The invasive *Corbicula* species (Bivalvia, Corbiculidae) and the sediment quality in Flanders, Belgium

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ABSTRACT. *Corbicula species*, *C. fluminea* and *C. fluminalis* (Bivalvia, Corbiculidae) started to invade the Belgian section of the river Meuse, and some of the connected canals in the early 1990s. During 1999 and 2000, sediment samples from 33 watercourses in Flanders, Belgium were collected and analysed. The clam was found in six watercourses. *C. fluminea* was present in all of the six watercourses, whereas *C. fluminalis* was found only in three canals. Overall, the density of *Corbicula* species averaged around 200 individuals/m^2, except for four places connected with the river Meuse where the density was higher than 1000 individuals/m^2. In 63% of the invaded sites, the clam was the most abundant taxon. Most of the sites (89%) colonised by *Corbicula* species were (slightly to heavily) polluted by organic contaminants and heavy metals. However, no correlation between the clam density or proportion and the quality of the sediment was observed. Including *Corbicula* species in the Biotic Sediment Index calculation altered biological sediment quality classification in 52% of the cases. The results show that colonisation of *Corbicula* species in Belgium is continuing to expand.

KEY WORDS: *Corbicula*, invasion, abundance, sediment quality.

INTRODUCTION

Corbicula species (Bivalvia, Corbiculidae) are native to Asia, Africa and Australia where they form an important component of the benthic community. In the 1930s, the clam was introduced in the United States and rapidly spread across the country, causing considerable damage to hydro installations and becoming one of the most important molluscan pest species ever introduced (McMahon, 1983). In the early 1980s the presence of *Corbicula* species in some of the European rivers, e.g. Dordogne - France; Tajo - Portugal; Miño - Spain, Portugal (Araujo et al., 1993) was evidence of the invasion of the clam in Europe. In the beginning of the 1990s, successfully established populations of the clam were recorded in Germany and the Netherlands (bij de Vaate & Greijdanus-Klaas, 1990; Haesloop, 1992). In the same period, two species *C. fluminea* (Müller, 1974) and *C. fluminalis* (Müller, 1974) were also found in the Belgian section of the river Meuse and in some of the large connecting canals (Swinnen et al., 1998).

Invasive species of *Corbicula* originally attracted attention as an economically important fouling organism in irrigation and drainage canals, water distribution and industrial water use systems. However, its ecological influence on natural systems has recently become of major concern. In comparison with most freshwater bivalves, the clam is reported to have a high growth rate and a short life span. It also appears to have a relatively high annual production and high filtering rate. Such characteristics have led to speculation that the clam has the capacity to alter the trophic and nutrient dynamics of aquatic systems and to displace native bivalves (Britton & Morton, 1982; Marsh, 1985; Isom, 1986; Ricciardi et al., 1995; Strayer, 1999). On the other hand, some investigators have claimed, on the basis of field studies, that the potential influence of *Corbicula* species on aquatic ecosystems does not appear to be dramatic, and thus believed that the clam would not be a threat to native bivalves (Stites et al., 1995; Miller & Payne, 1994, 1998; Dillon, 2000). Despite different opinions on the ecological effect of *Corbicula* species, the clam is considered as a biological pollutant and the proportion of individuals of *Corbicula* has been recommended as one of the metrics in biological assessment of water quality (Kerans & Karr, 1994; Carlisle & Clements, 1999; US EPA, 1999). The present study aims at contributing to the understanding of the ecological and environmental aspect of *Corbicula* species in Belgian watercourses. More specifically it set out

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to investigate whether or not there is a relationship between the distribution of the clam and the water/sediment quality.

MATERIAL AND METHODS

Sampling

The present study was conducted within the framework of an AMINAL project, which was set up to assess the sediment quality of all watercourses in Flanders, Belgium. The assessment was based on a combination of physico-chemical, ecotoxicological and biological data, i.e. a TRIAD assessment approach (MINISTRY OF FLEMISH COMMUNITY, 1998). For this purpose, during the spring of 1999 and 2000, 180 bottom sediment samples were collected from 33 watercourses. The sampling was performed as outlined in the standard protocol for sediment sampling (MINISTRY OF FLEMISH COMMUNITY, 1998). A Van Veen grab (surface 250 and 500 cm^2) was used to retrieve the sediment samples from depths varying between 1 and 5m. On arrival in the laboratory, samples were sieved over a pile of metal sieves (1 cm – 1 mm – 0.5 mm). Benthic macroinvertebrates including *Corbicula* species were sorted out and examined under a stereomicroscope.

Physico-chemical classification

Measurements of temperature (°C), dissolved oxygen (%), pH, and conductivity (mS/cm) of water at each sampling site were carried out *in situ*. The physico-chemical parameters measured for assessing the sediment are the following:

1. Clay (%) and organic matter (%)
2. Nonpolar hydrocarbons
3. Extractable organohalogens
4. Sum of the pesticides
5. Sum of 7 PCBs
6. Sum of 6 Borneff PAHs
7. Heavy metals: Cd, Cr, Cu, Ni, Pb, Hg, Zn and As

After being measured, each parameter was compared with its reference value, and the ratio of the measured and the reference value was calculated. All the ratios (indices) obtained were normalised by using logarithmic transformation (0<LOGINDEX<2). Samples were then classified into four classes (Table 1) and the highest class of all physico-chemical parameters was taken as the overall quality class (MINISTRY OF FLEMISH COMMUNITY, 1998).

TABLE 1

Sediment quality classification based on physico-chemical parameters.

Log Index	Class	Significance (compared to reference)
0 - < 0.4	**1**	Not deviating
0.4 - < 0.8	**2**	Slightly deviating
0.8 - < 1.2	**3**	Deviating
1.2 - < 2	**4**	Strongly deviating

Biological classification

The sediment quality was also assessed by means of the Biotic Sediment Index (BSI) (DE PAUW & HEYLEN, 2001). The BSI is an adapted version of the Belgian Biotic Index (DE PAUW & VANHOOREN, 1983; NBN, 1984), which is based on the taxonomic diversity of the benthic macroinvertebrate community and the presence or absence of indicator taxa in a given sediment sample. The BSI score can vary between 10 and 0, corresponding with four sediment quality classes (Table 2). The biological sediment quality was assessed using two approaches: (1) calculating the BSI without considering the presence of *Corbicula* species and (2) calculating the BSI considering *Corbicula* species as a taxon in overall diversity and in the mollusc indicator group.

TABLE 2

Sediment quality classification based on the BSI.

BSI	Class	Significance
7 - 10	**1**	Good biological quality
5 - 6	**2**	Moderate biological quality
3 - 4	**3**	Bad biological quality
0 - 2	**4**	Very bad biological quality

Statistical analysis

Linear regression (SOKAL & ROHLF, 2000) was used to examine the correlation between degree of pollutants in the sediments (physico-chemical classification) and (1) the densities (logarithmic transformed of the number of individuals per square meter); (2) the relative abundance (number of the clam in sample/total number of macroinvertebrates in sample) of *Corbicula* species.

RESULTS

Distribution

Corbicula species were found in 27 sampling sites of six different watercourses in Flanders, Belgium (Table 3). Besides the canals Albert and Bocholt-Herentals that were already successfully colonised by the clam (SWINNEN et al., 1998), *Corbicula* species was found in the canals Zuid-Willemsvaart, Dessel-Schoten and Willebroek, and in the river Dender. The clam was present in more than 80% of the sampling sites of the canal Herentals-Bocholt, the canal Albert and the canal Zuid-Willemsvaart. In the canal Dessel-Schoten, *Corbicula* specimens were found in three out of ten sampling sites. Ten sites of the river Dender (from Appels to Geraadsbergen) were also sampled, and so far, the clam was found in only one site (Appels).

TABLE 3

Watercourses in Flanders colonised by *Corbicula* species.

Watercourses	N° of sampling sites	N° of sites inhabited by the clam	Sampling date
Canal Bocholt-Herentals	8	7	April, June 1999
Canal Zuid-Willemsvaart	10	8	June 1999
Canal Albert	8	7	May 2000
Canal Dessel-Schoten	10	3	April 1999
Canal Willebroek	5	1	May 2000
River Dender	10	1	March, April, May 2000

Likewise, of the five sampling sites (from Willebroek to Vilvoorde) in the canal Willebroek, only one site (Willebroek) was invaded by species of *Corbicula*.

Two species, i.e. *Corbicula fluminea* (Müller, 1774) and *Corbicula fluminalis* (Müller, 1774), were identified in the samples. The former species was present in all of the 27 invaded sites, while the latter one was found in one site of the canal Albert, two sites of the canal Bocholt-Herentals, and in four sites of the canal Zuid-Willemsvaart.

Density and relative abundance

Sediments of 89% of the sites in which *Corbicula* species was found were strongly deviating (44%), deviating (19%) or slightly deviating (26%) from the chemical-physical standard. Only 11% of the sites had a sediment quality not deviating from the uncontaminated references.

Densities of *Corbicula* species in canal Bocholt-Herentals, canal Albert, canal Zuid-Willemsvaart and canal Dessel-Schoten, are given in Fig. 1. In general, the densities, averaged across all sampling sites, were less than 200 clams/m^2. There were only four sites (A2, B2, B9 and C1) where the clam density reached one thousand or more specimens per square meter. The sites of the canal Willebroek and the river Dender inhabited by *C. fluminea* showed densities of 164 and 60 clams/m^2, respectively. In 63% of the invaded sites, benthic communities were dominated by the clam. Especially in site C7 (canal Albert) no macroinvertebrates were found except *Corbicula* species.

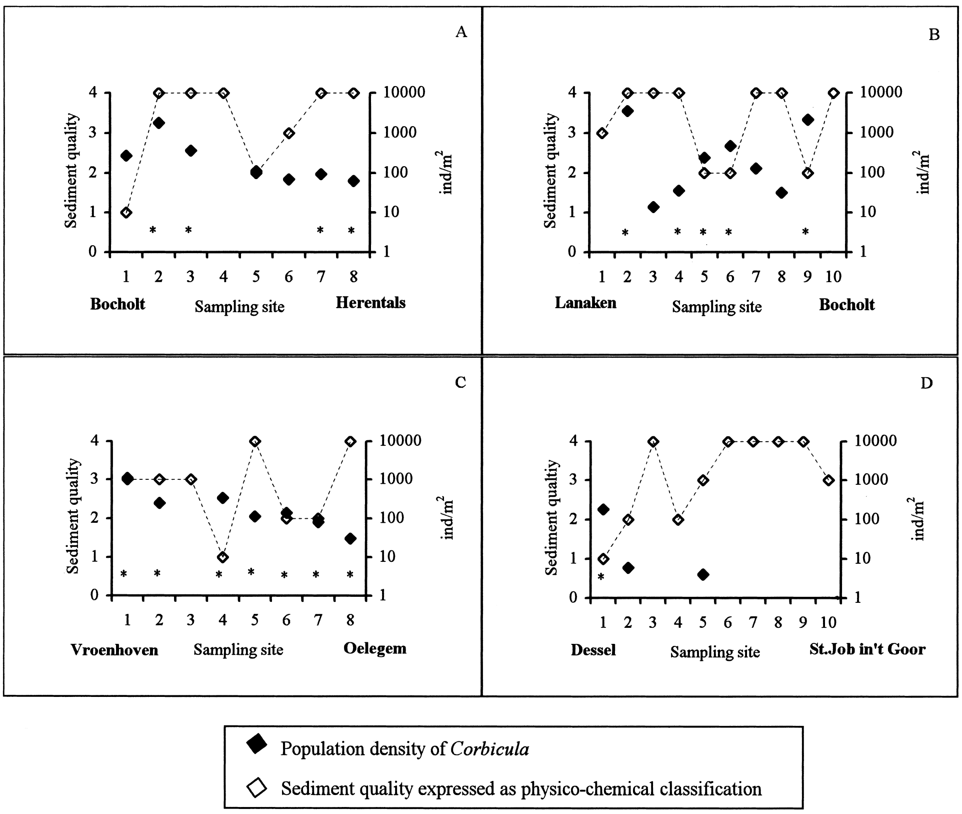

Fig. 1. - Population abundance of *Corbicula* species in (**A**): canal Bocholt-Herentals; (**B**): canal Zuid-Willemsvaart; **C**: canal Albert and **D**: canal Dessel-Schoten. *: Sites where the clam was the most abundant macroinvertebrate taxon.

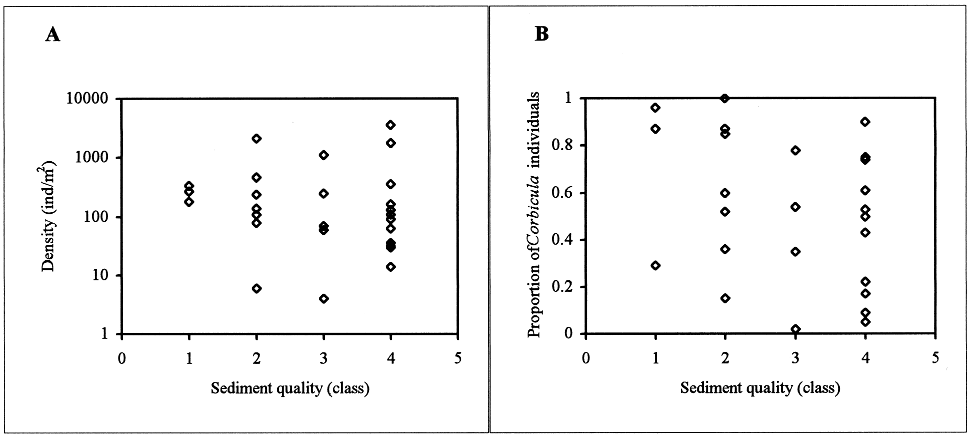

Fig. 2. – Relationship between (**A**) population densities of *Corbicula*; (**B**) proportion of *Corbicula* individuals and the sediment quality expressed as physico-chemical classification in six Flemish waters.

Fig. 2A gives the relationship between the clam density and the physico-chemical sediment quality, and shows no significant correlation (r = 0.15, p>0.05).

The ratio between the clam abundance and total macroinvertebrate abundance in the canals Bocholt-Herentals, Albert, Dessel-Schoten and Zuid-Willemsvaart ranged from 0.05 to 1 (Fig. 3). The proportion of individuals of *Corbicula* species in relation to the abundance of the whole benthic community in the canal Willebroek and the river Dender was 0.17 and 0.02, respectively. Similarly to the density, the relative abundance of the clam appeared to have no correlation (r = 0.24, p>0.05) with the physico-chemical quality index (Fig. 2B).

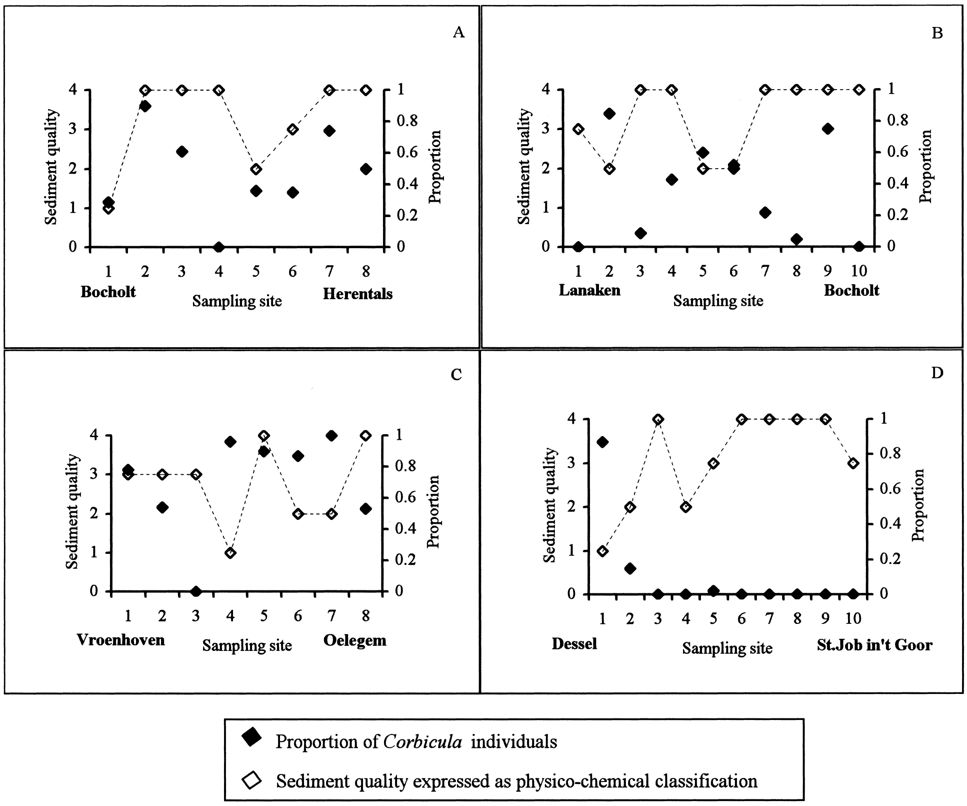

Fig. 3. – Contribution of *Corbicula* species in relation to the abundance of the benthic macroinvertebrate community in (**A**): canal Bocholt-Herentals; (**B**): canal Zuid-Willemsvaart; (**C**): canal Albert and (**D**): canal Dessel-Schoten.

Corbicula species and biological assessment of sediment quality

The sediment quality was also assessed by means of the Biotic Sediment Index (BSI). The distribution of samples over four classes is represented graphically in Fig. 4. The BSI values calculated without considering *Corbicula* species classified the sites as follows: 33.3% in class 1; 29.7% in class 2, 18.5% in class 3, and 18.5% in class 4 (Fig. 4A). However, when *Corbicula* species was included in the calculation of the BSI, the number of sites in class 1 increased to 55.5%, and no sediment was classified as biologically very bad quality (class 4) (Fig. 4B).

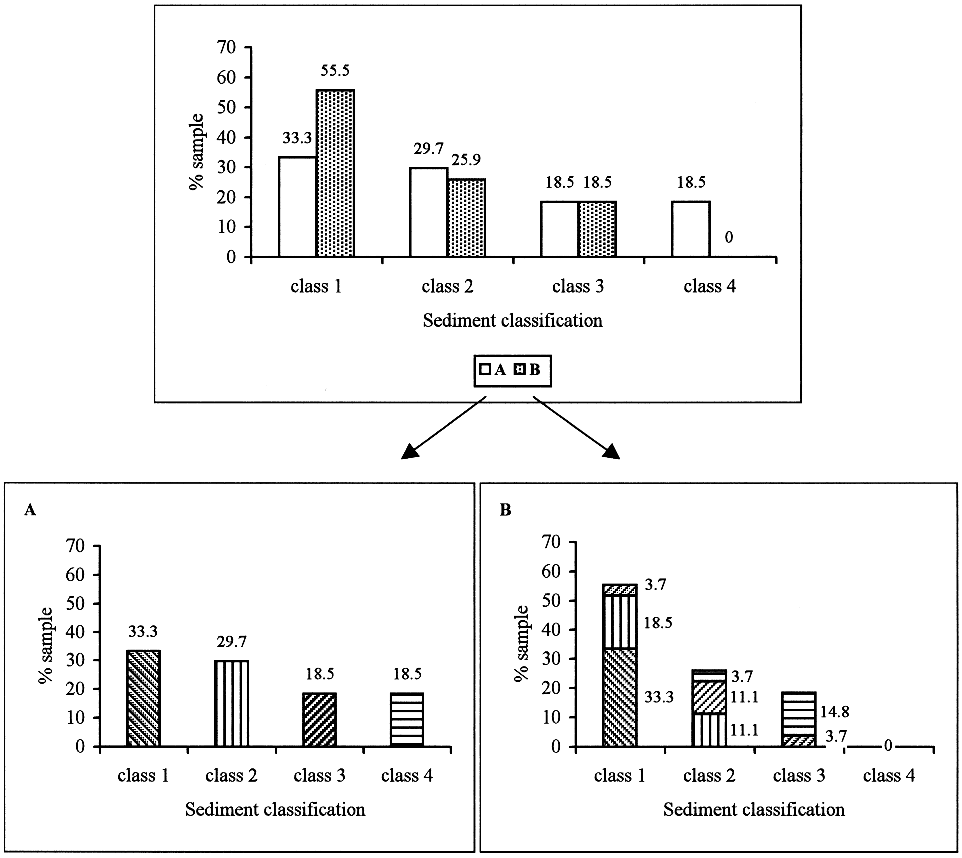

Fig. 4. – Ranking of sediment quality classification based on the Biotic Sediment Index (BSI). (**A**): *Corbicula* species were not considered in the calculation of the Index; (**B**): *Corbicula* species were considered as a (single) taxon in overall diversity and in the mollusc indicator group when calculating the Index. Of the samples shifted in class 1, 18.5% were from class 2 and 3.7% were from class 3. Also, 11.1% and 3.7% of samples from class 3 and 4, respectively, were shifted to class 2. The remaining samples of class 4 (14.8%) were shifted to class 3, leaving no samples in class 4.

DISCUSSION

Of the 33 watercourses investigated, six waterbodies were found to be invaded by *Corbicula* species (Fig. 5). As can be seen, the three watercourses, i.e. canal Albert, canal Bocholt-Herentals, and canal Zuid-Willemsvaart, were completely colonised by the clam. Also, the establishment of *Corbicula* species appeared to shift northward to the canal Dessel-Schoten. Furthermore, the expansion of the clam was moving westward to the canal Willebroek and the river Dender. The presence of *Corbicula* in Belgium was first recorded in 1992 and the genus is represented by two species *C. fluminea* and *C. fluminalis* (Swinnen et al., 1998). According to the authors, Viersel (canal Bocholt-Herentals) and Tihange (river Meuse) were the farthest west and south locations where the clam had established. The results of the present survey show that the current distribution of *Corbicula* species is broader in comparison with the one reported by Swinnen et al. (1998), confirming the suggestion of the authors that the distribution of the clam is still continuing to expand.

It has been reported that *C. fluminea* and *C. fluminalis* do not live together in any ecosystem (Morton, 1986). Yet, mixed populations of the two species have been found in Dutch, German and French parts of the river Rhine. The dissimilarities of the two species in reproductive strategy, spawning periods and different food resources were suggested as the explanations for their successful co-existence (Rajagopal et al., 2000). In the present survey, the co-occurrence of *C. fluminea* and *C.*

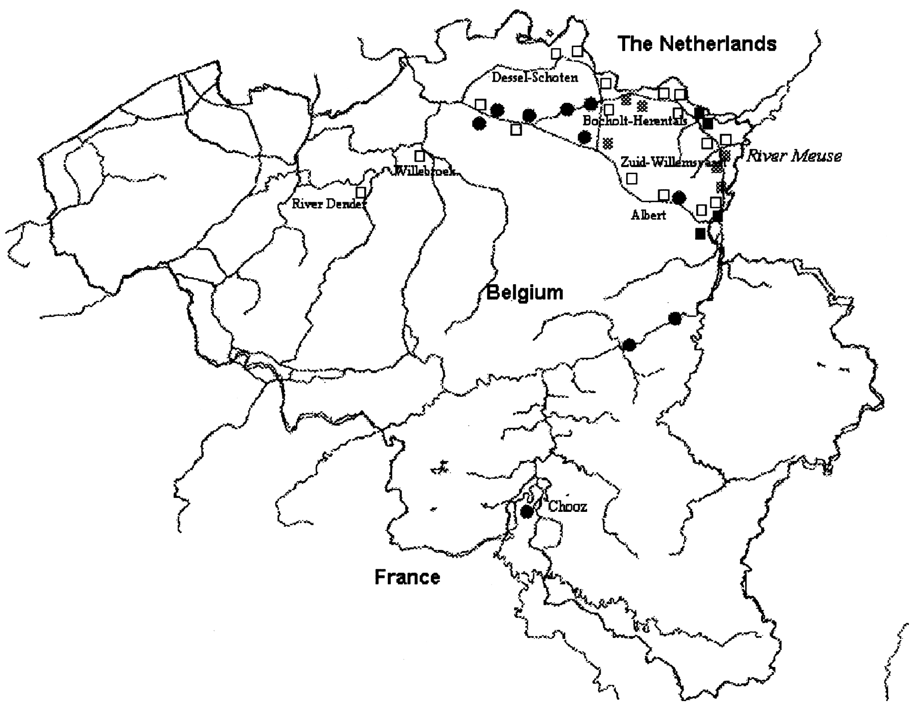

Fig. 5. – Current distribution of *Corbicula* species in Flanders, Belgium. ● : distribution of the clam reported by SWINNEN et al. (1998); □ : *C. fluminea* and *C. fluminalis*; ▩ : *C. fluminea*; ■ : sites where more than one thousand *Corbicula* specimens (*C. fluminea* and *C. fluminalis*) per square meter were found.

fluminalis was also found in several sites of the canals Albert, Bocholt-Herentals, and Zuid-Willemsvaart (Fig. 5). However, the co-existence of the two species was not (longitudinally) perpetual over the length of the above-mentioned canals. This discontinuity in co-inhabiting of *C. fluminea* and *C. fluminalis* in the Flemish waters seems to corroborate the conclusions made by RAJAGOPAL et al. (2000) that beside reproductive strategy, spawning periods and food preferences, other environmental factors are also of importance for their co-existence.

The geographic distribution of *Corbicula* in North America was reported to be limited to areas below latitude 40°N due to intolerance of the clam to severe winter conditions (BRITTON & MORTON, 1982). Temperatures below 2°C were suggested as the major restriction on the distribution of the clam (MCMAHON, 1983). Despite this prediction, *Corbicula* species in America was recently found to continue to move northward (KREISER & MITTON, 1995). Thermal refuges provided by power plants, spring inputs etc., and evolution of the cold tolerance of the clam, were thought to be the two reasons for this phenomenon. Waterbodies receiving heated water (e.g. the cooling-water ditches) were also suggested to be the places for *C. fluminalis* populations to survive during extremely cold winters in Germany (HAESLOOP, 1992). In Flanders, Belgium, survival of *Corbicula* species during winter seems not to be restricted, as in winter water temperatures are usually not lower than 2°C (FLEMISH ENVIRONMENTAL AGENCY, 2000). Moreover, thermal effects of power plants located in the region where the clam was found could also be responsible for its rapid colonisation and stabilisation. As extremely cold winters are rare, and the clam was recently introduced, successful establishment of *Corbicula* species in Belgian watercourses appears to be linked to suitable survival conditions rather than to its adaptation to the coldness.

In general *Corbicula* densities in Flemish watercourses were low in comparison with other populations, which often exceed 1000 individuals/m^2 (DILLON, 2000). It has been documented that in the beginning of the invasion, densities of *C. fluminea* were low (few specimens per square meter). During its establishment, it could increase to more than ten thousand per square meter, and after that the population seemed to stabilise around 2000 individuals/m^2 (GRANEY et al., 1980). The average density of *C. fluminea* in the Potomac River has also been reported to have increased from a few individuals per square meter to more than one thousand specimens per square meter after four to five years of invasion (COHEN et al., 1984). In the present survey, the four sites where the clam densities were greater than a thousand individuals/m^2 were in the waters connected with the river Meuse. After these points the clam densities averaged around 200 individuals per square meter (Fig. 1 and Fig. 5). This observation on the clam densities seems to support the suggestion of SWINNEN et al. (1998) that the colonisation by *Corbicula* species in Belgium originated from the river Meuse, and spread out through the service water system of power plants along the river and some of the connecting canals.

High densities of *Corbicula* species were often found to be concurrent with its dominance in the benthic community (SICKEL, 1986). Yet, in the present study the clam was the most abundant group in 63% of the invaded sites, irrespective of its density (Fig. 1). This finding could probably be explained by the capacity of the clam to re-inhabit following an environmental disturbance (MILLER & PAYNE, 1998). In 89% of the sites where *Corbicula* species established, sediments were slightly or heavily contaminated by organic pollutants and heavy metals. With regard to the sampling time, it has been reported that the population abundance of *Corbicula* varied between seasons with the highest density in spring (PHELPS, 1994; STITES et al., 1995). In the present study, seasonal variation between densities/samples could be rejected as all sampling was performed in the same period, i.e. the spring.

Corbicula species were found in both polluted and unpolluted sediments, and no correlation between physico-chemical sediment quality and the abundance of the clam was observed (Fig. 2A). Similar results were reported by BOLTOVSKOY et al. (1997), who also found no association between environmental stress and *C. fluminea* density. Although the previous study indicated that low dissolved oxygen concentrations were associated with reduced *C. fluminea* densities (BELANGER, 1991), the present survey shows that one of the highest population densities of the clam in the canal Bocholt-Herentals (1870 individuals/m^2 – site 2A, Fig. 1) was in fact found in the location where the dissolved oxygen concentration was the lowest (45% saturation value) of all. The ratio of *Corbicula* abundance and the total macroinvertebrate abundance has been documented to increase with increasing environmental perturbation (KERANS & KARR, 1994). In the present study, the relative proportion of *Corbicula* species at each site was also analysed, and no correlation pattern between it and the sediment quality was observed (Fig. 2B).

The interactions between invasive species and water quality have been investigated by numerous authors. Widely monitored water quality variables such as transparency, concentration of soluble inorganic nitrogen and phosphorus, and dissolved oxygen have been reported to alter due to the invasion of *Corbicula* and *Dreissena* species (COHEN et al., 1984; FOE & KNIGHT, 1985; LAURISTEN, 1986; WAY et al., 1990; PHELPS, 1994; CARACO et al., 1997). These exotic bivalves can also affect the performance of biological indices of water quality causing a change in the index without a corresponding change in water quality (STRAYER, 1999). With regard to the BSI, the presence of the recently introduced *Corbicula* species in benthic macroinvertebrate diversity has been expected to lead to a misreading of sediment quality. Indeed, the results of the present study demonstrated that, with inclusion of the clam as a taxon in the overall diversity and in the mollusc indicator group, the BSI values had changed in 52% of the cases. In all of these altered cases, the biological quality of the sediment shifted from a lower to a higher class (Fig. 4).

In conclusion, the exotic clam species *C. fluminea and C. fluminalis*, which recently invaded several Belgian waters, are continuing to extend their colonisation. Most of the places (89%) where *Corbicula* species were found were (slightly to heavily) polluted by organic contaminants and heavy metals. However, no correlation between the clam density, clam proportion in relation to the abundance of the benthic community, and the quality of the sediment was found. The present study shows a clear influence of *Corbicula* species on the performance of the BSI. It is, therefore, suggested that for the time being the clam should only be considered as a taxon in the overall species richness when calculating the index. Further investigation of the impact of *Corbicula* species on the biological assessment of water and sediment quality is recommended.

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REFERENCES

ARAUJO, R., D. MORENO, & M.A. RAMOS (1993). The Asiatic clam *Corbicula fluminea* (Müller, 1774) (Bivalvia: Corbiculidae) in Europe. *Am. Malacol. Bull.*, 10: 39-49.

BOLTOVSKOY, D., N. CORREA, D. CATALDO, J. STRIPEIKIS, & M. TUDINO (1997). Feeding selectivity of *Corbicula fluminea* (Bivalvia) on natural phytoplankton. *Archiv für Hydrobiologie*, 138: 483-507.

BELANGER, S.E. (1991). The effect of dissolved oxygen, sediment, and sewage treatment plant discharges upon growth, survival and density of Asiatic clams. *Hydrobiologia*, 218: 113-126.

BIJ DE VAATE, A. & M. GREIJDANUS-KLAAS (1990). The Asiatic clam, *Corbicula fluminea* (Müller, 1774) (Pelecypoda, Corbiculidae), a new immigrant in the Netherlands. *Bulletin Zoölogisch Museum Universiteit van Amsterdam*, 12(2): 173-177.

BOOZER, A. & P. MIRKES (1979). Observations on the fingernail clam *Musculium partumeium* (Pisidiidae), and its association with the introduced Asiatic clam, *Corbicula fluminea*. *Nautilus*, 93: 73-83.

BRITTON, J.C. & B. MORTON (1982). A dissection guide, field and laboratory manual for the introduced bivalve *Corbicula fluminea*. *Malacological Review*, *Supplement 3*: 1-82.

CAIRNS JR, J. & J.R. BIDWELL (1996). Discontinuities in technological and natural systems caused by exotic species. *Biodiversity and Conservation*, 5: 1085-1094.

CARACO, N.F., J.J. COLE, P.A. RAYMOND, D.L. STRAYER, M.L. PACE, S.E.G. FINDLAY & D.T. FISCHER (1997). The zebra mussel invasion in a turbid river (the Hudson): phytoplankton response to increased grazing pressure. *Ecology*, 78: 588-602.

CARLISLE, D.M. & W.H. CLEMENTS (1999). Sensitivity and variability of metrics used in biological assessments of running waters. *Environ. Toxicol. Chem.*, 18: 285-291.

COHEN, R., P.V. DRESIER, E. PHILIPS, & R. CORY (1984). The effect of Asiatic clam, *Corbicula fluminea*, on phytoplankton of the Potomac River, Maryland. *Limnol. Oceanogr*., 29: 170-180.

DE PAUW, N. & S. HEYLEN (2001). Biotic index for sediment quality assessment of watercourses in Flanders, Belgium. *Aquatic Ecology*, 35: 121-133.

DE PAUW, N. & G. VANHOOREN (1983). Method for biological quality assessment of water courses in Belgium. *Hydrobiologia*, 100: 153-168.

DILLON JR, R.T. (2000). *The Ecology of freshwater molluscs*. Cambridge University Press, Cambridge (509pp).

FLEMISH ENVIRONMENTAL AGENCY (VMM). (2000). Waterkwaliteit – Lozingen in het water 2000. Report, Vlaamse Milieumaatschappij, Erembodegem, Belgium.

FOE, C. & A. KNIGHT (1985). The effect of phytoplankton and suspended sediment on the growth of *Corbicula fluminea* (Bivalvia). *Hydrobiologia*, 127: 105-115.

GRANEY, R., D. CHERRY, J. RODGERS & J. CAIRNS (1980). The influence of thermal discharges and substrate composition on the population structure and distribution of the Asiatic clams, *Corbicula fluminea,* in the New River, Va. *Nautilus*, 94: 130-134.

HAESLOOP, U. (1992). Establishment of the Asiatic clam *Corbicula* cf. *fluminalis* in the Tidal Weser River (N. Germany). *Archiv für Hydrobiologie*, 126: 175-180.

ISOM, B.G. (1986). Historical review of Asiatic clam (*Corbicula*) invasion and biofouling of waters and industries in the Americas. *Am. Malacol. Bull.*, *Special Edition* 2: 1-6.

KERANS, B.L. & J.R. KARR (1994). A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. *Ecological Application*, 4: 768-785.

KREISER, B.R. & J.B. MITTON (1995). The evolution of cold tolerance in *Corbicula fluminea* (Bivalvia: Corbiculidae). *Nautilus*, 109: 111-112.

LAURITSEN, D.D. (1986). Filter-feeding in *Corbicula fluminea* and its effect on seston removal. *J. N. Am. Benthol. Soc*., 5: 165-172.

LEFF, L., J. BURCH & J. MCARTHUR (1990). Spatial distribution, seston removal, and potential competitive interactions of the bivalves *Corbicula fluminea* and *Elliptio complanata*, in a coastal plain stream. *Freshwater Biology*, 24: 409-416.

MARSH, P.C. (1985). Secondary production of introduced Asiatic clam *Corbicula fluminea* in a central Arizona canal. *Hydrobiologia*, 124: 103-110.

MCMAHON, R.F. (1983). Ecology of an invasive pest bivalve, *Corbicula*. In: RUSSELL-HUNTER (ed), *The Mollusca*, *Vol. 6, Ecology*, Academic press, New York: 505-561.

MILLER, A.C. & B.S. PAYNE (1994). Co-occurrence of native freshwater mussels (Unionidae) and the non-indigenous *Corbicula fluminea* at two stable shoals in the Ohio River, USA. *Malacological Review*, 27: 87-97.

MILLER, A.C. & B.S. PAYNE (1998). Effects of disturbances on large-river mussel assemblages. *Regulated Rivers: Research & Management*, 14: 179-190.

MINISTRY OF FLEMISH COMMUNITY (1998). Manual for the characterisation of sediments in Flemish watercourses through the TRIAD approach (in Dutch). Department of Environment and Infrastructure, AMINAL, in co-operation with the Flemish Environmental Agency.

MORTON, B.S. (1986). *Corbicula* in Asia – an updated synthesis. *Am. Malacol. Bull.*, *Special Edition*, 2: 113-124.

NBN (1984). Qualité biologique des cours d'eau. Détermination de l'indice biotique se basant sur les macro-invertébrés aquatiques. NBN, T92-402 (in Dutch and French). Institut Belge de normalisation (IBN).

PHELPS, H.L. (1994). The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River Estuary near Washington, D.C. *Estuaries*, 17: 614-621.

RAJAGOPAL, S., G. VAN DER VELDE & A. BIJ DE VAATE (2000). Reproductive biology of the Asiatic clams *Corbicula fluminalis* and *Corbicula fluminea* in the river Rhine. *Archiv für Hydrobiologie*, 149: 403-420.

RICCIARDI, A., F.G. WHORISKEY & J.B. RASMUSSEN (1995). Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. *Can. J. Fish. Aquat. Sci.*, 52: 1449-1461.

SICKEL, J.B. (1986). *Corbicula* population mortalities: factor influencing population control. *Am. Malacol. Bull.*, *Special Edition* 2: 89-94.

SOKAL, R.R. & F.J. ROHLF (2000). *Biometry. The principles and practice of statistics in biological research*. W.H. Freeman and Co., New York (887pp).

STITES, D.L., A.C. BENKE & D.M. GILLESPIE (1995). Population dynamics, growth, and production of the Asiatic clam, *Corbicula fluminea*, in a blackwater river. *Can. J. Fish. Aquat. Sci*., 52: 425-437.

STRAYER, D.L. (1999). Effects of alien species on freshwater molluscs in North America. *J. N. Am. Benthol. Soc*., 18: 74-98.

SWINNEN, F., M. LEYNEN, R. SABLON, L. DUVIVIER & R. VANMAELE (1998). The Asiatic clam *Corbicula* (Bivalvia: Corbiculidae) in Belgium. *Biologie*, 68: 47-53.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (US EPA) (1999). Rapid protocols for use in the streams and wadeable rivers. Periphyton, benthic macroinvertebrates and fish. EPA 841.B.99.002.

WAY, C.M., D.J. HORNBACH, C.A. MILLER-WAY, B.S. PAYNE & A.C. MILLER (1990). Dynamics of filter feeding in *Corbicula fluminea* (Bivalvia: Corbiculidae). *Can. J. Zool*., 68: 115-120.

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