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The state of the environment of the Loosdrecht lakes

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Abstract

The Loosdrecht lakes are a system of shallow, interconnected, peat lakes in the centre of The Netherlands. The main environmental functions of the Loosdrecht lakes are nature and recreation. From the point of view of the Dutch policy, a Specific Environmental Quality ('Bijzondere Milieukwaliteit') should be set for these lakes.

The most serious environmental problem of the area is eutrophication. The Loosdrecht lakes have, by increasing external phosphorus loading, changed, from clear lakes with few macrophytes, followed by a period of abundant characean growth, to turbid lakes dominated by cyanobacteria and detrital matter. Eutrophication was counteracted by use of sewerage systems and dephosporization of the supply water. The resultant decrease in external phosphorus loading did not result in a decrease of turbidity by suspended particles.

The eutrophication of the lake ecosystems was described as a series of phases. One of those phases, the status around 1940, has been used as an ecological reference system.

By means of a graphical presentation technique, the so-called 'AMOEBE-approach', the state of the environment of the Loosdrecht lakes has been visualized. Thirty-two ecological parameters, including both biotic and abiotic factors, have been selected and quantified. Concrete target values for these parameters have been derived from historical reports and from Lake Western Loenderveen, located close to the Loosdrecht lakes, but less eutrophic.

The general conclusion is that the state of the environment of the Loosdrecht lakes is far from what is required with respect to a Specific Environmental Quality, as many of the selected parameters, like water transparency, total phosphorus, mineral nitrogen, cyanobacteria, bream, pike, macrophytes, birds and otter, deviate by over an order of magnitude from their desired levels.

Introduction

The state of the environment of the Loosdrecht lakes is well-documented. This is especially true for the water quality. Data on this topic have been collected for about a century. Historical data have been reported by The Amsterdam Municipal Waterworks (Heymann, 1922; Van Heusden, 1942 and Geelen, 1955). From 1964 until present the water quality of the Loosdrecht lakes has been monitored by the Water Authorities of the Province of Utrecht (Province of Utrecht 1975, 1982 and 1989). Papers describing the former flora and fauna of the area are: Van Heusden (1942), Geelen (1955), Leentvaar & Mörzer Bruins (1962) and Prud'homme Van Reine & Van Der Meulen (1961).

In the last two decades the Loosdrecht lakes have become important topics of ecological research. The project 'Water Quality Research Loosdrecht lakes' (WQL), which has been undertaken from 1979 to 1991, was a research programme involving eight institutes (Loogman & Van Liere, 1986).

In this paper we describe the lakes' morphology and present information on their creation, hydrology and history of eutrophication. The present environmental state is compared to a chosen, former, mesotrophic phase. We make use of the so-called 'AMOEBE-approach', a graphical presentation technique which has been developed by Ten Brink & Hosper (1989) for The Dutch Water Management Plant (Ministry of Traffic and Public Works, 1989). AMOEBE means 'General method for ecological assessment' (Algemene Methode voor Oecologische BEoordeling) and was devised for policy makers and environmental management authorities.

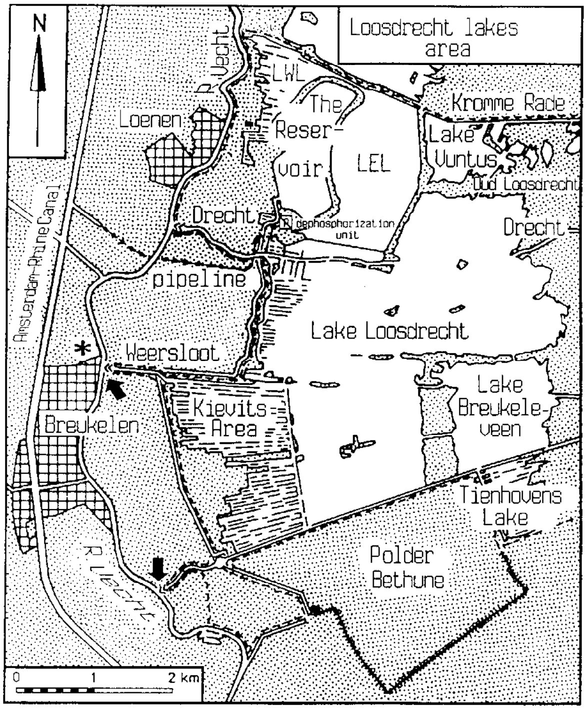

Fig. 1. A map of the Loosdrecht lakes area. Arrows indicate the sluices used to supply water from the R. Vecht to the lakes. L. Eastern Loenderveen (LEL), L. Eastern Loenderveen (LEL) and The Reservoir are hydrologically separated from the Loosdrecht lakes' system.

Description of the lakes

General

The Loosdrecht lakes (Fig. 1), a system of shallow, interconnected lakes, are typical of Dutch peat lakes. They lie in the centre of the Netherlands in the Province of Utrecht in an area of *Sphagnum* peatland. The Loosdrecht lakes (Lake Loosdrecht, Lake Breukeleveen, Lake Vuntus and Kievits Area) are bordered by the River Vecht to the west, Lake Eastern Loenderveen (LEL) to the north, the Pleistocene, ice-pushed sand ridge 't Gooi to the east and Polder Bethune and Tienhoven lakes to the south. The total water area of the lakes is 14.5 km^2, including the Kievits Area. The mean depth is 1.85 m and the total water volume is 20.10^6 m^3. The catchment area is 44 km^2, including Lake Western Loenderveen (LWL), the Reservoir and Lake Eastern Loenderveen. The hydraulic retention time of the Loosdrecht lakes is about six months. More detailed information on the morphometry and topography of the Loosdrecht lakes has been reported by Gulati *et al.* (1991) and Van Liere *et al.* (1991).

Creation of the lakes

The Loosdrecht lakes originated from human activities. In medieval times the land was drained for agricultural purposes. In 1633, so-called 'industrial peatmining' was started. The peat was dredged from underneath the watersurface and left to dry on adjacent banks. In this way an area with cuts ('trekgaten') and banks ('legakkers'), was formed. As the peatmining continued, the banks got smaller and subsequent wind and wave action eroded the banks. A system of shallow, interconnected lakes originated. The pattern of cuts and banks has been preserved in certain parts of the lakes, especially in the Kievits Area, which was mined at the end of the 19th century. At this time the Loosdrecht lakes had already attained their present morphometry (Van Liere *et al.*, 1991). More details on the creation of the lakes have been reported by Gulati *et al.* (1991).

Hydrology

For about 150 years the hydrology of the Loosdrecht lakes has been largely controlled by technical operations (Engelen, 1986). Halfway through the 19th century several polders, including Polder Bethune, were reclaimed. Consequently groundwater, which initially percolated into the lakes, seeped for the greater part to the lower lying polders. To maintain water levels during dry spells in summer, water from the River Vecht was pumped into the lakes.

In 1932 the Amsterdam Municipal Waterworks started to use water from the Polder Bethune for drinking water supply. Water from the Polder Bethune was pumped into Lake Loosdrecht and then to L. Loenderveen, and from there through a pipeline to Amsterdam. Since 1959 most of the water from Polder Bethune has flowed through a separate canal directly into a deepened part of Lake Loenderveen, called the 'Reservoir' (Fig. 1). The water let into the Reservoir is dephosphorized. The remaining water from Polder Bethune has flowed untreated into the Loosdrecht lakes.

The exploitation of water from Polder Bethune, and the withdrawal of groundwater of 'Het Gooi', resulted in the requirement for the continued inlet of allochthonous water to the Loosdrecht lakes. Until 1984 the River Vecht, which was highly polluted with organic waste and nutrients from the city of Utrecht, remained the main source of supplemental supply. In 1984 the inlet of water from the River Vecht was replaced by inlet of dephosphorized water from the Amsterdam-Rhine Canal.

The environmental problems of the area

The main environmental problems of the Loosdrecht lakes are eutrophication as a result of the high external phosphorus loading in past decades, accumulation of heavy metals, especially cadmium, in the sediments (Kühnel, 1985), the destruction of banks by erosion in the 18th and 19th centuries and the disturbance of the fauna by recreation and habitation over the second half of the 20th century. Eutrophication research has been the major focus of the Water Quality Research Loosdrecht lakes programme (WQL) and is well-documented (Van Liere, 1992). This paper mainly focusses on the eutrophication of the lakes but comments on some aspects of other environmental problems are also made.

Eutrophication

Due to a prolonged external nutrient loading in this century the Loosdrecht lakes have become eutrophic. Important sources of external nutrients, especially phosphorus, have been the supply of water from the R. Vecht, the discharge of untreated sewage from surrounding villages, run-off from the eastern hinterland and recreation.

Until 1944 the external phosphorus loading was estimated to be 0.6 g P m^{-2} y^{-1} (Gulati *et al.*, 1991). Between 1944 and 1984 the mean external phosphorus loading was about 1.0 g P m^{-2} y^{-1}. In 1976, an extremely dry year, the external phosphorus loading was as high as 4.0 g P m^{-2} y^{-1}. Due to measures taken by The Amsterdam Municipal Waterworks and The Water Authorities of the Province of Utrecht the external phosphorus load has been reduced to 0.35 g P m^{-2} y^{-1} since 1984. These measures included the sewering of surrounding villages between 1970 and 1986 (sewage is now transported to purification plants outside the lake area) and replacement of the inlet of highly polluted water from the R. Vecht by the inlet of dephosphorized water from the Amsterdam-Rhine Canal in 1984.

The high and prolonged external nutrient loading has had dramatic consequences for the environment of the Loosdrecht lakes. In about 50 years the Loosdrecht lakes have changed from oligotrophic ecosystems, with a clearly visible bottom, into highly eutrophic ones, with low transparency (Secchi-disc depth <0.4 m). The course of eutrophication of the Loosdrecht lakes is described below as a series of phases. A similar approach has been used by Moss (1989) to describe the eutrophication of the Norfolk Broads (UK). Although the exact distinction of the phases is arbitrary, Moss' concept (1989) is supported by other studies (Van Liere *et al.*, 1991; Janse & Aldenberg, 1990; Scheffer, 1989 and Gulati *et al.*, 1991).

Phase 1
Time span: 1800–1920
Characterization: strongly nutrient limited (oligotrophic)

Clear water (Heymann, 1922); a virtual absence of submerged waterplants (Best *et al.*, 1984); a estimated fish population biomass of about 50 kg ha^{-1} (Lammens, pers. comm.);

Phase 2
Time span: 1930–1955
Characterization: nutrient limited; domination by submerged macrophytes (mesotrophic)

Clear water (Van Heusden, 1942); well-developed submerged vegetation of *Characeae* (open water) and *Potamogetanaceae* (periphery) (Van Heusden, 1942); a relatively large amount of zooplankton compared to phytoplankton (Geelen, 1955); a well-developed population of zebra mussels (*Dreissena polymorpha*) (Leentvaar & Mörzer Bruijns, 1962); a large population of hibernating waterbirds, especially pochards (*Anthya ferina*), tufted ducks (*Anthya fuligula*) and coots (*Fulica atra*) (Leentvaar & Mörzer Bruijns, 1962); a resident population of otters (*Lutra lutra*) (Creutzberg *et al.*, 1969); an estimated fish biomass of about 250 kg ha^{-1}, the dominant species being pike (*Esox lucius*, 45 kg ha^{-1}) and bream (*Abramis brama*, 50 kg ha^{-1}) (Lammens, pers. comm.); annual average concentrations of chlorophyll *a* about 25 $\mu g\,l^{-1}$ (Geelen, 1955; CUWVO, 1988; Hofstra, 1990) and total phosphorus about 5.5 $\mu g\,P\,l^{-1}$ (Van Liere *et al.*, 1991); a mineral nitrogen concentration of about 17 $\mu mol\,l^{-1}$ (summer average) (Van Liere *et al.*, 1991);

In Lake Breukeleveen Phase 2 was followed by a period of abundant growth of tall, submerged, floating and emergent macrophytes, especially *Potamogetonaceae* (Prud'homme Van Reine & Van Der Meulen, 1961). This period lasted from 1955 to 1965.

Phase 3
Time span: 1960–1980
Characterization: nutrient limited; cyanobacteria domination (eutrophic)

No waterplants submerged (Best *et al.*, 1984); dense cyanobacterial growth, limited in its growth by light-energy, the dominant species being *Oscillatoria redekei*, *Oscillatoria limnetica* and possibly the recently discovered prochlorophyte *Prochlorothrix hollandica* (Van Liere *et al.*, 1991); a large population of small zooplankters (Gulati, 1984); no fresh water mussels; no otters, few hibernating waterbirds (Morel, 1989; Hofstra, 1990); a fish biomass of about 300 kg ha^{-1}, dominated by bream (180 kg ha^{-1}) and pike-perch (*Stizostedion lucioperca*, 40 kg ha^{-1}) (Lammens, pers. comm.); annual average concentrations of chlorophyll *a* about 100 $\mu g\,l^{-1}$ and total phosphorus about 100 $\mu g\,P\,l^{-1}$; a mineral nitrogen concentration of about 60 $\mu mol\,l^{-1}$ (summer average) (Van Liere *et al.*, 1991);

Phase 4
Time span: 1980–present
Characterization: high internal phosphorus loading rate; detritus domination (eutrophic)

Like Phase 3 but seston (<150 μm) is now dominated (50–75 per cent) by detritus (Van Liere *et al.*, 1991).

Phase 4 is at present a stable state of the lakes. Measures that have been taken to reduce the external phosphorus loading rate to the Loosdrecht lakes have resulted in only a small decline of total phosphorus concentration since 1984. The ecosystem is apparently well-buffered against changes in external nutrient supply, due to high internal nutrient loading rates (Van Liere & Janse, 1992).

Accumulation of heavy metals in the Loosdrecht Lakes

The main sources of heavy metals to the Loosdrecht lakes are the inlet of allochthonous water (carrying polluted sediment), atmospheric deposition, agricultural effluents and local emissions (Kühnel, 1985). The inlet of water from the R. Vecht caused peak concentrations of heavy metals in the sediments in the Kievits Area and in the southern part of Lake Loosdrecht (Table 1). The average concentration of heavy metals in the sediment of the Loosdrecht lakes as a whole is lower. Between 1979 and 1984 the cadmium concentration in the sediment of the Loosdrecht lakes has increased sharply (Kühnel, 1985).

Destruction of banks

Topographical maps show that most residual banks, the strips of land that remained after the industrial peatmining, have disappeared. The destruction of the banks as well as eutrophication has contributed to the present amount of detritus in the Loosdrecht lakes. On windy days significant amounts of detritus are resuspended lowering the transparency of the water. The finer fraction of detritus, which consists merely of remnants of algae, may remain suspended for days or even weeks (Gons & Van Keulen, 1989).

Table 1. Concentrations (mg kg^{-1}) of cadmium, zinc and lead in the sediments of the Loosdrecht lakes (spatial average of six stations) and Kievits Area (spatial average of six stations) (Kühnel, 1985), estimated background concentrations (Hofstra, 1990), and General Environmental Quality (GEQ) target values for fresh water systems from the Dutch Water Management Plan (Ministry of Traffic and Public Works, 1989à.

	Cadmium	Zinc	Lead
Loosdrecht lakes	6.3	17	90
Kievits area	17.5	928	168
Background (reference value)	0.3	100	30
Objective (GEQ)	2	480	530

Disturbance of the fauna by recreation and habitation

Since World War II the Loosdrecht lakes area has become increasingly populated. Recreation in the area is still on the increase. In recent decades yachting harbours, camping sites and holiday cottages have been constructed.

A decline in the breeding populations of Sedge Warbler (*Acrocephalus schoenobaenus*), Bittern (*Botaurus stellaris*), Little Bittern (*Ixobrychus minutus*), Night Heron (*Nycticorax nycticorax*) and Purple Heron (*Ardea purpurea*) and the extinction of the otter (*Lutra lutra*) may be partially attributed to disturbance (Morel, 1989; Creutzberg *et al.*, 1969). However, a study by Reijnen (1988) on the environmental aspects of water recreation demonstrated that quantified dose-effect relationships are not yet available.

Policy aims and ecological target values for fresh waters in The Netherlands

A 'General Environmental Quality' (GEQ; 'Algemene Milieukwaliteit') is the policy objective for all ecosystems in The Netherlands, both terrestrial and aquatic. GEQ guarantees 'health and maintenance of plants, animals, goods and forms of use' (Ministry of Housing, Physical Planning & Environmental Protection, 1985). In some areas a 'Specific Environmental Quality' (SEQ; 'Bijzondere Milieukwaliteit') is required, corresponding to specific functions, such as nature, drinking water supply, recreation or fisheries The Water Authorities of the Province of Utrecht have assigned the following functions to the Loosdrecht lakes: nature (Loosdrecht lakes), drinking water supply (Polder Bethune and Lake Loenderveen) and recreation (Loosdrecht lakes). Therefore a SEQ seems appropriate for the area.

Ecological target values for the Loosdrecht lakes

Ecological target values for various freshwater types, including shallow lakes, matching to SEQ target values, have been drafted by a workgroup 'CUWVO' (1988). The CUWVO target values, however, should merely be regarded as general guidelines and not as operational tools for environmental quality assessment (Kroes, 1987). So far, concrete and verifiable ecological target values, for both biotic and abiotic parameters, have been set only for a few Dutch aquatic ecosystems. The Loosdrecht lakes, unfortunately, do not belong to them. To assess the state of the environment of the Loosdrecht lakes operational ecological target values have first to be set.

Lakes originating as a result of peatmining and receiving seepage water could have clear, nutrient-poor water with corresponding plant and animal communities (CUWVO, 1988). Therefore Phase 2 above, corresponding to the situation around 1940 and being a well-documented period in the ecological history of the Loosdrecht lakes, has been chosen as a 'frame of reference'. Target values for 32 ecological parameters that prevailed during this period have been chosen (Hofstra, 1990; Hofstra *et al.*, 1991) and are summarized in Table 2 in which also the present, Phase 4, values of the different parameters are summarized.

Criteria for the selection of parameters

A first choice of the ecological parameters was made according to expert judgement. A final selection of the parameters was made according to the method of Klijn *et al.* (1990). The criteria of Klijn *et al.* (1990) were: firstly, parameters should correspond to specific environmental functions of the area in study, especially nature, drinking water, recreation, agriculture, forestry and fishery. Secondly, parameters should reflect the environmental problems of the area. Thirdly, data on the parameters should be available and fourthly, parameters should appeal to the interest of policy makers.

A graphical presentation of the state of the lake environment

In the Dutch Water Management Plan (Ministry of Traffic and Public Works, 1989) a graphical presentation technique, called the 'AMOEBE approach' was introduced. AMOEBE is an abbreviation for 'Algemene Methode voor OEcologische BEoordeling', which means 'General Method for Ecological Assessment'. The method was designed for policy makers and environmental authorities and has been applied to the North Sea, the River Rhine and some terrestrial ecosystems (Ten Brink & Hosper, 1989; Klijn *et al.*, 1990; Latour *et al.*, 1990). In Fig. 2 an AMOEBE, containing the parameters from Table 2, is presented. The sequence of the parameters corresponds to the method of Klijn *et al.* (1990).

Evaluation of the state of the environment

The AMOEBE (Fig. 2) clearly demonstrates that the state of the environment of the Loosdrecht lakes does not match with the frame of reference. Some parameters, total phosphorus, cadmium, cyanobacteria, diatoms and seston have increased since 1940. Others, transparency, green algae, zebra mussel larvae, *Characeae*, pike, sedge warbler and otter, are below their target value. Only a few parameters, oxygen, calcium-ions and salinity, approach their aims.

The AMOEBE-approach forces the choice of concrete target values for ecological parameters. A complete and verifiable set of target values can only be obtained if the study area is well-documented. The Loosdrecht lakes are a good example of such an area. But even if historical data are lacking or incomplete the setting of ecological aims is an indispensable step in environmental quality assessment (Public Health Council, 1989). In fact, it should be the first step in

Table 2. A survey of the present concentrations/values (Phase 4) and target values (Phase 2) for 32 ecological parameters (after Hofstra, 1990).

Parameter	Present concentration/ value		Desired concentration/ value	
Abiotic parameters				
Transparency (yearly average, Secchi-disc depth, m)	0.4	*a	1.9	*a
Sestion < 150 μm (yearly average, mg C l^{-1})	8.0	*b	0.2	*cd
Total phosphorus (yearly average, mg P l^{-1})	0.1	*a	0.0054	*ef
Soluble Reactive Phosphorus (yearly avg., mg P l^{-1})	0.002	*b	0.0015	*g
Mineral nitrogen (*1, summer average, mg N l^{-1})	0.840	*a	0.238	*a
Salinity (*2, summer average, mg l^{-1})	305	*a	231	*a
Calcium-ions (summer average, mg l^{-1})	49.0	*a	40.8	*a
Sulphate (summer average, mg l^{-1})	19.2	*a	33.6	*a
Bicarbonate (summer average, mg l^{-1})	153	*a	92	*a
pH (summer average, pH-units)	8.9	*a	7.8	*a
Oxygen (summer average, mg O_2 l^{-1})	10.4	*a	11.0	*a
Cadmium (in sediment, mg kg^{-1})	6.3	*h	0.3	*f
Plankton (yearly averages)				
Zebra mussel larvae (fresh weight, mg l^{-1})	0	*c	0.0038	*e
Total zooplankton (carbon , mg C l^{-1})	0.575	*d	0.075	*de
Total cyanobacteria (fresh weight, mg l^{-1})	30.6	*b	1.25	*e
Total diatoms (fresh weight, mg l^{-1})	0.81	*b	0.06	*e
Total green algae (fresh weight, mg l^{-1})	0	*b	0.48	*e
Chlorophyll *a* (mg l^{-1})	0.1	*a	0.025	*fi
Vegetation-groups unit: Total covering according to Tansley (1946) (sum of Tansley abundance terms)				
Characeae (4 species)	0	*fjk	15	*fjk
Potamogeton-group (10 species)	1	*fjk	11	*fjk
Menyanthus-group (7 species)	2	*fjk	14	*fjk
Thelypteris-group (15 species)	6	*fjk	25	*fjk
Nymphaea-group (7 species)	14	*fjk	18	*fjk
Butomus-group (6 species)	11	*fjk	15	*fjk
Caltha-group (10 species)	14	*fjk	24	*fjk
Fauna				
Pike (fresh weight, kg ha^{-1})	1	*l	45	*l
Bream (fresh weight, kg ha)	180	*l	50	*l
Otter (*3, nr. individuals)	0	*f	15	*m
Pochard (*4, nr. individuals)	750	*f	7500	*o
Sedge Warbler (*5, breeding pairs)	5	*n	50	*f
Little Bittern (*5, breeding pairs)	1	*n	5	*f
Great Crested Grebe (*5, breeding pairs)	70	*n	20	*f

Remarks
*1 Sum of the ions NO_2^-, NO_3^- and NH_4^+
*2 Sum of ions SO_4^{2-}, HCO_3^-, Cl^-, Mg^{2+}, Na^+ and K^+
*3 Number of individuals in Southern Vecht lakes area (Crutzberg *et al.*, 1969)
*4 Number of individuals hibernating in the Loosdrecht lakes ares (Leentvaar & Mörzer Bruijns, 1962)
*5 Number of breeding pairs in Soutern Kievits Area (Morel, 1989)

References supporting this table
*a Van Liere *etal.*, 1991; *b Breebaart *et al.*, 1989; *c Gulati 1990, pers. comm.; *d Gulati, 1984; *e Geelen, 1955; *f Hofstra, 1990; *g Amsterdam Municipal Waterworks, 1940; *h Kühnel, 1985; *i CUWVO, 1988; *j Best *et al.*, 1984; *k Runhaar *et al.*, 1987; *l Lammens, pers. comm.; *m Creutzberg *et al.*, 1969; *n Morel, 1989; *o Leentvaar & Mörzer-Bruijns, 1962.

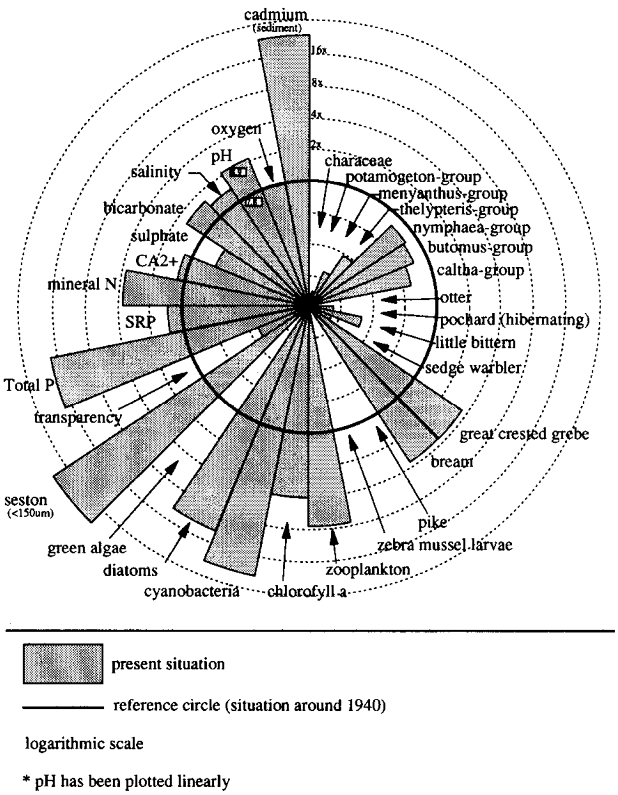

Fig. 2. 'AMOEBE' presentation of the state of the environment of the Loosdrecht lakes. The circle (thicker line) corresponds to a state of the ecosystem (around 1940; see 'Phase 2' under the text), used as an ecological frame of reference. The shaded parts represent the present state of the environment ('Phase 4'). The magnitude of deviations from the circle indicates the extent of unfavourable environmental conditions, which are due to a number of courses, described in the text, such as eutrophication, disturbance of the fauna and destruction of banks. Note that the graph has been plotted on a logarithmic scale except for pH.

translating general policy aims to directives for management.

One must bear in mind, however, that the target values that have been set in this study are based on a variety of sources, including historical reports and data from Lake Western Loenderveen (Hofstra, 1990). No attempts have been made to describe seasonal fluctuations or spatial variation in each parameter. Therefore, the target values should be considered as a rough draft of Specific Environmental Quality for the Loosdrecht lakes. Exact upper and lower limits for each parameter have not been established, nor could have been at this stage. In the future a more precise definition of ecological aims for the area might be desirable, for instance if, by proper management, the lakes approach their Phase 2 situation again.

Although we are unable presently to formulate exact ecological aims, a general conclusion can be generated from this study: the state of the environment of the Loosdrecht lakes is poor with respect to the Specific Environmental Quality that is required, especially with respect to its main functions, nature and recreation. Measures that combat eutrophication are strongly recommended.

Conclusions

1. The Loosdrecht lakes have changed in the past century from a oligotrophic ecosystem with very clear water into a highly eutrophic one with very low transparency.
2. The state of the environment of the Loosdrecht lakes is poor with respect to the Specific Environmental Quality target values that are required for the area.
3. The situation around 1940, described in the text as 'Phase 2', is recommended as a concrete and verifiable ecological frame of reference or target, corresponding to the policy aim of Specific Environmental Quality.
4. The AMOEBE presentation technique, devised for policy makers, is a valuable tool in environmental quality assessment as it visualizes in one glimpse the state of the environment of an area as well as a frame of reference, i.e. level desired.

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