

Distribution and ecology of the mayflies (Ephemeroptera) of Flanders (Belgium)

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Abstract – A literature survey and the identification of all available collection material resulted in a checklist and distribution maps for the mayflies occurring in Flanders. In addition, the relationship between the occurrence of mayflies and water characteristics was analysed. Of the 32 species that have been recorded, six are now extinct in Flanders (three of which are potamal species), while the majority of the remaining species are rare and their populations are often strongly isolated and therefore extremely vulnerable. Waters with relatively low oxygen levels and high conductivities were characterized by the most tolerant mayfly species *Cloeon dipterum* and *Caenis robusta*. However, most other species only occurred at higher oxygen concentrations and lower conductivities and could be separated into two groups. The first group mainly occurred in waters with a high pH and were often restricted to the loamy region or to stagnant waters, while the second group occurred in waters with a lower pH and mainly occurred in the Campine region. For most mayfly species, sustainable populations can only be achieved when their current habitats are adequately protected and, in addition, measures should be taken to connect and enlarge the remaining populations.

Key words: Checklist / distribution maps / ecoregions

Introduction

River management in Flanders has been conducted at the river basin level using wastewater treatment plants and imposed standards of effluent concentrations. Although these measures resulted in a significant improvement of the chemical and ecological water quality since the 1980s (VMM, 2010), many Flemish water bodies still lack the good ecological status that the European Union Water Framework Directive (WFD) requires by 2015 (European Council, 2000). The use of biotic indicators, such as macrobenthic fauna, fish fauna, phytoplankton, phyto-benthos and macrophytes, is required by the WFD to assess the ecological water quality.

In the past, the Flemish Environment Agency used the Belgian Biotic Index (BBI; De Pauw and Vanhooren, 1983), which has been adopted as a standard method for assessing river water quality by means of macroinvertebrates by the Belgian Institute of Normalization (IBN, 1984). Recently, however, the Multimetric Macroinvertebrate Index Flanders (MMIF; Gabriels *et al.*, 2010) was developed in order to meet the requirements of the WFD. In both indexes, mayflies are recognized as one of the most

sensitive groups of macroinvertebrates, which are characteristic for waters with a high ecological quality.

In Belgium, nature conservation policy is the responsibility of the regional governments (Flanders, Brussels and Wallonia), and a regional scale is therefore appropriate to perform faunistic studies or when developing red lists. Flanders, which is the Dutch-speaking part of Belgium, has a population of 6.2 million inhabitants and a high population density of 456 citizens.km⁻². About 88% are connected to a sewage system; however, only 70.3% are actually treated (VMM, 2009). Flanders is also heavily industrialized, and the agriculture causes a heavy pressure as 53% of the land is used for (mainly intensive) agriculture (VMM, 2009). In addition, thousands of weirs have been built for flood control, hundreds of kilometres of artificial banks have been installed and the majority of the river channels have been straightened. To obtain a good water quality in all water bodies, which should be the case by 2015 according to the WFD (European Council, 2000), there is still a lot of work to be done. At the moment, most attention is focused on watercourses with the poorest water quality; however, ameliorating water quality from bad to poor or moderate will not help populations of sensitive organisms. A first step should thus be to protect the sites that still have a high water quality.

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Fig. 1. Map of Flanders with indication of the different ecoregions: dune area (black), polder area (horizontal stripes), sandy region (white), Campine region (dots) and loamy region (vertical stripes); the location of Flanders has been marked on the map of Europe.

In addition, most suitable habitats are now isolated and therefore populations are extremely vulnerable to extinction, while recolonization is hardly possible. Therefore, also intentional interventions are needed that are directed to the connection of isolated populations by solving the present bottlenecks that prevent the necessary expansion of the remaining populations. To efficiently allocate restoration efforts, ecological models could be useful for the assessment of these bottlenecks in the river basin (Mouton *et al.*, 2008).

Despite their importance as water quality indicators, mayflies have hardly received any attention in Flanders. Knowledge about the distribution of sensitive aquatic invertebrates such as mayflies could help to define priorities in water management, and locations containing rare species or a high species richness deserve priority in nature conservation. In the present study, a checklist of the mayflies occurring in Flanders is presented, distribution maps for all species are plotted, and the relationship between the occurrence of the different species and the water characteristics is analysed.

Materials and methods

All available Ephemeroptera from Flanders and Brussels (a map indicating the ecoregions is presented in Fig. 1) were identified to species level using the identification keys by Bauernfeind and Humpesch (2001) and Eiseler (2005). Most collection material was present in the Royal Belgian Institute for Natural Sciences, where also the samples of the Flemish Environment Agency are conserved. In the context of water quality monitoring by the Flemish Environment Agency, macroinvertebrates have been sampled at several thousand sampling points since 1989. However, it should be noted that especially running waters are monitored, while stagnant waters are underrepresented. During monitoring, macroinvertebrates are sampled using a standard handnet, as described by Gabriels *et al.* (2010). With the handnet, a stretch of 10–20 m is sampled during approximately 5 min. Sampling effort is proportionally distributed over all accessible aquatic habitats. This includes the bed substrate (stones,

sand or mud), macrophytes (floating, submerging and emerging), immersed roots of overhanging trees and all other natural or artificial substrates, floating or submerged in the water. Each aquatic habitat is explored, in order to collect the highest possible diversity of macroinvertebrates. For this purpose, kicksampling is performed. In addition to the handnet sampling, animals are manually picked from stones, leaves or branches. Conductivity, pH, oxygen content and water temperature are measured at each sampling point. The highest point in the study area has an altitude of only 288 m and the whole region can thus be considered as lowland.

To analyse the distribution and ecology of mayflies, literature data as well as all available data from the collections and the water quality monitoring data from the Flemish Environment Agency were brought together in one dataset. In addition, about 30 field trips were carried out during the last two years to collect missing data. However, only the monitoring data of the Flemish Environmental Agency could be linked to environmental variables. A direct gradient analysis was applied to determine which environmental parameters might be responsible for the differences in species composition, since environmental variables were explicitly incorporated in the analysis. To test whether a linear or unimodal method was needed, a Detrended Correspondence Analysis (DCA) was performed. Since the Length of Gradient (LoG) was greater than four, a unimodal method was needed, and therefore, the Canonical Correspondence Analysis (CCA) option from the program package CANOCO (Ter Braak, 1988) was applied. A log-transformation ($\log(x+1)$) was applied prior to the CCA to normalize the data.

Results

For the present study, more than 130 000 mayflies were identified, mainly larvae. They represented 5985 records, of which only 343 dated from before 1990. Of the 32 species that were recorded for Flanders and Brussels (Table 1), four were not previously reported, *Caenis lactea*, *Ephemera glaucops*, *Electrogena ujhelyii* (previously reported as *Electrogena lateralis*) and *Rhithrogena picteti*

Table 1. Checklist of the Ephemeroptera in Flanders.

Order Ephemeroptera
Family Ameletidae
1. <i>Metreletus balcanicus</i> (Ulmer 1920)
Family Baetidae
2. <i>Baetis fuscatus</i> (Linnaeus 1761)
3. <i>Baetis lutheri</i> (Müller-Liebenau 1967)
4. <i>Baetis muticus</i> (Linnaeus 1758)
5. <i>Baetis rhodani</i> (Pictet 1843)
6. <i>Baetis scambus</i> (Eaton 1870)
7. <i>Baetis vernus</i> (Curtis 1834)
8. <i>Centroptilum luteolum</i> (Müller 1776)
9. <i>Cloeon dipterum</i> (Linnaeus 1761)
10. <i>Cloeon simile</i> (Eaton 1870)
11. <i>Procloeon bifidum</i> (Bengtsson 1912)
Family Heptageniidae
12. <i>Ecdyonurus dispar</i> (Curtis 1834)
13. <i>Electrogena ujhelyii</i> (Sowa 1981)
14. <i>Heptagenia flava</i> (Rostock 1878)
15. <i>Heptagenia sulphurea</i> (Müller 1776)
16. <i>Rhithrogena picteti</i> (Sowa 1971)
Family Leptophlebiidae
17. <i>Habrophlebia fusca</i> (Curtis 1834)
18. <i>Leptophlebia (Leptophlebia) marginata</i> (Linnaeus 1767)
19. <i>Leptophlebia (Leptophlebia) vespertina</i> (Linnaeus 1758)
20. <i>Leptophlebia (Paraleptophlebia) submarginata</i> (Stephens 1835)
21. <i>Leptophlebia (Paraleptophlebia) wernerii</i> (Ulmer 1920)
Family Ephemeridae
22. <i>Ephemera danica</i> (Müller 1764)
23. <i>Ephemera glaucops</i> (Pictet 1843)
24. <i>Ephemera vulgata</i> (Linnaeus 1758)
Family Potamanthidae
25. <i>Potamanthus luteus</i> (Linnaeus 1767)
Family Ephemerellidae
26. <i>Serratella ignita</i> (Poda 1761)
Family Caenidae
27. <i>Brachycercus harrisella</i> (Curtis 1834)
28. <i>Caenis horaria</i> (Linnaeus 1758)
29. <i>Caenis lactea</i> (Burmeister 1839)
30. <i>Caenis luctuosa</i> (Burmeister 1839)
31. <i>Caenis pseudorivulorum</i> (Keffermüller 1960)
32. <i>Caenis robusta</i> (Eaton 1884)

(previously reported as *Rhithrogena savoiensis* or *Rhithrogena semicolorata*), and all these species are also new for the Belgian fauna. Six species were not observed since 1990: *Metreletus balcanicus*, *Baetis lutheri*, *Ecdyonurus dispar*, *Heptagenia sulphurea*, *R. picteti* and *Potamanthus luteus* (Fig. 2). Most of the 26 remaining species have a restricted distribution (Fig. 2).

Most mayflies were mainly found in waters with a high oxygen content, but some, especially *Cloeon dipterum* and *Caenis robusta*, also tolerated relatively low oxygen levels (Fig. 3). The latter two species also tolerated relatively high conductivities (Fig. 3). Several species, such as *Baetis fuscatus* and *Procloeon bifidum*, were mainly found in the

Campine region, where watercourses contained acid or circumneutral water (Fig. 3). Other species, such as *Baetis rhodani* and *E. ujhelyii*, mainly occurred in the loamy region, where watercourses contained alkaline water.

In a CCA, the first and the second axis had an eigenvalue of 0.22 and 0.12, respectively. Conductivity and oxygen content explained most of the variance in the species composition of the mayflies along the first axis, while pH explained most of the variance along the second axis (Fig. 4). The relatively tolerant species *C. dipterum* and *C. robusta* were characteristic for waters with a low oxygen content and a high conductivity, while most species preferred higher oxygen concentrations and a lower conductivity. Along the second axis, the species could be separated into species preferring a low pH such as *P. bifidum* and *Heptagenia flava*, which were characteristic for the Campine region, and species preferring alkaline waters such as *B. rhodani* and *E. ujhelyii*, which were characteristic for the loamy region, but also species typical for stagnant waters such as *Caenis horaria*.

Discussion

In the present study, the eutrophication gradient, represented by conductivity and dissolved oxygen concentration, was the most important factor determining mayfly community composition. Also in other studies about Ephemeroptera, eutrophication has often been reported as the main factor affecting species assemblages (*i.e.* Hrovat *et al.*, 2009). Apart from eutrophication, pH also influenced community composition, with the Campine region, which is characterized by a relatively low pH, containing different species compared to the loamy region and stagnant waters, which have a higher pH. This is in accordance with the fact that mayflies are generally reported as one of the most acid-sensitive macroinvertebrate taxa (Lepori *et al.*, 2003; Tixier *et al.*, 2009). *B. rhodani* has even been used as an indicator for acidification due to its sensitivity to acidity (Raddum and Fjellheim, 1984; Tixier *et al.*, 2009).

Neither Flanders nor Belgium contains any endemic species and most species recorded in Flanders have a West Palaearctic or even a Transpalaearctic distribution, which is usually the case for lowland species (Beketov, 2009). Using the categories proposed by the IUCN Species Survival Commission (IUCN Species Survival Commission, 1994) and adapted for Flanders (Maes and Van Swaay, 1997; Maes *et al.*, 2003), mayflies were divided into categories according to their rarity. Of the 32 species that have been reported (Table 1), six species are extinct in Flanders: *R. picteti* was last observed in 1964, *M. balcanicus* in 1953, *B. lutheri* in 1946, *H. sulphurea* in 1918 and two species were not recorded since they were recorded by De Selys-Longchamps (1888): *E. dispar* and *P. luteus*. With the exception of *M. balcanicus*, all species that are extinct in Flanders still occur in Wallonia (southern part of Belgium). Amelioration of the ecological water quality could therefore induce the recolonization of

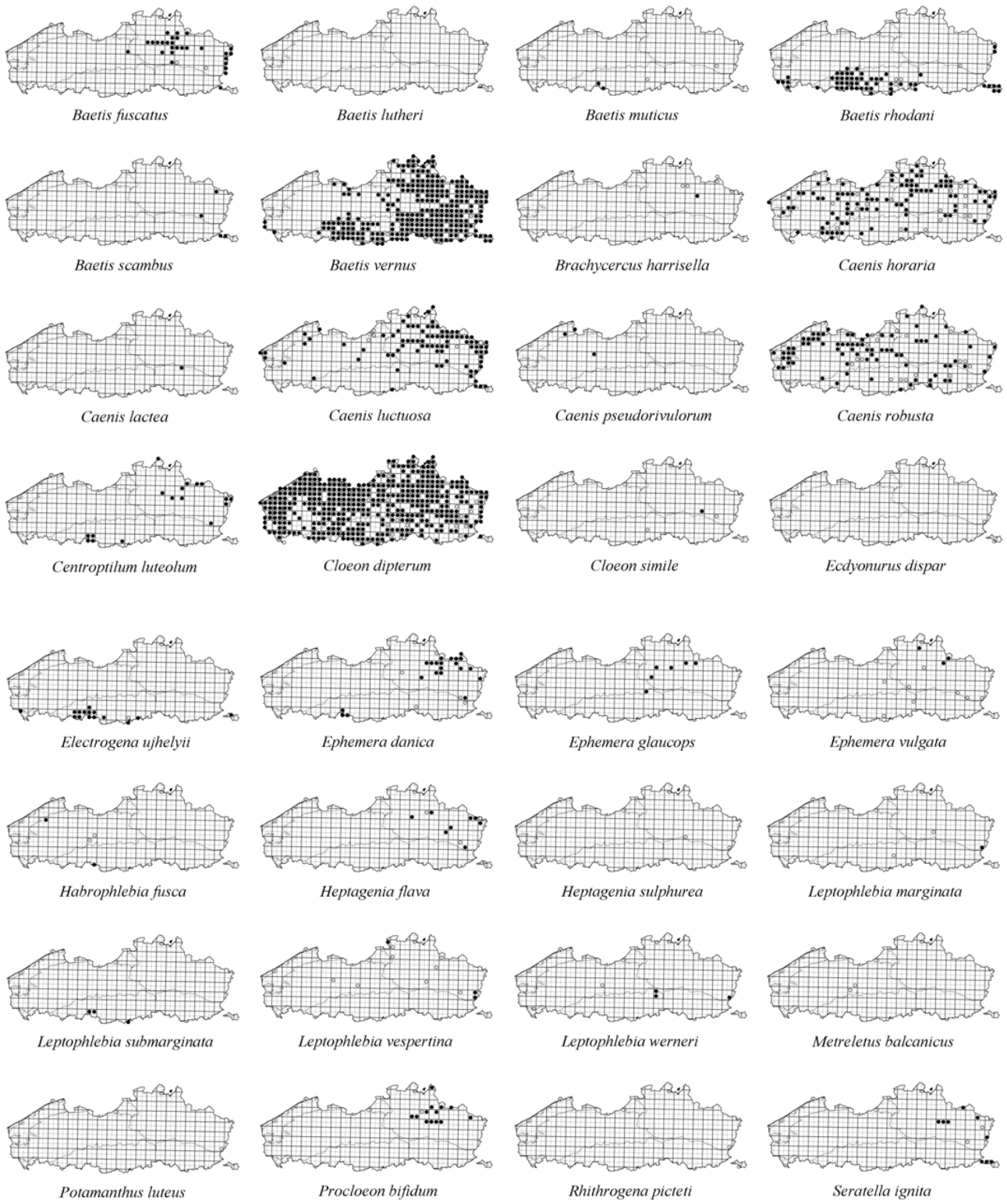


Fig. 2. Distribution of the mayflies in Flanders before 1990 (○) and since 1990 (●), with indication of the ecoregions and a grid of 5 × 5 km UTM squares.

Flanders by these species without much difficulty. Due to the lack of historical records, however, several species were probably already extinct before they were ever recorded.

Fifteen of the remaining species are very rare and occur in less than 2% of the 5 × 5 km UTM squares, five species are rare and occur in less than 5% of the squares, and three species are fairly rare as they occur in less than 15% of

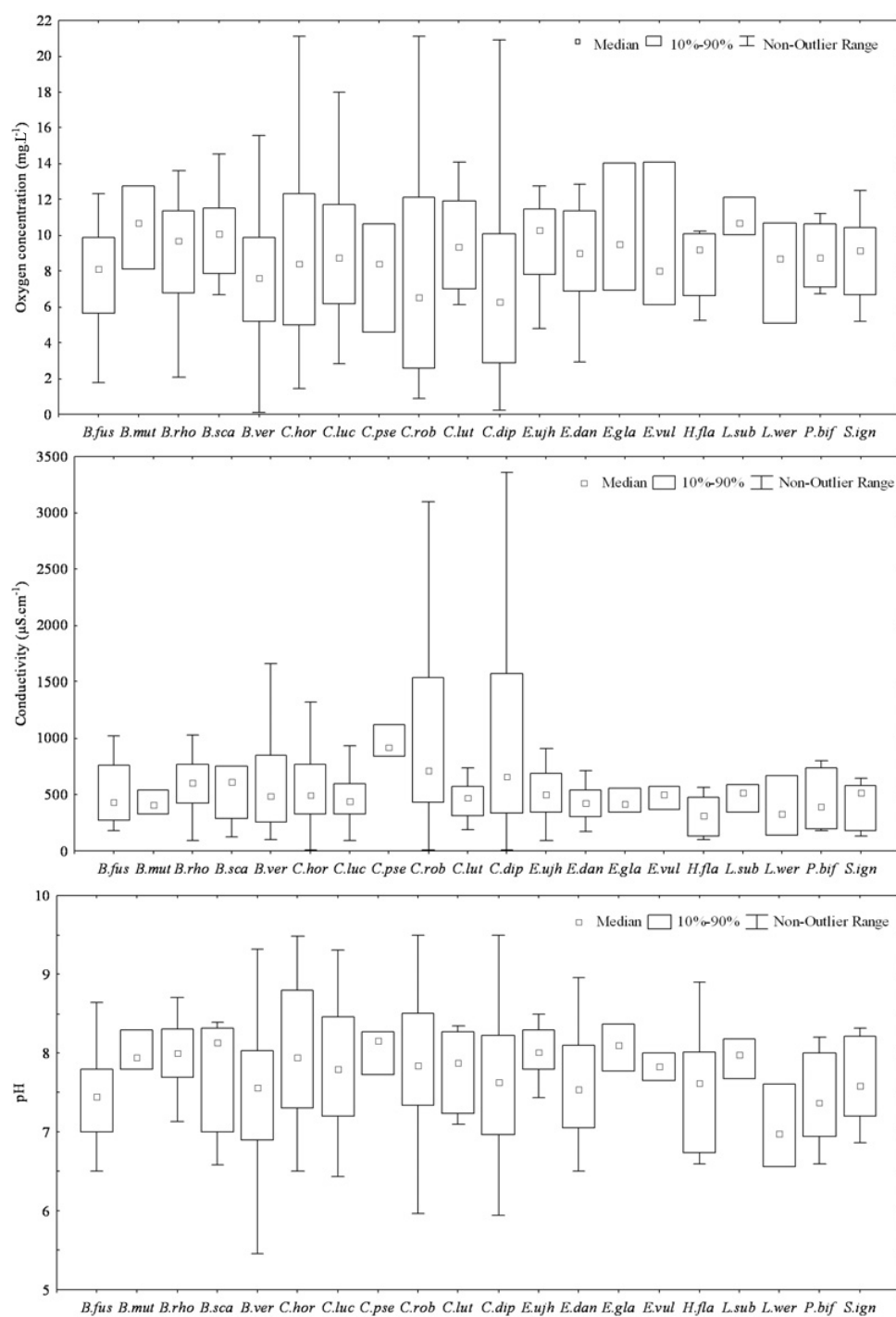


Fig. 3. Box and whisker plots of oxygen concentration, conductivity and pH in the watercourses containing *Baetis fuscatus* (*B.fus*; $n = 108$), *Baetis muticus* (*B.mut*; $n = 4$), *Baetis rhodani* (*B.rho*; $n = 283$), *Baetis scambus* (*B.sca*; $n = 14$), *Baetis vernus* (*B.ver*; $n = 1881$), *Caenis horaria* (*C.hor*; $n = 268$), *Caenis luctuosa* (*C.luc*; $n = 311$), *Caenis pseudorivulorum* (*C.pse*; $n = 7$), *Caenis robusta* (*C.rob*; $n = 158$); *Centroptilum luteolum* (*C.lut*; $n = 31$), *Cloeon dipterum* (*C.dip*; $n = 1857$), *Electrogena ujheyii* (*E.ujh*; $n = 99$), *Ephemera danica* (*E.dan*; $n = 89$), *Ephemera glaucops* (*E.gla*; $n = 7$), *Ephemera vulgata* (*E.vul*; $n = 6$), *Heptagenia flava* (*H.fla*; $n = 13$), *Leptophlebia submarginata* (*L.sub*; $n = 5$), *Leptophlebia weneri* (*L.wer*; $n = 8$), *Proclotron bifidum* (*P.bif*; $n = 26$) and *Serratella ignita* (*S.ign*; $n = 26$).

the squares (Fig. 2). Only three species are not rare in Flanders: *C. horaria*, *Baetis vernus* and *C. dipterum*. *B. vernus* is known to be a relatively tolerant species

(Beketov, 2004; Tixier *et al.*, 2009), while *C. horaria* is known from eutrophic conditions and *C. dipterum* has even been found in hypertrophic conditions (Menetrey

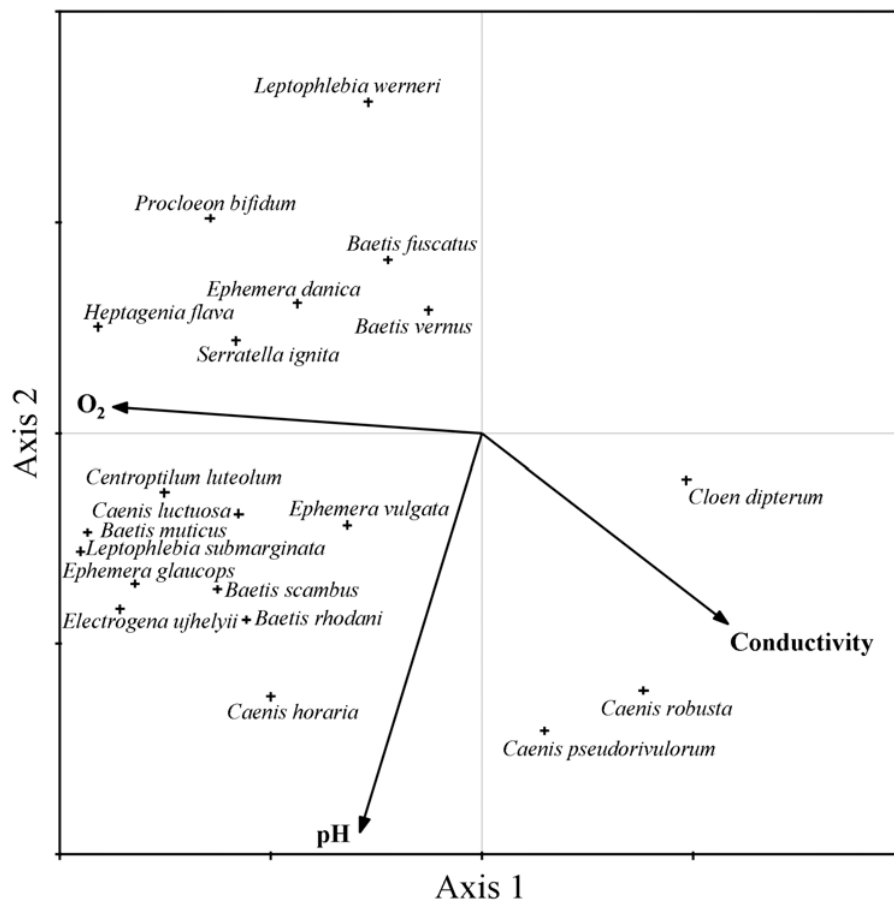


Fig. 4. Biplot of the species scores and the environmental variables pH, conductivity and oxygen concentration.

et al., 2008), and the latter is the European species that exhibits the greatest saprobic index among mayflies (Tachet *et al.*, 2000). Insufficient historical data are available to calculate trends and, therefore, no red list is presented. However, it is obvious that a number of the remaining mayfly species in Flanders are endangered. Most remaining mayfly populations are especially vulnerable since they are restricted to springs located in isolated forest remnants. Species that are restricted to large streams, such as *E. dispar*, *H. sulphurea* and *P. luteus*, still do not stand a chance in Flanders. Among river macro-invertebrates, only stoneflies seem to be worse off, with barely one species present in more than 10% of the squares (Lock and Goethals, 2008).

Because the network of the Flemish Environment Agency is very elaborate, it can be assumed that the maps give a good idea of the present distribution of the mayfly species occurring in running waters. However, much less information is available about the species living in stagnant waters because these types of waters are not monitored routinely by the Flemish Environment Agency. Species such as *C. lactea*, *Caenis pseudorivulorum*, *Cloen simile* and *Leptophlebia vespertina* might therefore be more common than indicated by the distribution maps (Fig. 2).

Conclusion

Of the 32 mayfly species that have been recorded in Flanders, already six became extinct, while most of the remaining species are rare. Only a few species that are able to tolerate relatively low oxygen levels and high conductivities are still common. It can only be hoped that the WFD will encourage Flanders to undertake the necessary steps to achieve an ecological water quality that is sufficient to support sustainable populations of sensitive aquatic invertebrates such as most mayfly species.

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