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REDEVELOPMENT OF LANDSCAPE UNITS – GOVERNING OF LAKE AND WETLAND ECOSYSTEMS WITH EMPHASIS ON SWEDISH EXPERIENCE

Sven Björk

Department of Ecology, Limnology, Lund University, SE-223 62 Lund, e-mail: Sven.Bjork@limnol.lu.se

Abstract
Already in the earliest days of limnology, with regional limnology as the main field of research, it was quite clear that lake ecosystems reflect the character of their catchment areas. At the same time, paleolimnological studies proved that it is possible – by means of stratigraphic and fossil analyses of sediment – to reconstruct the ecological development of both the individual lake and its surroundings. The simple fact that surface water and groundwater are carriers of solid and dissolved matter from catchment to lakes means that the shoreline should not be looked upon as a line of demarcation, but as a zone connecting terrestrial and aquatic ecosystems. A lake together with its catchment area constitutes, therefore, the primary ecological and management unit of a river basin. Water bodies are the mirrors in which the original state – and recent care, management and mismanagement – of the catchments are reflected.

Key words: lake restoration, redevelopment of landscape, wetlands, management, export of humic substances, catchment management, European Union Water Framework Directive

TERMS AND AIMS

When lakes close to cities and municipalities became overloaded by sewage and industrial wastewater – and suddenly transformed from environmental assets to environmental problems – the cause of their degradation was so evident that it was possible for limnologists and citizens to convince politicians to allocate money for counter-measures. The term *point source* was introduced to denote a concentrated outlet of sewage, chemicals, *etc.*, while a *diffuse source* signifies the leakage of matter from the drainage basin to its lake and tributaries. A well-known example of diffuse leakage is the supply of nutrients from agricultural land to surface waters.

Highly-efficient treatment plants, equipped with phosphorus precipitation and nitrogen removal, were successively constructed in order to save lakes and get them back as environmental assets. In some cases the polluted lakes were no longer utilized as receivers of sewage and industrial wastewater as this was completely diverted and treated. However, it sometimes turned out that not even complete diversion would save the lake ecosystem; in spite of the considerable investment in treatment plants the system did not recover. The intensive *external nutrient loading* had created the requirements for heavy *internal nutrient loading*: resulting in *irreversible damage* in the form of lasting *hypertrophication* – appearing as intense plankton blooms, oxygen deficiency, fish kills, *etc.*

However, in most cases, investments in efficient treatment, or complete diversion, of polluting wastewater resulted in recovered lakes. Well-known examples of water bodies where the external loading, before it was brought under control, had not yet reached the critical point when the prerequisites for long-lasting internal loading had developed are: Lake Vättern (Sweden), Lake Mjösa (Norway), Lake Constance (Germany, Austria, Switzerland) and Lake Washington (USA). Such large lakes, with powerful ecosystems, recover rapidly after the external loading has been normalized; it has been possible to nip the eutrophication in the bud.

The other category of lakes, those in which long-term heavy pollution had caused irreversible damage, provided the very first subjects for *ecosystem redevelopment*. Although the compulsory first step – normalization within the range of possibility of the external loading (elimination of point sources) – had already been taken, the ecosystems of these lakes had not improved. It was therefore necessary to take corrective, restorative measures in the lake ecosystem itself: with the goal to bring back a system characterized, first of all, by a functional balance between production and degradation of organic matter.

At the same time, studies on shallow lakes – in which the water level had been lowered – showed that it was mostly impossible to revert to the previous character of the lake simply by raising the water level. In such cases it is also necessary to take preparatory in-lake measures.

The expression *ecosystem redevelopment* is used as a neutral phrase for an activity aiming at the improvement of a degraded system in an effort to bring it back to conditions as similar as possible to those existing before the degradation. Redevelopment has been used as a superior term (UNESCO-

MAB Conf. on Ecosystem Redevelopment, Budapest 1987, Björk 1988) for both all the preparatory work to normalize the external loading and the corrective measures in the lake ecosystem itself, *i.e. lake restoration sensu stricto*. After the external loading has been brought under control, in-lake restorative operations are also necessary – before raising the water level for the correction of damage in lakes where the water level has been lowered. Hypolimnetic aeration (with or without addition of precipitating agents), artificial circulation through bubbling, treatment of sediment for control of nutrient release and lasting regulation of pH-conditions, can also be designated as true restoration activities. The removal and treatment of toxic substances in contaminated lakes also belong to this category. A characteristic of lake restoration activities is that measures taken produce immediate results – provided the necessary preparatory work has been done properly.

Although well-documented limnological redevelopment activities started less than 50 years ago, a rich terminological flora has already developed. In his inaugural dissertation, Scharf (1996) preferred to use the designation *lake therapy* (German *Seentherapie* [Behandlung], from Greek *therapeuein*, to serve, take care of) as the superior term, which included measures in the catchment area as well as in the lake itself. He prefers therapy rather than the term restoration – pointing out that it is impossible to treat a collapsed lake ecosystem in such a way that, in all respects, it resembles the conditions during an earlier stage in a lake's developmental history.

Scharf (1996) also rightly criticizes opportunistic terms (like 'biomanipulation') and cosmetic methods pretending to bring a lake back to health. He exemplifies this in the following illustrious way: "As in the case of almost every [clock] movement, also in the case of ecotechnical [lake] management, the pendulum makes a short-term deviation in one direction. Temporarily, one even has the self-belief that one can clean up lakes and river reservoirs by means of algae and water-fleas instead of by way of expensive sewage-treatment plants"; ["Wie bei fast jeder Bewegung, so schlug auch bei den ökotechnologischen Verfahren das Pendel kurzfristig zu weit nach der einen Seite aus. So glaubte man zwischenzeitlich, anstelle teurer Kläranlagen das Abwasser mit Hilfe von Algen und Wasserflöhen in Seen und Talsperren reinigen zu können."] So-called biomanipulation should be taken for what it is, a sometimes-possible method to tune up a lake ecosystem that has already been restored to a nutrient concentration as close as possible to the regio-limnological level.

The recent developmental history and management of the originally clear-water Lake Vesijärvi, Finland, includes a complete series of changes: starting with pollution and followed by ecosystem degradation, toxic plankton blooms, diversion of sewage, remaining internal loading, efforts to remove roach *en masse*, reduced cyanobacterial biomass and increased transparency, intensive exploitation of lakeshore areas, re-appearance of cyanobacterial blooms and a new lake redevelopment project. The clearly-described case of Lake Vesijärvi is summarized by Kairesalo & Vakkilainen (2004 with references).

The treatment of a lake ecosystem by limnologists is often appositely compared to a doctors' treatment of a human patient. In both cases, the past history of the disease, an *anamnesis*, has to be obtained. This should include all relevant internal and external facts about the patient. These facts are necessary for a more-informed diagnosis on the basis of which a decision on therapeutic treatment is made.

It is then of utmost importance that a *catamnesis* is obtained, *i.e.* to document the history of the patient subsequent to treatment and recovery. Such documents, including also all mistakes and unforeseen problems, have to constitute the fundament of experiences for future successful therapeutic applications in other lakes. The observation period following treatment has to be of such duration that it can be proved, without objection, that a lasting result – a properly functioning ecosystem – has been obtained. Various measures advertized as miraculous remedies for bringing sick lakes back to health have only an ephemeral effect; and can cast a bad reputation on other seriously-applied methods that are used to achieve sustainable results. Catamneses that describe a true return from miserable to promised good conditions are rare.

The application of therapeutic terminology to limnological healing brings with it a special advantage: its high pedagogic value in efforts to mediate an understanding to the general public of how important it is to care and treat limnic ecosystems. A doctors' terminology also offers illustrative terms to characterize the different measures available to treat a lake: according to limno-medical and limno-surgical methods in order to restore a balanced metabolism.

The aim of true restoration projects is to attack the roots of the evil and govern the ecosystem back to a lasting, well-functioning part of the landscape. If a cosmetic treatment with only a short-term effect is applied in critical situations, it should be clearly explained that the treatment is by way of a temporary measure to overcome an acute problem. Scharf (l996) is of the opinion that "The word 'restoration' as a designation for measures in a lake was somewhat improperly chosen, because restoration means to bring back something to its original condition". ["Das Wort 'Restaurierung' für Maßnahmen im See wurde etwas unpassend gewählt. Restaurieren heißt wiederherstellen" or (Hupfer, Scharf 2002) "etwas in den ursprünglichen Zustand bringen".] However, because 'Wiederherstellen' also means "etwas wieder instand setzen", *i.e.* to put right, repair or recondition, and because it is impossible to preserve a specific stage in a continuously-changing lake ecosystem, the term restoration might well be used for all practical purposes. The main thing is that a well-functioning ecosystem is redeveloped in lasting harmony with the catchment. It must not, in detail, be exactly the same as in the former juvenile landscape. (The *Semperopera* [opera house] in Dresden has been restored, to function the same way as before its destruction by bombs, despite structural deviations!)

From the very outset, the term *restoration* was used only for activities carried out in a lake itself, in order to adjust and govern the structure and function of the ecosystem. It was also stressed that restoration does not imply the permanent reinstatement of a lake to the conditions prevailing during a specific phase in its development. In practical environmental protection and management, the meaning of the term 'lake restoration' is the re-creation of the conditions in a lake in such a way that acceptable environmental conditions are reestablished. As a rule the restorative measures imply the re-establishment of a lake – according to current local interests – for which it used to be suitable before its degradation (Björk 1968, 1988). The ecosystem design includes the determination of the concentration level of nutrients, balanced metabolism and – whenever possible – control of food webs.

The important thing is that the landscape unit, the lake and its catchment, is looked upon as an ecological entity and treated as such. A terminological flexibility is useful and necessary to be able to get a broad understanding among different audiences for the message that – the landscape has to be healed and carefully treated. Thereby it ought to be easy to explain the necessity to get both the external and internal loading under control and to redevelop a lake according to regio-limnologic conditions.

Redevelopment-restorative-therapeutic treatment of lakes and their catchments has so far dealt only with single water bodies characterized by degraded ecosystems. In the future, the landscape unit to be treated has to be widened to comprise entire river basins.

METHODOLOGICAL CASE STUDIES

Because a plethora of various methods, variants, and combination of techniques have already been described – for example in Eiseltová (1994) and by Hupfer & Scharf (2002), both with a great number of references – no further descriptions are given here. With reference to presented papers, some main types of procedures are briefly exemplified by prototype and principally-important projects, considered methodologically representative, in the following below. The post-treatment development of the various ecosystem types has been well described on the basis of long-term studies: making it possible to critically evaluate the result in comparison with the goals set up for the eco-technical treatment and prognoses presented for the development of the ecosystems.

Macrophyte control

Lake Hornborga (30 km^2), Västergötland, Sweden (Fig. 1–2)

Since 1802, this large eutrophic lake has been lowered five times in unsuccessful attempts to obtain arable land. After its complete draining in 1932–1933, the bottom, dry in summer but soft and impossible to cultivate, became overgrown by macrophyte vegetation, the wettest part by *Phragmites australis* (11 km^2, Fig. 1) and the rest by mainly *Carex* and *Salix*. In l954, the water level was raised 80 cm within a diked-in part of the lake. Thereby better growth conditions were created for the common reed.

Because the former Lake Hornborga was considered one of the most valuable waterfowl lakes in Northwest Europe, proposals for its restoration with the aim to secure its ornithological value were presented to the Swedish Government. In l967, a team of ornithologists, limnologists, technologists, hydrologists, economists, and agriculturists started the necessary fieldwork. The limnological restoration plan (Plan/73), presented in l972-73, included convincing arguments in favor of restoration, descriptions of elaborated

Fig. 1. The drained Lake Hornborga in 1967, overgrown with *Phragmites australis*. Photo Sven Björk 1967-08-04.

Fig. 2. Lake Hornborga in 2002, after raising the water level by ca 80 cm. Water depth in the middle of the photo transect *ca.* 1.1 m. Photo Sven Björk 2002-08-15.

methods for bottom treatment and the governing of macrophyte vegetation, redevelopment of water and ice movements, and the raising of the water level by 1.5 m. Water level and general functional features of the wetland ecosystem would then correspond fairly well to the conditions prevailing during l877–1904 and attain the primary aim of the restoration project, *i.e.* to secure a sustainable development for the ecosystem. The lake's status during the latter part of the l9th century is well documented and describes Hornborgasjön as the most perfect waterfowl lake in Sweden.

Although large drainage projects had also hit the catchment, the external loading of the lake was not alarming. Sewage was diverted and efficiently treated and the threat of incipient chemical pollution from a uranium-producing plant stopped because the factory was closed down.

Ecological prognoses for the development of the restored wetland were, together with cost calculations for the necessary measures, given in Plan/73. The limnological restoration was unanimously accepted by the Riksdag (Parliament) in l977, and in l982, the Water Court and Government granted permission to raise the water level by 1.4 m, in two steps (1.0 + 0.4 m). In the meantime, the large-scale methodological demonstration activities continued.

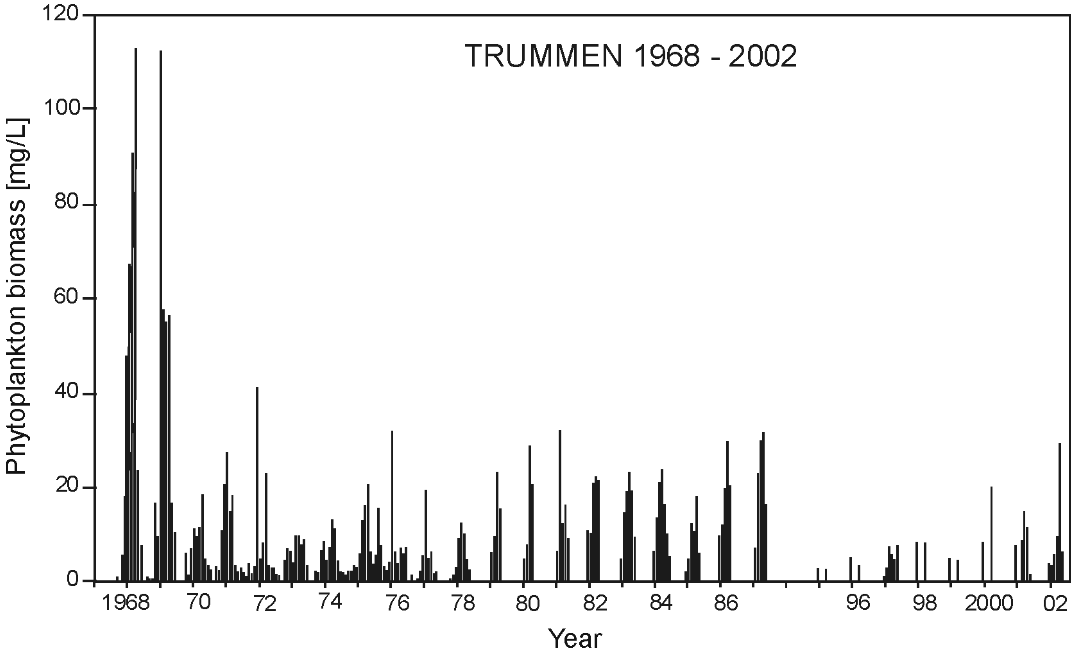

Fig. 3. Lake Trummen. Monthly values of phytoplankton biomass, mg$\cdot$l^{-1}. The turn of the months June-July indicated. The restoration was performed in 1970–1971. Data from Gertrud Cronberg.

However, civil servants of the Swedish Environmental Protection Agency presented additional plans for dikes around the wetland, finally reaching a total length of 25 km. Later, this plan was abandoned and replaced by a suggestion to reduce the raising of the water level to only *ca.* 80 cm. In l995, the level was raised according to this proposal to meet the strictly ornithological wishes. The consequences of this reduction in the planned increase in water depth were not analyzed in any environmental impact assessment.

In accordance with the prognoses given in Plan/73, plaur formation (root felt of *Carex*, *etc.*, because of methane accumulation loosened from the bottom, and coming to the surface) soon started after the rise in water level and ice movements occurred. The bird life has improved considerably. Incorrectly-treated bottom areas are characterized by intense production of methane. Unforeseen has been the strong increase in the number of greylag geese (*Anser anser*) efficiently consuming reed-bed plants. The striking reduction of *Phragmites* has forced more than 75% of the marsh harriers (*Circus aeruginosus*) to breed in *Salix* bushes instead of in reed-beds (in 2001 a total of 36 breeding pairs were recorded at the lake).

The ecosystem has, of course, not yet (2004) stabilized but is still characterized by instability. Since the reduced raising of water level was implemented, the precipitation and water supply to the lake has so far been above normal.

The well-documented Lake Hornborga case vividly illustrates the possibilities to redevelop lakes that were drained, overgrown and seemingly irreversibly damaged. In addition, it also exemplifies the risks of how an unskilful administration could prolong the procedure and unnecessarily raise the costs of obtaining an ecosystem's sustainable development.

References: Björk 1973, 1994a, 1999, Claeson 1999, Swanberg 1973, Pettersson 2002, Hertzman & Larsson 1999.

Internal nutrient control

Sediment removal

Lake Trummen (1 km^2), Växjö, Sweden (Fig. 3)

This brown-water lake was used for swimming until the 1920s, but then became heavily polluted by an outlet of sewage, and from l941 to 1957 also by wastewater from a flax factory. Although the external loading became normalized in 1958, no improvement of the lake ecosystem was seen during 1959–1970. Due to the intensive *Microcystis* bloom, summer transparency remained at about 15–20 cm.

Limnological-paleolimnological investigations and the design of restorative methods were carried out during 1968–1970 (earlier data also available). Removal by suction dredging of black, nutrient-rich sediment, accumulated during the pollution period, was undertaken in 1970–1971. Recovery processes and continued structural and functional development have been documented during the years of 1970–2004 and the studies continue. Urbanization of the catchment area has periodically had a negative influence on the lake. The long-term development is illustrated in Fig. 3 by the phytoplankton biomass.

As to test studies on the possibilities to govern the ecosystem by means of food web management see below.

References: Andersson 1985. Andersson, Berggren & Hamrin 1975. Andersson, Berggren, Cronberg & Gelin 1978. Bengtsson & Fleischer 1971. Bengtsson, Fleischer, Lindmark & Ripl 1975. Björk *et al.* 1972, 1985b, 1988, 1994c. Björk & Digerfeldt 1965. Digerfeldt 1972. Cronberg 1982. The development of automatically-controlled suction-dredging technology has been described in Björk (1985a, 1994b) and Pokorny & Hauser (1994).

Sediment treatment

Lake Lillesjön (4.2 ha), Värnamo, Sweden

In the originally oligotrophic, but through sewage discharge, severely and, without restorative measures, irreversibly-damaged Lake Lillesjön the total phosphorus concentration periodically increased to more than 3 mg·l^{-1} in the hypolimnion, and varied from 0.1 to 2 mg·l^{-1} in the epilimnion. Periodically *Lemna minor* covered almost the whole water surface.

After the diversion of sewage discharge in 1971, restoration was implemented in 1975 by means of the Riplox method (Ripl 1976a); injection of a solution of calcium nitrate in the top sediment layer. According to this method, treatment of a chemically-reduced sediment results in: 1) oxidation of organic matter and iron compounds; 2) release to the atmosphere of nitrogen gas; and 3) precipitation of phosphorus.

After treatment of the sediment, the total phosphorus concentration dropped to about 0.04 mg P·l^{-1} in the whole water column. The oxygen demand of the treated sediment reached the same low values characteristic of unpolluted lakes in this region and the ecosystem has preserved this character. The heterotrophic organism community of the polluted lake was succeeded by a normal plankton community rich in species. The improved light conditions in the water made it possible for submerged macrophytes to colonize the organic sediment bottom. After its restoration, the former hypertrophic receiver of sewage is available for recreation, for swimming, boating and angling.

References: Ripl 1976a, b, 1994.

Phosphorus precipitation

The processes at the water-sediment interface leading to internal nutrient loading were first described and explained by Ohle (l955, 1965, 1971) and Thomas (1955, 1963). The sudden appearance of the hypertrophication phenomenon was, in 1955, expressed in German as “rasant” by Ohle and “saltant” by Thomas. Lake restoration methods based on phosphorus precipitation principles are described by Wolter (1994a) and Hupfer & Scharf (2002).

Lake Groß-Glienicker (67 ha), Berlin, Germany

In the l970s and l980s, the lake became polluted by sewage, partly via groundwater. After diversion of the sewage discharge, it turned out that the thermally-stratified lake did not recover. Hydrogen sulphide was formed in the rapidly oxygen-depleted hypolimnion and the development of cyanobacteria reduced the transparency to less than l m. Profound pre-investigations of the ecosystem and its relations to the catchment focused on the concentrations and seasonal interactions of iron, sulphur and phosphorus.

In order to decrease oxygen consumption and initiate oxidative degradation of oxygen-demanding organic matter accumulating at the bottom, hypolimnetic aerators were installed in 1992. In this manner, the prerequisites for the binding of phosphorus to trivalent iron were created. The second step in the treatment was addition of iron in the form of wet, fine-grained iron hydroxy-oxide and dissolved iron chloride was added to the lake water to enhance the phosphorus-binding capacity even further. Before treatment, the phosphorus concentration of the lake water had been about 0.6 mg P·l^{-1}; after treatment it was reduced to *ca.* 0.05 mg P·l^{-1}.

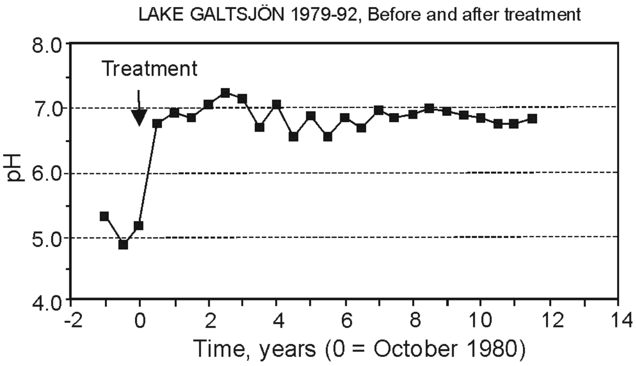

Fig. 4. Lake Lilla Galtsjön 1979–1992, before and after treatment wih sodium carbonate. From Lindmark (1993).

As the oxygen conditions in the hypolimnion improved, aeration was reduced from 1998 onwards. After the algal blooms disappeared, submersed vegetation has been able to develop. In accordance with the aim of the restoration project, Lake Groß-Glienicker has been redeveloped to a lasting asset for recreation, bathing, and fishing in the densely-populated Berlin area.

Reference: Wolter 1994b.

Aeration methods as tool for restoration of lakes

The technical development of hypolimnetic aerators is summarized by Verner (1994a, 1994b), who also describes their use with and without the addition of agents for the adsorption and precipitation of phosphorus. The first installation of the Limno aerator was made in 1971 in Lake Grebin, Schleswig-Holstein, Germany (Ohle 1972). The aeration was combined with the addition of benthonite.

Treatment of acidified lakes

Lake Lilla Galtsjön (15 ha), Ronneby, Sweden (Fig. 4)

Because airborne pollution is considered important in the acidification and biological impoverishment of water bodies, normalization of such external loading demands quite other measures than solely mastering that emanating from the local catchment. Furthermore, in the case of acidified lakes, the wide spectrum of differently-reacting ecosystems calls for a rich variety of methods. The individual lake-catchment–unit demands a tailor-made treatment. However, in spite of this, the liming of both terrestrial biotopes and water bodies has been introduced as a standardized remedial measure.

For making the treatment of acidified humic lakes ecologically correct and lasting, Ripl (l976b) developed the Contracid method. By the addition of sodium carbonate solution to the acidic lake sediment, adsorption and exchange processes are controlled and a lasting neutralization obtained; the sediment functions as a reversible cation exchanger. In addition to the above, a slight phosphorus fertilization of the water stimulates the re-establishment of the biological community characteristic of humic waters (Ripl, Lindmark 1979). According to the original Contracid method, a sodium carbonate solution was injected in the sediment by means of an Atlas Copco sediment harrow (cf. Ripl 1994, Fig 1). Later, soda ash briquettes have been used (Lindmark 1990).

The injection method was first applied in Lilla Galtsjön, a lake representative of a very large group of Swedish soft-water, acidified humic lakes. The alkalinity was zero and pH varied between 4.8 and 5.3 during the year. Available data from recent decades document a decrease in pH. At the end of the l970s, the plankton community was poorly developed, submerged *Sphagnum* had spread over increasingly larger bottom areas, overgrowing the *Lobelia* and *Isoetes* mats. No reproduction of roach (*Rutilus rutilus*) took place, and that of perch (*Perca fluviatilis*) was disturbed. In all aspects, the ecosystem showed signs of damage typical of that from acidification.

In October 1980, the lake was treated according to the Contracid method. A 10 percent sodium carbonate (Na_2CO_3) solution was injected into the sediment by means of the Atlas Copco sediment harrow. The treated bottom area amounted to 25 percent of the total lake area. The injection of the solution did not cause any extremely high and then rapidly decreasing pH values as is the typical effect of liming. On the contrary, the initial rise in alkalinity and pH was moderate and then reached characteristic, stable levels – with fluctuations caused by bioactivities in the ecosystem and by the typical spring supply of acid water in connection with the melting of winter snow.

The quantitatively poor, pre-treatment, phytoplankton community contained about 30 algal species; in 1982, the plankton development had stabilized to a community containing about 80 species. The expanding *Sphagnum* mats had disappeared, leaving the littoral zone for the typical vegetation of isoetides. In the fish population, a normal representation of age classes of roach indicated reproduction in a way that used to be normal before acidification. The lake has developed to be the official open-air bath of the region.

The aim of the project, subsequent to the Contracid treatment, is to follow the long-term development of a humic lake ecosystem under the continuous influence of acid deposition (Fig. 4). Up till now, studies of the system include the period 1958–2003 and the studies continue.

References: Ripl 1976b. Ripl & Lindmark 1979. Lindmark 1984, 1990, 1993.

Food web management

For lake ecosystems in which the nutrient status has been restored after eutrophication, it might be possible to 'tune up' their trophic state by means of food web management. The governing of fish populations, which has long traditions among professional fishermen, has been practised to favor the production of fish species of a specific value. When actions have been taken to reduce whitefish and to favor predatory fish, this has also resulted in better opportunities for the development of zooplankton populations grazing plankton algae. For a period of time, these since long well-known facts have recently generated much excitement and frequent exaggerations when announced as simple, cheap and quick means to bring eutrophicated lakes back to health. Biomanipulation, cascading and top-down methods have been launched.

Stimulated by the observations on the impact of fish on plankton communities presented by Hrbácek (1962 and later), Gunnar Andersson carried out a series of cage and whole-lake experiments in Lake Trummen to elucidate what governing effect fish species might have on an ecosystem with a restored nutrient level. After removal of the bottom cover of black sediment and the highly-significant nutrient reduction had been realized, intensive fishing during the period l976-79 was carried out in the lake. The populations of bream and roach were reduced by l6 tons (l90 kg per ha), while predators, pike and perch, were left. There is hardly any doubt that a synchronous decrease in phytoplankton biomass, as well as in total phosphorus and nitrogen, was caused by this intensive selective fishing. Reduction of planktivorous fish took place also in 1994, 1996–1997 and 2000. It has, however, not been possible to obtain any lasting effect (cf. Fig. 3). Lake Trummen is not an isolated body of water, but has in- and outflows making it possible for fish to pass from connected lakes. The occasional development of a food resource, such as large planktonic animals, is utilized by both invading and in-lake reproduced fish.

References: Hrbácek 1962. Hrbácek, Dvorakova, Korinek & Prochazkova 1961. Andersson 1984, 1985. Andersson, Berggren, Cronberg & Gelin 1978.

THE CHANGEABILITY OF THE LANDSCAPE

For the first restoration projects, dealing with lakes heavily polluted from point sources, it was easy to define the cause of ecosystem degradation and also easy to convince even politicians what measures had to be taken to normalize the external loading and to correct the internal metabolism.

In the European region, point sources with the character of "red spots" have largely been eliminated. However, the landscape as a whole has become exploited and under the pressure of market economies, based on the idea of continuous economical growth, further exploitation meaning continuous ecological decline takes place at a constantly accelerating rate. Urbanization, drainage projects, industrialized forestry and agriculture, road construction, landscape fragmentation, unlimited traffic increase, extraction of groundwater, infiltration into the ground of a variety of substances, *etc.*, all results in an uncontrolled degrading influence on the liquid which from various diffuse sources is collected in lakes and influences their ecosystems.

So far, the drawing up of red lists of endangered plants and animals and the recording of successively-exterminated species are the generally most well-known signs of ecologists' efforts to point out the negative structural changes of the landscape. Holistic syntheses of the functional conversion of the ecology of the landscape are, however, still largely missing. This is understandable, because the all-embracing changes now taking place are very complex and composed of a multitude of processes, each characterized by lag-phases at different steps in the chains of events. Most changes take place fairly slowly and not at all so dramatic and instantly evident as, for example, the directly observable collapse, within a couple of decades, of a lake ecosystem overloaded by sewage.

When prognoses describing the complex ecological effects on the landscape of exploitation projects are presented, it is difficult to achieve any degree of understanding among politicians as well as in the environmental courtroom. In the

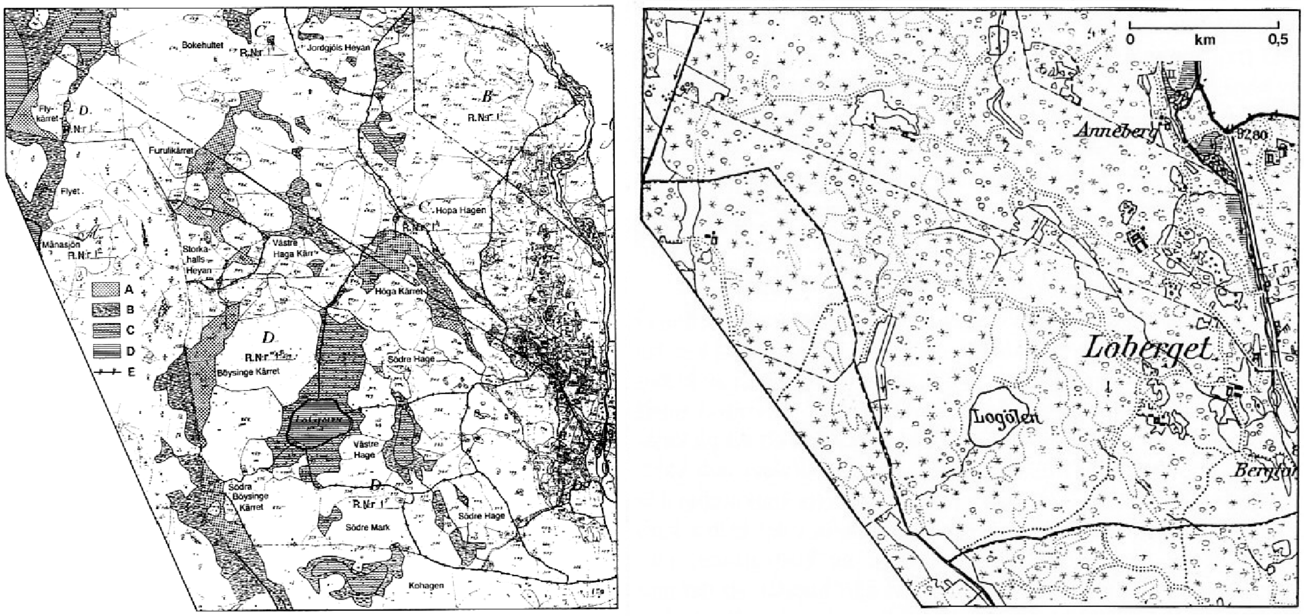

Fig. 5. The Loberget area in the Province of Blekinge, Southern Sweden. Left: The distribution of wetlands according to land survey maps 1817–1836. A = fens designated as arable after drainage; B = fen; C = raised bog; D = lakes; E = fencing around wood pasture. Right: The same area according to an economical map of 1918. The wetlands are drained and transformed to arable land and to meadows for hay production. The productive areas connected with the farms by a system of roads. Lakes have been lowered and brooks straightened.

latter case, judges, district-court judges, *etc.*, are supposed to be able to evaluate ecological facts – but under the pressure of politicians and exploiters, do not have the competence to comprehend more deeply other than simple, direct cause-and-effect relationships. Because of a lack of ecological knowledge, they do not understand the long-term consequences of a series of ecological processes. Therefore, the application of the principle of the rule of caution – a most prominent paragraph of all environmental law – is rare.

Amongst all the different types of environmental changes and all the different substances being added to and transported by water, humic matter has here been chosen to illustrate the more or less 'hidden' processes currently running in the forest landscape transformed by man.

Export of humic substances from the Loberget catchment area

The catchment

In recent years, limnologists have repeatedly reported a continuous darkening of the water- colour in Swedish watercourses. Background facts important for understanding this country-wide but slow and not very conspicuous environmental change are here described from the province of Blekinge, south-eastern Sweden. Until about 1800, the forested region of Loberget ("Lynx Hill") was rich in wetlands – oligotrophic fens with peat deposits (Fig. 5). On the directives of state-employed land-surveyors, practically all wetlands were drained during the first half of the l9th century. The aim of this intensive dewatering of the landscape was to obtain more arable land and areas for fodder production. The forests were largely utilized for grazing.

A fine-meshed system of ditches and canals was hence constructed; it efficiently drained the landscape as a whole and caused a permanent lowering of the average ground-water level. The consequent aeration of the upper layers of peat deposits initiated compaction and mineralization processes: with surface lowering as a result. Therefore, after some decades, the organic soil surface again approached the groundwater level and during a period efforts were made to deepen the ditches. The forested minerogenic soil, consisting of archaean moraine, shows a podsolic stratigraphy. Until about 1700, beech forests were typical for the region; they have successively been replaced by spruce.

Although fields and pastures representing the old wetlands were abandoned more than 50 years ago, the drainage system still works efficiently. In this respect, the Loberget area is representative not only of the forested regions of Southern Sweden but of a large part of Fennoscandia.

The water leaving Loberget is highly humic and shows a typical seasonal variation in colour, which is negatively correlated with the flow (Björk, Granéli, Anesio in prep.). At strong winter flow, connected with high ground-water levels, the colour is of magnitude 400–600 mg $\text{Pt}\cdot l^{-1}$. At weak summer flow and low ground-water levels following dry periods, the colour is typically between 800 and 2000 mg $\text{Pt}\cdot l^{-1}$.

In the light of the present soil and infiltration conditions on the one hand, and the flow and watercolour on the other, it is very likely to suppose that the reason for low colour during high flow periods is that the main part of the run-off water emanates from mineral soil where it has passed the podsol profile. The reason for high colour during periods of low flow would, on the other hand, be a proportionally larger part of water from the lower parts of the landscape, i.e. the peaty former wetlands. In both cases, the humic matter of the run-off water constitutes, of course, a mixture of young and old

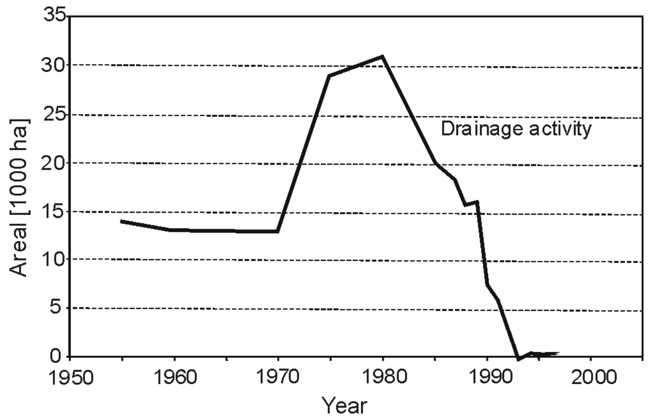

Fig. 6. Drainage of forest wetlands in Sweden 1950–1996. From the Swedish Environmental Agency 2001.

material. It seems, however, reasonable to suspect that young material dominates under high-flow conditions and older material under low-flow ones.

Another conceivable explanation would be that the export of humic matter is governed by temperature- and humidity-dependent metabolic processes taking place in the superficial layers within both organogenic and minerogenic soil areas. In the latter case, the surface is covered by accumulated litter, mainly from coniferous trees.

Seasonal variation in water quality and the age of transported humic substance

The sampling site is located in the brook collecting water from Loberget Hill, including the lowered Lake Logylet (Fig. 5). Water samples were taken at about monthly intervals during the period August 2000 to July 2002. In order to cover the successive, fairly rapid increase in watercolour in connection with decreasing flow, weekly sampling was also performed.

Watercolour, pH, and secific conductance were determined in connection with the sampling. More than 50 mg dry humic substance from each water sample was obtained after acidification and evaporation. ^{14}C datings were made by accelerator mass spectrometry (AMS) at the Radiocarbon Dating Laboratory, Department of Quaternary Geology, Lund University. Contrary to the highly variable colour values, the values of specific conductance and pH remained stable: pH 4.1–4.3; conductance 50–62 µS cm^{-1}.

The age of the humic substance is very young in all samples and independent of the watercolour. Among the 18 samples, two are somewhat deviating, corresponding to the ^{14}C-value of the atmosphere 1984–1986 and 1966, respectively. Both samples were taken in winter periods with strong water flow. The remaining l6 samples all correspond to the atmospheres ^{14}C-content 1996 or later. Calibration of the ^{14}C ages to calendar years (subtraction of the carbon-14 concentration caused by the nuclear bomb experiments in the l960s) shows that all samples are younger than l950. The age determinations unequivocally prove that a minimum of humic substance emanating from old organogenic deposits had left the catchment area during the sampling period.

The age of the humic matter leads to the conclusion that the drainage of Loberget has resulted in improved conditions for rapid degradation of recent organic matter in both minerogenic areas and the no-longer permanently wet, but alternatively-wet-and-aerated surface layers of former vast wetlands, where the groundwater level previously used to be permanently located at the surface.

As a result of the drainage, the hydrological regime has been altered in such a way that the straightened brooks and new ditches become, alternatively, completely dry and flushed with water, rapidly reflecting precipitation conditions. This is in sharp contrast to the former buffered regime which resulted in a more continuous flow of water. The change from deciduous to coniferous forest in a large part of Loberget has undoubtedly also implied a change in the quality and quantity of the humic matter produced and leaving the area.

While intact and well-functioning mires are characterized by minimized losses of matter, the overall environmental changes in the Loberget catchment have initiated an intensive export of humic substance from recently-produced and quickly-degraded organic matter. Further manipulation of the landscape may aggravate the situation. The landscape is literally bleeding.

Ecological effects following landscape drainage

The effects of landscape drainage are long-term in character and take time to be fully developed and easily noticed. The recent increase in the flow of acidifying humic substances from forested regions involves the risk of the settling of flocks of organic matter in watercourses. In the case of the Mieln, the river collecting water from Loberget and other similar forested areas, it used to be a clear-water stream characterized by a clean, minerogenic bottom inhabited by freshwater pearl mussel (*Margaritifera margaritifera*). In addition to several physical changes in the river course (damming, *etc.*), the spaces in between the stones paving the bottom have become filled with precipitated humic matter obstructing the normal development cycle of the pearl mussel. This type of biotope degradation has hit watercourses all over the country and is considered as one of the most serious reasons for the mussel's decline in reproduction. In the Mieln, the recent population of mussels consists of only a few adult specimens – protected according to the directives to try to preserve red-list-species. Without the re-creation of the environmental conditions suitable for reproduction, the pearl mussel will soon disappear from the Mieln as it has elsewhere.

So far, the darkening of the River Mieln water is, to all appearances, mainly a result of the intensive drainage of the landscape. While the goal for the first explosion in drainage was to increase the cultivable land and fodder production area, the aim of recent drainage has been to increase forest productivity. Not until the dewatering of the Swedish forest landscape had reached such a point that hardly any wet areas were left, was further drainage forbidden (Fig. 6). However, the destruction of wetlands continues, nowadays in connection with 'infrastructural improvement', *i.e.* the construction of new road networks. Thereby the landscape is being even more fragmented – as more efficient drainage systems are made, wetlands are excavated, peat and sediment masses deposited and organogenic soils subject to rapid mineralization. Altogether, this means both acidification and a further increase in the export from land to water of humic substances.

Watercourses like the Mieln, draining sparsely-inhabited forest areas and flowing into the Baltic, are exploited for their water supply within the densely-populated coastal zone. In the waterworks, the increasing colour means a degradation of water quality and increasing treatment costs to prepare it for public supply.

One to two thirds of total nitrogen transported by rivers and reaching the coastal waters of the Baltic is dissolved organic nitrogen (Stepanauskas 2000). While the rest, nitrogen in inorganic form, has a direct eutrophicating effect, nitrogen bound to humic matter has earlier been considered not to be available for primary production in the sea. It has, however, been demonstrated (Carlsson, Edling, Béchemin l998) that humic matter isolated from river water has a stimulating effect on bacterial production in coastal waters.

In the food web, the increase in bacterial biomass means an increase in grazing heterotrophic flagellates, which in their turn are consumed by ciliates, *etc.* (Carlsson 1993). The metabolism of unicellular planktonic animals results in a release of ammonium nitrogen utilized by phytoplankton. A direct uptake of nitrogen bound to humic matter is, however, also possible. Since it is estimated that 25–50% of humus-bound nitrogen would be taken up by phytoplankton and because one to two thirds of the total amount of nitrogen transported to the coast is in the form of dissolved organic, this portion of nitrogen makes a considerable contribution to the eutrophication of coastal waters.

REDEVELOPMENT OF ECOSYSTEMS IN THE PERSPECTIVE OF THE EU WATER FRAMEWORK DIRECTIVE

The first limnological restorative/therapeutic activities had the character of scientific demonstration projects. The developmental history of individual water bodies, including their degradation phase, was well known in these cases. Different types of polluted and lowered lakes, with ecosystems degraded in different ways, were selected to illustrate with what methods they could be restored. Through measures taken within the lake itself – after the external loading had been brought under control – the ecosystem was governed in order to change the structure of the system and give it a lasting function, making the lake suitable to use for specific purposes. The results from the research projects were intended to serve as models for general application of redevelopment methods in society.

Population growth, migration, globalization, and the market economy, in combination with the idea of constant economic growth, are now, as already mentioned, all leading to the destruction of nature and crippling of ecosystem structure and function at a rate never experienced. The landscape as a whole is affected and changing, mostly in such a way that local recycling processes and minimized losses of matter from land to water are replaced by systems characterized by increasing transport of substances from river basins to the sea.

Because environmental degradation takes place at such a rapid rate and in constantly changing ways, legal tools to counteract damage are mostly old-fashioned and inoperative already if and when they appear. Not even the fundamental rule that ‘prevention is better than cure’ has made any breakthrough in the application of environmental legislation. So far, violations of existing environmental laws do not result in any serious penalty. Present laws applied within the environmental sector are mainly based on the political ideology of exploitation of natural resources and economic growth. Furthermore a deplorable lack of ecological knowledge among the members of environmental courts can be demonstrated by the fact that the real purport of ecological prognoses, including multi-stage processes, is not even understood. The position in society of ecology as the basis for sustainable development is very weak.

The recently-launched European Union Water Framework Directive might, however, mean an important step forward: as it implies an attempt to open the eyes of political and administrative decision-makers and force them to see and understand the necessity of a holistic approach to water management. With the river basin as the correct ecological landscape unit and management entity, it creates the basic requirements for a redevelopment of local matter recycling systems. The purpose of the Water Directive (Article 1, a) “is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems”. Among the environmental objectives in Article 4, the principle is that “Member States shall protect, enhance and restore all bodies of surface water” and “protect, enhance and restore all bodies of groundwater”.

The water framework directive and ecosystem redevelopment

Provided the EU Directive is followed, it should demand a tremendous mobilization of redevelopment forces in order to re-establish the ecological balance among the systems of individual river basins.

As a scientific discipline, limnology has always been closely connected to protection, management and utilization of all kinds of inland water bodies. Now, when the EU Water Framework Directive not only states that further degradation of aquatic ecosystems should be prevented but the status of the damaged systems should be improved and protected, this calls for large numbers of experienced limnologists for the large-scale application of redevelopment methods. And when the Directive insists upon ecologically-sound relations among terrestrial and aquatic ecosystems, this requires input of both limnological and paleolimnological knowledge. This is because the primary ecological land-water relationships, on which the character of the aquatic ecosystems is based, have largely become distorted and hidden. However, the archives in peat and sediment deposits are mostly still available for analysis – for obtaining hints on the structure of former connections between terrestrial and aquatic ecosystems.

With a knowledge of past and present conditions available, realistic plans for the best possible environmental redevelopment can be elaborated.

Ecosystem-oriented research demands teamwork to cover as many aspects as possible of systems´ structure and function. Ecosystem redevelopment research offers excellent opportunities to train teams of students of ecology. Basic research intended to give results for direct application has certain advantages: 1) the individual student has to penetrate as deeply as possible into the specific problem he/she has got to tackle; 2) at the same time, the separate investigations are carried out in close cooperation with the other members of the team. Together, this exchange of experiences results in a broad, holistic understanding of structure, function and development of ecosystems as well as the relations between water bodies and catchments. It is also an advantage that the studies mostly have to be carried out and reported within a restricted time and that the research can be continued by studies during and after redevelopment measures have been taken.

Skilled ecologists, having a holistic approach to ecosystems´ function in time and space and trained for realistic evaluation of the possibilities to govern systems according to specific goals, are necessary for the application of the EU Water Framework Directive. Among the model examples of teamwork, mediating the members with a holistic approach to ecosystem development and the ability to grasp the point of governing different types of degraded systems, one is the Eifel Maar project headed by Burkhard Scharf (Scharf & Björk 1992). The study includes the long-term development of lakes and catchments, summarizes earlier ecosystem data, describes the recent processes of degradation, as well as the planning and implementation of measures for reduction of external loading and for in-lake governing of ecosystems. The necessity to cover both time and space in the analytical program – in order to synthesize a true picture of the relations between catchments and lakes – is excellently demonstrated by Scharf in his monograph on the Eifel Maar lakes.

The environmental goal of the EU Water Framework Directive, Article 4, 1a and b, is to restore and protect the surface- and groundwater localities within river basins. To fulfil this goal, it would be necessary to raise the groundwater level over large areas in order to get back wetlands and to re-create earlier systems of local matter cycling, including the metabolic processes which used to result in high quality water.

As is well known, today's agriculture and forestry is far from the recycling model. The former cycling of matter between farm and fields was temporarily, to some extent, transferred to the city and its nearest surroundings. However, the intense urbanization, the global extension of the supporting area of the cities, the introduction of water as the carrier of waste products mixed with toxic substances preclude the reuse of priceless nutrients and organic substances. This fact has long been well known. The development from a recycling society (Schramm 1997) to the recent violent process of change leading to the present situation is in a splendid way described by Mlrald (2000, 2002). He refers to Liebig (1840), Chadwik (1842), Müller (1860), Hugo (l862), von Liebig (1865), Heiden, Müller, von Langsdorff (1885) and other advocates of about l50 years ago for recycling systems. In spite of their powerful input of knowledge and strong arguments brought forward to the present, the one-way transport system – now trafficking global highways by land and sea – the robbery system ('Raubwirtschaft' according to Liebig) has continued and to all appearances become firmly fixed. Therefore, redevelopment of local matter recycling systems in order to restore and preserve the water bodies of the landscape needs a really powerful input of ecological knowledge. Even if a respect for ecological facts was reflected, to some extent, in present environmental legislation, the effect – in the form of landscape redevelopment – will not come off until laws are being mediated by environmental courts with solid ecological competence and power. Local courts still mostly act as justifying organs for a continued exploitation of the landscape, thereby little suspecting and unaware of the long-term consequences for our water resources.

REFERENCES

Andersson G. 1984. The role of fish in lake ecosystems – and in limnology. Nordisk limnologisymposium, Fagerfjell, Norge. *Norsk Limnologforening*, 189–197.

Andersson G. 1985. The influence of fish on eutrophic lake ecosystems. *Proceedings of the International Congress of Lake Pollution and Recovery*, Rome, 112–115.

Andersson G., Berggren H., Hamrin S. 1975. Lake Trummen restoration project. III. Zooplankton, macrobenthos and fish. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 19, 1097–1106.

Andersson G., Berggren H., Cronberg G., Gelin C. 1978. Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. *Hydrobiologia* 59, 9–15.

Bengtsson L., Fleischer S. 1971. Sedimentundersökningar i sjöarna Trummen och Hinnasjön 1968–1970. (Sediment investigations in the lakes Trummen and Hinnasjön 1968–1970.). *Vatten* 1, 73–94 (in Swedish with English summary).

Bengtsson L., Fleischer S., Lindmark G., Ripl W. 1975. Lake Trummen restoration project. I. Water and sediment chemistry. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 19, 1080–1087.

Björk S. 1968. Metodik och forskningsproblem vid sjörestaurering. *Vatten* 1/68, 57–71.

Björk S. *et al.* 1972. Ecosystem studies in connection with the restoration of lakes. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 18, 379–387.

Björk S. 1973. Statens naturvlrdsverks utredning beträffande Hornborgasjöns framtid. Den limnologiska delutredningen. Förutsättningar, metoder och kostnader för Hornborgasjöns restaurering. *SNV PM* 280, 2 (Second ed. 1978.).

Björk S. 1985a. Lake restoration techniques. *Proceedings of International Congress of Lake Pollution and Recovery*, Rome, 281–291.

Björk S. 1985b. Scandinavian lake restoration activities. *Proceedings of International Congress of Lake Pollution and Recovery*, Rome, 373–381.

Björk S. 1988. Redevelopment of lake ecosystems – A case-study approach. *Ambio* 17, 90–98.

Björk S. 1994a. Treatment of overgrown shallow lakes – macrophyte control: Lake Hornborga, Sweden. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB publ.* 32, 154–168.

Björk S. 1994b. Sediment removal. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB publ.* 32, 82–88.

Björk S. 1994c. Restoration of lakes through sediment removal – Lake Trummen, Sweden. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB publ.* 32, 130–140.

Björk S. 1999. Hornborgasjöns restaurering. In Claeson H. (ed.), *Hornborgasjöns krönika – 200 lr med sänkningar, trätor och naturvlrd.* ISBN 91-630-8398-1, 322–378.

Björk S., Digerfeldt. G. 1965. Notes on the limnology and post-glacial development of Lake Trummen. *Botanisker Notiser* 118, 305–325.

Chadwick E. 1842. Report on the sanitary conditions of the labouring population of Gt. Britain. New edition 1965 (M.W. Flinn), Edinburgh.

Carlsson P. 1993. Structuring of marine phytoplankton communities by humic substances and trophic interactions. Dissertation of the Department of Ecology, Marine Ecology, University of Lund.

Carlsson P., Edling H., Béchemin C. l998. Interactions between a marine dinoflagellate (*Alexandrium catenella*) and a bacterial community utilizing riverine humic substances. *Aquatic Microbial Ecology* 16, 65–80.

Claeson H. 1999. *Hornborgasjöns krönika – 200 lr med sänkningar, trätor och naturvlrd.* – ISBN 91-630-8398-1, 380 pp.

Cronberg G. 1982. Phytoplankton changes in Lake Trummen induced by restoration. Long-term whole-lake studies and food-web experiments. *Folia Limnologica Scandinavica* 18, 119 pp.

Digerfeldt G. 1972. The post-glacial development of Lake Trummen. Regional vegetation history, water level changes and palaeolimnology. *Folia Limnologica Scandinavica* 16, 104 pp.

Eiseltová M. l994. Restoration of lake ecosystems – a holistic approach. *International Waterfowl and Wetlands Research Bureau, IWRB publ.* 32, 182 pp.

European Union 2000. Framework directive in the field of water policy. Directive 2000/60/EC. http://europa.eu.int/scadplus/leg.

Heiden E., Müller A., v. Langsdorff K. 1885. Die Verwerthung der städtischen Fäkalien. Hannover.

Hertzman T., Larsson T. 1999. Lake Hornborga, Sweden – the return of a bird lake. *Wetlands International Publication* 50.

Hrbácek J. 1962. Species composition and the amount of the zooplankton in relation to the fish stock. *Rozpravy CSAV* 72, 116 pp.

Hrbácek J., Dvorakova M., Korinek V., Prochazkova L. 1961. Demonstration of the effect of the fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 14, 192–195.

Hugo V. 1862. Les misérables. (Part 5, book 2, p. 184–209). Collection Nelson, Edinburgh.

Hupfer M., Scharf B.W. 2002. Seentherapie: Interne Maßnahmen zur Verminderung der Phosphorkonzentration. Handbuch Angewandte Limnologie 14, Erg. Lfg. 4/02, 1–67.

Kairesalo T., Vakkilainen K. 2004. Lake Vesijärvi and the city of Lahti (southern Finland). Comprehensive interactions between the lake and the coupled human community. *SIL (Societas Internationalis Limnologiae) News* 41, 1–5.

Liebig J. 1840. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie. Braunschweig.

Liebig J. von. 1865. Letters on the subject of the utilization of the metropolitan sewage, addressed to the Lord Mayor of London. London.

Lindmark G. 1984. Acidified lakes: Ecosystem response following sediment treatment with sodium carbonate. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 22, 772–779.

Lindmark G. 1990. Soda ash briquettes in lake sediments – a new approach in reclamation of acidified waters. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 24, 173–178.

Lindmark G. 1993. Soda ash for mitigation in acidified waters. Long-term lake response and efficiency. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 25, 494–499.

Mlrald E. 2000. Jordens kretslopp: Lantbruket, staden och den kemiska vetenskapen 1840–1910. (Cycles of Earth: Agriculture, the city and chemical science, 1840–1910.). *Idéhistoriska skrifter* 33, Dept. Historical Studies, Umel, Sweden, 261 pp (in Swedish with English summary).

Mlrald E. 2002. Everything circulates: Agricultural chemistry and recycling theories in the second half of the nineteenth century. *Environment and History* 8, 65–84.

Müller A. 1860. Gödselboken eller grunderna för gödselämnenas behandling i städer och pl landet. Stockholm.

Ohle W. 1955. Die Ursachen der rasanten Seeneutrophierung. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 12, 373–382.

Ohle W. 1965. Nährstoffanreicherung der Gewässer durch Düngemittel und Meliorationen. *Münchener Beiträge* 12, 54–83.

Ohle W. 1971. Gewässereutrophierung. (Water bodies and their surroundings as ecological units in their importance for the eutrophication of waters.) *Gewässerschutz, Wasser, Abwasser*, Aachen, 437–456.

Ohle W. 1972. Zur Seentherapie – Ein Forschungsprojekt am Grebiner See. *Schrift des Max-Planck-Instituts für Limnologie anläßlich des Besuchs des Symposium Semisaeculare der Societas Internationalis Limnologiae in Plön am 4. Oktober 1972*, 49–52.

Pettersson B. 2002. Kärrhökars boplatsval i Hornborgasjön före och efter restaureringen. *Vlr flgelvärld* 2, 24–25.

Pokorny J., Hauser V. 1994. Restoration of lakes through sediment removal – Vajgar fish pond, Czech Republic. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 141–153.

Ripl W. 1976a. Biochemical oxidation of polluted lake sediment with nitrate. A new restoration method. *Ambio* 5, 132–135.

Ripl W. l976b. Prozeßsteuerung in geschädigten See-Ökosystemen. *Vierteljahresschrift der Naturforschenden Gesellschaft Zürich* 121, 301–308.

Ripl W. 1994. Sediment treatment. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 75–81.

Ripl W., Lindmark G. 1979. The impact of algae and nutrient composition on sediment exchange dynamics. *Archiv für Hydrobiologie* 86, 46–65.

Scharf B., Björk S. (eds.) 1992. Limnology of Eifel maar lakes. *Archiv für Hydrobiologie/Ergebnisse der Limnologie* 38. 348 pp.

Scharf B.W. 1996. Seentherapie. Habilitationsschrift, Technische Universität Braunschweig, 1–3.

Schramm E. 1997. Im Namen des Kreislaufs: Ideengeschichte der Modelle vom ökologischen Kreislauf. Frankfurt am Main.

Stepanauskas R. 2000. Utilization of terrestrially derived dissolved organic nitrogen by aquatic bacteria. Dissertation 1041, Depertment. of Ecology, Limnology, Lund University. 115 pp.

Swanberg P.O. 1973. Hornborgasjön som flgelsjö. Ornitologisk undersökning i Statens naturvlrdsverks utredning om sjöns framtid. *SNV PM* 280, 3 (Second ed. 1978).

Swedish Environmental Protection Agency 2001. From swampy pits and mosquito-hells to flourishing wetlands. An evaluation of work towards an environmental quality objective. *SEPA, Report* 5146 (In Swedish with English summary).

Thomas E. 1955. Stoffhaushalt und Sedimentation im oligotrophen

Aegerisee und im eutrophen Pfäffiker- und Greifensee. *Memorie dell'Istituto Italiano di Idrobiologia, Supplement* 8, 357–465.

Thomas E. 1963. Experimentelle Untersuchungen über die Schlammbildung in unberührten und kulturbeeinflussten Seen der Schweiz. *Wasser und Abwasser*, 1–21.

UNESCO-MAB Conference on Ecosystem Redevelopment: Ecological, Economic and Social Aspects, 5-10 April 1987, Budapest, Hungary.

Verner B. 1994a. Aeration. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 69–75.

Verner B. 1994b. Aeration of the hypolimnion as a tool for restoring eutrophic lakes. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 119–129.

Wolter K.-D. 1994a. Phosphorus precipitation. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 63–68.

Wolter K.-D. 1994b. Restoration of eutrophic lakes by phosphorus precipitation – Lake Gross-Glienicker, Germany. In Eiseltová (ed.) *International Waterfowl and Wetlands Research Bureau, IWRB, publ.* 32, 109–118.