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Research article - *CORRECTED PROOF*

Present status of the North American *Umbra pygmaea* (DeKay, 1842) (eastern mudminnow) in Flanders (Belgium) and in Europe

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Abstract

The eastern mudminnow *Umbra pygmaea* (DeKay, 1842) originates from the eastern part of the United States of America and was transferred to Europe already at the beginning of the 20th century. This paper summarizes the current distribution in Europe and adds an extended dataset of eastern mudminnow records in Flanders (Belgium). The core of the European distribution seems to be the southeast of The Netherlands and the northeast of Flanders. Eastern mudminnow is established in lotic waters in Flanders and was found on 76 locations over the last 15 years. Neutral pH and high oxygen concentrations positively correlate with the presence of eastern mudminnow. The abundance of *U. pygmaea* decreases significantly with an increase of the number of fish species. The length-frequency distribution shows a peak at 7.0 cm and total length of *U. pygmaea* specimens varies between 3.4 and 13.7 cm. The overall length-weight relationship for all *U. pygmaea* specimens in Flanders shows a positive allometric growth. Fulton's condition factor for all eastern mudminnow specimens caught in Flemish rivers is 1.22. Assessment of *U. pygmaea* on its potential invasiveness in Flanders results in a low to medium risk.

Key words: non-indigenous fish species, distribution, abundance, condition factor, ecological impact, invasiveness, risk assessment

Introduction

North America is together with Asia the most important donor region for fish introductions in Europe (Lehtonen 2002). Also in Flanders (Belgium), five out of 14 introduced fish species have a North American origin (Verreycken et al. 2007). One of these species is the eastern mudminnow *Umbra pygmaea* (DeKay, 1842) (Figure 1) which is a freshwater fish of the family Umbridae. This small family consists of four freshwater species in two genera (Kottelat and Freyhof 2007): the monotypic genus *Novumbra* with the Olympic mudminnow *Novumbra hubbsi* Schultz, 1929 and the *Umbra* genus containing the European mudminnow *Umbra krameri* Walbaum, 1792 and two North American species namely the central mud-minnow *Umbra limi* (Kirtland, 1840) and the eastern mudminnow.

The native North American range of *U. pygmaea* (Figure 2) includes the Atlantic and Gulf slopes from southeastern New York (including Long Island) to St. Johns River drainage in Florida and west to Aucilla River drainage in Florida and Georgia, USA (Froese and Pauly 2009).

The eastern mudminnow was introduced to Europe (France, Belgium, Germany and The Netherlands) in the early 20th century (Welcomme 1988; Lehtonen 2002; Froese and Pauly 2009). Despite the long period since its first introduction in Europe, to date these introduced populations have hardly been studied. The objectives of this paper were to: a) summarize the distribution of *U. pygmaea* in Europe and examine its current distribution in Flanders (northern half of Belgium), b) analyze the length-weight and length-frequency relation, and occurrence of this fish species in relation to other fish species and abiotic parameters in order to assess population dynamics and c) assess the potential invasiveness of the Flemish population.

Methods

To reconstruct the introduction history of *U. pygmaea* in Europe, historical and recent data were acquired from various published and 'grey' literature sources (e.g. reports, books, personal communications and manuscripts). Data for The Netherlands were obtained from 'NatuurBank Limburg' (database of the Natuurhistorisch Genootschap Limburg) and the 'Atlasproject Vissen in Noord-Brabant' (database of Stichting RAVON, Bureau Natuurbalans-Limes Divergens BV Nijmegen and several other organisations). Recent fish data for Flanders were extracted from the online Vis Informatie Systeem database (VIS 2009) of the Research Institute for Nature and Forest (INBO), which compiles data from fisheries surveys undertaken between 1993 and 2008 at over 2100 locations (on rivers, canals and stagnant waters) throughout Flanders. Most locations were sampled twice or more in this period to be able to evaluate fish stock changes. All fishes were caught with electric fishing gear or fyke nets. After identification, of most fish specimens, total length (TL) to the nearest mm and wet weight to the nearest 0.1 g were measured at the sampling sites and after measurements the fish were returned to the water.

In this study, a subset of 275 sampling sites in sub-basins where *U. pygmaea* is present (number of sites with eastern mudminnow = 76, see Figure 4) was used to examine the relation between the presence of *U. pygmaea* with other species and other parameters (temperature, turbidity, O_2, pH, river width and depth, water velocity, conductivity).

Of the 1510 individuals of eastern mudminnow caught, 968 specimens were individually weighed and measured. Individuals with an observed weight that diverged more than 50% from the expected weight (W') (n = 34) calculated from the length-weight relationship $W'=aL^b$ (where L is observed TL, a is the regression intercept and b is the regression slope) were discarded from the dataset as they were probably mistakes. The discarded data were randomly distributed over the sampling sites and their removal therefore does not bias the results.

Figure 1. Eastern mudminnow *Umbra pygmaea* (photo: Rollin Verlinde – Vildaphoto).

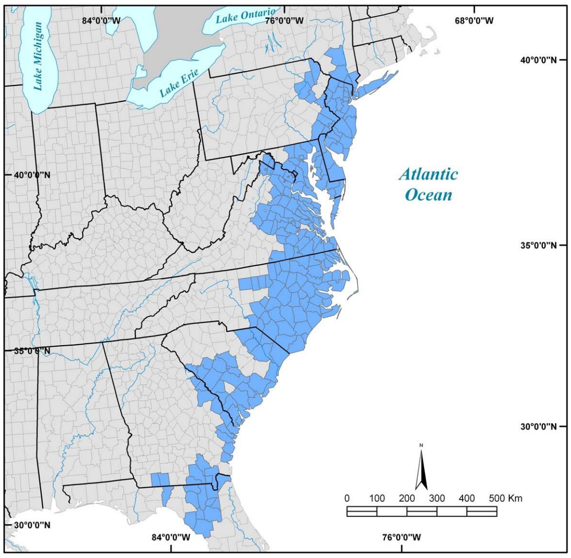

Figure 2. Native distribution of *Umbra pygmaea* in the United States of America (redrawn after NatureServe 2009).

Length-weight relationships and length-frequency distributions were calculated for 934 specimens. Logarithmic transformations of the length and weight generally provide a linear relationship suitable for expressing length and weight in fishes. Data on the sex of the fish were not available, the length-weight relationship for males and females however does not seem to differ significantly in native populations (Panek 1981) nor in introduced populations (Dederen et al. 1986). Fulton's condition factor ($K_{Fulton} = 100W/L^3$) for *U. pygmaea* was calculated on the whole Flemish dataset. Relative condition factors for eastern mudminnow from the different river zones were calculated using K_{rel} = W/W' where W = observed weight and W' = expected weight (Le Cren 1951), calculated using the length-weight conversion produced from all specimens. K_{rel} values >1 or <1 indicate that the individual is in better or worse condition, respectively, than the average individual of the same TL range. K_{rel} can also be used to compare body condition in between populations of the same species.

Each sample site was assigned to a river typology ('bream', 'barbel' and 'upstream') on the basis of the river width combined with the slope according to Huet (1949) and Breine et al. (2004). The 'bream zone' has the lowest water velocity due to the largest river width and no steep slope while the 'upstream zone' has the highest water velocity due to the smallest width and the steepest slope. 'Barbel zone' is intermediate between the 'bream' and the 'upstream zone'. Each of these zones has its characteristic fish fauna (Huet 1949).

The relation between the presence of *U. pygmaea* and other parameters (number of species, temperature, turbidity, O_2, pH, river width and depth, water velocity, conductivity) was analysed using a Generalized Linear Mixed Effect Model in TIBCO Spotfire S-Plus 8.1 for Windows (Insightful 2007). Variation in length-weight relationships, condition factors for subpopulations of different river zones and relative and absolute abundance of eastern mudminnow in relation to the number of species present were tested with a Tukey HSD test in Statistica 8 (StatSoft 2008). Relative abundance was defined as 100× the number of mudminnows divided by the number of all specimens of all fish species at a site and absolute abundance as numbers of individuals caught per 100 m continuous electrofishing of a river stretch.

To assess the potential invasiveness of eastern mudminnow in Flanders, two risk analysis tools were used: the Freshwater Fish Invasiveness Scoring Kit or FISK developed in the UK (Copp et al. 2005, 2008) and the Belgian ISEIA-protocol (Branquart 2007).

FISK is an adaptation of the Weed Risk Assessment by Pheloung et al. (1999). It uses 49 questions in eight categories (Domestication, Climate and Distribution, Invasive elsewhere, Undesirable traits, Feeding guild, Reproduction, Dispersal mechanisms, Persistence attributes) and takes into account the confidence (certainty/uncertainty) ranking of the assessors. FISK scores range from −11 to 54 and it originally classified non-native species into "low risk" (score <1), "medium risk" (1≤ score ≤6), "high risk" (score >6) classes (Copp et al. 2005). In Copp et al. (2008), the threshold of ≥19 was introduced to discriminate between invasive and non-invasive species and the high risk class with scores between 6 and 19 was reclassed into "medium risk". This way FISK is able to distinguish accurately (and with statistical confidence) between potentially invasive and non-invasive species of non-native fishes.

The ISEIA protocol (Branquart 2007) assesses the potential of non-native species for spreading and colonising natural habitats as well as the adverse impacts on native species and ecosystems. It uses ten questions in four categories (Invasiveness, Impact on species, Impact on ecosystems and Invasion stage) to assign invasive alien species to an alert, watch or black list. High impact species present in Belgium are on the black list while those with a moderate or unknown impact are included in the watch list. The alert list consists of high impact species present in neighbouring countries but not yet recorded in Belgium. Low impact species are not included in a list. The ISEIA protocol uses invasion histories documented in peer-reviewed publications and in scientific reports from Belgium and neighbouring areas rather than the species' intrinsic attributes.

Results

Distribution in Europe

In Europe, the eastern mudminnow was introduced in six countries namely Germany, Belgium, The Netherlands, France, Poland and Denmark. Figure 3 shows the past and current European distribution. Kottelat and Freyhof (2007) only mention the first five countries while Lehtonen (2002) reports *U. pygmaea* for Denmark, France, Belgium and The Netherlands. Most authors (e.g. Welcomme 1988; Holčík 1991; Lechtonen 2002) seem to agree on 1913 as first introduction date in Europe. However introduction probably already happened at the end of the 19th century as Wolter (2009) attributes the occurrence of the eastern mudminnow in the river Oder (northeast Germany) to escapes from (aquaculture) experiments in ponds with North American fish species by Max Von dem Borne at the end of the 19th century. Also Nijssen and de Groot (1987) suspect that eastern mudminnow was introduced in The Netherlands around 1900. It was probably used in aquaculture

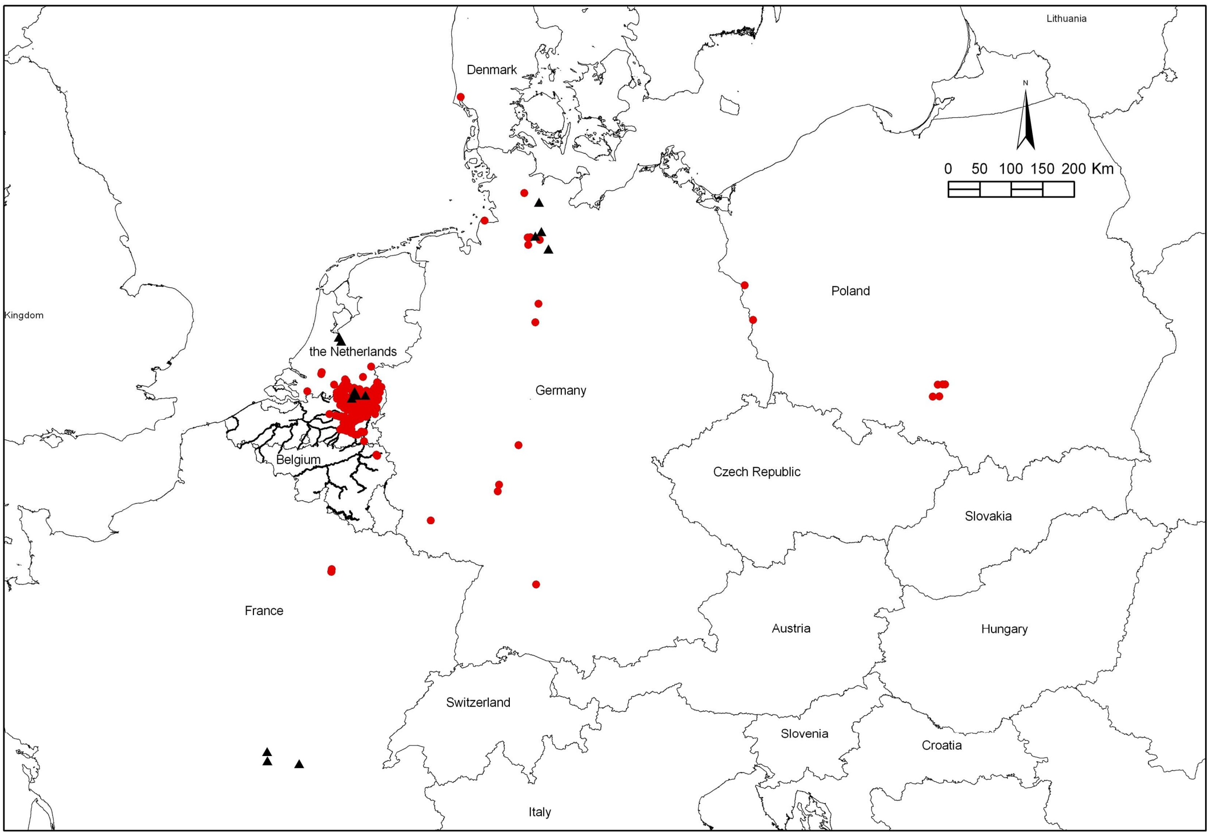

Figure 3. Overview of the distribution of *Umbra pygmaea* in Europe (▲: observations pre-1980, ●: since 1980) (map reproduced from literature data for all countries with additional information from the database VIS for Flemish records, NatuurBank Limburg and Atlasproject Vissen in Noord-Brabant for The Netherlands, A. Witkowski (pers.comm.) for Poland and P. Keith (pers.comm.) for France).

ponds in Valkenswaard and spread through dispersal from there.

Vooren (1972) reviewed the introduction as moderately successful only in the Netherlands and Belgium, although France and Germany were mentioned as 'receiving countries'. Guidou and Keith (2002) point out that the naturalisation of the eastern mudminnow in some sites in Belgium is the origin of the introduction in the Marne in the 1970-80s. At that time the majority of ponds in Argonne were exploited by Belgian pisciculturists who have unintentionally spread *U. pygmaea* in several ponds there.

The core of the current distribution of the eastern mudminnow in Europe is the south-eastern part of The Netherlands (provinces Limburg and Noord-Brabant) and the northeast of Flanders (provinces Antwerpen and Limburg). The distribution in The Netherlands completely links up with the distribution range in Flanders and together they form the largest distribution area of *U. pygmaea* outside its native range.

In Table 1 we provide more information on the European distribution for each country including possible pathways, year of first introduction and first record, number of unique sites with eastern mudminnow, distribution range and main references.

Distribution in Flanders

Detailed information on the distribution of *U. pygmaea* in Flanders is shown in Figure 4 and coordinates are given in Annex 1. In 76 locations, 1510 specimens were recorded during fish stock assessments with numbers caught per sampling effort (100 m continuous electrofishing

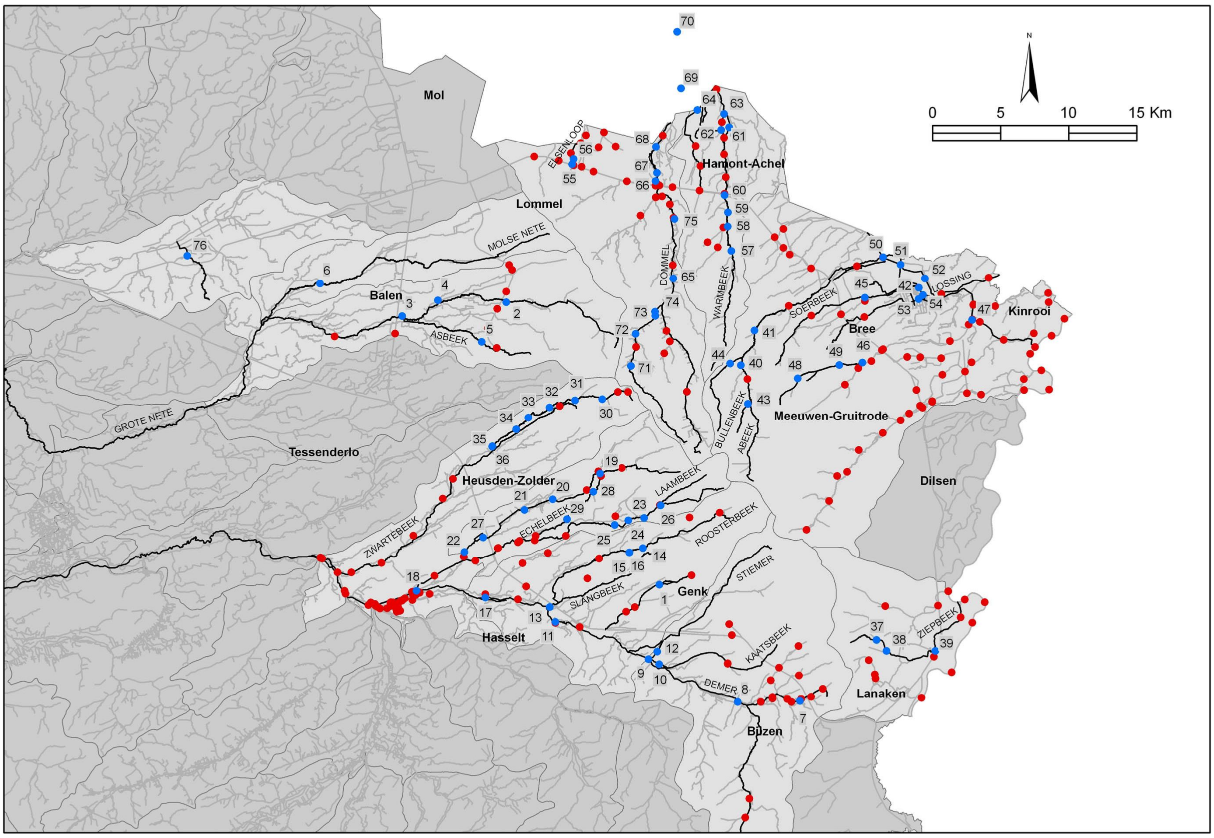

Figure 4. Sub-basins in northeast Flanders where *Umbra pygmaea* was caught (●: survey site with *U. pygmaea* records, ●: survey site without *U. pygmaea*) (numbers correspond with sample sites in Annex 1).

on one site on a certain day) ranging from 0.2 to 644.0 individuals/100m (28.8 % between 0.1-1.0 ind./100m, 51.2 % between 1.1-10.0 ind./100m, 17.6 % between 10.1-100.0 ind./100m and 2.4 % between 100.0-1000.0 ind./100m). All sampled locations with *U. pygmaea* were located in the northeast of Flanders belonging to three of the eleven river basins in Flanders: Demer, Nete and Meuse basins.

Population characteristics of the Flemish population

Length-frequency distribution

The length-frequency distribution of all captured and measured individuals (n = 934) of the riverine Flemish population is given in Figure 5. Total length (TL) varied between 3.4 and 13.7 cm and the length histogram showed a peak at 7.0 cm.

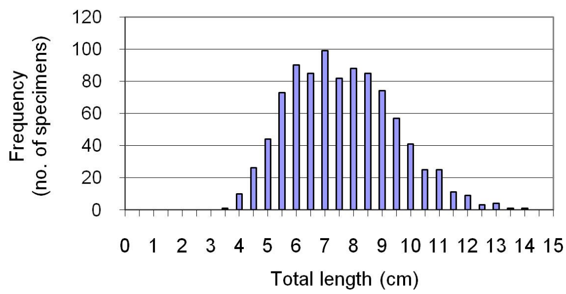

Figure 5. Length-frequency distribution of 934 eastern mudminnows caught in lotic waters in Flanders during fish stock assessments between 1995 and 2008 within the framework of the Freshwater monitoring network of INBO.

Table 1. European distribution of *U. pygmaea* in Europe with, for each country, possible pathways, year of first introduction and first record, population established and/or invasive, number of unique sites with eastern mudminnow, distribution range and main references.

Country	Pathway	Year of first introduction/ record	Established/ invasive	No. of unique sites	Distribution range	Main references
Belgium	Dispersal from The Netherlands (?)	1920 (?)/1949	Yes/No	78	Northeast Flanders (provinces Limburg and Antwerpen) and 2 sites in Wallonia	Poll (1949) Philippart (2007) Verreycken et al. (2007)
Denmark	Release of live bait	?/1987	Yes/No	1	Oksbøl (West Jutland)	Atlas of Danish Freshwater Fish (2007)
France	Introduced in pond	1910-1911/ 1913	Yes/No	6	Argonne (Marne) and Central France (near Lapalisse)	Guidou and Keith (2002) Keith and Allardi (2001) Ph. Keith (pers.comm., 2009)
Germany	Food for aquaculture of N. American salmonids Aquarium releases	1910 (?)/?	Yes/?	18	Neighbourhood of large cities of counties Hamburg, Hessen, Niedersachsen and Schleswig-Holstein and River Oder system	Geiter et al. (2002) Wolter (2009)
Netherlands	Escapes from aquaculture facilities Dispersal from Germany/Belgium	1900s (?)/?	Yes/Yes?	829	Provinces Noord-Brabant and Limburg and local observations outside this core area	NatuurBank Limburg (2009) Atlasproject Vissen in Noord-Brabant (2009) Crombaghs et al. (2000) de Nie (1996)
Poland	Aquarium releases	1920s (?)/ 1995	Yes/?	7	River Mietzel, R. Oder /R. Liswarta and R. Mala Panew catchments	Wolter (2009); Witkowski et al. (1995, 1997) Kostrzewa (1998)

Length-weight relationships

The overall length-weight relationship for all *U. pygmaea* specimens in Flanders was $W=0.0075L^{3.243}$ or $\log_{10}W = -2.127+3.243\log_{10}L$ ($n = 934$, $r^2 = 0{,}966$, confidence interval (-95%, +95%) log a = -2.160 and -2.093, confidence interval (-95%, +95 %) b = 3.204 and 3.282).

Table 2 shows, for each river with a mudminnow population ≥20 specimens, the parameters a and b, and the coefficient of determination (r^2) of the length-weight relationship. All regressions were significant ($p<0.05$). The sampled rivers are shown on Figure 4.

Condition factor

Fulton's condition factor (K_{Fulton}) for all eastern mudminnow specimens together was 1.22±0.006 st.err. The mean relative condition factor (K_{rel}) for individuals grouped according their site typology 'bream', 'barbel' and 'upstream' was respectively 0.98, 1.00 and 1.05 with a significant difference between the 'bream' and 'upstream' ($p <0.01$) and 'barbel' and 'upstream' zone ($p <0.01$) but not between 'bream' and 'barbel' ($p = 0.052$) (Figure 6).

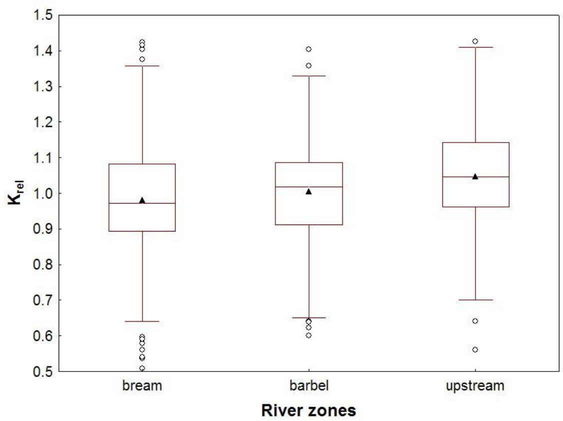

Figure 6. Boxplot of mean relative condition factor (K_{rel}) for different site typologies 'bream', 'barbel' and 'upstream' (with median (–), mean (▲) and 25 % - 75 % percentiles (box) and non-outliers range (outside box)). 'Bream' and 'barbel' zones differ significantly from 'upstream' zone but are not significantly different from each other (Tukey HSD test).

Table 2. Total length (cm) weight (g) relationship for *Umbra pygmaea* sampled from different rivers in Flanders where W = aL^b (a is regression intercept and b is regression slope); n = sample size, CI = confidence intervals, r² = coefficient of determination.

River	n	Length range (cm)	a	B	CI *a*		CI *b*		r²
					-95.00 %	+95.00 %	-95.00 %	+95.00 %	
ABEEK	21	5.2–10.5	0.0208	2.734	0.0099	0.0434	2.374	3.095	0.930
BOLISENBEEK	45	5.8–11.4	0.0075	3.270	0.0046	0.0122	3.034	3.507	0.948
DEMER	36	5.2–11.1	0.0045	3.490	0.0027	0.0074	3.250	3.730	0.962
DOMMEL	72	5.1–13.0	0.0074	3.232	0.0048	0.0112	3.037	3.427	0.940
HUTTEBEEK	72	4.2–8.7	0.0069	3.312	0.0046	0.0106	3.062	3.563	0.909
LOSSING	40	5.5–13.2	0.0098	3.124	0.0059	0.0162	2.888	3.360	0.950
MANGELBEEK	147	4.6–9.6	0.0104	3.073	0.0087	0.0124	2.975	3.170	0.964
NIEUWBEEK	20	5.4–12.5	0.0081	3.163	0.0043	0.0152	2.858	3.473	0.963
ROOSTERBEEK	156	4.4–11.2	0.0077	3.247	0.0061	0.0098	3.128	3.367	0.949
WARMBEEK	92	5.0–13.7	0.0059	3.345	0.0041	0.0086	3.174	3.517	0.944
ZIEPBEEK	102	3.4–13.0	0.0057	3.364	0.0043	0.0074	3.213	3.515	0.951
Overall	803								

Table 3. Mean values (with minimum and maximum) of the environmental parameters recorded on sample occasions with and without *Umbra pygmaea* in a subset of 275 sampling sites in sub-basins where *U. pygmaea* was recorded (significant p-values in bold) (n = number of occasions a certain parameter was recorded).

Abiotic parameters	With *U. pygmaea*				Without *U. pygmaea*				Comparison of means
	mean	min	max	n	mean	min	max	n	P
pH	7.04	5.15	8.43	84	7.22	3.7	8.59	339	**0.007055**
Water velocity (m s^{-1})	0.53	0.01	4.4	54	0.52	0.01	3.7	135	0.971479
Dissolved oxygen (mg l^{-1})	9.7	3.3	20.4	83	8.3	0.4	20.3	363	**0.000120**
Conductivity (µS cm^{-1})	394	127	1245	85	445	5	1245	357	**0.049016**
Water temperature (°C)	10.7	0.1	19.3	87	12.9	1.0	25.0	368	**0.000057**
Mean depth (m)	0.51	0.15	1.20	76	0.49	0.05	1.50	221	0.729112

Environmental conditions

In Table 3 mean values (with minimum and maximum) of the environmental parameters (units see Table 3) conductivity, mean depth of the river, pH, water velocity, water temperature and dissolved oxygen are shown for sample occasions with and without *U. pygmaea*.

At the sampling sites with *U. pygmaea* mean pH and mean water temperature were significantly lower and mean dissolved oxygen and mean conductivity significantly higher than at sites without this fish species.

Only pH and dissolved oxygen explained the presence versus absence of *U. pygmaea* (Generalized Linear Mixed Effect Model, $p < 0.05$). High oxygen concentrations and a neutral pH (=7) were positively correlated with the presence of eastern mudminnow in Flemish rivers.

Impact of eastern mudminnow in Flemish rivers

Co-inhabiting fish species

At all sites where eastern mudminnow was caught the average fish assemblage consisted, in relative number of specimens, mainly of gudgeon *Gobio gobio* (Linnaeus, 1758) (18.2 %), three-spined stickleback *Gasterosteus aculeatus* Linnaeus, 1758 (16.6 %), topmouth gudgeon *Pseudorasbora parva* (Temminck & Schlegel, 1846) (10.7 %), stone loach *Barbatula barbatula* (Linnaeus, 1758) (10.6 %), pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758) (8.4 %), roach *Rutilus rutilus* (Linnaeus, 1758) (7.7 %), gibel carp *Carassius gibelio* (Bloch, 1782) (6.4 %), eastern mudminnow (6.1 %) and brook lamprey *Lampetra planeri* (Bloch, 1784) (3.5 %). The other species represented each less than 2 % and together 11.7 % of the numbers caught at these sites.

Figure 7 presents the occurrence of fish species (in %) at sample occasions with fish in the subset of 275 sampling sites in sub-basins where *U. pygmaea* is present. Co-inhabiting species that were present in more than 40 % of the sample occasions where mudminnows were found are gudgeon, three-spined stickleback, nine-spined stickleback *Pungitius laevis* (Cuvier, 1829), stone loach, roach, eel *Anguilla anguilla* (Linnaeus, 1758) and pumpkinseed.

Ruffe *Gymnocephalus cernua* (Linnaeus, 1758), pikeperch *Sander lucioperca* (Linnaeus, 1758), bullhead *Cottus* sp., spined loach *Cobitis taenia* Linnaeus, 1758, respectively caught on 16.1, 6.6, 6.4 and 4.3 % of the sample occasions, together with eight others fish species (occurring in very low percentages) (Figure 7) were never recorded together with eastern mudminnow.

Mudminnows occurred in communities with as few as one species (*U. pygmaea* itself) and as many as 19 fish species. Both the relative abundance of eastern mudminnow (regression $y = 174.8\ x^{-1.94}$, $p < 0.05$, $r^2 = 0.616$) and the $\log_{10}$ absolute abundance (regression $\log_{10} y = 0.848 - 0.366 \log_{10} x$, $p < 0.05$ but $r^2 = 0.038$) were inversely related to the number of species present.

There was no significant correlation between the numbers of eastern mudminnow and the numbers of fish predators (pike *Esox lucius* Linnaeus, 1758, pikeperch *Sander lucioperca* (Linnaeus, 1758) and perch *Perca fluviatilis* Linnaeus, 1758 > 20 cm) in a sample site in Flemish lotic waters.

Impact assessment of eastern mudminnow

Mean score for eastern mudminnow in Flemish lotic waters using the Freshwater Fish Invasiveness Scoring Kit (FISK) (applied by two Belgian assessors) was 14, placing the species in the 'medium risk' category (Copp et al. 2008).

Eastern mudminnow was not allocated to one of the lists (alert, watch or black list) of the ISEIA protocol (Branquart, 2007); with an ISEIA score of 8 (out of 12) it was not considered invasive.

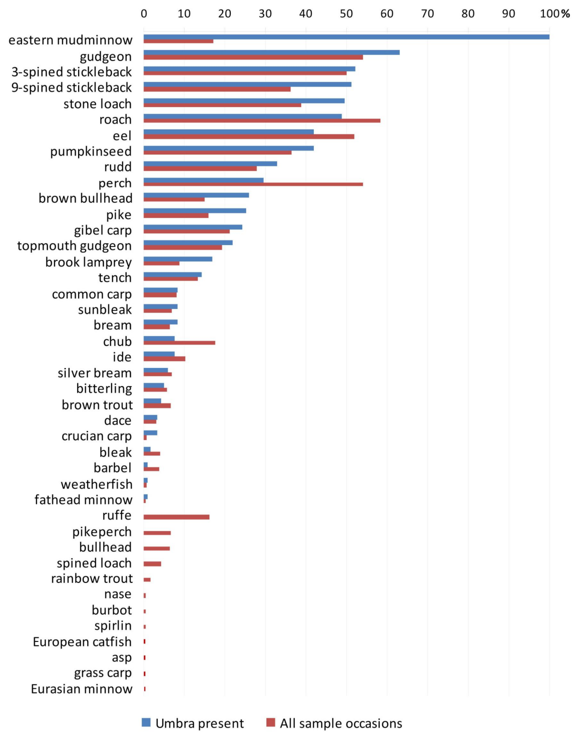

Figure 7. Presence of fish species (in %) at sample occasions (n = 119) where *Umbra pygmaea*,eastern mudminnow was caught compared to the presence of fish species (in %) at all sample occasions with fish (n = 745) of this study.

Discussion

Distribution

Despite the fact that *U. pygmaea* was already introduced into Europe in the early 1900s, their current presence is confined to six countries Belgium, Denmark, France, Germany, Poland and The Netherlands. The distribution of the eastern mudminnow in most of these countries seems to be limited to one (Denmark) or a few localities (e.g. France, Poland). However the area which comprises the south-eastern part of The Netherlands and the north-eastern part of Belgium harbours eastern mudminnow in many localities (> 900) (this study) in waters with sometimes dense populations (Leuven et al. 1984).

The recent extension of the non-native area to Denmark and Poland was mainly human mediated (use as live bait fish or as aquarium fish) but also in the other countries where it was introduced, dispersal was aided by human activities. In The Netherlands, acidification of shallow and lentic soft waters has had an important impact on their fish assemblages and has favoured the distribution and densities of the eastern mudminnow (Dederen et al. 1986, Leuven and Oyen 1987). In moorland pools where *U. pygmaea* has little competition from other species, this fish may even play an important role as a top predator (Dederen et al. 1986). In Belgium, earthen fish culture ponds which are emptied every year, may act as a major source of mudminnow specimens for riverine populations. This theory is supported by the similar restricted distribution of other North American species of lentic waters like pumpkinseed and brown bullhead *Ameiurus nebulosus* (Lesueur, 1819) in this area (Verreycken et al. 2007). Also, Guidou and Keith (2002) point out that *U. pygmaea* was unintentionally spread to several ponds in the Argonne (Marne region, France) in the 1970-80s by Belgian pisciculturists, who at that time exploited the majority of the ponds in this region. Crombaghs et al. (2000) suggest that the colonization of upper parts of rivers by new individuals of eastern mudminnow is facilitated by the flooding of adjacent lentic waters.

After the initial dispersal following its introduction (Burny, 1984), distribution of the Flemish populations of eastern mudminnow remained relatively unchanged in the 1980s and 1990s (Vandelannoote et al. 1998) and also over the last decade changes in frequency of occurrence (presence or absence) and abundance were very small (Verreycken et al. 2007). Therefore it seems likely that eastern mudminnow will remain part of the Flemish ichthyofauna and that its distribution area probably will not change dramatically.

Population characteristics

Length-frequency distribution

The total length of the mudminnows caught in rivers in Flanders ranged from 3.4 to 13.7 cm. This is in agreement with length data recorded in its native range (TL min. 2.4 and max. 12.3 cm; 263 specimens (Panek 1981)) and in other areas of its introduced range. Froese and Pauly (2009) mention 15 cm TL for Germany and Kottelat and Freyhof (2007) 12 cm SL for Europe as maximum lengths. Guidou and Keith (2002) report minimum and maximum length of the Marne population (France) as 4.1–9.9 cm (595 specimens) without specifying what type of length was measured (total, fork or standard length; note that total and fork length are equal in *U. pygmaea* because of its convex tail). Dederen et al. (1986) use 'body length' (presumably for TL) and found a maximum body length (451 specimens) of 12.7 and 8.6 cm for females and males respectively for the Dutch population. Although the maximum total length recorded in Flemish waters exceeds those from most neighbouring countries and from its native range, it fits in with the arithmetically determined ultimate length for the Dutch populations (16.0 ± 2.3 cm, Dederen et al. 1986).

The length-frequency distribution (Figure 5) suggests natural reproduction in lotic waters of Flanders (or at least in adjacent, connected lentic water bodies), but smaller specimens are less prominently present than can be expected in natural fish populations. Also in Dutch streams and brooks, Crombaghs et al. (2000) notice hardly if any juveniles or subadults and suggest that the eastern mudminnow not or barely reproduces in these waters, which they explain by the presence of predators.

Length-weight relationship

In literature, length-weight relationships of *U. pygmaea* in its introduced and even its native range are rare. We therefore include in Table 1 the length-weight relationship of eleven rivers in northeast Flanders (minimum 20 specimens per stream). As our data were collected in the framework of the Flemish Freshwater Fish Monitoring Network and not for the purpose of this study, unfortunately the collection of the data on a stream did not always occur in the same season as recommended by Froese (2006).

The overall length-weight relationship for all *U. pygmaea* specimens in Flanders is $W=0.0075L^{3.243}$ as compared to the Dutch population ($W=0.0034L^{3.55}$, Dederen et al. 1986). When compared to the mean *a* and *b* of the populations of eleven streams with a mudminnow population ≥20 specimens (Table 2; $a=0.0081\pm0.0013$ std. err.; $b=3.214\pm0.060$ std. err.) we found a significant difference for constants *a* ($p < 0.01$) and *b* ($p < 0.001$) in The Netherlands and Flanders. This may be a consequence of the different sample sites types (lentic waters in the Netherlands versus lotic waters in Flanders). Prediction would be that individuals from riverine populations would be more slender-bodied (e.g. pumpkinseed populations (Brinsmead and Fox 2002)) than from lacustrine populations, reflected by a different *a* and *b* in the length-weight relationship. However also other factors (e.g. pH, alkalinity, water conductivity) may play an important role here. For instance, water conductivity (as a surrogate of water productivity (Copp 2003)) was very different between the two sample regions. Dederen et al. (1986) collected their fish at conductivities between 0–383 µS cm^{-1} while eastern mudminnows in our study were sampled at a mean conductivity of 394 µS cm^{-1} (min 127–max 1245 µS cm^{-1}).

Condition

K_{Fulton} for all *U. pygmaea* individuals from Flemish rivers together was 1.22±0.006 st.err., however no other K_{Fulton}-values from native or introduced populations of eastern mudminnow were available for comparison.

K_{rel} for different river zones 'bream', 'barbel' and 'upstream' was respectively 0.98, 1.00 and 1.05. Contrary to what one would expect of a species which prefers lentic waters (Kottelat and Freyhof 2007), the relative condition factor of the 'upstream' zone (highest water velocity due to small river width combined with a steeper slope (Breine et al. 2004)) is significantly higher than K_{rel} of the 'barbel' ($p < 0.01$) and the 'bream' zone ($p < 0.001$). To best compare the condition of fish from different waters, data should be from fish of the same length, age, and sex; and should have been collected on the same date (or at least the same season). The ratio, highest K_{rel} for 'upstream', then 'barbel' and 'bream', however goes for the total dataset as well as for the data divided up by season. More research is needed to elucidate the cause for these contradictory results.

Environmental parameters

Eastern mudminnow occurs in Flemish rivers in a broad range of environmental parameters (Table 2). Surprisingly eastern mudminnow was captured at a mean water velocity of 0.53 m s^{-1} (with extremes up to 4.4 m s^{-1}) which is much higher than the values in the Netherlands (all observations <0.60 m s^{-1}) (Crombaghs et al. 2000) but not different from the mean water velocity of the sampled sites without *U. pygmaea* in Flanders. Other authors (e.g. Poll 1949; Dederen et al. 1986) already reported on the exceptional adaptation skills of this species to extreme temperatures, oxygen contents and pH. *U. pygmaea* was therefore in The Netherlands also found in a wide range of conditions and habitats. However, Crombaghs et al. (2000) were able to define the preferred biotic and abiotic parameters in river systems of the Netherlands. Wider ditches (4 to 5 m) deeper than 0.5 m with a sandy or muddy substrate and low water velocity (<0.30 m s^{-1} with about 40 % of the observations <0.05 m s^{-1}) characterise the habitat where eastern mudminnow was mainly found. On these sites often dense vegetation was present. In our study, only high oxygen contents and a neutral pH (=7) were positively correlated with the presence of eastern mudminnow in Flemish rivers.

Impact of eastern mudminnow in Flemish lotic waters

Eastern mudminnow is mainly considered as harmless (Froese and Pauly 2009). This fish species however has proven to reproduce in the wild and can become established (i.e. form self-sustaining populations) in countries where it was introduced (Table 1). Spread potential seems low (Crombaghs et al. 2000) and is probably limited by the presence of piscivorous fish species (Dederen et al. 1986), the latter however could not be confirmed in this study. Its slow dispersal in Europe since its introduction, except for human aided dispersal (e.g. Guidou and Keith 2002), and its confined distribution seem to confirm its low spread potential. On the other hand *U. pygmaea* has a great potential to colonise a broad range of habitats (Crombaghs et al. 2000, this study), which advantages this species to extend its distribution range in extreme habitats (Dederen et al. 1986). Especially in ditches with dense vegetation or in waters without other fish species (e.g. acid moorland pools) where viable and very dense populations of eastern mudminnow can occur (Leuven et al. 1984; Crombaghs et al. 2000). In these habitats they may be considered as high impact species since they may play a significant role as a top predator there (Dederen et al. 1986). Vooren (1972) reported that eastern mudminnow also predates on larvae of amphibians.

Co-inhabiting species

Consistent with Panek (1981) (for native populations), we find that the (relative) abundance of eastern mudminnow is inversely related to the number of fish species present. Dederen et al. (1986) concluded that the abundance of mudminnows was inversely related to the presence of predatory fish species. The impact of the presence of *U. pygmaea* on other (indigenous) fish species is hard to evaluate as many factors influence the fish species composition and diversity and accurate data of fish assemblages of rivers before the introduction of eastern mudminnow are very rare.

Co-inhabiting species that are present in more than 40 % of the sample occasions where mudminnows were found are gudgeon, three- and nine-spined stickleback, stone loach, roach, eel and pumpkinseed (Figure 7). These species are representatives of both rheophilic (e.g. gudgeon, stone loach) and eurytopic fish groups (e.g. roach, three-spined stickleback) (van Emmerik 2003). The eurytopic eastern mudminnow (van Emmerik 2003) indeed inhabits a broad range of habitats. Crombaghs et al. (2000) also reported nine-spined stickleback, three-spined stickleback and tench *Tinca tinca* (Linnaeus, 1758) to be present in >40 % of the sites where mudminnows have been found, with stone loach and gudgeon both at around 35 % of the sites, which largely corresponds to our findings. Species like ruffe, pikeperch and bullhead were each present in more than five percent of the sample occasions (ruffe even >16 %) but were never recorded together with *U. pygmaea*. This study also shows that eastern mudminnow is a substantial part of the fish fauna in rivers of northeast Flanders and is capable of maintaining viable populations there.

Impact assessment

To assess the potential impact of eastern mudminnow in Flemish lotic waters two different tools were used. FISK, when applied by Belgian assessors, placed this species in the 'medium risk' category of becoming invasive (score of 14) while eastern mudminnow was not allocated to one of the lists of the ISEIA protocol and thus considered non-invasive. Copp et al. (2008) however allocated *U. pygmaea* to the high risk category (score of 24.0) of potentially invasive species. The paucity of (peer-reviewed) publications on the introduced range and the ecological impact of the eastern mudminnow may explain the differences in outcome of the assessors (UK versus Belgium) and of both assessment tools as the results are probably mainly based on expert judgement. The few publications that deal with the ecological impact (and distribution) of eastern mudminnow are mainly about extreme habitats where this fish can occur in high densities and often is the only fish species present. Answers from the Belgian assessors in the risk assessment were based on their knowledge of the distribution and impact of *U. pygmaea* in lotic waters in Flanders with low densities of this fish. In these rivers it seems appropriate that *U. pygmaea* is categorized as a species with "low to medium risk" of becoming invasive.

In summary, this preliminary research provides some basic data about the Flemish eastern mudminnow population in Flanders. There certainly exists a need for more research on this species in its introduced range e.g. life history traits like fecundity, age and growth data and food preference in lotic water systems. Also a genetic survey of the different *U. pygmaea* populations in Europe could teach us more about the history and source of its introduction.. As the heart of the non-native distribution range comprises the southeast of The Netherlands and the northeast of Flanders, the use of combined data from both areas could be the basis of a more profound research of this introduced species.

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Annex 1. Sample sites in Flanders where *Umbra pygmaea* was recorded, with CPUE (number of specimens per 100m electrofishing) (blank = not fished, 0 = no eastern mudminnows caught). Number in first column corresponds with number shown on the map in Figure 4.

Map ref. Fig. 4	Location	Latitude/ Longitude	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	Zusterkloos-terbeek	50°58'12"N 05°25'04"E									13					
2	Grote neet	51°09'30"N 05°15'41"E		0						0				2		
3	Grote neet	51°09'00"N 05°09'06"E								1				0		
4	Balengracht	51°09'37"N 05°11'22"E		0						1					2.4	
5	Asdonkbeek	51°07'57"N 05°14'05"E			0					3.1					3	
6	Mol neet	51°10'19"N 05°03'56"E		0								2				0
7	Munsterbeek	50°53'30"N 05°33'47"E							30							
8	Demer	50°53'30"N 05°29'53"E	1				3.5		0.4					0		
9	Demer	50°55'15"N 05°24'19"E	0.4				2.6		0							
10	Kaatsbeek	50°55'02"N 05°24'59"E	2						0							
11	Demer	50°56'46"N 05°18'31"E	0				3.5		0					0		
12	Stiemer	51°19'00"N 05°25'24"E	3						1							
13	Slangbeek	50°57'22"N 05°18'10"E	4						0							
14	Roosterbeek	50°59'39"N 05°24'04"E	60						51							
15	Roosterbeek	50°59'29"N 05°23'13"E	10.7						4							
16	Roosterbeek	50°59'29"N 05°23'13"E							18							
17	Demer	50°57'46"N 05°14'08"E	0				0.2		0							
18	Demer	50°58'04"N 05°09'49"E	4				0		0					0		
19	Mangelbeek	51°02'40"N 05°18'28"E	14						0							
20	Mangelbeek	51°01'39"N 05°18'27"E	113						2							
21	Mangelbeek	51°01'15"N 05°16'40"E	1						9.1							
22	Mangelbeek	50°59'36"N 05°12'51"E	1						4							
23	Laambeek	51°00'52"N 05°24'10"E	2						0							
24	Laambeek	51°00'47"N 05°23'11"E	1						0							
25	Laambeek	51°00'36"N 05°22'19"E	0						2.5							
26	Huttebeek	51°01'21"N 05°25'13"E	74													
27	Mangelbeek	51°00'10"N 05°14'02"E	7.5						4							
28	Echelbeek	51°01'56"N 05°21'00"E	1						0							
29	Echelbeek	51°00'51"N 05°19'19"E	0						1							
30	Zwartebeek	51°05'36"N 05°21'38"E									644					
31	Zwartebeek	51°05'35"N 05°19'56"E									73					
32	Zwartebeek	51°05'18"N 05°18'19"E							1		52					
33	Zwartebeek	51°04'55"N 05°16'58"E							0		25					
34	Zwartebeek	51°04'27"N 05°16'12"E							1		10					
35	Zwartebeek	51°03'48"N 05°14'41"E							2		0					
36	Zwartebeek	51°03'46"N 05°14'41"E									6					
37	Ziepbeek	50°55'52"N 05°38'39"E										8		9		
38	Ziepbeek	50°55'26"N 05°39'16"E	0					122		13		2		30		
39	Ziepbeek	50°55'24"N 05°42'20"E								5				0		

Annex 1 (continued).

Map ref. Fig. 4	Location	Latitude/ Longitude	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
40	Abeek	51°06'53"N 05°30'24"E				1		0								
41	Abeek	51°08'15"N 05°31'18"E				3						0				
42	Abeek	51°09'50"N 05°41'42"E				0	14	5	0			0				
43	Bullenbeek	51°05'20"N 05°30'49"E						1								
44	Gielisbeek	51°06'57"N 05°29'44"E				1		0				0				
45	Soerbeek	51°09'29"N 05°38'17"E				1		7				0				
46	Wijshager-beek	51°06'55"N 05°38'03"E		1				0								
47	Itterbeek	51°08'31"N 05°45'01"E		2			0	1	0				0			
48	Wijshager-beek	51°06'19"N 05°33'58"E		9				7								
49	Wijshager-beek	51°06'49"N 05°36'37"E		1					0				1			
50	Oude lossing	51°11'04"N 05°39'28"E		2					0					8		
51	Lossing	51°10'46"N 05°40'35"E		20												
52	Lossing	51°10'12"N 05°42'06"E		3					6					14		
53	Horstgater-beek	51°09'23"N 05°41'40"E		9					0					0		
54	Nieuwbeek	51°09'33"N 05°41'57"E		14					3					6		
55	Kleine fosse	51°14'57"N 05°19'56"E			1											
56	Kleine fosse	51°15'10"N 05°20'02"E			1											
57	Warmbeek	51°11'25"N 05°29'54"E				3		0				0				
58	Warmbeek	51°12'24"N 05°29'42"E				2		6				1.25				
59	Warmbeek	51°12'47"N 05°29'44"E				4										
60	Warmbeek	51°13'39"N 05°29'32"E				0						1				
61	Warmbeek	51°16'21"N 05°29'53"E				10	7	49.6	10			0				
62	Oude beek	51°16'15"N 05°29'23"E										1				
63	Oude beek	51°19'53"N 05°29'35"E				0		1				0				
64	Prinsenloop	51°17'03"N 05°27'54"E				2						0				
65	Dommel	51°10'22"N 05°26'13"E				0						7			0	0
66	Dommel	51°14'15"N 05°25'11"E				33										
67	Dommel	51°14'34"N 05°25'17"E													1.8	2.5
68	Dommel	51°15'36"N 05°25'15"E				6						0			0.5	0.5
69	Dommel	51°17'55"N 05°26'53"E													0	2
70	Dommel	51°20'10"N 05°26'42"E													9	1
71	Bolisenbeek	51°06'55"N 05°23'28"E										14				
72	Bolisenbeek	51°08'11"N 05°23'48"E				1		0				0				
73	Bolisenbeek	51°08'53"N 05°25'03"E				13						2				
74	Bolisenbeek	51°09'03"N 05°25'02"E										10				
75	Oude dommel	51°12'44"N 05°26'21"E				8						3.3				0
76	Larumse loop	51°11'29"N 04°55'34"E												3		