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Molluscan diversity in tidal marshes along the Scheldt estuary (The Netherlands, Belgium)

L. Bruyndoncx[1], K. Jordaens[2], T. Ysebaert[3,4], P. Meire[5] & T. Backeljau[1,2,*]
[1]*Royal Belgian Institute of Natural Sciences, Vautierstraat 29, B-1000 Brussels, Belgium*
Tel: 32 2 627 43 39. Fax: 32 2 627 41 41. E-mail: Thierry.Backeljau@naturalsciences.be
[2] *Evolutionary Biology Group, University of Antwerp (R.U.C.A.), Groenenborgerlaan 171, B-2020 Antwerp, Belgium*
[3]*Institute of Nature Conservation, Kliniekstraat 25, B-1070 Brussels, Belgium*
[4]*Netherlands Institute of Ecology, Centre for Estuarine and Coastal Ecology, NIOO-CEMO, P.O. Box 140, 4400 AC Yerseke, The Netherlands*
[5]*Ecosystem Management Research Group, University of Antwerp (U.I.A.), Universiteitsplein 1, B-2610 Wilrijk, Belgium*
*(*Author for correspondence)*

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Abstract

The mollusc fauna of 64 sites in 31 tidal marshes was surveyed along a salinity gradient from freshwater to marine conditions in the river Scheldt (Belgium–The Netherlands). A total of 10 649 specimens involving 31 taxa were identified. Salinity turned out to be a major factor in mollusc assemblages in the Scheldt estuary, but other factors can not be excluded. In the marine part five species were common, compared to the brackish part where only *Assiminea grayana* was abundant. In the freshwater zone species richness was highest (24). There was a significant correlation between flooding frequency and species richness in the tidal freshwater marsh 'Durmemonding'. Finally, the survey confirmed the distribution of the amphibious hygromiid snail *Pseudotrichia rubiginosa*, a species which in Belgium only occurs in the marshes of the tidal freshwater part of the Scheldt and its tributaries.

Introduction

Estuarine tidal flats and saltmarshes cover only about 0.01% of the earth's surface (Meire et al., 1997). They are characterized by many ecological, physical and chemical gradients and are indispensable for water filtration, sediment stabilisation, oxygen transport and high primary production (Meire et al., 1997). A case in point is the Scheldt estuary in the Netherlands and Belgium which has a remarkable combination of tidal mud- and sandflats and marshes along an entire salinity gradient. As a result, it harbours a noteworthy fauna and flora (Van Damme et al., 1995). The Scheldt marshes are, however, severely threatened by the industrial expansion of the harbour of Antwerp and the concomitant pollution and physical alteration of natural habitats (e.g. dredging, dumping, construction, etc.) (Meire et al., 1992; Van Damme et al., 1995). Therefore, there is a need for a management plan in which nature conservancy and sustainable development of the Scheldt estuary are reconciled in order to conserve its remarkable fauna and flora. This requires a sound basic knowledge of the fauna, flora and ecology of the area. However, previous biological investigations of tidal marshes and flats along the Scheldt focused mostly on plants (Hoffmann, 1995), birds (Ysebaert et al., 2000), benthic organisms (e.g. Ysebaert et al., 1992) and terrestrial arthropods (Desender & Maelfait, 1999). The malacofauna of this area received only little attention. Yet, the Scheldt estuary harbours, amongst others, a number of regionally threatened and rare mollusc species, such as the

amphibious hygromiid snail *Pseudotrichia rubiginosa* (Rossmässler, 1838), which in Belgium, only occurs in the tidal freshwater parts of the river Scheldt and its tributaries (Vader, 1977; Keppens & Keppens, 1989). Moreover, malacological studies in other European estuaries and river-floodplains (e.g. Wolff, 1973; Warwick et al., 1991; Obrdlík et al., 1995; Van den Brink et al., 1996; Killeen, 1999) neither paid particular attention to marshes that flood regularly during spring tide-neap tide cycles along a salinity gradient. Therefore, the present study aimed at (1) estimating the molluscan diversity of the tidal marshes along the Scheldt estuary, (2) determining the relationship between mollusc richness and salinity, and (3) establishing effects of tides and flooding on the mollusc assemblages.

Materials and methods

Description of the study area

The river Scheldt originates in France (Saint-Quentin), runs through Belgium and flows into the North Sea near Vlissingen (the Netherlands). The part of the river between Ghent and Vlissingen (i.e. Scheldt estuary; Fig. 1) is subject to tidal conditions, resulting in a salinity gradient from seawater near the river mouth (>16.5 psu) (i.e. marine zone; MZ), over a marine transition zone (MTZ) (16.5 psu to 10 psu), to brackish (BZ) (10 psu to 0.25 psu) and freshwater conditions (FZ) (< 0.25 psu) (Kuijper, 2000). The 'boundaries' of these four salinity zones are highly variable, both seasonally and between years (Van Damme et al., 1995).

Estimation of molluscan diversity

Field sampling and identification

From October 1998 till January 1999, molluscs were sampled along the entire salinity gradient of the Scheldt estuary (Fig. 1). Sampling was restricted to tidal marshes, i.e. areas that are regularly inundated during spring tides, but not during daily high tides. Sixty-four sampling sites were surveyed in 31 marshes. Sampling was done by hand picking for 20 min in an area of 10 m^2 by two persons and by sifting out surface litter 'by eye', collected in a frame of 20 × 20 cm (Marquet, 1979). Because of the lack of litter at the marine sites, molluscs were only sampled by hand.

Living species were identified according to Adam (1960), Kerney et al. (1983), Gittenberger et al. (1984), Glöer & Meier-Brook (1994) and Devriese et al. (1997). The collection has been deposited in the Royal Belgian Institute of Natural Sciences, Brussels were it is registered under catalogue number IG 28791. For salinity data (average values of 1996), we relied on The Institute of Nature Conservation (Belgium) and Rijkswaterstaat (The Netherlands).

Data analysis

Molluscs were recorded as presence/absence (p/a) data by pooling the samples obtained by hand picking and sifting. In addition to species richness (i.e. the number of species), species diversity was quantified by Whittaker's diversity measure (Wilson & Shmida, 1984) using the program BIODIV (Baev & Penev, 1993). In order to investigate the relationship between species richness, species diversity and salinity, Spearman rank correlations (Sokal & Rohlf, 1995) were calculated using the software package STATISTICA v5.1 (StatSoft, 1995). Sampling sites were classified into groups according to species composition (p/a) using the classification algorithm TWINSPAN (Two-way indicator species analysis) (Hill, 1979; Clarke, 1993) implemented by the program PC–ORD v3.10 (McCune & Mefford, 1997).

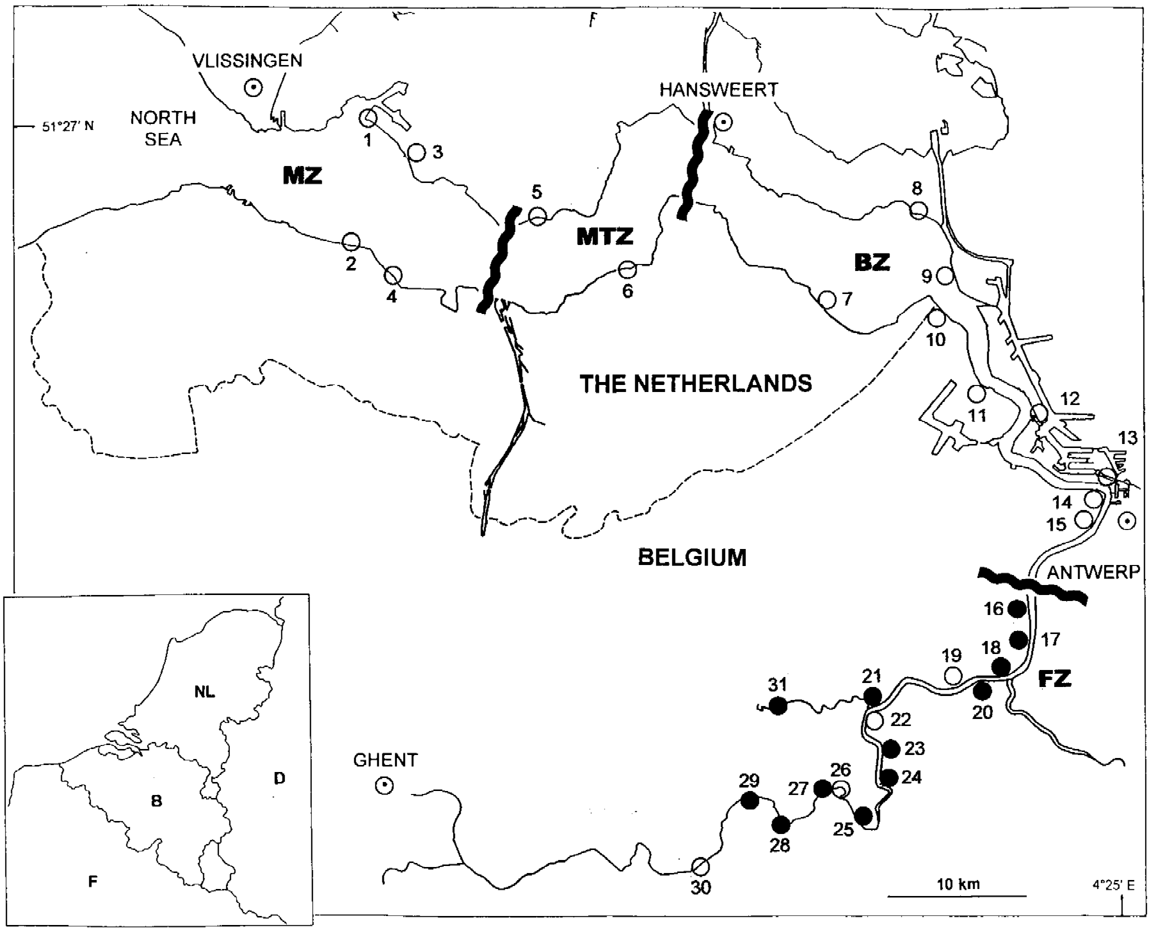
Faunistic resemblance between sampling sites, based on p/a data, was calculated using the Bray-Curtis similarity index (Clarke, 1993; Legendre & Legendre, 1998). To ordinate the data, the resulting similarity matrix was subjected to non-metric multidimensional scaling in two dimensions (MDS, Kruskal & Wish, 1978), as suggested by Clarke & Ainsworth (1993) with the PRIMER software package (Clarke & Warwick, 1994).

The salinity data of the sampling points were superimposed on the MDS plot for 'visual correlation' (Warwick et al., 1991).

Spring tide-neap tide cycle survey

Sampling scheme

To investigate to what extent the sample timing in the tidal cycle has an influence on the estimation of species richness, a freshwater tidal marsh in Tielrode (i.e. Durmemonding, Fig. 1) was visited five times during a spring-neap tide cycle: 20 March 1999 after spring tide (ST); 26 March 1999 after neap tide (NT); 30 March 1999 between NT and ST; 3 April 1999 after ST and 12 April 1999 after NT. Five sampling points with different flooding frequencies were surveyed during low tide. Five litter samples (20 × 20 cm) were sifted out



THE NETHERLANDS
1 Rammekenshoek, Ritthem (1, 2)
2 Schor van Hoofdplaat (3, 4, 5)
3 Kaloot, Borssele (6)
4 Paulinapolder, Biervliet (7, 8)
5 Zuidgors, Ellewoutsdijk (9, 10, 11)
6 Hellegatspolder, Hontenisse (12, 13, 14)
7 Saeftinge, Prosperpolder (15, 16)
8 Schor bij Bath (17, 18)
BELGIUM
9 Het Groot Bultenschoor, Zandvliet (19, 20, 21, 22)
10 De schor van Doel, Beveren (23, 24, 25, 26, 27, 28)
11 Fort Liefkenshoek, Antwerpen (29)
12 Schor bij de Van Cauwelaertsluis, Antwerpen (30)
13 Oosterweel, Antwerpen (31)
14 St-Annastrand, Antwerpen (32)
15 Galgenweel, Burcht (Antwerpen) (33, 34, 35)
16 Barbierbeek, Kruibeke (36, 37)
17 Kallebeekveer, Hemiksem (38)
18 Schor bij Rupelmonde (39)
19 Het Kijkverdriet, Steendorp (Temse) (40)
20 Schor bij de Notelaar, Hingene (Bornem) (41, 42, 43, 44)
21 Schor aan de Durmemonding, Tielrode (Temse) (45, 46, 47, 48)
22 Het Stort bij Weert (49)
23 Het schor van Branst, Bornem (50, 51)
24 Schor van Mariekerke, St. - Amamds (52)
25 Groot schoor van Hamme, Hamme (53)
26 De schorren van de Vlassenbroekse polders, Dendermonde (54)
27 Het Groot Schoor van Grembergen, Dendermonde (55)
28 Nieuwe schor voor Appels, Dendermonde (56, 57, 58, 59, 60)
29 Schor van Zele, Zele (61)
30 Konkelschoor, Berlare (62)
31 De Rietsnijderij, Waasmunster (63, 64)

Figure 1. The Scheldt estuary and the location of the sampling sites (numbers of plots in parentheses), with indication of the four salinity zones. MZ: marine zone; MTZ: marine transition zone; BZ: brackish zone; FZ: freshwater zone. Filled dots represent the presence of *Pseudotrichia rubiginosa*.

for each point at each collection day. The weight of the litter was determined after drying for 48 h at 75 °C. Additionally, soil samples of up to 10 cm depth were taken on the lowest and highest points and were sieved using a 1 mm-grid sieve in order to check for subterranean molluscs. Data of the flooding frequencies were provided by the Institute of Nature Conservation (Belgium).

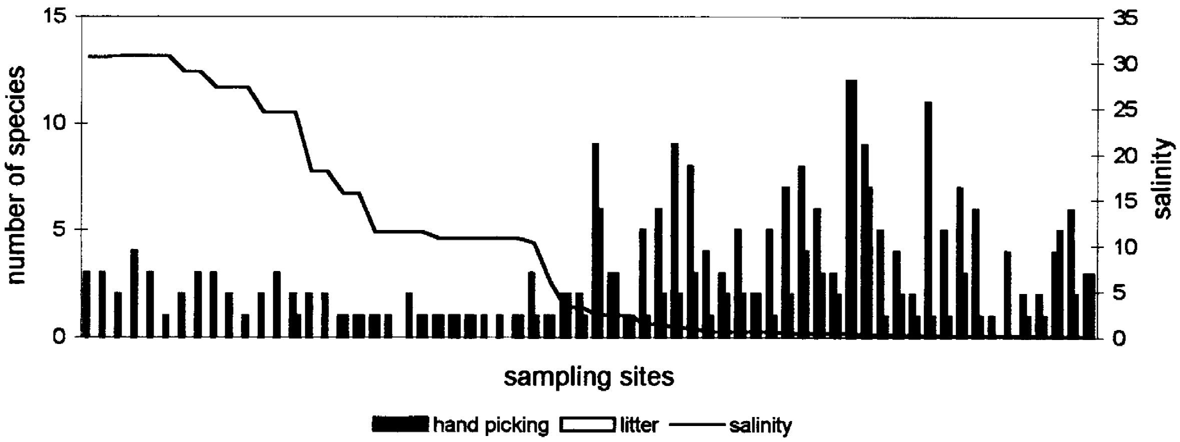


Figure 2. Species richness and salinity (‰) of the 64 sampling sites; the sites are ordered from left to right according to decreasing salinity starting from Vlissingen and ending at Berlare.

Data analysis

A Kruskal–Wallis H-test (Sokal & Rohlf, 1995) was used to evaluate differences between the five sampling days or between the five sampling points. A 'multiple-comparisons' test (Conover, 1980) was used as post-hoc test to check for differences between sampling days or points. The influence of the flooding frequency on the estimation of species richness was tested using a Spearman rank correlation. All computations were implemented by STATISTICA v5.1 (StatSoft, 1995).

Results

Molluscan diversity

We found 10 649 specimens involving 31 taxa (Table 1). In the marine part (downstream Hansweert) five species were abundant, i.e. *Myosotella myosotis, Alderia modesta, Limapontia depressa, Assiminea grayana* and *Hydrobia* sp. In the brackish area between Hansweert and Antwerp, only *Assiminea grayana* was common (more than half of all specimens collected during this study belonged to this species). Finally, in the freshwater part, *Zonitoides nitidus*, *Lymnaea* sp. and *Succinea putris* were the most abundant species. We also found a number of land snails which in the Red List of Flemish terrestrial gastropods are mentioned under the categories 'Vulnerable' (i.e. *Balea biplicata*, *Euconulus fulvus* and *Monacha cantiana)* or 'Rare' (i.e. *Arianta arbustorum* and *Pseudotrichia rubiginosa*) (pers. comm. H. van Loen).

Species richness (Fig. 2) was weakly, but significantly negatively correlated with salinity (N=64, r_S=−0.50, p<0.001). In the freshwater tidal area, the overall species richness was much higher (24 species versus five in the marine and two in the brackish zone) but there was a large variation between the different sampling sites (range: 1–12 species). Whittaker's diversity measure showed that species diversity increased significantly with decreasing salinity (N=64, r_S=−0.41, p<0.001).

The result of the TWINSPAN classification is presented in Figure 3. The first level of division is based on the presence or absence of indicator species *Myosotella myosotis*. Sampling sites which lack this species are assigned to group 1. The indicator species corresponding to group 0 are *Succinea putris, Zonitoides nitidus*, *Lymnaea* sp. and *Deroceras laeve*. The second division level of group 1 is characterized by the p/a of *Assiminea grayana*. The second division of group 0 did not yield further obvious groups. The three resulting groups are not an exact representation of the previous described classification based on salinity (MZ; MTZ; BZ and FZ). This suggests that also other factors explain the selection of indicator species and classification based on salinity is not appropriate.

The two-dimensional MDS plot (stress = 0.062) classified the sampling localities in two not clearly separated 'clusters'. After superimposing the salinity categories (MZ; MTZ; BZ and FZ), the ordination of the sampling sites tended to reflect a salinity 'gradient', even though the FZ sites were relatively well-separated from the others and particularly from the MZ and MTZ sites (Fig. 4). The results of the

Table 1. Systematic list of species sampled in this study

Gastropoda	
Hydrobiidae	*Arion silvaticus* Lohmander, 1937
Hydrobia sp.	*Arion intermedius* Normand, 1852
Potamopyrgus antipodarum (Gray, 1843)	**Zonitidae**
Assimineidae	*Vitrea crystallina* (Müller, 1774)
Assiminea grayana Fleming, 1828	*Oxychilus draparnaudi* (Beck, 1837)
Stiligeridae	*Oxychilus cellarius* (Müller, 1774)
Alderia modesta (Lovén, 1844)	*Zonitoides nitidus* (Müller, 1774)
Limapontiidae	**Agriolimacidae**
Limapontia depressa Alder & Hancock, 1862	*Deroceras laeve* (Müller, 1774)
Ellobiidae	*Deroceras reticulatum* (Müller, 1774)
Carychium minimum Müller, 1774	*Deroceras panormitanum* Lessona & Pollonera, 1882
Myosotella myosotis (Draparnaud, 1801)	**Euconulidae**
Lymnaeidae	*Euconulus fulvus* (Müller, 1774)
Lymnaea sp.	**Clausiliidae**
Planorbidae	*Balea biplicata* (Montagu, 1803)
Planorbidae sp.	**Helicidae**
Cochlicopidae	*Monacha cantiana* (Montagu, 1803)
Cochlicopa sp.	*Pseudotrichia rubiginosa* (Rossmässler, 1938)
Valloniidae	*Trichia hispida* (Linnaeus, 1758)
Vallonia sp.	*Arianta arbustorum* (Linnaeus, 1758)
Succineidae	*Cepaea nemoralis* (Linnaeus, 1758)
Succinea putris (Linnaeus, 1758)	
Endodontidae	**Bivalvia**
Discus rotundatus (Müller, 1774)	
Arionidae	**Sphaeriidae**
Arion rufus (Linnaeus, 1758)	*Pisidium subtruncatus* Malm, 1855

MDS ordination and the TWINSPAN analysis do not correspond completely, which corroborates that salinity is not the only determining factor in mollusc assemblages in the Scheldt estuary.

Spring tide-neap tide survey

Species richness was not significantly correlated with the weight of the dried litter (results not shown). The number of species sampled after spring tide did not differ significantly from that sampled after neap tide (results not shown). The moment of sampling in the spring tide-neap tide cycle had no influence on the number of collected species.

A strongly negative, significant relationship between species richness and flooding frequency was observed (N=24, $r_s = -0.84$, $p<0.001$), indicating that the lesser a marsh floods, the more species were found.

Discussion

Our results clearly indicate a change in the composition of the malacofauna of the tidal marshes along the Scheldt estuary. The four groups obtained after superimposing the salinity on the MDS plot are not clearly distinguishable, which probably imputes to the variable boundaries of the salinity zones. Salinity seems to be an important factor, but is certainly not the only one. The alternation of aquatic and terrestrial phases in the marshes creates a diversity of micro-habitats. The difference between these humid, aquatic and dried out, terrestrial sampling sites and other factors like flooding frequency, microhabitat, vegetation, water temperature, soil texture, presence of other organisms (e.g. birds) are expected to have an influence on the mollusc assemblages too.

The relationship between species richness, species abundancy and salinity in estuarine gradients is well known, since salinity is a main factor in the dis-

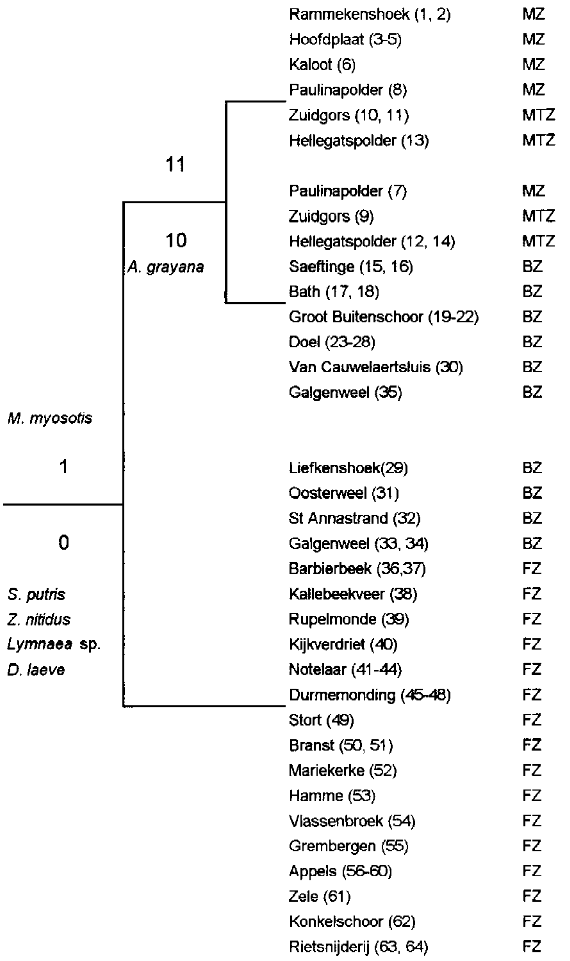


Figure 3. Dendrogram showing the result of the TWINSPAN-classification of the sampling sites with corresponding indicator species. MZ: marine zone; MTZ: marine transition zone; BZ: brackish zone; FZ: freshwater zone.

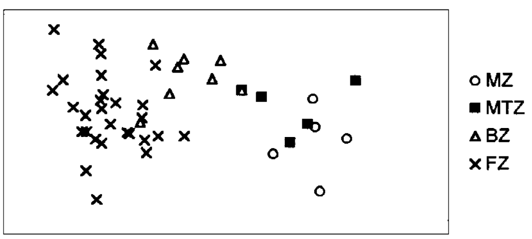


Figure 4. MDS ordinations of the 64 sampling sites, with symbols corresponding to the salinity. MZ: marine zone; MTZ: marine transition zone; BZ: brackish zone; FZ: freshwater zone. (stress = 0.062)

tribution of estuarine organisms (e.g. Odum, 1988; Ysebaert & Meire, 1991; Hoffmann, 1995). This also applies to the distribution of the malacofauna along salinity gradients (Remane, 1934; Davies, 1972; Wolff, 1973; Gainey et al., 1977; Bishop & Hackney, 1987). However, our data do not allow direct comparisons with those of Remane (1934), Desender & Maelfait (1999) or other studies (e.g. Davies, 1972; Obrdlík et al., 1995; Killeen, 1999), for we considered both 'terrestrial' and 'aquatic' species, while in previous studies either aquatic or terrestrial species were considered. Moreover, other studies did not cover entire salinity gradients. Compared to Killeen (1999), the Scheldt freshwater marshes harbour more species than tidal freshwater marshes in the river Thames, its estuary and associated river systems. In a study of the former freshwater tidal area of the Biesbosch, The Netherlands (Heyligers et al., 1961), fewer mollusc species were observed, but those recorded were comparable to the species found in our study. Interestingly, Heyligers et al. (1961) did not find *Pseudotrichia rubiginosa*. Compared to the data on the macrohabitats of shelled non-marine gastropods in Europe (Falkner et al., 2001), our mollusc assemblages are similar to those of 'tidal flats' and 'alluvial forests'.

Desender & Maelfait (1999), who described the diversity of terrestrial arthropods in the tidal marshes along the Scheldt estuary, found that species diversity is highest in the brackish area. They did not take the marine part of the estuary into account, but instead investigated sites along the Belgian coast, where species richness was lowest compared to the brackish and freshwater parts of the estuary. Our data show more resemblance to the diversity and the distribution of plant species in the marshes along the Scheldt estuary, i.e. brackish and freshwater marshes have less plant species in common and the plant species diversity in the freshwater marshes is almost twice as high (Hoffmann, 1995).

Our research at the freshwater marsh 'Durmemonding' suggested that flooding frequency negatively affects species richness but that the moment of sampling in the spring tide-neap tide cycle does not affect the number of observed mollusc species.

As a follow up of the study of Vader (1977), we investigated the persistence and distribution of *Pseudotrichia rubiginosa* and recorded the species in the same as well as in some additional marshes. This suggests that the species is not declining despite the human impact on its habitat.

During our survey, only random samples were taken. This may have flawed the representativity of our samples to some extent because mollusc populations can be very patchy (Keppens & Keppens, 1988). Moreover, gastropod activity depends strongly on weather conditions (Crawford-Sidebotham, 1972; Keppens & Keppens, 1988), so that in cold or dry periods slugs and snails become inactive and hide under substrates. Hence, we expect that during our survey there were several 'uncontrolled' variables (e.g. weather, season) that may have affected our sampling efficiency. Because of these sampling problems only p/a data were used for analysis, while by combining hand picking and sifting out litter, a more complete picture of the malacofauna could be obtained. Yet, further work is needed in order to obtain more precise data on species abundances and distributions, before a reliable assessment can be made of the importance of the Scheldt estuary for molluscan biodiversity. Nevertheless, in view of the exclusive persistence of *P. rubiginosa* and the occurrence of a number of other vulnerable and threatened mollusc species, it is obvious that at least the freshwater marshes of the river Scheldt are of importance for molluscan conservation.

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