MAAE, HYUL	HEFI, NESU, NEDI, PYEL, CYCA	18	44133	25150	fine sand with little clay	
11					0	66.7	PYEL, COAR, NEDI, HYUL, MABA	MABA, NEDI, PYEL, COAR, ETEO	8	31867	6910	fine sand with little clay	also COVO present
12			30/08/06		0	2000	COVO, PYEL, COMU, MABA, OLIG	COVO, NEDI, NEME, COMU, MABA	11	26667	9600	mud with clay	also COAR present
13					0	66.7	OLIG, HYUL, COVO, NUDI, NEDI	NEDI, HYUL, OLIG, COVO, NUDI	9	18000	1387	clay	
14					0	1733	OLIG, HYUL, CORO, COMU, COVO	NEDI, HYUL, COMU, COVO, CORO	10	21667	6120	mud with clay	
15		Biomon	22/09/06		0	66.7	PYEL, HEFI, HYUL, CYCA, COVO	HEFI, MABA, CORO, HYUL, NEDI	15	18667	22111	fine sand with little mud	
16	OS *		28/09/06		6.6	66.7	ACTI, ABRA, AULA, OSTR, CORO	ENDI, ASCI, NEFI, ACTI, LACO	27	5733	121076	fine sand and mud with shells	

Five most abundant species per sample are shown in order of abundance; ABRA=*Abra sp*; ACTI=ACTINIARIA; ASCI=ASCIDIACEA; AULA=*Autolytus langerhansi*; BITE=*Bithynia tentaculata*; COAR=*Corophium arenarium*; COMU=*Corophium multisetosum*; CORB=*Corbicula sp*; CORO=*Corophium sp*; COVO=*Corophium volutator*; CYCA=*Cyathura carinata*; DIPT=DIPTERA; ENDI=*Ensis directus*; ETEO=*Eteone sp*; HEFI=*Heteromastus filiformis*; HYIN=*Hypania invalida*; HYUL=*Hydrobia ulvae*; LACO=*Lanice conchilega*; LIAR=*Lipiniella arenicola*; MAAE=*Manayunkia aestuarina*; MABA=*Macoma balthica*; NEDI=*Nereis diversicolor*; NEFI=*Neoamphitrite figulus*; NEME=NEMERTEA; NESU=*Nereis succinea*; NUDI=NUDIBRANCHIA; OLIG=OLIGOCHAETA; OSTR=Ostreidae; PICA=*Pisidium casertanum*; PIHE=*Pisidium henslowanum*; PISU=*Pisidium supinum*; POAN=*Potamopyrgus antipodarum*; PYEL=*Pygospio elegans*; STIC=*Stictochironomus sp*; TUBI=Tubificidae; VAPI=*Valvata piscinalis*
* OS=Oosterschelde

Table 3:

Region	Water type	Depth of occurrence (m)	Salinity (‰)	Temperature (°C)	Species frequently co-occurring	Species significantly related, depth not considered (sign. level)	Species significantly related at similar depth (sign. level)
Haringvliet n=4	Stagnant freshwater basin	2.20 ± 0.53	Ranges between 0.4 – 0.6 [1]	13.8 ± 5.5 [5]	BITE (100%) CORB (100%) DRPO (100%) TUBI (100%) VAPI (100%)	DRPO ($+1.55*10^{-10}$) VAPI ($+1.12*10^{-8}$) BITE ($+1.60*10^{-5}$) NEMA ($-1.12*10^{-8}$) COFL ($-2.63*10^{-6}$) GAZA ($-3.73*10^{-5}$)	DRPO ($+3.88*10^{-5}$)
Westerschelde n=11	Tidal estuary	0 (intertidal flats)	11.7 ± 5.2 [2] and 16.1 ± 4.6 [3]	12.5 ± 5.2 [2] and 12.5 ± 5.9 [3]	NEDI (100%) COVO (91%) MABA (82%) PYEL (82%)	NEDI ($+4.9*10^{-103}$) COVO ($+5.35*10^{-6}$) HAAR ($-1.82*10^{-7}$)	NEDI ($+1.31*10^{-35}$) COVO ($+2.30*10^{-5}$)
Oosterschelde n=1	Tidal saltwater basin	(6.6)	30.6 ± 1.1 [4]	11.5 ± 6.1 [4]	n.a.	n.a.	n.a.

[1] measured at the Haringvliet sluices (Bavelaar & Ligtenberg, 2004); [2] measured monthly between May 2000 and April 2002, and [3] measured monthly between October 2004 and September 2006, near Waarde, Perkpolder, Baalhoek and Bath; [4] measured monthly near Krabbenkreek – Keeten between October 2004 and September 2006; [5] measured at the Haringvliet sluices between November 1999 and October 2001 (Waterbase, 2006).

BITE=*Bithynia tentaculata*; COFL=*Corbicula fluminea*; CORB=*Corbicula sp*; COVO=*Corophium volutator*; DRPO=*Dreissena polymorpha*; GAZA=*Gammarus zaddachi*; HAAR=*Haustorius arenarius*; MABA=*Macoma balthica*; NEDI=*Nereis diversicolor*; NEMA=NEMATODA; PYEL=*Pygospio elegans*; TUBI=Tubificidae; VAPI=*Valvata piscinalis*

n.a. = not available as n=1