

Sven Björk

Limnological Methods for Environmental Rehabilitation

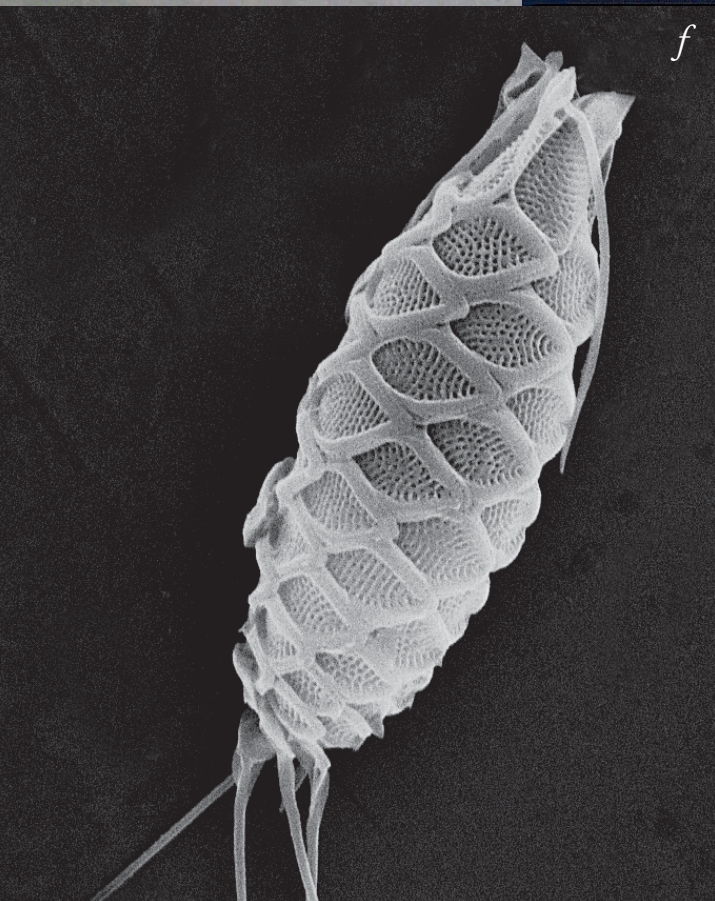
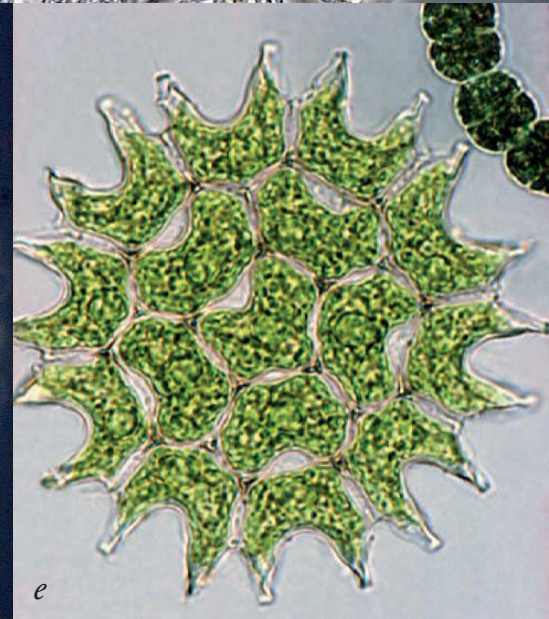
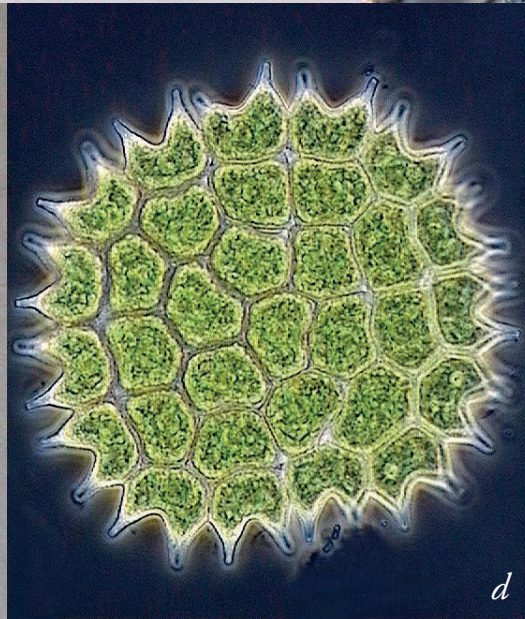
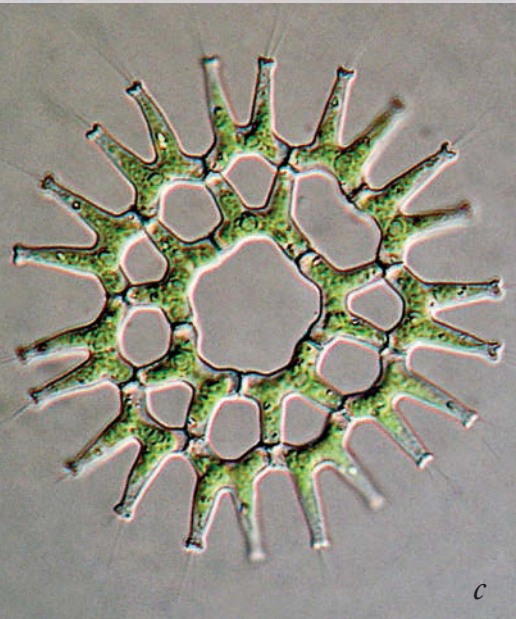
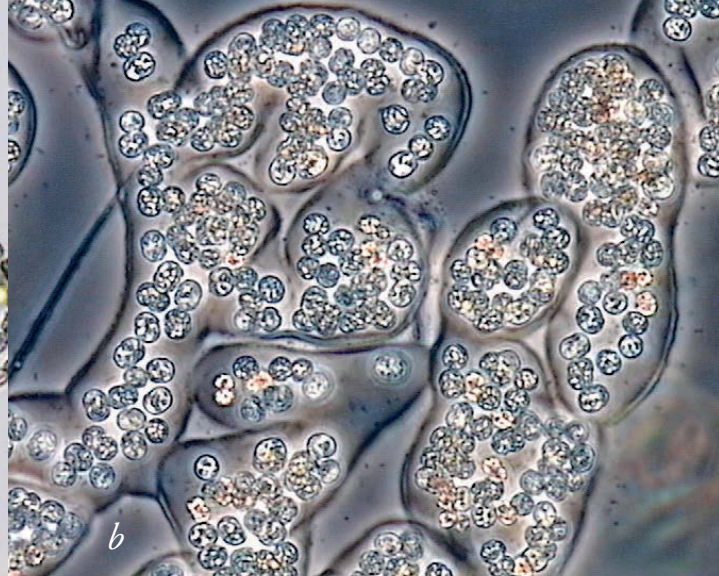


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Limnological Methods for Environmental Rehabilitation

The Fine Art of Restoring Aquatic Ecosystems

Sven Björk



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With 489 figures and 17 tables



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Limnological Methods for Environmental Rehabilitation:
The Fine Art of Restoring Aquatic Ecosystems

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Front and back cover picture series: Lake Hornborga over 45 years, 1967-2012 (see chapter II 1. B.)

Back cover: Diffuse aeration/de-stratification to increase the oxygen concentration of shallow lakes. – From Atlas Copco 1985.

Inner covers and flyleaves: “Before the thunderstorm”. Photo: Hans Berggren/N.

Page 2. Lake Trummen, examples of phytoplankton species.

a) *Anabaena lemmermannii*, b) *Microcystis wesenbergii*, c) *Pediastrum angulosum*, d) *Pediastrum boryanum*, e) *Pediastrum duplex*, f) *Mallomonas eoa*, g) *Dinobryon divergens*. - From Gertrud Cronberg.

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Dedication to the City of Växjö

The book is dedicated to those city fathers in Växjö, who enabled the restoration of Lake Trummen.



Sten Sandström, Sten Tengwall, and Arnold Guntsch

“The Greenest City in Europe is the result of all the environmental work that has been and will be carried out in Växjö, both private and public”. So the BBC coined the concept of Växjö, in agreement with the European Union which in 2007 bestowed its inaugural award for sustainable development on the city. But green policy started with the transformation of a green lake to a blue one.

During the 20th century the green colour was a *signum* for an integral part of the Växjö city landscape, namely its lakes. Although the city shared this phenomenon with many other cities, very early the Växjö chain of problematic lakes became the subject of scientific investigations and were diagnosed as being sick due to overfeeding.

Lakes are the true eyes of the watershed, reflecting the state of the surrounding landscape, including its natural character and all the various activities of man. As reliable indicators of the health of the landscape as a whole, lakes respond by colour. Among these the colour green does not mean OK. On the contrary it is a warning, especially when it turns into the bluegreen tone caused by cyanobacteria, in which case it indicates a very troublesome sickness, causing oxygen deficiency with fishkills and unpleasant odours. This was the message mediated by the Växjö lakes, in the case of Lake Trummen until 1970.

In the second half of the 1960s, the Trummen problems had to be solved in conjunction with the planning of a hospital, a university campus and residential areas in the immediate vicinity of the lake. At this juncture a

most stimulating ecological-political-administrative co-operation was initiated, with the aim to transform Lake Trummen from a serious environmental problem to a much appreciated, environmental asset. For the Institute of Limnology and other ecological departments of the Lund University this involved the type of basic and applied research

which provided a spring-board to global activities.

In all respects, the Lake Trummen restoration project holds the prominent position of prototype and model for treating a sick lake ecosystem back to health. The co-operation among ecologists, politicians and administrators was outstanding. In this team-work it was most stimulating for the ecologists to experience a complete comprehension of the structure and function of ecosystems, the necessity to accomplish eco-surgical operations and to respect the ecological prognoses presented. The political unanimity concerning environmental improvement was impressive.

In community efforts to secure a sustainable environmental future it is logical to start with the lakes, to turn them blue. They will then function as indicators, recording how successful the greening management of the catchment is. Växjö is blessed with such indicators even in the heart of the city where Carl Linnaeus started his schooling on May 10, 1716. Today the Linnaeus University, founded close to the south-western shore of the restored Lake Trummen, has about 25 000 students.

In grateful appreciation of the smooth co-operation with the common goal to restore Lake Trummen, the ecological team dedicates this book to the memory of Sten Sandström, Chairman of Växjö Finance Department, Sten Tengwall, Director of Växjö Building Construction and Arnold Guntsch, PhD, Headmaster and Växjö City Councillor.

Sven Björk

I. The Fine Art of Restoring Aquatic Ecosystems

Historical Notes

Already in the nineteen-tens Einar Naumann, biologist at the University of Lund, Sweden, made it clear that the ecological character of lakes, with their environmental conditions and communities of organisms, reflect the character of their drainage basins. The results of his studies on regional limnology and production biology led him to the introduction of the useful terms *eutrophic* and *oligotrophic* lake types, *i.e.* lakes rich in plant nutrients and with a high production of organic matter and lakes poor in nutrients and with a low productivity, respectively. He described the function of the lake ecosystem long before the term ecosystem was launched and stressed how important it is that results of basic research on freshwater systems be applicable to the protection of freshwater resources. In 1921 Einar Naumann suggested the foundation of the International Association of Theoretical and Applied Limnology. Together with the German Professor of Hydrobiology, August Thienemann, the idea was realized the following year. In 1929 Naumann was appointed professor at the University of Lund, the first in the world with the title Professor of Limnology. He died already in 1934.

In the argumentation for the necessity of a permanent chair of limnology at the University of Lund, the importance of limnological research for rational management of freshwater resources and, of course, for training of limnologists to make this possible, was stressed.

Sven Thunmark was appointed Einar Naumann's successor. During and after World War II Swedish lakes and rivers became more and more heavily loaded by sewage and untreated industrial waste water. Especially the paper pulp industry caused tremendous damage to river systems. Now Thunmark energetically acted as a teacher, also of engineers, and for the construction of efficient wastewater treatment plants. It was very hard work, easier to convince politicians on the shores of lakes nearest those towns and cities in which they hoped to be re-elected, but more or less impossible to reach industrial leaders. Gradually a boom of construc-

tion of sewage treatment plants for phosphorus removal was initiated. The numerous cellulose industries polluting inland waters closed down, and joined into much smaller number of much bigger units. Giant industries were constructed on the shores of the Baltic, a recipient considered big enough to swallow the waste, now with access to stepwise better treatment methods.

According to guiding principles presented by the Swedish government at the time when the senior author of this book became the successor of Sven Thunmark, a sufficient number of students should receive a training enabling them directly to take up positions outside the universities. However, greenhouse products needing a long acclimatization and schooling period before becoming realistic and productive professionals of water management should be avoided.

In 1967 the office of the Chancellor of the Swedish Universities presented to the Government the official report "Development Plan for the Biological Basic Research Sector" (Biologiutredningen, 1965). Concerning limnology it states that modern limnology is to a great extent characterized by a dynamic outlook with the ecosystem as the natural unit. The limnologist does not stop at the analytical stage but synthesizes the results to reach a general picture of the function of the ecosystem. There is no distinct limit between theoretical and applied limnology because the results of basic research can be directly applicable, while applied research often has to solve problems of theoretical interest. It is stressed that limnological research and experts are needed for the planning and accomplishment of water conservation and protection. "There is need for massive efforts of research and technology to put an end to the present misuse of water resources." That after the government experts (appointed in 1965) had come to these conclusions, it is surprising that they suggested the chair of limnology at the Lund University should be withdrawn. The experts' suggestion was, however, not granted.

It is quite unnecessary to stress that there is, all over the world, still (2013) a great need for heavyweight limnologists able to bridge the gap between theory and practice. They must be able to solve practical problems at all levels, from planning to management of water resources.

As professional limnologists in society must cooperate with and convince politicians, administrators and engineers, they must explain the causes of problems and the methods to solve them in a simple, understandable way, free from what is considered academic snobbery. Otherwise the results of basic limnological research will be preserved within the protected workshops of university institutes.

Because so few limnologists trained at Swedish universities are able to get positions and remain at academic institutions, it was necessary to try to prepare the majority of the doctoral candidates for their coming life as professionals in society. One way of doing this was to apply a program that for some decades was followed at the Institute of Limnology in Lund. Since the middle of the 1960's efforts were made at this institute to combine training and research in basic and applied limnology within the framework of projects for restoring and managing lake ecosystems. The doctoral students worked together in teams. Through ecosystem-oriented investigations they got broad experience in the systems' structure and function while at the same time penetrating the sector of their own research in depth. A very essential point was learning about the diversity of ecosystems which required that generalizing and theorizing was done with great care. Through the development of different kinds of restoration methods tailor-made for differently affected lakes and wetlands, a vivid picture of the response pattern of ecosystems was gained in before-and-after studies. The projects were carried out in the field in communication with politicians, administrators and engineers, who automatically kept the students responsible and close to realistic levels in their ideas and suggestions for lake management.

Training of limnologists for professional assignments takes time, at least 5 years beyond the three years of basic studies in general biology, including 30 weeks' full-time training in general limnology. During their post-graduate period the students should also gain experience of subtropical and tropical systems as well as sub-arctic lakes and wetlands.

The very first restoration project was initiated in the light of a small article describing restoration principles and the establishment of an ecological inter-disciplinary teamwork for the redevelopment of the severely polluted lake ecosystem of the Swedish Lake Trummen type (Björk 1966). In order to get more arable land in Sweden, the water level in thousands of shallow lakes was lowered in the late 19th and early 20th centuries. These waters became rapidly overgrown, above all by the common reed (*Phragmites australis*). After the senior author had defended a PhD-thesis on the ecology of the mentioned species (Björk 1967), he was asked by the Swedish EPA to investigate the possibilities to restore the drained Lake Hornborga (Hornborgasjön) to the ecological characteristics it used to have as a famous bird lake. In this way Hornborgasjön became our second research project for demonstration of lake restoration methods and their results. As the international interest in redevelopment of damaged lake ecosystems increased, we were also asked to design several projects abroad, in every case tailor-made according to structure and function of the specific ecosystem.

When organizing the research teamwork it was quite clear that much research must be devoted to the role of the sediment in the metabolism of lake ecosystems and that lakes in several cases could be managed *via* the sediment. In this connection, and because the sediment archive reflects the developmental history of the lake, a long-term, very fruitful co-operation was established between the Departments of Limnology and Quaternary Geology at Lund University.

From Restoration of Individual Ecosystems to Redevelopment of Landscape Units. Terms and Aims.

Already in the earliest days of limnology, with regional limnology as the main field of research, it was, as mentioned above, 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 catchments to lakes, means

that the littoral zone 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 catchments are reflected. Thus, the management of lake and wetland ecosystems has to start on land.

When lakes close to cities and municipalities became overloaded by sewage and industrial waste-water - 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 catchment area 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 sewage treatment plants, equipped with phosphorus precipitation and nitrogen removal technology, were in Sweden successively constructed in order to save lakes and return them as environmental assets. In some cases the polluted lakes were no longer utilized as receivers of sewage and industrial waste-water, as this was entirely diverted and treated elsewhere. However, it sometimes turned out that not even complete diversion would save lake ecosystems; in spite of the considerable investments in the construction of treatment plants the systems 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 waste-water resulted in recovered lakes. Well-known international 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 Mjøsa (Norway), Lake Constance (der Bodensee in 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, constituted 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 generally impossible to reinstate 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 any 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 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. In lakes where the water level has been lowered, in-lake operations often means corrective treatment of the damaged bottom. Hypolimnetic aeration (*i.e.* aeration in the hypolimnion, with or without addition of precipitating agents), artificial circulation through bubbling, treatment of the sediment to control 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.

Sometimes the term *lake therapy* rather than restoration is used - pointing out that it is impossible to treat a collapsed 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).

Scharf (*op.c*) also rightly criticizes opportunistic terms (like 'biomanipulation') and cosmetic methods pretending to bring a lake back to health. He exemplifies this in the following illustrative way: "As in the case of almost every [clock] movement, also in the case of eco-technical [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 waterfleas instead of by way of expensive sewage-treatment plants". 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 regional 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 lake-shore 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 doctor's treatment of a human patient. In both cases the past history of the disease, an *anamnesis*, has to be established. This should include all relevant internal and external facts about the patient. These facts are necessary for a well-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.* a documentation of the history of the patient subsequent to treatment and recovery. Such documents, including also all mistakes and unforeseen problems, have to constitute the foundation of experience 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 doubt, 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 give other correctly-applied methods that are used to achieve sustainable results a bad reputation. *Catamneses* that describe a true return from miserable to promised good conditions are still rare.

The application of therapeutic terminology to limnological healing brings with it a special advantage, namely its high pedagogic value in efforts to mediate an understanding to the general public of how important it is to care and treat aquatic ecosystems. A doctor's 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 balanced metabolism.

The aim of true restoration projects is to attack the roots of the evil and to direct 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 stated that the treatment is a temporary measure to overcome an acute problem. The main thing is that a well-functioning ecosystem is redeveloped in lasting harmony with the catchment. It is not necessary that, in detail, it must be exactly the same as in the former, juvenile landscape. 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 and sustainable environmental conditions are reestablished. As a rule the restorative measures imply the reestablishment of a lake - according to current local interests - for which it was previously suitable before its degradation (Björk 1968, 1988). The design for the ecosystem 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 provide a broad understanding among different audiences of the message that the landscape must be healed and carefully treated. This should facilitate the explanation for the necessity to get both the external and internal loading under control and to redevelop a lake according to regio-limnological 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.

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; in this book described as the Lake Trummen and Lake Hornborga projects in Sweden. The developmental history of the 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 then selected to illustrate the methods by which they could be restored. Through measures taken within the lake itself - after the external loading had been brought under control - the ecosystem was managed in order to change the structure of the system and give it a lasting function, making the lake suitable for use for specific purposes. The results of the research projects were intended to serve as models for general application of redevelopment methods.

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 before experienced (Fig 1-2). 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 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 overall political ideology of exploitation of natural resources for job generation 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 significance of ecological prognoses, including multistage processes, is not even understood. The position in society of ecology as the basis for sustainable development is very weak.

The European Union Water Framework Directive might constitute a 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 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".

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 basins.

As a scientific discipline, limnology has always been closely connected to protection, management and uti-

lization 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 also that 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 between 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 the 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 been given 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 experience results in a broad, holistic understanding of structure, function and long-term 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 the function of ecosystems 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.

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

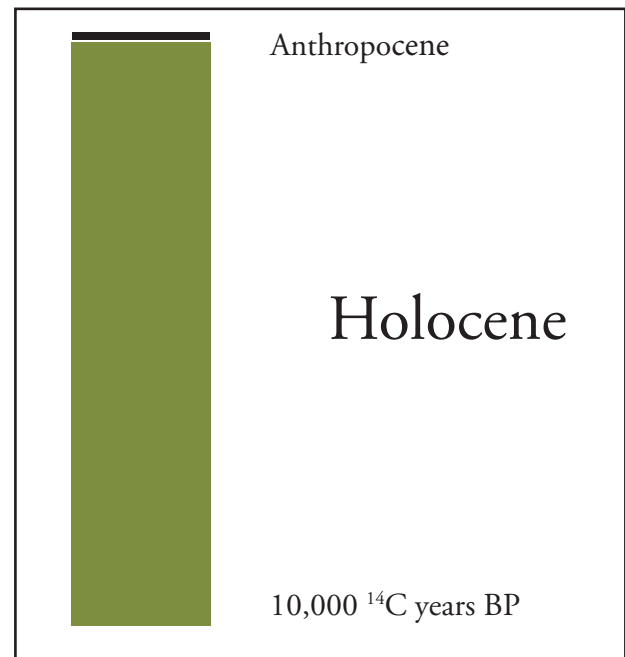


Fig 1. Holocene, the present geological era following the latest glacial period, began ca. 10 000 ¹⁴C years BP (Before Present), i.e. ca. 11 500 calendar years ago. Anthropocene is the denomination of the short, most recent period of devastating human impact on the environment.

extent, transferred to the city and its nearest surroundings. However, the intense urbanization, the global extension of supporting area of 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 Mårald (2000, 2002), who refers to Liebig (1840) etc. Instead of local recycling of matter, the one-way transport system - now trafficking global highways by land, sea and air - the robbery system ('Raubwirtschaft' according to Liebig), has continued and to all appearances become firmly fixed. Therefore, redevelopment of the recycling of local matter in order to restore and preserve the water bodies of the landscape needs a really powerful input of ecological knowledge.

Even if, to some extent, respect for ecological facts was reflected in present environmental legislation, the effect - in the form of landscape redevelopment - will not be realized until laws are drafted by environmental courts with solid ecological competence and power. In Sweden local courts still mostly act as justifying organs for a continued exploitation of the landscape, without suspecting or being aware of the long-term consequences for our water resources.

Anthropogenic Lakes and Wetlands

The introduction by the limnologist, phycologist and paleoecologist Eugen Stoermer of the term *Anthropocene* as the denomination of the present epoch was, indeed, very welcome. He had been using the term in his lectures since the 1980s at the Center for Great Lakes and Aquatic Sciences, University of Michigan, to describe the current time in Earth's history. It includes the recent period during which man's rapacity and ruthless exploitation has disabled the function of the globe's ecosystems (Fig 1-2).

The need for a terminological manifestation to stress the man-made impoverishment of our common living-space has hatched several suggestions of denomination. Among these *Anthropocene* has been widely spread and accepted after Stoermer's term was launched in an article together with Paul Crutzen, Professor at Max Planck Institute, Mainz. Crutzen made his academic career in atmospheric chemistry at the Meteorology Institute of Stockholm University and was in 1995 one of the Nobel Prize winners in Chemistry.

"To assign a more specific date to the onset of the 'anthropocene' seems somewhat arbitrary, but we propose the latter part of the 18th century [the Industrial Revolution], although we are aware that alternative proposals can be made" (Crutzen and Stoermer 2000). Starting with the 'industrial revolution' and expanding to the present boundless global economic-technical exploitation of natural resources, this epoch is characterized by all the destructive effects which make the future environment precarious. And this situation has been created by economic-political forces using the slogan 'economic growth'; a term lacking definition and goal.

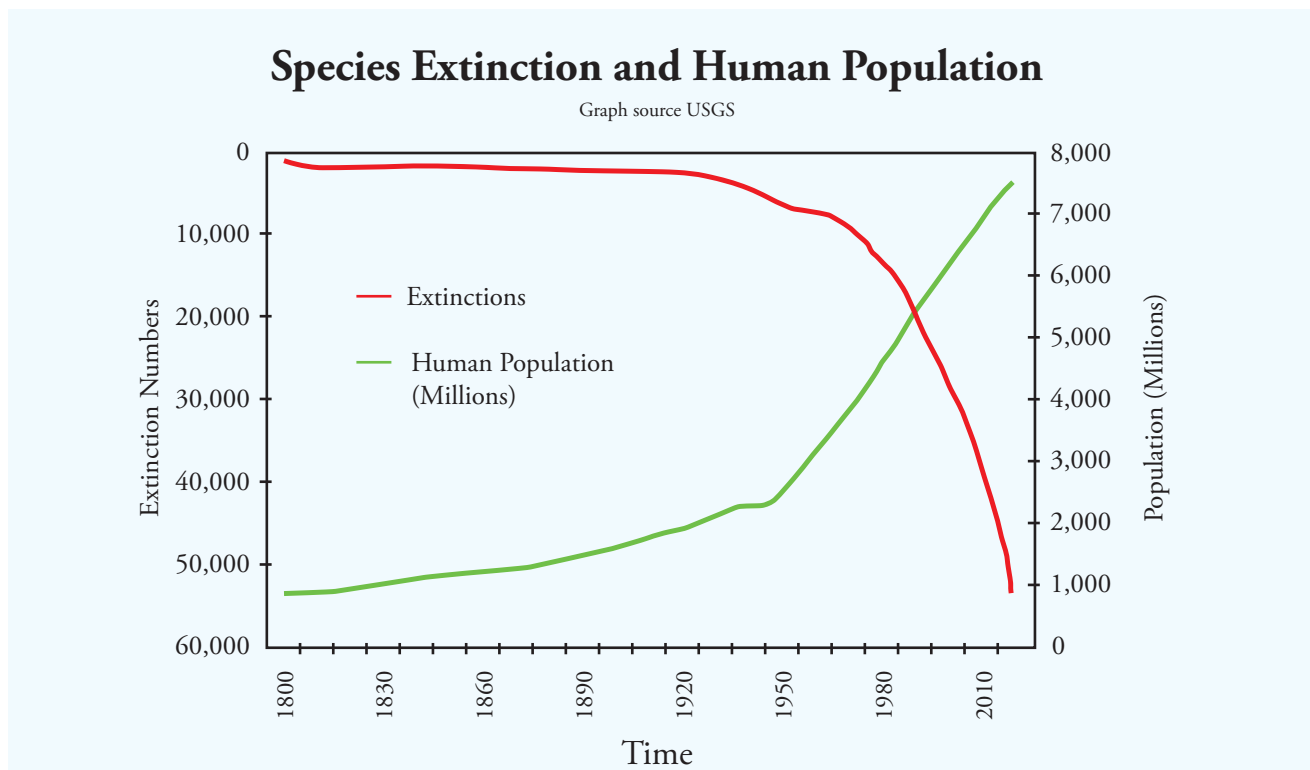


Fig 2. Irreversible habitat destruction results in species extinction and loss of ecosystem services.

It is a most remarkable example of lack of analytical mental exertion that this slogan has so uncritically been accepted in spite of the obvious fact that its application within a restricted space is an absurdity. At the same time the computer-stored multi-milliard figures for economic transactions are losing cover in the form of natural resources.

The change of the globe's environment is escalating at a speed which is increasing year by year with many ecological processes auto-generating. The increase in food production has resulted in the well-known population explosion; in 50 years the global population has doubled to about 7 000 million. The population is now increasing at a rate of net 1 million in 4 days and 1 000 millions in 13 years. This is also the number of new jobs political parties and governments have to create at the same time as industries and companies favor automation, in the common efforts also in the planning of society to slim every organization.

It is no wonder that the mass extinction of species (Fig 2) cripples the function of aquatic and terrestrial ecosystems. Add to this CO₂-emission, global warming and sea-level changes, which at present catch most of the environmental interest of the man in the street. Urbanization, drainage of lakes and wetlands, extraction of groundwater, infiltration into the ground of a variety of substances, straightening of brooks and rivers, acidification of inland waters and the sea, industrialized, uniform forestry and agriculture countrywide, road construction, landscape fragmentation, unlimited traffic increase, exhaustion of fish populations etc. etc. All this is done under the banner with the slogan "Unlimited Economic Growth", into the blind alley

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, further exploitation, meaning continuous ecological decline, takes place at a constantly accelerating rate. So far, the drawing up of red lists of endangered plants and animals and the recording of successively-extirpated species are the generally most well-known signs of ecologists' efforts to point out the negative structural changes in the landscape. Holistic syntheses of the functional conversion and disabling of the ecological function of the landscape are however, still largely missing. This is un-

derstandable, 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 are not at all so dramatic and instantly evident as, for example, the directly observable collapse, within a couple of decades, of a city lake ecosystem overloaded by sewage.

When prognoses, describing the complex ecological effects on the landscape of exploitation are presented, it is in Sweden today difficult to achieve any degree of understanding among politicians or in the environmental court-room. In the 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 than simple, direct cause-and-effect relationships. It is an embarrassing fact that the Swedish environmental judicial system includes not a single ecologist with competence at the post-doctoral level. Because of the lack of ecological knowledge, the members of the court cannot be expected to grasp 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.

"A global agenda for change" - this was what the World Commission on Environment and Development was asked to formulate. It was an urgent call by the General Assembly of the United Nations: to propose long-term environmental strategies for achieving sustainable development by the year 2000 and beyond" (Our common future, 1987). Now, in 2012, the Rio+20 conference gathered 45 000 people for summing up the results of Rio I and 'discuss' the future. The results of the political negotiations are characterized as vague and lacking concrete proposals.

In spite of political mega-conferences there is no doubt, that the destruction of the world's ecosystems continues because globalization and the oligarchic economy with ruthless power rules the 'development'. Against a restricted number of persons and companies governing the exploitation, political counteractions are useless because the political forces are not reliable, full of renegades and traitors as they are. The ultimate reason for this is, of course, that knowledge about ecological connections is so weak and has such a powerless position

in society, that it is regularly neglected. Very typical for nature-destructive companies is the manner in which isolated facts concerning ecological processes are used in efforts to make their ravaging operation respectable. A well-known example from Sweden is the statement by the forest industries that their mode of forestry, *i.e.* clear-cutting and uniform spruce plantations, creates a better climate. Today such messages are delivered to the public and politicians via specially trained PR-people (often blonds); a lady who ingratiatingly explains how important the industrialized forestry is for accumulation of CO₂ - without mentioning the irreversible damages caused by draining, ground treatment destroying soil stratification and vegetation, monocultures instead of biodiversity etc.

At the time of the UN Conference on the Human Environment in Stockholm 1972 serious general interest in environmental protection was demonstrated in Sweden, namely, to stop further environmental destruction and to repair what had been damaged. Under skilled and powerful direction by the National Environmental Protection Agency, founded in 1967, efficient sewage treatment plants were constructed all over the country and the big lake restoration projects in the Lakes Trummen and Hornborgasjön were started immediately. Compared to the intensive activity during the period under skilled leadership starting in 1967, the later input of initiatives and activities by the Swedish EPA make a tame impression.

From January 1, 1999, a new Environmental Code, conforming with EU-directives, came into force in Sweden. As already mentioned, the ecological intentions of the code have, however, not been put into action. And in Sweden, in the second decade of the second millennium, the legislation governing forestry causes tremendous ecological damage. Furthermore, the Swedish Government proposes:

- that laws for the protection of the littoral zone of inland and coastal waters and
- that laws for the protection of relics of antiquities be relaxed,
- that the demand for Environmental Impact Assessment be simplified in order to make the planning process for construction of roads etc. quicker, and
- suggests to stop printing of The National Encyclopedia of the Swedish Flora and Fauna, *i.e.* the com-

plete bunch of keys to the knowledge of biological diversity in Sweden. The consequences of these suggestions are further described below, under the title "III Conditions and Actions Aggravating Anthropogenic Nature. Examples from Sweden" (p. 328).

Political decisions concerning environmental issues are generally made on the basis of arguments rooted in economics and, therefore, are typically short-sighted. Ecological prognoses are missing or simply neglected. Ecosystems' adaptation to man-made changes in the prerequisites for biodiversity and efficient function are sometimes immediately evident, but often very slowly noticeable. For ecologists it is, in this respect, a great fortune to experience long periods of observations on the ecological stability and changes of a landscape. As a simple but convincing example of this the author of this book has experienced the following revolutionizing changes in the Southern Swedish landscape. In the nineteen thirties and during a period after World War II one of the summer duties of the author was daily to clear the windscreen of his father's car from crushed insects. In spite of low speed and short rides, the screen became besmeared. Still in the nineteen fifties the graphic designer of this book (HB) had the same summer task at gas stations, an attractive job because of the tips. Today we can drive a whole day along the same roads without getting any spots on the screen. During one single generation the biodiversity of the forests along the roads have changed completely, from mixed deciduous-conifer to dense uniform, industrial spruce monocultures deprived of plant- and animal species. The political acts passed, according to which the forests are doomed to be managed, have brought about these radical changes in the landscape.

As the changes of the anthropogenic landscape escalates it becomes more and more difficult to correct the mistakes. In the forests the podsol filter is broken up by giant machines before the planting of new spruce generations, the natural ground vegetation is replaced by a needle felt and the water leaking from the intensively drained plantations and drained peaty wetlands is turned brown by humic matter and iron. At the same time the soils of the chemically treated agricultural landscape, also with drained wetlands and sterilized biodiversity, is leaking nutrients and biocide rests. The landscape is bleeding.

An ultimate form for environmental destruction is landscape dewatering leading to desertification and climate change. The problem is analysed in Kravčík *et al.* 2007: "Water for the recovery of the climate – A new water paradigm".

Thus, in spite of all international conventions and meetings - concerning sustainable development, global climatic change, biological diversity etc., all with Swedish political leaders speaking - the present Swedish Government disarms the defense to secure a sustainable development on the basis of an ecologically sound environment. The prospect to correct ecological mistakes and to restore lakes and wetlands becomes more and more difficult, because - in the anthropogenic landscape - the catchments have often been so radically transformed and ecologically impoverished, that the prerequisites for successful redevelopment of the waters have got lost. One is no longer dealing with catchment damage possible to repair, now damage in the form of an irreversible blockade of primary nature resources prevents restoration of whole landscape units. The author exemplifies this by the description (Chapter III E) of the long-term consequences following the construction of a four-line highway across a wetland which, before drainage, was characterized by unique biodiversity and its efficiency as an ecological filter. The permission for this road construction was based on the fact that ecological arguments were totally disregarded, also in the court of environmental law (p. 336).

There is no doubt, the arguments for the introduction of a specific name for the present epoch, Anthropocene, are well-grounded. The impoverishment and disabling of ecosystems and natural resources has not stopped. On the contrary, present and projected degradation of the formerly living landscape becomes more and more grave.

Among measures suggested to cure the lack of comprehension of ecological management in the design of the society, improvement of education in biology at all levels in schools is most often demanded. It is striking that not only politicians but civil servants and community clerks as a rule have passed a curriculum completely void of even basic biology in school. When serving in their positions in the society it is for them, in the totally dominating atmosphere of economic thinking and act-

ing, not even possible to understand ecological arguments. When appointing a Minister for Justice it goes without saying that a jurist is selected. But in the case of a Minister of the Environment there are no demands for ecological knowledge. After the establishment in Sweden in 1987 of a Ministry for the Environment 10 ministers have until 2013 been appointed; 2 Bachelors of Law, 3 Masters of Political Science, 2 economists and 3 politicians in general.

Although the ministry has access to Divisions for Climate, for the Natural Environment and for Environmental Analysis as well as a plethora of governmental agencies and foundations, economic-political aspects rule the decision-making, not the holistic ecological approach necessary to ensure a sustainable development.

In spite of this, the Ministry declares, in the 2012 internet information about its intentions, that "*Sweden aims to be the green forerunner. Entrepreneurs and politicians in other countries will turn to this country, to Sweden, to find out how to respond to the environmental issues of the future. It is here that solutions and ideas will be found for reducing emissions from our cars, phasing out hazardous chemicals, preserving nature and cleaning our seas. We will show that it is possible for a rich, industrialized, high-tech country to develop in harmony within the boundaries of the natural environment.*"

The possibilities under the present strict economic-political leadership in a realistic way to preserve the Swedish natural environment, to clean our seas and to develop in harmony within this natural environment are described below, under the heading "Conditions and Actions Aggravating Anthropocentric Nature. Examples from Sweden" (p. 328).

The Lund lake restoration team was lucky to start in the 1960s, during a period characterized by an honest wish to redevelop degraded ecosystems in order to secure a sustainable function for the future, in its turn dependent on ecologically harmonic relations between the aquatic units and their terrestrial catchment areas. And the team had the fortune to start the ecological investigations and restoration activities in Lake Trummen in Växjö, the city governed by politicians and administrators with the goal to make the environment ecologically sustainable.

II. Restoration Projects

Possibilities and Problems to Realize Limnological Restoration Projects

The complete accomplishment of a project for sustainable restoration of a lake or wetland is not only to carry out analytical ecologic investigations of an ecosystem, to synthesize the results into diagnoses and to transform the plan into remedial actions. Experience of numerous more or less fully developed projects has provided extensive information on several associated problems. For instance, sudden changes in political command can interrupt the accomplishment of a project, and unskilled contractors entering the project can make mistakes, jeopardizing the ecological goals.

For the team working ecologically on designing the restoration plan it has often been a problem to communicate the basic ecological argumentation concerning the application of specific methods and precautionary measures. And worst of all is the situation when the restoration plan is communicated by administrators to contractors not chosen on the basis of documented experience and knowledge but because they presented the lowest bid or referred to political or other infrastructural relations.

Whenever possible the status of the systems to be modified, the methods of treatment and the recovered ecosystems are in this book described by pictures.

Selected Examples of Projects

1. *Swedish Model and Demonstration Projects*

A. Lake Trummen.

Trummen was selected as the representative for the group of lakes polluted by sewage and transformed to a hypertrophic ecosystem suffering from the typical symptoms, namely heavy blooms of cyanobacteria in summer and oxygen deficiency in combination with fish-kills in winter.

In spite of the fact that sewage discharge had been stopped, the lake did not recover. Without limnological healthcare the ecosystem had remained irreversibly damaged. The heavy internal loading was cured through suction dredging.

In the case of the Trummen project some basic analytical data are included. As to the other projects described here the rule has been not to burden the descriptions with information which nevertheless must form a vital constituent for the ecological diagnoses and prognoses. In general the aim in this book is to provide information about problems, solutions and whenever possible, long-term results, while the detailed analytical material remains in the reports and publications included in the lists of papers for "Further reading" at the end of the book.

B. Lake Hornborga.

This lake is the typical representative of the great number of Swedish waters and wetlands in which the water level has been lowered or the objects have been completely drained, as a rule with the dream to obtain arable land.

A perfect team-work resulted in a restoration plan approved by the Government and parliament. The recommended ecological treatment included bottom restoration and a rise in the water level. This plan was, however, replaced by a course of action which transformed the lake into a series of new and serious problems. Now it is again necessary openly to reveal what has gone wrong and to make use of the Hornborga case for pedagogic purposes. This constitutes a really important lesson to be learned, about completely unnecessary, extremely expensive and time-consuming mistakes, again causing unsustainable ecological conditions in the lake, which before lowering, was considered one of the most valuable bird-lakes in North-western Europe.

C. Other Types of Restoration Methods

- a. Aeration
- b. Sediment Treatment
- c. Treatment of Acidified Lakes

2. Projects abroad

Requests for help for the restoration of aquatic systems abroad came primarily from international and governmental agencies for aid. At the university institutional level the projects were selected with the aim to create possibilities for students in teamwork to widen their experience of ecosystems outside the temperate zone.

The systems investigated consisted of lakes and lagoons as well as of coastal and high-altitude wetlands at various latitudes.

At the very end of Chapter II we return to Sweden with a report on a micro-project dealing with a tailor-made restorative treatment, designed for and successively put to the test in a tiny lake. The micro-project is put in relation to the gigantic undertaking to restore the waters of the Rio Bogota region in Columbia.

The following Chapter III deals with basic and serious problems concerning water management in Sweden.

1. Swedish Model and Demonstration Projects

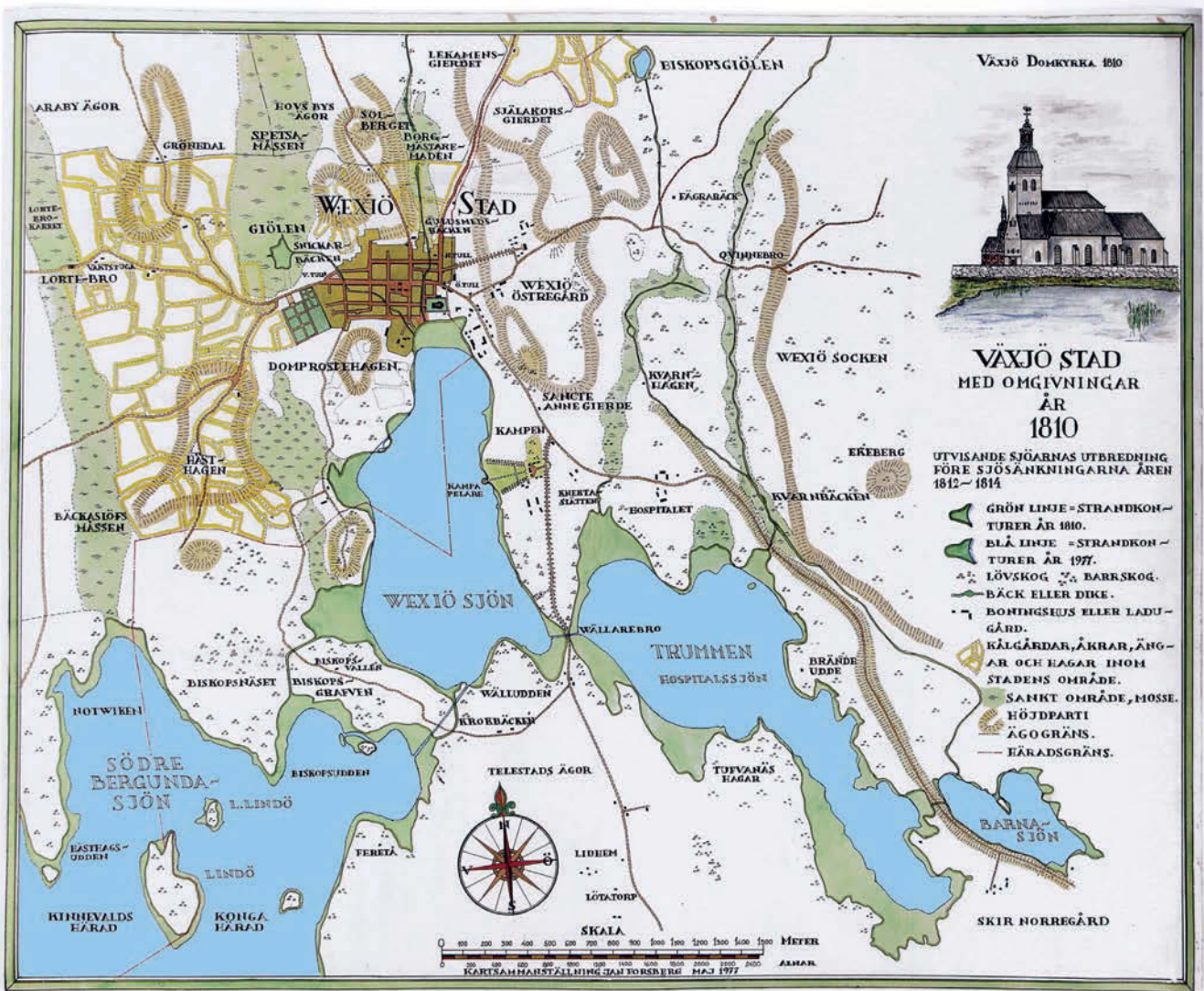


Fig 3. Växjö in 1810. Map showing the area of the lakes before and after the lowering in the years 1812-1814 of the water level. The littoral green zone denotes the loss in lake area. - The compilation of maps made by Jan Forsberg, Engineer, Växjö

A. Lake Trummen

Background

In Sweden, thanks to the intensive construction of sewage-treatment plants with phosphorus precipitation, the conditions in hundreds of eutrophicated lakes have improved. Nevertheless, some lakes had been so severely affected that they did not recover - they were irreversibly damaged.

Lake Trummen in the city of Växjö (Fig 3-4) in south-central Sweden was a good example of the large group of polluted lakes which had deteriorated within and around urbanized areas. The originally oligotro-

phic, brown-water Lake Trummen (drainage area 12 km², lake area 1 km² and depth, until 1970, 2 m) had been used for swimming and for water supply, at least to some degree, until the 1920s (Fig 5). Up to 1957-1958, it was exploited as a recipient of sewage from the city of Växjö and, from 1943 to 1956, of waste-water from a flax factory.

The pollution problems in the 1940s of the Växjö lakes (Fig 6) were described by Thunmark (1945). The summer Secchi disk transparency of Lake Trummen was then 40-50 cm. *Microcystis* spp. dominated the

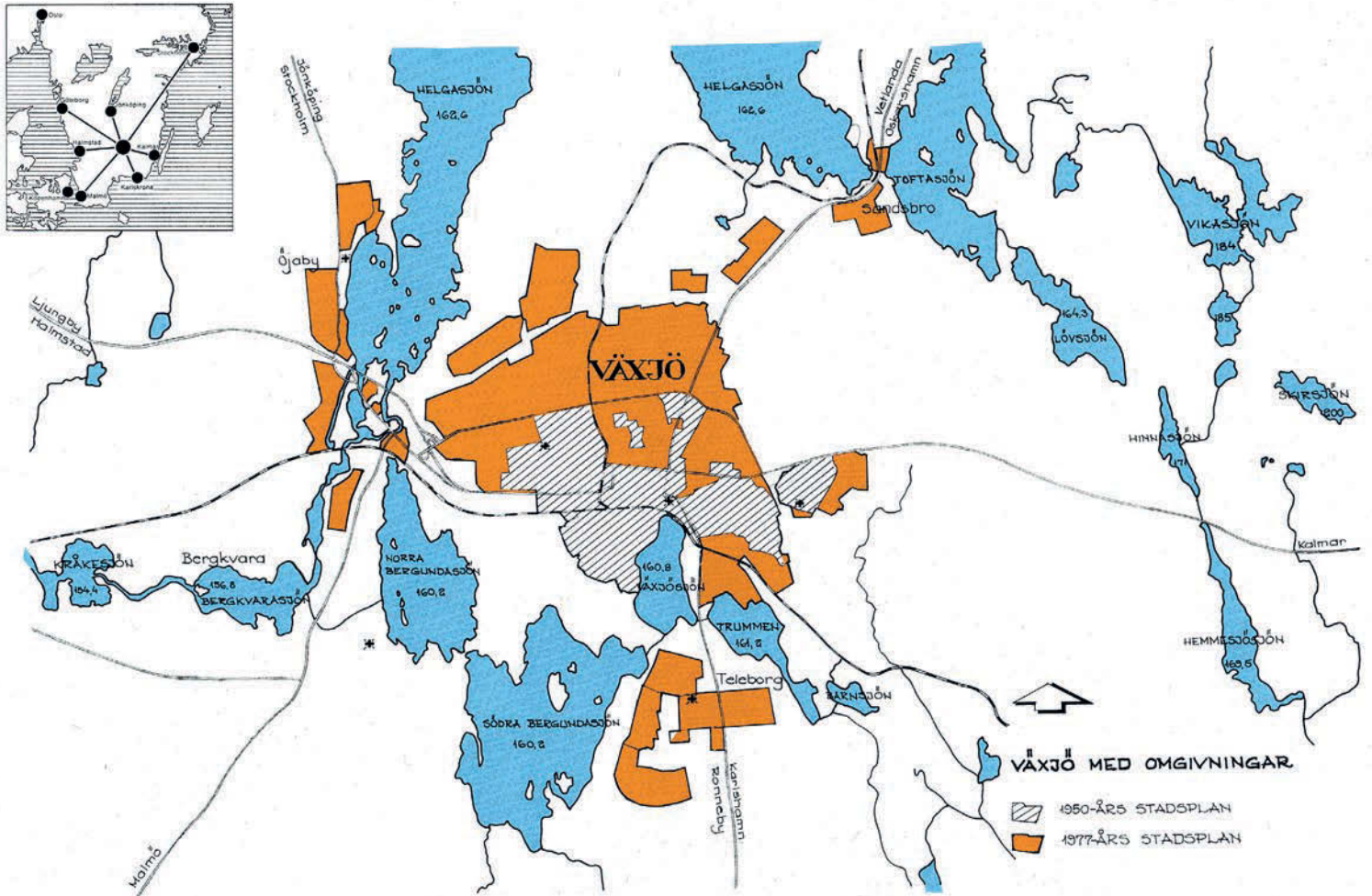


Fig 4. The city of Växjö with its lakes. City plan 1950 (hatched) and 1977 (brown).



Fig 5. Relaxing boat trip on Lake Trummen in the 1920s.

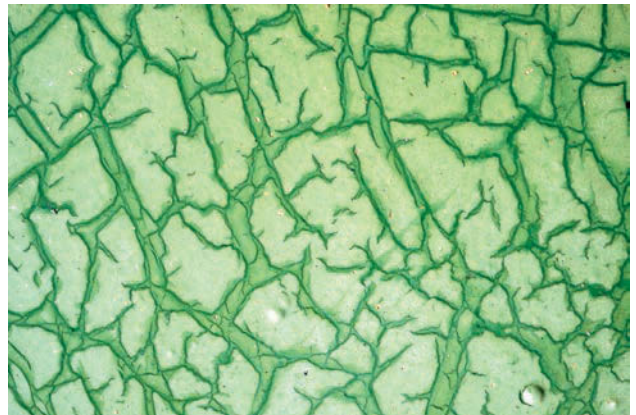


Fig 6. Plankton bloom in Lake Södra Bergundasjön. - SB 1967.



Fig 7. Vegetation development in Lake Trummen. Floating stands (plaur) of cattail (*Typha latifolia*). - SB 1954.

water bloom but periodically also *Scenedesmus naegeli* made the lake water turbid. A comprehensive, detailed and most fascinating description of the culturally-influenced development of the Väjö lakes, with Lake Väjö (Väjösjön) as the type example, is presented by Forsberg (1993).

Lake Trummen and the other Väjö lakes were frequently visited by student excursions for demonstration of the character of collapsed ecosystems.

Ecological and geological analyses synthesized to a restoration plan

In 1951 the senior author started investigations on the macrophyte vegetation in Lake Trummen (Björk 1967).

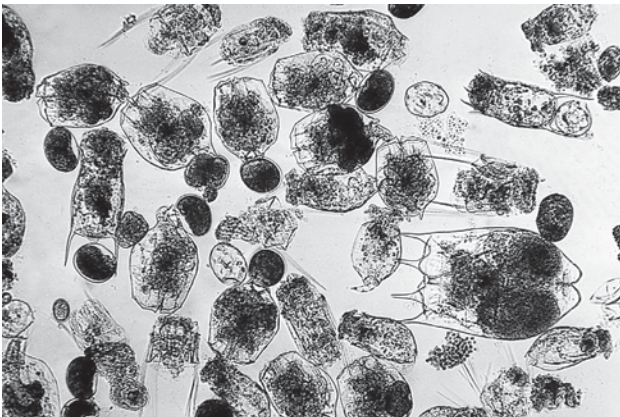


Fig 8. Net plankton with the rotifers *Brachionus angularis*, *B. calciflorus*, *Keratella quadrata*, and *Polyarthra dolichoptera*. - SB 1960-04-19.

These also included studies on the bottom substratum and the formation of floating stands of emergent macrophytes, *i.e.* plaur. Observations made during sediment studies 1954 (Fig 13), among other things the presence of subfossil fruits of *Trapa natans*, inspired Digerfeldt (1972) to carry out investigations on the long-term development of the Lake Trummen - including the water level fluctuations - and the surrounding landscape. By means of chemical analyses, pollen and diatom analyses and ¹⁴C-datings the history of Lake Trummen was revealed from deglaciation to modern pollution.

In 1960-61 water and plankton samplings were carried out monthly from break-up of the ice to freeze-up. Thereby the typical seasonal rhythm of the lake ecosystem became clear; with summer Secchi disc transparency between 10 and 20 cm and with pH-values close to 10.

In early spring (March 1960, Björk & Digerfeldt 1965) there was, under the ice, a rich development of nanoplankton, especially small centric diatoms, causing a greenish colour of the water from ice to bottom. After the break-up of the ice (April 1960) the nanoalgae community was succeeded by a mass development of rotifers (Fig 8). In May the frequency of rotifers was still high.

The heavy summer plankton bloom (Fig 9) characteristic of Lake Trummen and caused by *Microcystis* and *Anabaena* spp. was in 1960 dominated by *Microcystis flo-aquae*. In October the high production of cyanobacteria was followed by diatoms (*Asterionella formosa* and *Melosira* spp.) and in November and December the rotifers formed



Fig 9. Plankton bloom of cyanobacteria. - SB 1969.



Fig 10. Massive fish-kill in late winter. - SB 1969.

a new maximum and again constituted the totally dominating part of the net plankton.

The ice conditions during the winter 1960-1961 were fairly irregular. Periods with a thin ice coating alternated with periods when the ice broke up or ice-holes occurred. Due to this, the changes in the environmental conditions as well as the changes in the aspect of the plankton differed considerably in certain respects in early 1961, from those observed in the corresponding period of 1960.

In March 1961 a mass development of *Synura uvella* characterized the plankton. In April there was a *Me-*



Fig 11. Emergent vegetation with *Equisetum fluviatile*, *Schoenoplectus* and *Phragmits*. - SB 1954.

losira maximum and in May a *Micractinium pusillum* maximum. During June and above all in July *Anabaena planctonica* was responsible for a vigorous plankton bloom, which in August was continued by *Microcystis flos-aquae*.

In the northern bays of Lake Trummen luxuriant stands of *Equisetum fluviatile*, *Phragmites australis*, *Schoenoplectus lacustris* and *Typha latifolia* were expanding lakewards. The outer front of the zone of emergent plants consisted of *Equisetum fluviatile*, while the other species were found nearer the shore (Fig 11). In openings in the stands of emergent plants a thick



Fig 12. In the open areas among the macrophyte stands the moss *Riccia fluitans* developed a 3 cm thick layer at the water surface. Swimming tracks of coot (*Fulica atra*) are indicated by the growth patterns of the duckweed (*Lemna minor*). - SB 1954.

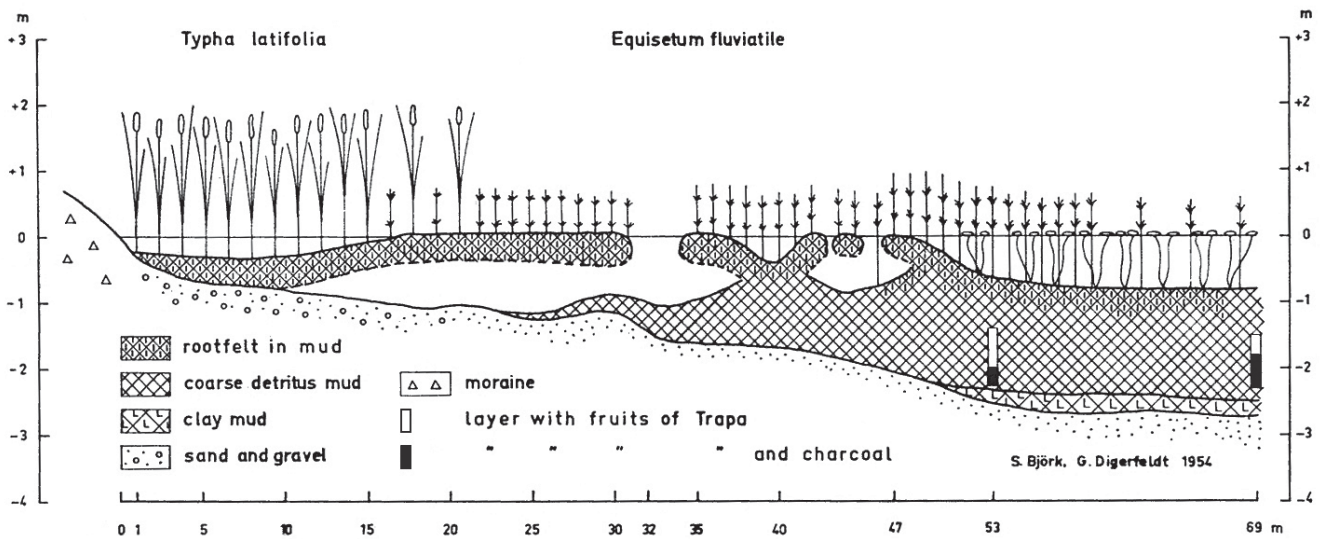


Fig 13. Transect through a *Typha-Equisetum* plaur area. - Björk & Digerfeldt 1965.

layer of *Riccia fluitans* occurred and *Lemna minor* was frequent (Fig 12). Since about 1960 *Ricciocarpus natans* was common in Lake Trummen. Large-leaved *Nuphar luteum* and *Nymphaea alba* occurred in the zone of floating-leaved plants as well as among the stands of emergent plants.

In the hypertrophic Lake Trummen formation of plaur (from popular Romanian idiom, cf. Rodewald-Rudescu 1974) was common. Fairly large areas of dense *Equisetum fluviatile* as well as stands of luxuriant *Typha latifolia* (Fig 7) and *Schoenoplectus lacustris*, all superficially rooted in the loose upper gyttja layers, were lifted up due to gas accumulation and developed as characteristic plaur. In Fig 13 a transect from 1954 through a plaur area is shown.

From the middle of the fifties, the northern part of the bay shown in Fig 11 was filled in with waste, stones and soil. Thereby the gyttja was pushed up in front of the filling and the emergent vegetation was expanding more rapidly further towards the centre of the lake.

The primary paleolimnological and limnological investigations definitely revealed that:

- 1) the long-term development of Lake Trummen was in accordance with the general course characterizing

- the oligotrophic lakes of the nutrient-poor region,
- 2) the recent hypertrophic character of the lake had been caused by the discharge of sewage and industrial waste water,
- 3) the loose, top, FeS-coloured (brownish black) sediment, covering the consolidated brown gyttja of the oligotrophic lake, had been deposited during the pollution period,
- 4) the seasonal behavior of the ecosystem indicated an internal loading in addition to the external one,
- 5) the shallow Lake Trummen had been trapped in the "vicious circle" of internal nutrient loading according to the recirculation mechanisms described by Ohle (e.g. 1964, 1965) and Thomas (1965, 1967).

On the basis of these facts a restoration plan was presented (Björk 1966, 1968 a, b). It involved in the first place the removal of the black top sediment, *i.e.* the sludge layer deposited during the recipient period. This had to be done before the area around the lake was built up, otherwise there would be nowhere available for sediment deposition.

An inevitable demand for a successful redevelopment of the lake ecosystem was first of all to re-normalize the external loading as nearly as possible to its natural regio-

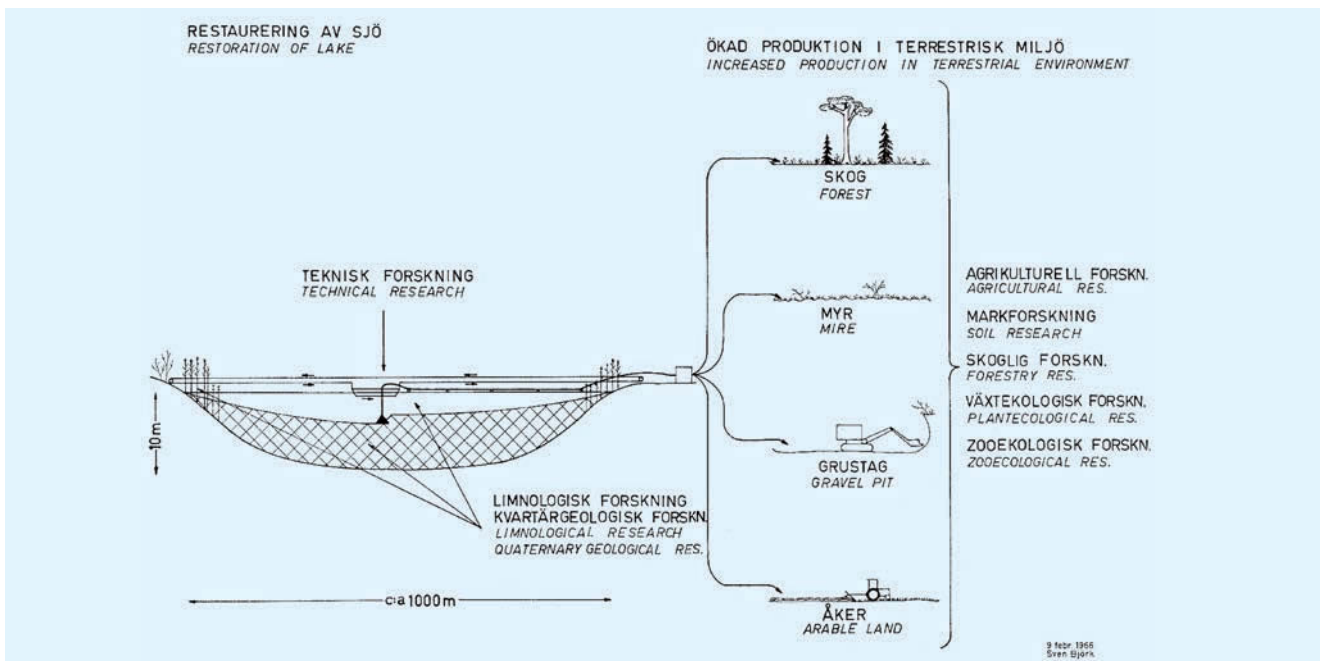


Fig 14. The proposal of the principle for ecological research in connection with the restoration of a lake by suction dredging of polluting sediment. - SB 1966.

limnologic conditions and thus recreate the unpolluted Lake Trummen system.

Before effecting the restoration plan, thorough multidisciplinary ecologic investigations were needed in order 1) to confirm the correctness of the presented restoration plan and 2) to establish an ecological-technical cooperation in order to get access to limnologically acceptable dredging equipment.

In the first sketch of the restoration project (Fig 14) ecological and technical cooperation is emphasized in order to cover most of the areas necessary to control and thus obtain a holistic view of problems and ecological connections.

At that time, the city authorities were obliged to face the Trummen problem in connection with the plans for the urbanization of this area, namely a big regional hospital, a university campus and residential districts. Of course, the simple, narrow-minded technological solution of filling the lake was considered, but the authorities decided to follow the above proposal to restore the lake. Later, the restoration project developed into a very successful co-operation between limnologists, paleolimnologists and other ecologists, politicians, technologists and administrators. The scientific pre-project

investigations carried out during 1968-1970 were designed as typical ecosystem studies.

Long-term development of the lake Trummen ecosystem

In his doctoral thesis "The post-glacial development of Lake Trummen - Regional vegetation history, water level changes and palaeolimnology" Gunnar Digerfeldt (1972) stresses that the limnological character of a lake is determined primarily by the geological and geochemical nature of the surroundings. On the basis of a large number of radiocarbon datings in a main profile it was possible for him in a most splendid manner to determine the rate of sediment deposition during different periods of the lake development. By *rate of deposition* he means the quantity of deposition per unit time expressed in mm sediment/year and in the state of consolidation at the determined level.

The deposition rate represents in itself valuable paleolimnologic information - the deposition being the result of the external addition of matter and the total lake metabolism (production and degradation). In addition, the determination is necessary for a cor-



Fig 15. Before the lowering of the water level and its pollution by sewage and industrial waste water, Lake Trummen was a low-productive, brown-water lake poor in nutrients, reminiscent of the one in this photo, a regio-limnologically representative lake. - SB 1957.

rect calculation of the results of the chemical sediment analyses. If the results are to be comparable and really reliable as a basis for the interpretation of the paleolimnologic development they must be calculated per unit time. This method of calculation presupposes a determination of the deposition rate.

It appears that the deposition rate for the Pre-Boreal period took place at a mean rate of 2.1 mm/year and for the earlier part of the Early Boreal at 1.2 mm/year. From the later part of the Early Boreal period until the Early and Late Atlantic periods a marked and continuous decrease is recorded; from c. 0.9 mm/year to c. 0.4 mm/year. Then there is a slight increase of the rate, which culminates around the transition between the Early and Late Sub-Boreal periods. From the latter period and onwards it appears to have become distinctly decreased. The lowest rate for the Early Sub-Atlantic period amounts to only c. 0.2 mm/year.

The uppermost c. 40 cm of the profile consists of FeS-coloured gyttja deposited during the recent pollu-

tion period. Provided that the formation of this gyttja began around 1900, the lowest c. 5 cm were deposited at a mean rate of only c. 1.3 mm/year. The starting of the flax-processing factory (cf. below) during the beginning of the 1940s and the accelerated increase of the macrophyte vegetation at that time is pollen-floristically registered c. 20 cm below the present sediment surface. From this it can be calculated that the uppermost FeS-coloured gyttja was deposited at a mean rate of c. 8 mm/year. The mean rate for the whole pollution period will be c. 3.8 mm/year.

The data obtained on 1) deposition rate and 2) element concentrations per volume within the different levels of the sediment profile made it possible for Digerfeldt (*op.c.*) to calculate the annual deposition and total accumulation in the lake of organic carbon, nitrogen and phosphorus per m² as well as throughout the development of the ecosystem from Pre-Boreal to and including the recent pollution period (Fig 16-17).

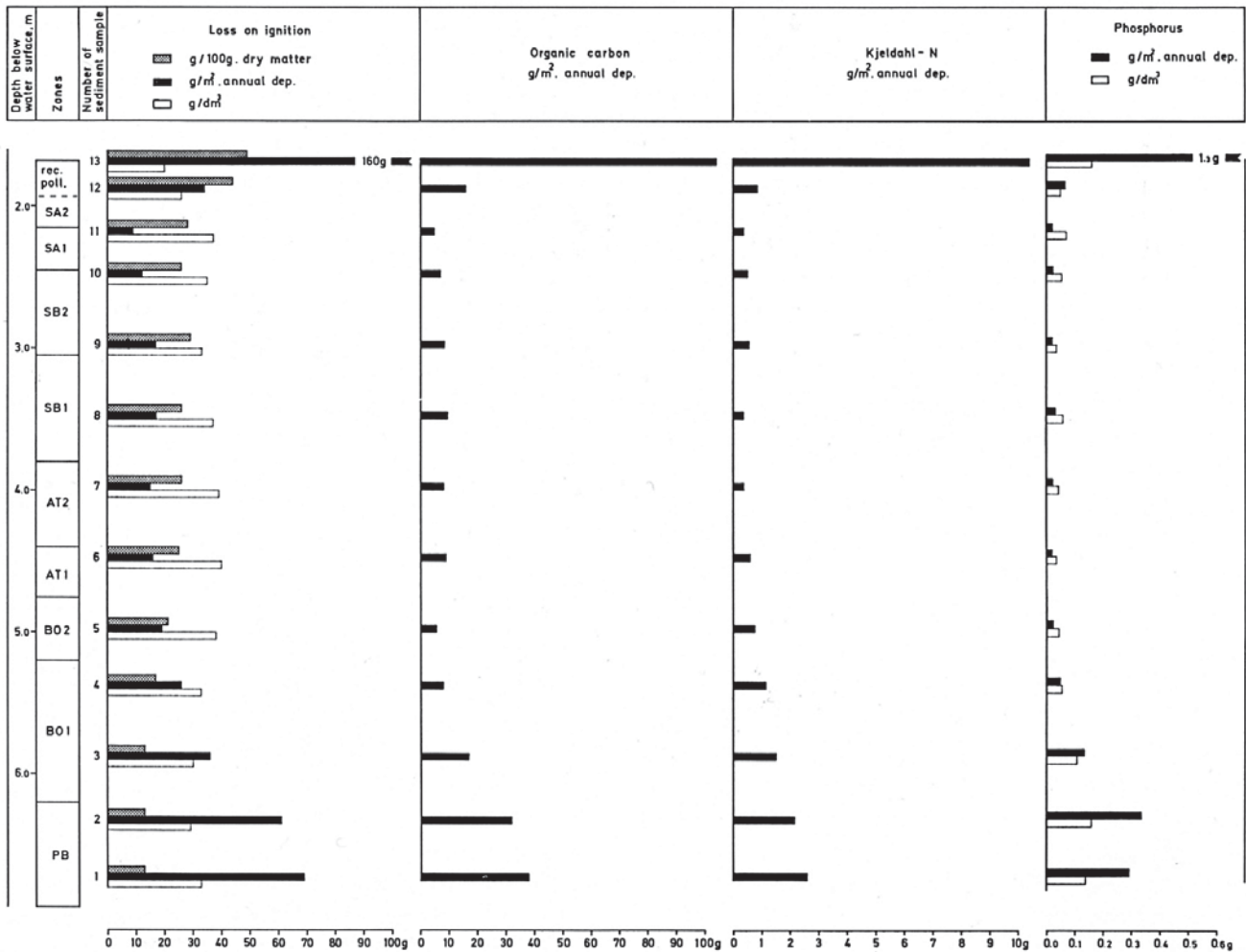


Fig 16. The variation in loss on ignition, in the amount of organic carbon and Kjeldahl-N per annual deposition. The loss on ignition is also calculated per unit dry matter and unit volume. The variation of phosphorus is calculated per unit volume and per annual deposition.

PB = Pre-Boreal, BO 1 = Early Boreal, BO 2 = Late Boreal, AT 1 = Early Atlantic, AT 2 = Late Atlantic, SB 1 = Early Sub-Boreal, SB 2 = Late Sub-Boreal, SA 1 = Early Sub-Atlantic and SA 2 = Late Sub-Atlantic Zone. rec. poll. = recent pollution. - Digerfeldt 1972.

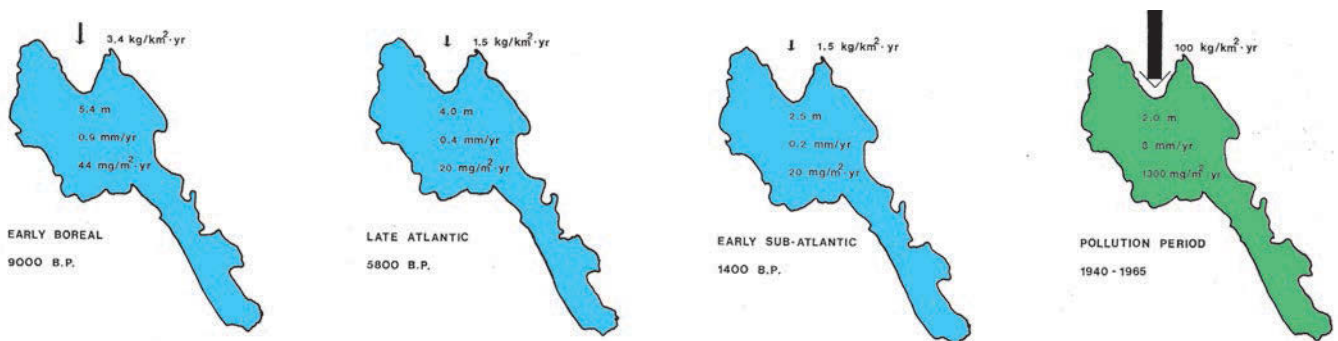


Fig 17. Lake Trummen. The transport of phosphorus (indicated by arrows) from the catchment area to deposition in the sediments during four periods. The figures within the lake denote lake depth, rate of deposition and the amount of phosphorus per annual deposition. - Compiled on the basis of data from Digerfeldt (1971). Björk 1972.

General description and type of disturbance of Lake Trummen

An extensive survey concerning the human impact on the lake during the nineteenth and twentieth centuries has been compiled by Lettevall (1969, 1977). During the 19th century the water level of Lake Trummen was lowered about 90 cm. The present level was established in 1884. According to maps from the 17th century the water level then seems to have been somewhat higher than before the lowerings. Until 1936 Lake Trummen was the water supply for the baths and laundry of the St. Sigfrid Hospital, located close to the lake.

From the beginning of the 20th century waste water from the hospital's bath, brewery, laundry and kitchen emptied into the lake. In 1936 water closets were installed and Trummen became the recipient of all sewage from the hospital. Before discharge into the lake, sewage was treated in a purification plant involving pre-sedimentation and a biological bed.

In May 1943 a flax factory was built close to the lake, and Trummen became the recipient of the untreated waste water; corresponding to 12 000 personal equivalents (pe). The factory was closed at the end of 1956.

In 1957-58 the sewage from altogether 4 500 pe was diverted from Lake Trummen to a new treatment plant discharging into Lake Södra Bergunda. When sewage discharge was stopped it was thought that Lake Trummen would recover, but it did not.

Recent changes in the lake ecosystem due to eutrophication

Before being polluted, Lake Trummen was an oligotrophic lake with humic water (Fig 15). The winters of 1940-42 were severe and for the first time oxygen deficiency was reported. In the winter of 1944 Brundin (1947, 1949) found no oxygen at all in the central part, but there was a strong smell of H₂S.

Before the lowering of water level and pollution there was but a sparse macrophyte vegetation. By 1920 an expansion of the reed-beds was noted. A dredger was, therefore, used for macrophyte cleaning from 1918 until about 1930. Since 1945 there has been plaur formation (floating stands of macrophytes) and sludge floats on the lake surface.

The pollution became more and more severe and in the 1940s the hypertrophic ecosystem collapsed. This was followed by regular fish-kills due to total oxygen depletion in winter and the summer transparency decreased to 15-20 cm by cyanobacteria ('blue-green algae'), in particular *Microcystis*. The submerged vegetation had disappeared but the expansion of the macrophyte stands and the plaur formation continued. Winter oxygen deficiency resulted in fish-kills and in the summer there was oxygen deficiency during the night.

In the first stage of eutrophication there was, of course, a rise in the production of, for example, bivalves, but later these disappeared. Large quantities of *Anodonta* shells were, therefore, found in the top sediment. Above the well-consolidated brown sediment deposited in the unpolluted lake, a 20-50-cm thick layer of unconsolidated brownish black mud developed during the recipient period. The differences in nutrient content, heavy metals, micro-fossils etc. between the brown sediment and the black mud were striking.

The bird fauna of the polluted lake was characterized by a big colony of *Larus ridibundus*. In the 1950s and beginning of the 1960s, the overgrown bays began to be filled with all types of human waste (Fig 18).

Despite the sewage and industrial waste-water discharge to the lake being stopped in 1957-1958, the lake did not recover - a very interesting but not surprising fact to limnologists and a severe problem for the city authorities. About 10 years after the diversion of waste-water from the lake, the summer transparency was still only 15-20 cm.

The ecological teamwork

Organization

The Lake Restoration Researchers Team was in 1966 established at the university of Lund. Lake Trummen was suggested to be the first undertaking. Later on the program expanded to include also other whole-lake projects, involving different combinations of lake/wetland types, ecological problems and eco-technical methods. The Institutes of Limnology, Microbiology, Plant Ecology and Quaternary Geology were represented in the group. A lively cooperation with engineers was, of course, necessary to ensure that



Fig 18. Degradation of the shores of the heavily polluted Lake Trummen. - SB 1969.

practical problems were solved in a way acceptable to ecologists.

Within the framework of a practical project of this sort there are excellent opportunities for training young limnologists and other ecologists. For comparison with the severely polluted Lake Trummen, investigations were also planned for Lake Hinna (Hinnasjön), an unspoiled lake located 5 km ENE Lake Trummen (Fig 4). The team in Lund consisted of about 20 ecologists, each with his/her special part of the scientific program. However, the investigations were organized in such a manner that the demands for depth as well as for breadth in everyone's studies should be fulfilled in order to yield a thorough bank of knowledge of the structure, function and resilience ability of the ecosystems.

In January 1967 the team informed the Växjö town authorities about the ecological diagnoses concerning the future development of the seemingly irreversibly damaged Lake Trummen and explained, at the same time, that the lake could be restored by an eco-technical operation. To be able to present a detailed plan for this technical undertaking, ecosystem-oriented pre-investigations had to be carried out. Thanks to the very co-operative attitude of the city it was possible to start these studies already in 1968 and to gain a broad understanding of the structure and function of the collapsed eco-

system during two years of intensive fieldwork. During this period the city authorities were continuously updated on results and became definitely convinced about the realism of the restoration method.

Field investigations

The project included three stages: 1) investigations March 1968 to June 1970 in the irreversibly damaged ecosystem, 2) investigations during and immediately after the suction dredging of the lake from July 1970 to June 1973 and 3) follow-up studies from July 1973 to 1980. Lake Trummen is still (2013) subject to control investigations. In this way it became possible to make ecological before-and-after comparisons and to record the long-term stabilization of the ecosystem.

It should be stressed that in this, as in other lake restoration projects, ecological-technical teamwork is required. Technical research in the Lake Trummen project included, among other things, intensive studies of suction pumping methods which avoid turbidity while keeping to a minimum the water content of the pumped mud (gyttja). In the winter of 1969 small quantities of gyttja were taken from the lake in order to study the effects of freezing and drying (Fig 19). In March and August 1969 the city financed experimental pumping by a suction dredger of about 5 000 m³