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Shifts in macrophyte species composition as a result of eutrophication and pollution in Dutch transboundary streams over the past decades

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Abstract

The catchment areas of transboundary streams in the Netherlands have been subject to increasing agricultural and industrial activities over the past decades. To evaluate the effects of these activities on the aquatic vegetation, a study has been carried out in 28 Dutch transboundary lowland streams. Recent data on distribution of 58 aquatic plant species and their growth forms were compared with historical data and were correlated with abiotic variables. Most of these streams lost species that are characteristic for streams and are sensitive to turbidity, eutrophication and pollution (e.g. *Potamogeton alpinus, P. polygonifolius, P. densus, Ranunculus peltatus ssp. heterophyllus, Callitriche stagnalis* and *Myriophyllum alterniflorum.*) Species, not common in streams but tolerant to turbidity, eutrophication or pollution (e.g. *Potamogeton trichoides, Elodea nuttallii*) appeared in many streams or increased in abundance. There was also a shift in growth forms: submerged species decreased or were replaced by emergent/floating-leaved species. Correspondence analysis was carried out to study the relation between the observed changes and the abiotic characteristic of the streams. The magnitude of the shift in species composition was positively correlated with the PO_4^{3-} concentration and pH (which was highly correlated with Cd^{2+}) of the water. This leads to the hypothesis that increased input of sewage, agricultural and industrial water causes a change in species composition and main growth forms of aquatic plant species in lowland streams.

1. Introduction

Most of the regional rivers and streams in the Netherlands are lowland streams (Hynes, 1975; Haslam, 1987). They are characterized as having fine sediments and a low velocity, creating a habitat for aquatic macrophytes and hence a diverse ecosystem. The ecological function of macrophytes is two-fold. As primary producers, they provide energy in the form of carbon compounds to the system. Furthermore, they act as a substrate and provide shelter for macrofauna organisms, fish and amphibian species (Gessner, 1955; Hynes, 1970; Haslam, 1978; Tolkamp, 1981).

Part of the Netherlands can be considered as the delta of the rivers Rhine, Meuse and Scheldt with their tributaries (regional streams). About 130 regional streams are transboundary and have their origin in Belgium or Germany. The total foreign catchment area of these streams is 9,400 km^2. They are of interest in solving eutrophication and pollution problems in the context of administration and legislation (Mesters, 1990).

Concentrations of most nutrients, metals and heavy metals in these transboundary streams are high. Their chemical composition appears to differ depending on the country of origin (Molenaar & Bleuten, 1992). Those, crossing the German-Dutch border, are mainly affected by agricultural activities. High nutrient levels are frequently encountered in these streams (Van Dijk *et al.*, 1992). Those crossing the Belgian-Dutch border are affected by agricultural activities but also by the discharge of unpurified sewage and (metallurgic) industrial wastes (Molenaar & Bleuten, 1992). In these streams, high levels of nutrients and high levels of heavy metals, especially Zn, Pb and Cd, occur.

The continued increase of agricultural and industrial activities leads to an ongoing release of nutrients, particulate organic matter and heavy metals. To evaluate the effect of these activities on the macrophytic vegetation in transboundary streams during the last two decades, a comparative study has been carried out in which species composition, growth form of the aquatic species and a series of abiotic parameters have been investigated in 28 transboundary streams.

The aim of this study was to answer the following questions:

- Has there been a change in aquatic plant species composition and in species abundances in the transboundary lowland streams over the last two decades?
- Has the distribution of growth forms (emergent, floating-leaved or submerged species) changed during this period?
- Is there a correlation between such vegetational changes and abiotic parameters (nutrient level, catchment area)?

2. Methods

2.1. *Data collection*

28 transboundary regional streams in the Netherlands were studied (Fig. 1). Sampling sites were located midway along the length of the stream. The locations were preferably at or close to the national border, in order to enable comparisons with measurements on abiotic parameters, collected by Molenaar & Bleuten (1992). Historical data on macrophytic composition for each of these streams were collected from literature and unpublished data. Field sampling was carried out between 1985 and 1991 at the same locations where the historical data had been collected. Locations, sampling years, and data on velocity and stream dimensions are given in Table 1.

At each location, relevés of variable size were made. This size depended on the stream dimensions. In general, a stretch of 20 to 50 m in length was studied. The width of each relevé equalled the stream width. In each relevé, the presence and abundance of each aquatic macrophytic plant species was recorded by visible observations from the water surface. Abundances were determined according to a modified Tansley scale for each species (1: sparse; 2: rare; 3: occasional; 4: locally frequent; 5: frequent; 6: locally abundant; 7: abundant; 8: codominant; 9: dominant).

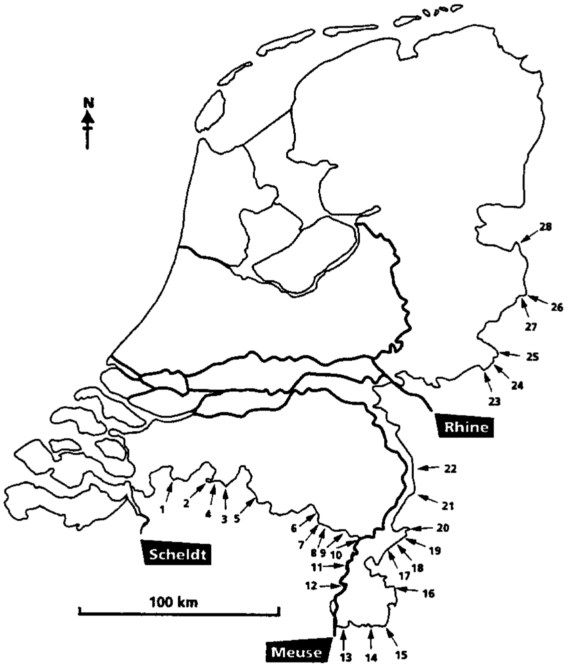

Fig. 1. Map of the Netherlands with the transboundary streams studied. Streams are numbered according to Table 1.

Taxonomic nomenclature followed Heukels & Van der Meijden (1983). If necessary, the indicator for abundance in the historical data was translated into the modified Tansley scale.

2.2. *Data analysis*

Shifts in species presence between the historical and the recent situation were grouped into three categories:

- occurring only in the recent situation (+)
- occurring in both periods (o)
- occurring only in the historical situation (−).

In addition, changes in average abundance per species were calculated by subtracting the abundance values for the historical period from those of the recent period.

Five types of growth forms were distinguished: three main types, emergent (E), floating-leaved (F) and submerged (S), and two intermediate types, emergent/floating-leaved (EF) and floating-leaved/submerged (FS). Species of the type 'EF' are emergent species in lentic waters, but can also be floating-leaved in

Table 1. List of the 28 streams studied. For each stream, sampling year, source of the historical and recent data and some additional information on average summer values of velocity, depth, width and channelization (chann) are given (missing data are indicated with '..'). Notes indicate the source-codes of the sampling years: 1. unpublished data of the 'Dutch Stream Research Group' (Beken Werkgroep Nederland, Achter Clarenburg 2, 3511 JJ Utrecht, The Netherlands); 2. unpublished data of H. W. J. van Dijk (Ariënsware 22, 8014 TE Zwolle, The Netherlands); 3. unpublished data of the Rijksherbarium Leiden, The Netherlands; 4. field data C. M. L. Mesters. Stream numbers are used in the other Tables and Figures

Stream		Data source		Additional information			
Nr	Name	Historical	Recent	Velocity$^{(m/s)}$	Depth$^{(m)}$	Width$^{(m)}$	Chann.$^{(y/n)}$
1	Weerijs	1980^1	1991^4	0.20	0.7	12	y
2	Hollandse loop	1978^1	1991^4	0.40	0.6	5	n
3	Strijbeekse beek	1975^1	1991^4	0.16	0.6	6	y
4	Merkske	1978^1	1991^4	0.17	0.4	3	n
5	Grote Beerze	1974^1	1991^4	0.30	0.6	6	y
6	Dommel	1946^3	1991^4	0.90	0.7	6	y
7	Tongelreep	1971^2	1991^4	0.20	0.3	5	y
8	Sterkselse Aa	1971^2	1991^4	0.20	0.3	3	n
9	Itterse beek	1970^2	1987^1	0.30	0.2	5	y
10	Uffelse beek	1970^2	1987^1	0.50	0.3	7	y
11	Rennebeek	1970^2	1987^1	0.00	0.3	3	y
12	Raambeek	1970^2	1987^1	0.10	0.2	3	y
13	Jeker	1936^3	1990^4	..	1.0	7	n
14	Gulp	1970^2	1985^1	..	0.2	4	n
15	Geul	1970^2	1989^1	0.90	0.6	6	n
16	Vlootbeek	1970^2	1988^1	0.05	0.6	6	y
17	Roode beek	1976^1	1990^4	0.05	0.5	3	n
18	Boschbeek	1976^1	1988^1	..	0.1	2	n
19	Maasnielderbeek	1970^2	1986^1	0.05	0.1	1	y
20	Swalm	1970^2	1990^4	0.80	0.6	6	n
21	Eckeltse beek	1971^2	1988^1	0.05	0.2	2	y
22	Kroonbeek	1971^2	1988^1	0.40	0.2	4	..
23	Slinge	1975^1	1990^4	..	0.6	8	n
24	Beurzerbeek	1976^1	1990^4	0.10	1.0	9	y
25	Berkel	1983^1	1990^4	..	2.0	14	y
26	Ruenbergerbeek	1972^1	1986^3	..	..	..	y
27	Dinkel	1972^1	1989^4	..	..	..	n
28	Puntbeek	1932^2	1986^3	..	..	..	y

streams (e.g., *Glyceria fluitans* and *Sparganium emersum*). Species of the type 'FS' have floating leaves but a considerable part of the shoot remains submerged (e.g. *Callitriche platycarpa* and *Luronium natans*). The changes in species composition were expressed as changes in species number per growth form for each stream.

To explain changes in the aquatic vegetation in the streams, correspondence analysis (CA, Ter Braak, 1985) was carried out. The assumption of this method is that the occurrence of all species in the sites studied is determined by a set of (unknown) environmental variables. CA constructs an ordination diagram in which the sites are ordinated based on their species composition only. As the species composition of each site represents a specific environmental condition, the orthogonal axes of the ordination diagram can be considered to be environmental axes that best explains the variation in species composition of the sites. Species abundances were logarithmically transformed to give less weight to dominant species. Since the environmental data are not directly incorporated in the analysis, the axes represent 'theoretical environmental variables' (Jongman *et al.*, 1987).

To identify the 'theoretical environmental variables' driving the first CA-axis, a Pearson correlation

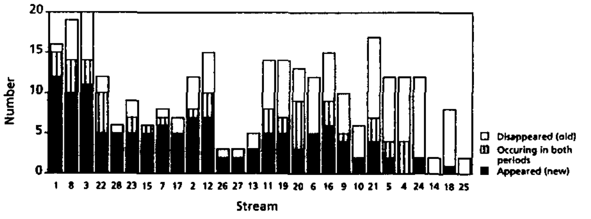

Fig. 2. Changes in species number per stream. Species are clustered in 'appeared species' (only found in recent years), 'disappeared species' (only found in historical years) and species 'occurring in both periods' (found in historical as well as in recent years). Streams are numbered according to Table 1 and are ordered from highest increase in species to highest decrease in species (see Table 3).

analysis was carried out (SAS Inc., 1985). For each site, the distance and the direction between the CA-value of the historical and of the recent data along the first ordination axis was calculated and correlated with the following abiotic variables (available for the recent situation only from Molenaar & Bleuten, 1992): catchment area, drainage, pH, conductivity (EC: μS/cm), O_2 (mg/l), NH_4^+ (mg/l), NO_3^- (mg/l), NO_2^- (mg/l), PO_4^{3-} (mg/l), Cd^{2+} (mg/l) and Cl^- (mg/l). Additionally, the correlation between the abiotic variables was tested (Table 4). As data on these parameters were not available for all streams, part of the differences found are discussed with literature data.

3. Results

There were no significant overall changes in average species number per stream (Table 2), nor were there any significant differences in species number between the streams crossing the Belgian-Dutch border and those crossing the German-Dutch border. In many individual streams, however, there were very strong shifts in the number of species (Fig. 2). An increase in species number was observed in nine streams, while a decrease in species number was observed in eight streams. In eleven streams, simultaneously many species disappeared and other species became established (Table 3). Thus, some streams showed drastic changes in species composition.

3.1. *Species*

Three species categories were distinguished according to their differences in distribution over the period studied (Fig. 3, Table 3).

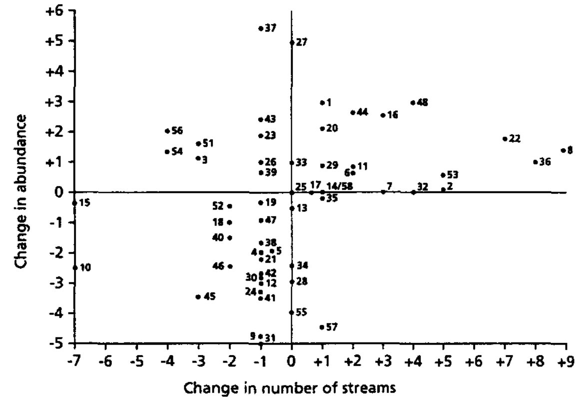

Fig. 3. Scatter diagram of the species plotting the changes in number of streams each species occurred in (horizontal axis) versus the change in abundance of the species (vertical axis) between the two periods. Species are numbered according to Table 2.

A considerable group of species ('I-species', e.g. *Elodea nuttallii, Potamogeton trichoides, Glyceria fluitans* and *Callitriche platycarpa*, upper part of Table 3) increased in presence and abundance. Most of these species were only found in the recent years, although some species (e.g. *Agrostis stolonifera, Rorippa amphibia, Callitriche hamulata*) were found both in the historical and in the recent situation. Their average abundance was always higher in the recent than in the historical situation (Fig. 3). Conditions for these species therefore seem to have improved during the period studied.

The second group of species ('ID-species', central part of Table 3, e.g. *Sparganium emersum* (emergent/floating-leaved), *Potamogeton natans* (floating-leaved), *Nitella flexilis* (submerged) and filamentous algae (floating)) increased in presence and abundance in many streams, but they decreased in presence and abundance in many other streams. However, when all streams were considered, they showed no net change in presence or abundance. The growth conditions for these species may have changed per stream, possibly related to stream management activities.

The third group of species ('D-species', lower part of Table 3) declined in presence and abundance or even disappeared from streams in which they used to grow in the historical situation. *Ranunculus peltatus, R. fluitans, Elodea canadensis, Alisma plantago-aquatica* and *Sagittaria sagittifolia* generally decreased in distribution, although in some streams they occurred in both periods. *Potamogeton alpinus, P. densus, P. polygonifolius, P. perfoliatus* and *Myriophyllum*

Table 2. Mean total species number, mean species number per border and mean percentage of species per type of growth form. Values presented are given as mean ±1 se. Different letters (given for the percentages) indicate a significantly different growth form composition in either the historical or the recent situation (Tukey a posteriori test after a two-way ANOVA; SAS Inc., 1985). The differences between the periods were calculated using a paired t-test (SAS Inc., 1985). Significant differences are indicated with * ($p < 0.05$) or n.s. (not significant)

	n	Species number		Difference
		Historical	Recent	
All streams	28	6.0 ± 0.70	6.5 ± 0.81	n.s.
Belgian-Dutch border	15	6.1 ± 0.90	7.5 ± 1.19	n.s.
German-Dutch border	13	5.8 ± 1.10	5.2 ± 0.98	n.s.
	n	**Percentage**		**Difference**
Growth forms		Historical	Recent	
Emergent	28	17.1 ± 4.6 b	18.2 ± 3.2 ab	n.s.
Emergent/floating-leaved	28	15.4 ± 3.0 b	26.2 ± 4.2 a	*
Floating-leaved	28	14.7 ± 4.0 b	16.2 ± 4.3 ab	n.s.
Floating-leaved/submerged	28	10.2 ± 2.3 b	8.8 ± 1.7 b	n.s.
Submerged	28	42.6 ± 5.9 a	23.2 ± 4.1 a	*

alterniflorum, however, totally disappeared. Except for *P. polygonifolius* these species are all submerged. For these species, decreasing in presence and abundance, the growth conditions apparently deteriorated during the period studied.

3.2. *Growth forms*

Generally speaking, a slight shift was observed from submerged towards floating-leaved and emergent species (Fig. 4). Two-way Analysis of Variance (ANOVA, Table 2) showed significant differences in growth form for each time period ($F = 10.48$ and $p = 0.0001$) and a significant interaction between growth form and period ($F = 3.94$ and $p = 0.004$).

In the historical situation, the percentage of species with submerged growth form (S) was significantly higher than that of all other growth forms ($p < 0.05$). In the recent situation, this difference only remained with floating-leaved submerged species. This was due to the percentage of submerged species (S) becoming significantly lower ($p = 0.024$) and, in contrast with this, the percentage of emergent/floating-leaved species (EF) becoming significantly higher in the recent period ($p = 0.047$).

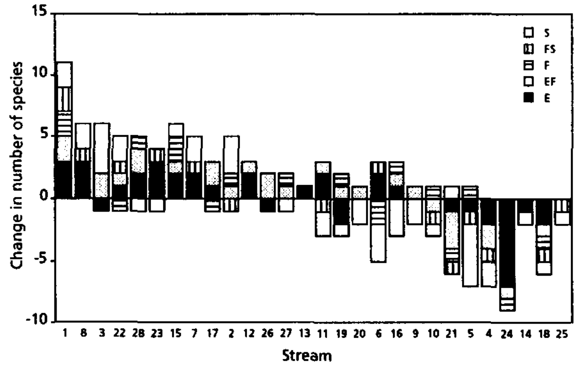

Fig. 4. Shift in number of species per growth form per stream: + = net increase, – = net decrease. E = emergent, F = floating-leaved, S = submerged, EF and FS are intermediate, for explanation see text. Streams are numbered according to Table 1.

3.3. *Correlation with abiotic variables*

The CA-analysis showed a limited variation within and between the streams; many of the streams were situated near the origin (Fig. 5). However, the magnitude of the shift along the first ordination axis was significantly negatively correlated with the area of the catchment upstream of the sample site ($R = 0.74$; $p = 0.0003$), pH ($R = -0.59$; $p = 0.0012$) and PO_4^{3-} concentration in the water ($R = 0.74$; $p = 0.0015$). The variables 'area' and PO_4^{3-} were strongly positively

Table 3. Survey of changes in species composition in the streams studied. Streams are ordered according to the changes that have been recorded. Species are grouped in the three categories: 'I-species' (species with net increase in presence and abundance), 'D-species' (species with net decrease in presence and abundance) and 'ID-species' (species with no net changes). The change of each individual species in the streams is indicated with: + (occurring only in the recent situation), − (occurring only in the historical situation) and 0 (occurring in both periods). Information is also given on the growth form of each species: E = emergent, F = floating-leaved, S = submerged, EF and FS are intermediate forms, for explanation see text

Species				Streams																											
				With more species									With equal number of species											With less species							
Nr	grfr	Name		1	8	3	22	28	23	15	7	17	2	12	26	27	13	11	19	20	6	16	9	10	21	5	4	24	14	18	25
'I-species'																															
8	FS	*Callitriche platycarpa*	Kütz.	+	+	+	+				+	+		+				−	+	0	+	0	+		0						
36	EF	*Phalaris arundinacea*	L.	+	0	+	0	+	+	+				+	+			+	+			+			−			−			
22	EF	*Glyceria fluitans*	(L.)R.Br.		−	+	0	+				+	+		+				0	+			+		+	0					
2	EF	*Agrostis stolonifera*	L.		+	0	+		−				0	+					+	+	+	+			−	+	0	−			
53	E	*Rorippa amphibia*	(L).Besser	+	+			+	+				+								+	+			−			−			
48	S	*Potamogeton trichoides*	Cham. et Schld.	+									+	+									+	+		−					
32	E	*Nasturtium microphyllum*	Rchb.	+		+				+				+																	
16	S	*Elodea nuttallii*	(Planch.)St.John	0	+									+							+		+			−					
6	S	*Callitriche hamulata*	Kütz. ex Koch	+	0	+	0						+	−						0			−		+						
11	E	*Cardamine pratensis*	L.				+											+				+						−			
7	FS	*Callitriche obtusangula*	Le Gall	+	+						+																				
44	S	*Potamogeton pectinatus*	L.	0							+				+																
1	E	*Alopecurus geniculatus*	L.															+													
58	E	*Veronica beccabunga*	L.							+							+														
17	E	*Equisetum arvense*	L.																			+									
14	E	*Eleocharis palustris*	L.															+													
35	F	*Nymphoides peltata*	(Gmel.)O.Kuntze																											+	
'ID-species'																															
20	S	*filamentous algae*			+	+	+			+			+	0		−	+	−	−	0		−			0	−	−	+			
29	E	*Myosotis laxa/palustris*	Lehm./L.		+			+	+		+		+	0					−	+		−				−		−	−		
39	S	*Polygonum hydropiper*	L.			−						+	−					+	+			+			−	−		−			
43	F	*Potamogeton natans*	L.		−	0		+				−									−			+		+				−	
23	E	*Glyceria maxima*	(Hartm.)Holmb.									+	−		−			0	+			0					−				
57	E	*Sparganium erectum*	L	+	+				+		+																−	−		−	
25	F	*Lemna gibba*	L.	+	0	+	−			+				−				0	0			0			−						
56	EF	*Sparganium emersum*	Rehm.	+	0		0		0		0	+		−		+			−	0	−	−	0	−	−	−	0	+		−	
33	S	*Nitella flexilis*				0	0												−						+						
28	E	*Mentha aquatica*	L.																						+			−			
55	S	*Scirpus fluitans*	L			+															−										
26	F	*Lemna minor*	L.	+		−	−																								
27	FS	*Luronium natans*	(L.)Raf.																							0					
13	S	*Eleocharis acicularis*	(L.)R. et Sch.		−	+																			0						
'D-species'																															
51	S	*Ranunculus fluitans*	L.							0							−			0	−		−								
54	EF	*Sagittaria sagittifolia*	L.											−		+		−		0			−	−			−				
3	E	*Alisma plantago-aquatica*	L.			+								+				−	−						−		−	−			
52	S	*Ranunculus peltatus* *spp heterophy* llus *Schrank*		+	+															−	−					−	−				
15	S	*Elodea canadensis*	Michx.		−		+		−									−		−	−	−	−				−				
10	FS	*Callitriche spp.*			−	−			+		−		−						−						−	−	0			−	
34	F	*Nuphar lutea*	(L.)Sm.	0	+	−			0				+																		−
19	E	*Equisetum palustre*	L.										−	0					−		+										
47	S	*Potamogeton pusillus*	L.			+												−						−							
41	S	*Potamogeton crispus*	L.								+											−								−	
18	E	*Equisetum fluviatile*	L.			−																						−			
40	S	*Potamogeton alpinus*	Balb.											−						−											
46	F	*Potamogeton polygonifolius*	Pourr.									−																		−	
45	S	*Potamogeton perfoliatus*	L.																				−	−	−						
37	E	*Phragmites australis*	(Cav)Trin. ex Steud.			−																					0				
42	S	*Potamogeton densus*	L.														−														
30	S	*Myriophyllum alterniflorum*	DC.					−																							
12	S	*Ceratophyllum demersum*	L.	−																											
24	S	*Juncus bulbosus*	L.																											−	
50	FS	*Ranunculus aquatilis*	L.																												
38	EF	*Polygonum amphibium*	L.																				−								
4	E	*Apium inundatum*	(L.)Rchb.f																			−									
5	E	*Apium nodiflorum*	(L.)Lag.																										−		
21	E	*Glyceria declinata*	Bréb.																											−	
9	F	*Callitriche stagnalis*	Scop.																	−											
31	S	*Myriophyllum spicatum*	L.															0													−

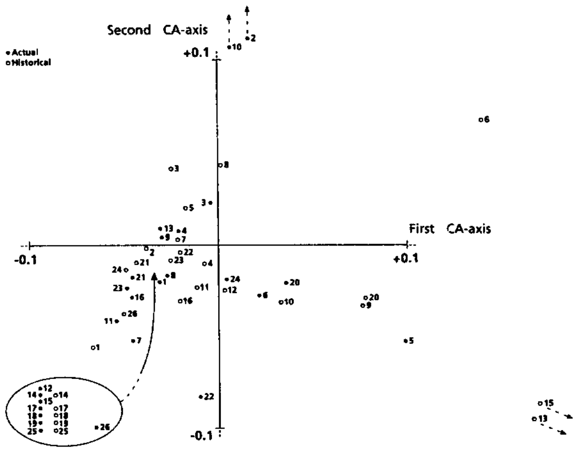

Fig. 5. Results of the correspondence analysis, showing actual and historical position of the streams along the first and second orthogonal CA-axes. Streams are numbered according to Table 1.

inter-correlated and, additionally, PO_4^{3-} was significantly positively correlated with NH_4^+, NO_3^- and discharge (Table 4). The variable pH was positively correlated with Cd^{2+}.

4. Discussion

Aquatic vegetation in Dutch transboundary streams has changed significantly over the past two or more decades. Not only has a shift in species composition occurred, but also a remarkable shift in growth forms of the aquatic plant species. Increased loads of sewage water, household waste water and agricultural run-off are the most probable causes of these shifts. They can result in eutrophication, sedimentation of organic matter, increased turbidity and accumulation of heavy metals. Eutrophication is expected to result in increasing species abundances and competition may then lead to dominance of few species. Sedimentated organic matter, heavy metals and turbidity are all expected to result in decreasing species number and abundances. Although the influences of these factors are difficult to separate with the data available, the following discussion section will be used to generate hypotheses on the separate effects of each factor.

4.1. *Eutrophication*

Eutrophication is often considered not to affect stream vegetation (e.g. Westlake, 1973). However, Spink (1992) concluded that a characteristic stream vegetation is best developed at low values of pH and PO_4^{3-} concentration in the water. The increase in presence of *C. platycarpa* and *P. trichoides* in German rivers in Lower Saxony during the last 40 years was attributed to eutrophication (Wiegleb *et al.*, 1991).

The increase in presence of *Callitriche platycarpa, C. obtusangula* and *Glyceria fluitans* in this study indicates an increased nutrient load (Haslam, 1978; Van den Dool & Bruinsma, 1991; Wiegleb *et al.*, 1991). Also the increase in presence of *Elodea nuttallii* and *Potamogeton trichoides*, species that normally do not occur in streams, suggests increased nutrient loads (Haslam, 1978; Wiegleb *et al.*, 1991). *Ranunculus peltatus ssp. heterophyllus*, a species that is sensitive to eutrophication (Spink, 1992) decreased in presence in many streams.

As natural streams are characterized by increased concentrations of nutrients in downstream direction (Dawson *et al.*, 1978) there is a natural gradient of nutrient concentrations. The input of sewage and agricultural run-off leads to an increased nutrient load in all stream zones. Thus, an increase in eutrophication, although also a positive agent for plant growth, will cause a loss of species that are characteristic for streams. Submerged species decrease in abundance and in presence, in favour of emergent species (Agami, 1984). The natural trophic gradients disappear, allowing a limited number of species to dominate the entire stream system.

4.2. *Organic material*

Another key factor in the functioning of stream systems is organic material. Sedimentation of this material on the stream bed may result in a higher sediment nutrient availability. Sedimentation on the plants will lead to increased shading.

Submerged aquatic plants promote the sedimentation of particulate organic material that is transported downstream, due to their dense growth form which reduces stream velocity (Dawson, 1981; Brookes, 1986). Sedimentation upon the plants may have been the crucial factor for the disappearance of *Elodea canadensis, Myriophyllum alterniflorum, Ranunculus aquatilis, R. peltatus* and *R. fluitans*, as these species all require clear water and easily trap sediment in their dense canopies (Dawson, 1981). Some emergent species, however, are favoured by a thick organic sediment layer. *Nasturtium microphyllum* and *Veronica beccabunga* may adjust their rooting levels during sedimentation (Brookes, 1986) to protect themselves

Table 4. Pearson correlation analysis (SAS Inc., 1985) of the present-day environmental variables (area = the upstream catchment area, EC (conductivity), pH, NH_4^+, NO_3^- and PO_4^{3-}, Cl^-, Cd^{2+} and discharge) with each other and with the change (relative value) of the value for each stream on the first CA-axis in the historical and in the recent situation. The results are expressed in the following parameters: Pearson correlation coefficient (*r*), probability (*p*) and number of observations (*n*)

		First CA-axis	Area	EC	pH	NH_4^+	NO_3^-	PO_4^{3-}	Cd^{2+}	Cl^-
Area	*r*	−0.74								
	p	0.0015								
	n	15								
EC	*r*	−0.43	0.48							
	p	0.10	0.07							
	n	15	15							
pH	*r*	−0.59	0.42	0.27						
	p	0.012	0.09	0.32						
	n	17	17	15						
NH_4^+	*r*	−0.23	0.32	0.14	−0.14					
	p	0.37	0.21	0.62	0.59					
	n	17	17	15	17					
NO_3^-	*r*	0.24	−0.08	0.34	−0.39	−0.25				
	p	0.39	0.79	0.22	0.15	0.38				
	n	15	15	15	15	15				
PO_4^{3-}	*r*	−0.74	0.63	0.34	0.46	0.56	0.67			
	p	0.0015	0.012	0.21	0.08	0.03	0.006			
	n	15	15	15	15	15	15			
Cd^{2+}	*r*	−0.53	0.31	0.004	0.57	−0.25	−0.40	0.19		
	p	0.07	0.33	0.99	0.05	0.44	0.19	0.56		
	n	12	12	12	12	12	12	12		
Cl^-	*r*	−0.16	0.34	0.64	0.04	−0.02	0.21	0.16	−0.22	
	p	0.53	0.18	0.01	0.89	0.94	0.46	0.57	0.49	
	n	17	17	15	17	17	15	15	12	
Discharge	*r*	−0.56	0.97	0.58	0.33	0.41	0.13	0.60	0.02	0.46
	p	0.07	0.0001	0.06	0.32	0.21	0.71	0.05	0.95	0.15
	n	11	11	11	11	11	11	11	9	11

from being smothered by deposited sediment. This way, they can optimally take advantage of the higher nutrient availability in sediments rich in organic material.

The differences in nutritional strategy between different growth forms (Denny, 1972) may also be responsible for shifts from submerged to emergent species as percentages of organic matter in the sediment of up to 20 percent enhance plant growth by a higher nutrient availability (Barko, 1983; Barko & Smart, 1983, 1986).

The natural gradient in lowland streams with respect to organic matter (low in up-stream zones, high in down-stream zones) will disappear under continuous extra input of particulate organic matter. Growth conditions for emergent species will probably improve in all stream zones.

4.3. *Heavy metals*

Particulate organic matter is also known to be an important carrier for heavy metals (Johnson & van

Hook, 1989). Although some metals (e.g. zinc) naturally occur in the stream system in very small amounts (Hutchinson, 1975), pollution from metallurgic industries increases the load of heavy metals to toxic levels. In some streams along the Belgian-Dutch border (e.g. Dommel, Tongelreep) cadmium and zinc are released and enter the streams with surface water (Molenaar & Bleuten, 1992). High concentrations of Cd may have played a major role in the deterioration of the stream vegetation in the Dutch transboundary streams.

Although heavy metals are toxic elements for many organisms (Schuster, 1979; Jana & Choudhuri, 1980; Guilizzoni, 1991) it is not clear if they play a significant role in the shift in plant species. Many plant species are able to accumulate enormous amounts of heavy metals (e..g *Phalaris arundinacea* (Abo-Rady, 1980)) without showing any growth response. Still, the decline of *Potamogeton perfoliatus* and of *S. sagittifolia* (Wiegleb *et al.*, 1991) may be an indication for heavy-metal pollution, as these species are sensitive to this environmental hazard (Barko & Smart, 1983; Greger & Kautsky, 1991).

4.4. *Turbidity*

The release of sewage and agricultural run-off results in an increased load of particulate organic matter, causing turbidity and thus reduced light availability in all stream zones.

The disappearance of many submerged species that require clear water (e.g. *Potamogeton polygonifolius, P. alpinus, P. densus, Ranunculus spp., Callitriche stagnalis* and *Myriophyllum alterniflorum*) is in accordance with an overall decreasing trend in streams in the Netherlands as well as in adjacent countries (Butcher, 1933; Haslam, 1978; Wiegleb, 1984; Mennema *et al.*, 1985; Van der Meijden *et al.*, 1989; Wiegleb *et al.*, 1991; Spink, 1992). The decline of these submerged species has been accompanied by an increase in emergent/floating-leaved species (e.g. *Glyceria fluitans*). These species do not depend on clear water as most of the plant parts are above the water level. The shift from submerged to emergent/floating-leaved species therefore may be attributed to turbidity.

4.5. *Cutting regime*

In addition, the current cutting regime may have favoured specific tolerant species. Rigorously removing the above-ground parts of the aquatic vegetation reduces the growth conditions of the stream-characteristic species. As a continuous high load of nutrients and organic matter causes a disruption of the stream gradient and a disappearance of microhabitats, the stream may be colonized by non-stream species (e.g. *Elodea nuttallii* and *Potamogeton trichoides*). Once established, they may be more tolerant to cutting than the stream-characteristic species. Especially *E. nuttallii* is known to have a high regeneration ability so that it can easily regrow from belowground parts after a vegetation cut (Van der Meijden *et al.*, 1989). Such very competitive species (Dawson *et al.*, 1978) compete with apparent success for light and microhabitats in the stream system. As these species are often firmly embedded in the stream sediment, removal of them will be difficult. Being highly competitive (Spink, 1992) they reduce the growth conditions for stream-characteristic species (e.g. *Ranunculus, Callitriche spp, Potamogeton natans*).

5. Synthesis and conclusion

A hypothetical process of deterioration of the natural diversity of stream vegetation caused by eutrophication, turbidity and pollution along a stream gradient is schematically summarized in four phases (A, B, C and D, Fig. 6).

An increase in eutrophication and turbidity will cause a loss of sensitive stream-characteristic species (phase A). Stream-characteristic species that are tolerant to these impacts will increase in abundance. Submerged species decrease in abundance and in presence, in favour of emergent species (Agami, 1984).

The cutting regime in streams may add to this process (phase B). Rigorously removing the above-ground parts of the aquatic vegetation reduces the growth conditions of the stream-characteristic species. A continuous high load of nutrients and organic matter causes a disruption of the stream gradient and a disappearance of microhabitats. This phase is characterized by a colonization of the stream by non-stream species. The stream vegetation will then consist of stream-characteristic and non-stream species. As the latter are often firmly embedded in the stream sediment it will be difficult to remove them from the stream. Being highly competitive species (Spink, 1992) they reduce the growth conditions for stream-characteristic species. This will result in phase C, in which only non-stream species occur in the stream. Ongoing eutrophication and pollution will result in phase D, in which the stream is almost devoid of plant species.

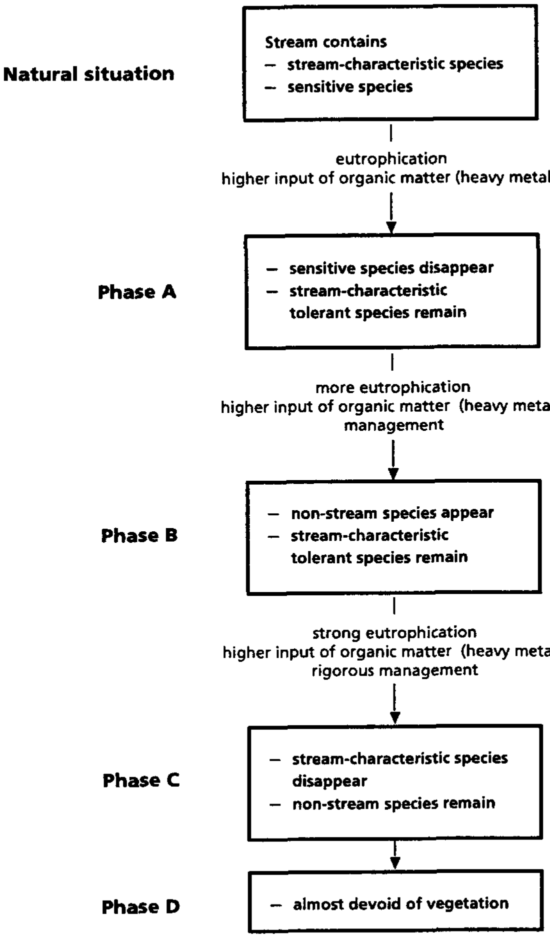

Fig. 6. Scheme of (human) influences and evolution of streams by increasing impacts.

It is not clear where to place the impact of heavy metals. It is suggested that they influence the stream vegetation in each phase, because of the toxic effects on biochemical processes in the plants (Jana & Choudhuri, 1980).

Most of the transboundary streams in this study can be categorized in phase B (e.g. Dommel, Itterse Beek and Weerijs) or phase C (Hollandse loop, Jeker and Uffelse beek). No streams can be categorized as 'natural' and few streams can be categorized in phase A (e.g. Geul and Swalm) or phase D (e.g. Boschbeek and Berkel).

The four phases are induced by different degrees of the same impact factors (sewage, agricultural and industrial wastewater). As the effects of these impact factors are strongly correlated, it is difficult to separate their relative importance. Further research is necessary to test this hypothetical scheme of deterioration.

It is, however, important to realize that the gradual increase of nutrients and organic matter along a stream gradient is a natural process, creating a zonation in stream vegetation. Human activities that increase the load of nutrients and organic matter will lead to uniform abiotic conditions in the whole stream system, reducing zonation and finally destroying the natural stream gradient.

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