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Inner Mongolia Lake Restoration Project
Lake Wuliangsuhai Comprehensive Study
Extension

Basic Processes of Lake Wuliangsuhai

Norwegian Institute for Water Research

– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

Lake Wuliangsuhai is the 8th largest lake in China and only 170 km^2 of 300 km^2 is at present considered as open waters due to widespread reed vegetation. The massive pollution loads from domestic, industrial and agricultural sources threats the existence of the lake. A collaboration project was implemented to study the lake status, trends and threats and to propose Management and Control Plans to secure the lakes existence as a lake. This report provides an overview and results from one of the sub-projects.

This report presents an overview of the basic processes in the lake's ecosystem, which are necessary for development of sound alternative restoration strategies. It reviews the restoration measures, such as partial removing of lake sediments or vegetation, which may lead to unwanted blooming of phytoplankton due to changed competition for light and nutrients.

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Inner Mongolia Lake Restoration Project

Sub-Project 5:

Basic Processes of Lake Wuliangsuhai

Final Report

Preface

This is one in a series of reports of the Project: 'Inner Mongolia Lake Restoration Project'. Inner Mongolia Environmental Science Institute (IMESI) has through the Inner Mongolia Science and Technology Committee and the State Science and Technology Commission applied to Sida and NORAD for financial support to carry out a three years' restoration project in Lake Wuliangsuhai in Inner Mongolia, the Peoples Republic of China.

IVL and NIVA are the consultants of the project. Mr. Jonas Fejes (IVL) with the assistance of Ms. Luo Dongmei has carried out the studies on exchange of phosphorus between sediment and water. Dr. Li Qingfeng at the Agricultural University of Hohhot, Inner Mongolia and his students has performed the studies on reproductive strategies of submerged vegetation and reed. Prof. Shang Shiyou (Agricultural University of Hohhot) performed the experiments with harvesting and re-growth of submerged vegetation. Mr. Lu Quanzhong (IMESI) has been responsible for the dredging project in co-operation with Mr. Li Yawei (EPB), Mr. Zang Fenqing (Wulateqianqi Environment Monitoring station) and Mr. Finn Medboe (NIVA). The remaining topics that are treated in this report have been studied mainly by Mr. Bjoern Faafeng (NIVA).

The purpose of the "Basic Process of the Lake Wuliangsuhai Ecosystem" is to understand the basic processes in the lake's ecosystem, which are necessary for development of sound alternative restoration strategies.

Restoration measures, such as partial removing of lake sediments or vegetation, may lead to unwanted blooming of phytoplankton due to changed competition for light and nutrients. The spread of reed to new areas of the lake depends on inputs of nutrients in combination with shallow enough areas for the reed to settle.

The following topics have been treated in this subproject:

- Reproductive strategies of reed and submerged vegetation
- Water depth at the edge of the reed stands
- Exchange of phosphorus between sediment and water
- Changes in water quality in dredged areas of different depths.
- Theoretical background for possible changes in water quality after restoration
- Theoretical background for Biodiversity – Landscape Ecology
- Acceptable nutrient loading.

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Contents

1 SYNOPSIS ON LAKE EUTROPHICATION AND RESTORATION

High amounts of nutrients, large areas of shallow water and a suitable climate provide ideal conditions for the growth of macrophytes in Lake Wuliangsuhai. The competitive abilities to reed and submerged vegetation have excluded some original species that were found in the lake a few decades ago. Obviously reed (*Phragmites australis* and *Typha* spp.) and the submerged plant *Potamogeton pectinatus* were the winners of this competition. This study shows that these species have well adapted reproductive strategies and effective re-growth abilities in Lake Wuliangsuhai. The maximum depth at the edge of the reed stands was 1.2 m.

With favourable environmental conditions and sufficient nutrient supply from Hetao Irrigation Area, the vegetation in Wuliangsuhai has an annual total production capacity of 180,000 tons of biomass. For reed, an annual production output of 136,000 tons (currently 70,000-100,000 tons) is achievable. Based on the 1 mg/g dry weight of phosphorus concentration in the reed harvestable part estimated by Hedelin (2001), the calculated phosphorus removal by harvesting reed was 136 tons annually, which is almost equivalent to the estimated annual net input to the lake during the irrigation season. If *Typha* and *P. pectinatus* were also harvested accordingly, a net gross balance of phosphorus would be more than attained. Whether harvesting will reduce the water nutrient level, however, remains a question. Emergent macrophytes take their phosphorus exclusively from the sediment, while submerged species obtained phosphorus both from the surrounding water and from the sediment. It can be concluded that no immediate reduction of water nutrient level should be expected after harvesting due to the large reservoir of nutrients available in the sediment.

A tree-year harvesting experiment of submerged plants was performed during the project period. The average standing biomass of the whole test area was 1 483±116 g $DW \cdot m^{-2}$, and it was observed that the biomass of submerged plants in test areas after harvesting were similar after ca. 60 days. From 1999 to 2002, hydrophytes were harvested in test areas near Xiaoouzo and Erdiar area. The annual average harvesting was performed in strips covering an area of 23.35 km^2 within a total area of 69 km^2. A total wet weight of hydrophytes of 51 000 tons were harvested, leading to the removal of 16.83 tons N and 1.734 tons P from the lake.

Reed and submerged vegetation efficiently participate in the self-purification processes of lakes. It is therefore important to maintain relatively large areas of reed around the outlets from the drainage canals to maintain slow water seepage into the main lake basins. This also applies to the discussion about efficient water flow from one section of the lake to the next. From a self-purification point of view, the widening of canals between lake basins is undesirable.

A eutrophic lake can switch from a macrophyte dominated (clear water) state to a phytoplankton dominated (turbid water) state if the macrophytes are eliminated or severely destructed. In the case of Lake Wuliangsuhai, such a switch is an unlikely event under the current harvesting practice of submerged plants and production magnitude (which is today very small). Harvesting of submerged vegetation should be limited to 10 - 25 % of open water area, not to provoke unwanted environmental changes.

A dredging experiment was carried out to test in small scale the technical and economic potential as well as the limnological aspects of deepening the lake at designated areas. Dredging is a costly way of deepening the lake. However, unless increasing the water level in other ways is possible, dredging is recommended. The bottom at the experiment site, which is assumed to be representative for the lake, was easy to dredge with adequate equipment. Most of the chosen areas for dredging will be located at distances from the shore that will require barge-dredging with pipelines and booster stations for transportation of dredged material to the shore, unless construction of nearby islands is of interest. The dredged material was found to be suitable and quite valuable for agricultural use (soil improvement) as well as for erosion control. Also use as construction material for roads proved successful. A combination of dredging and increase of the water level should be explored further, to establish the costs and consequences of the latter.

Measurements in the test-areas of excavation performed approximately one year after the dredging showed that the water quality in terms of pH, Tot P and Tot N was almost the same as before dredging. The submerged vegetation had re-colonised with the same species as before dredging, and the abundance was about the same as before at the 0.5 m and 1.0 m test areas, whereas the re-colonisation of the 1.5 test areas had been markedly slower.

The sediment exchange experiments show that the release of phosphate did not increase from sediments to water under anaerobic conditions compared to aerobic ones.

During the last 15-20 years the water quality of Lake Wuliangsuhai has become severely deteriorated. The discharges of organic matter and nutrients into the lake from the Hetao area are so large that the concentrations of these variables have reached class V or above V according to the Chinese Water Quality Standards. Winter kills of fish because of anoxic water is common, and the biodiversity in terms of species numbers of zooplankton, macrophytes and fish has also been significantly reduced during this period. Unless severe measures are taken to reduce the pollution inputs to the lake, the water quality will probably become even worse than today. Reduced water input and a lower water level would be additional threats to the lake. The high sedimentation rate because of large inputs of organic matter and particles as well as high internal production of plant material implies that the lake will tend to become a marsh wetland within few decades.

In this investigation we made a calculation exercise to see how large the reductions in phosphorus input should be to achieve alternative water quality classes according to the Chinese Water Quality Standards. The main input of water and pollutants is the Main Drainage Canal. We have estimated a transport of ca.105 tons P per year in the irrigation season. If we assume additional inputs during the non-irrigation period of 30 tons, there will be a sum of 135 tons P annually. The mean water transport is $533*10^6$ m^3. This means a volume weighted concentration of 0.253 mg P/L. Assuming different goals and using the different standards for rivers and lakes, the necessary reductions in P inputs via the Main Drainage Canal will be as follows:

Goal	Class III for lakes 0.050 mg P/L	Class IV for lakes 0.100 mg P/L	Class III for rivers 0.200 mg P/L
Required P-reduction in Main D. C. (tons)	Ca. 110	Ca. 80	Ca. 30
% reduction	Ca. 80	Ca. 60	Ca. 20

2 INTRODUCTION

This is one in a series of reports of the Project: 'Inner Mongolia Lake Restoration Project'. Inner Mongolia Environmental Science Institute (IMESI) has through the Inner Mongolia Science and Technology Committee and the State Science and Technology Commission applied to Sida and NORAD for financial support to carry out a three years' restoration project in Lake Wuliangsuhai in Inner Mongolia, the Peoples Republic of China.

IVL and NIVA are the consultants of the project.

2.1 Aims Of This Subproject

The purpose of the "Basic Process of the Lake Wuliangsuhai Ecosystem" is to understand the basic processes in the lake's ecosystem, which are necessary for development of sound restoration strategies.

Restoration measures, such as partial removing of lake sediments or vegetation, may lead to e.g. unwanted blooming of phytoplankton due to changed competition for light and nutrients.
The vigorous growth of reed may be a result of inputs of nutrients (eutrophication). An additional cause is the input of large amounts of particles, which over years have provided shallow enough areas for the reed to settle.

Reproductive strategies of submerged vegetation

The objectives of this study were:

- To understand the reproductive feature of main macrophytes in the lake;
- To evaluate the roles of macrophytes for the lake and for the local societies;
- To make suggestions for controlling/utilizing macrophyte resources, and;
- To contribute for the overall managerial strategies for the lake and the surroundings.

This study will clarify to what extent the dominating macrophytes have sexual or vegetative reproduction. This is essential for understanding the natural expansion of vegetation and also the re-vegetation of harvested areas and the effects of repeated harvesting.

Water depth at the edge of the reed stands
The aim of this sub-study was to find the maximum depth to which the reed has settled in the lake. Continued expansion of the reed belts is considered one of the most serious threats to the lake. By increasing the water depth of the lake, this process may be retarded or even stopped.

Exchange of phosphorus between sediment and water
Phosphorus from pollution sources in the Hetao is one of the main causes of eutrophication of Lake Wuliangsuhai. However, due to the dynamics of the lake ecosystems most of the phosphorus is trapped in the lake sediments and immobilized. Some of the trapped P may be resuspended into the water and stimulate to further growth of plants. P may also release from the sediment into the water by different chemical reactions (high pH and anaerobic conditions). The importance of the last mentioned release mechanism is studied by laboratory experiments.

Changes in water quality in dredged areas of different depths
Small areas of lake bottom sediment was dredged to test the feasibility of the dredging equipment – and to study the effects on water quality after dredging. The last mentioned issue is discussed in this project.

Theoretical background for possible changes in water quality after restoration
Technical restoration measures in lakes may lead to unexpected and unwanted effects. One of these is the possible switch in shallow, eutrophic lakes from a clear-water stage with submerged vegetation, to a turbid stage with high densities of phytoplankton. A brief presentation of the relevant mechanisms is given.

Theoretical background for Biodiversity - Landscape Ecology
'Biodiversity' is normally describing the total number of plant and animal species in an ecosystem.
However, the concept and mechanisms of biodiversity are often misunderstood. To achieve a high biodiversity is considered positive, and is one of the primary goals of this project. A short description of decisive factors for biodiversity in shallow lakes is given.

2.2 Eutrophication of lakes – A short introduction

Eutrophication is a process whereby a shallow water body gets richer in nutrients, leading to higher biomass production (e.g. water plants, algae, fish, plankton, etc.), and gradually a transformation of the water body into wetland. Eutrophication of lakes is one of the major environmental problems of today, a problem closely connected to the development process of a society.

Basically a slowly evolving natural process, eutrophication is speeded up by human activities, such as discharge of domestic and industrial wastewater, agricultural drainage water, and discharge products from fish farming. Also deposition of nutrients from the air may be a contributing factor. Natural components of the eutrophication process include a large number of various parameters ranging from annual temperature distribution, to soil types in the catchment area.

Eutrophication is labelled a major water resources problem by the Chinese government. China's water resources, characterised by scarcity and uneven temporal and geographical distribution, are subjected to severe pressures of a densely populated and rapidly developing society. As a consequence water resources are commonly exposed to high nutrient loads and an increasing number of lakes are showing severe eutrophication problems.

The vast grasslands and other semi-arid areas of the Inner Mongolia Autonomous Region (referred to as Inner Mongolia) have a number of typical, shallow grassland lakes. These lakes and their water systems are important to local communities, but for various reasons they have been found particularly vulnerable to eutrophication. The lakes, and the rivers in their catchment areas, do often provide the sole source of drinking, industrial, and agricultural water in the area. They provide fish to local markets, make up an important source of reeds for pulp and paper production, etc. Many of the lakes have, moreover, high biodiversity value, e.g. as significant locations for nesting and migration of several hundreds of species of birds. Finally, and maybe most important, the lakes constitute pillars of the local ecological system. These include, except for the direct availability of water, also soil moisture, microclimate, regulation of temperature, etc.

Behind human induced eutrophication problems lie unsustainable water utilisation, leading to yet sharpening conflicts between different uses and users. As long as water management authorities fail to take the available water resource as the starting point for distribution and regulation of water, water related conflicts are bound to increase. What is needed is a shift towards water management that starts from the available water resource and devotes its efforts on managing the conflicting demands for a limited resource.

2.3 Lake Wuliangsuhai

The large and shallow Lake Wuliangsuhai, situated in the Autonomous Province of Inner Mongolia, P.R. of China, is the largest internal lake in the northwest China (read more about its water quality and pollution loading in the project report no. 3: Monitoring). It is an important and unique ecosystem in the vast semiarid grassland region and has multiple functions of climate buffering, wildlife refuge, irrigation/drainage water adjustment, primary production, tourism, etc. At present, the most conspicuous problem with Lake Wuliangsuhai is that the lake surface is rapidly giving way for reed beds that today cover roughly half of the lake. A closer look reveals typical eutrophication characteristics with deteriorating water quality in terms of higher nutrient status, high biomass production causing high sedimentation rate of organic matter, which in turn leads to increasingly shallow waters where reed beds can take root, and so on.

The eutrophication of the lake is a result of large amounts of nutrient inputs from the Hetao area, which is an intensively cultivated agricultural plain entirely dependent on irrigation water from the Yellow River.

The pre-feasibility study reveals conflicting interests between using the lake as a recipient for agricultural drainage and municipal wastewater, for production of reeds, for fishing, and keeping the lake as a lake. The wish of the local government (Bayannoar League of Inner Mongolia) is to keep the lake and make it more productive, while at the same time reduce the input of nutrients from municipalities, agriculture and industry.

On the basis of the mini LFA workshop that was carried out during the Swedish-Norwegian mission to Inner Mongolia in September 1997 the focal problem was identified as “unsustainable water usage in Hetao area”. This problem is caused primarily by “conflicting interests between different usage of the limited water resources”, by “lack of knowledge about the actual situation of the lake and the catchment area” and by “deficient management skills and facilities for local sustainable water usage”. The result is “deteriorating lake water quality” leading eventually to that the “lake disappear”.

3 METHODS

Basic Processes of the lake ecosystem have been studied by means of different methods (experiments and theoretical studies):

Submerged vegetation:
- reproductive strategies of the submerged vegetation

Reed:
- reproductive strategies of the reed
- water depth at the edge of the reed stands

Sediments:
- exchange of phosphorus between sediment and water

Effects on the lake ecosystem by dredging and harvest of submerged vegetation:
- changes in water quality in dredged areas of different depths
- theoretical background for possible changes in water quality after restoration

Biodiversity - Landscape Ecology:
- theoretic background for changes in biodiversity

3.1 Reproductive strategies of Reed and submerged vegetation

Investigations were carried out to study vegetation species distribution, specific composition, and competition as well as reproduction strategies. This information is necessary to understand the importance of biological processes for the eutrophication and maintenance of the lake ecosystem. Results from experiments carried out in Lake Wuliangsuhai will provide valuable insights into the lake's ecosystem and may, hence, be valuable tools to select the most feasible restoration measures.

Observations were made on-site in the lake for specific composition, plant reproductive structures, and growth behaviour (e.g., tillering, rooting). Measurements were made both in the lake and in the laboratory for plant biomass production, nutrient contents, seed germination, etc.

3.2 Water depth at the edge of the Reed Stands

The water depth was measured in the open water along the edge of the reed belts in central parts of the lake to have a picture of the maximum growth depth of the *Phragmites* and *Typha* vegetation. GPS co-ordinates were measured simultaneously to allow identification of the different measuring points.
All depths were adjusted to represent average annual lake level (1018.5 m).

3.3 Exchange of Phosphorus between Sediment and Water

P-exchange
Sampling and experiment set ups

Intact sediment cores were taken with a tube corer in the deepest part (at 2,2 m depth) of Lake Wuliangsuhai on 22. April 2002. The acrylic tube had an inner diameter of 5,0 cm and a length of 50 cm. The sediment cores taken for the experiment contained about 12-18 cm sediment and ca. 32-35 cm overlaying water. 25 L of surface water from the lake was also taken.

Figure 3.1
Sediment sampling at Lake Wuliangsuhai *Intact sediment cores with lake water on top*
Photos: Jonas Fejes

The intact cores were transported to the laboratory (IMESI, Hohhot) the same day as the sampling. Transport temperature was 20^{o}C and in daylight. All preparations of the sediment cores for the experiment were made in 17^{o}C (room temperature).

The nutrient exchange experiment was run at 17 ^{o}C in darkness and under aerobic and anaerobic conditions. Aerobic conditions in the overlaying water were maintained by a continuous flow of air from an aquarium pump. In these experiments there was no need for stirring of the water. The anaerobic conditions were obtained by N_2-bubbling through the water for 3-4 days. Thereafter the bubbling was stopped.

Figure 3.2 Sediment exchange experiment set up April 2002 at IMESI in Hohehot.
Photo: Jonas Fejes

Figure 3.3. Exchange of water *Sampling of water for analysis*
Photos: Jonas Fejes

Analysis
Two days after sampling the overlaying water, except 2 cm of water, was exchanged with new lake water from a 25 L bottle. The lake water was carefully introduced into the tubes without disturbing the sediment surface. All cores were filled up to 25 cm of overlaying water.

Before sampling the anaerobic cores were bubbled by N_2-gas for 1 hour. After sampling the cores were sealed to next sampling. Water was sampled every 3 days, at what 10 ml sample was taken out by pipette. When water level was lower than 25 cm the tubes were filled up with lake water to 25 cm.

3.4 Dredging Experiment

The dredging experiment was planned to be financed entirely from the Chinese funding sources. The original plans called for 3 million RMB for this experiment alone, to dredge 100 000 m^2 (0,1 km^2). Delays in Chinese funding of the project caused limitations in the extent of the experiment that was implemented.

All scientists involved in the project agreed on the importance and necessity of the experiment. After several delays and reductions in scope, - the field work was carried out during the summer of 2002 with the aim to dredge ca.. one fifth of the original area.

Plans and discussions prior to starting up

Three practical ways of doing the excavation were discussed:

1. Excavation during winter – from the ice
2. Excavation during the summer season
3. Dredging from a barge-rig during summer

The details for the experiment are outlined in the attached description which also explains the follow-up when the excavated areas are completed. The major differences between the three alternatives lie in the transport of the excavated material. Use of excavators requires loading and reloading of trucks. This method is usually chosen when necessary transport is limited or not necessary at all. The method is the cheapest when cleaning or dredging canals of limited widths, or when the dredged material can be deposited locally, e.g. when constructing new islands.

In our case both for the experiment and for large scale dredging of several square-kilometres, it is necessary to transport dredged material over kilometres or at least hundreds of meters. Then pumps and floating pump-lines are most feasible for transportation.

Equipment

Figure 3.4. Dredging barge in action on lake Wuliangsuhai

A small barge was brought up by a private contractor from Jiangsu province near Shanghai to dredge three 50 by 150 meter basins to depths of 50, 100 and 150 cm below the original bottom which at this site was ca. 70 cm. The job was estimated to finish within 6 to 8 weeks, but due to practical difficulties the contractor had to change the cutter-head without additional expenses, and the work had to be extended into September.

Figure 3.5 Cutter-head no. 2 of dredger

Correct choice of cutter-head suitable for the soil is essential to get a good and economical result.

Figure 3.6 Pipe-line transports the excavated material to the shore

Figure 3.7 Excavated material pumped into the lagoon

Figure 3.8 Sedimentation lagoon

Figure 3.9 Discharge from sedimentation basin

Figure 3.10 Deepest of three excavated basins

Location

The dredging site was some three hundred meters off the east shore of the lake a few km south of the Fish Farm. A three man crew handled the entire operation.

Two lagoons were constructed on the shore to separate and store soil and release excess water back to the lake.

3.5 Effects of test dredging on water quality

Three areas of the lake bottom each measuring 60 x 60 meters were dredged during June 2002 down to depths of 0,5 m, 1,0 m and 1,5 m, respectively. The area is situated some 2 km south of the Fish Farm on the eastern side of the lake. A 6 m section of the original lake bottom was left untouched between each basin.

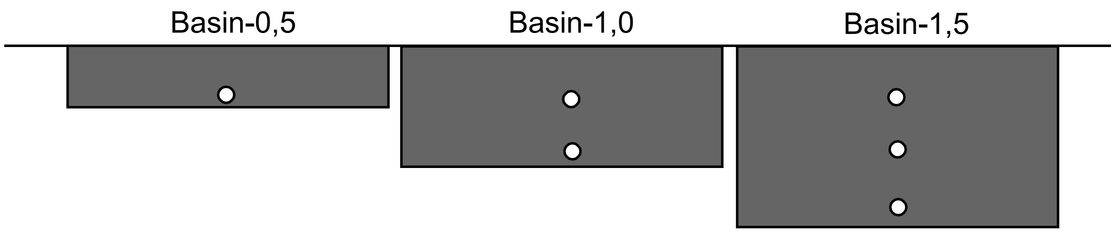

Figure 3.11 Sketch of the cross section of test areas dredged. Length and depth are not drawn on scale. Suggested sampling points are marked.

The dredged bottom material was removed by dredging and pumping to a reservoir that was constructed for this purpose on the lake's shore.

Suggestion for monitoring
After the dredging a sampling programme was started. Samples were taken in the middle of each basin (called: 'Basin-0,5', Basin-1,0' and 'Basin-1,5').

Samples were taken from the following depths:
Basin-0,5: 0,4m
Basin-1,0: 0,4m, 0,9m
Basin-1,5: 0,4m, 0,9m and 1,4m.

The following was measured in each basin:

- Secchi disc transparency
- Temperature
- Oxygen
- Total N, NO3-N, NH4-N
- Total P, PO4-P
- CODmn
- Chl-a

4 RESULTS

4.1 Reproductive strategies of Reed and submerged vegetation

4.1.1 Specific composition of the macrophytes

In a 3-years period from 2000 to 2002, 8 aquatic macrophytes, i.e., *Phragmites australis, Typha latifolia, Potamogeton crispus, P. pectinatus, Najas marina, Chara spp, Myriophyllum spicatum,* and *Ceratophyllum oryzetorum*, were found in the lake. In comparison with a previous survey in 1986-1990, three species of *Potamogeton* and one species of *Typha* had disappeared. *C. oryzetorum* was a newly found species. The other species were heavily suppressed by three dominant species of species of P. *australis* (common reed), *T. latifolia* (cattail) and *P. pectinatus. P. australis* and *T. latifolia* covered about 40% and 15% of the lake surface, respectively, while *P. pectinatus* was almost the only visible submerged vegetation which occupied 27% of the lake surface. The remaining species were only in negligent states in terms of their populations and biomass.

Reeds were distributed in the places with an average water depth of 80cm (0-140cm). The highest plant density of reed population reached 150 shoots/m^2, with a average of 91.6 shoots/m^2. Typha lived in an average water depth of 100 cm and the average density was 13.4 shoots/m^2. In a Potamogeton dense populated area, 147 shoots/m^2 were found at the lake bottom, which weighted 240 g in dry matter.

4.1.2 Reproductive strategies of the macrophytes

Reed *(Phragmites australis)*
Well developed rhizomes were observed and a large number of substantial tiller shoots emerged from the rhizomes. No seeds were collected during the study. However, seedlings were occasional found in the shallow offshore areas, indicating this species was capable of seed reproduction.

Potamogeton pectinatus
Well developed rhizomes were found, and being capable of producing tiller shoots. This plant was also a good seed producer. A great amount of seeds were produced through the summer to the autumn. Although a hard seed coat may retard the immediate germination of new seed in some extents, the relative long life of the seed can ensure the recruitment of seedlings. A considerable amount of seedlings found in the shallow water areas was a good indication for its seed reproduction ability. P. pectinatus was also capable of asexual reproduction. In an experimental trial that plant segments with 2-3 nodes were placed in the lake bottom or in the mud. A few (less than 15%) of the segments generated new roots and shoots after about one month. Although the regeneration percentage was low, the mean was enormous in considering the large amount of fragments left behind after the artificial harvesting of the plant.

Typha latifolia (Typha)
A few, but strong rhizomatous tillers were produced by this plant (Photo 2). In comparison with reed plant, the magnitude of the tiller production was much lower. No seeds were collected, but

few seedlings were found in shallow water areas, indicating the plant was capable of sexual reproduction.

Ceratophyium oryzetorum
Seeds of *C. oryzetorum* were collected and subject to germination test. High germination percentage was found with freshly collected seeds. No vegetative regeneration was observed in a similar experiment as for the P. pectinatus.

Other species
Neither seeds nor vegetative regeneration were observed in other species due to the scarce of plant materials.

4.1.3 Re-growth of main macrophytes species

Observations on the re-growth of the two main macrophytes (reeds and *P. pectinatus*) were made in 2001 and 2002 growth seasons. Reeds had very strong re-sprouting abilities. Although most of shoots came out from the lake bottom at the nodes of rhizomes in the new spring growth season, a number of aerial tillers were produced from the node just below the cutting point if the plant was cut in the growing season above water surface.

P. pectinatus had strong branching and recovery growth abilities. New branches were produced prolifically at almost every node and from the nodes below the cutting point if the plant was cut. After harvesting, plant population density was recovered within 2 months when the plants were harvested in August at a level of about 50 cm below water surface.

4.1.4 Productivity of main macrophytes

Productivities of the two main macrophytes (reeds and *P. pectinatus*) were estimated based on samples from several locations. On average, reed had a water content about 75%. Oven dried biomasses for whole plants (10 cm above ground/sediment), above water surface part, and harvestable part (20 cm above water surface) of reeds were 1.58 kg/m^2, 1.19 kg/m^2, and 1.02 kg/m^2, respectively, when harvested in mid September. Dried biomasses for Typha were 0.565 kg/m^2, 0.447 kg/m^2, and 0.384 kg/m^2 for the similar parts, respectively. A yield of 0.343 kg/m^2 dry matter (1.429 kg/m^2 wet weight) was obtained for *P. pectinatus* when harvested at early July. This may not be the peak yielding period in consideration of the climate in the region.

Calculations for total production were made based on above mentioned figures and the macrophyte occupied areas from satellite images. Total biomass and harvestable biomass (in dry weight base) for Typha were 28,187 tons and 19,157 tons, and for reeds were 211,184 tons and 136,334 tons, respectively. These figures agree well with the annual reed production of 7,000-10,000 tons from the lake by the local Statistic Bureau. Annual production of *P. pectinatus* was estimated to be 31,417 tons if harvested in July. In sum up, the lake was considered at least having 180,000 tons of harvestable plant biomass annually.

DISCUSSION

4.1.4.1 Specific composition

Rich nutrients, shallow soil bed and suitable climate in the lake provide an ideal condition for the macrophyte growth. However, competitive exclusion limited the further development of some original species, which were found by a previous survey in late 1980's. Obviously, reed and *P. pectinatus* were winners in the competition battle. Relying on its strong rhizomatous spreading ability, reeds quickly invaded the shallow areas of the lake. Once established, the dense tillers and high canopy gave the plant advantage over other species in light reception, and possibly, nutrient absorption by its well developed rhizomatous root system.

P. pectinatus employed another strategy for its competition battle for space, in which reproductive methods way played an important role. Both sexual and vegetative reproduction abilities enable the plant to easily conquer new territories, and even become an infestatious species. Both the two plant species have strong recovery/re-growth abilities in comparison with other species. Advantages in reproduction and growth qualified them to become the almost exclusive species in the lake. It seems that their dominant role will remain for as long as the lake's life unless a big disturbance occurs.

There is no evidence for the winner of competition battle between these two species. Surely, they are exclusive to each other, in the fact that they are not co-exist in the same spots. However, it is hard to see which one is expanding, while the other is withdrawing, with the limited information collected so far.

4.1.4.2 Reproduction/regeneration

Reed has been long known as a noxious weed, not easy to get ride of, in agricultural practices. In the particular case of Lake Wuliangsuhai, reeds were regarded by the locals as valuable natural resources for their livelihoods. Its strong regeneration ability, together with the rich nutrient supply from the lake, makes it a retainable/sustainable resource for the locals.

P. pectinatus was used to be regarded as a weed too. It is only in the recent year, with the shortage of animal feeds in the surrounding areas; the plant was appreciated for its value as a feed resource, although its quality was questioned due to its too high salt content (near toxic). Diverse reproductive methods and high recovery growth make this plant the most persisting vegetation in the lake. In positive sense, it is a reliable and sustainable feed resource, and in negative sense, it is the most noxious weed to get ride of.

4.1.4.3 Nutrient removal by harvesting

With a favourable environmental condition and sufficient nutrient supply from the eutrophic lake, vegetation in Wuliangsuhai has an annual production capacity of 180,000 tons of biomass. For reeds, an annual production output of 136,334 tons (currently 70,000-100,000 tons) was achievable. Based on the 1 mg/g dry weight of phosphorus concentration in the reed harvestable part estimated by Hedelin (2001), the calculated phosphorus removal by harvesting reeds was 136 tons annually, which is almost half of the annual net income of the lake. If *Typha* and *P. pectinatus* were also harvested accordingly, a net gross balance of phosphorus would be easily attained.

Whether harvesting will reduce the water nutrient level remain a question. Graneli and Solander (1988) stated that emergent macrophytes took up their phosphorus exclusively from the sediment, while submerged species obtained phosphorus both from the surrounding water and from the substrate. It is therefore clear that no immediate reduction of water nutrient level should be expected after harvesting. The long term effects of harvesting macrophytes remains an interesting topic for further investigation.

4.1.4.4 Biomass production and biological filling

An annual production of some 200,000-300,000 tons of biomass by macrophytes is, in any sense, a considerable volume. By calculation with the lake area (approximately 300 km^2), even half of the biomass left in the lake will make an annual deposition of 0.3-0.5 kg/m^2. In another subproject of this project, a recent 1-cm annual organic deposition or 0.1-0.2 cm sedimentation were estimated. The deposition from dead macrophytes is obviously an important contributing factor. The lake is situated on a very flat floodplain; only to its southeast is a slope adjacent to the lake. A large area of adjacent land in its northwest is even lower than the lake itself. Physical filling by soil erosions only occurred in certain locations and in special years of climate turbulence. Suspended particles brought by inlet water were, of course, another factor for the filling up process. However, to what extent this process is comparable with the biological filling by macrophytes remains a question. Removing a partial biomass from the lake by macrophyte harvesting may be a way to alleviate the problem of biological filling, and therefore, to delay the transition of the lake to a swamp.

4.1.4.5 Transition from macrophytes to phytoplankton

Theoretically, a eutrophic lake can switch from a macrophyte dominant (clear water) state to a phytoplankton dominant (turbid water) state if the macrophyte population is eliminated or severely destructed. In the case of Lake Wuliangsuhai, such a switch is considered an unlikely event with the current harvesting practice and production magnitude. In reed production, more than half of the bio-residues remained in the lake, which sustained the plant re-growth as well as being an organic waste deposition. The strong regeneration and recovery growth of reeds gave no chance for phytoplankton blooming. The current harvesting extent of *P. pectinatus* is far below the reproduction and re-growth of this plant population in the lake. In the shallow lake Wuliangsuhai, macrophytes are presently the winners in the competition with phytoplankton. At this stage, danger of the lake bio-filling by the over infestation of macrophytes is far beyond the danger of lake eutrophic transformation. However, ecological risks exist if large disturbances were brought on the current ecosystem. Change of vegetation composition and structure may result in a number of changes in habitat environments which, in turn, will inevitably affect the livings of other organisms and the biodiversity of the system. Fish and birds are among the most vulnerable organisms to such disturbances. Therefore, harvesting of submerged vegetation should be limited to certain areas, not to provoke unwanted environmental changes.

4.1.4.6 Composition and structure of lake vegetation

Shallow soil bed, favourable climate, and rich nutrients supported the macrophytes to grow over the phytoplankton and become the dominant vegetation form in the lake. Diverse reproductive strategies and strong regenerating/recovery abilities of reed, *Typha* and *P. pectinatus* qualify them to be the conquering species over the others. This simple eco-structure in the lake is stable and is likely to remain for a long time unless severe disturbance occurs.

4.1.4.7 Biomass production, nutrient removal and biological filling

Biomass production by the macrophytes is huge and even a partial removal of the biomass by harvesting can remove a substantial amount of nutrient from the lake, although the reduction of water nutrient concentration may not be easily seen in a short period. Biomass removal may also reduce the biological filling of organic materials to the lake, and hence retard the process of lake disappearing.

Alternation of eutrophic states

Transformation from a macrophyte dominant state to a phytoplankton dominant state in the lake is an unlikely event under the current utilization and management regime. There is little risk for increased harvesting of macrophytes in the lake owning to the strong reproductive/regenerating/recovery growth of the major macrophytes. Cautions should be taken for threatens on biodiversity integrity and ecosystem stability brought by large human disturbances.

Current harvesting practice

The current reed harvesting practice, in which a large part of the biomass is harvested during winter, is basically sound. Early harvesting may leave the plant a bushy form which will affect the re-growth in the coming year. Under water harvesting, although being able to remove more biomass, may adversely affect the regeneration (Weisner, 1990), and is impractical in terms of machinery and labour requirements. More Typha should be harvested for the simple reason of reducing the biomass as much as possible.

The current harvesting capacity for *P. pectinatus* seems far below the control point for infestation, and could therefore be increased. Either for utilization, or for elimination, *P. pectinatus* is a plant hard to control due to its diverse reproductive ways and strong recovery growth. However, it is important to avoid harvesting too large areas, to prevent a switch to a phytoplankton dominated state. Up to 10-20 % of the area covered with submerged vegetation could possibly be an acceptable quantity.

4.1.4.8 Management for lake vegetation

As the major goal of the project is "to keep the lake as a lake" and the organic deposition by macrophytes was identified as the main contributing factors for the biological filling up of the lake, slowing down or stopping the expansion of macrophytes seems the most proper approach for prolonging the life of the lake. However, for the local and regional society, the macrophyte is an important source of raw materials (pulp and feed, in particular). It is therefore a long-time goal to maintain the productivity of the lake vegetation for the benefit of the people in the area. The difficulty of a management plan lies on the conflicting attitudes to the macrophyte vegetation. To treat it as a problem (biological filling up, navigation of boats, reduced water surface, reduced habitats for waterfowl and fish etc.), the management should aim at controlling measures. To treat it as a resource (as feed for sheep and cattle, as green fertilizer, source for biogas production etc.), emphasis should be placed on optimising the production and utilization ways.

As elimination of macrophytes in the lake seems unnecessary and impractical, making maximum utilization maybe the focus of a realistic management plan for the lake and the surrounding local societies.

4.2 Harvesting and re-Growth of submerged vegetation

In 1998 a hydrophyte harvester fleet (9 GSCC-1.4H) was designed and manufactured. This fleet is composed of 1 hydrophytes harvester and 1 towing boat with 4 loading barges. Each barge can carry 5 tons. The working speed of the hydrophytes harvester is 2.2 km/h, the harvesting width is 1.4 m, and the harvesting capacity is about 4.5 mu/h (667 square meters per mu, e.g. ca. 3 000 m^2/h).
The productivity of this fleet is 12 tons W.W./h,

From 2000 to 2001, an experimental research base was built in Lake Wuliangsuhai, and a special ecological management dock with necessary equipment was established. 2 special ecological management docks were built and 8 sets of 9GSCC—1.4H hydrophytes harvester fleets were devoted.

From 1999 to 2002, hydrophytes were harvested in test areas near Xiaoouzo and Erdiar area. The annual average harvesting was performed in strips covering an area of 23.35 km^2 within a total area of 69 km^2. A total wet weight of hydrophytes of 51 000 tons were harvested, leading to the removal of 16.83 tons N and 1.734 tons P from the lake.

A feasibility study was carried out in Xiaoouzi and Erdiar area, with a total harvesting area of about 13 400 mu (ca. 8.9 km^2) corresponding to a submerged plant amount of 12 000 tons (W.W.). An estimated 19.8 tons of N and 2.04 tons P were transferred out of the lake, which accounts for 1.82% of the all-year input N amount and 3.09% of P amount, respectively.

The feasibility study was carried out from 1999 to 2002 to study 3 topics:
- re-growth after hydrophytes were harvested
- the plant-algae interactions, and
- ensure stable and permanent operation of the hydrophytes harvesting project.

The experiment scheme was as follows:

1) Experiment time and method:
   carry out the control experiment of hydrophyte harvesting in different months of 1999, 2000 and 2001, examine the hydrophytes harvesting amount per unit area, compare the biomass changes, and continue to monitor in 2002;
2) experiment area:
   construct 6 experiment area with area 50 m × 50 m and average water depth 0.95m;
3) experiment equipment:
   9GSCC-1.4H hydrophytes harvester boats, Harvesting in 6 experiment areas and other water areas is about 1 650 ha from 1999 to 2002, hydrophytes harvesting experiment time and harvesting amount in 2001 is shown in the following table.

Attached (epiphytic) algae may be in a dispersed and a free-floating state. At high temperatures they float on the water surface layer attached to Fennelleaf Pondweed (*Potamogeton pectinatus*). These algae attach on the Fennelleaf Pondweed to form dense algae mats, but all disappear in windy or rainy days. Each patch of floating algae is less than 0.35 m^2, and the aggregated area of floating algae is estimated to 2-4 % of the open water surface. After submerged plants are harvested, the water environment is improved in the experiment area, due to the disappearance of the Fennelleaf Pondweed and the attached algae. The water transparencies of the harvesting areas were almost the same as that of untouched areas, with transparencies over 1m.

The reproduction ability of Fennelleaf Pondweed is very strong, and growth speed is very high. Usually, Fennelleaf Pondweed restore to the original biomass after 55□ 60days of harvesting, moreover, production of the second year is not affected.

After carrying out 3 years of harvesting experiments, the biomass variation of submerged plant of test area was continually monitored from June 2002 to October 2002. The average standing biomass of the whole test area was 1 483±116 g $DW \cdot m^{-2}$, and it was observed that the biomass of submerged plants in test areas

Table 1. The experiment results of hydrophyte harvesting (cutter underwater down to a depth of 0.7 m)

Experiment area No.	Reaping time	Reaping amount tons (d.w.)	Water depth (m)	Water temperature	Note
1#	May, 26 June, 27	1.60 0.65	0.9 0.8	7 15	Water level declines, and the leakage rate of reaping and gather is 8% Simultaneous reaping calculates the average
	August, 20 October, 24	3.02 3.75	0.7 1.1	21 6	
2#	June, 27	3.53	0.8	15	Simultaneous reaping calculates the average
	October, 24	3.75	1.1	6	
3#	May, 26	1.52	0.9	7	Simultaneous reaping calculates the average
	October, 24	3.75	1.1	6	
4#	October, 24	3.75	1.1	6	Simultaneous reaping calculates the average
5#	August, 20	3.32	0.7	21	Simultaneous reaping calculates the average
	October, 24	3.75	1.1	6	
6#	July, 21	3.46	0.7	20	Water level declines, and the leakage of reaping and gather is 8%
	October, 24	3.75	1.1	6	Simultaneous reaping calculates the average

and in control areas area were not significantly different. Therefore, it is concluded that the used technique of harvesting submerged plants can permanently carry on for years without reducing the growth potential.

The co-operation with the feedstuff corporation of Tumoteyouqi, produced 18 200 tons of assorted feedstuff with hydrophytes, corn straw, and alfalfa, which is applied in cattle breeding and enclosing barn breeding.

Bundling forage is applied in Daheihe Milk Supply Base of Huhhot Neilun Natural Milk Corporation and Xunri Corporation and is fed to cattle instead of other plants. The result is that 3.7223×10^6 RMB is saved, and newly adding profit and tax is 5.2×10^6 RMB. Thus the total income was 8,9 mill. RMB during this experiment.

4.3 Water depth at the edge of the Reed Stands

The maximum depth at the edge of the reed stands was found to be 1.2 m. It is reasonable to assume that the reed is able to expand into deeper areas in periods with very low lake water level, whereas increasing the water depth either by increasing the lake water level or dredging is likely to prevent the reed from expanding into deeper areas, or even to draw back. However, it has not been possible at the present stage of the project to quantify such relationships between variations in lake water level and expansion of reed.

4.4 Exchange of Phosphorus between sediment and water

The results from the sediment exchange experiment are shown in the chart below. The results show that the release of phosphate is similar for the anaerobic, aerobic and control during the first 33 days of the experiment. After 41 days there are some differences between the phosphate release from the sediment in anaerobic and aerobic conditions. These differences may be an experimental error and should not be considered a realistic condition. Normally sediment exchange experiment is only set up for 30 days, and during that period there is no statistical difference between the anaerobic and aerobic conditions.

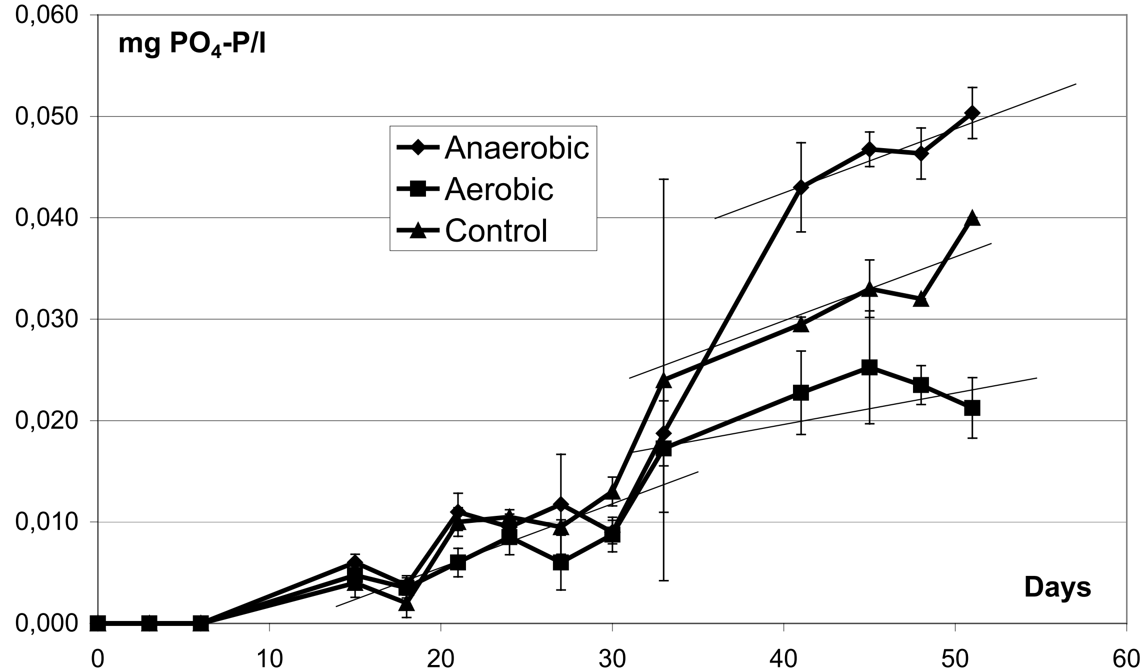

Figure 4.1 Accumulated phosphate release during 51 days from the sediment exchange experiment set up.

4.5 Dredging Experiment

The purpose of this experiment was to test in full scale the technical and economical potential and limitations as well as the limnological aspects of deepening the lake in designated areas. Already from the outset in 1997 this experiment was considered as one of the more important as well as the most expensive experiment of many others that is included in the project.

Soil characteristics

The dredged soil separated easily from the accompanying water in the lagoons, and the discharge water from the lagoons had low particle content.

A soil-sample was analyzed at NGI (The Norwegian Geotechnical Institute) to check the soil mechanics. The results confirmed that the soil at the test area is very easy to dredge with the chosen equipment. The Chinese conducted tests on the soil for growth-characteristics and potential use for erosion control.

Analyses are also carried out on the water returned to the lake.

Increasing the water level

Dredging is a costly way of deepening the lake. In earlier times the lake was considerably deeper according to interviews with elderly fishermen from the lake-shore villages. The level of the lake was higher, but in order to reclaim land and to lower the drainage canals the lake level was manipulated. It should be looked into the consequences of increasing the level again. Increments of only 10 cm will have positive effects on dredging costs which have to be compared with increasing pumping- costs, building of dykes, loosing land and reed-areas etc. A combination of a 10 to 50 cm or more increase of the water level with dredging should be investigated.

Costs

The Chinese have estimated the costs of dredging to 15RMB per m^3 based on the experiment. This price is slightly lower than what a similar operation would cost in Norway. We want to point out that a large scale dredging of the assumed 25km^2 will have considerably lower price per unit than the field experiment costs. To estimate the cost of large scale dredging will require more work.

Conclusions and recommendations

- The bottom at the chosen site, with the chosen equipment was easy to dredge
- We assume the site to be representative for the lake bottom in general
- We recommend to build one or more dredging- rigs and operate them with local workers during the season from April to October as the cheapest way of dredging
- We assume that a total of 25 km^2 be dredged at designated areas in the lake.
- Most of the chosen areas for dredging will be located at distances from the shore that will require barge-dredging with pipelines and booster stations for transportation of dredged material to the shore, unless construction of nearby islands is of interest
- The dredged material is suitable and quite valuable for agricultural use as well as for erosion control
- If we assume a price of 15 RMB per m^3 of dredged material all inclusive, an increase of the water level of 10 cm represents a saving of 100 000 m^3 dredged material or 1.5 mill. RMB per km^2.
- A combination of dredging and increase of the water level should be explored further, to establish the costs and consequences of the latter.

4.6 Effects of Test Dredging on water quality

The results of the water quality monitoring after the dredging experiments are given in the following table.

Tab 4.1. Primary results of water quality analyses after the dredging experiment.

Water depth	Station	Sampling depth	Date	pH	Total N (mg/l)	Total P (mg/l)
0.6m	shallow	0,2	25.06.2003	8,16	3,16	0,05
1.0m	medium	0,8	25.06.2003	8,11	2,43	0,043
1.4m(shallow)	deep	0,2	25.06.2003	8,13	3,28	0,103
1.4m(m)	deep	0,8	25.06.2003	8,06	2,91	0,082
1.4m(deep)	deep	1,3	25.06.2003	8,10	3,66	0,094
0.5m	shallow	0,2	06.07.2003	8,12	3,71	0,056
1.0m(shallow)	medium	0,2	06.07.2003	8,45	4,59	0,052
1.0m(deep)	medium	0,8	06.07.2003	8,35	3,07	0,039
1.5m(shallow)	deep	0,2	06.07.2003	8,36	3,32	0,05
1.5m(m)	deep	0,8	06.07.2003	8,45	4,07	0,039
1.5m(deep)	deep	1,3	06.07.2003	8,27	9,61	0,043
1.0m	shallow	0,3	03.08.2003	8,30	3,64	0,759
1.5m(shallow)	medium	0,2	03.08.2003	8,50	3,3	0,03
1.5m(deep)	medium	1,3	03.08.2003	8,47	3,71	0,026
2.0m(shallow)	deep	0,2	03.08.2003	8,48	4,25	0,039
2.0m(m)	deep	1	03.08.2003	8,42	3,12	0,026
2.0m(deep)	deep	1,5	03.08.2003	8,50	3,32	0,035
0.5m	shallow	0,3	10.10.2003		4,28	0,031
1.0m(0.3m)	medium	0,3	10.10.2003		3,86	0,031
1.0m(1.1m)	medium	1,1	10.10.2003		4,16	0,031
1.5m(0.3m)	deep	0,3	10.10.2003		4,28	0,06
1.5m(0.8m)	deep	0,8	10.10.2003		3,73	0,094
1.5m(1.1m)	deep	1,1	10.10.2003		3,05	0,035

The measurements performed approximately one year after the dredging, showed that the water quality in terms of pH, Tot P and Tot N was almost the same after dredging as before. The submerged vegetation had re-colonised with the same species as before dredging, and the abundance was about the same as before at the 0.5 m and 1.0 m test areas, whereas the re-colonisation of the 1.5 test areas had been markedly slower.

5 SOME ADDITIONAL CONSIDERATIONS

5.1 Acceptable Nutrient Loading

One way to find a value for how large an acceptable P-loading for the lake can be is to set a goal for the P-concentration in the lake or in the inlet water (not taking into account the self-purification effect when the water enters the lake), according to Chinese Water Quality Standards. The main input is the Main Drainage canal. We have estimated a transport of ca.. 105 tons P per year in the irrigation season. If we assume additional inputs during the non-irrigation period of 30 tons, there will be a sum of 135 tons P annually. The mean water transport is $533*10^6$ m^3. This means a volume weighted concentration of 0.253 mgP/L. Assuming different goals and using the different standards for rivers and lakes, the necessary reductions in P inputs via the Main Drainage Canal will then be as follows:

Goal	Class III for lakes 0.050 mgP/L	Class IV for lakes 0.100 mgP/L	Class III for rivers 0.200 mgP/L
Required P-reduction in Main D. C. (tons)	Ca. 110	Ca. 80	Ca. 30
% reduction	Ca. 80	Ca. 60	Ca. 20

5.2 Possible restoration effects on the Lake Ecosystem

Three main concerns about the water quality of the lake are of current interest with dredging of lake sediments and large scale harvest of submerged vegetation. Below follows a short description, which should be further discussed and given a firmer theoretical and practical basis.

Disturbance of birds

Care should be taken not to disturb bird reproduction and feeding during critical periods of the season. This is of special importance to the habitats of rare and endangered bird species (see 2 bird survey reports of A. Svenson: spring migration in 2004 and autumn migration in 2000).

Disturbance of nutrient rich sediments

Dredging and mechanical harvest of plants in a lake might cause physical disturbance and redistribution of submerged plants and lake sediments rich in nutrients (P and N) into the water mass. Nutrients, which are normally attached to the sediment particles or dissolved in the water in between the sediment particles, may be released to the lake water and then boost the growth of macrophytes and/or phytoplankton.

Increased turbidity is also an unwanted disturbance of the lake ecosystem in itself. Turbidity will affect most of the plant and animal species living in the water. If high turbidity persists over a long time, the biodiversity of the lake may be dramatically reduced, like it probably is in the open water basin close to the Main Pumping Station.

Deep vs. shallow lakes

Although a simple linear relationship can be established between phosphorus (P) concentration and phytoplankton density in deep lakes, such simple models cannot be developed for shallow lakes. Deep lakes with low P concentrations are normally clear unless particles or coloured humic substances are suspended in the water. With increasing P concentration, a proportionate increase in phytoplankton density is normally found in deep lakes. Hence, deep lakes with low P concentration (oligotrophic lakes) are normally clear while those with high P concentration (eutrophic) are normally turbid due to high phytoplankton concentration (see figure below).

In shallow, nutrient-poor (oligotrophic) lakes an increase in P concentration primarily leads to growth of more submerged vegetation. Even at quite high P concentrations the water of such lakes remains clear, if the high density of submerged plants persists ("stable clear water state"). This is partly due to the incorporation of the surplus P into macrophytes instead of into phytoplankton. In such situations the submerged macrophytes are competitive to the phytoplankton.

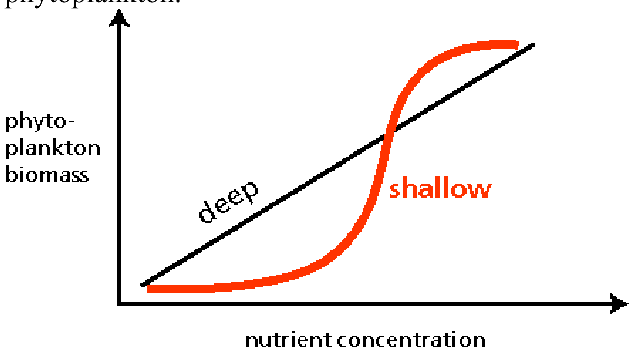

Figure 4.2. In a deep lake the concentration of phytoplankton normally increases linearly with the concentration of the limiting nutrient (normally phosphorus or nitrogen). In shallow lakes a similar increase in nutrient concentration is primarily directed into growth of submerged vegetation. Therefore the water remains clear. High growth rate of phytoplankton often takes place at much higher nutrient concentration than in deep ones.

In deep lakes, the described process is reversible. If the input of nutrients is reduced, the nutrient concentration in the lake water drops causing lower growth rate of phytoplankton, and the water again becomes clear.

Unfortunately, in shallow lakes a turbid situation may persist for a long time, even if the nutrient loading is reduced. Such a situation ("stable turbid water state") may persist for years until eventually the submerged plants are disturbed or destroyed by plant eating fish or birds, reduced water level, erosion by ice, plant diseases or harvesting. If so, the phytoplankton may utilise the surplus P, increase their biomass, and then reduce the light intensity in the water sufficiently to reduce the growth of macrophytes. In such cases blooms of blue-green algae (Cyanobacteria) are often the result. Such a situation is normally considered much more unfavourable than a dense growth of submerged macrophytes.

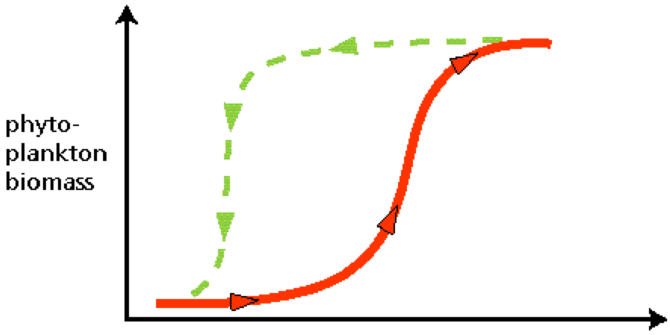

Figure 4.3. Shallow nutrient-poor (oligotrophic) lakes tend to remain in a clear water state after moderate increase in P (low phytoplankton density) - or in a turbid water state after strong increase in P (high phytoplankton density) irrespective of considerable variations in nutrient concentration. The phytoplankton concentrations are independent of phosphorus and nitrogen over a wide range of nutrient concentrations.

These are the fundamentals of "The two stable states hypothesis". Shallow lakes tend to remain in either a clear water state - or a turbid water state. In the clear water state the water transparency is high due to a low concentration of phytoplankton, while in the turbid state a high phytoplankton density is found. The situation depends mainly on whether the water mass contains a dense population of submerged macrophytes or not.

Switching from one state to the other may be caused by different factors. This will be discussed in some detail below.

Table 4.2 Switches between clear and turbid stable states (modified from Moss 1998)

Switches from clear to turbid state	Switches from turbid to clear state
• **Destruction of plants:** - Mechanical harvesting - Boat damage - Herbicides - Grazing by cattle, birds, fish, crayfish - Raising of water level • **Interference with buffer mechanisms** - Reduce zooplankton activity by contaminants/toxins - Increase salinity above 5 per mill. (o/oo) - Reduce predatory fish by O_2-depletion or over-fishing	• **Alteration of the fish community to promote large zooplankton grazers** - Removal of planktivorus fish - Stocking of predatory fish • **Reduce nutrient inputs** - Reduce pollution - Reduce release from sediments • **Lower water level**

5.3 Biodiversity - Landscape Ecology

One of the main goals of this project is to sustain or increase the biodiversity in Lake Wuliangsuhai.

Since this is not a straightforward task, some theoretical basis will be described. The literature on this field is vast and only a few important considerations relevant for the project will be given.

Biodiversity is for practical reasons often defined as the total number of co-occurring species in an ecosystem. This includes their genetic diversity, and in this respect encompasses all natural variation from molecular and genetic levels to the species level. Further the biodiversity includes variation beyond the species level, up to the landscape level. However, for simplicity, the primary focus of this setting will be the species level. The ideas presented here are in general agreement with the textbook of i.e. M. A. Huston (1996): Biological Diversity. The coexistence of species on changing landscapes. Cambridge University Press.

Understanding lake biodiversity requires fundamental insights into different aspects of biology as well as sciences such as geology, ecology, evolution, biogeochemistry, climatology, limnology and how these processes interact on the species level. These factors should be thoroughly considered before management of ecosystems takes place.

The concept of biodiversity must be subdivided into tractable concepts to show meaningful patterns and regularities; a few of those relevant for this project will be discussed here.

5.3.1 Concepts

Some concepts of importance for understanding biodiversity are mentioned below.

Competitive exclusion
This concept suggests that two species cannot co-exist when they have identical needs of a resource in limited supply; they have the same ecological niche. Two such species will compete for reproduction, growth, habitat or survivorship in a way that one species will decrease and the other will increase in population size. In the end the "looser" might be totally excluded from the area where the competition takes place. Often the latter is not the result, since environmental factors are constantly changing affecting the competition between the two. Instead one species will often dominate over the other.

Dominance
A community of plants, animals or bacteria, normally consists of a few dominant species, a somewhat lower abundance of sub-dominants, and a higher number of rare species. Due to changes in the environment some of these rare species may get an opportunity to reproduce and take over as a sub-dominant or a dominant species.

Zonation
Species tend to be most abundant under conditions near their physiological optima. This applies both to physical factors (e.g. temperature, moisture, light intensity and day length) and chemical factors (e.g. nutrient content, pH, salinity). In addition, the species have to succeed in the competition with other species for food, reproduction, space, and avoid being eaten or affected by parasites. Regular spatial patterns of species distribution can be observed along environmental gradients, e.g. plant species from shallow waters in a lake to dry land, or bird species from grassland into a desert. These patterns of species distribution are denoted "zonation". Similar zonations tend to exist in different sites under similar environmental conditions.

Seasonal succession
Increasing temperature, light intensity and day length from spring to summer cause changes in species composition due to different adaptations to critical resources. Changes in physical factors often induce chemical and physiological changes. Changes in species composition through the yearly cycle follow similar patterns from year to year and are often to a large extent predictable. Due to such seasonal successions the biodiversity changes dramatically through the year, especially in temperate regions with large climatic differences between summer and winter seasons. The seasonal fluctuations on shorter and longer scales provide a broad range of environmental conditions that often allow a large number of species to co-exist at a given moment.

Environmental disturbances
Unpredicted changes in the environment often occur, such as storms, floods, droughts, extreme wind, precipitation or temperature. When these disturbances are large enough, they may severely impact the normal seasonal successions by mortality on one or more of the present species. The competition between species may also be altered following the disturbance, giving other species the chance to dominate. An "intermediate disturbance hypothesis" is established and widely accepted, which suggest low species diversity both at very low and very high intensity or frequency of disturbances. Accordingly, this hypothesis suggests that disturbances of intermediate intensity or frequency lead to the highest biodiversity. Over time, ecosystems tend to have an average diversity that reflects the dynamic equilibrium between short-term disturbances and competitive exclusion.

Endemism and invasion
Long term adaptation, distribution and exclusion of species may lead to exclusive presence of a certain species in a restricted area. Examples may be plant species that are only found on a certain mountaintop, or bird species that have developed on an island in the ocean. Such species are, of course rare and often at the brink of extinction. Such species call for special attention when it comes to human exploitation of their habitat.

Invaders, on the other hand, are species with great success in spreading to, and surviving in, new ecosystems. Often invaders manage to out-compete species which have been established in an environment over long time. Humans have introduced numbers of plant and animal species from far away places for the purpose of growing food, textiles or other useful products. Some of these highly productive species have a high potential of success in both establishment and further invasions, once natural distribution barriers are overcome. This may sometimes lead to great damage to natural ecosystems. Many examples of such "pests" (e.g. plants, mussels, birds and fish) are given in the literature. *Potamogeton pectinatus* is an example of a submerged freshwater plant with global invasion success in temperate lakes. The result of such invasions is often a pronounced reduction in biodiversity or other deterioration of the environment.

Ecotones
Ecotones are transitional zones between different habitats or ecosystems, e.g. between land and lake, or between grassland and desert. Ecotones are often narrow strips of area characterised by steep ecological gradients and high species richness. The species combinations in ecotones may be unique compared to the adjacent habitats. This so-called "edge-effect" causes e.g. favourable conditions for many bird species in the transition zones at the lake shore or marsh edge, because of good availability to environments to breed, feed, hide etc. In this respect ecotones have an important role in maintaining biodiversity on a local and regional scale. Ecotones are sensitive to environmental changes, like humidity change and climate change, and are therefore "early warning" ecological indicators of special value.

Habitat fragmentation and habitat loss
When disturbing an ecosystem by physical (construction work) or chemical (pollution) intervention, fragmentation of the habitat may be the result. Corridors of migration may be cut off, or the habitats reduced so much in size that their ecological function is altered. Ultimately, when further destruction of the habitat takes place, a habitat loss may be the result. It is not only necessary to protect single endangered species - the proper functioning relies on the whole complex of biodiversity in the wetland ecosystem.

5.3.2 Habitat types in a shallow lake ecosystem

A shallow lake like Lake Wuliangsuhai consists of sections with different characteristic environmental qualities. These environments have pronounced differences in productivity, plant and animal biomass, species diversity, vulnerability to human impacts etc. In the following five different environments relevant to Lake Wuliangsuhai are described. A preliminary description of plant and animal species diversity is suggested.

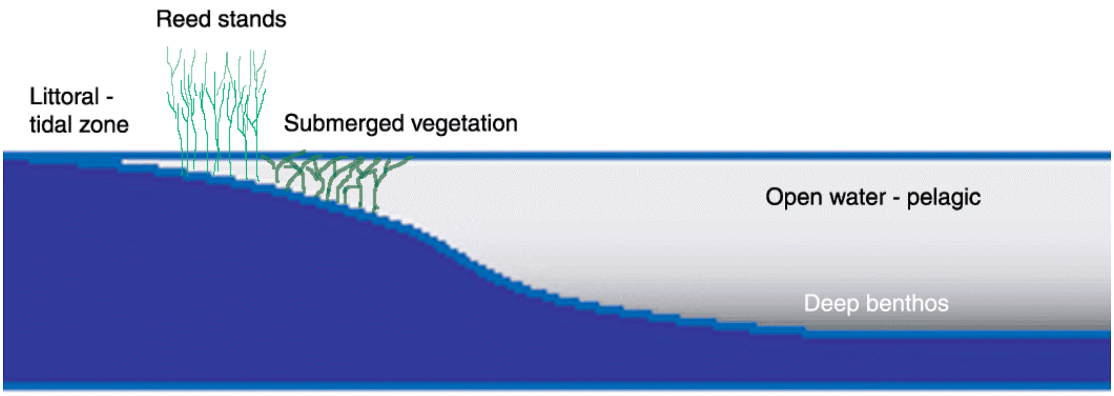

Figure 4.4 Division of a shallow lake in 5 different functional habitats. Additional habitats like islands or marshy forest could be added.

In general, lake environments are characterised by much lower biodiversity than terrestrial ones. This is both attributed to their low structural heterogeneity and to the "young" age in geological terms of most lakes, with short time to both species invasion and evolution of new species. Opposite to deep lakes, shallow ones are often productive with a high standing plant biomass.

Deep benthos
These are bottom areas in the lake too deep to be inhabited by green plants, due to lack of light. Such areas are dominated by animals and living on and in the sediment relying on the organic content and the micro-organisms of the sediment or the deep water as their main source of food. They rely on supply of organic particles from the lake catchment, the plankton or more shallow parts of the lake. Examples of such animals are insect larvae, mussels and sponges.

Actually, no water depth larger than 3.2 m have been measured in the lake lately. For the purpose of the systematic of this presentation we call this environment "Deep pelagic", to distinguish it from benthic communities within the plant communities. Even though such areas have limited distribution in Lake Wuliangsuhai, their inhabitants may play an important role as food for fish and birds. We have no information about the species of benthic animals from this type of environments in the lake.

Normally, deep benthic communities are stable compared to e.g. pelagic environments, due to stable physical and chemical environment. However, pollution or extreme climatic events may considerable affect these environments. In Wuliangsuhai the organic pollution and the high plant production cause oxygen depletion during winter, which has a dramatic impact on the biota in this environment every year.

Table 4.3 A rough evaluation of diversity of the most typical plant and animal groups in deep benthos habitats in Lake Wuliangsuhai.

	low diversity	medium diversity	high diversity
Insects		□	
Zoobenthos		□	
Phytobenthos	□		
Phytoplankton		□	
(Macrophytes)			
Zooplankton		□	
Fish	□		
(Birds)			

Open water – pelagic

The pelagic part of the lake is the water above the deep benthos. In these parts the phytoplankton, zooplankton and pelagic fish dominate. The only primary producers in this environment are the phytoplankton that converts light energy from the sun to biomass by means of chlorophyll, just the same way as other plants. The main difference with other plants is that phytoplankton consists of microscopic, free-floating algae with no cell differentiation to form roots, stems, branches and leaves. Phytoplankton constitutes, together with pelagic bacteria and organic particles, the food for filter-feeding zooplankton. In addition some zooplankton species are predators on smaller zooplankton. Zooplankton may be important food for many fish species.

The pelagic food chains are much less important in shallow lakes than in deep ones, because of the high plant production in the reed and submerged parts of the lake, and that the pelagic constitutes a restricted part of the lake.

The pelagic environment is vulnerable to pollution events and extreme climatic conditions. Due to short generation times of phytoplankton, the pelagic food chains may rapidly change both in species distribution, diversity and productivity.

Table 4.4. A rough evaluation of diversity of the most typical plant and animal groups in open water – pelagic habitats in Lake Wuliangsuhai.

	low diversity	medium diversity	high diversity
Insects	□		
(Zoobenthos)			
(Phytobenthos)			
Phytoplankton			□
(Macrophytes)			
Zooplankton			□
Fish	□		
Birds			□

Submerged vegetation

In a large part of the lake shallow enough for plant growth, submerged vegetation has established. These are vascular plants (with roots, stems, branches and leaves). The submerged plants are connected to the sediment by roots, which collect a certain part of the nutrients they need from the sediments. During summer the stems normally grow long enough to reach the surface of the lake. Many submerged plants start growing in the spring from seeds, or from small wintering shoots on the sediments, so-called tubers. Other species may survive the winter as intact plants.

The dominant submerged plant in Lake Wuliangsuhai, *Potamogeton pectinatus*, seems able to survive the winter as intact whole plants. Another species observed in the lake, which may form winter shoots, is *Ceratophyllum* sp. The dense cover of submerged plants make a physical environment well fit for a rich flora and fauna. Also *Potamogeton* has a low content of cellulose, which makes it a feasible food item for plant-eating birds and fish. When the Potamogeton reaches the surface during early summer, the floating mass of plants is a suitable surface for insects, attached algae and birds.

This type of submerged plant environment is known to be resistant to most disturbances in a lake. Once established this species will normally persist for ages.

Table 4.5 A rough evaluation of diversity of the most typical plant and animal groups in submerged vegetation habitats in Lake Wuliangsuhai.

	low diversity	medium diversity	high diversity
Insects			□
Zoobenthos			□
Phytobenthos			□
Phytoplankton	□		
Macrophytes	□	□	
Zooplankton			□
Fish		□	
Birds			□

Reed stands

The most prominent feature of Lake Wuliangsuhai is the widespread reed stands covering ca. 50% of the lake surface. The by far most dominant is *Phragmites australis*, a species distributed world-wide in temperate lakes and marshes. The sub-dominant is a bulrush, *Typha* sp. These species grow in water depths down to ca. 0,7 m. The reed marsh is the habitat of a high number of birds and insects. Under water in such areas also a rich community of micro-organisms, attached algae, insect larvae and other invertebrates may be found. However, these communities have not been the targets of the present investigation.

Typical of a reed marsh is waterlogged conditions and anaerobic soils. The reed is expected to be a very stable environment of the lake, resistant to most normally occurring disturbances.

Table 4.6 A rough evaluation of diversity of the most typical plant and animal groups in reed habitat in Lake Wuliangsuhai.

	low diversity	medium diversity	high diversity
Insects			□
Zoobenthos			□
Phytobenthos			□
Phytoplankton	□		
Macrophytes	□		
Zooplankton			□
Fish	□		
Birds	□		

Littoral zone

In Wuliangsuhai restricted areas of the lakeshore without or with sparse plant cover are found. These areas are very different from those with reed or submerged vegetation. One feature of such areas is that their plant and animal communities are much more vulnerable to changing water levels than those protected with plants. A moderate to high level of disturbances (humidity, temperature, erosion etc.) may cause rapid seasonal successions and high competition, predation and competitive exclusion of species in these areas. Terrestrial run-off and water movements continuously replenish nutrients and suspended organic particles, and growth rates and competition are therefore often quite high.

Table 4.7 A rough evaluation of diversity of the most typical plant and animal groups in littoral habitats in Lake Wuliangsuhai.

	low diversity	medium diversity	high diversity
Insects			□
Zoobenthos			□
Phytobenthos			□
Phytoplankton		□	
Macrophytes	□		
Zooplankton			□
Fish			□
Birds			□

5.3.3 Ecosystem size and complexity

The following few figures are included to give some information about the diversity on the habitat and ecosystem level. The main message is that a larger ecosystem has the possibility to house more habitats, and therefore more biodiversity, than small ones. The second message is that the shape of the habitats decides the size of the edge between one habitat and its neighbours. The larger these 'ecotones' the higher biodiversity can be expected.

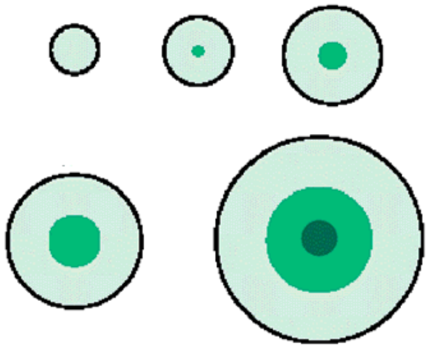

Figure 4.5. Illustration of theoretical ecosystems of different total areas and how total areas determine the number of different habitats possible, given the fact that a habitat needs a certain size to be functional. Each habitat is given a different colour. The figure also illustrates the effects of size on the area of edges between habitats(or 'ecotones'). Increasing size results in more habitats and more ecotone areas, that means also increased number of species.

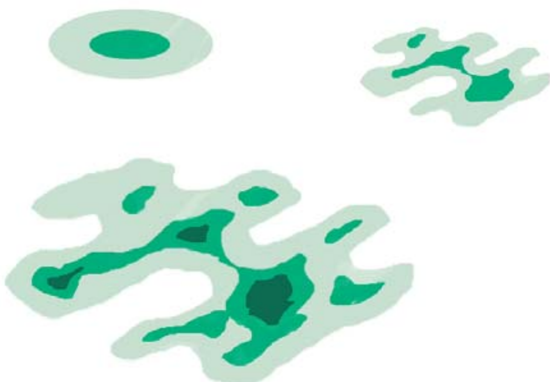

Figure 4.6 Effects of lake size and habitat diversity of a theoretical lake. Different colours represent each habitat type.

These concepts could easily be applied when planning restoration measures in the lake. Below is an application of the theories below on Lake Wuliangsuhai. The sizes, location, depths etc. of deeper areas should be developed in more detail.

Figure 4.7 Example of how dredging of some areas could add to the increase in habitat diversity and, hence, the biodiversity of the lake. Construction of islands and peninsulas are other examples illustrating the same principles.

5.3.4 Self-purification processes

When rivers or canals enters a lake through shallow areas with dense populations of reed or submerged vegetation, the sedimentation rate of particles, nutrients and organic matter are substantially increased compared to entering the lake water masses more directly. Substances like P, N, heavy metals (Pb, Cu, Hg) and persistent organic pollutants are often to a large extent adsorbed to or imbedded in organic particles that are allowed to settle when the water speed is reduced and the inlet water passes slowly through such areas. Besides, the water plants and algae use nutrients in their primary production and thereby incorporate them in organisms that can be harvested or may enter into the food chains. Wetlands are also well known for their importance in the denitrification process, hence transforming nitrate to gaseous nitrogen that is lost to the atmosphere. This process may account for up to 50-80 % reduction of the TN input to a lake if the conditions are favourable. Shallow water with vegetation is also used as a final step for purification of outlet water from sewage treatment plants, farmlands etc. (artificial wetlands).

Generally speaking the purification effect is positively related to the extent of the wetland area. In Lake Wuliangsuhai the large reed belts surely has an important function in the purification of inlet water from the canals. However, estimating the amount of pollutants retained in the reed belts is not easily done. Although the self-purification processes are probably high for inorganic and organic particles, P, N, several heavy metals and even particle bound organic pollutants, they will be low for dissolved salts (cf. report from sub project 3).

It is therefore important to maintain relatively large areas of reed belts around the outlets from the drainage canals – and to avoid too efficient water transfer to the next lake basins via canals.

6 REFERENCES

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Appendix

Results from sediment exchange experiments
(mg Phosphate/L)

	Anaerobic (1-4)				Aerobic (5-8)				Control (9-11)		
Core no	1	2	3	4	5	6	7	8	9	10	11
2002-04-23	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
2002-04-26	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
2002-04-29	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
2002-05-08	0,007	0,005	0,006	0,006	0,005	0,003	0,006	0,005	0,003	0,005	0,019
2002-05-11	0,004	0,003	0,003	0,005	0,005	0,003	0,003	0,003	0,001	0,003	0,013
2002-05-14	0,010	0,009	0,013	0,012	0,005	0,008	0,006	0,005	0,011	0,009	0,023
2002-05-17	0,010	0,008	0,011	0,009	0,009	0,009	0,010	0,006	0,011	0,010	0,059
2002-05-20	0,008	0,016	0,016	0,007	0,002	0,007	0,008	0,007	0,010	0,009	0,058
2002-05-23	0,010	0,010	0,008	0,008	0,011	0,009	0,008	0,007	0,014	0,012	0,003
2002-05-26	0,020	0,014	0,020	0,021	0,023	0,022	0,014	0,010	0,010	0,038	0,022
2002-06-03	0,045	0,038	0,048	0,041	0,028	0,024	0,019	0,020	0,030	0,029	0,021
2002-06-07	0,047	0,049	0,045	0,046	0,032	0,027	0,019	0,023	0,035	0,031	0,024
2002-06-10	n.a.	0,046	0,049	0,044	0,026	0,024	0,022	0,022	n.a.	0,032	0,025
2002-06-13	n.a.	0,048	0,050	0,053	0,020	0,018	0,025	0,022	n.a.	0,040	0,026