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Potential re-establishment of diadromous fish species in the River Scheldt (Belgium)

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Abstract This study (2002) documents on the inland penetration off diadromous fish species into the tidal and non-tidal part of the River Scheldt and on the impact of two lock-weir complexes. Long-term trends in oxic conditions show the river is undergoing a natural recovery process, nevertheless five of ten diadromous species recorded were still restricted to the brackish part of the estuary. Despite poor conditions, five species reached the upper freshwater part of the estuary. Erratic free-flowing conditions at the tidal weir offered limited opportunities for some diadromous species to migrate into the non-tidal part of the river. Upstream migration over the second barrier is almost completely blocked. Rehabilitation schemes to restore self-sustaining populations of diadromous fish in the cross-border River Scheldt need to include the building of fish bypasses and improved wastewater treatment and habitat restoration programmes.

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Fish and diadromy in Europe (ecology, management, conservation)

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The status of the 14 diadromous fish species in Flanders (northern part of Belgium) is critical according to the Red List of Vandelannoote & Coeck (1998), which is based upon the IUCN (1994) criteria. Eight species are extinct (European Atlantic sturgeon *Acipenser sturio* L., allis shad *Alosa alosa* L., twaite shad *Alosa fallax* Lacepède, European whitefish *Coregonus lavaretus* L., houting *Coregonus oxyrhynchus* L., sea lamprey *Petromyzon marinus* L., Atlantic salmon *Salmo salar* L., sea trout *Salmo trutta* L.), four are rare (i.e. river lamprey *Lampetra fluviatilis* L., smelt *Osmerus eperlanus* L., thin-lipped grey mullet *Liza ramada* Risso and flounder *Platichthys flesus* L.) and two species are currently considered not to be threatened (i.e. three-spined stickleback *Gasterosteus aculeatus* L. trachurus form and eel *Anguilla anguilla* L.). However the latter species is considered as "outside safe biological limits" (ICES, 1999) and it is planned by the European Union to decide on emergency steps to protect the eel in the autumn of 2006.

Estuaries provide a vital migratory route for different species. Blockage of this route through migration barriers or other environmental impacts, such as pollution, can prevent species to reach crucial habitats and therefore disrupt the completion of their life cycles. In several European countries all

diadromous species, except for the European eel, have become extinct as a result of habitat fragmentation (Lucas & Baras, 2001).

In the late 1970s symptoms such as temporal anoxia and organism death were common features in the upstream part of the River Scheldt (Soetaert et al., 2006). The start of water treatment programmes around this period, however, resulted in an improvement of the water quality (Soetaert & Herman, 1995) and as a consequence fisheries researchers gained interest in the brackish region. Maes et al. (1998a) recently caught six diadromous species in the brackish water part of the Scheldt estuary (i.e. eel, flounder, river lamprey, thin-lipped grey mullet, smelt and twaite shad, which was believed to be extinct).

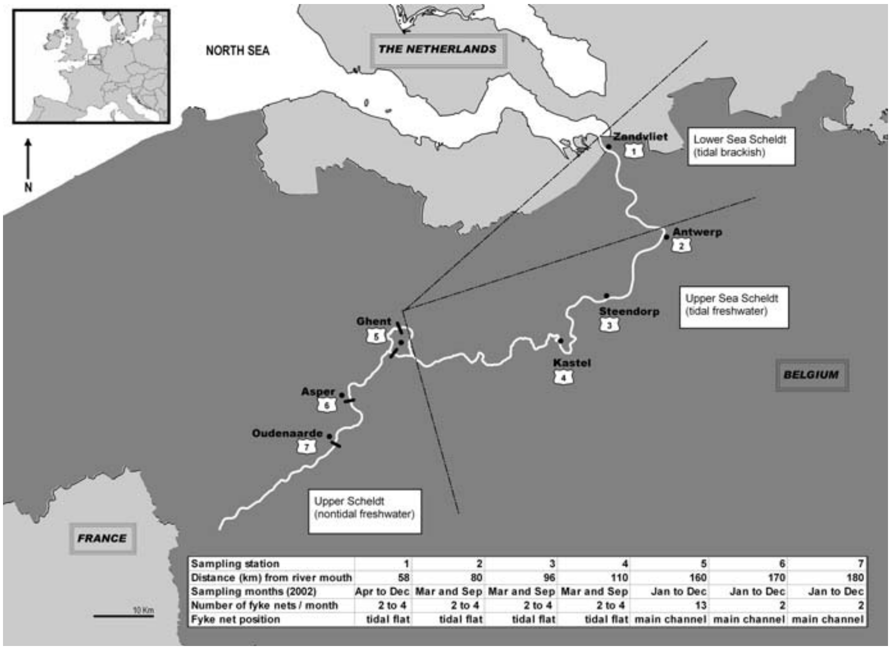
Up till recently the upper freshwater tidal zone has faced a lack of interest by fisheries researchers and is therefore poorly documented. In this article, we report on a year-round (2002) study and we illustrate how far upstream the diadromous species penetrate into the River Scheldt. Water quality and opportunities for diadromous species to negotiate the first two migration barriers are discussed.

The estuary of the river Scheldt extends from the mouth at Vlissingen (km 0—The Netherlands) to Ghent (km 160—Belgium), where the first river obstruction, a lock-weir complex, impairs the tidal wave in the Upper Scheldt (Fig. 1). It is one of the few remaining estuaries in Europe with an exceptional tidal freshwater area (Meire et al., 2005). The non-tidal part of the River Scheldt between the French–Belgian border and Ghent is strongly fragmented by weirs equipped with shipping locks (Asper—km 170, Oudenaarde—km 180,…).

Fish were sampled with fyke nets (i.e. double traps). Each trap had a length of 5 m with a mesh size of 8 mm in the latter part. Traps were emptied after approximately 24 h.

Detailed information on sampling is given in Fig. 1. One sampling point was situated in the brackish part while the other sampling points covered the entire freshwater part of the estuary. Since migrating fish accumulated in front of the weirs, two traps were set in the main channel right under the weirs of Ghent, Asper and Oudenaarde to assess the barrier effect of the first two complexes. Handling of the fish was restricted to a minimum. All fish were identified, measured, weighted and released. The three-spined stickleback trachurus forms were distinguished from other three-spined stickleback forms and river lampreys were sexed if possible.

The River Scheldt is a typical rain-fed lowland river with maximum discharge during winter months (maximum daily discharge recorded in the Upper Sea



Sampling station	1	2	3	4	5	6	7
Distance (km) from river mouth	58	80	96	110	160	170	180
Sampling months (2002)	Apr to Dec	Mar and Sep	Mar and Sep	Mar and Sep	Jan to Dec	Jan to Dec	Jan to Dec
Number of fyke nets / month	2 to 4	2 to 4	2 to 4	2 to 4	13	2	2
Fyke net position	tidal flat	tidal flat	tidal flat	tidal flat	main channel	main channel	main channel

Fig. 1 Sampled section of the River Scheldt (Belgium). From upstream to down-stream there are: the Upper Scheldt, the Upper Sea Scheldt (under the influence of dynamic tide) called tidal freshwater, and so on. Lock-weir complexes are located by ▌ and sampling sites by •. Map showing the estuary, non-tidal part and nomenclature of the River Scheldt, the location of the tidal lock-weir complex at km 160, consecutive lock-weir complexes at km 170 and 180 and all sampling points in the brackish (km 58), freshwater (km 80, 96, 110 and 160) and non-tidal part (km 170, 180) of the river

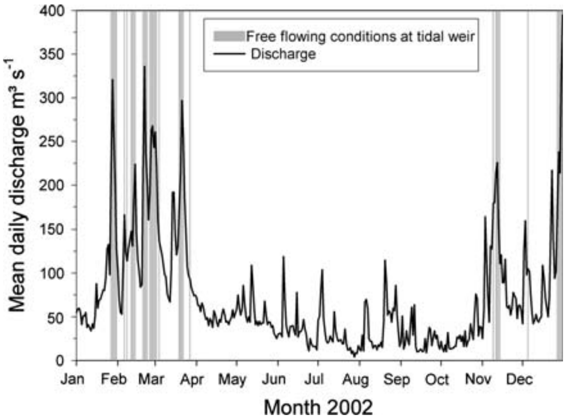


Fig. 2 Mean daily discharge ($m^3\ s^{-1}$) off the River Scheldt at Ghent in 2002 and days when free-flowing conditions occurred for at least 4 h a day at the tidal weir of Ghent indicated by |

Scheldt at Ghent: 395.2 $m^3\ s^{-1}$ in December) (Fig. 2). During events of heavy rainfall, when water from the Upper Scheldt Basin needs to be evacuated rapidly along the tidal weir (km 160), free-flowing conditions occur by lifting both weir-valves. In 2002, free-flowing conditions at the tidal weir occurred for at least 4 h a day during 33 days (Fig. 2). This suggests that in only 9% of the days during the year 2002 free-flowing conditions occurred, which is even an overestimation since the event of free-flowing conditions did not always last for the entire 24 h. These free-flowing conditions were only observed during November up to March. Free-flowing conditions never occurred at weirs at km 170 and 180 because of different management: a permanent water level difference (>2 m) up- and down-stream of these weirs is maintained in function of navigation. Fish passage is possible only via the shipping locks, but due to a lack of attraction flow fish passage through the shipping lock is accidental.

A total of 48 fish species was recorded. The number of diadromous species per 24-h per fyke net (N/24 h) recorded at up- and down-stream sampling points is given in Table 1. Most diadromous species ($n = 10$) were recorded at Zandvliet (km 58), five species, i.e. twaite shad, thin-lipped grey mullet, Atlantic salmon, sea trout and Siberian sturgeon were

Table 1 List of diadromous species caught at sampling points in the brackish (km 58) and freshwater (km 80, 96, 110 and 160) part of the Scheldt estuary and in the fragmented part of the River Scheldt at sampling points down-stream the second (km 170) and third (km 180) lock-weir complex between January and December 2002

Scientific name	Common name	Life cycle category	Zandvliet (km 58)	Antwerp (km 80)	Steendorp (km 96)	Kastel (km 110)	Ghent (km 160)	Asper (km 170)	Oudenaarde (km 180)
Acipenser baerii	Siberian sturgeon	A	<0.1						
Alosa fallax	Twaite shad	A	0.4						
Anguilla anguilla	Eel	C	0.1	1.3		1.5	2.4	4.5	2.4
Gasterosteus aculeatus[a]	Three-spined stickleback[a]	A[a] and F[a]	<0.1	0.5		0.3	1.1	9.2	6.0
Lampetra fluviatilis	River lamprey	A	<0.1				0.9	7.3	0.7
Liza ramada	Thin-lipped grey mullet	C	<0.1	0	0	0	0	0	0
Osmerus eperlanus	Smelt	A	0.2					<0.1	
Platichtys flesus	Flounder	FC	6.3	16.5	5.5		17.5		
Salmo salar	Atlantic salmon	A	<0.1						
Salmo trutta	Sea trout	A	<0.1						

Life cycle categories according to Thiel & Potter (2001) (F = freshwater, S = saltwater or marine straggler, C = catadromous, A = anadromous, O = marine estuarine opportunist) except for flounder (FC = facultative catadromous) and thin-lipped grey mullet (C = catadromous (Béguer et al. 2007)), and mean number per 24 h (N/24 h) based on the total catch are presented

[a] Mean number per 24 h for the three-spined sticklebacks trachurus (A), semi-armatus and leiurus (F) form are summed

limited to this down-stream sampling point. Exotic Siberian sturgeons are probably escaped fish farm individuals. At Antwerp (km 80), Steendorp (km 96) and Kastel (km 110) the recorded number of diadromous species was lower (respectively $n = 3$, $n = 1$ and $n = 2$) due to limited sampling efforts.

Investigation of the oxygen conditions between the mid-1960s and now show that the oxygen concentrations were always highly undersaturated in the riverine part (6–35% saturation) (Soetaert et al., 2006) although a slow improvement of the average oxygen saturation can be noted from the 1980s onward. In summer, oxygen concentrations often reach very low levels in the most upstream part (Herman & Heip, 1999). As observed during our sampling in September 2002 temporarily anoxic conditions at the upstream freshwater sampling points cause fish mortality. The absence of salmon, thin-lipped grey mullet, sea trout and twaite shad at upstream freshwater sampling points can be explained by the fact that until now the estuary is only frequented by straying individuals. Hypoxic events are probably the most important factor limiting opportunities for diadromous species to reach the upper estuary (Maes et al., 2005). Although Maes et al. (1998b) reported that these migrating fish still were restricted to the brackish environment, our results prove the recovery process is expanding towards the upper freshwater part of the estuary. Five diadromous species reached the most inner part of the estuary namely river lamprey, eel, flounder, smelt and three-spined stickleback trachurus form (Table 1). Since pollution does no longer seem to form a permanent migration barrier for at least a part of the diadromous fish population, they still have to negotiate the tidal lock-weir complex in Ghent (km 160) to reach the non-tidal part of the river. During high discharge and high tides, the tidal weir is completely lifted creating opportunities for upstream migrating fish to pass the free-flowing tidal weir (Fig. 2). Similar results were reported by Winter & Van Densen (2001) for non-salmonid fish to pass weirs in the River Vecht (The Netherlands). Peak abundances of river lamprey and three-spined stickleback trachurus form were recorded in February under the second weir at Asper (km 170). A small fraction of them was recorded under the third weir at Oudenaarde (km 180) from February to April. Chances of meeting a free-flowing tidal weir were highest in February. On the other hand chances to pass the non-tidal complex at Asper (km 170) were very limited. Due to the different management of this weir, free-flowing conditions were never reached. Upstream migration via the shipping lock was the only possibility to negotiate the complex. The few smelts were recorded in March only under the second weir. High numbers of upstream migrating young of the year (0+) flounder were recorded in June at sampling points down-stream of the tidal weir. The 0+ flounder resided in the inner part of the estuary until September. Chances for flounder to meet a free-flowing tidal weir from June until September were absent. Mainly from April to October eel appeared under the three consecutive weirs with peak abundances in June and August (mean size 337 mm) under the second weir. The higher catches of eel in front off the weirs during summer months are an indication of upstream dispersal attempts of eel. A study in the River Fremur (France) showed that high dams inhibited upstream eel migration and reduced recruitment by yellow eels. After eel passes were installed, fish became more abundant upstream. It was concluded that eel passes are important to conserve and/or to recover eel stocks (Laffaille et al., 2005).

The Mersey estuary (England) can be set as an example of how wastewater treatment programmes can remedy the poor oxygen conditions in estuaries and rivers. Until relatively recently the estuary had long anoxic reaches in the upper estuary during summer. Dissolved oxygen in the Mersey estuary is now generally above 60% saturation, with salmon now being found at the tidal-limit (Jones, 2006). In Flanders, the households connected to a purification plant increased from almost none in 1970 to 30% in 1990, then to 60% in 2002. It was estimated that the discharge of biochemical and chemical oxygen demand (BOD, COD), phosphorus (P) and nitrogen (N) were reduced with 28%, 51%, 60% and 60%, respectively, from 1994 to 2002 (Maeckelberghe, 2002). Due to the overall improved water quality the upper estuary and the non-tidal river have now re-established some of their importance as migratory route (flounder, eel, river lamprey, smelt, three-spined stickleback trachurus form) and/or as nursery area (flounder). Through wastewater treatment of Brussels from 2006 onwards (water treatment plants are under construction) a further and consistent

improvement of the water quality is expected (Van Damme et al., 2005). Next to pollution it is clear that the presence of consecutive lock-weir complexes on the River Scheldt also has a negative impact on the upstream migrating diadromous fish populations. Wastewater treatment programmes have to be extended over the whole catchment area of this cross-border river, fish passes need to be built at the tidal weir and in the non-tidal river part and present and future fish assemblages need to be monitored.

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