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Changes in the composition of the plankton of the rivers Rhine and Meuse in the Netherlands during the last fifty-five years[1]

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With 5 figures and 5 tables in the text

Hydrography and chemistry

The river Rhine is in many aspects a life string of Western Europe. This is comparatively also the case with the river Meuse. The Rhine is a combined glacier- and rainfed river which makes the discharge more regular than that of a purely rainfed river such as the Meuse. The latter is a gated river, owing to the construction of seven stows build in the years between 1924 and 1936 in the Dutch region of the river, 19 gates are in Belgium and 59 in France.

The residence time of a water particle in the Rhine from the Bodensee until the border of the Netherlands numbers 12 days at average discharge and in Holland itself 2 days, making a total of two weeks. The residence time of a water particle in the river Meuse amounts to approximately three weeks until the Dutch border at average discharge and one week in the Netherlands itself, making a total of one month in the drainage basin. (pers. comm. Ir. J. W. van der Made).

Large population centers with heavy industry, agriculture, cattle-breeding and its aliniated industries are situated in both drainage basins. It is difficult to offer exact figures for the load in inhabitant equivalents over various years owing to the construction of the central sewage system, the use of water for industrial purpose and improved drainage for agriculture. In order to give an idea about the increase in pollutional load in recent years two figures are available: 38 × 10^6 i.e. in 1961 (Krul 1961) and 85 × 10^6 i.e. in 1972 (ten Berge) in the river Rhine. A similar increase might be expective in the river Meuse.

As one inhibitant equivalent of organic pollution requires 54 g oxygen per day (Imhoff 1969) for mineralization and as water in equilibrium with air at 20 °C will contain 8.5 g/m^3 of oxygen only, it will be realized that in this river the process of reaeration is severely taxed. A simple calculation goes to show that without reaeration from the atmosphere the water of the Rhine does not even contain half the oxygen needed for the mineralization of its pollutional load, except the oxygen production of the phytoplankton which is low depending on high turbidity values.

Discharge	pollut. load i. e.	Water quant. 1 i. e.
m^3/sec.		m^3/day
2200	85×10^6	$\frac{22\,00 \times 3600 \times 24}{85 \times 10} = 2.4$

oxygen in 1 m^3 20 °C. g/m^3	oxygen available in solution 1 i. e. g O_2/day	ox. consumption 1 i. e./day g O_2/day
8.5	$2.4 \times 8.5 = 20$	g 54

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[1] Delta Institute for Hydrobiological Research, Yerseke, the Netherlands, Communication nr. 120.

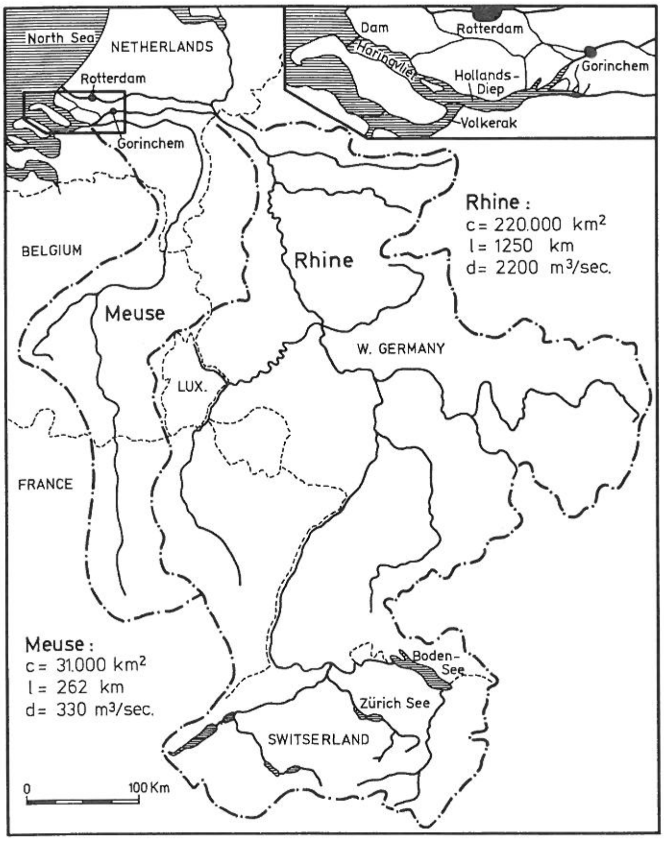

Fig. 1. Catchment area of the rivers Rhine and Meuse. c = catchment area, l = length, d = average discharge.

Actually reaeration increase the oxygen content at the Dutch border to values around 50 %. This makes the Rhine one of the most heavily loaded major rivers in the world. Autumn minima of 2.6 mg/l oxygen or 27 % saturation have been found.

The numerous gates in the Meuse approximately double the residence time of the water in this river and greatly enhance the reaeration. For these reasons saturation with oxygen here amounts to about 80 % on the average (Peelen 1974 b). When, however, in 1969 from 26th July till 2nd August the gates in the Netherlands were lowered in connection with reconstruction works, the river became free flowing again. This reduced the residence time and oxygen content went down as far as 1 mg/l or 12 % saturation. During that period some fish kills took place.

Next to destructable organic substances severe poisons are quite often dumped in the river, as for instance in 1969 when concentrations of 1 μg/l Endosulfan could be detected (Anonymus 1970). The number of chemicals of industrial origin dumped in both rivers enumerated to date has reached the hundred mark, many of them yet insufficiently identified (Sontheimer 1971). The lethal and sub-lethal action of these substances and their decomposition products together with possible synergetic actions between them in aquatic organisms is most insufficiently known.

Urbanization and industrilization also cause an increase of the nutrients. Although in 1916 no phosphate P could be detected in the water, in particular after 1962 a large

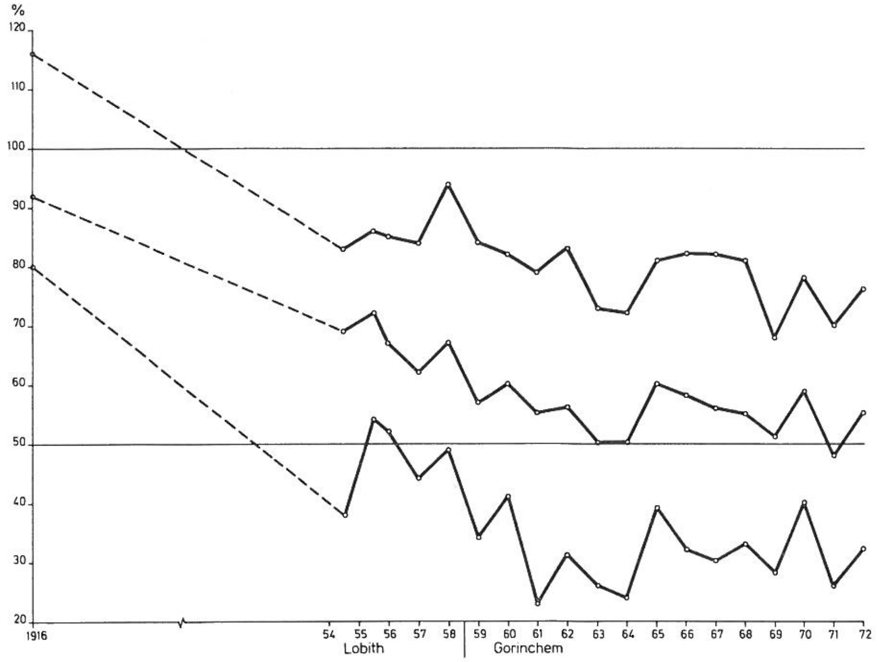

Fig. 2. Minimum, average and maximum oxygen saturation values of the Rhine water.

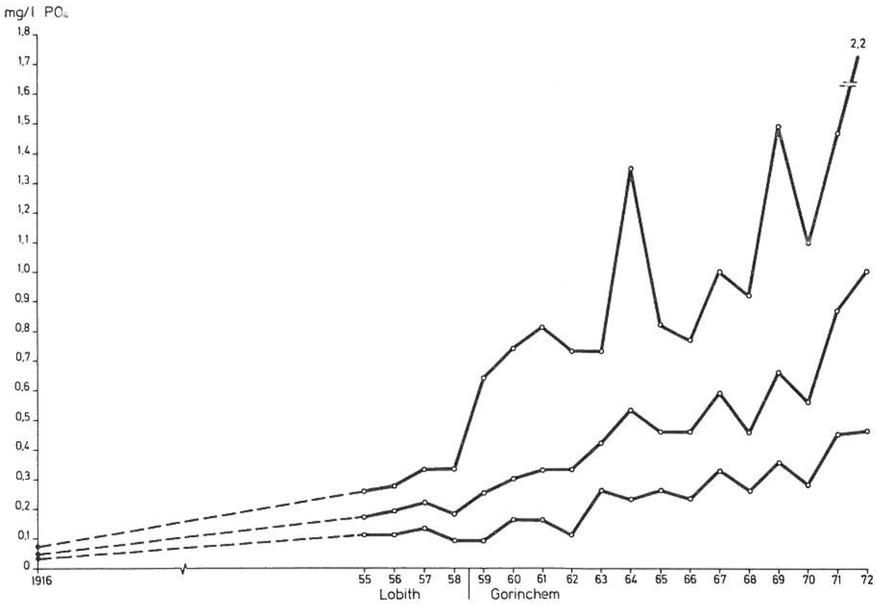

Fig. 3. Minimum, average and maximum PO_4''' content of the Rhine water.

increase took place. Afterwards the synthetic polyphosphate of the washing powders appeared on the scene and some times later the mechanized animal husbandry.

The N content of the Rhine water showed a drastic rise from 2.0 mg/l in 1916 (DE LINT) to 7.0 mg/l in 1971 (ANONYMUS 1956—1972).

The chloride content rose from an original value of 40 kg/sec (35 mg/l) in 1880 to more than 365 kg/sec (250 mg/l) in 1971. Potash mining in the Alsace area accounts for 36 % of this increase (TEN BERGE 1973). In summers with low discharge the limit of 300 mg/l Cl′ is surpassed during a certain period in the Netherlands and the Rhine water can no longer be classified as fresh water.

The nutrient contents of the Meuse are equal or a little lower than those of the river Rhine. Only the chloride content is practically always below 100 gm/l Cl′ (KOOLEN 1970).

The concentrations of heavy metals, pesticides and herbicides are nearly always a factor 2 to 6 lower than in the Rhine (ANONYMUS 1973).

It was the aim of the present study to check whether the composition and the saprobic grade of the plankton of both rivers changed under the influence of the increasing eutrophication in a qualitative and in a quantitative way during the course of 55 years.

Plankton

The plankton of the rivers Rhine and Meuse has been studied in the beginning of this century by LAUTERBORN (1910), MARSSON (1907—1910) and KOLKWITZ (1912). DE LINT (1916—17) carried out a research in the Netherlands on the river Lek, a branch of the river Rhine. WIBAUT-ISEBREE MOENS (1956) studied plankton in various branches of the Rhine in 1954—55 as part of the International Research Programme.

In the Netherlands ROMIJN was the first in 1918 to study the plankton of the Meuse. WIBAUT-ISEBREE MOENS (1956) carried out a similar programme and in 1966—67 the plankton of the Meuse river was investigated by the R.I.Z.A. (State Institute for Purification of Sewage, ANONYMUS 1971).

As part of the so called Delta Plan, which is the programme for the closing of most of the open sea arms in the S.-W. Netherlands, the Delta Institute for Hydrobiological Research was established in order to investigate the biological effects resulting from these works.

In the Spui, a branch of the river Rhine, a quantitative study was carried out on the river plankton from 1966—67.

In April 1969 the Volkerak branch was cut off from the sea. The Haringvliet arm was closed by a dam through the mouth of the estuary in November 1970, but a very much reduced tidal movement still remained owing to the fact that, via Spui, Dortse Kil and Nieuwe Merwede, there is still a limited indirect connection with the sea.

The plankton in this area was decribed by PEELEN 1974 a. In Tab. 1 details of studies of the plankton of both rivers are summarized.

In Tabs. 2 and 3 the plankton composition of the rivers Rhine and Meuse is shown. The principal components only are given.

It is seen in these tables that *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* were either absent or very rare at first, but became common later on. These species originate from the Bodensee (LEHN 1973), Zürich-See (THOMAS 1971) and other eutrophicated waters.

Tab. 1. Historical review of research on plankton in Rhine and Meuse.

River Rhine					
author	de Lint	Wibaut	Peelen 1	Peelen 2	Peelen 3
year	1916—17	1954—55	1967—68	1969—70	1971—72
method	net	nanno-net	nanno-net	nanno-net	nanno-net
determination	estimation	estimation	counting	counting	counting
average	2,610	2,010	2,710	2,750	1,500
discharge m^3/sec		normal discharge 2,200 m^3/sec.			
River Meuse					
author	Romijn	Wibaut	R.I.Z.A.	Peelen 2	Peelen 3
year	1918	1954—55	1966—67	1969—70	1971—72
method	net	nanno-net	net	nanno-net	nanno-net
determination	estimation	estimation	estimation	counting	counting
average	310	250	490	310	190
discharge m^3/sec		normal discharge 330 m^3/sec.			

In Tab. 4 all representatives of the plankton as observed by the various authors who studied the rivers between 1916 and 1972, have been classified according to the saprobic system as revised by Sládeček (1973).

From the data given in Tab. 4 the following conclusions can be drawn: 1) in both rivers no statistically significant differences can be found between the results of older and recent investigation. In spite of heavily increased pollutional loads of different origin, no shift towards a polysaprobic plankton community can be observed. 2) Comparing the sums of the numbers of species of each category found by the different authors for each of the two rivers, a significantly reliable difference is seen between them (one sided χ^2 test, level 5 %).

In the Meuse xeno- and oligo-saprobic organisms, originating in the non-polluted small tributaries are less well represented. They probably settle down between the gates, whereas both β- and α-mesoprobic organisms take a greater share in the structure of the planktonic community. In the fast flowing Rhine the entire diversified input from the catchment area is rapidly flushed towards the sea and the plankton community does not stand a good chance to develop and to give a good image of the water quality. In the more stagnant Meuse — owing to its numerous gates — the plankton can develop better and create a β-mesosaprobic community more in agreement with its environment.

In order to compare the saprobic grade of the plankton communities of both rivers an average saprobic value sensu Sládeček (1973) was calculated by adding the various values derived from his list and dividing the sum by the total numbers of organisms.

Analyses of variance proved that apparent differences between the averages found were not statistically significant. So between 1916 and 1972 both rivers did not shift in saprobic grade (Figs. 4, 5).

The question arises whether or not the obviously increasing eutrophication and pollution did cause the total number of plankton to rise.

Here the difficulty is that the work of older authors was carried out semi-quantitatively by means of estimates and we can only guess at the criteria used.

Tab. 2. Phytoplankton and zooplankton of the Rhine 1916—1973.

Species	Order-phyta	na/ne	sapr.	DE LINT	WIBAUT	PEELEN 1	PEELEN 2	PEELEN 3
Phytoplankton								
Actinastrum hantzschii	Chloro	na	β	+	+	+	cc	c
Ankistrodesmus falcatus	Chloro	na	β-α		+	+	+	+
Aphanizomenon flos-aquae	Cyano	na	β			r	c	+
Asterionella formosa	Bacillario	na	0-β	cc	cc	cc	cc	cc
Ceratium hirundinella	Pyrro	ne	0	r	c	r	rr	rr
Coelastrum microporum	Chloro	ne	β		+	+	r	r
Crucigenia minima	Chloro	na		r	+	+	c	r
Crucigenia tetrapedia	Chloro	na	0-β		r	+	+	r
Cryptomonas reflexa	Chloro	na	0-β			c	c	c
Cyclotella comta	Bacillario	na	0		c	c	c	c
Diatoma elongatum	Bacillario	na	β-0		c	c	c	c
Dictyosphaerium pulchellum	Chloro	na	β		r	r	r	c
Dinobryon sertularia	Chryso	ne	0	+	+			
Eudorina elegans	Chloro	na	β	c	c	r	rr	rr
Euglena acus	Eugleno	na	β	rr	+	r	r	+
Fragillaria crotonensis	Bacillario	ne	β-0	cc	cc	cc	cc	cc
Melosira granulata	Bacillario	na	β	c	c	c	cc	cc
Melosira moniliformis	Bacillario	na				cc	cc	cc
Melosira varians	Bacillario	na	β	+	c	c	c	c
Microcystis aeruginosa	Cyano	ne	β	rr	r	+	+	+
Oscillatoria agardhii	Cyano	na	β	c	c	r	r	r
Pandorina morum	Chloro	ne	β	rr	c	+	c	+
Pediastrum boryanum	Chloro	na	β	r	c	+	+	+
Pediastrum duplex	Chloro	ne	β	rr	r	c	c	cc
Phacus acuminatus	Eugleno	ne					c	c
Phacus longicauda	Eugleno	ne	β-α	rr	r	c	+	rr
Rhizosolenia	Bacillario	ne	ϰ		+	+	r	cc
Scenedesmus acuminatus	Chloro	na	β			c	c	c
Scenedesmus quadricauda	Chloro	na	β		+	c	cc	c
Stephanodiscus astrea	Bacillario	na	0-β	cc	c	c	cc	cc
Synedra acus	Bacillario	na	β	cc	c	c	c	c
Synedra ulna	Bacillario	na	β		c	c	c	c
Synura uvella	Chryso	ne	β	+	+			c
Staurastrum paradoxum	Chloro	ne				r	+	rr
Tabellaria fenestra var. *asterionelloïdes*	Bacillario	ne	0-β	cc	cc	cc	cc	cc
Westella botryoïdes	Chloro	na			c	c	cc	c
				estimation		counting		

Species	Order-phyta	na/ne	sapr.	DE LINT	WIEAUT	PEELEN 1	PEELEN 2	PEELEN 3
frequency	cc			5	3	4	9	8
species	c			3	13	13	12	13
	+			4	9	9	6	6
	r			3	5	7	5	4
	rr			5	—	—	2	3
Zooplankton								
Asplanchna priodonta	Rotatoria	ne	0-β	rr	c	c	c	c
Bosmina longirostris	Crustacea	ne	0-β	rr	r	rr	rr	+
Brachionus angularis	Rotatoria	ne	β-α	r	c	c	c	c
Brachionus bakeri	Rotatoria	ne		rr	c	+	+	c
Brachionus pala + *amphiceros*	Rotatoria	ne		c	c	cc	c	cc
Brachionus urceolaris	Rotatoria	ne	β	rr	c	c	c	c
Daphnia longispina	Crustacea	ne	β	rr	rr	rr	rr	r
Filinia passa	Rotatoria	ne	0	rr	c	c	c	c
Keratella cochlearis + *tecta*	Rotatoria	ne	0-β	c	c	c	c	c
Keratella quadrata	Rotatoria	ne	0-β		c	c	c	c
Notholca longispina	Rotatoria	ne			+	+	+	+
Polyarthra platyptera	Rotatoria	ne		rr	c	rr	r	c
Synchaeta pectinata	Rotatoria	ne	β-0		r	r	+	c
Vorticella spp.	Ciliata	ne			c	r	c	cc
Zoothamnium spp.	Ciliata	ne	α-β			c	c	c
				estimation		counting		
Nannoplankton:								
cc 100,000 cells/l								
c 100,000—25,000 cells/l								
+ 25,000—10,000 cells/l								
r 10,000—2,500 cells/l								
rr 2,500—1,000 cells/l								
detection limit 500 cells/l								
Netplankton 64 μ mesh								
cc 1,000 cells/l								
c 1,000—250 cells/l								
+ 250—100 cells/l								
r 100—25 cells/l								
rr 25 cells/l								
detection limit 5 cells/l								
frequency	cc			—	—	1	—	2
species	c			2	10	7	9	10
	+			—	1	2	3	2
	r			2	2	2	1	1
	rr			7	1	3	2	—

Tab. 3. Phytoplankton and zooplankton of the Meuse 1918—1973.

Species	Order-phyta	na/ne	sapr.	ROMIJN	WIBAUT	R. I. Z. A.	PEELEN 2	PEELEN 3
Phytoplankton								
Actinastrum hantzschii	Chloro	na	β	r	cc	c	cc	c
Ankistrodesmus falcatus	Chloro	na	β-α		cc	+	+	cc
Aphanizomenon flos-aquae	Cyano	na	β			rr	+	r
Asterionella formosa	Bacillario	na	0-β	+	cc	cc	cc	cc
Attheya zachariasi	Bacillario	na	β-0		c	rr	+	+
Coelastrum microporum	Chloro	na	β	rr	c	+	+	r
Crucigenia minima	Chloro	na		rr		cc	cc	c
Crucigenia rectangularis	Chloro	na	α-β	rr	+	rr	c	c
Crucigenia tetrapedia	Chloro	na	0-β		+	+	c	c
Cyclotella compta	Bacillario	na	0		cc	cc	cc	c
Cymatopleura solea	Bacillario	na	α-β	+	r	c	r	+
Diatoma elongatum	Bacillario	na	β-0	+	cc	c	c	cc
Diatoma vulgare	Bacillario	ne	β	+	r	+	+	+
Dictyosphaerium pulchellum	Chloro	na	β	rr	cc	rr	r	c
Dinobryon sertularia	Chloro	ne	0		cc			
Eudorina elegans	Chloro	na	β		+	rr	+	r
Euglena viridis	Eugleno	na	β-P		rr	r	r	r
Fragillaria cap. *construens*	Bacillario	na	β	+	c	rr	rr	rr
Fragillaria crotonensis	Bacillario	ne	β-0	+	+	c	c	c
Melosira granulata	Bacillario	na	β		cc	c	cc	cc
Melosira varians	Bacillario	na	β	r	+	cc	cc	cc
Micractinium pussillum	Chloro	na	β	rr	cc	+	rr	rr
Microcystis aeruginosa	Cyano	na	β		rr	rr	+	c
Nitzschia acicularis	Bacillario	na	α	cc	cc	rr	+	
Oscillatoria agardhii	Cyano	ne	β		r	+	+	+
Pandorina morum	Chloro	ne	β		+	r	rr	c
Pediastrum boryanum	Chloro	na	β	rr	+	c	+	c
Pediastrum duplex	Chloro	ne	β	rr	+	c	+	c
Pediastrum tetras	Chloro	na	β		c	r	+	+
Scenedesmus acuminatus	Chloro	na	β	r	c	cc	cc	cc
Scenedesmus quadricauda	Chloro	na	β	+	c	cc	cc	cc
Stephanodiscus astrea	Bacillario	na	0-β		rr	c	cc	cc
Stephanodiscus hantzschii	Bacillario	na	α	c	cc	c	cc	cc
Synedra acus	Bacillario	ne	β	r	cc	cc	cc	cc
Synedra ulna	Bacillario	ne	β	r	+	r	rr	rr
				estimation			counting	
frequency	cc			1	12	7	11	10
species	c			1	6	9	5	11

Species	Order-phyta	na/ne	sapr.	ROMIJN	WIBAUT	R. I. Z. A.	PEELEN 2	PEELEN 3
	+			7	9	6	12	5
	r			5	3	4	2	4
	rr			7	3	8	4	3
Zooplankton								
Anureopsis hypeplasma	Rotatoria	ne		+	+	rr		
Asplanchna priodonta	Rotatoria	ne	0-β		+	rr	+	c
Bosmina longirostris	Crustacea	ne	0-β		+	rr	+	c
Brachionus angularis	Rotatoria	ne	β-α	r	c	r	c	c
Brachionus pala + amphiceros	Rotatoria	ne			c	r	c	c
Brachionus quadricauda	Rotatoria	ne			+	rr	+	c
Brachionus urceolaris	Rotatoria	ne	β	+	+	rr	r	r
Daphnia longispina	Crustacea	ne	β	+			+	r
Filinia passa	Rotatoria	ne	0		+	rr	c	c
Keratella cochlcaris	Rotatoria	ne	β-0	+	cc	+	+	c
Keratella cochlearis + tecta	Rotatoria	ne	0-β		c	rr	r	c
Keratella quadrata	Rotatoria	ne	0-β		+	rr	c	c
Notholca acuminata	Rotatoria	ne	0		+	rr	+	r
Polyarthra platyptera	Rotatoria	ne			+	rr	+	c
Synchaeta pectinata	Rotatoria	ne	0-β	rr	+	rr	+	c
Tintinnidium fluviatile	Ciliata	ne	0-β		c	r	c	cc
Vorticella spp.	Ciliata	na			+	+	+	+
Zoothamnium spp.	Ciliata	ne	α-β		r	r	+	+
					estimation		counting	
Nannoplankton								
cc 100,000 cells/l								
c 100,000—25,000 cells/l								
+ 25,000—10,000 cells/l								
r 10,000—2,500 cells/l								
rr 2,500 cells/l								
detection limit 500 cells/l								
Netplankton 64 μ mesh								
cc 1,000 cells/l								
c 1,000—250 cells/l								
+ 250—100 cells/l								
r 100—25 cells/l								
rr 25 cells/l								
detection limit 5 cells/l								
frequency	cc			—	1	—	—	1
species	c			—	4	—	5	11
	+			4	11	2	10	2
	r			—	1	4	2	—
	rr			2	—	11	—	3

Tab. 4. Classification of the plankton of the rivers Rhine and Meuse according to the saprobic system.

River Rhine											
Author	de Lint		Wibaut		Peelen 1		Peelen 2		Peelen 3		total number of species
Saprobity	species	%	species	%	species	%	species	%	species	%	
xeno	3	3.5	2	2.0	1	2.3	1	1.8	1	1.6	8
oligo	24	28.3	24	24.8	11	25.6	15	26.8	16	25.8	90
β meso	47	55.3	61	62.9	27	62.8	34	60.7	38	61.3	207
α meso	7	8.2	9	9.3	3	7.0	5	8.9	7	11.3	31
poly	4	4.7	1	1.0	1	3.3	1	1.8	0	0	7

River Meuse											
Author	Romijn		Wibaut		R.I.Z.A.		Peelen 2		Peelen 3		
Saprobity	species	%	species	%	species	%	species	%	species	%	total
xeno	1	2.0	1	0.8	1	0.9	0	0	0	0	3
oligo	8	16.3	27	22.3	21	19.3	15	26.8	10	22.2	81
β meso	33	67.4	75	62.0	69	69.3	32	57.1	30	66.7	239
α meso	6	12.3	16	13.2	15	13.8	8	14.3	5	11.1	50
poly	1	2.0	2	1.7	3	2.7	1	1.8	0	0	7

Tab. 5. Mean saprobic value according to Sládeček.

	River Rhine					River Meuse			
author	phyto-plankton		zooplankton		author	phyto-plankton		zooplankton	
	$\sim s$	$s_{\bar{x}}$	$\sim s$	$s_{\bar{x}}$		$\sim s$	$s_{\bar{x}}$	$\sim s$	$s_{\bar{x}}$
de Lint	2.02	0.21	1.78	0.29	Romijn	2.07	0.21	1.94	0.18
Wibaut	1.87	0.06	1.78	0.23	Wibaut	1.94	0.06	1.73	0.11
Peelen 1	1.82	0.10	1.82	0.15	R.I.Z.A.	2.12	0.16	1.73	0.13
Peelen 2	1.80	0.10	1.72	0.16	Peelen 2	2.01	0.11	1.55	0.15
Peelen 3	1.86	0.10	1.78	0.13	Peelen 3	1.96	0.08	1.77	0.14

$\sim s$ mean saprobic value, $s_{\bar{x}}$ mean standard error.
n phytoplankton 30—50 species, n zooplankton about 10 species.

In the Tabs. 2 and 3 our counts were diverted into the classifications used by the older authors as indicated in the tables. In spite of the absence of figures directly comparable with ours, it is clearly seen that the plankton of both rivers was quantitatively less well developed when investigated by de Lint (Rhine 1916) and Romijn (Meuse 1918), than in recent years. According to Lauterborn (1939) numbers in the Rhine increased rapidly after about 1890. When Romijn studied the Meuse it was still a free flowing river as the gates were constructed around 1936 in the Netherlands. In this case increasing residence time will have exerted an influence equal to that of the increasing pollution and eutrophication.

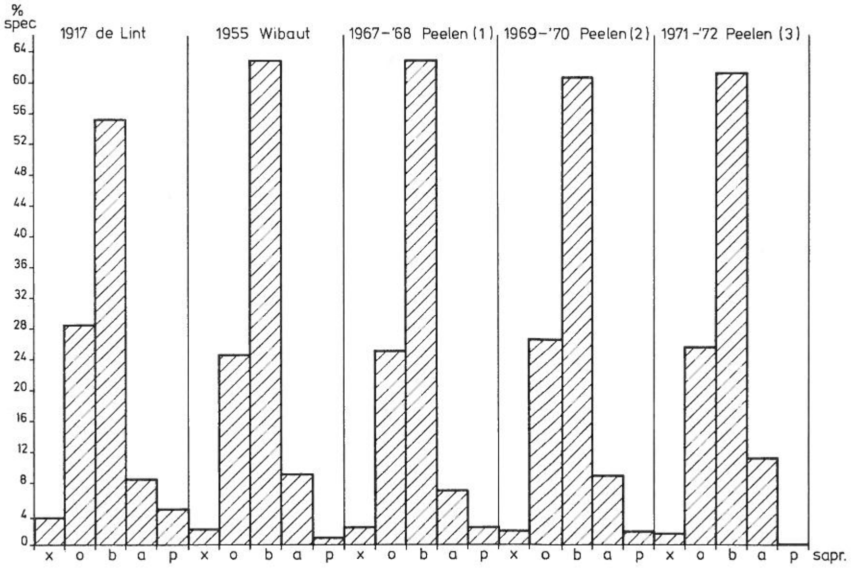

Fig. 4. Plankton composition in Rhine water according to the saprobic system of SLÁDEČEK (1973).

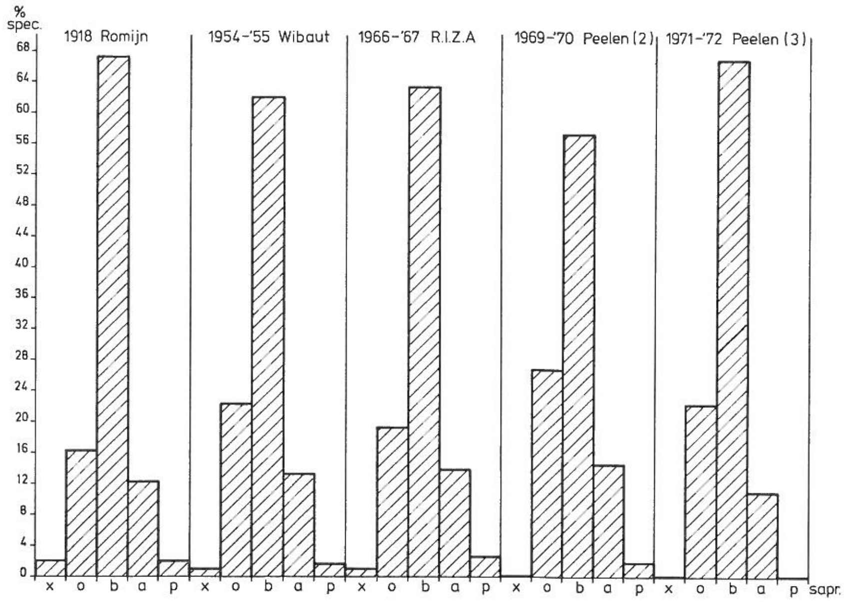

Fig. 5. Plankton composition in Meuse water according to the saprobic system of SLÁDEČEK (1973).

The closure of the mouth of the Haringvliet (Fig. 1) — the combined estuary of both rivers — in November 1970 severed the western-most estuarine part of them, known as the Hollands Diep — Haringvliet, from the sea and made it into a semi-stagnant waterbody.

In years previous to the closure the summit of the phytoplankton development in August reached values of about 500 cells/ml in the Rhine near Gorinchem and 1000 cells/ml in the Meuse at a similar distance from the coast. After the closure these figures rose to 1,500—8,000 cells/ml in the Rhine and 10,000—30,000 cells/ml in the Meuse, respetively. The zooplankton organisms rose from 300 animals/l in the Rhine and 600 animals/l in the Meuse before up to 6,000—20,000 animals/l in the Rhine and 3,000—8,000 animals/l in the Meuse after the closure of the Haringvliet, respectively.

The reason for these increases can be found in the reduced velocity of the current and therefore increase of residence time of the plankton in this part of the estuary. Moreover in the period after the closure the river discharge was rather small.

Conclusions

1) Substatial changes took place in the physico-chemical environment of the rivers Rhine and Meuse in the past fifty-five years.
2) Increased eutrophication of the backwaters of the Rhine, such as the Bodensee and the Zürich-See, brought β-mesosaprobic organisms such as *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* as far down stream as the part beyond the Dutch frontier. In the Meuse *Oscillatoria agardhii* is occasionally present.
3) No statistically significant change in the saprobic grade of the plankton of the Dutch parts of both rivers took place in the past fifty-five years. The new invading species belong to the same saprobic category — β-mesosaprobic — as the community as a whole.
4) Compared with 1916 an increase in total numbers took place. The closure of the Haringvliet — the estuarine end of both rivers — caused another increase in numbers, as the residence time of the plankters within this area was increased. The fact that the closure took place in a year of rather small river discharge enhanced this rise.

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Discussion

DICKMAN: It is noteworthy that the saprobic index did not appear to reflect the enormous change in the abundance of phytoplankton which you recorded over a ten-year period in both rivers. Would you care to comment on this?

PEELEN: The saprobic system only reflects the qualitative data not the quantitative ones. With the increase of the pollution the abundance of the plankton increases, too. With the increase of the nutrients the abundance increase of the last two years is depending on current reduction and a longer residence time of the water and the organisms.