GUIDELINES OF LAKE MANAGEMENT

Volume 3

Lake Shore Management

Editors:

S.E. Jørgensen and H. Löffler

International Lake Environment Comittee
United Nations Environment Programme

International Lake Environment Committee Foundation
Shiga-Kaikan Build.,
3-4-22 Kyomachi, Otsu,
Shiga 520, Japan

Tryk: Sangill Bogtryk & Offset

ISBN 87 87 257 220

FOREWORD

S. Evteev

As a result of socio-economic development in the lake basins lakes and lakeshores are becoming more and more complex in their structural, spatial and temporal dimensions as such development proceeds.

Perception of the functions of freshwater bodies, lakes in particular, has changed during intensified development along their lakeshores. Nevertheless, the achievements are often based on trial and error approach and then developed negative impacts become costly to be resolved. Sometimes the effects are nearly irreversible.

As an example can be given uncontrolled industrial development along the lakeshores in many parts of the world, with a consequence of heavy pollution of the lake waters. Extensive agriculture along the lakeshores has developed the shrinkage of lakes and increased salinity of their waters. Therefore when exploiting the lake basins we have to bear in mind that lakes and lakeshores form an important part of the ecosystems and landscapes.

In contrast with current practices, which take into account only the lake function as a source of water, all functions should be considered simultaneously and all interactions between environmental conditions, human activities and lakeshores as part of the ecosystems need to be reviewed and solved in the basin-wide scale.

The guideline book "Lakeshore Management" prepared under a joint programme of UNEP and ILEC is focused on the above problems and their sustainable solution. It is hoped that both researchers and practitioners concerned with the lakeshore management will find the book useful in their everyday work.

FOREWORD

Tatuo Kira

The whole spectrum of lake management may be divided into three fields in the special context, though these are, of course, closely related to each other. The management of lake water itself comes in the first place, and the second concerns the management of the whole catchment land area. In addition, the lakeshore management is no less important than the others for several reasons.

As emphasized in the text of this volume, the shore or littoral zone has the highest biological activity and productivity in a lake ecosystem, thus contributing greatly to biological resources of the entire lake, particularly in shallow of small lakes. It is also an unstable rension zone between land and water, where erosion and deposition as well as submergence and drying-out alternate from time to time. The ecological importance of land-water ecotone or transitional zone and its fragility have been frequently stated in recent literature. On the other hand, humen activities related to lakes tend to be concentrated on their shores with the result that littoral ecosystems are exposed to artificial disturbance or destruction. The careful management of the lakeshore is therefore a condition for the sustainable, environmentally sound utilization of our lake resources.

It may also be pointed out that the shore, when looked at from the lake in a way represents the face of the lake. Sailing along the shore in a boat one can easily imagine how the lake -- and even the entire catchment -- has been managed. Where the lake is managed in an environmentally sound way, the shore scenery is always *natural and beautiful* to the satisfaction on both the local residents and the sightseeing visitors.

These are the reasons why the International Lake Environment Committee (ILEC) has decided to allot one separate volume to the shore management. I take this opportunity to express my gratitude to the UNEP for their support and the ILEC-members, especially the two editors, for the efforts they have made, and it is my hope that the committee's intensions will be favourably accepted by the readers of this volume.

Otsu, Shiga, April 1990

Tatuo Kira
Chairperson
Scientific Committee of ILEC

Authors:

Tatuo Kira and Akira Kurata
Lake Biwa Research Institute
Otsu, Shiga, Japan

S.E. Jørgensen
Royal Danish School of Pharmacy
Copenhagen, Denmark

J.P. Ondok, K. Priban and J. Kvet
Institute of Botany, The Czechoslovakian Academy of Science,
Trebon, Czeschoslovakia

Ewa Pieczynska
Department of Hydrobiology, Zoological Institute,
The University of Warzaw, Poland

H. Löffler
Zoological Institute, The University of Vienna,
Austria

Milan Straskraba
Biomathematical Laboratory, Biological Research Centre
The Czechoslovakian Academy of Sciences
Branisovska, Czechoslovakia

Sándor Herodek
Balaton Limnological Research Institute
The Hungarian Academy of Sciences,
Tihany, Hungary

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CHAPTER 1

INTRODUCTION

1.1 SCOPE OF THE BOOK

The lake shore is as important for the lake as the membrane is for the cell. The shore is a filter for undesired releases into the lake and a buffer zone, which levels out the impacts on the lake coming from its surroundings. The shore may be considered the lake's protection zone.

Conservation of the natural conditions of the shore must therefore play an important role in lake management.

The shore is an ecotone (i.e. a transition area between two ecosystems - in this case a lake and a terrestrial ecosystem surrounding the lake). One can, for example, stand with one foot in water and the other on the bank - one foot in the hydrosphere and the other one in the lithosphere. These are radically different ecosystems containing very different environmental conditions and communities. Species may be expected to replace one another relatively abruptly due to this gradient in environmental factors.

Nature has developed transition zones or ecotones between ecosystems to make a relatively gentle transition. Ecotones may be considered buffering zones between two ecosystems. Lakes with an overexploited shore and with a reduced transition or buffering zone on the other hand become more vulnerable particularly to alteration in the lake environment.

Humans must use ecotone concepts when they design interfaces between human settlement and nature. Unfortunately, it is common practice to construct houses, hotels and so on close to a lake shore line. Under such circumstances, emissions coming from these settlements are transferred directly to the ecosystem. If a buffering zone was maintained, the emissions would be at least partly absorbed.

The scope of this book is to demonstrate the importance of the lake shore in a holistic lake management framework and discuss how the ecotone between lake and land can be maintained as an effective protection zone for the lake, and how the shore management can become an integrated part of the lake management.

1.2. ZONES

Lakes and ponds may be zoned on the basis of depth and type of vegetation that will appear over the course of time in freshwater areas. (Sêe Figure 1.1.)

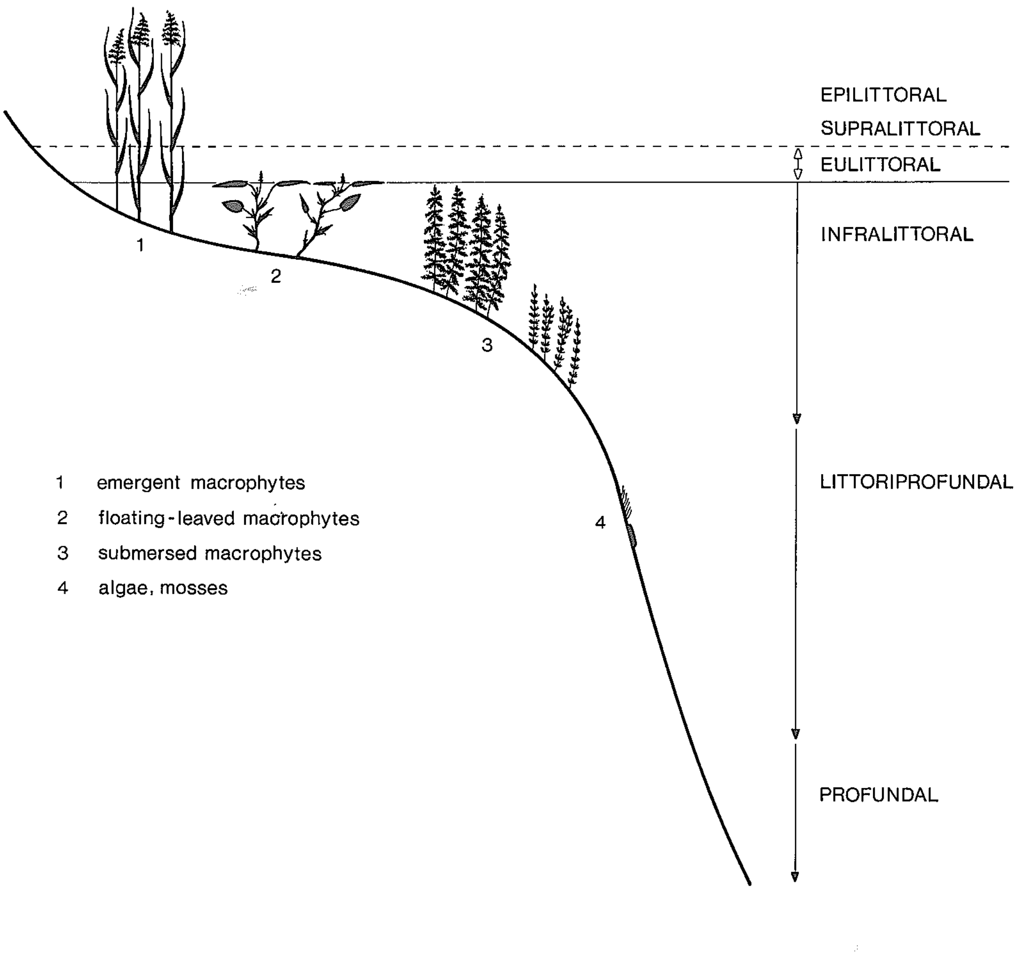

Fig. 1.1. Zonation of a lake.

The zone just above the edge of standing water is described as **the supralittoral zone.** This zone, although not submersed, is exposed to wave action along the margins of lakes during windy periods. Astatic lakes, lakes used as drinking water source or man-made reservoirs will, in addition to wave action, be exposed to variations in water depth comprising the eulittoral, which will imply that the supralittoral zone is variable over time.

The result of wave action and the subsequent abrasive effect of sand and pebbled shorelines means that life may be sparse in this zone. Certain emergent macrophytes and algae and animals will tolerate such conditions.

However, ecotones generally have a high diversity due to the so-called "edge effect". The main reason for this is simple. Where a terrestiral ecosystem, for instance a forest, grades into a lake some species characteristic of both systems are found side by side.

From the water's edge to a depth of a few meters is **the (infra-)littoral zone.** It is dominated by emergent or submersed macrophytes. Shallow lakes may be monozonal (i.e. they contain only one zone: the littoral zone). The life in this zone is highly dependent on the vegetation present. It is often the most productive zone in the lake and is therefore rich in planktone. It often demonstrates a typical example of "edge effect" with a high diversity of life forms - higher than the supralittoral zone or the open water (the pelagial zone). The vegetation is very beneficial to the fauna that thrive in this area. It serves as an anchorage for many of the aquatic organisms as well as breeding sites for snails, insects, etc., and birds. Even sparsely populated vegative areas will reduce wave action in the area, which in turn will minimize turbidity (see also Chapter 3). Another important feature is the production of oxygen by photosyntethic activity of the submersed hydrophytes. Below the (infra-)littoral is a transitional zone, the littoriprofundal with algae and sometimes mosses. It finally is followed by the profundal which is lacking any photosynthetic organisms.

The ecotone between water and land - the shore - consists of these four zones: the supralittoral, the eulittoral, the (infra-)littoral and the littoriprofundal zones. Sometimes a distinct wet zone above the supralittoral may be characteristic in rocky shore sections. This conveniently is called epilittoral. The question that this book seeks to answer is: how can we manage this transition area to the benefit of the entire lake.

CHAPTER 2

EVAPOTRANSPIRATION IN LITTORAL VEGETATION

J.P. Ondok, K. Pribán and J. Kvet

Transpiration in littoral hydrophytes and helophytes is supposed to be high as these plants live in areas, where water supply is not a limiting factor and thus they can transpire at the potential rate (Grundwell, 1986).

Littoral hydrophytes have very little control of their stomatal aperture. Their stomata can remain open even on sunny days at mid-day. Lack of stomatal control in hydrophytes has been discussed by Penman (1963), Idso (1968) and van Bavel (1968).

Total transpiration in littoral vegetation is enhanced by its large leaf surface area. Dense stands of *Phragmites australis, Typha latifolia, T. angustifolia* and *Glyceria maxima* can, for example, be 3 m tall and their leaf area index can exceed, B. Grundwell (1986) explains, the high evapotranspiration rate of littoral vegetation also by its low aerodynamical resistance to the heat flux between atmosphere and the plant stand. This conviction is based on measurements of several authors quoted by Grundwell (1986).

The literature on evapotranspiration in littoral vegetation is not rich. Reviews of the literature data have been written by Linacre (1976), Idso (1981), Ingram (1983) and Grundwell (1986). A great variation of sometimes contrasting results reported by various authors is mainly given by the methods used for evaluating the evapotranspiration. These methods involve mainly direct measurements with lysimeters, tanks and containers of different kind and size; or the evaluation of meteorological data such as the Bowen ratio or data from aerodynamical measurements.

The earliest results originate from measurements in tanks installed in the littoral zone of a North American lake (Otis, 1914, cited by Gessner, 1959, and Bernatowicz et al., 1976). The highest evapotranspiration rates for tanks with selected species were as follows: *Potamogeton nodosus, Typha latifolia, Acorus calamus, Pontederia cordata, Scirpus validus* and *Nymphaea odorata* - 0.138 to 0.648 mm h^{-1}, that of *Potamogeton nodosus* being the highest among all species followed.

Higher rates of evapotranspiration have been estimated (on the basis of gravimetric transpiration measurements) by Kiendl (1953 and 1954) for littoral stands of *Phragmites australis* and *Glyceria maxima* in Central

Europe. Maximum monthly sums of evapotranspiration were 384 mm (August) in *Phragmites* and 333.6 (July) in *Glyceria*. According to this author, under favourable meteorological conditions, the evapotranspiration in stands of these two species is much higher than the evaporation from a free water surface. For example, a stand of *Glyceria maxima* has been reported to evaporate 58 mm (sic!) during one single day. Gessner (1959) concluded on the basis of these results that stands of emersed littoral macrophytes act as "parasites in water economy of their habitats". But those estimates of evapotranspiration, extrapolated from results of gravimetric transpiration measurements, seem much too high.

Rudescu (1065) and Rodewald-Rudescu (1974) evaluated the evapotranspiration of *Phragmites australis* stands in the Danube delta using Popov-type lysimeters located at the Maliuc Experimental Station. His results also indicate a high evapotranspiration of reed stands: monthly sums of evapotranspiration even exceeded 500 mm. The ratio between transpiration and of evaporation of water within the reed stands changed during the season within the range of 1 to 3.2. Transpiration was three times as high as evaporation in the warmest months of the growing season.

Tuschl (1970) measured the transpiration of *Phragmites australis* plants at the Neusiedler See lake (Austria) during the 1966 and 1967 growing season, using the gravimetric method. The daily sums of transpiration attained markedly high values of 12 to 13 mm d^{-1}. Bernatowicz et al. (1976) studied evapotranspiration in stands of three helophytes: *Phragmites australis, Typha latifolia* and *T. Angustifolia*, growing in the Mazurian lakes (Poland). Their evapotranspiration was measured in tanks installed within stands of the same species in the littoral zone of the lake and simultaneously on an elevated dam near the lake. In the first case total seasonal evapotranspiration was about 400-600 mm, which was by about one third less than that in tanks installed on the dam.

Smid (1975) measured the evapotranspiration of a littoral stand of *Phragmites australis* in a large fishpond (Nesyt, Moravia, Czechoslovakia) by the method of heat balance. the daily sums of evapotranspiration fluctuated within the range of 1.4 to 6.9 mm during the season. Values of daily transpiration in three contrasting Phragmites stands (one terrestrial and two littoral) are given by Kvet (1973) and Rychnovska and Smid (1973). They were determined by the gravimetric method on four summer days and ranged between 6.9 and 11.4 mm d^{-1}.

The evapotranspiration of communities of helophytes, and commonly also of all plants inhabiting wetlands of different types, has been studied several times from the standpoint of whether this vegetation reduces or enhances evaporation as compared with that from open water. The E_t/E_w-ratio (where E_t is evapotranspiration of a plant stand and E_w is evaporation from open water) was used for comparing the data from different habitats. The question of their ratio is explored in reviews by Linacre (1976), Idso (1981), Ingram (1983) and Grudwell (1986). Linacre (1976) concludes that tall helophytes reduce lake evapotranspiration while high values of E_t reported in the literature can be explained by the "oasis effect" and heat advection - usually not considered in evaluations of evapotranspiration. The "oasis effect" arises from advection of thermal energy from dry habitats adjacent to lakes of wetlands. This is true for many helophyte stands which form narrow stripes along lake or pond shores or along river banks surrounded by dry land, e.g. fields, steppes or arid lands.

Advection also affects the tank measurements, as stated by Grudwell (1986). Snyder and Boyd (1987), who measured evapotranspiration of *Eichhornia crassipes* and *Typha latifolia* cultivated in tanks, evaluated the peripheral surface area by which additional energy is intercepted by plants in the tanks. For example, the plant stands occupied 5.77 m^2 and the average peripheral area was 14.6 m^2 for *Typha latifolia*. This difference suggests that advection of energy played a considerable role in total energy consumed by the experimental stands for transpiration and evaporation.

On the contrary, Idso (1981) asserts that the presence of vegetation increased evaporative water loss from a water surface. Ingram (1983), evaluating bog and fen evaporation, concludes that "actual evapotranspiration from bogs is approximately equal to their potential evapotranspiration, while on the little evidence that from fens is greater".

Grundwell's (1986) conclusions are more differentiated:

a) Evapotranspiration from hydrophyte stands can exceed that from open water due to the increase of surface area, lower aerodynamical resistance of stands, etc.;

b) the conflicting results of various authors are due to poor experimental design;

c) The E_t/E_w-ratio depends on the state of growth, species, climate and stand density;

d) aboveground biomass and leaf area index can be useful indicators of the E_t/E_w-ratio.

The question whether the E_t/E_w-ratio is normally equal to, higher or lower than 1 in lake littorals thus remains inresolved, but the following practical conclusions can be made tentatively on the basis of various authors' data:

1. E_t/E_w is about 1 in large, continuous and more or less homogeneous communities of emergent hydrophytes and helophytes if the weather conditions are favourable for transpiration, the plants are vigorous and do not suffer from water stress. Under less favourable both weather conditions and plant state, E_t/E_w may be less than 1 in such stands. A thick litter cover, if present, strongly reduces evaporation from wetland vegetation.

2. E_t/E_w > 1 in ecotonal littoral, riparian and other similar plant communities forming relatively narrow stripes or islets of wetland vegetation surrounded by dry land. The E_t/E_w-ratio will increase with increasing heat advection from dry to wet areas and will also be positively correlated with the stand height, aboveground biomass and leaf area index - provided the plants are well supplied with water and weather conditions are favourable for transpiration.

TABLE 2.1
The Transpiration/Evaporation values within the reed bed

Place	Tr/E/(x/1)		Author
Hungary	1.1 - 1.9	(1931)	Haraszty (1931)
Berlin	1 - 7	(1950)	Kiendl (1953), Gessner (1959)
Hungary	1.1 - 1.9	(1931)	Ruttkay (1964)
Danube-delta	0.98-3.42	(1951-58)	Rudescu (1960 & 65)
Danube-delta	Mean 1.54	(1961)	Stoenescu & Voicu (1963)
Valdai	Mean 1.5	(1953)	Urivaev (1953)
Beni Ounif (Sahara)	Mean 3	(1954)	Stocker (1954)
Ilji-delta	Mean 1.8	(1954)	Kuznetzov (1959)
Ilji-delta	Mean 1.6	(1955)	Kuznetzov (1959)
Ilji-delta	Mean 1.8	(1957)	Ghelbuh (1960)
Ilji-delta	Mean 1.2	(1958)	Ghelbuh (1960)
Ilji-delta	Mean 1.6		Kuznetzov (1959)
Kengirsk-Area (Kazachstan)	0.5 - 0.6		Novikova (1963)

Source: Rodewald-Rudescu, 1974.

TABLE 2.2
Transpiration/Evaporation during different months

Date and place	Mean Evapotrans- kg/m^2 day	Trans- piration kg/m^2 day	Evapo- ration kg/m^2 day	Tr/E-ratio
11.5 Berlin	6.24	3.20	3.24	1.0
25.5 Berlin	3.94	2.50	1.44	1.6
27.7 Berlin	12.06	9.82	2.24	4.4
22.8 Berlin	18.30	16.01	2.29	7.0
17.10 Berlin	3.51	2.79	0.72	3.9
June - Danube-delta	4.85	3.36	1.49	3.25
July - Danube-delta	12.08	8.06	4.02	2.0
August - Danube-delta	17.08	11.39	5.69	2.1
Sept. - Danube-delta	11.05	7.82	3.23	3.42

Source: Rodewald-Rudescu, 1974.

TABLE 2.3
Total transpiration in kg/m^2/month

Month	Glycerietum 1951	Phragmitetum 1950
January	0.0	0.0
February	0.0	0.0
March	0.3	0.0
April	20.0	19.1
May	144.1	86.1
June	362.3	188.1
July	333.6	255.9
August	320.7	384.1
September	218.0	240.1
October	120.0	119.5
November	42.5	12.0
December	26.6	0.0
Total kg/m^2/Year	1588.1	1304.9

Source: Rodewald-Rudescu, 1974

TABLE 2.4
Transpiration/Evaporation (Tr/E) data, most, of not all from within the stand

Plant		Tr/E	Investigated Area	Author
Typha	mean min.-max	1.75 1.2-3.0	Valdai (1949-56)	Kuznetzov (1959)
Typha latifolia		3.1	Europe (1914, 59)	Otis (1914) after Gessner (1959)
Typha angustifolia		0.5-0.6	Kazachstan (1962)	Novikova (1963)
Typha	mean min-max	2.6 2.2-2.9	Nijnedevitzki (1953-55)	Evstigneev & Popov (1957)
Typha		1.75	Iajebitzi (1953)	Kuznetzov (1959)
Typha		1.85	See Ribnii-Sakril	Kuznetzov (1959)
Carex	mean min-max	1.45 1.0-2.0	Valdai (1949-56)	Kuznetzov (1959)
Scirpus	mean min-max	1.35 1.0-1.7	Valdai (1949-56)	Kuznetzov (1959)
Scirpus validus		1.2	Mid-Europe (1950-55)	Seidel (1955) Gessner (1959)
Alisma plantago	mean min-max	1.25 1.2-1.4	Nijnedevetzki (1953-55)	Evstigneev & Popov (1957)
Acorus calamus		2.5	Europe (1914, 59)	Otis (1914) after Gessner (1959)
Pontederia cordata		2.0	Europe (1914, 59)	Otis (1914) after Gessner (1959)
Sparganium eurycarpum		2.3	Europe (1914, 59)	Otis (1914) after Gessner (1959)
Nymphaea odorata		0.9-1.0		Otis (1914) after Gessner (1959)
Nymphaea		0.9-0.99	Valdai (1949-54)	Kuznetzov (1959)
Lemna	mean min-max	0.84 0.74-0.91	Nijnedvitzki (1951-54)	Kuznetzov (1959)

Source: Rodewald-Rudescu, 1974

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CHAPTER 3

EROSION AND FILTRATION

S.E. Jørgensen

3.1 FILTRATION BY THE TRANSITION ZONE

The transition zones (mainly the supralittoral and littoral zones) have been shown to remove organic and inorganic material from water that flows through them. They have several attributes which influence the chemicals (natural or artificial) that flows through them (Sather and Smith, 1984). This effect is most pronounced for particulate matter, which is removed almost completely in the transition zone, provided that the zone is sufficiently large and kept under natural conditions. The importance of the transition zone, reducing the amount of suspended matter carrying nutrients or toxic substances reaching the open water (the limnetic zone), is obvious.

Erosion is the transport and disintegration of soil. An area with high erosion will imply a high load of particulate matter to adjacent aquatic ecosystems.

The amount of particulate matter entering the transition zone by erosion is dependent on a number of factors:

- slope of the surrounding land (**land morphology**);
- **soil characteristics** particularly its composition and particle size distribution;
- amount and distribution of precipitation (**climatic conditions**);
- **land vegetation;**
- **land use** including agricultural and industrial activities. Road building is likely to have major effect on lakes, especially if care is not taken to reduce erosion;
- **water utilization and management.**

The chemical composition of particulate matter entering the transition zone by erosion is also dependent on a number of factors. The most important of these factors are:

- **climatic conditions;**
- **soil characteristic** particularly its composition and particle size distribution;
- **land vegetation,**
- **population density** of the area;
- land use including **agricultural and industrial activities;**
- **traffic intensity;**
- **local environmental legislation.**

The filtration of the suspended matter imply that the nutrients, biodegradable and toxic matter are adsorbed on its surface and thus remain in the transition zone. The fate of this material is discussed in section 3.3. and in the next chapter on the water quality aspects of shore management. The next section 3.2. will present the possibilities for quantifying the input of particulate matter to the shore zone.

3.2. QUANTIFICATION OF EMISSIONS TO THE TRANSITION ZONE

Table 3.1 gives an estimation of the nutrient input to lakes from non-point sources. It has been estimated by Lewis et al (1984) that 20-50% of the nitrogen input and 30-90% of the phosphorus input is carried by particulate matter. Is has been suggested that almost all the particulate matter accumulates in the shore zone, provided that the lake posesses a proper supralittoral and littoral zone with vegetation of macrophytes. Exceptions may be found where major tributaries enter the lake at high flow rates.

TABLE 3.1.
Sources of nutrients

Export scheme of phosphorus E_P and nitrogen E_N (mg m^{-2} y^{-1}) 1)

	E_P		E_N	
	Geological classification		Geological classification	
Land use	Igneous	Sedimentary	Igneous	Sedimantary
Forest runoff				
Range	0.7 - 9	7 - 18	130 - 300	150 - 500
Mean	4.7	11.7	200	340
Forest + pasture				
Range	6 - 16	11 - 37	200 - 600	300 - 800
Mean	10.2	23.3	400	600
Agricultural areas				
Citrus	18		2240	
Pasture	15-75		100 - 850	
Cropland	22 - 100		500 - 1200	

The figures are based on an interpretation of the following references: Dillon and Kirchner (1975), Lønholt (1973) and (1976), Vollenweider (1968) and Loehr (1974).

These figures are representative and should only be applied if other, more accurate, estimations are not available. In the case of pronounced erosion in the area, it is not possible to use the figures in Table 3.1, rather the modelling approaches mentioned and refered to in chapter 8 should be used as better estimation methods.

Another approach to the estimation of the transport to the littoral zone is proposed and applied by Lewis and Grant (1979). It relates the annual precipitation to the annual transport of particulate matter from the watershed to the transition zone:

$$L = a^* P^b \tag{3.1}$$

where L is the load calculated for instance as mg per m^2 and year, and P is the precipitation in mm or in liter per same unit of area as L (m^2), while a and b are constants. A regression analysis between L and P shows generally an excellent fit for data from the same watershed, but the problem is to find a and b for a watershed when there is limited data available. The same relationship is valid for particulate matter, nitrogen, phosphorus, heavy metals and toxic organics, but of course varying for a and b. Table 3.2 gives some a and b values found in various case studies. (Lewis et al., 1984)

TABLE 3.2.
Values of a and b in equation (3.1)

L in mg/m^2*y and P in mm/y

Case	Component	a	b
Background Undisturbed area	P	0.000782	1.37
	N	0.0841	1.15
Residential on sewer	P	0.00400	1.22
	N	0.308	1.10
Urban on sewer	P	0.00842	1.29
	N	0.783	1.10
Residential areas on septic tanks	P	3.44	0.759
	N	0.705	1.00
Interstate highways	P	0.00209	1.799
	N	1.71	1.13
Agricultural land	P	0.000716	1.725
	N	0.0954	1.29
Medium intensity	Pesticides (totally)	0.0000073	1.824
Industrial area	P	0.000553	1.54
	N	0.0843	1.26
	Heavy metals	0.0000089	1.76
Agricultural land High intensity	P	0.00125	1.682
	N	0.181	1.28
	Pesticides	0.0000523	1.795

If a few or no data are available it may be possible to use the values for a and b shown in this table, taking the nearest example to the case study under consideration. The factors mentioned in section 3.1. are in this context of great importance and the following list should be considered in addition to the values in Table 3.2 when estimating a and b:

- Increased application of intensive agriculture will result in an increase in the values of a and b for particulate matter, nitrogen, phosphorus and pesticides. A loss 0.2 - 5% of the pesticides applied or 1- 500 g/ha*year is generally recorded from agricultural areas (Jørgensen et al 1990).
- Increased industrial activity means an increased a-value for heavy metals and toxic organics.

- Both a and b will increase rapidly with high slopes in the surrounding area.
- Tropical climate will imply an increased value of b due to the occurrence of heavy rainfalls.
- Heavy metals and pesticides have a very high adsorption affinity to soil, particularly when it is rich in humus and/or clay. If sand comprises less than 50% of the soil then more than 98% and in many cases as much as 99.9% of heavy metals and pesticides will be adsorped in the soil particles (Jørgensen et al 1990).

TABLE 3.3.
Acculumation of heavy metals in plants in macrophytes. Simpson et al., 1983.

		June	July	September	November (as litter)
Biomass	g/m^2	200	725	500	725
N	g/m^2	6.0	15.1	11.5	9.4
P	g/m^2	0.45	0.95	0.60	0.90
Cd	mg/m^2	0.52	0.81	0.72	1.72
Zn	mg/m^2	55	53	53	270
Pb	mg/m^2	4	10	16	118

3.3 FATE OF THE PARTICULATE MATTER IN THE TRANSITION ZONE

Most of the particulate matter entering the littoral zone will settle there, except during very heavy rainfall events. Fig. 3.1 gives an overview of the possibilities for further transformation of this material.

Organic biodegradable matter, in general, is easily decomposed as the bacterial biomass in the littoral zone. In a 5 cm layer as much as 0.4 - 65 g of bacterial biomass per m^2 may be found (Ulehlova 1978). The high content of organic matter in the littoral zone implies that it is often anaerobic and denitrification occurs. A denitrification rate as high as 2727 kg /ha*y has been measured in a reed swamp adjacent to a lake (Jørgensen et al 1988). The nutrients carried by the particulate matter will fertilize the littoral zone and it is often rich in macrophytes and algae. It is possible to remove the nutrients from the zone by harvesting the macrophytes. Kurata and

Satouchi (1989) and Kurata and Vira (1986) have estimated the harvest of *Phragmites communis* from a lagoon adjacent to Lake Biwa will imply a removal of 36.6 g nitrogen and 4.3 g phosphorus per m^2.

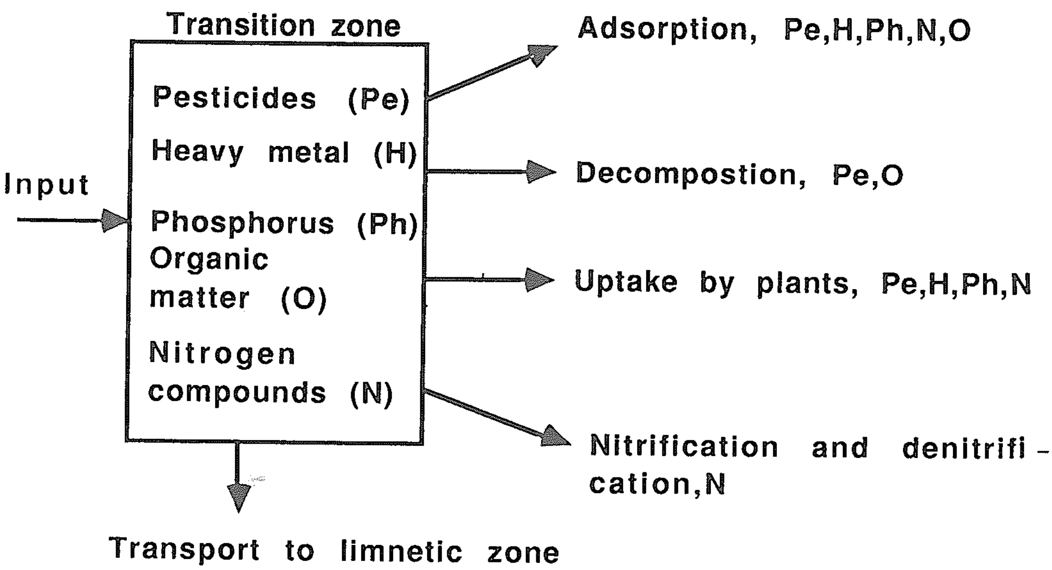

Fig. 3.1. Processes in the transformation zone.

Pesticides carried by the particulate matter to the littoral zone will accumulate in the sediment and slowly decompose through bacterial activity in accordance with the biodegradability of the pesticides. The biological half life of pesticides is significantly lower in the mud of the littoral zone than in soil. Pesticides may accumulate in the macrophytes - especially the more water soluble types.

Heavy metals are adsorbed in the mud in the littoral zone. However, the minor amount of heavy metal solutions in the interstitial water could accumulate in the plant biomass, as demonstrated in Table 3.3.

The role of the shore area for lake water quality is discussed in the next chapter in detail.

3.4 CONCLUSIONS

The transition zone between a lake and its surroundings serves as a filter for particulate matter. The amount of particulate matter entering the lake is highly dependent on the management of the lake environment. Every decision which results in an alteration in the land uses of the watershed may change the emissions from the land to the lake and thereby influence the water quality of the lake. Fortunately, the transition zone will accumulate most of the particulate matter coming from non-point sources and the nutrients, biodegradable organic matter, heavy metals and toxic organics carried by the particualte matter will therefore not reach the limnetic zone and thereby not effect to the same extent the water quality of the lake. This emphasizes the importance of conserving the transition zone and the need for proper shore management. It is however equally important to reduce erosion and other sources of particulate matter inputs to the lake. Although the particulate matter is better handled in the transition zone, the protective ability of this zone is limited. These problems will be discussed further in Chapters 8 and 9.

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CHAPTER 4

WATER QUALITY ASPECTS

Akira Kurata & Tatuo Kira

4.1. INTRODUCTION

The following features of lakeshore area are particularly important with respect to their close relationship with water quality.

Active interaction between water and sediments

The interaction between lake water and bottom sediments takes place most actively in the shallow lakeshore zone or littoral zone. A large portion of suspended matter, carried into lake by inflowing water, precipitates on the bottom of the littoral zone and various kinds of soluble substances are released from bottom sediments into the water. In addition, wind and wave action causes the agitation and re-suspension of fine particulate matters, either organic or inorganic, in the surface layer of bottom sediments, thereby enhancing the interaction. The quality of near-shore water thus depends on such physical properties of sediments as particle size and on their chemical content, like the concentrations of nitrogen and phosphorus compounds and metal elements. These processes are obviously affected by shore geology, lake water level fluctuation, and other conditions.

High Biological Activity

Solar radiation may penetrate through the whole water column of the littoral zone, allowing submersed higher plants (macrophytes) to grow densely. The surface of submersed macrophytes as well as the bases of emerged plant shoots growing on land/water border zone offer suitable substrata for the massive growth of micro-organisms such as bacteria, fungi, actinomycetes, yeast, algae and minute animals. The resulting high biological productivity also sustain large populations of benthic animals like annelid, shellfish, insects and infant fish. The activity of organisms, especially of microbes, in the shallow shore zone is much higher than in deep open water (pelagic zone), and causes rapid cycling of nutrients and other substances. The quality of shore water is therefore continiously changing, and the inflow from the lake's watershed adds considerably to the variability of water quality in the littoral zone.

Water purifying function

Littoral ecosystems with their "luxury" growth of emergent and submersed plants play a role similar to that of wastewater treatment plants. Suspended solids in inflowing water tend to be readily deposited while passing through the littoral zone including wetlands, lagoons and submersed macrophyte stands, which thus serves as a kind of primary treatment system. Deposited organic matter is actively mineralized by abundant heterotrophic microbes as in secondary treatment systems, and immediately taken up by microbial plants. If the biomass of plants and animals is harvested and removed, the shore ecosystems may play an additional function as a tertiary treatment system.

The functions of shore ecosystems has come to be evaluated more and more by scientists and environment managers. The necessity for their conservation in order to restore lake environments and landscape is now widely recognized, and attempts are being made to utilize them to maintain or improve lake water quality.

In this chapter, the water quality aspects of the lakeshore zone are reviewed mainly from the following three points of view:

a) Chemical interaction between lake water and nearshore bottom sediments.
b) Hydro-dynamic and other physical processes affecting water/sediment interaction.
c) Assessment of the water-purifying function of lakeshore ecosystems.

4.2. PHYSIO-CHEMICAL PROCESSES TAKING PLACE IN LAKESHORE ZONE

Mixing of inflowing water with lake water

Inflowing river water mixes with lake water at the river mouths in the shore zone. The mixing is not a simple continuous process, but a complicated stochastic process strongly influenced by estuarine topography, quantity and velocity of river water, water temperature, lake water current if any, wind and wave action, etc. In cases where river water is heavily loaded with suspended matter or cooler than the lake water, for instance, the inflowing river water may flow down along the bottom slope to reach the deep lake bottom area (profundal zone) very quickly. On the other hand, when the temperature difference between river and lake water is reversed, warmer river water may spread over cool lake water surface. Sometimes a sharp discontinuous boundary or water front is observed in estuarine areas for some period before complete mixing is reached. These aspects of mixing are specific to each lake and have to be studied individually in order to understand the dynamic changes in water quality of nearshore water.

Groundwater inflow

Under favorable climatic and topographical conditions, a large amount of groundwater may enter lakes as underground flow across their shoreline, eventually mixing up with lake water on seeping out from the bottom of littoral zone. In Lake Biwa, for instance, the estimated annual groundwater inflow ($1.1g*10^9$ t yr^{-1}) amounted to about one-fourth of annual total surface (river)water supply to the lake. In such cases, interruption of groundwater flow may result in disruptions to the lake water balance. The effect of inflowing groundwater on littoral water quality may be quite significant, except where the lake and ground water are similar in quality.

Water quality changes by mixing

The quality of river water is generally different from that of lake water, but undergoes remarkable changes on entering lakes. The load of suspended solids is rapidly deposited on lake bottom due to the drastic reduction in the speed of water movement, while certain chemical substances in river water are immobilized and also deposited. Soluble compounds of phosphorus and silica, both of which are important nutrients for phytoplankton and other plants, for example, combine with metal compounds under aerobic conditions to produce insoluble compounds unavailable for primary producers (Wetzel, 1983). This process is especially the case with inflowing groundwater, which is generally anoxic and therefore contains phosphorus as soluble orthophosphate (PO_4^{-3}). When the water seeps out from lake bottom through its aerobic surface layer, however, the greater part of PO_4-P precipitates and remains in sediments.

It is also widely known that soil particles play a very important role in these depositing processes and that they also trap other fine particles in water by agglutination while falling to the bottom. In fact, lake water is often observed to become very clean and transparent immediately after a flood that carries turbid water into the lake.

Chemical composition of bottom sediments in relation to particle size

The effect of lake sediments on water quality differs greatly depending on their particle size. An example of the correlation between particle size and organic matter (in terms of COD), total nitrogen (T-N), and total phosphorus (T-P) contents of nearshore bottom sediments of Lake Biwa is shown in Fig. 4.1. Apparently, the concentrations are the higher, the finer the particle size. The concentrations tend to decrease slightly with increasing depth from sediment surface (Fig. 4.2).

Where the lake bottom is covered with fine-grained mud (clay or silt), more nutrients are supplied to overlaying water which can become eutrophic and more productive. The organic matter produced is later deposited on the bottom and further enriches the sediments with nutrients. The progress of this water/sediment interaction tends to amplify the difference in water quality between shore zones covered by sediments of different particle sizes.

Release of nutrients and other substances from bottom sediments into water

Owing to the decomposition of organic matter by metabolic activities of microbes and benthic animals, water that fills the space between sediment particles (interstitial water) contains nutrients (NH_4-N, NO_3-N, PO_4-P, etc.) at higher concentrations than in free lake water. The concentrations of nutrients in interstitial water are usually higher in sediment surface than in deeper layers, and nutrients are released upwards into lake water by diffusion from time to time even under calm conditions. Strong winds agitate sediment particles in shallow waters, resulting in more efficient recurrence of nutrients from sediments.

Under aerobic conditions, which normally prevail in the shallow bottom of nearshore zone, nitrogen compounds such as ammonia are readily released from sediments by diffusion, while the release of reactive (available for plants) forms of phosphate are very limited. In shallow, heavily eutrophied (hypereutrophic) lakes, however, bottom sediments often become anaerobic due to the consumption of oxygen for organic matter decomposition, and are subject to quite different chemical processes. Through deoxidizing reactions, phosphate and metals (toxic heavy metals also) which have remained insoluble under aerobic conditions turn into soluble forms and are released from the bottom of the lake. Anoxic conditions also provoke denitrification or the reduction of nitrate into N_2O and N_2 and the production of H_2S from sulphates and methane from carbohydrates.

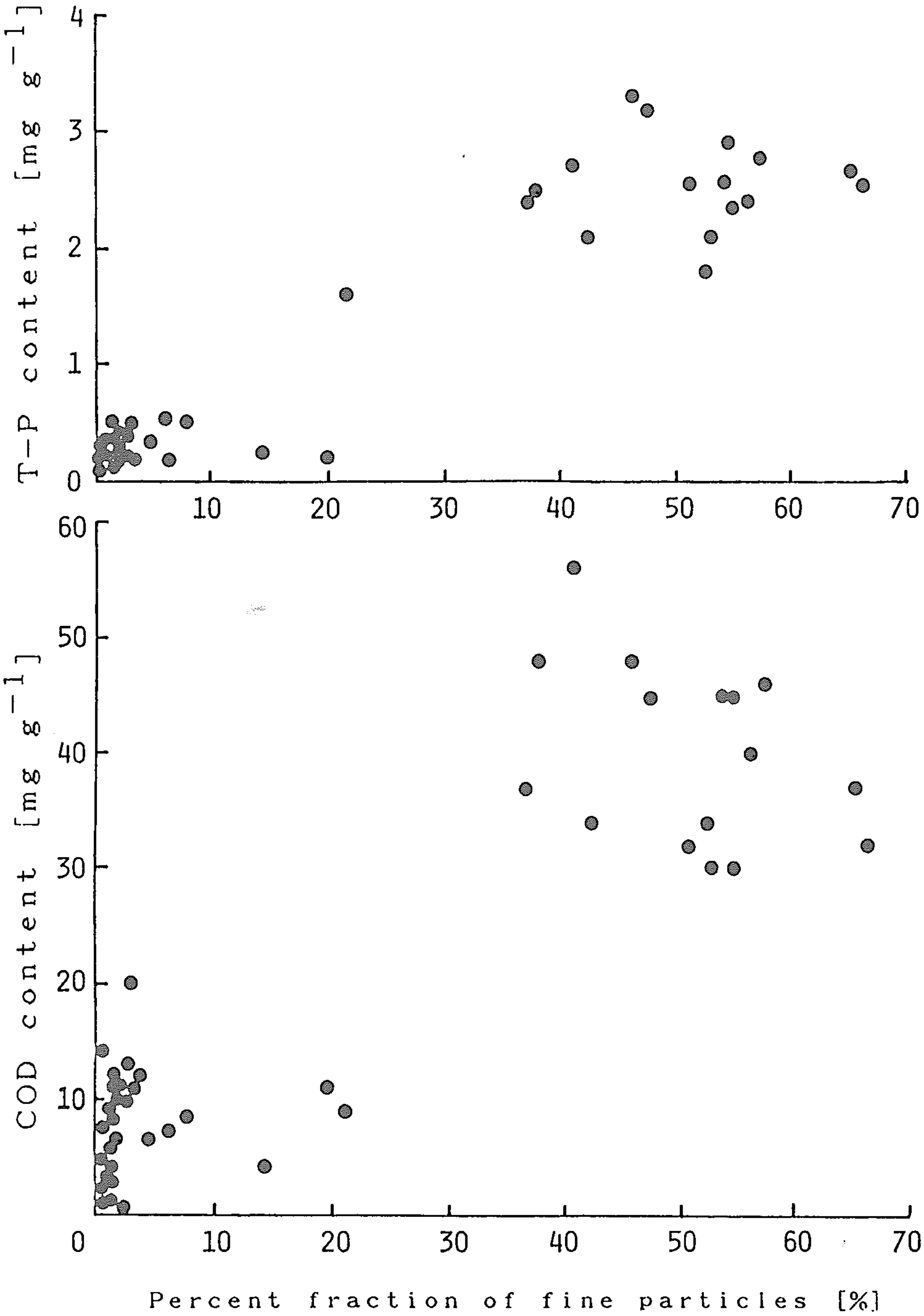

Fig. 4.1. Correlation between the percentage of fine particles (clay + silt; diameter < 53 μ m) of sediments and their COD and total phosphorus (T-P) contents. Samples were collected from the beachline of Lake Biwa (south basin).

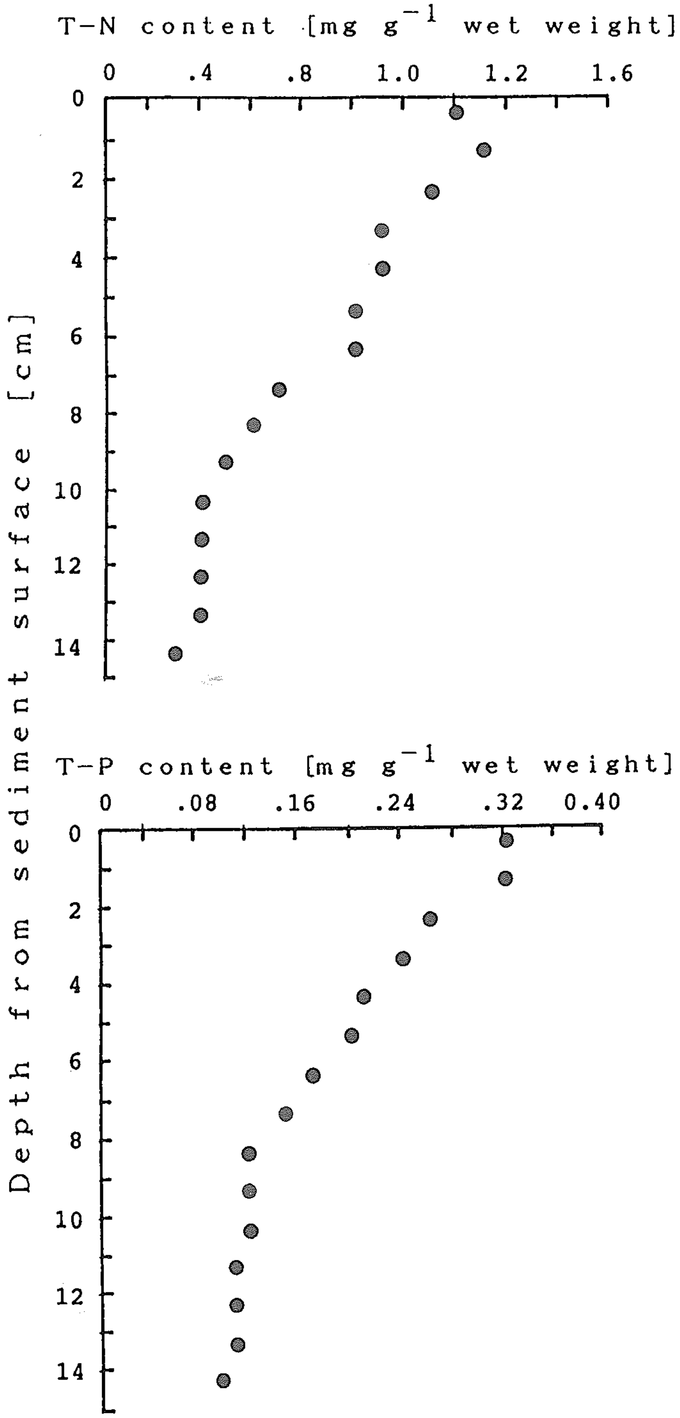

Fig. 4.2. Profiles of total nitrogen (T-N) and total phosphorus (T-P) content of bottom sediment at the center of the south basin of Lake Biwa. Water depth: about 4 m. Courtesy of Dr. H. Maeda.

Re-suspension of bottom sediments and its effect on water quality

On windy days, water in the shallow nearshore zone often becomes turbid due to the re-suspension of fine sediment particles from stirred lake bottom. Fig. 4.3 gives an approximation of the extent of re-suspension taking place under different wind velocities.

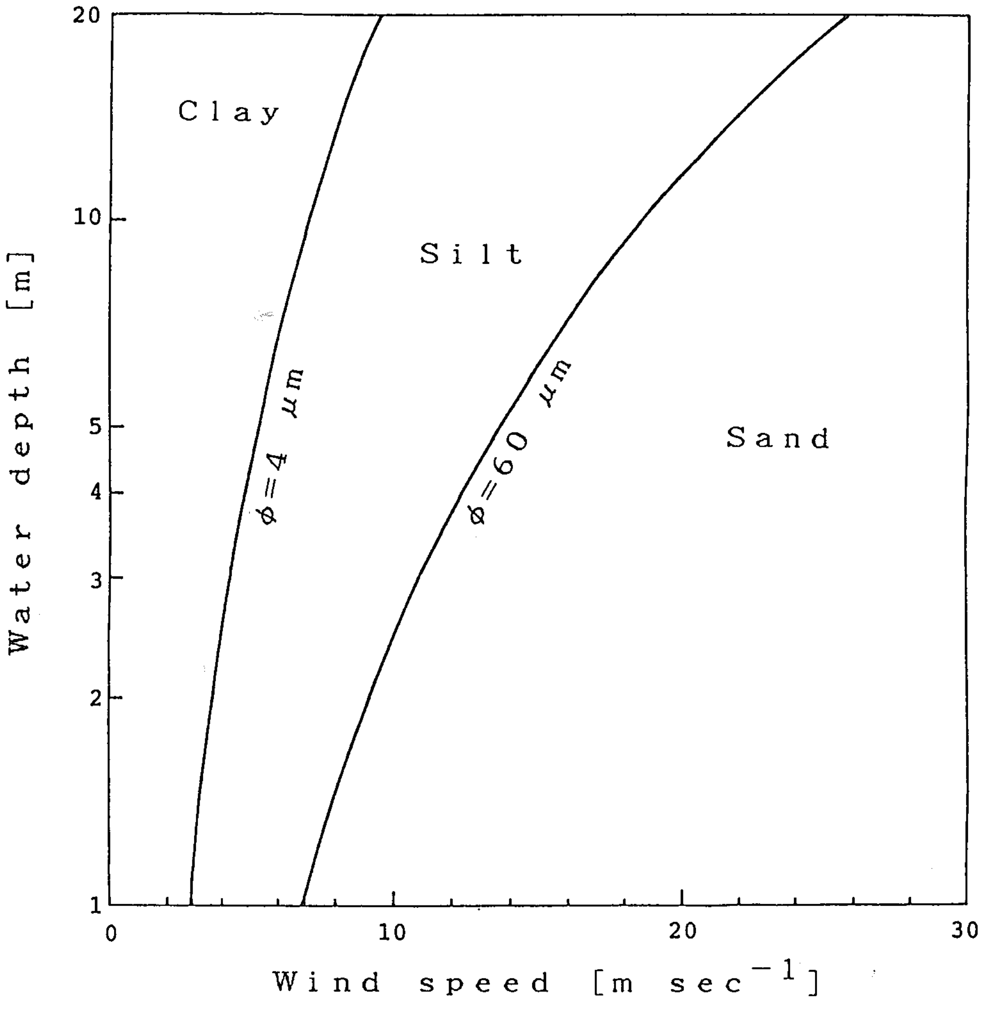

Fig. 4.3. Critical lines for bottom sediment particles of two different sizes (4μm and 60 μm in diameter) to be re-suspended in water under various combinations of wind speed and water depth. A fetch (distance of open water surface on windward side) of 10 km and a water content of sediment of 50% is assumed. Courtesy of Dr. M. Kumagai, LBRI.

Generally speaking, strong winds over 5-6 m sec^{-1} may disturb whole columns of water in shallow near-shore zones down to 2-3 m depth, and cause the re-suspension of mud particles. Even when water has become fully turbid, however, the agitation rarely goes deeper than several millimetres from the bottom.

Re-suspended mineral particles quickly settle on the bottom again when the wind ceases, but organic particles tend to remain longer in the water, where they are subject to microbial decomposition, and together with released interstitial water, enrich the water with nutrients. According to a study made in Kasumigaura, a shallow hypertrophic lake in Japan, the amount of precipitation of re-suspended sediment particles was ten times as large as that of autochthonous (produced by organisms in the lake) matter.

4.3. EFFECT OF PLANT AND ANIMAL ACTIVITIES ON THE QUALITY OF NEAR-SHORE WATER

Enhanced siltation

Dense stands of emergent, floating or submersed plants reduce water movement and accelerate the deposition of solid particles suspended. Zones of wetland vegetation behind the shoreline, as well as of submersed plants in shore water, retain a large portion of sediments flowing into the lake from land areas through this sedimentation function. Organic particles and certain solutes are also removed with the deposited mineral matter by co-precipitation as previously stated.

The continuous progress of siltation results in a build-up of the bottom or a decrease in water depth. This causes the advance of littoral vegetation towards the lake center. In a shallow lake receiving a large amount of eroded soil due to inadequate land uses in its catchment area, the whole lake surface may be filled with aquatic plants in short time. On land above lake water level, on the other hand, wetland plant communities tend to be successively replaced by more mesic types of vegetation with the progress of sedimentation. Littoral plant communities are therefore basically unstable and have to be properly managed in order to maintain specific lake uses such as fishery, surface transportation by boats, etc.

Uptake and removal of nutrients from water by shore organisms

Favored by the supply of nutrients from land and by abundant water, wetland vegetation is known for its high primary productivity. The aboveground biomass of herbaceous emergent plants, the representative component of wetland vegetation amounts to 15-35 t(metric) ha^{-1} in the temperate zone (reed, cattail, etc.) and up to 150 t ha^{-1} in the tropics (e.g. *Cyperus papyrus*) (Westlake, 1975). The biomass of underground organs is even larger than that of aboveground shoots, due to the enormous accumulation of thick rhizomes. The annual net production of organic matter by these herbaceous perennials is usually 1.5-2 times as large as their growing season aboveground biomass. These values indicate that emergent plant communities of wetlands are as productive as, or even more productive than, upland forests or grasslands (Bradbury & Grace, 1983; Wetzel, 1983).

Nutrient uptake by these emergent plant communities is also correspondingly large. The aboveground biomass of reed (*Phragmites communis*) stands around Lake Biwa in summer generally ranges between 5 and 15 t ha^{-1}, and the average net production may amount to 15-20 t ha^{-1} yr^{-1}. Based on the mean nitrogen and phosphorus contents in different organs of the plant, the corresponding annual nutrient uptake is estimated at 200-250 kg N $ha^{-1}yr^{-1}$ and 20-25 kg P $ha^{-1}yr^{-1}$.

Submersed macrophytes are also an efficient collector of nutrients. In the southern basin of Lake Biwa, a shallow eutrophic water body (mean water depth 3.5 m) with a surface area of 5800 ha, explosive growth of an exotic submersed plant, *Egeria densa*, took place in the 1970's, covering 268 ha in the littoral zone in 1975. Its total net production for the whole basin was estimated at 2,100 t yr^{-1}, which corresponded to a nitrogen uptake of 73 t N yr^{-1}. This amount was equivalent to about 7% of the annual total inflow of nitrogen into the basin (Tanimizu & Miura, 1976).

However, uptake by plants does not necessarily mean the removal of absorbed nutrients, because sooner or later they are released into lake again with the death and subsequent decomposition of plant biomass (except the partial loss of nitrogen due to denitrification). A certain amount of nutrients may also be lost from their normal cycle in the lake system, when part of the biomass is buried deeply in bottom deposits by rapid sedimentation.

Periodical harvesting of plant biomass, therefore, effectively helps the water-cleaning function of nearshore vegetation. Water hyacinth (*Eichhornia crassipes*), a tropical floating aquatic weed, is one of the most efficient absorbers of water-borne nutrients and has often been employed in wastewater treatment (Gopal, 1987). The maximum rates of nutrient uptake by water hyacinth grown in effluent water from municipal sewage treatment plants (secondary treatment) are estimated at 6-8 kg N $ha^{-1}day^{-1}$ and 1.1-1.6 kg P $ha^{-1}day^{-1}$, being equivalent to the daily amounts of N and P emission from a population of 700-1000 average Japanese (Sato, 1988). Such high rates can only be attained under the optimum density (number per unit water surface area) of the plants maintained by continuous harvest of excess biomass.

Decomposition and mineralization of organic matter

Compared with open water or pelagic zone, the shallow near-shore zone areas have much higher population density of heterotrophic microorganisms, because of the abundance of organic matter supply by inflowing river water and vigorous growth of macrophytes. In addition to free-living microbes in water, attached or periphytic bacteria, fungi, yeasts, actinomycetes and micro-algae cover the surface of submersed macrophytes and basal underwater parts of emerged plant shoots, often as dense mats.

Accelerated rates of organic matter decomposition and nutrient cycling in the littoral zone are the result of the activity of abundant heterotrophic microorganisms that characterize this part of lake ecosystem. Feeding of micro- and macro-fauna also contributes to the enhancement of organic matter decomposition.

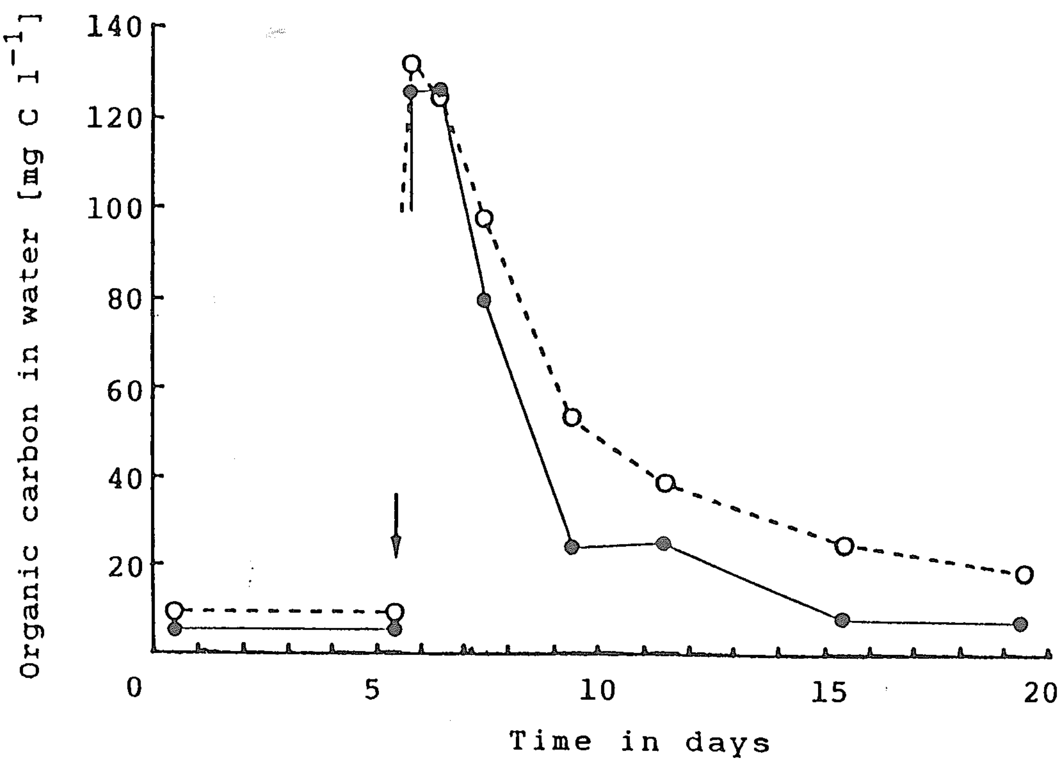

Fig. 4.4. Removal of organic matter from water by beach sand of Lake Biwa simulated by a laboratory experiment. Water added with a mixture of polypeptone, yeast extract and glucose was circulated through sand layer under light (A) and dark (B) conditions. Algae and microfauna developed poorly in the dark. Arrow indicates the time of organic matter addition. Courtesy of Dr. T. Nakajima, LBRI.

High biological activity of shore zone is not limited to submersed or emerged vegetation areas. Bare beaches of sand, gravel or mud also play a significant role in organic matter decomposition. Beach sand on the shore of Lake Biwa was found to contain more than 100 times as much heterotrophic bacteria per volume as found in open lake water. The removal of organic matter by lakeshore sand simulated by laboratory experiments is shown in Fig. 4.4.

It is noteworthy that the coexistence of microfauna increased the rate of organic matter disappearance. The whole system of plants, animals and microbes is apparently responsible for the cleaning of lake water by organic matter decomposition.

Denitrification

Denitrification is the process in which nitrates (NO_3-N) or nitrites (NO_2-N) are reduced into nitrous oxide (N_2O) or nitrogen (N_2) gas by certain microorganisms generally limited to anoxic habitats. Anaerobic conditions prevail in subsurface layers of waterlogged soil, though the surface layer in contact with lake water or atmosphere generally remains aerobic. In highly eutrophic (hypereutrophic) lakes, however, both the bottom mud and the overlying subsurface water layers may become anoxic, particularly in summer, due to the consumption of dissolved oxygen by microbial decomposition. Denitrification results in the liberation of a considerable amount of nitrogen as N_2O and N_2 under such conditions.

On the bottom of a hypertrophic inlet of Lake Kasumigaura, it was estimated that 67-84% of nitrogen in bottom sediments newly deposited every year were lost by denitrification, with loss rates of 20-27 mg m^{-2} day^{-1} on an annual average (Aizaki et al., 1981).

Even in the littoral zone of less eutrophic lakes, where the whole water column remains nearly saturated with oxygen, some anaerobic microhabitats may occur, e.g. inside thick mats of periphytic microorganisms. Denitrification was detected in periphyton that colonized stem bases of reed. Various types of denitrifying microorganisms were also found even in water of a natural lagoon attached to Lake Biwa. A wide range of denitrification rate, 0.03-700 mg N m^{-2} day^{-1}, has been reported from wetlands dominated by emersed plants (Howard-Williams, 1985).

4.4. WATER-CLEANING FUNCTION OF LAKESHORE ECOSYSTEMS

Role of wetland vegetation and its uses for cleaning wastewater

The water-cleaning function of wetland vegetation is not limited to nutrient removal, but may involve the removal of synthetic detergents (Table 4.1), toxic chemicals (Table 4.2) and noxious microbes such as coliform bacteria. Structure and processes of wetland ecosystems and their modelling as the basis for these functions have recently been dealt with by several authors (Hamilton & Macdonald, 1980; Prince & D'Itri, 1985; Mitsch, 1986; Jørgensen et al., 1988; Hook et al., 1988a and b; Mitch & Jørgensen, 1989). Howard-Williams (1985) reviewed theoretical and applied aspects of nitrogen and phosphorus cycling and retention in various types of wetlands.

There are a number of reports on the use of emergent plants, water hyacinth and natural wetlands for cleaning municipal wastewater or sewerage effluents by natural wetlands (e.g. Mitch & Jørgensen, 1989).

Attempts to remove nutrients from river water by directing it into natural or artificial lagoons, ponds or marshes have also been made in some lakes to suppress their eutrophication.

In Lake Balaton of Hungary, for instance, a marshy depression called Kis Balaton is being reconstructed into a reservoir for nutrient removal from the water of Zala River, which transports 25-30% of total nutrients load into the lake. The already completed part (18 km^2 wide) proved to be able to retain 80% of inflowing sediments, 60% of biologically available phosphorus, 46% of total P, 58% of nitrate nitrogen, and 25% of total N on a 2.5-year average (Misley, 1988).

TABLE 4.1.
Removal of synthetic detergent (linear alkylbenzenesulfonate, LAS) and nutrients from domestic wastewater by wetland vegetation dominated by reed (Inaba & Sudo, 1988; Hosomi et al., 1988).
Greywater from 45 families was discharged into this area for 12 years. This experiment was conducted on a limited area of 474 m^2 within the wetland vegetation.

Date	LAS [g day $^{-1}$]			Percent removal		
	Input	Output	Percent Removal	COD	T-N	T-P
August 1986	91.8	6.7	97	76	75	60
October	104.0	35.4	66	72	55	60
December	76.5	30.0	61	77	47	53
January 1987	75.5	55.4	27	76	18	77
February	86.8	29.9	66	66	27	51
March	96.1	27.3	72	-	-	-
April	44.1	5.6	87	-	-	-
June	60.5	6.8	89	-	-	-

TABLE 4.2.
Percentage removal of pesticides from the effluent of an agro-chemical factory by a continuous series of four oxidation ponds 187 ha in total area (Liu, 1985).
The ponds are part of an inlet of Ya-Er Lake in Hubei Province, China, which had been severely polluted by the effluent resulting in the extinction of submersed macrophytes and poisoning of local inhabitants and livestock during the preceding 10 years.

	Concentration before treatment [mg l^{-1}]	Removal [%] 1976-1977 Dec-Feb	1976-1977 Mar-Nov	1979-1980 Dec-Feb	1979-1980 Mar-Nov
COD	647.000	44.6	74.6	54.6	77.2
Organic phosphate	41.750	33.4	72.5	54.8	77.6
Parathion	1.659	90.7	99.0	94.0	99.5
Malathion	0.213	81.9	99.8	87.3	98.7
Dimethoate	0.196	59.6	85.1	74.8	92.7
p-Nitrophenol	8..274	92.6	98.4	90.7	100.0
BHC	0.814	51.6	81.9	78.4	87.1

Nutrient retention and removal in a small lake - a Japanese example

Behind the shoreline of 235 km of Lake Biwa, the largest inland water body in Japan, some 30 small lagoons and ponds (locally called *inner lakes*) of various sizes had once existed, though many of them were reclaimed and turned into cultivated fields in order to increase food production during and immediately after World War II. Most of them are connected with the main body of Lake Biwa via channels and maintain nearly the same water level as the main lake.

Nishi-no-ko, the largest of existing inner lakes, proved to play an important role in removing nutrients from river water that passes through the lake to enter Lake Biwa (Kurata & Satouchi, 1989). The surface area of Nishi-no-ko is 2.9 km^2 and its catchment land area is 42 km^2 of which 86% is covered by wet paddy fields. Reed, *Phragmites communis*, forms dense stands along the shore, occupying 60 ha and 107 ha respectively below and above the mean water level. Reed stems are harvested in winter for commercial screen production, a noted local product, while the open water surface is extensively utilized for the culture of freshwater pearl clams, *Hyriopsis schlegeli*.

Water flux and concentrations of total nitrogen, total phosphorus and COD were monitored once every week over a one-year period in 1983-84 in all streams and channels flowing into and out of the lake. The annual balance of the nutrients and organic matter is given in Table 4.3 and shows that the amounts of nutrients flowing out from Nishi-no-ko to Lake Biwa was considerably less than the amounts of their inflow (29% in T-N and 33% in T-P respectively). Since the lake water is fairly eutrophic, the rate of nutrient uptake by plankters is quite high. More important, however, is the uptake by reed and other emerged plants, submersed waterweeds, and periphytic microorganisms including various algae which grow vigorously on the surface of these aquatic plants. Denitrification in anaerobic habitats may also contribute to the loss of inflowing nitrogenous compounds.

TABLE 4.3.
Annual balance of waterborne organic matter (COD), total nitrogen (T-N) and total phosphorus (T-P) in Nishi-no-ko, a small lake attached to Lake Biwa (Kurata & Satoucchi, 1988).

	Input	Output	Balance
COD [t yr^{-1}]	457.6	511.4	-53.8
T-N [t yr^{-1}]	281.3	200.2	81.1
T-O [t yr^{-1}]	13.6	9.2	4.4

Water was enriched with organic matter while flowing down through the lake, as shown by the annual balance of COD. It is noted that the balance of N and P for the whole lake was nevertheless negative.

The so-called self-purification or nutrient-removing function in Nishi-no-ko was greatly enhanced by biomass harvest. The harvest of reed stem and pearl clam resulted in the significant removal of N and P from the lake system as estimated in Table 4.4. An annual harvest of red stems of 910 metric tons (dry weight) removes with it 16.4 t yr^{-1} of nitrogen and 2.3 t yr^{-1} of phosphorus, while N and P contents of 70.000 pearl clams annually harvested amounts to 4.0 t of N and 0.27 t of P. In addition, vigorous growth of exotic waterweeds such as *Elodea nuttallii, Egeria densa* and *Cabomba caroliniana* has recently become a nuisance for pearl culture, and they are frequently removed by the local people. The removal of N and P with waterweed harvest was estimated, respectively, at 10.4 t and 1.5 t based on the record of an early summer harvest.

TABLE 4.4.
Removal of nutrients from Nishi-no-ko by biomass harvest (Kurata & Satouchi, 1988).

	T-N [t yr^{-1}]	T-P [t yr^{-1}]
Reed	16.4	2.3
Submersed plants	10.5	1.5
Pearl clam	4.0	0.27
Fish	0.3	0.02

Further adding to the removal by fishing, the total amount of annual nutrient removal by biomass harvest were expected to amount to about 31 t N yr^{-1} and 4 t P yr^{-1} (Table 4.6), which were equivalent to 35% and 93% of N and P retained by the lake system per year. The above estimates of nutrient removal are not very accurate, but may be sufficient to show the usefulness of such harvest for water quality amelioration.

4.5. ECOLOGICAL PRINCIPLES OF LAKESHORE MANAGEMENT FOR BETTER WATER QUALITY

Aside from the standpoints of fisheries and landscape conservation, lakeshore ecosystems must be carefully managed in order to maintain good water quality, particularly in the planning of development projects.

Natural shore ecosystem versus artificial shore structure

Ecologically speaking, *natural shorelines should be preserved as far as possible* in order to assure the water-cleaning capacity of littoral ecosystems as well as their high biological productivity. Most important is *the protection of wetland ecosystems* around lakes, including emergent herbaceous communities, lagoons and ponds, and in tropical regions swamp forests and scrubs. They are well adapted to water level fluctuation and wave action, and thereby protect shorelines effectively. They also serve as breeding and spawning grounds for certain fishes and other animals, playing a very important role in fishery resource conservation and in sustaining the whole lake ecosystem.

The preservation of submersed plant communities is also important for the same reasons. *Nor should vegetation-free beaches be ignored* for reasons stated previously. In addition, *the protection of animal components* of nearshore ecosystems *should not be overlooked.* Animals living on lake bottom or plant surfaces contribute to the rapid turnover of organic matter in the littoral zone and hence to water-cleaning processes.

In many cases, however, the natural lakeshore has to be partly replaced by artificial embankment or other structures for economic or safety reasons (to prevent flooding and erosion disasters, etc. Even in such cases, *shore structures should be as consistent as possible with the functions of littoral ecosystems.* If embankments are needed to protect agro-rural or urban areas from flooding and erosion, it is recommended that *a zone of natural shore vegetation (or beach) of a certain width is left between the bank and lake water.* The cross section of the bank should be so designed as to fit in with this situation.

Loose structure made of natural materials such as rock and pebbles are preferable to concrete-covered compact structure since the former can support much more diverse and richer aquatic organisms than the latter. This is also advantageous for the maintenance of groundwater flow into the lake.

Where embankments must be located in direct contact with lake water surface, care should be taken to *make the change in underwater microtopography as small as possible.* Vertical walls standing in water are probably the worst, because they tend to accumulate fine mud deposits and totally eliminate benthic flora and fauna. The extension of such a structure should, therefore, be minimized.

Possible measures to prevent lake water quality degradation.

For lakes with polluted inflowing water threatening their water quality, the most effective measure is probably the construction of sewage systems and/or diverting wastewater or treated effluent to locations outside their catchment areas. Where these measures are not feasible and pollutant loads are more or less limited in amount, natural ponds or lagoons with surrounding wetland vegetation may be effectively used for cleaning river water before it enters the lakes as stated in 5.4.

It should be noted, however, that wetland systems is not a substitute for sewerage treatment plants. The water-cleaning capacity on a land area basis of wetland systems is much less powerful than that of man-made treatment plants, and therefore concentrated release of pollutants from large cities or big industrial areas can only be met by large-scale technology such as efficient sewage treatment system. If a wetland system used as retention reservoir is too heavily loaded with pollutants, it would certainly be turned into an ugly hypereutrophic pool in which original wetland organisms could barely survive, losing water-cleaning capacity itself as well as its natural beauty.

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CHAPTER 5

LITTORAL HABITATS AND COMMUNITIES

Ewa Pieczynska

5.1. PHYSICAL AND CHEMICAL CHARACTERISTICS OF HABITAT

Size and configuration of the littoral zone

The magnitude of littoral zone in relation to the lake size varies greatly. As the large majority of lakes all over the world are small and shallow this zone covers a considerable part of water bodies and the littoral plays an important role in the lake ecosystem functioning, (Wetzel, 1990).

Generally, the littoral zone of lakes extends from the lake shore (above the area influenced by wave action) to the lower edge of rooted aquatic plant areas. The terminology for lake shore zonation varies in the literature (Hutchinson, 1967; Pieczynska, 1972; Wetzel, 1983a). The most common definitions are presented in Chapter 1, Fig. 1.1.

The range of littoral zone depends to a great extent on the configuration of shore terraces and the areas adjoining the water body. Water transparency determines the depth range of the macrophyte growth.

The size of the littoral zone may change from year to year and during the annual cycle because of water level fluctuations, which are responsible in periodic drying and flooding of littoral areas. Erosion and accumulation can change the configuration of the littoral sediments.

The great variability of these factors causes the range of littoral regions to differ considerably from lake to lake and within a single lake. Within any water body, depending on the configuration of the shore region, there are habitats with vast shore regions and others where this zone has a very small area (Fig. 5.1). For example in Lake Sniardwy, Poland with its extensive shore shallows the shore line moves on the average 53 m (1.9-206 m at various sites) during one year with a difference in water level of 41 cm (Piecynska, 1972).

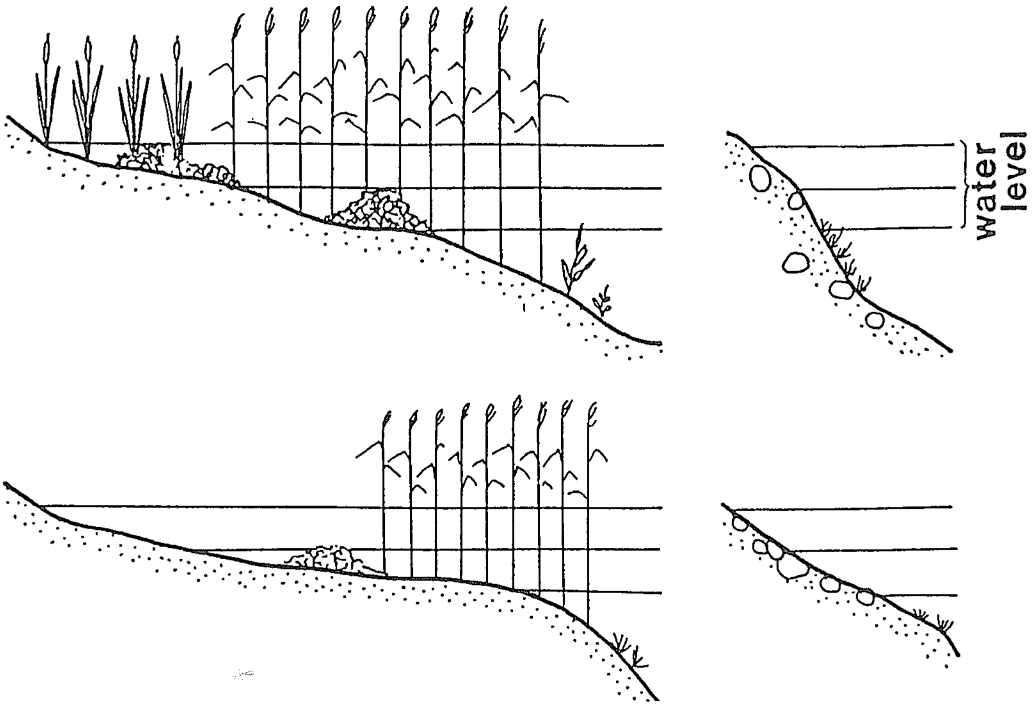

Fig. 5.1. The influence of water level fluctuation, littoral slope, and detritus accumulation on the configuration of shore zone of lakes.

Water chemistry, bottom sediments

Many factors are responsible for specific environmental conditions in the littoral zone of lakes. On a world-wide scale ,climate, and soil and rock types are of primary importance. Physio-chemical properties of water and sediments vary greatly from lake to lake and in particular parts (Björk, 1967; Planter, 1973; Pieczynska, 1976; Dykyjova and Kvet, 1978; Dall et al., 1984; Carignan, 1985; Gunatilaka, 1988).

The chemistry of the littoral water is determined by many local factors, such as; a) nature of the areas surrounding the lake, b) lake water chemistry, c) exposure to waves, and many others. Macrophytes are also responsible for habitat differentiation within one particular lake. Kairesalo (1984), for example, has shown great differences in the chemical composition of water within the stand of *Equisetum* (Fig. 5.2).

Sandy and stony shores with poor vegetation exposed to waves are, in general, less specific and less heterogenous compared to organic-rich, detritus-dominated parts of littoral overgrown with rich vegetation.

Nearshore shallows and small lake-site water bodies, partly separated from the lake, have especially heterogenous physico-chemical conditions. Atmospheric precipitation, winds, ice-cover, detritus accumulation and many other physical parameters are of greater importance here than in the deeper parts of the lake (Pieczynska, 1972).

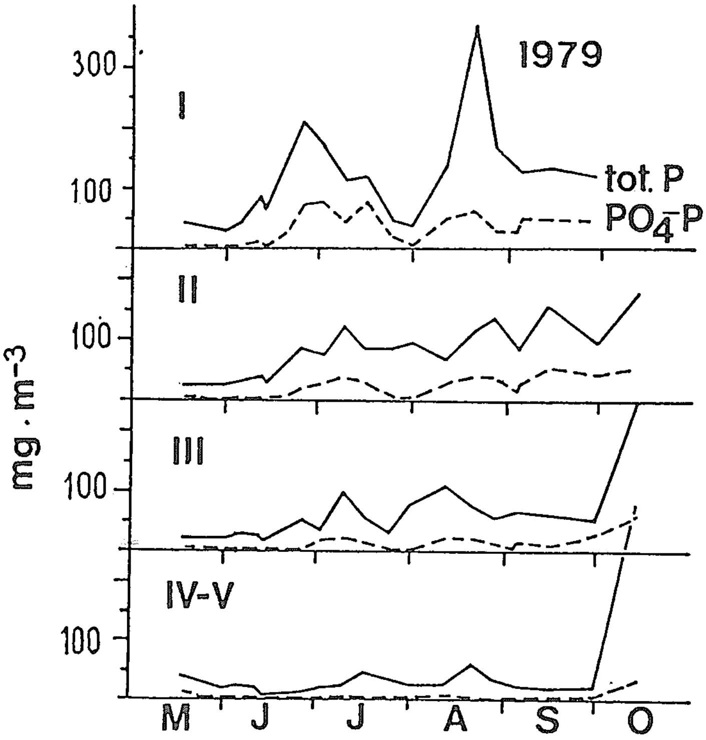

Fig. 5.2. Concentration of total phosphorus and phosphate phosphorus in the water at different zones of *Equisetum fluviatile* stand in Lake Pääjärvi in 1979 (inner zone - I and II; mid zone - III; outer zone - IV and V) (from Kairesalo, 1984).

Sedimentation processes and sediment formation are particularly specific to the lake littoral zone and differ greatly from those in the profundal zone (Moeller and Wetzel, 1988).

Heterogenous sediments are typical for places with rich vegetation where plant litter accumulates. Spatial variability of the contribution of various sediment components (plant detritus, gravel, remains of shells) differ not only from lake to lake but also within one water body (Pieczynská et al., 1984). Gunatilaka (1988) has demonstrated, for example, great vertical differences in sediment structure and its chemical composition at two sites in the reed belt of Neusiedlersee (Fig. 5.3, Table 5.1).

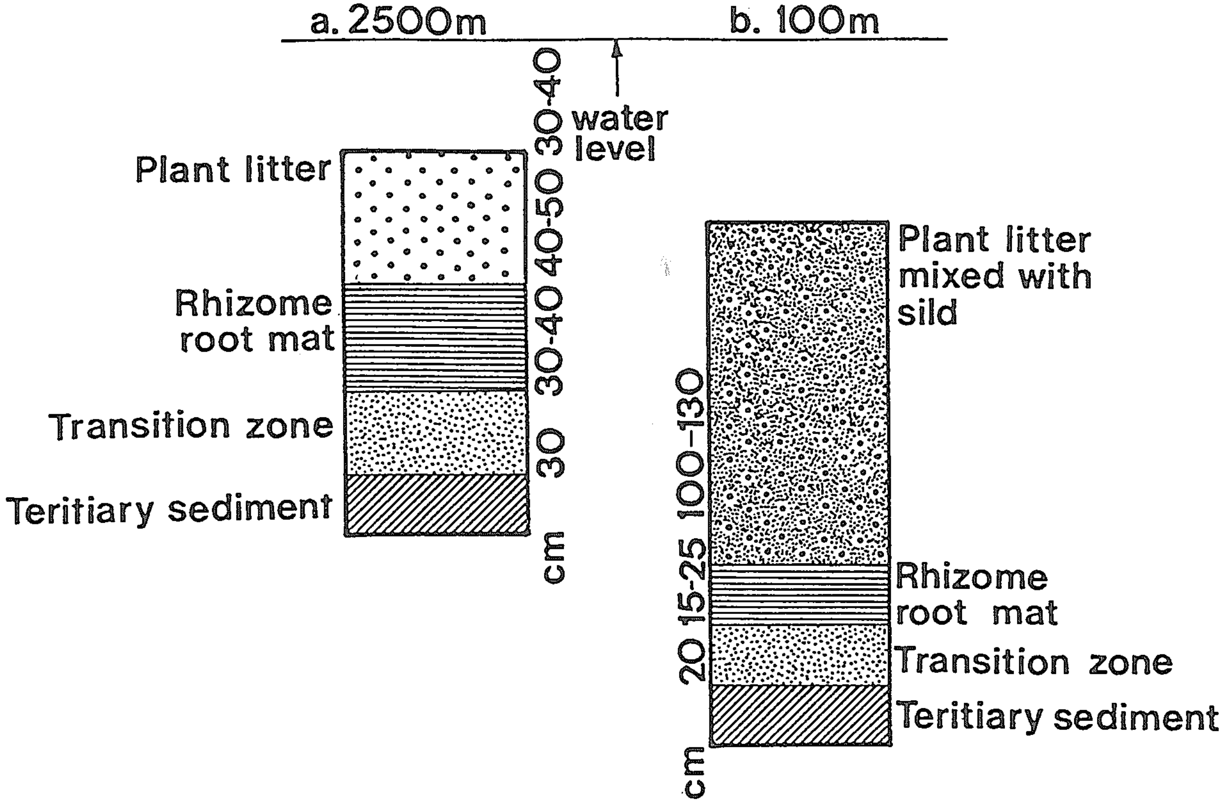

Fig. 5.3. Structure of bottom sediments in the different zones of *Phragmites australis* stand in Lake Seusiedler (a - 2500 m from open lake, b - 100 m from open lake) (from Gunatilaka, 1988).

TABLE 5.1.
The nutrient distribution in sediment profiles (Fig. 5.3) in *Phragmites australis* stand of Lake Neusiedler (from Gunatilaka, 1988).

	Redox. (mV)	Landward (2500 m from open lake) %C	%P	%N
Accumulation horizont	+200 to -220	20-30	0.09-0.13	0.19-0.47
Rhizome Root-mat region	-60 to -220	23-32	0.60-0.09	0.28-0.79
Transition zone	-100 to -220	15-22	0.06	0.10-0.20
		Lakeward (100 m from open lake)		
Accumulation Horizont	+400 to -200	08-20	0.04-0.06	0.09-0.32
Rhizome root-mat region	-60 to -200	18-28	0.06-0.09	0.25-0.60
Transition zone	-100 to -220	10-13	0.04-0.06	0.07-0.20
Tertiary sediment	-190 to - 230	08-09	0.06	0.10-0.20

Carignan (1985) found high spatial and temporal variability in nutrient contents in pore water in sediments colonized by *Myriophyllum spicatum*. Great differences were observed between sediments uncolonized and colonized by plants (Fig. 5.4).

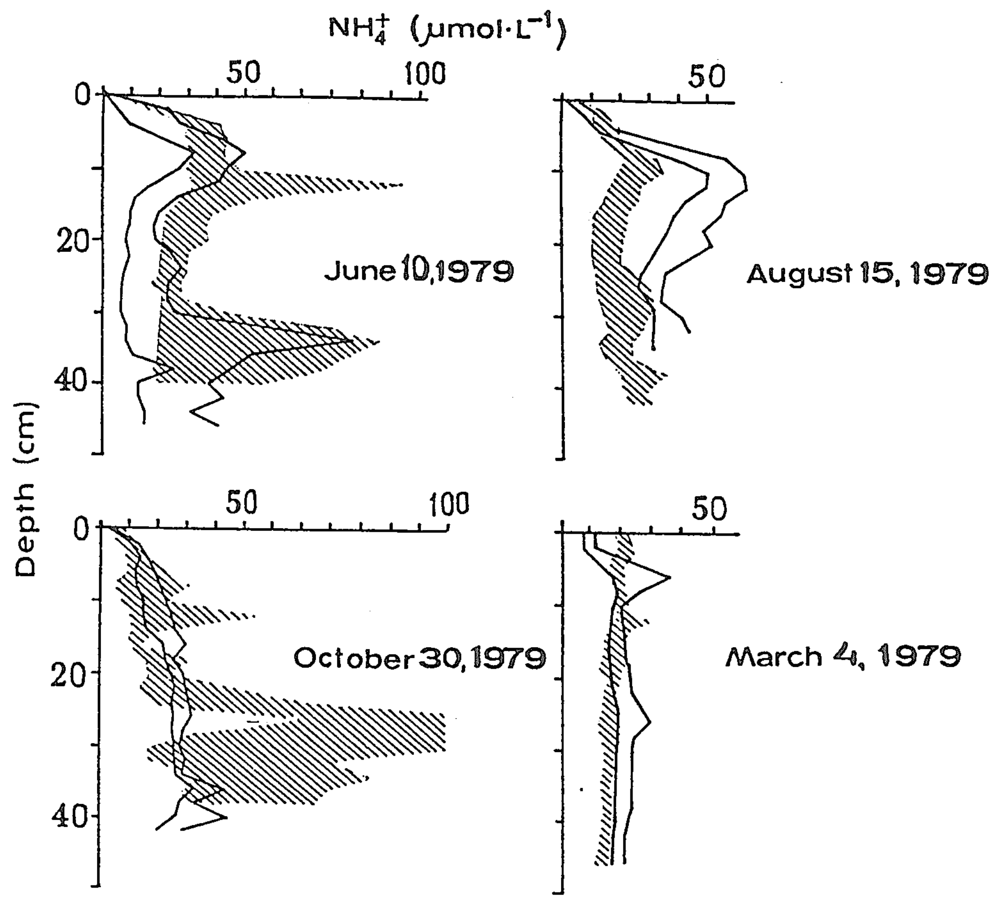

Fig. 5.4. Depth distribution and seasonal changes in NH^{+}_{4} concentrations in pore water in a littoral sediment colonized by *Myriophyllum spicatum* in the Lake Memphremagog. Sediments colonized by *Myriophyllum*(hatched areas), uncolonized (open areas), ± 1 SE of the mean (from Carignan, 1985).

5.2. PLANT AND ANIMAL COMMUNITIES

Littoral flora

Macrophytes are the most specific biotic element of the littoral zone of lakes. The term macrophytes refers to various taxonomic groups and various living forms of large macroscopic plants (primarily angiosperms but also some pteridophytes and macroalgae - e.g. Characeae). Various classification systems have been proposed for freshwater macrophytes (Sculthorpe, 1967; Hutchinson, 1975; Wetzel, 1983a). The commonly used simple division inclused the following groups (Fig. 5.5):

1. Plant attached to the substratum
   - emergent (*Phragmites, Typha, Glyceria, Eleocharis*)
   - floating, leaved (*Nuphar, Nymphaea*)
   - submersed (*Chara, Elodea, Fontinalis*).
2. Freely floating (*Lemna, Eichhornia, Trapa, Salvinia*).

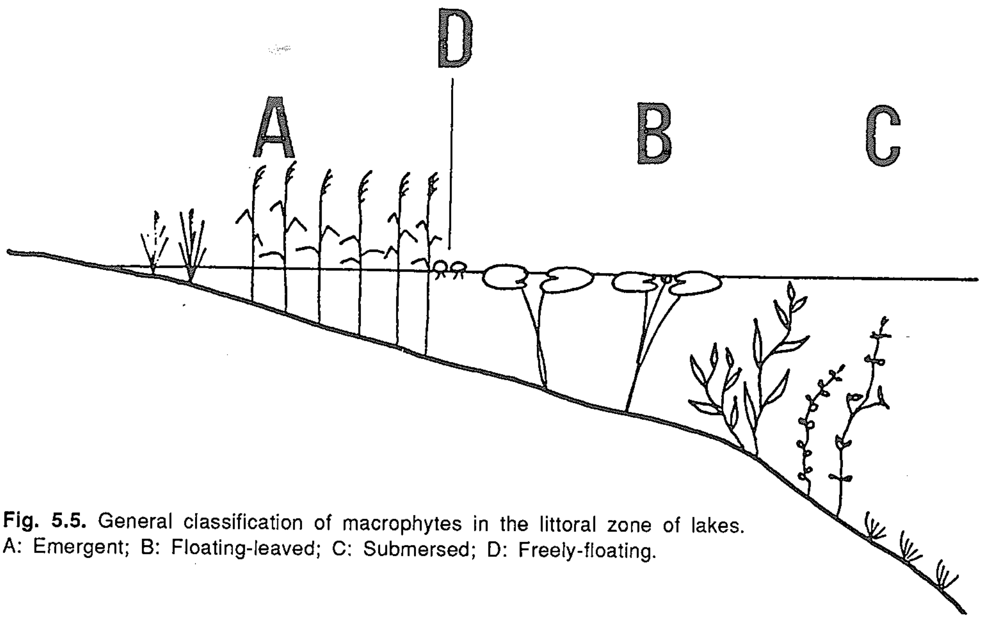

Fig. 5.5. General classification of macrophytes in the littoral zone of lakes. A: Emergent; B: Floating-leaved; C: Submersed; D: Freely-floating.

The lake macrophytes are commonly distributed in a distinct zonation from land to progressively deeper water. A large number of factors determine the plant distribution and at times the regularity of this distribution may be interrupted. For example, the occurrence of floating plants is restricted to protected areas as are floating plants, usually occur in relatively quiescent parts of the littoral water. Angiosperms usually grow to a depth not greater than 10 m; below this depth some submersed lower plants can be found.

The macrophytes in tropical lakes differ in many cases from those of temperate lakes not only in the species present but also in zonation and seasonal succession. The density of large freely-floating plants can be very high. Papyrus swamps should also be mentioned as typical for many tropical lakes. In certain lakes a layer of interwoven papyrus roots forms a compact thick floating mat covered with living vegetation (Fig. 5.6). The same part of the littoral zone can be occupied by two or even more species with different time of flowering and maximum development.

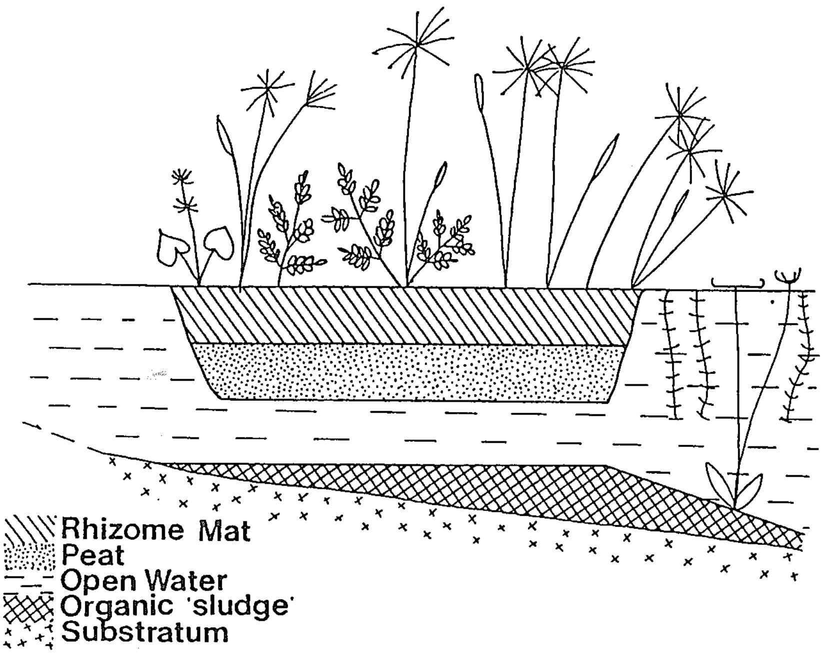

Fig. 5.6. Floating mat of the interwoven roots and rhizomes of papyrus, and its living vegetation in Lake Victoria (from Thompson, 1976).

In temperate zones many macrophytes regress and senesce under winter conditions of temperatures below 10°C and reduced light availability. Several very common plants (certain *Potamogeton spp., Elodea,* submersed *Scirpus, Fontinalis,* Characeae, others) overwinter with aboveground foliage intact throughout the cold periods. This foliage, although growing little, if any, provides an important, major substratum surface area for colonization and growth of epiphytic microflora (Wetzel, 1990). That epiphytic microflora has major functions in nutrient fluxes in the littoral zone.

The occurrence of qualitatively and quantitatively different communities of macrophytes in various lakes and several general relations between macrophyte cover and various environmental factors have been pointed out in various literature. Spence (1982), found that wave action, sediment and light climate can influence the zonation of macrophytes in lakes. The importance of these factors depends on the amount of vegetation within or below the wave-mixed zone.

Duarte et al. (1986), on the basis of data from 139 lakes, found that the distribution of emergent macrophytes is strongly correlated with lake morphometry and, in particular, by its average slope. Biomass and distribution of emergent macrophytes are, on the average, of course proportional with and correlated to the area of lake. Underwater light was found to best describe the cover and biomass of submersed plants.

Duarte and Kalff (1986) on the basis of studies of lake Memphremagog (Canada) have correlated the slope of the littoral zone to the biomass of submersed macrophytes, which probably results from the difference in physical stability of sediment between steep and gently sloping littoral zones. In contrast, Möller and Wetzel (1988) demonstrated that both the slope and physical presence of rooted macrophytes were controlling sediment stability.

In contrast to the limnetic zone, there is a great variety of living forms of algae in the lake littoral. The following can be distinguished:

- planktonic algae;
- algae attached to the surface of macrophytes and other solid natural and artificial substrata;
- algae growing on and among bottom sediments;
- loosely connected with substratum algae, aggregated and forming mats partly floating in water or lying on the bottom.

The term periphyton is commonly used for algae attached to different kinds of substratum. But there are also different terms for algae growing on various kinds of substrata, e.g. epipelic algae (growing on sediments), epiphytic (growing om macrophytes), epizooic (growing on the surface of animals) and epilithic (growing on the surface of rocks and stones) (Wetzel, 1983a).

The occurrence of various ecological groups of algae is controlled by a complex range of factors (physical and chemical characteristics of water and distribution of various substrata).

Species composition and horizontal distribution of algae change constantly (Marvan et al., 1978; Kairesalo, 1984). This is especially visible in the case of algae growing on plant surface and is determined by plant growth and senescence.

Algae loosely connected with substratum periodically develop very abundantly, especially in littoral shallows (Pieczynska, 1976; Marvan et al., 1978). Attached algae dominate on exposed rocky and stony shores. Their distribution is determined by the water level fluctuations (Kann, 1982).

Littoral animals

Large numbers of invertebrate species inhabit littoral waters, sediments, macrophytes and other solid substrata. Both the community structure and the animal density visibly change over the course of time and reflect a complex range of factors: (a) changes in physical environment, (b) macrophyte distribution, and (c) pattern of life cycle of particular species, e.g. time of insect emergence and animal migration.

Increase in animal numbers and species diversity were observed in isolated littoral shallows with muddy bottom and a great amount of detritus and rich vegetation. In such habitats, semi-aquatic forms, typical for shore zones, are extremely abundant. Pieczynska (1972) found, for example, representatives of 12 families of Diptera in the eulittoral of Lake Mikolajskie (in contrast to 3 families in the deeper part of the littoral).

The increasing invertebrate abundance on isolated shores is not a rule. For instance, Dvorak (1978) found that the quantity of macroinvertebrates was greater in the littoral section of fishponds affected by pelagial water than in the rather isolated biotopes. The author suggested that, among other things, trophic conditions (accumulation of phytoplankton on non-isolated parts, which is a food source for macroinvertebrates) are responsible for these differences.

Macrophytes are abundantly colonized by many taxonomic groups of invertebrates (Soszka, 1975; Dvorak and Best, 1982; Crozet, 1982). Distribution and seasonal changes in composition and density of these animals depends to a great extent on the morphology and phenology of plant species.

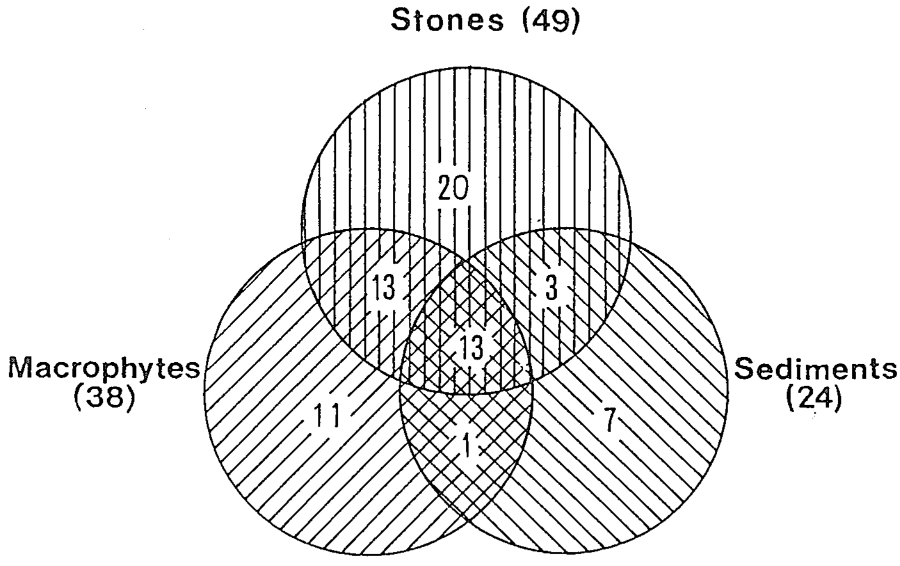

Fig. 5.7. Numbers of *Polycelis nigra* and *P. tenuis* (Turbellaria) colonizing stones in Windermere (average number caught in two minutes) (from Macan and Maudsley, 1969).

Bottom sediments and stony shores are also abundantly colonized by invertebrates (Pennak, 1940; Brittain and Lillehammer, 1978; Dall et al., 1984; Macan and Maudsley, 1969; Jonasson, 1984). Their numbers differ greatly from place to place even within one lake (Fig. 5.7).

Different kinds of substrata at the same site may be colonized by species common for other substrata as well as by specific ones (Fig. 5.8).

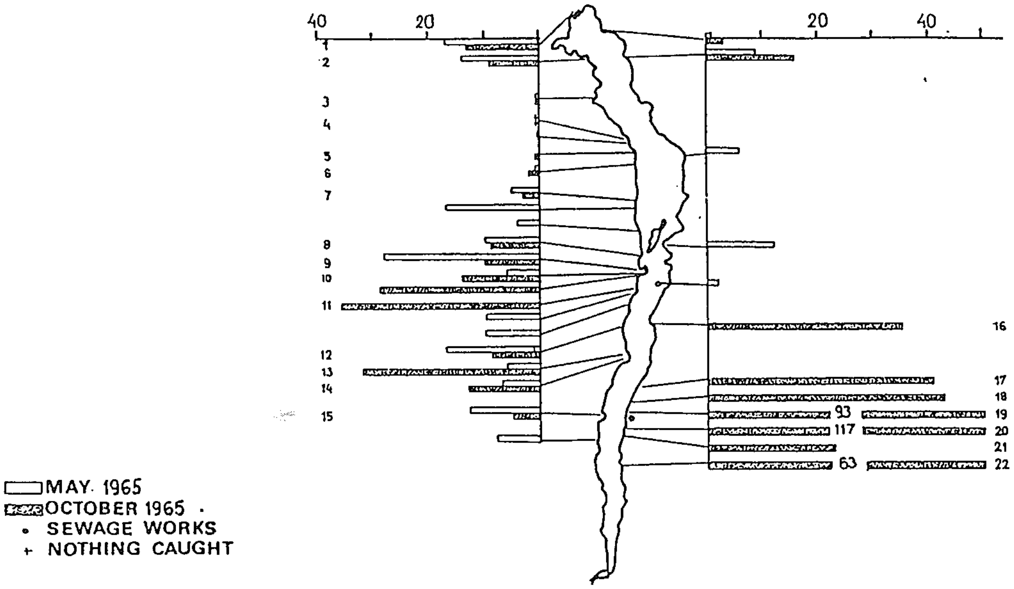

Fig. 5.8. Comparison of the number of macroinvertebrate species colonizing three types of littoral substrata in Lake Geneva (Petit-Lac) (from Crozet, 1982).

Littoral invertebrates represent various trophic status. Berrie (1976) divided freshwater invertebrates into five categories according to their feeding habits:

1. Suspension feeders (filtering suspended particles or organisms from the water).

2. Shredders and grazers (which prefer to bite pieces off plants or from large particles sich as leaf litter).

3. Gatherers and scrapers (which move around collecting food particles from the substratum).

4. Deposit feeders (which line in the bottom sediments and ingest this material).

5. Predators (which consume other animals).

It is important to point out that in heterogenous littoral habitats representatives of all these categories of animals occur abundantly. Dvorak and Best (1982) grouped macrophyte-associated macrofauna according to the food source and feeding mechanisms into six categories and found great differences in their proportion on various macrophyte species (Fig. 5.9).

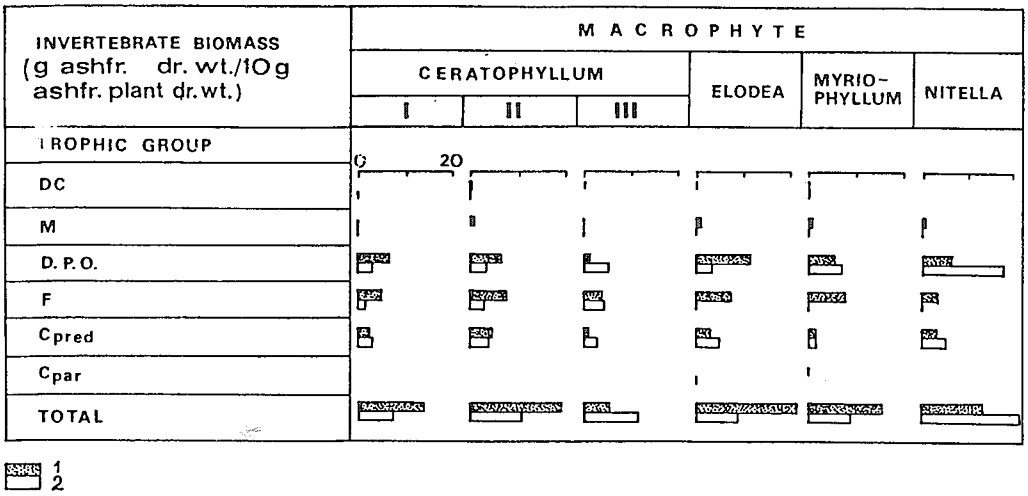

Fig. 5.9. Distribution of the macroinvertebrate trophic groups on the submersed macrophytes in May (1) and June (2) in Lake Vechten. DC - plant-feeders; M - miners; D, P, O - detrivores, periphytiscarpers, omnivores; F - filtrators; C_{pred} - predating carnivores; C_{par} - parasitic cernivores (from Dvorák and Best, 1982).

Littoral zones of lakes also form important habitats for many fish species (de Nie, 1987). They use macrophyte stands, as spawing, rearing and feeding grounds. For instance, Grash (1978) (after de Nie, 1987) on the basis of studies of lakes in northern Germany provided a list of 17 adult fish species which show preference for various parts of the littoral zone as feeding habitats. Deufel (1978; after de Nie, 1987) showed that for 19 fish species in Lake Constance, the reed belt is an important spawning and feeding habitat.

The lake littoral is utilized by many species of birds. Seasonal differences in their number and species diversity are determined by breeding seasons, and migration periods, which vary in different geographical regions. Various species of birds are adapted to particular plant zones and use sites of various depth as nesting or feeding grounds (Dobrowolski, 1973; Hudec and Stastny, 1987).

Rich populations of mammals are recorded in the shore zone of lakes. For example, Pelikan (1978) found 31 mammal species in reedswamp of Nesyt fishponds in Czechoslovakia.

Kozakiewicz (1985) found that lakeside habitats of two Masurian lakes in Poland are constantly inhabited by a community of small mammals (rodents and insectivores) which can penetrate the submersed part of the shore zone. The muskrat occurs in high densities in some macrophyte zones. (Pelikan, 1978; Toivonen and Merilainen, 1980). The muskrat uses large quantities of macrophytes, for both food and lodge-building, and can destroy large areas of macrophyte stands.

5.3. PRODUCTION AND DECOMPOSITION PROCESSES

Primary production

Littoral zones of lakes are the most productive systems in the world. Emergent plants in temperate zones attain a productivity level of 30-45 mt ha^{-1} $year^{-1}$ and in tropical zones 65-85 mt. Submersed macrophytes are by comparison less productive (see Table 5.2).

TABLE 5.2.
Annual net primary productivity of aquatic communities (Wetzel, 1983a)

Type of ecosystem	Approximate net organic (dry) productivity (mt ha^{-1} $year^{-1}$)	Range (mt ha^{-1} $year^{-1}$)
Marine phytoplankton	2	1-4.5
Lake phytoplankton	2	1-9.0
Freshwater submersed macriophytes		
Temperate	6	1-7,0
Tropical	17	12-20
Marine submersed macrophytes		
Temperate	29	25-35
Tropical	35	30-40
Marine emergent macrophytes (salt marsh)	30	25-85
Freshwater emergent macrophytes		
Temperate	38	30-45
Tropical	75	65-85+

Algae production is highly differentiated and has a fluctuating intensity (Wetzel, 1964; Pieczynska, 1972; Schindler et al., 1973; Komarkova and Marvan, 1978; Adams and Prentki, 1982; Gons, 1982 and others). Many factors limit the algae primary production. In near-shore shallows these include the periodical drying-up of environment due to water level fluctuations and shading by macrophytes and near-shore trees. In one lake there are sites with very high algae production and others where production of algae is not significant (Pieczynska, 1972).

Comparison of lakes in which primary production of periphyton, plankton and macrophytes has been analysed simultaneously under natural conditions (Wetzel, 1983a - literature review) shows that attached algae are a major source of autochthonous organic matter in the littoral zone of some lakes whereas macrophytes are the source in others. Primary production of attached (epiphelic or epilithic) algae dominates in lakes with sandy or stony shores and poor vegetation. In habitats with rich near-shore vegetation, emergent macrophytes are usually the main source of organic matter.

Allochthonous particulate input

Particulate organic matter entering littoral zones allochthonously from terrestrial systems can consist of products of drainage basin erosion, atmospheric precipitation, litter fall, underground and surface inflows and, at some sites, of sewage and waste (Fig. 5.10). Most of the quantitative estimations of these inputs deal with litter fall. Particulate allochthonous detritus is of minor importance in most lakes, with exception of some oligotrophic and small eutrophic lakes with a heavily forested shoreline (Szczepanski, 1965; Wetzel et al., 1972; Gasith and Hasler, 1976; Odum and Prentki, 1978; Le Cren and Lowe-McConnell, 1980, Carpenter et al., 1983; Pieczynska et al, 1984). Although the role of litter fall may be negligible in relation to the whole water body, it can be a very important source of organic matter and nutrients in littoral region. Usually the bulk of litter falls onto the near shore part of water body (Szczepanski, 1965; Gasith and Hasler, 1976; Pieczynska et al., 1984). The input of allochthonous detritus changes in time due to climatic conditions and phenological cycles of near-shore vegetation. In the temperate zone, maximum values are observed between September and November, and the input begins to increase in August.

The accumulating authochthonous organic material of lake origin may be also an important source of organic matter in the lake littoral. Accumulation of planktonic organisms on lake shores is well known in limnological literature as the "shore effect". Plankton accumulates abundantly, mainly during algae blooming, especially during and following strong wave actions. Near-shore shallows are also supplied by material accumulating from deeper parts of the littoral zone. It is well known that periphyton, detritus of various origin and macrophytes accumulate on lake shores (Sebestyen, 1950; Björk, 1967, Pieczynska, 1972; Dykyjova and Kvet, 1978). The majority of accumulated material is from damaged macrophytes. They can be the major source of organic matter in eulittoral zone of lakes.

For example, in Lake Mikolajskie (Pieczynska, 1972) in one year on 1 m area of the shore line about 8100 g dry weight of macrophytes accumulates and more than 90% of this material is emergent vegetation (*Phragmites australis*).

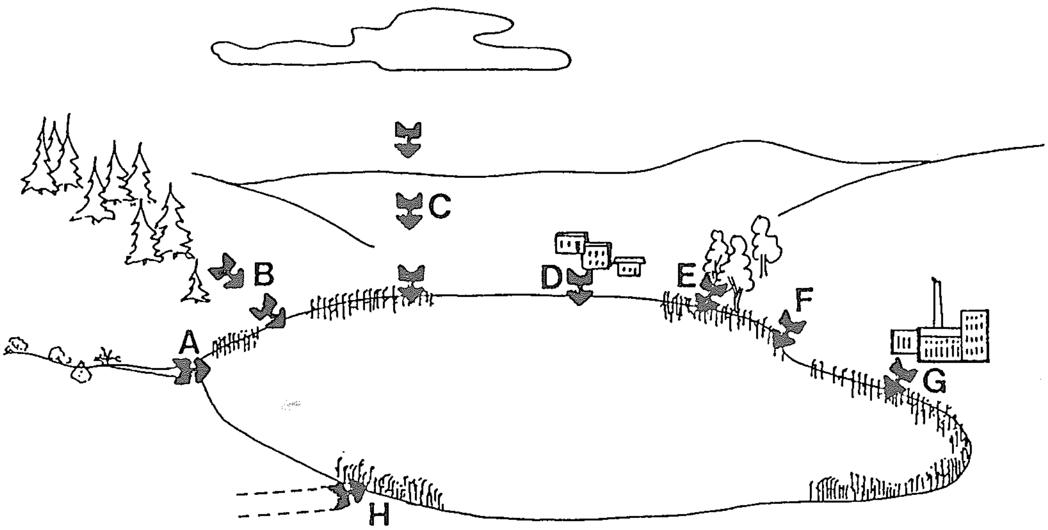

Fig. 5.10. The main potential sources of allochthonous matter in the littoral zone of lakes. A - river tributaries, B - products of surface erosion, C - atmospheric precipitation, D - domestic sewage, E - litterfal, F - products of shore erosion, G - industrial sewage, H - underground inflows.

Decomposition and detritus processing

Different kinds of organic matter produced in littoral zone or imported from adjacent habitats can have a different fate. The organic matter may be consumed by animals, breakdown and decompose at different times and in different ways. Some of the organic matter may be released into the environment during the life of organisms. Some of it may be sedimented at various stages of decomposition or exported out of the system. But primarily the lake littoral can be described as a detritus-dominated system in which direct grazing losses are small and most of the primary producers die and undergo decomposition. This process is mainly because of relatively high biomass of vascular plants of which only a small amount is directly utilized herbivorously. Thus one of the most important processes in the littoral is the conversion of live organic material into detritus.

Detritus is commonly defined in the literature as non-predatory losses of organic carbon from any trophic level (Wetzel, 1983a). Thus, it includes both dissolved and particulate organic matter. Various origins of allochthonous and authochthonous detritus can be distinguished in lake littoral zones. Allochthonous detritus originating from airborne litter fall mainly accumulates in the littoral.

Autochthonous input of detritus into the shore zone is highly differentiated. Living organisms supply the detritus pool by means of secretion of dissolved organic compounds and egestion of faeces.

Secretion by submersed macrophytes may be the main source of dissolved detritus in most of the littoral habitats (Wetzel and Manny, 1972; Hough and Wetzel, 1975; Wetzel, 1983a).

As a result of egestion, grazers and carnivores convert the living biomass to detritus in the form of faeces. Detrivores convert detritus into another, usually a much more fragmentated form. There are many estimates of animal egestion but mainly from the physiological point of view. Only in a few cases simultaneous data on animal egestion and abundance in natural habitats exist. Such data have been obtained for several animal populations abundant in the littoral zone of Lake Mikolajskie (Table 5.3). The very high faeces production indicates the importance of animal egestion in detritus conversions and processing.

TABLE 5.3.
Annual production of faeces estimated for several animal populations in Lake Mikolakskie

Animals analysed	Faeces g dry weight m^{-2} of lake surface	References
Dreissena polymorpha	49.78	Stanczykowska, 1977
Gastropoda	19.12	Kolodziejczyk, 1984
Fulica atra *Anas platyrhynchos*	1.02	Halba, 1975
Rutilus rutilus, *Scardinius erythrophthalamus*	0.96	Prejs, 1984
Acentropus niveus, *Nymphula nympheata,* *Paraponyx stratiotata*	0.17	Glowacka, 1976

Natural death of littoral organisms is estimated mainly in relation to macrophytes. Such data are easier to obtain for emergent vegetation which in general has a more regular phenology. Death losses of submersed vegetation may vary greatly in time depending on plant species, its phenology, and in tropical and temperate regions. It is obvious that rapid deterioration of habitat conditions can produce high mortality of animals. This may, for example, be an effect of water level fluctuation, the destructive role of wave action, and the activities of man (Pieczynska, 1986).

The role of animals in damaging other live organisms is also important. Berrie (1976) indicated the importance of shredding for the enrichment of detritus pool. Destruction of macrophytes due to animal moving, mining, building of cases, also seems to be of great importance. In some cases, the amount of food destroyed can exceed the amount consumed (Kolodziejczyk, 1984; Pieczynska, 1986). It has also been found that losses of submersed plants due to mining are very high (Urban, 1975). However, the amount of plant material remaining in the littoral zones of lakes is nearly always less than 10% of total production (Wetzel, 1983a). Most macrophyte productivity is decomposed by microflora.

Organic material produced in the littoral zone of lakes or imported vary considerably with regard to the susceptibility to decomposition.

Studies on decomposition of dead organisms or its remains in littoral zones of lakes deal mostly with macrophytes (literature review - Dickinson and Pugh, 1974; Ulehlova, 1976; Le Cren and Lowe-McConnell, 1980; Wetzel, 1983a, Polunin, 1984). Relatively, there are also abundant data on the decomposition of allochthonous leaf litter (Dickinson and Pugh, 1974; Hodkinson, 1975; Gasith and Lawacz, 1976; Barnes et al., 1978; and others). Other organisms are very rarely analysed.

Table 5.4 presents results from experiments conducted in a shallow littoral zone overgrown by *Phragmites australis* in two Masurian lakes in Poland, where techniques of mesh bags were used. The highest rates of disappearance were observed in the case of algae (*Cladophora glomerata*; *Gloeotrichia*) and mollusc tissues (bodies without shells) with up to 100% of the loss of initial dry weight occurring after the first 10 days of decomposition. Submersed macrophytes decomposed much slower. The slowest disappearance rate was observed in case of reed stalks (less than 1% during 10 days).

The slowest decomposition rate is that of organisms (or allochthonous litter) occurring most abundantly in the littoral zone. This is one of the reasons for high detritus accumulation in the shore zone of lakes. There is no doubt with regard to the higher decomposition rate of animals as compared with vascular plants. However, it should be pointed out that parts resistant to decomposition from a number of animals last for many years and may be a permanent structure of bottom sediments. This is especially the case of habitats where molluscs occur abundantly.

TABLE 5.4
Decomposition rate of various organisms. Percentage losses of dry weight after 10 days of in situ exposure. Lakes Majcs W. and Mikelajskie, July/August.

Material	% loss of dry weight mean	range
Phragmites australis (stalks)	<1	
Alnus sp. (leaves)	16	10-21
Phragmites australis (leaves)	18	9-23
Salix sp. (leaves)	20	12-29
Chara rudis	25	10-32
Potamogeton perfoliatus	30	16-43
Potamogeton lucens	33	15-40
Asellus equaticus	80	77-86
Lymnaea (Radix) sp.	82	78-87
Theodoxus fluviatilis	86	82-90
Cladophora glomerata	87	80-100
Gloeotrichia ochinulata	90	88-100
Dreissena polymorpha	94	90-100

From: Pieczynska 1986 (After Pieczynska 1972, Pereyra-Ramos 1981, Kolodziejczyk 1983, Pieczynska et al. 1984).

Decomposition rates of the same material can differ in various habitats. The intensity of this process is greatly influenced by environmental conditions.

Godshalk and Wetzel (1978) reported on differences in decomposition of 5 species of macrophytes representing submersed, floating-leaved, and emergent plants. The results of their experiments showed that temperature is the most important factor influencing decomposition rates and the conversion of particulate material to dissolved organic matter. While concentration of oxygen is most important for controlled decomposition and the conversion of dissolved organic matter to CO_2.

In highly heterogenous littoral systems great differences in decomposition are observed even within a very small area. Ulehlova (1976) showed great differences in cellulose decomposition at various macrophyte stands in fishponds. She also indicated differences between the kind and density of microflora colonizing *Phragmites australis* and *Typha angustifolia* at various decomposition stages (Fig. 5.11).

Also Pieczynská (1972) observed great differences in plant material decomposition within the shore zone of Lake Mikolajskie. The rate of disappearance of submersed macrophytes and tree leaves was the most rapid in swampy shore areas with periodical pools, lower values (up to four times) were obtained for the reed belt and the lowest for emergent part of the shore.

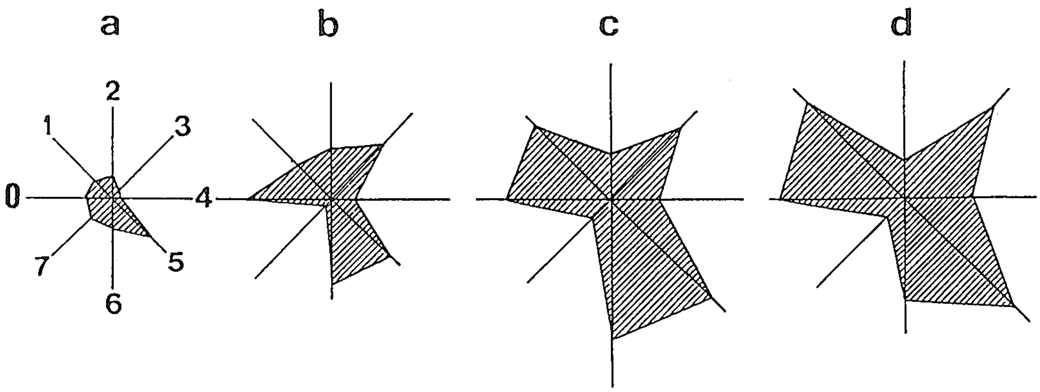

Fig. 5.11. Microbial polulations on different substrata in Nesyt fishpond littoral. a - standing dead *Phragmites australis*, b - standing dead *Typha angustifolia*, c - litter in pure *Phragmites australis*, d - detritus in pure *Phragmites australis*.
Connotation of axes (except 0 and 7 in 10^6 counts): 0, soil moisture in airdried sample (& of fressh weight); 1, organisms on pepton agar; 2, organisms on meat-pepton agar; 3, organisms on glucose yeast extract agar; 4, organisms on Ashby agar; 5, organisms on casein agar; 6, organisms on agar for cellulolytic bacteria; 7, 10^4 counts of organisms on agar for cellulolytic fungi. In a 1 cm corresponds to $12.5*10^6$ germs; in b, c, d to $12.5*1+^7$ germs (from Ulehlová, 1978).

5.4. THE IMPORTANCE OF MACROPHYTES IN THE LAKE LITTORAL

Nutrient cycling

Macrophytes have a central function in nutrient cycle of the shore zone of lakes. The intensity of nutrient uptake by roots and/or shoots, translocation, release by healthy plants and from decaying plants, exchange of elements within macrophyte/periphytom complexes, all determine the nutrient cycling in the littoral region (Fig. 5.12).

The role of macrophytes in nutrient budget is primarily determined by the site of nutrient uptake. It is obvious that for emergent plants the sediment is the prime nutrient source. But there are contradictory opinions regarding the factors regulating shoot or root proportion in nutrient uptake by submersed macrophytes.

Plant material produced in the littoral zone has various fates (Fig. 5.13). The importance of these pathways vary according to littoral types and changes during annual cycle.

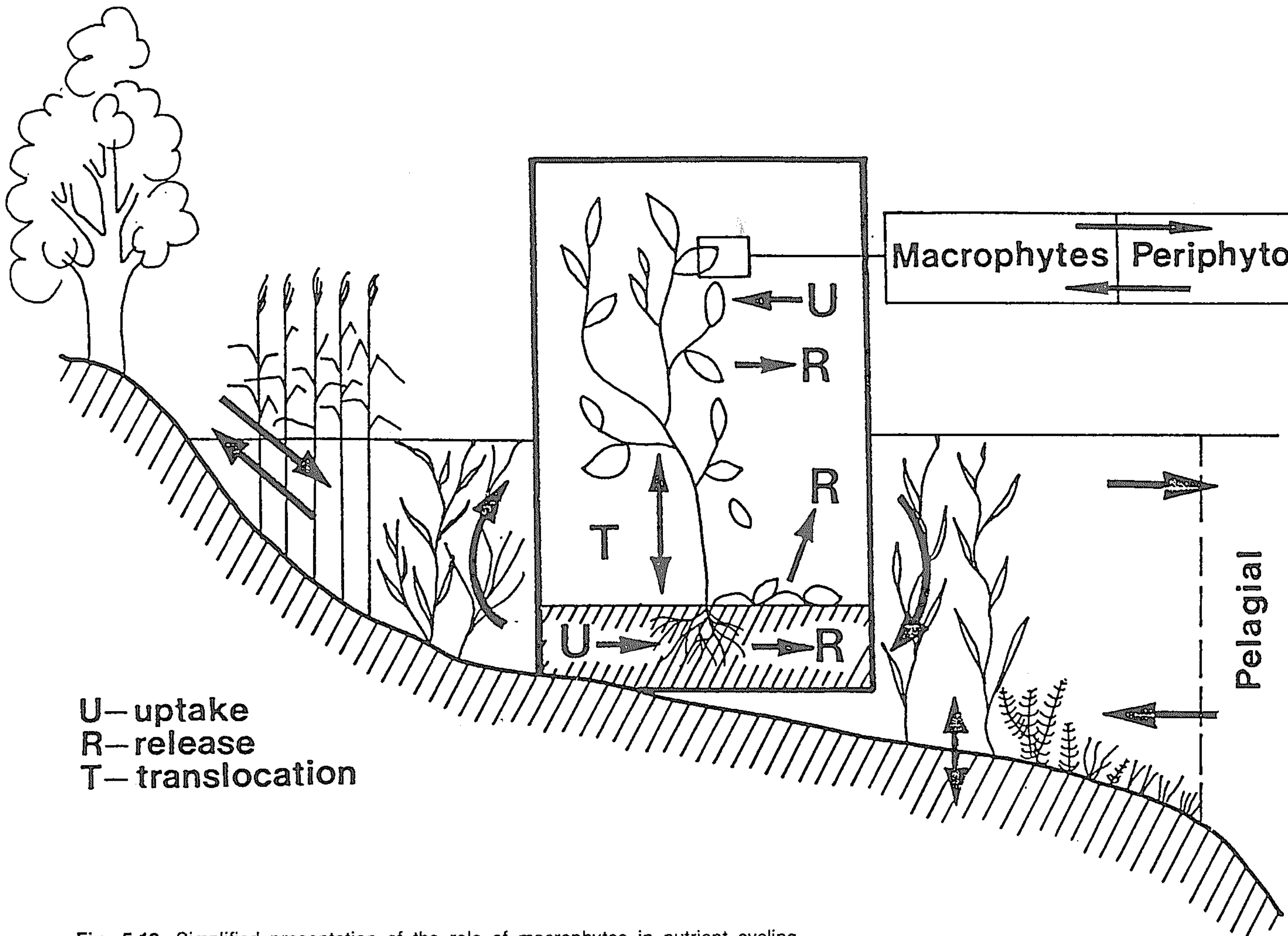

Fig. 5.12. Simplified presentation of the role of macrophytes in nutrient cycling.

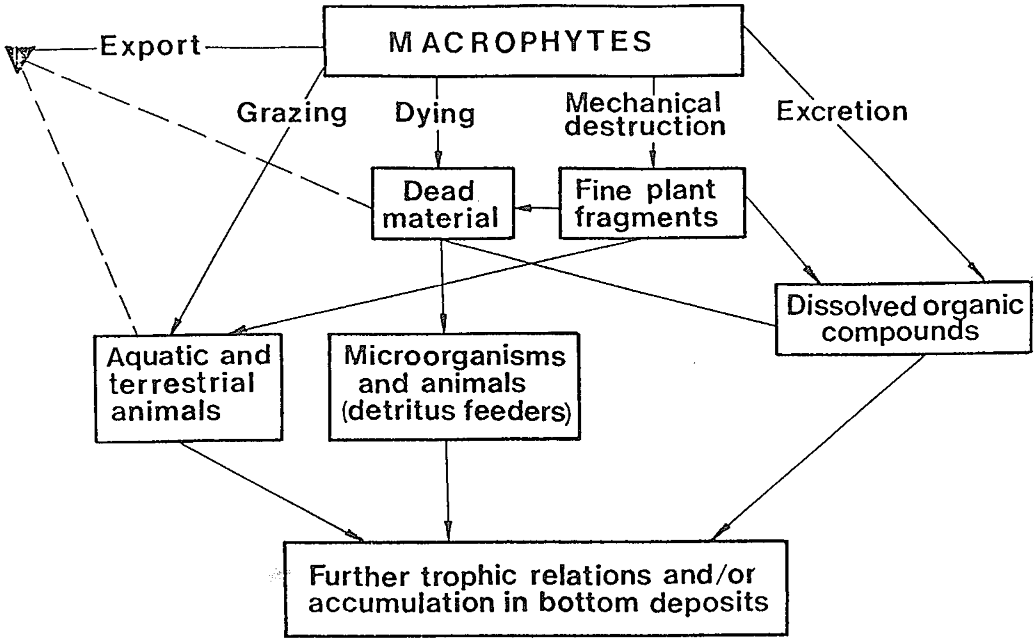

Fig. 5.13. Simplified presentation of the fate of macrophyte production in lakes.

This complexity means that only a few models of the role of macrophytes available in lake littoral metabolism and nutrient budget can be found in the literature. These were provided by Imhof and Burian (1972) for Lake Neusiedler, Wetzel and Allen (1972) for Lake Lawrence, Adams and Prentski (1982) for Lake Wingra, Sarvala et al. (1982) for Lake Pääjävi and Dykyjová and Kvet (1978) for fishponds in Czechoslovakia.

The importance of macrophyte decay in nutrient cycling is very high. In lakes with rich macrophyte production the release of phosphorus from plants after their death may be very significant as an internal source to the lake (Boström et al., 1982; Wetzel, 1983a). Prentki et al. (1979) and Carpenter (1980) suggested that in Lake Wingra the decomposition of *Myriophyllum spicatum* is the most important source of the phosphorus and organic carbon exported to the pelagic zone.

Relatively high values of release of phosphorus by living healthy plants have also been pointed out (McRoy et al., 1972), although other studies report minimal release from living macrophytes (Prentki et al., 1979). Nicholas and Keeny (1976) also suggested that live macrophytes are not significant sources of nitrogen for water.

Wetzel (1969), Allen (1971) and Wetzel and Allen (1972) have shown that dissolved organic substances, in addition to autolysis, leaching and products of bacterial decomposition, also originate by secretion from live plants. Although secretion rates vary greatly, macrophytes are capable of a significant contribution of dissolved organic matter to the total lake area.

Relation of macrophytes to periphyton and plankton

Submersed parts of macrophytes are usually colonized by various groups of autotrophic and heterotrophic organisms - epiphytes (periphyton). There is a great deal of controversy on the nature of the relationship between these organisms and their living substrata. Recently, a complex metabolic relationship has been suggested between attached microflora and macrophytes (reviewed by Wetzel, 1983a and b).

It has now been demonstrated conclusively that periphytic algae and bacteria can obtain a majority (>65%) of critical nutrients (e.g. phosphorus) from the supporting macrophyte (Möller et al., 1988; Burkholder and Wetzel, 1989, 1990). Despite this metabolic coupling with the host plant, the microfloral community assimilates large quantities of limiting nutrients from the surrounding water. This acquisition from the ambient environment allows for net community growth (Wetzel, 1990). In contrast, the nutrients within the periphytic community are intensively recycled; very little of the whole is released to the surrounding water (e.g. Riber and Wetzel, 1987).

In contrast to the pelagial zone, very specific for littoral situations is the close proximity of macrophytes and periphyton and also of various elements within periphyton community. This suggests the possibility of a direct exchange of nutrients and organic compounds between these components. Various substances taken by macrophytes from the water and then released by them to water must pass through the epiphytic community. Allen (1971) has shown that dissolved organic matter released extracellularly by macrophytes is rapidly incorporated by the epiphytic complex and then a portion is lost to the surrounding water. Wetzel (1983b) showed the potential fluxes of phosphorus (Fig. 5.14) suggesting that macrophyte and microflora complex on the plant surface can function as a highly integrated system.

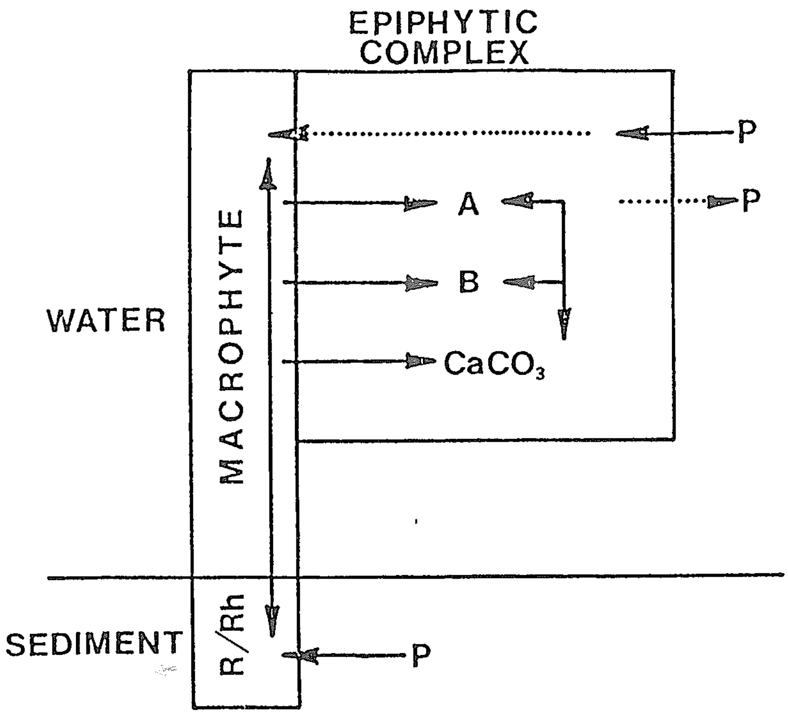

Fig. 5.14. Diagramic representation of the potential fluxes of phosphorus within macrophyte and the epiphytic complex consisting of algae (a), bacteria (b), and monocarbonate deposition (from Wetzel, 1983b).

Among other types of relationships, the shading effect of epiphytes on submersed macrophytes has also been indicated in literature. Losee and Wetzel (1983) have shown experimentally the selective attenuation of photosynthetically active radiation by various components of epiphytes. Sand-Jensen and Søndergaard (1981) have shown that shading by epiphytes is of decisive importance for the depth distribution of *Littorella uniflora*. In one lake with a high nutrient supply the epiphytes were responsible for 86% of light attenuation.

The influence of macrophytes on planktonic algae has been pointed out by many authors. The decrease in numbers, biomass or production of phytoplankton in dense macrophyte stands have been observed due to shading, competition on nutrients or production of inhibitors (Hasler and Jones, 1949; Hogetsu et al., 1960; Goulder, 1969; Straskraba et al., 1970; Dokulil, 1973; Brammer, 1979 and others).

The influence of macrophytes on phytoplankton may also be periodically beneficial. Landers (1982) has found, in a field experiment, that decomposing macrophytes (*Myriophyllum spicatum*) supplied surrounding water with nitrogen and phosphorus. Biomass of phytoplankton showed significant increases in response to this enrichment of environment.

Response to eutrophication and pollution

The commonly known symptom of lake eutrophication is the increase of phytoplankton biomass. Parallel to increasing eutrophication, the decrease in macrophyte biomass and cover (mainly submersed) is also usually observed (Eloranta, 1970; Lachavanne, 1982; Schröder and Schröder, 1982; Best et al., 1984; Ozimek and Kowalczewski, 1984; de Nie, 1987).

The majority of literature data on macrophyte decrease deal with submersed plants. Only in some circumstances the invasion of submersed plants is noticed (e.g. *Elodea canadensis*). With regard to emergent vegetation, there is observed both an expansion of plants, mainly reed in some shallow lakes (e.g. in Neusiedler Lake - Löffler, 1979; Gunatilaka, 1988) and distinct regression of plants at various localities (de Nie, 1987).

Among various factors which could be responsible for the decline of macrophytes, increasing phytoplankton biomass is often pointed out.

Wetzel and Hough (1973) presented a hypothesis (Fig. 5.15) which suggests that as the lake receives increased nutrient loading the growth of all groups of producers increases until the point when the light becomes a limiting factor. The light limitation associated with intense plankton and periphyton production results in a decrease of submersed macrophytes and associated periphyton. Since light is not a limiting factor for emergent plants then algae associated with these plants grow profusely.

Phillips et al. (1978), on the basis of studies of lakes in the Norfolk Lakeland in England have shown that the mechanism of submersed macrophyte suppression in shallow lakes may be more complicated. Their hypothesis implies that with a moderate nutrient input, macrophytes dominate, and organic suppression of phytoplankton by macrophytes is hypothesized thus producing relatively clear water. At high nutrient loading the reduction of macrophytes is noticed due to an increased growth of epiphytes and filamentous blanketing algae. This results in an increase in phytoplankton growth and further shading of macrophytes. Finally, phytoplankton dominates in such lakes.

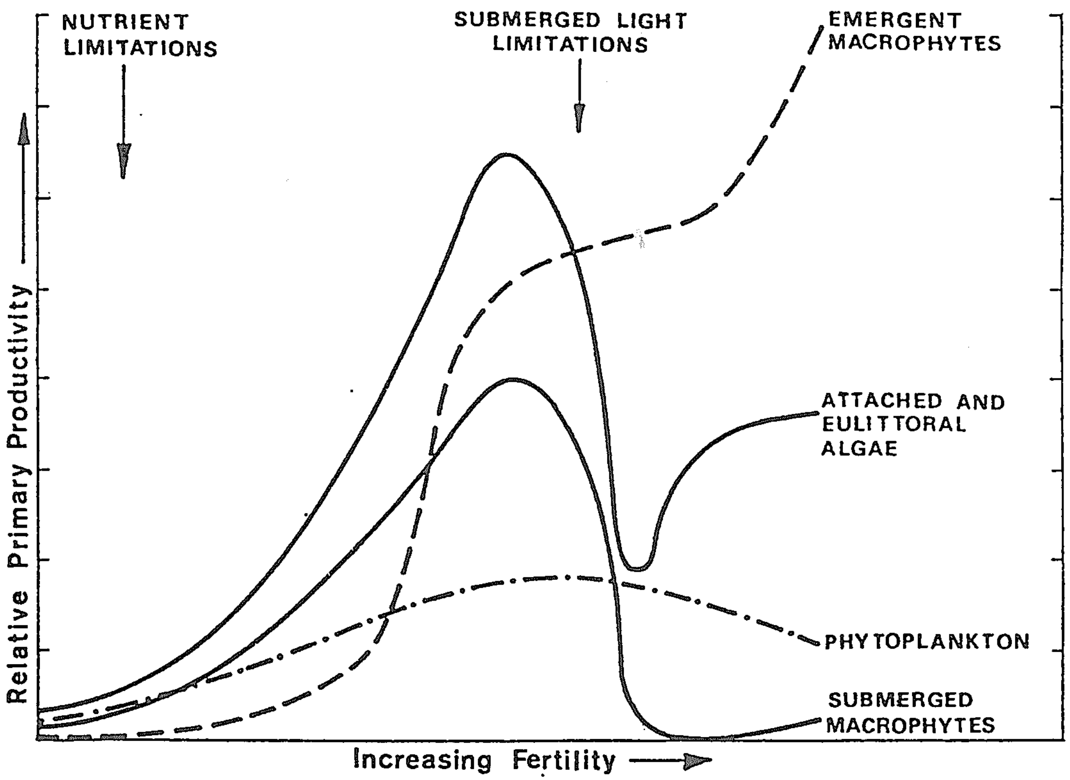

Fig. 5.15. Generalized relationship of primary production of emergent and submersed macrophytes, attached and eulittoral algae and phytoplankton in lake ecosystem of increasing fertility (from Wetzel and Hough, 1973).

The development of filamentous algae is also suggested as responsible for decline of emergent macrophytes (Schröder, 1987).

Among other factors connected with the loss of macrophytes, the direct toxic effect of high phosphorus levels and substratum enrichment in organic matter are also mentioned in the literature (Lachavanne, 1985).

Potential role of macrophytes in nutrient entrapment

Both the beneficial and detrimental effect of macrophytes on water quality are mentioned in the literature. Depending on the plant species and type of water body, macrophytes may accumulate nutrients, thus decreasing their concentration in water. Other plants, in different environmental conditions, could potentially mobilize nutrients from bottom sediments and the presence of macrophytes may accelerate eutrophication. Evidence for the latter, however, is weak.

Depending on the type of ecosystem examined one may find evidence in the literature that macrophytes are important (Bernatowicz, 1969) or insignificant in nutrients depletion from the water (Loenen and Koridon, 1978).

The amount of nutrient accumulated in plant tissue (per unit of plant weight) may be higher at the nutrient rich sites. But on the other hand, as noted before, a nutrient enrichment of lake water results in a decrease in macrophyte biomass. Thus, accumulation per unit area of littoral decreases.

Ozimek (1978), on the basis of studies of the response of submersed macrophytes to the pollution in Lake Mikolakskie, suggests that macrophytes cannot play a significant role in the nutrient entrapment in waters with high concentrations of pollutants. They are quickly destroyed and accumulate a relatively small amount of nutrients. Macrophytes are, however, of great importance in slightly polluted habitats where they grow abundantly.

It is obvious that the protective function of littoral zone of lakes is limited with the increasing pollution. A typical non-polluted littoral is overgrown by a dense macrophyte cover, rich plant and animal communities develop, and there are intense processes of self-purification of sewage and utilization of nutrients within the littoral. The protective function of the littoral is important. The long-term influence of increased pollution results in elimination of a considerable amount of macrophytes and associated organisms. The macrophyte zone becomes narrower, self-purification decreases and the protective function of littoral becomes less important.

Various field observations, field and laboratory experiments presented by Mickle and Wetzel (1978a and b), Gersberg et al. (1983, 1984, 1986) and others show that emergent macrophyte stands and submersed macrophyte-periphyton complexes can effectively remove various substances from through-flowing waters. This suggests that under some conditions macrophytes can be a protective barrier or a biological filter of nutrients and particulates.

These properties of aquatic macrophytes were successfully used, for example, in the restoration programme of Lake Jackson in the United States (Fernald and Cason, 1986). An underdrain filter system in the retention area and an artificial marsh system was constructed in this case. Another example is the project for restoration of Lake Balaton (Jolankai, 1988). The marsh wetland in the vicinity of the main tributary to the lake was reconstructed and used as a filtering system.

The role of macrophytes in nutrient entrapment differs in various ecosystems. It is determined by species composition of plants and physical characteristics of habitats. Macrophytes vary greatly in life cycle, physiology, morphology and anatomy. From the point of view of their protective function evergreen species (such as Characeae, *Elodea*, *Fontinalis*) are much more important as compared with, for example, certain *Potamogeton spp.* species growing only for several months during a year. Parameters which affect nutrient uptake from water or from bottom sediments are also very important.

Therefore when programming methods for nutrient removal by plants one should take into consideration numerous factors that may determine their effectiveness.

The littoral zone is significant in the functioning of water bodies, and requires special protection and control. Management practices should include the restoration of degraded sites and creation of new habitats which can serve as a protective barrier for nutrients and pollutants.

5.5. CONCLUSIONS

1. Most lakes in the world are relatively small and shallow so the littoral zone plays an important role in the lake ecosystem, productivity and the nutrient cycle. This zone determines the processes of lake eutrophication and may have an important protective function.

2. The littoral zone forms a varied habitat. The influence of the land and water body, water level fluctuations, various distributions of macrophytes, various detritus accumulations, all favour the formation of specific and mosaic habitats which are partly isolated from surrounding areas.

3. The littoral zone of lakes is colonized by very rich plant and animal communities. Macrophytes are an especially important biotic element

in the littoral zone. They are significant for spatial organization of environment, substratum formation for other organisms and nutrient cycling. Algae represent various ecological groups (planktonic, attached to the substratum and loosely floating).
Permanent and temporary inhabitants are represented among rich animal communities. Greater numbers of species and greater animal density are usually observed in the shore zone of lakes as compared with adjacent habitats. Representatives of various trophic groups - shifting proportions of herbivores, carnivores and detritivores - are found in littoral habitats.
The littoral zone is sometimes a very unbalanced system, characterized by frequent changes in the dominance of particular biotic elements.

4. Various sources of allochthonous and autochthonous organic matter occur in the littoral. The contribution of different groups of producers and of different kinds of allochthonous input vary in time and from place to place.

5. Organic matter produced and accumulated in the littoral zone has different fates. Dominance of macrophytes and allochthonous detritus, hardly accessible for grazers, result in dominance of microbial decomposition. As compared with limnetic zone of lakes, the littoral zone is in most cases a totally detritus dominated system.

6. The heterogenity of habitats and communities of both surrounding areas and the littoral zone itself results in a variety of relationships between the littoral zone and adjacent aquatic and terrestrial systems. In the littoral zone of each lake there is a number of variously functioning subsystems.

7. Increasing eutrophication and pollution of lakes is accompanied by changes in the littoral zone. Primarily the biomass and macrophyte cover decrease. Simultaneously, the biomass of filamentous, loosely attached algae increases.

8. Experimental research, as well as field studies, show that littoral systems (emergent macrophyte stands and submersed macrophyte/periphyton complexes) can be a protective barrier for nutrients and pollutants. The littoral region may play a significant role in lake protection and restoration programmes. Therefore, the littoral zone of lakes requires special protection and management.

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CHAPTER 6

IMPACT ON MAN

H. Löffler

6.1 INTRODUCTION

Littoral zones of lakes or lagoons are extremely sensitive land-water fringes and represent the most complex ecotones (see Chapter 5). Especially where distinct zonations such as epi-, supra-, eu-, infralittoral, etc. are developed already, a slight impact may result in profound changes (Kann, 1933, 1986). In this section, however, only the serious and profound changes in the littoral zones, which affect man either by threat to his health or even life or at least to his resources and activities, will be considered.

6.2 MORPHOMETRIC IMPACTS AND IMPACTS BY WATER-MOVEMENT

Lakes held by end-moraines, landslides, glaciers, volcanic ash or peat bogs may last often for a long period and even develop a variety of littoral vegetation. The destruction of such a fragile section of the littoral followed by the sudden eruption of the lake behind it may be released by earthquakes, excessive precipitation, ice- or (and) volcanic or other rock fall into the lake (Löffler, 1988). The most spectacular example of the latter kind was a rock and glacier fall of about 50 million m^3 from Mt. Huascaran (Cordillera Blanca, Peru) in 1970 into the lower Lake Yanganuco resulting in the death of about 18,000 people. Sometimes the accelerated growth of a morainic lake by the fast retreat of its glacier may increase the pressure against the end-moraine which finally collapses. Obviously, it is in all these cases listed not an impact from the littoral itself but its labile constitution.

Floods, water-movement from seiches and waves are the most common parameters which may either improve the littoral zonation and its persistence or which exert destruction tendencies on man-made establishments and achievements such as aquatic (paddies) or terrestic agriculture, roads and settlements or urban areas and different sites of recreation (sailing, boating, etc.). Other serious consequences may involve erosion or silting which often result in dramatic changes in the littoral morphology frequently combined with the alteration of the plant communities and of the general littoral aspects. Seiche movements and currents have contributed to the fast growth of the large phragmites belt of the shallow Neusiedlersee (Austria-Hungary) since the lake's last desiccation about 120 years ago and have accelerated the siltation of the western part (Löffler, 1979). Therefore, at present, the western shore communities are more or less cut off from the open lake. The shifting of Lop-Nor and sand-dune movements within Lake Chad prior to its rapid shrinking are examples of profound littoral changes in arid zones which can severely influence the traditional life of herdsmen, hunters and other socio-economic oriented communities.

Lagoons close to the coast are often subjected to tidal waves which turn fresh or slightly brackish bodies of water into highly saline ones and sometimes to ectogenic meromictic lakes (e.g. Hemmelsdorfer, Hutchinson, 1957). Drastic changes of the macrophytic vegetation will then influence the surrounding inhabitants involved in livestock management.

A more unusual event occurs with the piling up of ice in lakes and the erosional power of these ice flows. Though not a direct impact by the littoral, its shape and slope is responsible for the extent of possible destruction. Ice piles with a height of more than 15 m have been observed in Neusiedlersee and much larger ones are known from other lakes. Their shear force not only smashes solid concrete constructions but may also contribute to the formation of dams along a shore-line. The dam along the eastern shore of Neusiedlersee is most likely the result of such ice flows which occured during the last several thousands of years. With its main composition of sand and pebbles it is a rather dry structure.

6.3 HYDROLOGICAL IMPACTS

The hydrological influences on the littoral communities are closely related to the water-movement previously mentioned but in large astatic catchment areas additional long-term impacts on the littoral zone, sometimes of irreversible nature, do occur. They are either due to climatic fluctuations or to engineering work devoted to irrigation or diversion of affluents of a lake, a lagoon or a wetland. In semi-arid and arid zones the impacts involved most often concerns salinification and therefore brings about major changes in the vegetation of the littoral zone. Consequently, this means that useful plants, such as *Phragmites spp., Typha spp., Scirpus spp.*, etc. are replaced by a vegetation (if any at all) which may neither be used by man (production of mats, boats, etc. and construction of huts and thatching) nor by domestic stock for food. Dramatic examples of this kind are the Aral Sea, to a lesser extent Lake Niriz in Southern Iran and Lake Hamun at the Iran-Afghan border. With respect to Lake Hamun it should be mentioned that the traditional "Gaw-Dar" (herdsmen) culture faces its extinction if the vast typha stands should vanish. In all these cases, the surrounding areas are heavily exploited for irrigation. At the same time these are striking examples where a cost-benefit analysis was never undertaken even though it is badly needed. There are, however, also lakes which - due to most recent climatic changes - face a large reduction in area and volume (e.g. Lake Chad in Africa) and consequently their littoral and hence the resources of the dependant human population are heavily affected.

6.4 EUTROPHICATION

With only a few exceptions, eutrophication is almost always induced by man and generally it results at first in not only an increased growth of the littoral vegetation but also a decrease in species. At high nutrient loads, the reduction of submersed macrophytes is a common consequence of the increased growth of epiphytes and filamentous algae. This results in an increase in the phytoplankton growth and a further shading of the macrophytes. Finally, phytoplankton can dominate in such lakes (see Chapter 5). There is, however, a wide variety of scenarios which range from purely aesthetic impacts to serious implications for man's interests. In many alpine lakes, the excessive growth of algae (such as *Cladophora spp.*) may suppress the original littoral zonation of algae (See 6.1 and Kann, 1986). Additional parametres such as the possible increase of tensids may contribute to this phenomenon. More disturbing (particularly in relation to recreation such as swimming, boating) is the accelerated expansion of unwanted submersed macrophytes which in some cases (such as *Elodea canadensis*) are recognized as a nutrient pump, may contribute to further eutrophication. Explosive growth of macrophytes, however, may also occur in relation to the introduction of exotic species. Very little is understood about the growth of the low growing *Characeae* which can suppress large growing macrophytes and at the same time epipelic algae. Thus the management of *Characeae* in littoral zones used for recreation may become important. Excessive algal blooms (mainly blue-greens) often seriously suppress the growth of submersed macrophytes which in some cases are of economic value for man (e.g. *Myriophyllum sp.* in Indonesia). Expansion of the emergent vegetation contributes to siltation and decreases the area of open water. On the other hand, eutrophic influences of a not yet recognized kind are responsible for the extinction of emergent helophytic vegetation. An example of such a process is the reed belt of the lower part of Lake Constance (Untersee) where phragmites have been vanishing for years. In spite of numerous studies the parametres involved remain unclear. One hypothesis suggests that the allelopathic effect from *Cladophora* is responsible (Schröder, 1987). Another example of vanishing emergent vegetation concerns *Scirpus tatora* in Puno Bay of Lake Titicaca. It has been estimated that over a four-fold reduction in totora coverage in the inner Puno Bay has been taking place since the mid-1930s. Changes in lake level, channel dredging, harvesting and other factors may partly be responsible for this decrease, but cultural eutrophication intensifying over that period is most likely also involved (Bornejo & Aramayo, 1989). *Scirpus tatora* plays a significant socio-economic role for the native population (e.g. construction of boats, floating islands for aquaculture etc.).

On the other hand, excessive growth of helophytic vegetation may also be extremely undesirable. In many of the lakelets east of Neusiedlersee, well known for their waterfowl, this has become a problem since quite a few species of birds prefer open shore sections. They were abundant when phragmites were controlled by trampling of cattle some decades ago. With the end of cattle farming phragmites quickly started to overgrow the littoral zones.

However, in summarizing the more general aspects one must point out that the possible role of macrophytes (handcraft, thatching, fodder, food for man, fertilizer, biogas, drying up of freshly created polders, accumulation of toxic substances and nutrients, spawning site for fish, etc.) for man is still only tentatively known and therefore - with a few exceptions - the destruction and extinction of littoral macrophytes represents one of the major impacts.

6.5 LITTORAL ZONE POLLUTION

Compared with the marine coastal situation in many parts of the world, littoral zone pollution in lakes is generally of a minor importance. Oil spill, for example, is rather an exception and mainly limited to large lakes. There exist, however, risks of this kind when oil pipelines are transferred close to lake shores as it occured along the eastern shore of Lake Constance in the mid-1960s. On the other hand, an almost unlimited variety of harmful and toxic substances, such as detergents, pesticides, PCBs, derivates of asphalt and tar (such as the cancerogenic 3,4-benzpyrene), heavy metals, etc., become dangerous to man in a number of lakes and above all in the littoral zone where most of the resources, often the sustenance for the native population, are concentrated. Therefore, careful handling of the sanitation within given watersheds is of essential importance.

6.6 ACIDIFICATION

In contrast to the oil spill, which is mainly an impact on the marine environment and large rivers used for traffic, acidification concerns almost exclusively lakes within poorly buffered watersheds. The classical examples belong to Scandinavia and the eastern parts of Canada and USA. In some of these lakes an annually drop of 0.02 units of pH has been observed. One consequence is an increase of heavy metals which contributes to the death of fish, zooplankton and other organisms. Cerné Jezero, a small cirque in the Bohemian Mountains of CSR, has been studied since 1871. Already in 1891 a decrease of species of zooplankton was observed and in 1975 the last specimens of *Salvelinus fontinalis* disappeared. The pH dropped from 6 in 1871 to 4.6 about onehundred years later. There is only little information about the littoral zone but it appears that the impact has been much less severe in the area than within the pelagic part of the lake. Macrophytes (such as *Isoetes lacustris, Soarganium affine, Juncus bulbosus, Carex rostrata* and *Glyceria fluitans)* are still present but scarce. It is known, however, from the experimental acidification of small pond ecosystems and from field observations, that increased growth of *Sphagnum spp., Juncus bulbosus* and *Lobelia dortmanna* occurs whereas soft water plants such as *littorella uniflora* are likely to disappear (Gahnström & Andersson, in press). In contrast to the profundal zone of Cerné Jezero (z max. 40 m), where chironomids are at present missing, a variety of species still live in the littoral zone of this lake. Likewise chydorids and copepods are abundant there. Generally, it may be expected that the upper littoral is more resistant to acidification than the rest of a lake. Obviously, the renewal of terristrial debris and matter is one of the main parametres responsible for this protective influence. There is, however, no doubt that at least the loss of littoral fish species and the increase of heavy metals in the littoral system must be considered as a serious impact on man.

6.7 IMPACT FROM VERTEBRATES

Again, impacts of this kind are mostly induced by man. Exotic species, such as the grass carp (*Ctenopharyngodon idella*) may seriously influence and destroy the phytal region and thus the spawning sites of other fish species. Likewise the introduction of *Lepomis gibbosus* from North America in Central Europe has resulted in a serious depletion of food resources for other fish species of the littoral zone of backwaters of the Danube. Among birds the recent increase of *Fulica atra* in Central Europe has in some places heavily influenced the macrophytic vegetation (e.g. Lunzer Untersee, Austria). On the other hand, the endemic giant coot of Lake Atitlan recently became extinct after a denivillation of the lake level. Both cases are examples of impacts on the conservation of genetic diversity and on endangered species. Among mammals, the musk-rat (*Ondatra zibethicus*) from North America may be mentioned. It was introduced into Bohemia in 1905 and has since spread over large parts of Europe. Apart from damage to dams and other man-made constructions, it sometimes causes deterioration of littoral zones. Trampling of live-stock (see 6.4) strongly affects the emergent vegetation and the breeding sites of birds. In contrast to horses, (e.g. Camargue in France) cattle feeds only on sprouts of phragmites but avoids fully grown stands.

6.8 HEALTH RISKS

About 80% of all diseases affecting man are due to inadequate water or sanitation which include the effects of drinking contaminated water, water acting as a breeding ground for the carriers of diseases, and diseases caused by the lack of washing water (UNICEF, 1983; Löffler, 1988). Well-known infectious diseases such as typhoid, cholera, dysentery, diarrhoea, certain types of hepatitis, amoebic meningo-encephalitis, etc. are caused by viruses, bacteria and protozoa. In large and deep lakes it is almost exclusively in the littoral zone where such risks occur. But at the same time, this zone offers the easiest access to water for the native population. Likewise, the infection with schistosomiasis, feacioliasis, angyostrongylosis, etc. is mainly restricted to the littoral zone in large lakes. Parasites, whose vectors are snails like *Bulinus, Biompalaria, Thiara*, etc. are lacking in highly alkaline lakes. In the littoral zone of some of the subtropical and tropical lakes venomous snakes may be abundant.

6.9 CONFLICTING SCENARIOS

Recreation - conservation

With respect to conservation and the maintenance of genetic diversity, the loss of lake littoral zones is one of the most significant impacts on man - made by man and particularly by his recreational activities. Almost all of the lakes suitable for swimming, boating, yachting and holiday housing have lost their littoral communities - especially their vegetation - not only in industrial regions but increasingly in developing countries (e.g. Lake Atitlan, Guatemala). The loss of species diversity of littoral bound organisms is increasingly recognized not only by scientists but also by international organizations and even by local decision-makers. However, the destruction of the littoral ecotones still progresses rapidly.

Traffic, urbanisation and industry - recreation (conservation)

The reclamation of littoral zones by urbanization (e.g. Lausanne, Geneva, Chicago, Milwaukee, Detroit, Toledo, etc.) and by highways of railways is not only a serious impact on conservation and recreation but contributes considerably to the pollution of lakes. Only if a city or industry is concentrated at the outflow area of a lake can the harmful influences to a certain extent be mitigated (e.g. Zürich). Since, in most cases, the existing problems of such a kind have a long tradition (e.g. mule-tracks along lakes which later were turned into roads and highways), improvement of the present situation is unlikely to happen. Even the removal of traffic routes from lake shores is rather costly and therefore very few activities of this kind are at the planning stage or have even taken place (e.g. railway along the eastern shore of Lake Constance).

Agriculture - conservation

Again, reclamation here is the most common impact on valuable littoral zones. Formerly, an outstanding bird sanctuary, the some 100 km^2 large "Hanság" SE of Neusiedlersee, was drained and at present it is almost exclusively used for terrestrial agriculture. Lake Biwa has lost large portions of its phragmites belt which were replaced by paddies thus decreasing the lake's self-cleaning capacity. Pesticides and fertilizers used in agri- and horticulture additionally jeopardize protective efforts. Similarly, in some countries like Sweden, wetlands and littoral zones are reclaimed for forestry. The adverse but also positive influences by live-stock have already been mentioned in 6.4 and 6.7

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CHAPTER 7

IMPACT BY MAN

H. Löffler

7.1 INTRODUCTION

Like rivers and wetlands, shallow lakes and lake shores are threatened by a large variety of human impacts including:

- morphometric and hydrological changes;
- eutrophication;
- pollution from toxic substances and other matter (e.g. turbid material) including acidification;
- heating or cooling;
- introduction of exotic species.

By means of paleolimnological methods many human impacts can be traced back to ancient times. There is, however, no doubt that the majority of adverse changes occurred during the last few centuries or even during the last onehundred years (e.g. loading of lakes with heavy metals and pesticides).

Only after World War II were steps for sanitation (e.g. avoidance of nutrient loading and pollution) and restoration (e.g. removal of mud, precipitation of phosphorus in situ) increasingly performed and resulted in oligotrophication and general improvement of the water quality. Lately, the restoration of littoral zones and the general management of watersheds have been increasingly recognized as important measures for the conservation of lakes.

7.2 MORPHOMETRIC AND HYDROLOGICAL CHANGES

The complete elimination of lakes occurs mainly in connection with

- the regulation of rivers (removal of levees, ox bows, lakes and other types of lake basins produced by the dynamics of running water);
- the use of the tributaries of lakes for irrigation;
- the reclamation of shallow lake basins for a variety of purposes including waste disposal.

Even in small countries like Austria several hundred lakes have been lost. In addition, the area of volume of lakes is often changed by: -

- excavation of material;
- damming for various reasons, such as power plants, water storage, etc.;
- increased sedimentation and disposal of material;
- reclamation of littoral zones;
- the use of inflows for irrigation or other purposes.

Mining of gravel, diatomite (Jonasson, 1979), calcium carbonate (Rich, 1971), peat and other material may greatly influence the shape of lake basins. If locally exploited, the resulting deep hole may facilitate chemical stratification and oxygen depletion. On the other hand, mining activities world-wide have produced a multitude of new lake basins, which - in the case of coal mining - may be extremely acidificated.

Damming of natural lakes for various reasons has a long tradition and causes eutrophication (e.g. damming of Grosser Plönersee in the 13th century, Ohle, 1978), and/or the destruction of the littoral habitat. The latter persists in lakes with frequent changes of water level caused by power plants.

The uncontrolled activities of man within watersheds, erosion and landslides result in increased sedimentation and siltation of the littoral zones. In addition, dumping of material may accelerate the rate of sedimentation in lakes. The most remarkable case of this kind in Central Europe is Traunsee (Löffler, 1983), a deep prealpine lake (z_{max} 89 m), where, since the turn of the century, the alkali works near the mouth of the inflow release daily up to 30 metric tons of largely insoluble substances. Near the releasing pipe this material has piled up to more than 40 m and at present covers a large portion of the lake bottom. With a pH between 10 and 11 it moreover prevents any colonization by benthic animals living in undisturbed parts of the lake bottom. Far more often than large lakes, small and shallow ponds are used as depositories for material including garbage.

The most common practice within lake basins is the reclamation of the littoral zones for different purposes, such as: -

- agriculture and husbandry (including the commercial harvest of macrophytes);
- traffic;
- settlements and industry;
- recreation.

The reclamation of the littoral zones of lakes is an international problem and includes all kinds of terrestrial and aquatic farming (e.g.

paddies along shore sections of Lake Biwa). Cattle breeding and other stock farming may change the littoral zone of shallow lakes considerably. Trampling and feeding on emergent macrophytes may result in a complete loss of the littoral vegetation. Sometimes, like in shallow lagoons near Lake Titicaca, even the submerged vegetation is grazed by cattle (Löffler, 196x) and the use of macrophytes by man such as *Myriophyllum* for food (Indonesia), thatching, matting, construction of rafts is well known in different parts of the world (e.g. China, South Asia, Iran, Iraq, Lake Chad, Lake Titicaca).

Very often, lake shores have been, and still are, claimed for traffic development (viz. roads, railways, airports and shipping traffic). Their construction often causes eutrophication (see 7.3), but due to large amounts of released mineral turbid material sometines also oligotrophication may occur (e.g. road construction along the shore of Mondsee, Austria, during the late 1950s).

Since lake shores have been always preferred sites for the settling of man - evidenced by the lake dwellings of Neolithic and Bronce Age farmers (5900 - 4200 b.C.) in Europe - the number of large villages and cities, often with a variety of industrial entertainments, at lakes amounts to tens of thousands at present. The large cities at the Great Lakes in North America are just one example of this kind of development. In addition to the traditional settlements near lakes, recreation (in Central Europe in the last 150 years) have increasingly caused the reclamation of lake shores for holiday houses and lately also camps. So far, only a few countries (e.g. Sweden) have set up measures against the construction of such houses close to the shoreline.

Apart from the destruction of large shore sections by these building activities, eutrophication (see 7.3), pollution (see 7.4) and thermal impacts (see 7.5) are the consequences and at present successful sanitation or restoration of such afflicted lakes or sections of their shore often seems unfeasible.

The use of inflows to lakes for irrigation, energy or drinking water supply results in major changes of the water budget and in closed lakes morphometric alterations and increasing salinity or(and) alkalinity. Mono Lake in California, one of the oldest lakes in North America (about 500,000 years old), represents one example of this. Since 1941, the saline lake's level has dropped 11 m as a result of water diversion for the city of Los Angeles. Eventually, increased salinity would lead to destruction of brine shrimp and brine fly population and deprive hundreds of thousands of birds - among these those feeding on the shore - of their food. Another, even more dramatic case of this kind is the Aral Sea in USSR, part of the former Paratethys during the Miocene. More recently, water of its major influents Amu Darya and Syr Darya has been diverted for irrigation and therefore the water budget and salinity of this large closed (63,800 km^2) and saline lake have been seriously affected.

7.3 EUTROPHICATION

The influence of eutrophication (see chapter xx, guideline book no xx) on the littoral zone of lakes may very greatly. In alpine lakes with rock shores the well developed zonation of sessile (epilithic) algae (Kann, 19xx) in the upper littoral (supralittoral, eulittoral, infralittoral) of oligotrophic lakes is often replaced by a monotonous algal mat of *Gladophora sp.* and likewise the diversity of benthic animals decreases. In the same way, the emergent macrophytic vegetation, with its attached epiphytic algae, tends to increase but at the same time becomes more uniform and finally the helophytic vegetation may even vanish. The decrease of phragmite stands in Lake Constance is thought to be connected with eutrophication and the resulting development of sapropelic soil. The physiology of this destruction, however, is not yet fully understood and may include allelopathic elements. With increasing nutrient supply submersed macrophytes often become more important to the total primary productivity of lakes until the fertility of the whole system is subjected to severe light attenuation due to intense phytoplankton productivity (Wetzel, 1983) and(or) a dominance assumed by pleustonic plants. The bloom of *Salvinia molesta* short after the establishment of the Kariba Dam may be mentioned as an example, which, after the exhaustion of nutrients (released from the flooded terrestric vegetation), quickly became reduced to its present minor extent.

If dystrophic-oligotrophic lakes turn into an eutrophic-alkaline condition, a major change of the littoral vegetation and fauna will most likely take place (see below). Eutrophication and hence increased food sources in the open water causes some littoral animals to show a tendency to move into the littoral zone. This is known from several *Cladocera* species (e.g. *Chydorus spaericus*) and a few fish species, such as *Perca fluviatilis.*

Excessive loading of lakes with nutrients, mainly phosphorus and nitrogen, caused by man started in connection with slash and burn practices and deforestation in general. Erosion and therefore increased runoff of nutrients within watersheds are the common consequences of any forest clearing (Limens et al., 1970), especially if clear cutting is applied. Erosion with all its consequences may also cause profound changes in the chemical conditions of lakes other than just increasing nutrient contents. Forest clearance followed by field cultivation has changed Lake Lovojärvi in Finland from oligotrophic- dystrophic into alkaline-eutrophic (Huttonen & Tolonen, 1975). Obviously, this change must also have greatly influenced the littoral vegetation.

Likewise, erosion from mining and engineering activities in the watershed has occured extensively in the past. The impact of the construction of Via Cassia (171 b.C.) on Largo Monterosi, a small closed basin of volcanic origin north of Rome has caused eutrophication for a few centuries (Hutchinson, 1970). Damming of the shallow Grosser Plöner See in northern Germany (see 7.2, Ohle, 1978) about 700 years ago has on the other hand introduced an eutrophication period which still persists.

The development of agriculture within forested watersheds or watersheds with dense vegetation of some kind contributed greatly to erosion, eutrophication of soils and non-point source nutrient loading of inland waters. Erosion is increasingly enhanced if sparse plantations like vineyards and corn fields dominate. Very often, reclamation of littoral zones for agriculture resulted not only in the destruction of the shore vegetation but also in eutrophication.

The impact of urban systems and recreation facilities along lake shores may have limited effects on the littoral zone if a proper sewer system takes care of all the possible sources of nutrient (and pollution, see 7.4) loading. One of the main contributions to nutrient loading has been, and in many countries still is, the use of P-containing detergents. They have caused eutrophication in many inland waters and only recently have such agents been banned.

Finally, a large variety of industries may contribute to eutrophication if the resulting sewage is released untreated. Among these food producing and fertilizer industries, breweries, etc. take a prominant position. In many industrial countries, sewage plants with three or even four steps do take care of the waste water. Air pollution with nutrients, however, remain a problem still to be solved.

7.4 OTHER KINDS OF POLLUTION

Pollution, other than by nutrients, has increased exponentially during the industrial age. It comprises a huge variety of inorganic and organic compounds many of which affect the littoral zone. Mineral oil and its derivates, though much more of concern to the sea and large rivers where oil transportation takes place, is the most obvious example. The hazard of oil pollution in lakes is caused by pipelines along lake shores (e.g. Lake Constance), by shipping, by oil transportation and in rare cases also by oil production and by uncontrolled waste disposal close to lakes and ponds (e.g. oil barrels). The disastrous outcome of oil spilling for water quality and aquatic organisms is well known.

Another major impact on mainly soft water lakes and their littoral zones is the complex influence from airborne acidification - acid rain - and direct acidification by industry (e.g. pulp industry). As mentioned in 7.3, events of this kind, often resulting in annual pH decreases of as much as 0.2 units, may give way to a complete change of the lake ecosystem which frequently causes the extinction of fish and therefore is of considerable economic importance. Moreover, acidification of the watershed results in increased release of heavy metals from soil and thus contributes to fish kill particularly if aluminium is involved.

The littoral plays a significant role in the transfer of heavy metals from terrestrial non-point sources. It contributes greatly to the transformation of elementary metals or their inorganic compounds into biological relevant organic substances. In addition, like terrestrial plants, aquatic vegetation exhibits specific capacities for the uptake and enrichment of heavy metals and may significantly contribute to their cycling in the whole lake.

Among other pollutants pesticides may play an important role in the littoral zone. Herbicides, often used against massive growth of macrophytes in channels and running waters, were sometimes also put into action in lakes (e.g. Bayersoiner See, Kucklentz & Hamm, 1988). Case studies show an increase of nutrients due to the decaying plants. At present, the use of herbicides against undesirable weeds is prohibited in several countries. Apart from chemical weed control, campaigns against vectors of deseases such as malaria (DDT), schistosomiasis (molluscicides), etc. not only affect the littoral communities but also imply considerable health risks. In addition, a variety of other pesticides used in agriculture such as aldrine, etc. exert adverse influence on lake ecosystems. Their role in the littoral communities, however, is not yet understood. Among other organic substances, 3.4 benzopyrene and other polycyclic aromatic hydrocarbons stemming from asphalted and tarred roads have been reported from lakes (e.g. Lake Constance, Elster et al., 1963). At least 3.4 benzopyrene has been proved cancerogenic. Again, their influence on the littoral community is unclear.

7.5 HEATING AND COOLING

From several studies available, so far only from the northern temperate zones, it emerges that any heating of lakes - mainly by power plants - results in a general increase of the biomass and that individual lakes show peculiar shifts in planktonic species and sometimes also the immigration of exotic species. If the lake looses its cool hypolimnion, a dramatic change of the profundal fauna can be observed. Very little information exists, however, about the impact of heating on the littoral zone. In one Canadian lake an increase of *Elodea canadensis* was observed (Allen & Gorham, 1973) resulting in the replacement of macrophyte species which were dominant before. Increase of biomass and decrease of diversity often seem to be more general features than response of the littoral community to heating.

The construction of electric power plants sometimes implies the cooling of a lake, if it is used as a basin for the release of water which is the source of energy and which is sufficiently cold. Thus, the diversion of water from the River Tagliamento in northern Italy for such a power plant and its release to Largo di Cavazzo has resulted in a considerable drop of the epilimnic summer temperature. Since then carp have been replaced by trout and swimming is no longer part of the ongoing recreation. No information exists on subsequent changes in the littoral zone.

7.6 INTRODUCTION OF EXOTIC SPECIES

Among the most infamous cases of the introduction of exotic species by man is the stocking of Lake Titicaca with rainbow trout and of Lake Victoria with nile perch. The catastrophic effects on the endemic fish fauna of these lakes are a clear demonstration of thoughtless activities. Likewise, the introduction of chinese grass carp has often led to the complete destruction of submersed macrophytes in shallow lakes and littoral zones. On the other hand, the stocking with eel has profound effects on the littoral animals (amphibians, certain invertebrates) and spawn of fish. Stocking with fish where it was not present before results frequently in the extinction of certain invertebrates such as fairy shrimps (*Anostraca*), large species of *Cladocera* or *Copopoda*, etc.

Stocking of European lakes with fish species from North America during the late last century contributed to the introduction of pests like *Elodea canadensis* which has become the dominant macrophyte species in many European lakes, especially in the Alpine region. Similarly, many other species have been spread often on a worldwide scale. More recently, motor boating and sailing have also contributed to the dispersal of many species such as the mussel *Dreissena polymorpha*.

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CHAPTER 8

QUANTIFICATION AND MODELLING

S.E. Jørgensen

8.1 THE STATE OF THE ART MODELLING OF THE TRANSITION ZONE

Detailed modelling of the littoral and supralittoral zones is still in its formative stages. These zones may, however, be important for the entire lake ecosystem (as discussed throughout this volume). The modelling effort for these zones has, not surprisingly, mainly been in context of modelling for the entire lake ecosystem, in the form of submodels. The processes in the transition zone, of particular interest for the lake water quality, have been modelled (for instance, denitrification) and included models of entire lake ecosystems. While models focusing only on the littoral or supralittoral zone have hardly been developed. This may be completely acceptable, since modelling is a holistic approach attempting to get as broad an overview as possible.

The quantative role of the shore for the nutrient balance of the lake, for the filtration of particulate matter coming from the non-point sources, for the water quality in general and for the biota at the shore and in the lake ecosystem has been mentioned several times in previous chapters. The basic knowledge for modelling the important processes in the transition zone is therefore available.

The following sections are devoted to a presentation of submodels of the important processes in the littoral and supralittoral zone and finally this chapter is giving an example of the application of these submodels in a management model of the transition zone, used as a tool in management of a lake ecosystem.

As clearly presented in Guideline Book number 1 "Principles of Lake Management" Chapter 6 "Use of Models", it is not possible to develop a general model. It is necessary in each individual case to develop a model, which considers the characteristic features of the considered ecosystem. Consequently, it is not feasible here to present a general model for the shore ecosystem to be included in a management model of the entire ecoysystem. It is only possible to present a number of approaches to a quantitative description (submodels) of various processes, which may or may not be included in the final lake management model.

The biogeochemical submodels of greatest interest for modelling the littoral and supralittoral zone are:

1. Nitrification and denitrification.
2. Uptake of nitrogen and phosphorus by macrophytes.
3. Adsorption of phosporus, pesticides and heavy metals by soil and mud.
4. Uptake of pesticides and heavy metals by plants.
5. Erosion

It is not possible here to give a comprehensive presentation of these five submodels. For a more detailed treatment of these topics may be referred to Jørgensen (1990), Jørgensen and Gromiec (1989) and Mitsch et al (1988).

8.2 NITRIFICATION AND DENITRIFICATION

Nitrification

The nitrification process may be described as a first order reaction (see, for example, Jørgensen, 1983). The influence of temperature and moisture on the rate is expressed in the same way as with the mineralization process:

$$K = K_{max}\ f(T)\ f(\Omega) \tag{8.1}$$

where f(T) = $K_T(T*20)$ (Bowie et al., 1985), K_T is 1.02*1.08, averaging 1.05. A table function relating the rate constant with the moisture contents is shown in Table 8.1.

TABLE 8.1.
The relationship between moisture content and nitrification rate.

Moisture Content Ω, % of saturation	Nitrification Function, $f_2(\Omega)$
10	0.11
30	0.31
50	0.86
60	1.00
70	0.40
80	0.10
100	0.00

8.3 ADSORPTION PROCESSES

Adsorption and ion exchange are fast processes. In water quality modelling the selected time interval is often either weeks, days or hours. It implies that these processes can be described by means of equilibrium equations. The conditions for the equilibrium may change very rapidly, but a new equilibrium is attained very rapidly, too - in minutes or hours at the most.

In some cases a water quality model may use a short time interval, whereas the adsorption or ion exchange process is relatively slow. So there is a need for a description of the process rate. This chapter will therefore present not only the **equilibrium expressions** but also **the rate expressions**.

The most simple equilibrium expression uses a **linear adsorption isotherm**:

$$a = k_1 * C + k_2 \qquad (8.2)$$

where a denotes the concentration on the adsorbent, while C is the concentration in the liquid phase, and k_1 and k_2 are constants. At some adsorptions k_2 may be very small and equal to, or almost equal to, zero. In such cases k_1 expresses the number of times the concentration in the adsorbent is greater than the concentration in the liquid (water) phase and is then called the partition coefficient.

The **Freundlich adsorption isotherm** is expressed in the following equation:

$$a = k * C^n \qquad (8.3)$$

where k and n are constants, a is the amount of solute adsorbed per unit weight, and C is the equilibrium concentration of the solute in the liquid phase.

If n is equal to one in Freundlich's adsorption isotherm, k becomes the partition coefficient, as before.

Langmuir's adsorption isotherm is based on the following expression:

$$a = \frac{A_0 * C}{1 + b * C} \qquad (8.4)$$

where a and C are as defined above, b and A_0 are constants.

As can be seen, $a = A_0/b$ when $C - \infty$.

The Langmuir constant for several organic compounds which can be adsorbed on activated carbon has been found by Weber et al., 1964. Most types of waste water contain several substances which will be adsorbed in which case a direct application of Langmuirs adsorption isotherm is not possible.

Weber et al. (1965) have developed an equation (8.5) and (8.6) for *competitive adsorption of two substances* (A and B). In other words competitive adsorption can be described in the same way as a competitive enzymatic reaction:

$$a_A = \frac{A_{Ao} \; C_A}{1 + b_A * C_A + b_B * C_B} \tag{8.5}$$

$$a^B = \frac{A^{Bo} \; C^B}{1 + b_A * C_A + b_B * C_B} \tag{8.6}$$

8.4 UPTAKE OF NUTRIENTS BY MACROPHYTES

Plant uptake and translocation

The uptake of nitrogen, U, by the root system of the wetland plants is dependent on the following factors:

* nitrate concentration in the rootzone
* ammonium concentration in the rootzone
* biomass of the roots (BIR), g/m^2
* temperature
* nitrogen concentration in the roots (RN) in g per g.

All these factors are considered in the following equation:

$$U = BIR * K_9 \left[[NO_3\text{-}N]/(K_{9m} + [NO_3\text{-}N]) \right] x$$
$$\left[(RNmax * RN)/(RNmax - RNmin)\right] \tag{8.7}$$

where K_9 is dependent on the temperature by a similar expression as in equation (8.1) and by the moisture content by a table function. RNmax and RNmin indicate the upper and lower limits for the nitrogen concentration in the roots. The amount of nitrogen in the roots, ROOT-N, expressed as g per m^2 can be found from the following expression:

$$ROOT\text{-}N = BIR * RN \tag{8.8}$$

As mentioned above, BIR as a function of time is modelled by an empirical expression, which relates the climatic forcing function to the biomass for the considered plant species. It might also be possible to express BIR as function of time with a constant growth per day up to a certain maximum value for BIR.

The transfer of nitrogen, T_s from the roots to the plants is modelled by an equation similar to equation (8.7):

$$T = PL * K_{10} \left[(RN - RNmin)/RN(RNmax - RNmin)\right] x$$
$$\left[(PNmax - PN)/(PNmax - PNmin)\right] \tag{8.9}$$

where PL is the amount of plant biomass per m^2 and PN is g/g of nitrogen in plants. PNmax and PNmin indicate the upper and lower limits of nitrogen in the plants. The limits are dependent on the time and might be given as tables or graphs as in Fig. 8.1. The nitrogen content in plants (PLN), expressed as nitrogen per m^2, is found as:

$$PLN = PL * PN \tag{8.10}$$

The transfer of dead organic matter from plants and roots to organic nitrogen takes place over a period from autumn to the beginning of spring the following year. This process is described as a temperature dependent first order reaction with an almost complete transfer during the indicated period of time.

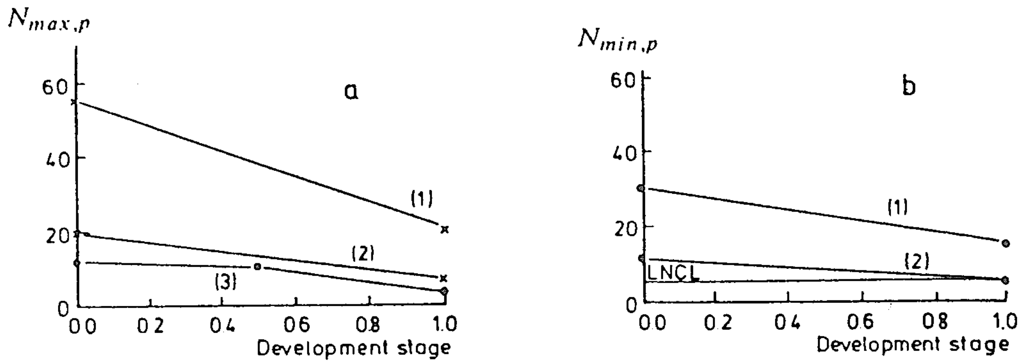

Fig. 8.1. The maximum N_{max}, P) and minimum (N_{min},P) nitrogen concentration for leaves (1), non-leaf material (2), and roots (3) of natural grassland vegetation as a function of phenological age (development stage, here defined as being 1.00 at maturity) (Jørgensen, 1986).

8.5 UPTAKE OF PESTICIDES AND HEAVY METALS BY PLANTS

Rohde 1972 states that three important factors influence the uptake of toxic matters by plants:

1) **The properties of soil** including the soil composition. Humus and clay have higher binding capacity than sand.
2) **pH.** Low pH will imply higher solubility in interstitial water of heavy metals and many pesticides.
3) **Redox potential** of the interstitial water. The influence is rather complex. Some heavy metals are bound very firmly as sulfides at low redox potential, while the adsorption capacity for heavy metals and pesticides are higher at high redox potential, (Lamm 1971).

Figure 8.2 illustrates the conceptual diagram of a model used for simulation of plant uptake of toxic matter. The key process is the equilibrium between bound and dissolved fractions. It should be determined experimentally or, if that is not possible, with reference to the available literature, see for instance Jørgensen (1975) and (1979).

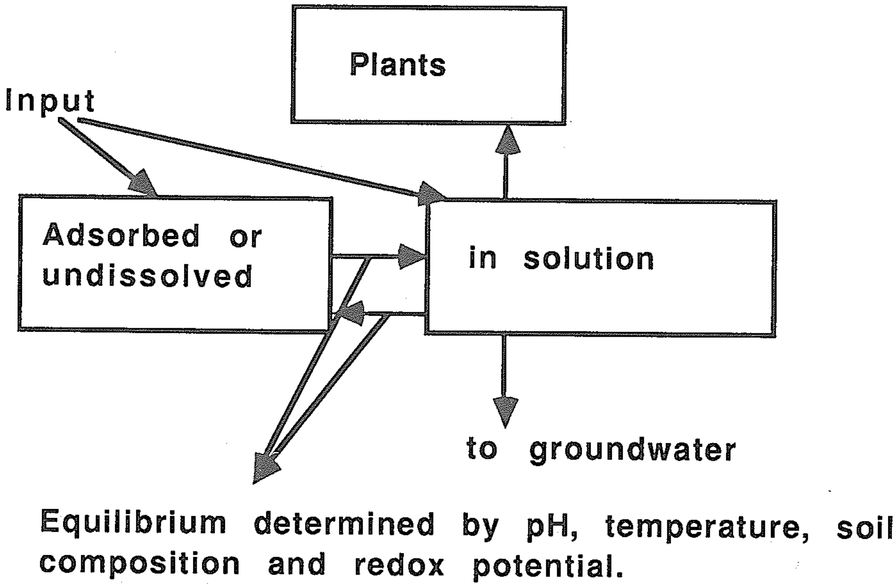

Fig. 8.2 Conceptual Diagram for a plant uptake model of toxis matters.

The influence of microbiological processes on the equilibirum is often diffcult to state. However, a fairly good approach may be obtained by used of a first order decompostion process for the release. The uptake by plants are also described by a first order reaction related to the soluble fraction. It is a rough but workable description, which in some cases has given an acceptable validation of the submodel, see for instance Jørgensen 1979.

8.6 MODELLING EROSION PROCESSES

Soil erosion caused by water consists of two phases: detachment of the soil particles and transport of particles. The erosion is either limited by the detachment or by the transport (Morgan 1986).

The erosion is either caused by raindrops (Morgan 1986) or by the shear stress on the soil surface from the runoff flow (Beasley et al 1980 and Kirkby 1980).

Numerous erosion models have been developed. A few, easy-to-use, models should be mentioned here: Usle (Morgan et al 1984), Creams (Leonard and Knisel, 1986), Answers (Beasley et al 1980) and Sem (Styczen and Høgh-Schmith 1988) . The Usle model is the most simple to use and requires only a limited data input. It is, therefore, recommended for situations where little data is available.

Details of the model can be found in the above mentioned reference and in to Wischmeier and Smith 1978. Only the core equation will be presented here to illustrate the important factors that determine the erosion:

$$A = R*K*L*S*C*P \tag{8.11}$$

where

A is the loss of soil by erosion per unit of area,
R is rainfall and run off factor, determined on basis of knowledge to the rain intensity,
K is the erodibility factor, which is characteristic for the soil,
L is the slope length,
S is the steepness of the slopes,
C is cover and management factor. It is different for trees, bushes, various crops and grass,
P is the support practice factor.

8.7 MODELS OF THE TRANSITION ZONE

The few but various approaches to modelling of the littoral and supralittoral zone reflect approaches taken from other aquatic and terrestrial systems. These models are still in their infancy, but their development has advanced significantly in recent years due to an increased interest in non-point pollution.

Interfaces play an important role in the dynamics of transitions zones, but they are generally more complex and less understood. Typical examples illustrating the complexity are sediment-water exchange of chemical species, interactions of water and soil, interstitial water and plants and free water solute and submerged vegetation, and the air-water interface including micrometeorological effects. The proximity of the water column to the sediments causes one medium to greatly affect the others and exchanges of chemicals are extremely complex. Processes such as absorption, ion exchange, mineralization, sedimentation, re-suspension, denitrification and leaching can all be important and are all related to the water-sediment interface.

The interface question is also significant for the dependence on outputs from neighboring ecosystems and interrelation with them. Often the boundaries of the shore are ill-defined or hydrologically complex. These phenomena point to the importance of shore modelling on a spatial scale.

The need for modelling of the transition zone is, however, urgent. The increasing influence of non-point pollution on the water quality of lakes calls for a more quantitative management of this important transition zone.

The questions to be posed to the model are obvious:

- How much of the non-point pollution will be eliminated in the transition zone?
- Can we manage the transition zone to improve this elimination? How?
- Should the transition zone be expanded to be able to cope sufficiently with the non-point pollution, for instance, by use of artificial wetlands? What would be the relation between the expansion of the adjacent wetland and the effect in this case?

A concrete example will illustrate this problem complex. Figure 8.3 illustrates what can be achieved concerning the nutrient budget by construction of a wetland to cope with the non-point pollution.

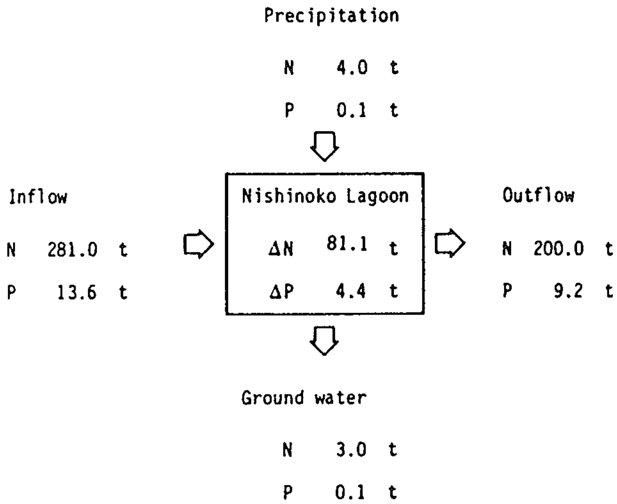

Fig. 8.3. Nitrogen and phosphorus budgets for Nishinoko Lagoon adjacent to Lake Biwa, Japan.

Table 8.2 (reproduced from Jørgensen and Jørgensen, 1989) illustrates what can be achieved by application of various restoration methods. The results in the Table were obtained through the use of a eutrophication model on Lake Glumsø, Denmark. The lake is shallow and has suffered from hyper-eutrophication. The waste-water was conveyed downstreams, but due to non-point pollution of nutrients from intensive agriculture, this was not sufficent to obtain the desired water quality. It was necessary, furthermore, to consider the application of various lake restoration methods, as shown in the Table. The possible results obtainable by various methods are compared here. A eutrophication model and a model of the reed swamp situated at the inflow point for the main tributary have been used to obtain these results. Simulation with different size of the reed swamp were carried out.

TABLE 8.2
Comparison of Lake Restoration Methods for Additional Restoration of Lake Glumsø, Denmark

Method	Model Changes	Results
Coverage of sediment.	No P and N release from "old" sediment.	Primary production decrease 30-40% on annual basis, but no change in maximum phytoplankton concentration.
Removal of sediment.	Exchangeable P and N set to zero at day zero.	
Precipitation of P in lake water.	Soluble P is removed to sediment at day zero.	Less than 10% reduction in primary production 1st year. No changes after 2nd year.
Use of wetland for nutrient removal from non-point sources.	Input of P and N from tributary reduced 50% and 90% respectively.	A continuous reduction of primary production to a level of 20% at year four and the following years.
Reduction of retention time.	Inflow of water, but not of P and N, is increased.	Less than 20% reduction in primary production.

The reed swamp model is presented in the next section to illustrate a model of the transition zone applied in practical lake management.

8.8 A CASE STUDY

It became clear from the development of a eutrophication model for the shallow Lake Glumsø in Denmark that non-point sources of nutrients are very significant, mainly due to intensive agriculture in the catchment area. That raises the question: Are we able to control these sources? There is a reedswamp at the inflow of the main tributary to Lake Glumsø. Would it be possible to control the non-point sources by use of a wetland? What is the potential of this wetland for removal of nutrients? Could the non-point sources be completely controlled? Would it be necessary to enlarge the wetland? How much?

An experimental unit was built in 1984 in the reedswamp, dominated by *Phragmites australis*, to try to answer these questions. It consisted of 12 flow-through basins 1 m * 10 m * 0.75. The basins were designed with no bottom to make as few changes of the flow pattern through the root zone as possible and they were operated with four different hydraulic loadings. The inflow and outflow of water were measured and the precipitation and evaporation were obtained from meteorological data. The exchange of water through the bottom was found by use of water balance calculations. Hydraulic conductivity was different in the basins, however, causing a different exchange of water through the bottom of each basin.

The experiments revealed a clear relationship between hydraulic load and the nitrate reduction in the surface water (Table 8.3). Lower hydraulic loads led to higher nitrate reduction, but higher hydraulic loads led to more nitrate being denitrified per unit of time and area. It is remarkable that, at the highest hydraulic load, the nitrate reduction was as high as 2,700 kg N/ha-yr. The phosphorus retention did not show any relationship with the hydraulic load. Concentrations of phosphorus in inflow and outflow water were approximately the same, although a minor retention was observed during the spring.

TABLE 8.3.
Relationship between nitrate reduction and hydraulic load in reedswamp experimental basins, Lake Glumsø, Denmark. One year is set at 270 days due to ice cover during winter. Data are average ± standard error.

Hydraulic Load, liter/m^2-day	Nitrate Reduction, percent	Nitrate Reduction, kg N/ha-yr
46±1[a]	65±4	521±17
57±4[b]	65±28	811±168
83±4[a]	65±2	976±6
92±16[b]	71±12	1,077±301
151±18[c]	52±19	1,310±451
312±31[c]	54±26	2,727±1,136

[a] tested in 1984 (n = 3)
[b] tested in 1985-86 (n = 6)
[c] tested in 1984-86 (n = 9)

The bottom water showed very low nitrate concentrations throughout the year, which implies that the denitrification is almost complete in the depth of 25 cm or more (Table 8.4). The retention of ammonium in the interstitial water varies from 0 to 50 percent, while the phosphorus concentration in the interstitial water was up to ten times higher than the surface water. However, analysis of the interstitial water in deeper, more calcium-rich, layers indicate that the phosphorus washout in the rootzone will be re-adsorbed there. The release of phorphorus can be explained by the mineralization of organic matter, including phosphorus compounds, by the denitrification process.

TABLE 8.4.
Nitrate concentrations in μg-N/l in inlet water and as a function of depth for twelve experimental reedswamp basins at Lake Glumsø, Denmark.

Depth, cm			Inlet Water	
25	50	75	Min	Max
22-36	9-16	6-11	4,000	12,000

The most important processes, namely nitrification, denitrification, mineralization and phosphorus adsorption, were examined in detail in the laboratory to obtain reasonable estimates of process equations and parametres in the model. Table 8.5 shows the results of the examination of the denitrification process. Based upon these investigations, it was possible to estimate, that a 0.5 ha wetland - a surprisingly small area - was sufficient to denitrify all the nitrate in the inflow to Lake Glumsø. This demonstrates the enormous denitrification potential that wetlands possess.

TABLE 8.5.
Denitrification rate as measured at 10°C in experimental reedswamp basin receiving 312 l/m^2-day (n= 12; 95% confidence limits shown).

Depth, cm	Denitrification, μg-N/g dry wt-day	Dry Weight, percent of wet wt.	Loss on Ignition, percent
0- 5	273±10	13.8±2.0	50.5±9.4
5-10	146±10	13.3±2.1	49.2±8.2
10-15	97±10	13.0±1.5	44.1±8.7
15-20	56±10	16.7±1.1	32.0±7.1

The model focuses on the possibilities of using wetlands as nutrient traps and to answer management questions such as:- How much nitrogen can be removed by denitrification? How much nitrogen and phosphorus is lost to groundwater and neighbouring surface waters? How much nitrogen and phosphorus can be removed by harvest of plants? What influence does the hydrology of the wetland have on the nutrient budget? It is, for example, possible to regulate the hydrology to achieve a more advantageous nutrient budget?

The model is presented in the conceptual diagrams shown in Figures 8.4 - 8.6. The boxes indicate the state variables and the lines indicate processes or pathways. There are 14 state variables (see Table 8.6) in the nitrogen diagram, 11 in the phosphorus diagram, and 5 in the hydrological submodel.

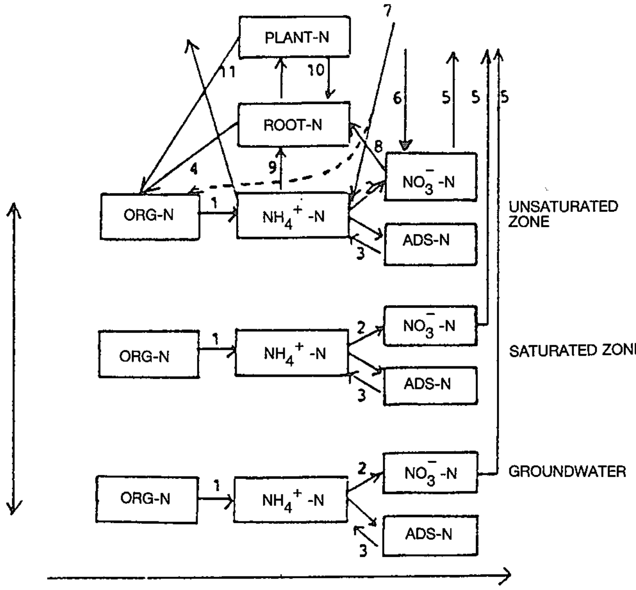

Fig. 8.4. Nitrogen submodel of Danish wet meadow. Horizontal arrows flow in one direction, vertical arrows flow upwards and downwards. Some flows are obtained from the hydrologic submodel. Process numbers are identified in text.

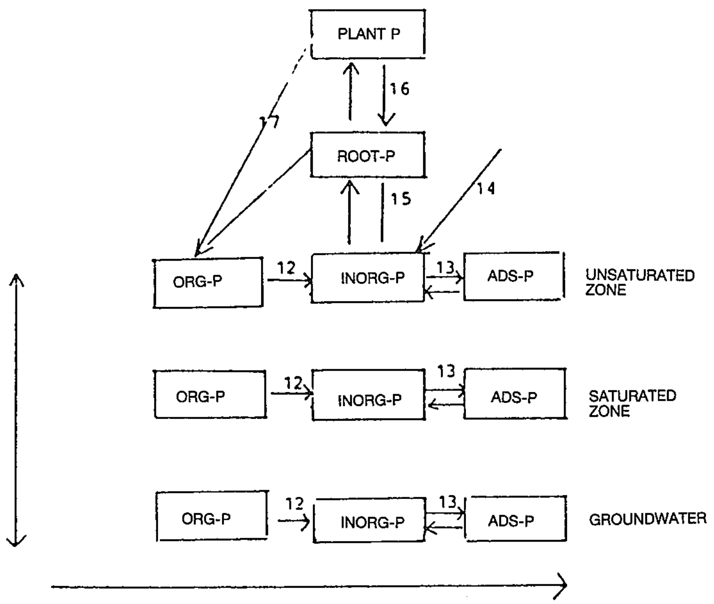

Fig. 8.5. Phosphorus submodel of Danish wet meadow. Flows are similar to those in the nitrogen submodel, Fig. 8.4.

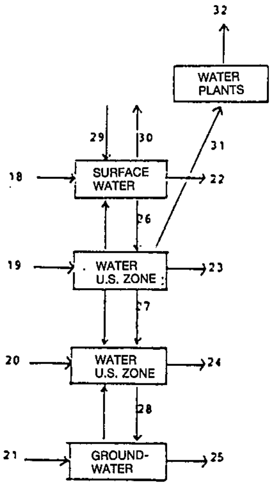

Fig. 8.6. Hydrologic submodel of Danish wet meadow. Flows 18 to 21 are horizontal inflows to parcel; 22 to 25 are outflows from parcel; 26-28 are exchanges of water between zones; 29 is precipitation; 30 is evaporation from surface; 31 is water uptake by plants; 32 is transpiration through plants.

TABLE 8.6.
State variables for wet meadow model

Name	Units	Total Number of Variables
Organic N	g N/m$_3$ soil	48
Soil moisture	ratio: water/capacity	48
NH_4-N	g N/m^3 soil	48
NO_3-N	g N/m^3	48
Root N	g N/m^2	12
RN	g N/kg	12
PLN	g N/m^2	12
PN	g N/kg	12
ADS-N	g N/m^3	48
Organic P	g P/M^3 soil	48
INP	g P/m^3 soil	48
ADS P	g P/m^3 soil	48
Root P	g P/m^2	12
PLD	g P/m^2	12
K_H	m/day	48
π	(potential) m^{-1}	48
Q	m^3	48

Forcing functions (see Table 8.7)

The forcing functions of the model are:

* precipitation (process 29 in the hydrologic submodel),
* nitrogen in rainwater (multiplied by 29 gives 6 in the nitrogen submodel),
* phosphorus in rainwater (multiplied by 29 gives 14 in the phosphorus submodel),
* inflows of water (18 to 21 in the hydrological submodel),
* evapotranspitation (30 to 31 in the hydrological submodel),
* temperature in each zone (measured but also bound from a relation between the soil temperature and air temperature),
* air temperature,
* soil pH,
* plant biomass.

This last forcing function, plant biomass, is measured as function of time, but for other wetlands it might be found by use of an empirical model, which gives the biomass as function of time for a selected number of various climatic conditions.

TABLE 8.7.
Forcing function for wet meadow model

Name	Unit	Source
PREC	m/day	KVL meteorological station.
N_p	g N/m^3	Literature/measurements.
P_p	g P/m^3	" "
Inflow Water	m^3/day	Measurements.
Evapotranspiration	m/day	KVL meteorological station.
Aerobic/Anaerobic	---	Measurement and/or f(Ω)
Temperature	°C	Measurements of function of air temperature
Solar radiation	energy/m^2	KVL meteorological station.
pH of soil	---	Measurements.
Root biomass BIR	kg/m^2	"
Plant biomass PL	kg/m^2	"

The model results are summarized below:

1. The denitrification rate is independent of the nitrate concentration, provided it is at least several mg/l.

2. If the concentration or organic matter is high (peat), the denitrification potential under anaerobic conditions (which is found a few cm under the surface) is about 14 g NO_3-N/m^3-day at 20°C. If the concentration of easily biodegradable organic matter becomes limiting,

the above-mentioned potential is proportional to the concentration of organic matter.

3. The hydraulic load should be adjusted to this denitrification potential to optimize the use of the denitrification potential.

4. The soil has a certain adsorption capacity in relation to phosphorus compounds. This capacity is, however, limiting and the harvest of plants seems to be the only long-term method for phosphorus removal in the wetlands.

5. It is possible, through the proper management of wetlands, to remove a considerable amount of nutrients, particularly nitrate nitrogen.

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CHAPTER 9

MANAGEMENT TOOLS

S.E. Jørgensen

9.1 MANAGEMENT OBJECTIVES

The transition zone is managed for environmental protection, for recreation, for aethetics and even for the production of renewable resources.

The specific goals of the management of the shore may be listed as follows:

1. Maintain the water quality of the transition zone as well as that of the lake.
2. Reduction of erosion.
3. Protection from flood.
4. Provide a buffer zone between human settlement and the lake.
5. Maintain a gene pool of plants and animals.
6. Control insect populations.
7. Provide habitats for fish spawning and bird nesting.
8. Produce renewable ressources. Phragmites are, for instance, used in many European countries as roof material.
19 Provide aestethic support for human beings.

Various management tools to achieve these goals are mentioned in the following sections of this chapter.

10.2 ZONING

The importance of the transition zone has been emphasized throughout this volume. The littoral and supralittoral zones play important roles as filters, buffer zones, nesting areas, etc. It is, therefore, necessary to maintain a transition zone of a proper size.

The transition zone is under threat from the impacts of human activities: human settlements, road construction, and industrial activities. This has been acknowledged in many countries and a protection belt of 10, 25 or even 50 meters has been introduced and required by the environmental legislation. There are, unfortunately, numerous examples of the irreversible consequences caused by omission of such a protection belt. The maintenance of a suitable protection zone will meet all the specific goals mentioned above without exception, which emphasize how important this tool is in management.

The possibilities of enlarging the transition zone have been illustrated in Chapter 8 by use of a model. In this case a wetland adjacent to a lake was enlarged to enable it to cope with the non-point pollution of nutrients. Model simulations showed that this management tool was one potential way to solve the problem.

9.3 CARRYING CAPACITY

The problem of adjusting the human impact on a lake ecosystem to the actual carrying capacity of the area has been illustrated by a very convincing case study presented by Gilliland (1983). The case study - Lake Tahoe - uses a model based on the impact by tourism in the area.

The same considerations are in principles valid for the transition zone. It is a buffer zone and has a limited buffer capacity. If the load exceeds the buffer capacity, then the transition zone will be overloaded and the water quality of the lake and the biota of the transition zone will be affected.

The buffer capacity is understood as the relative changes of a forcing function related to the (expected or observed) changes in a state variable. There are many different buffer capacities corresponding to each combination of forcing functions and state variables.

Buffer capacities of relevance to lake management and the transition zone are, for example:

1) How much more nutrients are the transition zone able to absorb? If the nutrient loading is increased by 10%, for example, how much will the nutrient input to the limnetic zone increase?

2) If the input to the transition zone of toxic substances - pesticides and heavy metals - are increased, how much more toxic substance will reach the limnetic zone? Have we, in other words, exhausted the ability of the transition zone to adsorb these compounds?

The balance between the carrying capacity and the impact on the system may be achieved either by increasing the carrying capacity of the transition zone or by reducing the impact.

Increased carrying capacity can be obtained through enlargement of the transition zone or by conservation of a high density of biota in the zone.

Reduction of the future impact (the forcing functions are decreased) is possible by use of improved waste water treatment, reduction of activities in the area (for instance, regulation of tourism), diversion of impacts from the lake to other systems (for instance, construction of alternative roads further away from the lake) or by use of proper planning for future activities.

The need for balance between carrying capacity and impacts illustrate the close relation between the environmental conditions of a lake and the planning in the entire lake region.

9.4 HARVEST OF MACROPHYTES

The compostion of macrophytes will reflect the composition of the transition zone. Macrophytes are able to take up not only nutrients but also pesticides and heavy metals as discussed in Chapter 8 (sections 8.4 and 8.5). The macrophytes are, of course, removed from the lake ecosystem when they are harvested. This may be a nutrient and toxic substance reduction of major significance for the lake ecosystem and should indeed be considered as supplement to other management possibilities.

The macrophytes are harvested in many chinese lakes (see Figure 9.1) to provide pig feed and mass balance considerations show that the nutrient removal by this process may be important for the entire nutrient budget of the lake. Depending on the magnitude of the external nutrient load, potential removal of phosphorus through weed harvesting has been estimated to 1.3 % (Peterson et al 1974), 20% (Wile 1975), 37% (Carpenter and Adams 1977) and 60% (Welch et al 1979).

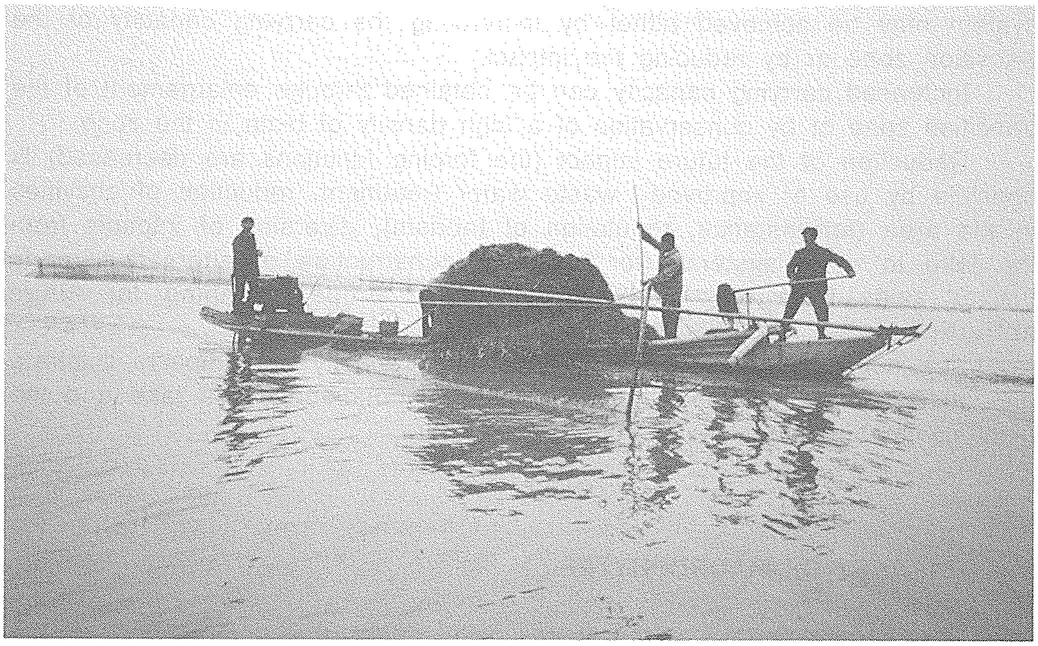

Fig. 9.1. Harvest of Macrophytes in Dianshan Lake, China.

The time of harvest is often important. Phragmites have the peak concentration of nutrients in Western Europe in late summer (August/September) and harvest at that time will often double or triple the nutrient removal compared with harvest 1-2 months later. Figure 9.2 shows the nutrients concentrations in *phragmites communalis* in a Danish reed swamp as function of the time and as can be seen in the figure the maximum concentration is obtained in early September.

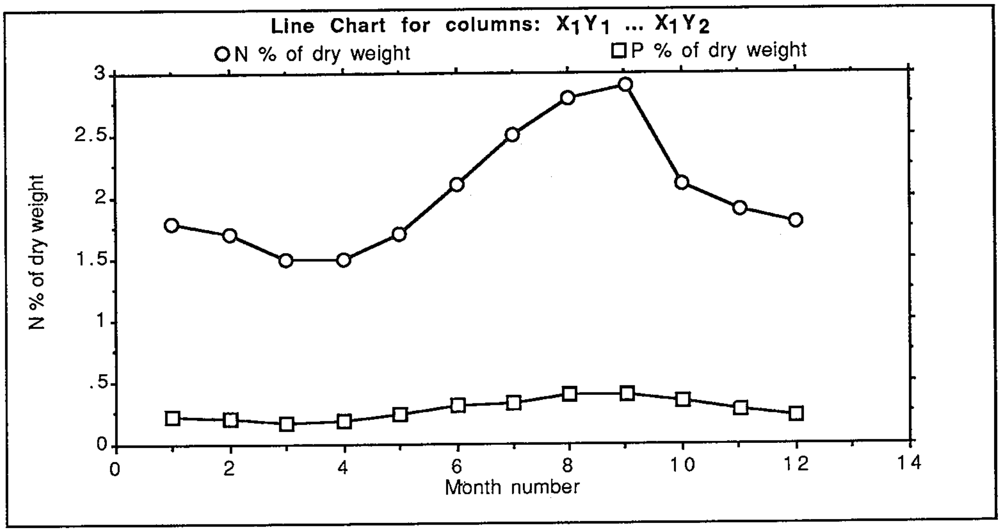

Fig. 9.2. N and P content in Phragmites communalis by month.

There appears to be a theoretical problem with the application of weed harvesting in order to lower the phosphorus concentration in a lake and hence the algal concentration. If rooted macrophytes obtain most of their nutrients from sediment, then what weed harvesting would actually be doing is reduction of an internal source rather than removing a portion of the annual inflow of phosphorus. If the internal supply of phosphorus is relatively large a reduction of lake phosphorus could results from harvesting and interrupting the transport of phosphorus from sediment to water via rooted plants. There may be other problems, however, because increased excretion of phosphorus and thereby of algal blooms have been observed following harvesting of weeds in some cases (Nicholis 1974). In addition, the harvestable biomass may be depleted with each succesive year of harvest. If external loading of phosphorus is relativley large, the phosphorus content of the lake cannot in general be reduced, even though large masses of weeds can be removed (Peterson et al 1974).

It can be concluded that each individual case should be examined carefully before this management tool is applied in practice. The examination should always include either use of quantification assessment (mass balances, see Chapter 5 "Assessment of Mass Balance" by R.A. Vollenweider, in Guideline Book Number 1, Principles of Lake Management) or models, see Chapter 8.

9.5 PROTECTION AND CONSERVATION

Measures to protect and conserve the littoral and supralittoral zone are important management tools. It is mainly a question of regulating the activities at the lake shore. The means are : regulations of hunting, tourisme and traffic, forest management and reforestration. Again it is a matter of either maintaining the carrying capacity of the transition zone to be able to absorb the impact or to reduce the impacts at their sources.
The clearing of forests or other reductions of vegetation at the shore are likely to increase water and nutrient yield to the aquatic ecosystems. Table 9.1. illustrates the effect on deforesration on hydrology and biogeochemistry.

TABLE 9.1.
Annual Net Export before and after deforestation (Likens et al., 1978)

Average values of	1963-66 before	1966-69 after	1970-73 after
Forest vegetation g/m^2 DW	800	0	250
Export kg/na of Part. matters	20	205	110
Nitrate	0	410	140
Potassium	2	30	8
Calcium	22	81	28

Road building is likely to have a major effect particularly if care is not taken to reduce erosion. Urbanization has, however, the greatest effect on water quantity and quality. The construction of buildings, pavements and impervious surfaces reduces the filtration of water and increases the overland flow. It implies an increased input of suspended matter to the transition zone.

9.6 AGRICULTURAL PRACTICE

Agriculture is the major source of non-point pollution reaching lake ecosystems. The transition zone may be able to absorb this pollution, but only to a limited extent, as already mentioned. It should therefore be considered a major management tool to change the agriculture practice to attempt to reduce the non-point pollution from this source.

Possible changes in agriculture practice of importance for a reduction of the non-point pollution are listed below:

1) **No agricultural activities** (including domestic animal hold) **in the supralittoral zone.** A protection zone should also be maintained in this context. Animal grazing can produce a similar effect as other agricultural activities, see Branson 1975.

2) **Reduced and controlled use of fertilizers,** particularly on fields adjacent to a lake ecosystem.

3) **Controlled use of domestic animal waste** as a natural fertilizer. It implies that the waste is not used on frozen or bare soil or that the waste is used for other purposes (production of biogas or compost).

4) **No, or at least controlled, agricultural activities on fields sloping to the water's edge.**

9.7 REGULATION OF HYDROLOGY

The proper utilization of the transition zone requires a fairly good distribution of the streams entering the lake. If an artificial expansion of the littoral zone is made, construction of a distribution system is considered essential to obtain efficiency.

Reduction in velocity as streams enter the littoral zone is another feasible regulation of hydrology. It will cause sediments and chemicals absorbed into sediments to drop into the littoral zone.

If the lake level is lowered and shallow sediments are allowed to dry, compaction and consolidation will occur. If aeration is sufficient, oxidation of organic matter should occur and the concentration of organic matter will decrease. Phosphorus release may actually increase following lake refilling due to the mineralization processes during the dry period. The longterm release may, however, be less a result of compaction and organic matter and more a result of oxidizing conditions resulting in a higher adsorption capacity of sediment for phosphorus. Jacoby et al (1982) claims a 50% consolidation of phosphorus from experiments with highly organic matter sediments from Long Lake, Washington.

These processes may be of great importance for the internal phosphorus of a lake, as illustrated by the development of a eutrophication model for a lake with level fluctuations, see Jørgensen (1986). As reservoirs often have significant changes in the water level, it is recommended to consider the importance of these processes in development of models and management strategies for reservoirs.

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CHAPTER 10

PLANNING

Milan Straskraba

10.1 INTRODUCTION

The aim of this chapter is to provide guidance in the preparation of management plans, what they should contain and respect. For a more general context, see Anon. (1983} and Jørgensen and Villenwelder (1989).

In the preceeding chapters different aspects of lake shore management were treated individually. For planning purposes it is not only necessary to treat the lake-shore problem as a whole but moreover, the lake-shore problem should be considered from the perspective of the whole lake watershed. Therefore, we will begin with a discussion of some of the major problems connected with the lake basin and then consider the combination of the individual aspects. Problems of how to divide the lake shore between the different uses and/or in which way to use the same shore areas for multiple purposes will be considered. The appropriate method for quantitative evaluation of such problems is the cost/benefit-analysis. This will be discussed in the final part of this chapter.

When planning, it is necessary to adopt a holistic system approach. The basic notion is to consider different system elements and their mutual interrelations, and the relation of the system to its surroundings. One major character of natural systems (as opposed to technical ones) is the importance of feedback between system components (Fig. 10.1). A major feedback exists, for instance, between land - lake-shore - water.

The activities on both nearby and more remote land areas determine both the features of lake shores (their vegetation, slopes etc.) and of water (the quantity and quality). Processes on lake shore determine what is going on in the lake. Feedback effects from the lake are represented by micro- to mesoclimatic changes determining vegetation characteristics on land. Feedback from the lake to shores are due to shore erosion, lake eutrophication leading to excessive plant growth, etc. (Fig. 10.2.)

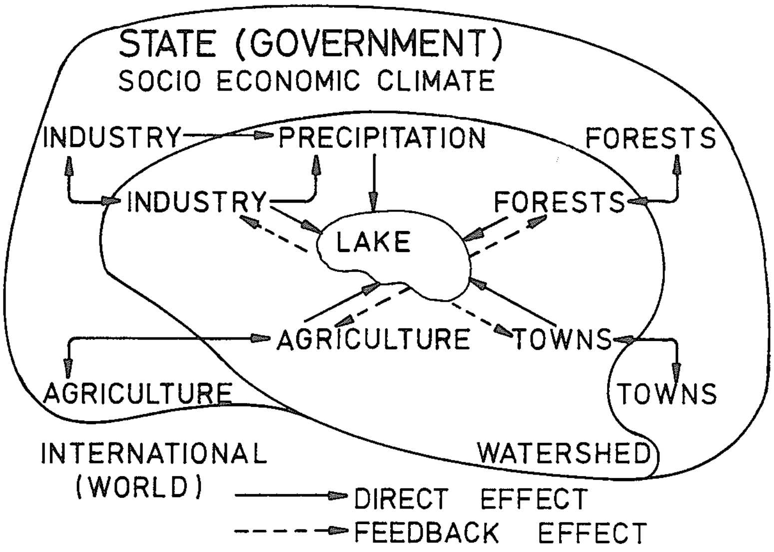

Fig. 10.1. Feedback relations between system components are characteristic for environmental systems.

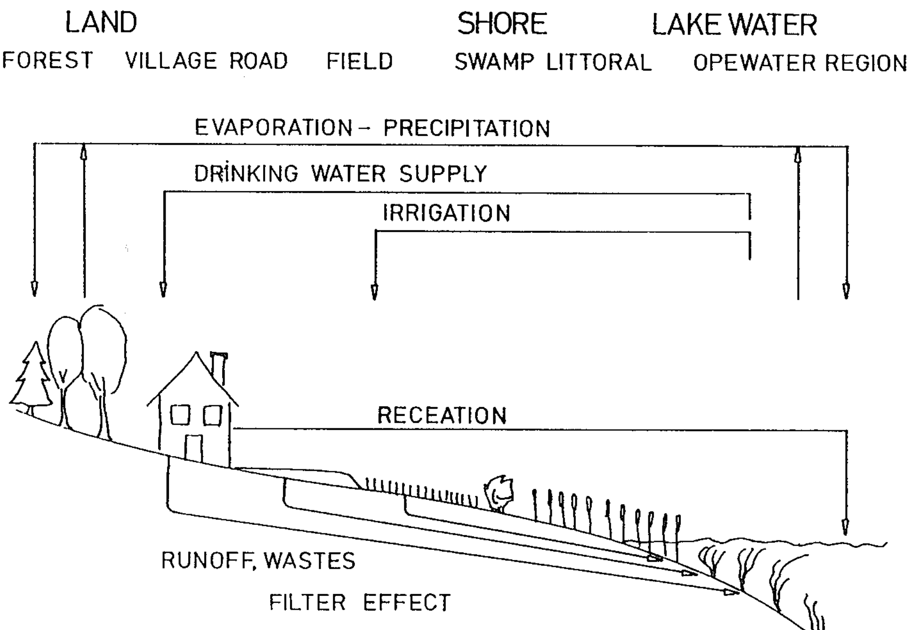

Fig. 10.2. The system's concept of land - lake shore - lake water interrelations.

Therefore, the system's concept dictates that the lake shore system with its natural and human related features is evaluated for management purposes. It cannot be treated as an isolated system because it bears close relations to its surroundings, represented by land areas on one side and the open lake on the other. Also, consideration of the feedback effects between components is important for management.

From the long-term perspective, focus for planning the environment-human development interface is on the sustainable development of the total environment, ensuring human survival. When planning generates natural resources degradation, future uses will be impoverished. Therefore, it is always necessary to consider carefully and from a broader perspective why and where investments and activities should be located as this may change the whole concept.

The planning process may be considered to consist of the following steps:

1) Specification of the objectives.

2) Inventory, forecase and analysis of basin, water and shore conditions.

3) Formulation of alternative plans.

4) Evaluation of the effects of the alternatives.

5) Comparison of alternative plans.

6) Selection of a recommended plan based on item 3).

10.2 WHOLE LAKE BASIN PROBLEMS

Water has the character of a transport medium, moving substances originating from one place to another, sometimes quite remote, place. From this point of view the watershed of the lake represents an area where different land uses and human activities affect water coming into the lake. This is the reason why it is impossible to separate the planning of activities on the lake itself from those going on elsewhere in the lake basin.

Physical and political boundaries within watersheds

Fig. 10.3 shows different political/physical extreme situations in relation to selected watersheds. On one hand, the watershed of a small lake often belongs to one local political unit, the diversification of activities within the watershed is not great, and these facts make planning much easier. If the lake in question is large, then the lake basin may stretch across many political units of higher order, up to states or provinces.

Industrial, agricultural and other human activities are usually rather diversified. This makes decision-making much more difficult - but not impossible. An example of successful international planning regarding such a situation is the Great Lakes Agreement (Vallentyne & Thomas, 1987). Following some disagreement between specialists, phosphorus was recognized as the source of the Great Lakes deterioration. Agreement was reached concerning permissible phosphorous loads for individual enterprizes including farmers (Loehr et al., 1980). An extensive campaign alower (??) the watershed resulted in the desirable drop in phosphorous concentrations and consequently in water quality improvement.

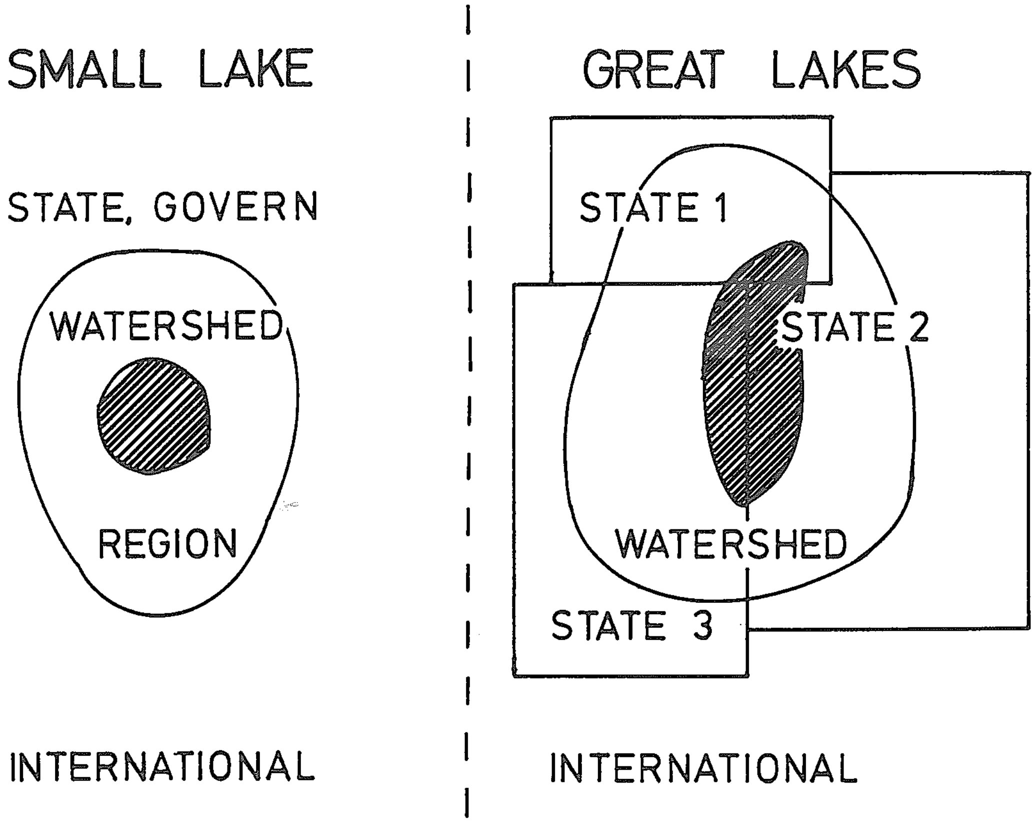

Fig. 10.3. Political and physical boundaries within different watersheds. A - a small lake basin situated in a forest area. The boundaries of the lowest, local political unit exceed those of the watershed. B - a medium size lake, with the watershed belonging to several local political units, physically divided into an urban-industrial area, a settlement and an agricultural area. C - a great lake.

Lake volume/watershed ratio

The ratio of the size of the watershed in respect to the size of the lake has another important aspect - a hydrological one. This ratio is reflected in the retention time of water in the lake, with consequences for water quality. Theoretical retention time is the ratio of the annual discharge of water from the watershed to the lake, to lake volume. In different geographical situations the specific discharge (per unit time per area) varies rather much. In dry regions it is not only much lower, but often also much more irregularly distributed over the year. In extreme situations, like in Australia, sometimes even between years. In wet regions, the same area will produce much higher discharge to the lake. The ratio affects limnological events in the lake, particularly in man-made lakes and riverine lakes at the lower end of the scale (i.e. with high discharge/low volume conditions). Here a transition from near-river situations to typical lake situations, in respect of lake water stratification, can be observed. Pollutants are spread over the whole water volume in nonstratified water bodies. Whereas in a fully stratified lake, major vertical and horizontal differences exist. Also, natural self-purification processes, including retention of nutrients and other pollutants depend on this ratio. Not only is the load of a particular substance to the lake much higher in the case of high discharges, but also its uptake, mineralization and accumulation in biota is usually much lower. Full development of lake plankton, as well as sedimentation of dead organisms is only possible when certain critical values of this ratio are exceeded.

Activities within the watershed

From a water quality point of view two basic types of sources of pollution can be distinguished: point sources and non-point (diffuse) sources.

Point sources are relatively easy to spot. Also, technical possibilities for their decrease or eradiction are well known and the problem is becoming a financial one rather than a technical one. Basic types of point sources are connected with different industries and settlements.

Non-point (diffuse) sources stem from both a number of small point sources (e.g. non-canalized population or farmer units) or they are of areal? character (e.g. ground and surface water pollution from chemicals applied to the fields). It is much more difficult to treat non-point sources (Krenkel & Novotny, 1980; Novotny & Chester, 1981). This is not only because measures have to be extended over large areas, but also because technical means are much less developed. One problem, which is spreading over vast areas in developed countries, is nitrogen entering waters in large quantities (particularly from agricultural activitie) and resulting in human health problems. In addition, certain types of pollutants may come to the watershed from outside. This is the case when acid rain causes acidification of water because of the gaseous emissions from the industry which by air are spread over extensive land areas up to entire continents.

The following major activities within the watershed have an impact on water quality:

a) *Industry.* Its effect on water quality are very diversified, depending on the type of industry products fabricated and chemicals used.

b) *Agriculture*. Soils have only a limited capacity to take up nutrients, which are used to increase crop production. The nutrients which are not taken up by the soil/plant system leach into the surface and groundwater and are the sources of water quality problems related to eutrophication. In many European countries the application of mineral nitrogen fertilizers in agricultural areas exceeded the value of 100 $kg/ha^{-1}.yr^{-1}$ (1981-82) and, in addition, the amount of organic nitrogen from animal wastes also increased due to higher livestock densities. Nitrogen emissions from intensive agriculture also share the responsibility for acid rain and forest die-back. Excess nitrate concentrations in water create health problems, particularly the deadly infant disease methemoglobinemia. Basic measures is the reduction of excess fertilization and modification of fertilizer type and time sequence of dosage in order to make the nutrients fully utilized by the plants. Other health problems are associated with the use of pesticides and other chemicals for crop protection. Transistion to sustainable agriculture is one long-term solution.

c) *Settlements* can basically be classified as urban and agricultural. The dominant type of pollutant is organic matter from domestic wastes. Non-canalized population produces less water pollution per person than the canalized ones, unless proper waste-treatment plants are installed.

d) *Forestry*. For many geographical locations, forests are the most natural type of vegetation, with optimum effects on the water quality. Therefore, preservation of large forest areas is the optimum state. Deforestation is always connected with water quality deterioration. However, some recent practices of intensive sylviculture in developed countries (fertilization, insecticide spraying etc.) also lead to negative water quality effects. Forests dying due to acid rain and air pollution has a negative effect on both water quality and quantity.

e) Traffic. Salt and other chemicals used are transported to water.

f) Road building and other construction works leading to vegetation and soil surface destruction causing an increased erosion and transport of the eroded material to the water.

The principal method of evaluating the importance of different activities for water pollution of the given watershed is by creating budgets of the critical pollutants. To obtain a budget for a substance in the watershed, two principal ways are possible:

a) Direct measurement or estimates based on simple empirical methematical models (Chapter 8).

b) Indirect estimate using simple models based on unit factors for different activities.

TABLE 10.1
An example of the budget of nutrient (phosphorus) load to a waterbody (kg. ha^{-1})

Activity	Amount	Units	Unit load	Total
Agriculture				
Fields	20.000	ha	1.5	30.000
Pastures	5.000	ha	0.5	2.500
Cattle	7.500	ind.	10	75.000
Atmosphere	40.000	ha	0.2	8.000
Inhabitants				
Canalized	1.500	inh.	0.8	1.200
Non-canalized, distant	800	-	0.01	8
Non-canalized, close to water	200	-	0.1	20
Town	1.200	ha	1.1	1.320
Industry				
Enterprise 1	-	-	-	780
Enterprise 2	-	-	-	6.000
enterprise 3	-	-	-	2.300
Total	-	-	-	127.128

An example of such budget is given in Table 10.1. Here both approaches were used - a) for industry and b) for the rest. It is also indicated which unit factors were used. Such models can be found e.g. in Jørgensen (1981), for 13 nutrients in Straskraba & Gnauck (1985) and Ryding & Rast (1990).

Whereas the first way is much more costly, the second is more uncertain. There are great geographical differences in the pollution per unit activity coming to the water. But these are not well reflected in the existing, mostly local, models. The uncertainty is much higher outside temperate regions from where most models originate

10.3 COMBINATION OF ASPECTS - COMBINED PROBLEMS.

Different aspects of lake shore management were discussed in Chapter 2 - 9. Here the concern is how to determine which remedious actions have to be planned and some kind of optimization of future developments which can be achieved.

One major issue, usually neglected in the evaluations, is the secondary effects. Take, for instance, an example of recreation. An estimate will be made of the number of lake shore visitors, their activities and distribution over the lake shore. Based on per capita/activity estimates, the primary effect will be evaluated with the methods discussed in previous chapters. However, secondary effects will be connected with constructions associated with recreation. Building of houses, hotels, kiosks and other facilities, construction of roads sometimes changes the hydrological conditions of the shore. Erosion associated with constructions increases the load of water. In some instances, these secondary effects can be more significant than the primary ones.

When planning lake shore development, two basic options can be adopted:

a) to divide the shore areas according to different activities;

b) to use the same areas simultaneously for several activities.

Option 1 is rather important primarily from a nature conservation point of view. As shown in chapter 5, certain areas of lake shores have to remain as intact as possible to preserve natural habitat and species diversity. The reasons are twofold: to preserve the world's genetic pool for a balanced development of the world and future human generations, and: to preserve for future possible human use the plant and animal species representing potential food, raw materials, natural control of pests, etc.

The first item is particularly urgent in the case of the great, ancient, lakes of the world, where the world's genetic pool heritage is, in part, located.

It should be understood that small nature preservation areas cannot function effectively. This is because animals have some minimum population numbers for survival, also certain minimum feeding areas (home ranges) are necessary. In general, such ranges increase in size proportionally to the animal size. Interrelations between plants and animals are very tight and the area has to be treated as a whole. Eradication of one major component produces complete restructuring of the biological associations. Therefore, it is necessary first of all to take care of the largest organisms in the given area. Moreover, an envelope of transitional areas between the conserved area and cultivated land should be created. Also, each habitat depends on its surroundings and certain general conditions of its existence. A marsh or swamp area cannot survive in a culturally desertified region.

Reed belts have a particularly advantageous function in respect to water quality (see Chapter 4). They serve both as protection agents against destruction (abrasion, erision) of the shore and as buffers taking up substances brought to the lake from land. Their preservation should be one of the major goals of lake development planning.

For some other activities, particularly for their intensive versions, the concentration of localized points is preferable to spreading over a broader, less intensive area. This is the case of settlements on smaller lakes - it is preferable to have one shore free for recreation and one more heavily populated, rather than having both sparsely occupied. From a water quality point of view this is also the question of point-sources versus diffuse sources, the latter being much more difficult to handle.

Option 2 - Simultaneous, multiple uses. It is, to a certain degree, possible to use one and the same area simultaneously for several human activities, without much mutual interference. Examples are reed bed development with fishing, and forestry with extensive recreation.

Particular care during planning of lake-shore activities should be taken when the lake is used as the present of potential drinking water supply. The direct and indirect impact of recreation on lake water quality is manifold and in such cases the recreational use should be rather restricted.

10.4 COST/BENEFIT ANALYSIS

This method of evaluation is commonly used for management and planning purposes. The analysis is based on the calculation of possible costs of different alternative activities and the benefits obtained (Cole & McKown, 1986). The measure used is the benefit-cost ratio;

BCR = (present value of all benefits/present value of all costs).

It provides the planner with a much more objective methodology for the comparison of alternatives. It only provides a comparative analysis in respect to the alternatives taken into consideration and says little about the existence of possible other, much more preferable, management options which may exist.

As an example, we consider the planning of a recreation centre for a small city on a lake shore.

Preliminary evaluations have shown two feasible solutions:

1) To clean-up a local lake which is now heavily polluted and eutrofied and build a swimming centre of the lake.

2) To build a highway to a more remote great lake and construct more diffuse recreation facilities on the lake.

For both alternatives the following costs and benefits are quantified (Table 10.2):

TABLE 10.2.
Costs and benefits to be evaluated in the given example of cost/benefit analysis.

Costs	Benefits
Treatment of the lake water	Improvement of water quality
Construction of the highway	Improvement of transport
Bathing facilities	Increase of land value
Boating facilities	Increase of income from fees
Sanitation facilities	Decreased transport to other regions
Land lost for other uses	Improvement of environmental quality
Decrease of environmental quality	

Considerable drawbacks of the cost/benefit analysis exist. First of all, it is difficult to translate all benefits and costs into a unified currency framework. Monetary units are not an appropriate measure of many benefits, particularly those associated with long-term environmental issues, estethic values and degree of satisfaction. It is also not easy to estimate the secondary costs of any activity. This is the reason for the recent use of energetic equivalents, of energy used for particular activities (Watt, 1983).

Therefore, the cost/benefit analysis can be considered only a partial solution to the problem and its results have to be evaluated with caution, particularly for purposes of environmental management. In general, environmental problems are of a global character, for which proper evaluation methods are only just being developed.

Pearce (1988) developed a methodology to estimate the true cost of a resource such as water. It is based on confrontation of supply, demands and process. In addition to current price and quantity of the resourse used, which are the items considered in the cost/benefit-analysis, the external and user costs (previous and future uses) are considered. Existing market forces do not respond to such questions loke aspects of a resource for which markets are not developed or use of resources which do not reduce the amount or quality for other users. External and user costs have to be estimated by interdisciplinary teams of experts. This evaluation will make it possible to sustain the waste assimilating and environmental amenity values of ecosystems which is normally undervaluated or completely ignored.

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CHAPTER 11

THE KIS-BALATON RESERVOIR SYSTEM AS A MEANS OF CONTROLLING EUTROPHICATION OF LAKE BALATON, HUNGARY

F. Szilágyi, L. Somlyódy, S. Herodek & V. Istvánovics

11.1 INTRODUCTION - EUTROPHICATION OF LAKE BALATON

Lake Balaton, the largest shallow lake in Central-Europe, is the most important recreational region of Hungary, providing more than one third of the total income from foreign tourism, and playing also a major role in the domestic recreation industry.

The length of Lake Balaton is 77.8 km with an average width of 7.7 km. The surface area is 596 km^2. The watershed of the lake is 5,775 km^2 (not including the lake surface). The lake is elongated with an average depth of 3.14 m. Hydrologically, it can be divided into four basins (Baranyi, 1974; Somlyódy & van Straten, 1986, see Fig. 11.1).

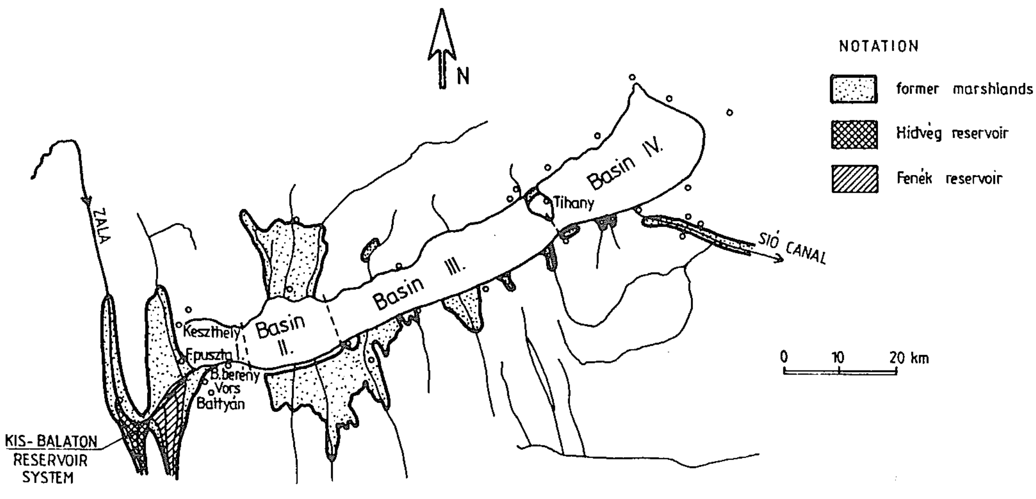

Fig. 11.1. Lake Balaton and its watershed.

Significant socio-economic development has been observed during the last two decades on the watershed. This development resulted in increasing external loads and consequently in algal blooms in the lake (Somlyódy & Tóth, 1987).

Eutrophication was particularly intensive in the most western basin (Keszthely Bay) representing only 4.3% of the total lake volume. While about one-third of the total external nutrient load is discharged into this basin frôm the River Zala. Consequently, the volume related loads are in order of magnitude higher here than in the less polluted eastern basin (Somlyódy & van Straten, 1983).

The multiannual mean values (1975-81) of the most important P load components (total P and biologically available P) are summarized in Table 11.1 for the entire lake and for its basin (Somlyódy & Jolánkai, 1986).

TABLE 11.1
Multiannual average external P loads for total P (TP) and biologically available P (BAP) of Lake Balaton (in tons/yr)
(Somlyódy and Jolánkai, 1986. See Fig. 11.1)

Load components		Basin 1	Basin 2	Basin 3	Basin 4	Total Lake
Tributaries	TP	84	56	22	4	166
	BAP	47	35	9	1	92
Direct sewage* TP = BAP		1	2	3	28	34
Other sewage TP = BAP		-	-	9	-	9
Urban runoff	TP	4	13	14	27	58
	BAP	1	4	4	8	17
Direct rural runoff	TP	4	8	12	5	29
	BAP	1	3	4	1	8
Atmospheric pollution	TP	1	4	6	7	18
	BAP	-	2	3	3	8
Total external load	TP	94	83	66	71	314
	BAP	50	46	32	41	169

* Without the load of sewage diversion.

Both total P and biologically available P loads are used in this discussion for the following reasons: 60-70% of the total P load reaching the lake is in particulate form. The majority of the latter is deposited in the sediment of the lake and is not directly utilized by algae. Thus, the short-term behaviour of the lake is primarily determined by the biologically available P. As shown in Table 11.1, half of the total P load entering Lake Balaton is in biologically available form. The tributary load decreases from west to east, while the direct sewage load has the opposite characteristic. Half of the total P load of the whole lake comes from tributaries. Urban runoff and direct sewage diversion also seem to be important components in total P loading (Somlyódy & Jolánkai, 1986).

Due to the external nutrient loads, Lake Balaton became more and more eutrophicated in the past two decades. According to OECD classification (Vollenweider & Kerekes, 1981), three basins of the lake fall into the eutrophic category and the basin IV into the mesotrophic category (see Fig. 11.2). The highest observed chlorophyl-a concentration has reached 250 mg.m^3 in the Keszthely basin, indicating hypereutrophic conditions. The highest annual primary production reached the 830 g c/m^2 (Herodek, 1986).

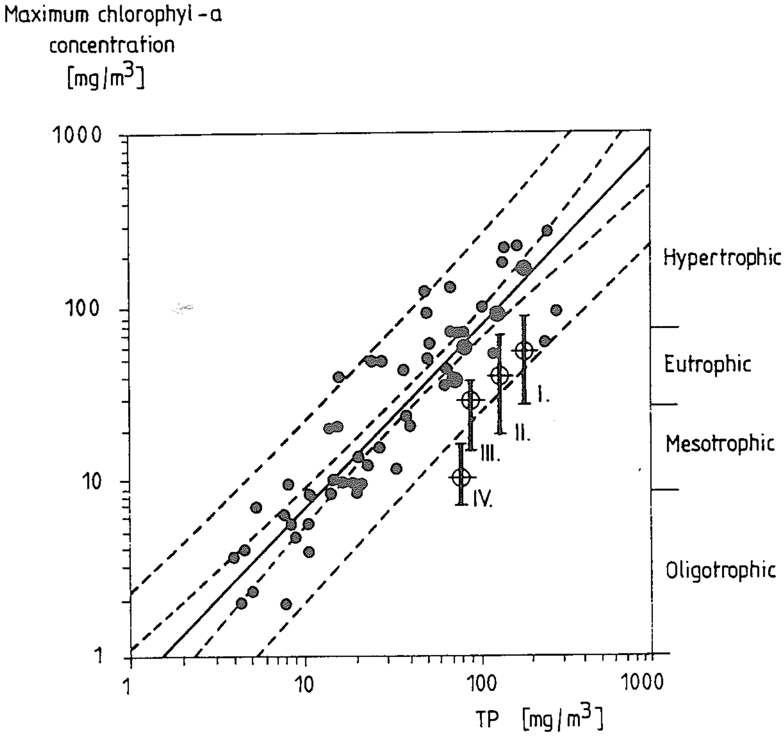

Fig. 11.2. Trophic conditions in Lake Balaton as compared to other OECD lakes (Somlyódy & van Straten, 1986). I, II, III, IV Basins of Keszthely, Szigliget, Szemes and Siófok, respectively.

O Average basin values for 1975-1979

I Range between minimum and maximum value

o Highest values in 1980

· Values of the OECD lakes (Vollenweider and Kerekes, 1981).

In order to control eutrophication of Lake Balaton, a project was initiated in 1982 to determine water quality, target levels, required control alternatives and associated costs. The main goal of these measures was to reduce the external nutrient loading of the lake (Láng, 1986). The proposal was approved by the Council of Ministers in 1983 and involved measures such as upgrading and extending of existing wastewater treatment plants, introduction of chemical phosphorus removal, construction of a regional sewage diversion system, establishment of a reservoir system of Kis-(Small-) Balaton in the vicinity of the mouth section of River Zala. The first element of the system of about 70 km^2 total surface area (Hidvég reservoir, 20 km^2) was put into operation in 1985, while the construction of the second stage (Fenék reservoir, 50 km^2) is expected by the mid '90s (Jón et al., 1987).

11.2 THE KIS-BALATON RESERVOIR SYSTEM

The Kis-Balaton reservoir system was partly constructed on a former marshland which dried out one century ago. At present, the water level and the flooded area is regulated.

The objective of the Kis-Balaton reservoir system is to reduce the nutrient loads of the River Zala by sedimentation, adsorption and biological uptake by bacteria, algae and aquatic macrophytes. The major parametres of the reservoir system are shown in Table 11.2, and the scheme of the Hidvég reservoir is shown in Fig. 11.3.

TABLE 11.2.
Characteristics of the Kis-Balaton reservoir system

	Reservoirs	
	Hidvég	Fenék
Water level (metres above Baltic Sea level	106.5	105.8
Surface area (mk^2)	18.0	51.0
Average depth (m)	1.14	1.2
Volume (10^6 m^3)	20.0	64.0
Retention time (year)	0.12	0.24
Inflow (m^3 s^{-1})	6.0	8.0
Total P load (g m-2 a-1)	5.28	appr. 0.98

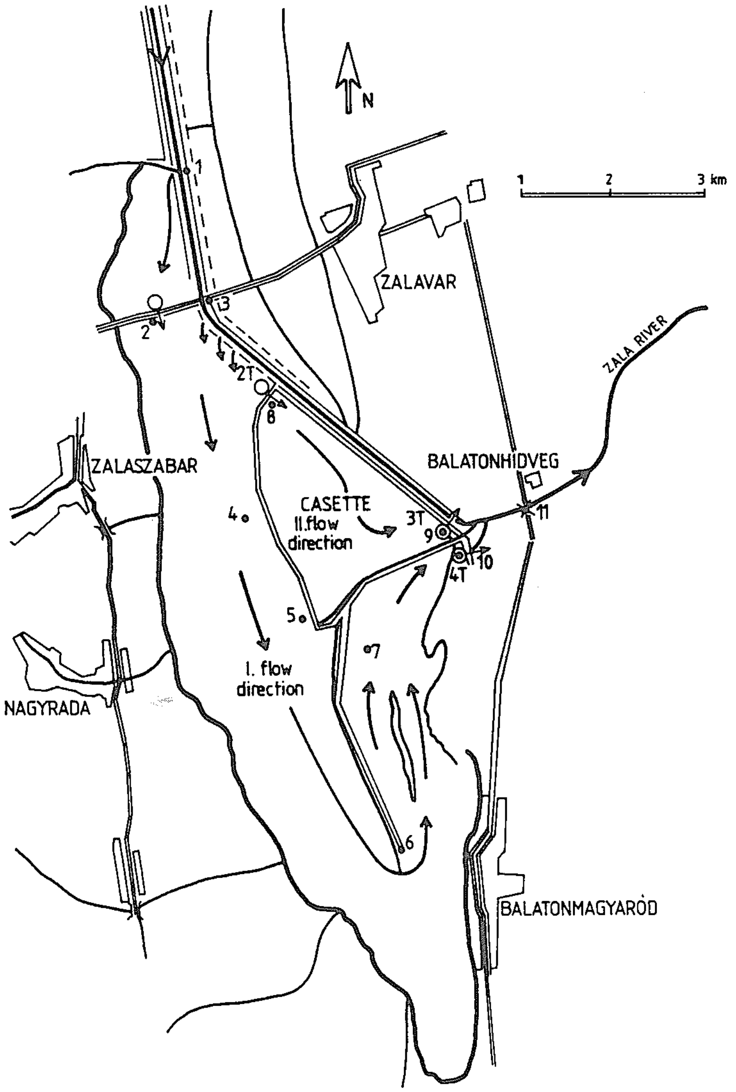

Fig. 11.3. Plan of the Hidvég reservoir of the Kis-Balaton Control System
o-> Gate
· Regular sampling sites
--> Flow direction of the water in the reservoir
=== Dyke
— Creek

The reservoirs of the Kis-Balaton system are extremely shallow (Table 11.2). The water residence time in the Hidvég reservoir (about 48 days) is long enough for the processes of nutrient removal. The total phosphorus load of this reservoir is rather high (approximately 15 $mg.m^{-2}d^{-1}$) exceeding about 5-6 times the forecasted load of the downstream planned reservoir. The flow and water level in the Hidvég reservoir is regulated by dykes and three gates (Fig. 11.3: Structures 2T, 3T and 4T). At the upper part of the reservoir, River Zala was closed by a dam. The river flow enters the reservoir through several cuts made in the flood level. The flow within the reservoir has two different routes (1) through the main reservoir, around the major diversion dyke (flow direction 1, see Fig. 11.3), and/or (2) through the internal (or sub)reservoir (called casette) via two regulating gates. The purpose of the casette is to retain and treat accidental pollution loads of River Zala which may occur occasionally.

11.3 RESEARCH AND MONITORING OF THE HIDVEG RESERVOIR

During the three years of operation on the Hidvég reservoir a multi-disciplinary research programme was carried out with the participation of more than ten institutes. Research was performed under the leadership of the Research Centre for Water Resources Development, VITUKI, and the reservoir is operated by the Western Transdanubian District Water Authority.

The objective of the study was to determine the efficiency of nutrient removal, to highlight processes and ecological changes affecting P and N removal rates and to prepare the optimal operation strategy for the reservoir.

The research included hydrological (monitoring network, water budget and flow forecasting), hydraulic (calibration of the gates, determination of flow patterns and retention time), and water quality studies. In addition to water budget and hydraulic studies, the main emphasis of the programme was to describe the water quality and identify the processes influencing it. The research included nutrient load measurements, water and sediment analysis, and studies of the structural and functional changes in the ecosystem (bacterioplankton, phytoplankton, zooplankton and vertebrates). The major components of phosphorus and nitrogen cycle (denitrification, nitrogen fixation, phosphorus uptake by phytoplankton, phosphorus adsorption on sediment particles, etc.) have been measured. A data base has been established on an IBM PC for handling about 200,000 - 250,000 data. Modelling of the nutrient budget has been initiated for relatively simple models.

Water quality of the reservoir was monitored at 11 stations (Fig. 11.3, locations 1 to 11). The sampling frequency and the number of parametres studied were different at each station. Daily nutrient load measurements were carried out at point 1 and 11 (in- and outflow). Major chemical components (suspended solids, chlorophyl-a, chemical oxygen demand/COD_{Mn}/, total-P, soluble reactive P, total-N, nitrate-N, nitrite-N, ammonia-N, pH, conductivity, dissolved oxygen) were measured twice a week at stations 1, 5, 8, 9, 10 and 11. Hydrobiological studies, referred to in Section 3, were carried out at each station monthly (winter) or bi-weekly (summer).

During 1986, 1987 and 1988 daily observations were also carried out at the inflow section at Zalaapáti in order to estimate nutrient loads. At Balatonhidvég streamflow was measured daily during 1986, while water quality samples were taken only twice a week. Since May 1987, daily sampling of the outflow at Balatonhidvég has been performed. The removal rate of the reservoir can be calculated through the analysis of the data at the inflow and outflow sections (Zalaapáti and Balatonhidvég, respectively). In the analysis rate of flow, suspended solids, total-P, soluble reactive-P, total-N, and nitrate-N were included by methods developed by Felföldy (1980).

The removal efficiency (M) of the reservoir was calculated as $M = (L_{in}-L_{out})/L_{in}$, where L_{in} and L_{out} are the input and outlet loads, respectively, and it was averaged for a period sufficiently long in comparison to the retention time.

11.4 RESULTS AND DISCUSSIONS

Water household

The most important components of the water balance of the Hidvég reservoir are surface inflow and outflow. The total catchment area of River Zala, including the reservoir, is about half (2,622 km^2) of that of Lake Balaton. The drainage basin area corresponding to the inflow section of the reservoir is 1,528 km^2, while the direct catchment of it is 246 km^2. Considering the average inflow rate of River Zala (i.e. 5.6 m^3/sec), the hydraulic load on the reservoir is 9.6 m/year. Taking into account also the direct catchment of the reservoir, the total hydraulic load can be estimated as 11.5 m/yr. Since nearly constant water level is maintained in the reservoir, outflow approximately equals the inflow. Subsurface inflow is negligable as indicated by the data of a series of groundwater observation wells around the reservoir (Szilágyi et al., 1988).

Precipitation on the reservoir surface is about 0.7 m/yr. This is less than 7% of the hydraulic load. Evaporation from the surface area amounts to 0.9-1.0 m/yr, less than 10% of the outflow rate.

Residence time

As it can be seen in Table 11.1, about 40 days is needed to fill up the reservoir at the average flow of the Zala River. The actual retension time was estimated on the basis of daily nitrate-N measurements at the in- and outflow stations, during a two-months' period in the winter, when the nitrate can approximately be considered as a conservative component. Gross-correlation analysis of data from the inflow and outflow sections were performed with different lag times. The correlation coefficients for flow and nitrate-N were plotted as a function of the lag time (Fig. 11.4).

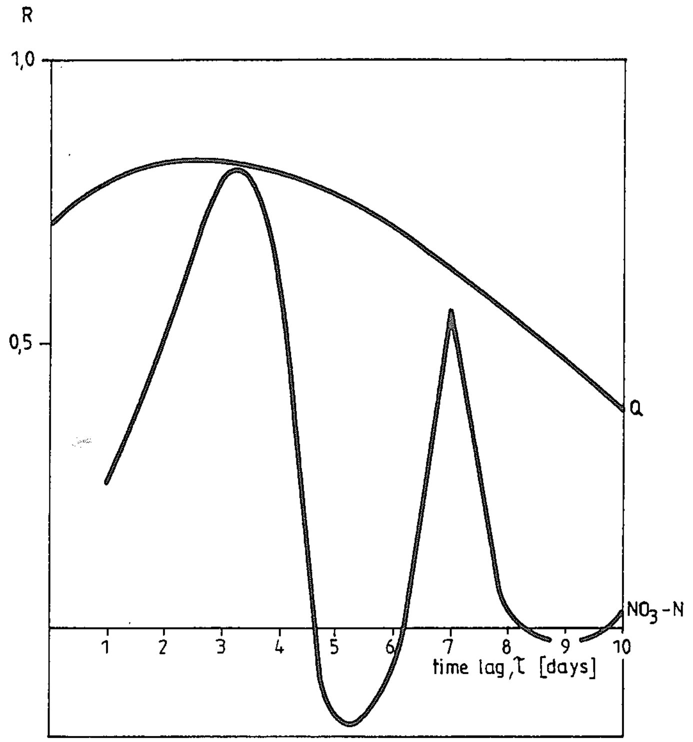

Fig. 11.4. Cross-correlations between parameters of inflow and outflow section of the Hidvég reservoir.

R = Coefficient of correlation
Q = Discharge rate of the water
NO_3-N = Nitrate-nitrogen

The water discharge plot does not show a peak, suggesting that the reservoir strongly attenuates the flow fluctuations of the Zala River. The two peaks of the nitrate-N curve at 3 and 7 days, respectively, coincide with the expected retention time of the casette and the main reservoir under the rather high flow conditions. Observations show that the retention time may vary between 2 and 50 days. The influence of this fluctuation on the water quality and the efficiency of removal is a subject for future study.

Development of a model system to aid the control of operation of the reservoir is underway. A component of this system is a one-dimensional hydrodynamic model using Saint-Venant equations (Szilágyi et al., 1988). This model is used to describe flow conditions in the reservoir and the short-circuited flow through the "casette". The model is also utilized to determine the residence time by assuming that the nominal residence time can be approximated by the time of travel calculated on the basis of the Saint-Venant equations. Descriptive use of the model with discharge data of the past 3 years yielded results indicating that residence time of the whole reservoir varies between 5 days and 60 days in the flow domain of 1 m^3/s - 105 m^3/s.

Hydrobiological characteristics of the reservoir

The water quality of River Zala is characterized by the oxygen levels below saturation values, pH is 7.3-8.3 and conductivity is 500-800 $\mu S\ cm^{-1}$. Among the nitrogen compounds nitrate-N is dominating (2-4 g m^{-3}), the concentration of ammonia-N varies between 0.3 g m^{-3} and 2.0 g m^{-3}, nitrite-N concentration is below 0.3 g m^{-3}. The concentration of total nitrogen may reach 6.0 g m^{-3}. Total Phosphorus varies from 0.1 g m^{-3} to 2.0 g m^{-3}, a significant part being soluble reactive-P (0.05-0.5 g m^{-3}). The chlorophyl-a concentration is below 20 g m^{-3}, the suspended solid concentration varies within a wide range (Major and Szilágyi, 1986; Szilágyi and Somlyódy, 1986).

The reservoir has not yet formed its own bottom sediment. A high humic content up to 350 mg g^{-1} characterizes the bed material. The $CaCo_3$ fraction is usually lower than 100 mg g^{-1} d.w. Total phosphorus concentration in the bottom material amounts to 2 mg g^{-1}, while nitrogen is below 25 mg g^{-1}. The bulk of both nutrients is unavailable for aquatic plants (more than 80-90%, Szilágyi et al., 1987).

The chemical data measured at 11 stations can be used to characterize the changes in water quality along the two main flow directions. The first direction is represented by stations 1, 2, 4, 5, 7, 10 and 11, and the second one by stations 1, 3, 8, 9 and 11 (See Fig. 11.3). The variations of the mean annual values of some major quality components are shown in Fig. 11.5/a - 11.5/b - 11.5/c.

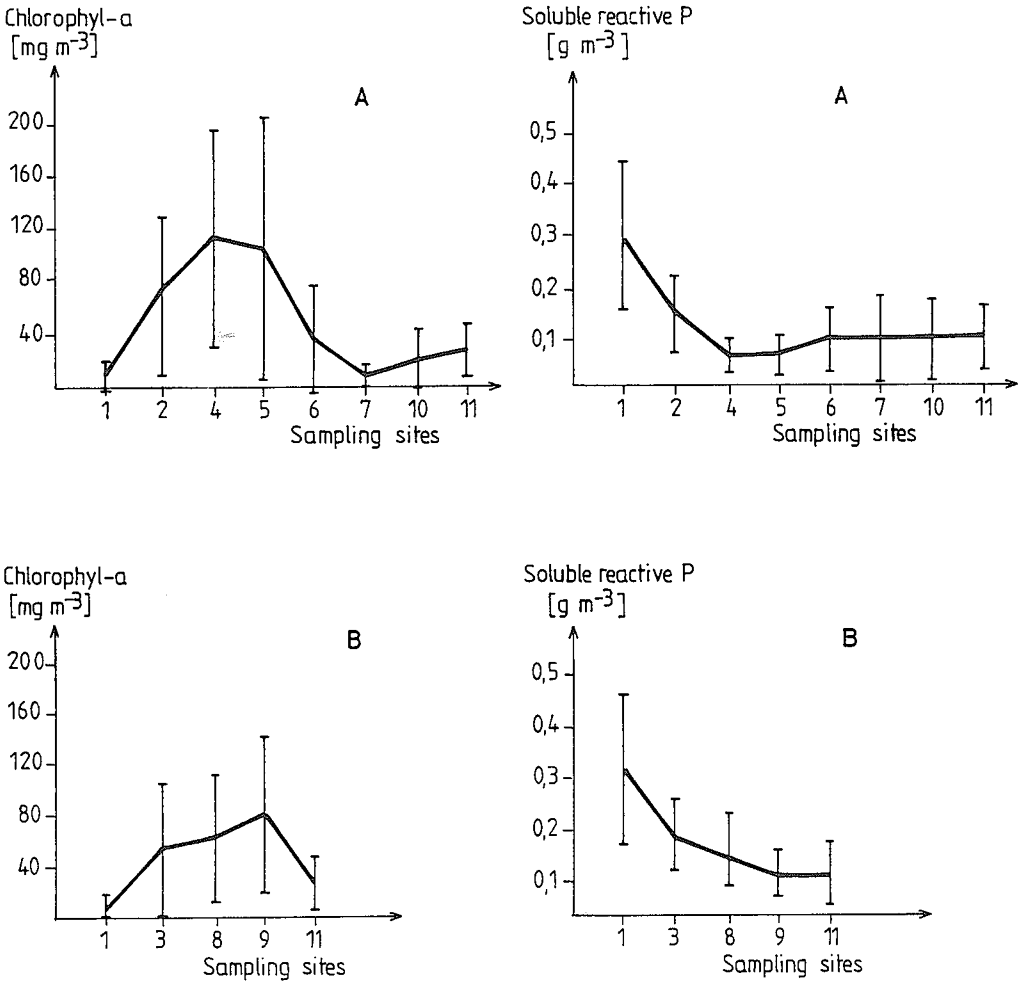

Fig. 11.5.a Mean annual values (——) and standard deviations (—) along the two flow directions of the reservoir (data from regular sampling sites, 1986, see also Fig. 11.3).

A = I. flow direction
B = II. flow direction

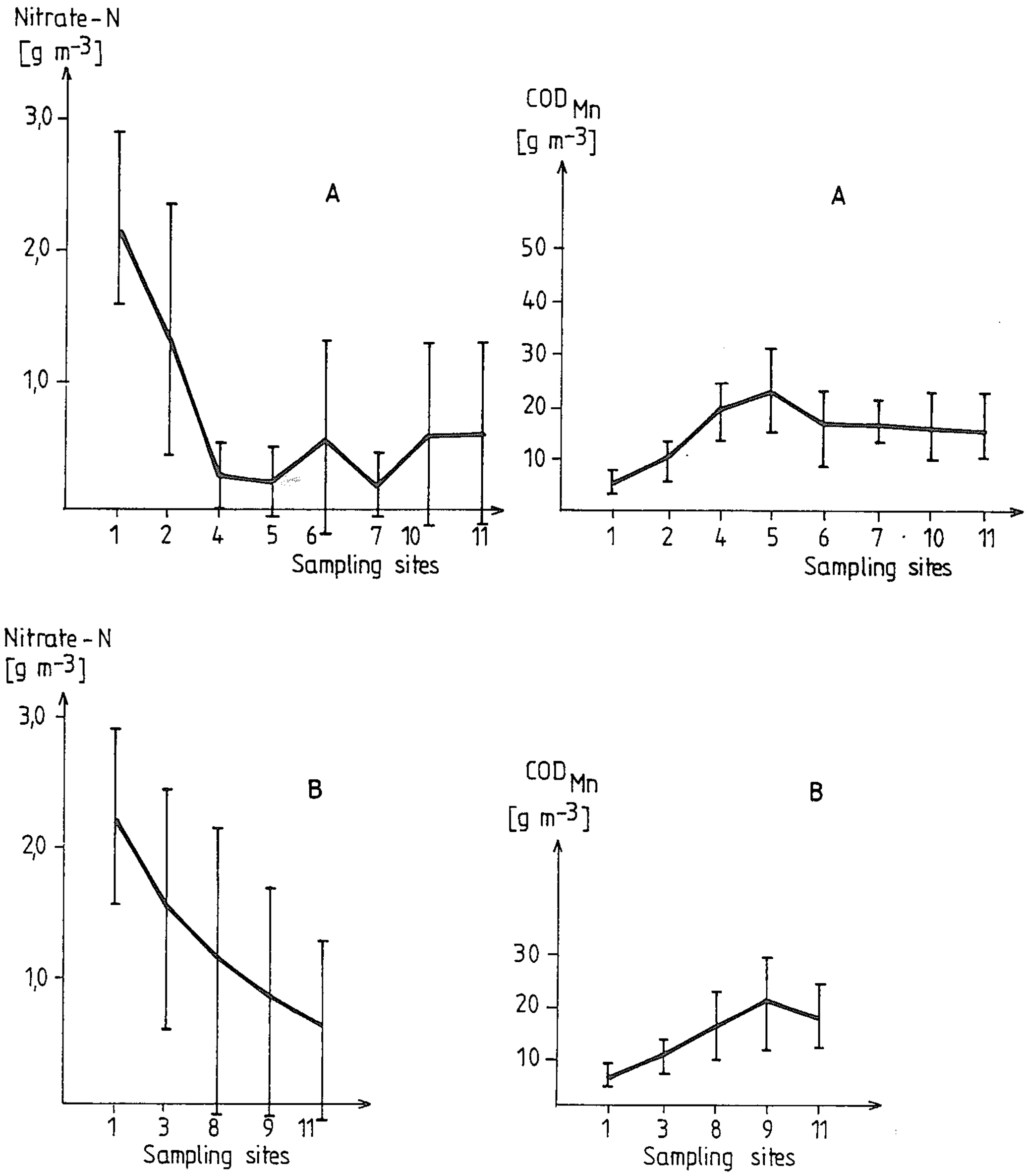

Fig. 11.5.b Mean annual values (——) and standard deviations (—) along the two flow directions of the reservoir (data from regular sampling sites, 1986, see also Fig. 11.3).

A = I. flow direction

B = II. flow direction

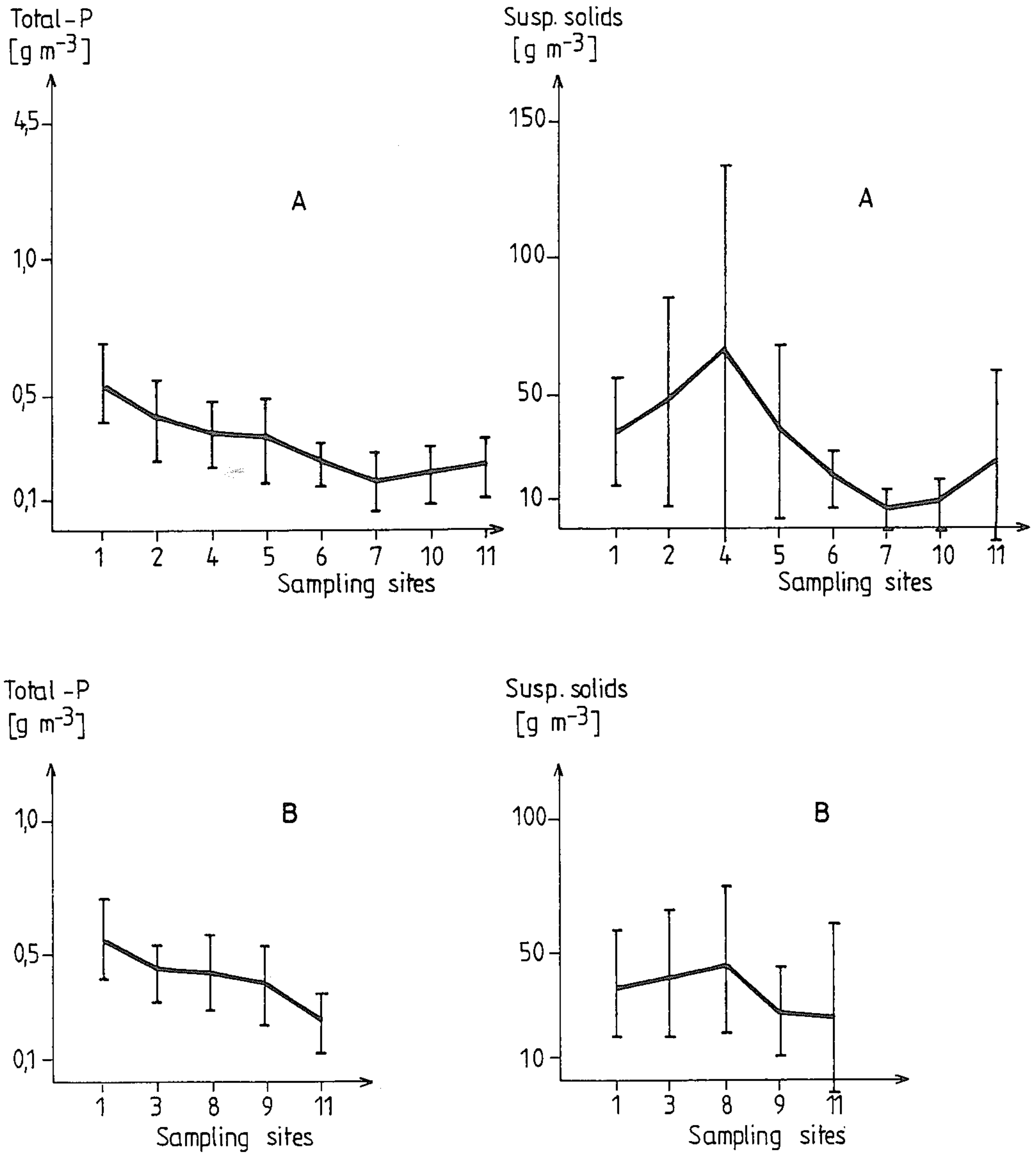

Fig. 11.5.c Mean annual values (——) and standard deviations (—) along the two flow directions of the reservoir (data from regular sampling sites, 1986, see also Fig. 11.3).
A = I. flow direction
B = II. flow direction

The vertical bar represents the standard deviation around the mean value. The spatial and temporal variation of the yearly average chlorophyl-a concentration (as the most important trophic indicator) along the main flow direction is plotted on Fig. 11.6.

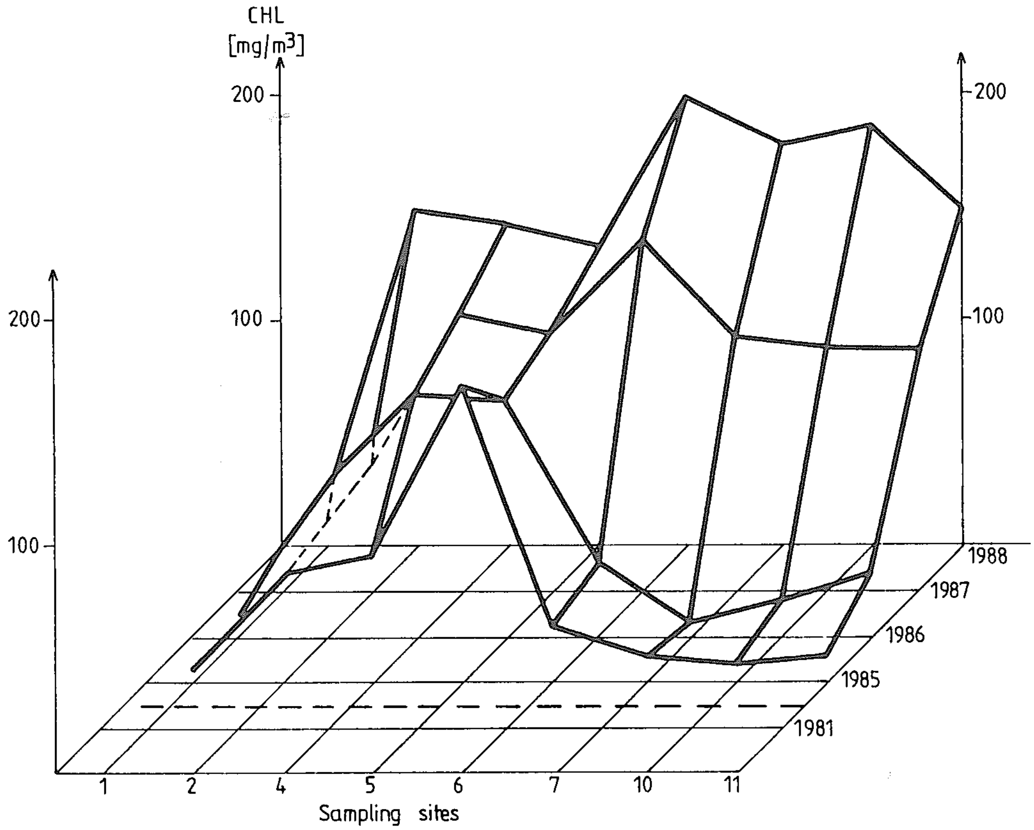

Fig. 11.6. Mean annual values of chlorophyl-a along the main flow direction of Hidvég reservoir (1985-88).

Nutrient load conditions vary significantly in the reservoir due to the variations of flow pattern and nutrient release from the soil. Water quality varies spatially as well, due to the different retention times. In the upper part of the reservoir, the water is always relatively rich in nutrients due to the direct effect of the inflowing River Zala.

In 1986 (which was the first full year of operation) the middle part of the reservoir area was characterized by low nutrient concentrations and intensive summer blooms of blue-green algae (*Anabaena flos-aqua*, *Microcystis aeruginosa*, *Microcystis flos-aquae*), with maximum chlorophyl-a concentrations reaching 400 mg m^{-3} (Fig. 11.5/a). In the lower part of the reservoir macrophytes' coverage was almost 100%. In respect of the total reservoir area the coverage was about 50% with a specific biomass production of 3.3 kg m^{-2}. The largest populations were represented by *Ceratophyllum submersum* and *Polygonum amphibium* (Pomogyi, 1987).

In the next two years algal bloom was also observed in the southern and eastern parts of the reservoir, and average and maximum chlorophyl-a concentrations increased at most of the sampling points. On the other hand, macrophyte coverage decreased by about 40% during the period of 1936-1988 in comparison to 1988. As indicated by Fig. 11.6 the chlorophyl-a concentrations measured in the inflow is an order of magnitude less than at the outflow section.

The spatial variation of chlorophyl-a indicates that nutrients were taken up mostly by algae and this resulted in frequent algal bloom and hypertrophic conditions.

Along both flow directions significant reduction (60-70%) of soluble reactive-P and nitrate-N concentrations could be observed (Fig. 11.5/a and 11.5/b). This decrease, however, was not linear and the rate of reduction being higher in the upper part of the reservoir. The reduction of soluble reactive-P can partly be attributed to the adsorption on solid particles, but for most of the year phosphorus uptake by phytoplankton was also significant. Denitrification was the dominating process in reducing nitrate concentrations with an average denitrification rate of 41.1 mg $m^{-2}d^{-1}$. The rate of nitrogen fixation was 30.1 mg $m^{-2}d^{-1}$ only (Szilágyi et al., 1987).

The soil of the reservoir bottom is rich in humic materials resulting in a high humic content of the water due to leaching and decomposition processes. This is reflected by the COD_{Mn} values observed and the brownish colour of water (Fig. 11.5/b). The COD_{Mn} value of water increases about four times during storage. It is also characterized by seasonal changes with high summer and low winter concentrations.

Total phosphorus and suspended solid contents have also decreased - similar to other nutrient forms - along both flow directions (Fig. 11.5/c). The rate of reduction was higher for suspended solid than for total phosphorus. This is explained by the fact that P is bound to smaller fractions relatively rich in P and particle size distribution of suspended solid changes during the storage (Szilágyi et al., 1987).

There were no significant differences in PO_4-P, TP, suspended solid, NO_3-N and COD patterns along the two flow directions of the reservoir, in the three years studied.

Figs. 11.5/a - 11.5/c indicate a marked scattering around the annual mean value. This is due to the high temporal variation of the water quality characteristics.

In addition to the decreasing concentration of nutrients, other favourable changes also occured in the quality of Zala water during storage in the reservoir. The bacterial counts decreased significantly (Szilágyi and Somlyódy, 1986, Szilágyi et al., 1987). The protozoa species characteristic of less contaminated water became pre-dominant, the number of macroscopic invertebrate species increased and the composition of the fish stock became more diverse (Csányi, 1986, 1987).

Phosphorus budget of the Hidvég reservoir

Processes playing a role in the phosphorus cycle of lakes and reservoirs are of biological, physio-chemical and chemical character (Gelencsér et al., 1982).

Many of these processes have not been investigated in details in the Hidvég reservoir, thus a full evaluation of the phosphorus household is not yet possible. However, some processes can be described to some extent on the basis of the available data (for example for uptake by phytoplankton, phosphorus adsorption, P storage in macrophytes).

Phosphorus uptake by phytoplankton

The rate of phosphorus uptake by phytoplankton were measured at sampling stations 1, 2, 5, 9, 10 and 11 (See Fig. 11.3) by the isotopic techniques (Herodek, 1987). The PO_4-P concentration of the water samples varied 5-359 mg/m^3, while that of chlorophyl-a between 5 and 1,500 mg/m^3. High concentrations of phosphorus were measured at the inflow of the Zala water. The highest chlorophyl-a was measured in the middle of the reservoir (station 4, 5 and 9).

Phosphorus uptake rates and the turnover times of orthophosphate are summarized in Table 11.3.

TABLE 11.3
Characteristics of the phosphorus adsorption isotherm of the soil in various areas of the reservoir (1987)

	Sampling points (see Fig. 11.3)				
	1	2	5	9	10
R^2	0.9	0.93	0.97	0.95	0.98
P_m, µg/g	59.0	70.0	129.0	42.0	45.0
b, $10^{-3}m^3/mg$	2.66	3.05	4.2	6.31	7.02
HK, mg/m^3	277.0	306.0	105.0	130.0	42.0
Saturation, %	42.0	48.0	31.0	45.0	23.0
Available P µg/g	25.0	34.0	40.0	19.0	10.0
Pore water PO_4-P, mg/m^3	257.0	277.0	113.0	-	85.0
PO_4-P in water, mg/m^3	254.0	183.0	38.0	5.0	57.0

The turnover of orthophosphate varied between 0.03 h and 200 h, which is over four orders of magnitude. The phosphorus uptake velocity ranged between 0.5 and 308 mg $P/m^3.h^{-1}$. The turnover time is the ratio of the P concentration of the water and the velocity of the uptake. The maximum uptake velocity, on the other hand, depends - among others things - on the concentration of chlorophyl-a and the water temperature. Short turnover values indicate that the orthophosphate load is recirculated several times by the planktonic organisms during storage in the reservoir. Planktonic uptake is an especially important component of the phosphorus cycling during periods with warm water temperatures. Phosphorus taken up by phytoplankton is transported into the sediment where, following mineralization, P is partly adsorbed to the sediments.

Phosphorus adsorption on the bed material

Measurements of the phosphorus adsorption properties of the bed material were carried out at the same location as those of the phosphorus uptake studies. The method is described elsewhere (Istvánovics et al., 1938). The data were plotted according to the Langmuir isotherm model.

$$P_o = P_m \frac{P_e}{b + P_e}$$

where P_e is the equilibrium phosphorus concentration of the suspension, P_m

is the maximum phosphorus adsorption capacity, b is a constant, and P_o is the initially adsorbed phosphorus on the sediment. The main characteristics of the adsorption isotherm of sediment samples are summarized in Table 11.3. Values of the determination coefficient R^2 indicate that measurement data fit the Langmuir equation well. The adsorption capacity of the bed material was in the range of 42-129 μ/g; this is relatively low in comparison to other lakes (Istvánovics et al., 1988). Values of the concentration limit which is equal to

$$\frac{P_o}{P_m - P_o} b$$

showed a decreasing tendency with the distance along the route of flow (from 300 mg/m^3 to 40 mg/m^3). This shows a similar tendency to the observed variation of PO_4-P concentration along the route of flow through the reservoir. The degree of phosphorus saturation

$$\frac{P_o}{P_m} * 100$$

was the highest at the station closest to the Zala River (sampling sites 1, 2 and 9), exceeding 40%. This degree decreased to about half along the route of flow in the reservoir. Phosphorus concentration in the pure water was similar to that of the limit concentration of the adsorption isotherm, indicating that absorption was of major importance in the regulation of the pore water P concentration. The PO_4-P concentration of the water was, at the same time, much lower than that of the pore water of the sediment samples taken from the same location. This fact stresses the importance of the internal load of phosphorus, although it cannot be quantified on the basis of the information available.

Uptake of phosphorus by macrophytes

According to botanical studies (Pomogyi, 1987) more than 40% (i.e. 8 km^2) of the total surface area of the reservoir was covered by macrophytes in 1987, corresponding to about 33,000 tons of fresh biomass. The phosphorus stored in this biomass can be estimated at 20 tons, which is about 54% of the total annual PO_4-P load of River Zala.

In order to quantify the amount of nutrient removed by macrophytes, the basic question is: which portion of phosphorus that comes from the water and which from the bed material, respectively? To estimate this ratio the model of Carigan (1982) was used (Herodec, 1988). The PO_4-P uptake from the sediment was estimated at 13% and 81% of the total uptake in the upstream part of the reservoir just at the inflow of River Zala (station 1), and in the vicinity of the outflow structure, respectively. Also taking the areal distribution of macrophytes into consideration, it can be concluded that about one third of the total uptake (about 6-7,000 t) originates from the water of the reservoir.

Phosphorus binding to the $CaCO_3$

The ions characterizing the water of Hidvég reservoir are Ca^{2+}, My^{2+} and HCO_3^- (see also "Hydrobiological characteristics of the reservoir"). Due to the primary production, biogenic $CaCO_3$ precipitation may occur according to the following relationship:

$$Ca^{2+} + 2\,HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O.$$

As indicated by the results of the calcium budget of the reservoir, the total Ca^{2+} inflow can be estimated as 25,000 t/yr, about 13-14% of which is retained by the reservoir. This results in about 8,000-9,000 t/yr $CaCO_3$ precipitation. The amount of phosphorus bound to $CaCO_3$ may be estimated as 20-23 t/yr. This is about 30% of the total PO_4-P load of the reservoir. It is not yet known which part of the phosphorus co-precipitated with the $CaCO_3$ and which part became attached to it by adsorption in the bed material.

Nutrient removal by the reservoir

During the planning and construction phase of the Hidvég reservoir the nutrient removal efficiency was anticipated at approximately 60%. No seasonal changes of this removal efficiency were reported in the preliminary studies. The nutrient removal efficiency of the reservoir can be estimated on the basis of inflow and outflow load data. In 1986, about 100 samples were taken from the outflow section, and thus the error of load estimation was about 10%. Since 1987 daily samples have been taken in the outflow section. The total load data together with the calculated annual average removal efficiency for suspended solids (SS), total phosphorus (TP), PO_4-P, total nitrogen (TN) and NO_3-N are given in Table 11.4.

TABLE 11.4.
Annual input load (L_{in}, $Mg.yr^{-1}$) and mean removal efficiency (M %) of the Hidvég reservoir (1986-88)

		Q $10^6 m^3$	SS	TP	PO_4-P	TN	NO_3-N
1986	L_{in}	214	12.552	92	46	1.097	531
	%		70	51	61	16	59
1987	L_{in}	268	36.302	123	64	1.172	680
	%		82	38	57	25	57
1988	L_{in}	156	7.494	82	45	653	408
	%		12	52	90	22	69

Notes: Q : Water discharge
SS: Suspended solids
TP: Total phosphorus
PO_4-P: Dissolved reactive phosphorus
TN: Total nitrogen
NO_3-N: Nitrate-nitrogen

In 1986, the average nutrient removal efficiency exceeded 50% with the exception of TN, while flow and load conditions were average. The removal of SS was especially effective.

In 1987, the flow through the reservoir was 20% higher than in the previous year. The excess flow was mainly due to the high flood (hundred year flood) in August, that lasted only a few days (?? > 100 m^3/s, Q = 5,6 m^3/s). Nutrient loads, mainly due to this flood and also to two smaller floods in the 2nd quarter, also exceeded those of 1986. The difference was especially marked in the case of suspended solid loads - the value was approximately three times that of the previous year. The removal efficiency of SS increased to 82%, most likely due to the better settling properties resulting from the higher than usual average particle size of suspended solids. Removal efficiency of TN had also increased, while that of TP decreased. No appreciable changes in PO_4-P and NO_3-N removal were observed.

In 1988, flow through the reservoir was 27% less than in 1987, due to the drought-like weather conditions. Comparing the data of these two years' loads of TP, TN and NO_3-N in 1988 were 11%, 40% and 23% smaller, respectively, than in 1986. PO_4-P load remained about the same. Removal efficiency of SS decreased to 12%, while that of PO_4-P and NO_3-N increased to 90% and 69%, respectively.

The data indicates that the removal of suspended solids depends on the flow, being inversely proportional to it. The significant increase of PO_4-P removal efficiency may be related to the observed planktonic eutrophication of the reservoir that is to phytoplankton uptake (see also "Phosphorus budget of the Hidvég reservoir").

When investigating the seasonal variation of nutrient removal efficiency, no appreciable seasonal fluctuation can be observed for SS, TP, PO_4-P and TN. The removal of NO_3-N, however, is low in winter (about 20%) and increases with the increase of water temperature (to more than 90%). As a consequence, the ratio of readily available N to P forms may have decreased in the reservoir in comparison to the water of the Zala River.

For the input loads in the Hidvég reservoir during the three years the following ranges can be estimated: SS: 7,494 - 36,302 t/yr; TP: 82-123 t/yr; PO_4P: 45-64 t/yr; TN: 653-1,172 t/yr and NO_3-N: 408-680 t/yr. The annual removal efficiencies were as follows: SS: 12-80%, TP: 38-52%, PO_4-P: 57-90%, TN: 16-25%, NO_3-N: 57-69%.

Data for the three years of operation of the reservoir are not yet sufficient to estimate the future nutrient removal properties. It may be concluded, however, that the nutrient retaining capability of the reservoir is satisfactory in respect to the most important nutrient forms: TP, PO_4-P and NO_3-N. The removal efficiency, however, is rather low for TN and in the case of low annual flows, also for SS. Consequently, it would be necessary to reduce the loads of the reservoir with special reference to phosphorus, which is the most important element from an eutrophication point of view.

It should also be noted that the load component originating from the direct catchment basin of the reservoir can only be roughly estimated, due to the lack of data. About 6 to 8% of the total nutrient load is carried by the three small creeks that flow directly into the reservoir. Consequently, the removal efficiencies of Table 11.4 are somewhat underestimated.

Effect of Hidvég reservoir on the water quality of the Bay of Keszthely of Lake Balaton

The operation of Hidvég reservoir can affect the water quality of the Bay of Keszthely in one or more of the following ways:

a) effects of significant algal masses discharged from the reservoir;
b) the variation of the N:P ratio of readily available forms during the summer period;
c) increased loads of humic materials;
d) decreased loads of nutrients (retention in the reservoir).

Significant algal masses formed in the reservoir and discharged from it into the bay may unfavourably affect the allochtonic organic material load of the Keszthely Bay. The rate of loss of algae has not yet been studied in the Zala River between the reservoir and the inflow section to the lake. It may be assumed, however, that algae discharged into the lake will not exercize significant "seeding" effect on the algal communities of the Bay of Keszthely. Since algal communities of the Bay of Keszthely are different from those of the Hidvég reservoir.

Before the construction of Hidvég reservoir, the N:P ratio of the readily available forms in the Zala water was about 10. This ratio decreased after the summer 1985, due to the more efficient removal of NO_3-N in comparison to PO_4-P. This means that the probability of summer blue-green blooms in the Bay of Keszthely did not decrease upon Hidvég reservoir coming into operation.

Increased loads of humic materials may have multiple effect on the Bay of Keszthely:

a) The aesthetic value of the lake water may deteriorate;
b) Humic substances may counteract the process of $CaCO_3$ cycling, which is an important process from an internal loading point of view (Gelencsér et al., 1982; Istvánivics, 1988).

Research projects aimed at studying these processes have already been started. Results, however, are as yet insufficient to allow for scientifically supported conclusions to be drawn on these questions.

As discussed in "Nutrient removal by the reservoir", the nutrient loads carried by River Zala into Lake Balaton have been significantly reduced by the Hidvég reservoir. Taking into consideration the significant further tributary, loads are discharged into the river downstream of the Hidvég reservoir, the overall nutrient load reductions in the inflow section to the lake was 20% for TP and about 46% for PO_4-P. According to the ecosystem models (Somlyódy and van Straten, 1986) this decrease should result, in the short-term, in a 20% improvement in the chlorophyl-a concentration (annual average).

Fig. 11.7 shows the annual average chlorophyl-a concentration of the Bay of Keszthely along with the variation (standard deviation) around the mean, for the period of 1973-1988.

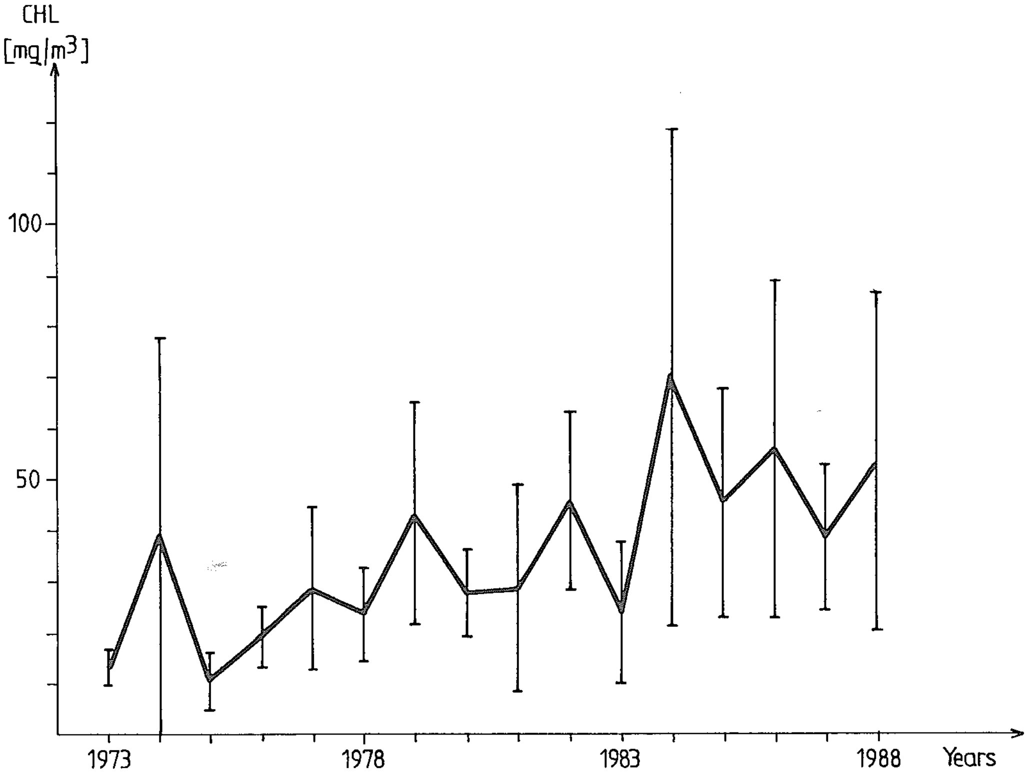

Fig. 11.7. Annual mean values (——) and standard deviations (——) of chlorophyl-a in Keszthely Bay of Lake Balaton (1973-1988).

The figure is based on annual 6 to 16 samples taken in the mid-bay. The annual mean value of chlorophyl-a shows an increasing trend until 1984. This tendency, however, is superimposed on significant inter-annual fluctuation. The latter is due, most likely, to hydrometeorological changes, and not to the variation of the external nutrient loads. While the improvement cannot be quantified from Fig. 11.7 (for that purpose more data are needed), it seems that since 1985 no increases of annual chlorophyl-a has been observed, but rather there has been a decreasing tendency. This may be due to the nutrient loads removed by the Hidvég reservoir. However, in order to verify this assumption further data are needed, since the annual and seasonal fluctuations of the chlorophyl-a concentrations were rather high (while sampling frequencies in the lake were rather low).

The effects of nutrient load reduction of this magnitude are hardly detectable in the Bay of Keszthely, for the following reasons:-

a) The internal phosphorus load of the bay is of the same order of magnitude as the external one (Gelencsér et al., 1982; Istvánovics, 1988).
b) The water quality of shallow lakes with large surface areas is strongly influenced by hydrometeorological factors.
c) The relationship between decreasing nutrient loads and improving water quality is, most likely, far from a linear one (Somlyódy and van Straten, 1986).
d) The phytoplankton of the bay is not phosphorus limited for a period in the summer. This leads to the dominance of blue-greens in the phytoplankton, which can fix the nitrogen from the air.

Hidvég reservoir has significantly reduced the nutrient loads arriving in the lake via River Zala. The rate of reduction was especially significant for phosphorus loads, which is the most important load component from the view point of eutrophication control. Nevertheless, other measures declared by the Government decree of 1983 will have to be carried out in order to improve the water quality of the western parts of Lake Balaton. Among these measures, the phosphorus removal at the largest effluent discharge (the STP of the City of Zalaegerszeg, which represents approximately half of the biologically available phosphorus load of the River Zala) and the construction of the second part of the Kis-Balaton reservoir system can be mentioned, together with non-point source control (melioration) to be implemented in the Zala catchment area.

11.5 SUMMARY

The water quality of Lake Balaton deteriorated in the last few decades through eutrophication. Half of the total phosphorus load in the lake was delivered by the Zala River. To reduce this load, a reservoir was constructed on the Zala River by 1985, which has a surface area of 18 km^2, a mean depth of 1.14 m and a water retention time of 0.12 of a year.

The yearly inputs of the reservoir had the following ranges in 1986-1988: Suspended solids 7,494-36,302 y/yr, total nitrogen 653-1,172 t/yr, NO_3-N 408-680 t/yr, total phosphorus 38-52 t/yr. The load reduction efficiencies of the reservoir were the following: Suspended solids 12-82%, total nitrogen 16-25%, NO_3-N 57-69%, total phosphorus 38-52%, PO_4-P 57-90%. The nitrate was removed mainly by summer denitrification. In the phosphate removal direct adsorption to the sediment and incorporation into macrophytes were supposed to be significant in the upper part of the reservoir, while algal uptake followed by sedimentation was the most important process in the lower part.

The eutrophication of Lake Balaton seems to have been arrested, but further efforts are needed to restore its mesotrophic water quality. Among these the most urgent is the phosphorus precipitation at the sewage treatment plant of the town Zalaegerszeg, and the construction of a second reservoir, downstream from the first one on the Zala River.

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CHAPTER 12

SHORE MANAGEMENT AT LAKE BIWA

Tatuo Kira and Taichiro Uda

12.1 INTRODUCTION

Lake Biwa is the largest inland water body in Japan. It is located in Shiga Prefecture, almost at the centre of Honshu (main island) of Japan (Fig. 12.1).

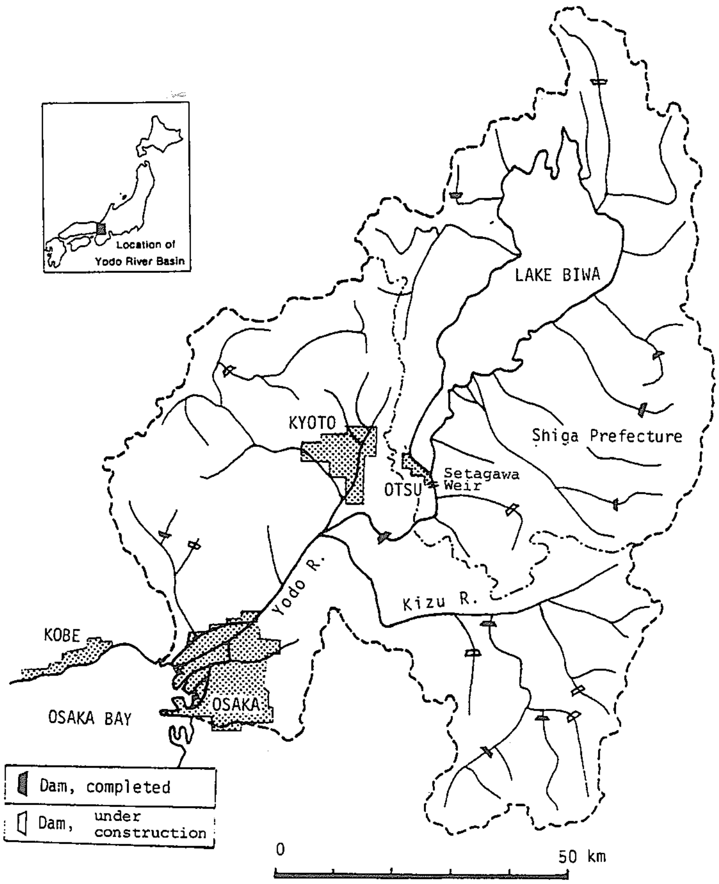

Fig. 12.1. Sketch map of the Yodo River/Lake Biwa drainage basin.

About 96% of the prefectural area is located in the catchment area of the lake and its single outlet, the Seta River. The catchment area of the lake itself is 4.7 times as large as the lake's surface (674 km^2). The lake measures 63.5 km along its longitudinal axis (NNE-SSW) and its width ranges from maximum of about 23 km to a minimum of 1.3 km (at the boundary between N and S Basins) (Table 12.1)

TABLE 12.1.
Dimensions of Lake Biwa (34 58' - 35 31' N, 135 52' - 136 17'E)

	Northern basin	Southern basin	Whole lake
Altitude [m]	-	-	85.6
Surface area [km^2]*)	616.0	58.0	674.0
Volume [109 m^3]	27.3	0.2	27.5
Maximum depth [m]	104.0	8.0	104.0
Mean depth [m]	44.0	3.5	41.0
Length of shoreline [km]	-	-	235.0
Residence time [yr]	5.5	0.04	5.5
Catchment land area [km^2]	-	-	3174.0

*) Including an area of 2.3 km^2 of five islands.

The lake consists of two contrasting basins, north and south. The southern basin is small and shallow with an average depth of 3.5 m, while the northern basin is much wider and deeper with an average and amximum depth of 41 m and 104 m respectively. The lake's freshwater mass of $27.5*10^9$ m^3 flows out from its southern end through the Seta River, which drains into the Yodo River and finally the Seto Inland Sea at Osaka (Fig. 12.1). Favoured by rich rain- and snowfall over the catchment area (1,600-2,500 mm/yr), the mean retention time of the lake water is on average only 5.5 years.

The history of human settlement around Lake Biwa dates back to the late paleolithic period. Archaeological evidence shows that fishing and rice cultivation were in prehistoric times the main ways of subsistence of local residents. The lake also served as inland transportation routes until the railway service became dominant in the late 19th century. The whole catchment area remained basically rural until the end of World War II, but rapidly industrialized from the late 1950s onward. The population of Shiga

Prefecture reached 1.2 million in 1989 and the prefectural industrial production amounted to $4.4*10^9$ yen per year.

At present, the lake plays a very important role as the biggest freshwater resource in Japan and a center for recreation and tourism. The drinking water for Kyoto is supplied from Lake Biwa via two canals built some onehundred years ago. The lake and its outlet river Yodo are also the source of city and industrial water to the Osaka/Kobe metropolitan area. The total population dependent on Lake Biwa and Yodo River for their tap water is now approximately 13 million, including some 700,000 residents of Shiga Prefecture who draw water directly from the lake.

12.2 LAKESHORE FEATURES

The lake basin is an old tectonic depression, whose bottom is still subsiding at an average rate of 1-2 mm/yr. The cross section of the basin is asymmetric; the western side is steeper than the eastern side, the deepest area being located near the western shore. The plains fringing the lake are, therefore, very narrow on the western side, and wider on the eastern side except in the northernmost part.

Originally, there were a number of lagoons, small lakes and ponds connected with the main lake by creeks, locally called *naiko* (meaning inner lakes or attached lakes), particularly along its eastern shore. However, many *naikos* have already been filled to create arable land and for improvement works along the lakeshore, thus making shorelines progressively sumpler and shorter. The present length of the whole shoreline is about 235 km.

The shore of Lake Biwa may be classified into 6 landscape units: i) rock cliff; ii) rocky shore; iii) pebble beach; iv) sandy beach; v) emersed plant (reed) stands), and vi) man-made structures (Figs. 12.2 and 12.3).

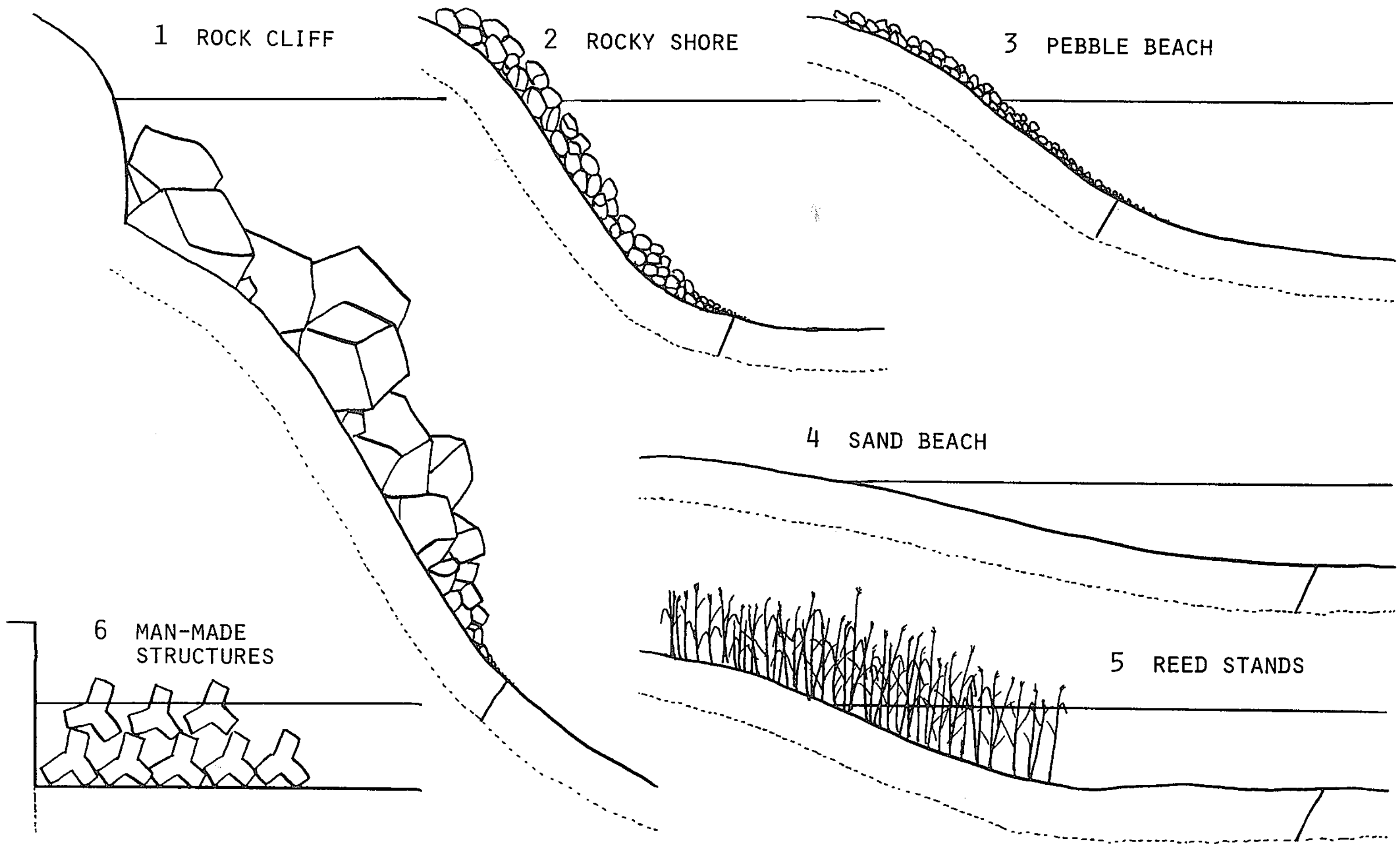

Fig. 12.2. Six types of lakeshore landscape in Lake Biwa (LBRI, 1988)

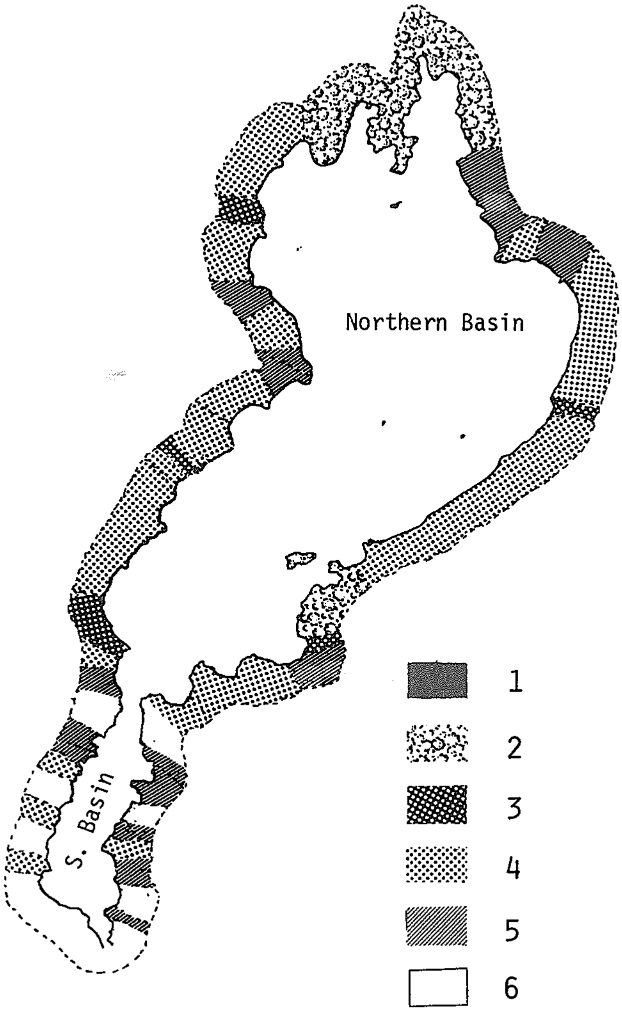

Fig. 12.3. Distribution of shore landscape types in Lake Biwa (LBRI, 1988). For type numbers see Fig. 12.2.

Rocky cliff is almost exclusively found on three small islands. More than half of the shoreline of the southern basin has been converted to embankments and other artificial structures. The sequence from i) to v) roughly corresponds to the decreasing slope and size of substratum (from rock and big boulders to sand and silt). Coarser substrata tend to be rich in macrobenthos and attached algae, while microbial activity predominates in finer substrata.

The average depth of littoral or photic zone is about 10-15 m in the northern basin and 4-5 m in the southern basin. Submersed plants (*Eloda, Hydrilla, Potamogeton, Vallisneria*, etc.) cover underwater areas of the littoral zone, especially in the northern basin, except where the shore is exposed to prevailing NW wind. Submersed plant zone and reed zone are important as spawning and breeding sites of some economically important fish species.

12.3 ARTIFICIAL MODIFICATION OF THE SHORELINE

The shore of Lake Biwa has been subject to artificial modification since ancient times, particularly where plains are located in close proximity to the shoreline. Local residents constructed stone walls along the shore to protect their houses and farmlands from flooding and erosion. Shallow littoral areas were filled to create new land, which were also fringed with man-made structures. Shore improvement works accelerated in recent years, especially after World War II, affecting the natural shore ecotopes considerably. For instance, the area of reed zone around the lake has reduced by half during the last 40 years.

Reclamation of naiko (attached lakes)

There were as many as 33 *naikos* in 1941, with their sizes ranging from 3 ha to 1145 ha (Fig. 12.4). They maintained more or less the same water level as that of the main lake, but were all very shallow, being less than 2-3 m in depth, and could be easily reclaimed by draining.

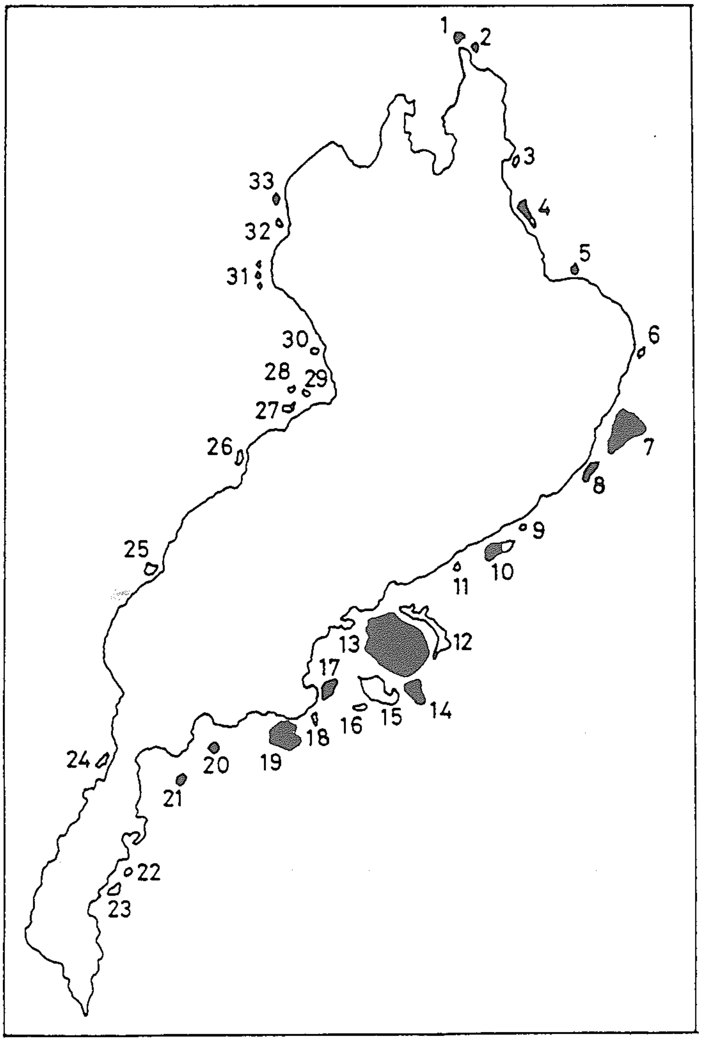

Fig. 12.4. Distribution of main naikos (attached lakes) (LBRI, 1988). Those filled in black have already been drained and disappeared.

During 1942-67, draining works commenced in 16 *naikos* in order to increase the area available for paddy fields to cope with food shortages during and immediately after World War II. They were entirely or partly reclaimed before 1971, and produced a total of 2521 ha of new land. The reclaimed land brought about the expected increase in food production. Ironically, however, the post-war progress in Japanese agriculture resulted in the overproduction of rice toward the end of the 1960s when the reclamation of the biggest *naiko*, Dai-nakanoumi (1145 ha), was completed.

In hindsight, it is now regretable that the reclamation was made at the expense of the *naikos'* different functions such as spawning site for fish, fishing ground, sedimentation pond, remover of nutrients from inflowing water (see Chapter xx, Table xx) etc.

Foreshore filling

Large-scale reclamation of foreshore area by filling was carried out mainly in Otsu city, the capital of Shiga Prefecture on the southern shore of the southern basin, during 1949-71. The reclamation was undertaken mostly by the municipal government for public affairs (but selling lands to the private sector resulted in a significant contribution to the city's finances).

In view of the anticipated undesirable effects of such reclamation works on lake water quality, aquatic ecosystems and shore landscape, however, the prefectural government decided in 1973 not to permit further foreshore reclamation except for such special cases that meet the conditions listed below.

a) The works must be nonprofit and in the public's interest (e.g. for constructing port facilities, public parks, roads erc.).

b) The undertaker must be the rightful owner of reclaimed land.

c) The works must not interfere with flood control, water utilization and river/lake management policies.

d) The works must satisfy the requirement of the laws for natural environment conservation and not spoil natural and social environments of Lake Biwa.

Flood control

The inindation of coastal lowlands due to the rise in lake water level, which tends to persist longer than river flooding, occurred frequently in former days. The worst case of flood disaster recorded took place in 1896, when an unusually high rainfall of 1,009 mm during 10 days in early September raised the lake water level up to 3.8 m above the normal level. About 15,000 ha of rice field and 28,000 houses were submersed for a maximum period of eight months. This event prompted improvement works on the Seta River, by which the headwaters of the river were straightened and the bottom was dredged to increase its draining capacity, and a flow-regulating weir was built across the river several kilometers downstream from Lake Biwa in 1905.

The mean water level was thereby lowered gradually by about 1 m during the following several decades, and the height and frequency of lake flooding were significantly reduced. However, the high water level around +1 m still occurs once every five years in average. Further measures to prevent flood damages such as banking of the lakeshore and increasing the capacity of river drainage, are being taken within the framework of the Lake Biwa Comprehensive Development Project in recent years.

Lake Biwa Comprehensive Development Project

The project is a 20-year (1972-91) joint scheme involving the national government, Shiga Prefecture and the governments of downstream prefectures (Osaka, Hyogo, etc.). Basically, it is a water resource development scheme, which is closely integrated with flood control and water quality conservation. To supply an additional amount of water of 40 m^3/sec constantly to downstream urban/industrial areas, it is necessary to allow the lake water level to fluctuate more widely between -1.5 m and + 1.4 m. This in turn requires the construction of an embankment (height: +2.6 m) along low shores (Figs. 12.5 and 12.6), while port facilities have to be improved so that they can maintain their function at low water levels.

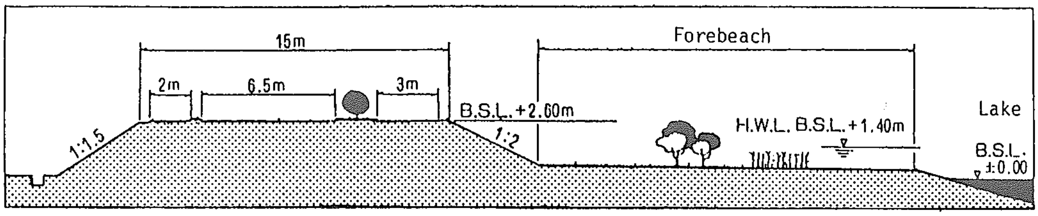

Fig. 12.5. Structure of the lakeshore embankment with a road on it and a forebeach zone supporting reed and willow stands.

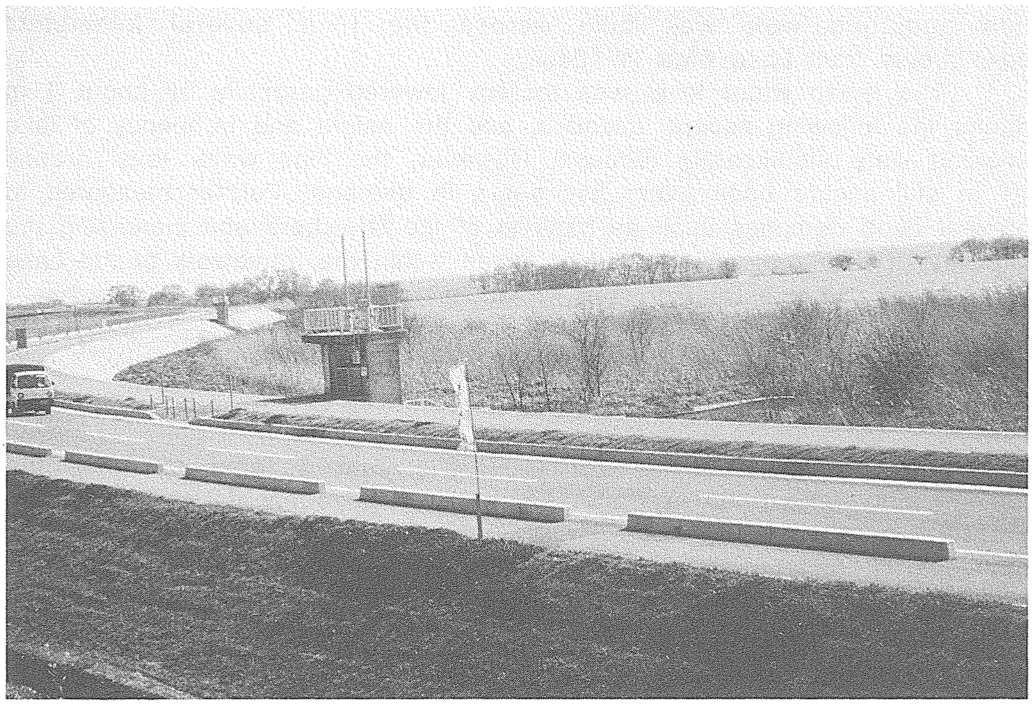

Fig. 12.6. Completed lakeshore embankment.

The lakeshore banks are also intended to prevent flood damage together with improvement works along inflowing rivers and the aforestation scheme. The Seta River was dredged again and the control weir was partly reconstructed to regulate water flow more exactly in time of very low or very high water levels. In addition, the sewerage networks with tertiary treatment plants are also being built to cover more densely populated parts of Lake Biwa's catchment area. These are the main components of this extensive development project.

Lakeshore embankment

The total length of lakeshore embankment now approaching completion amounts to 50 km (Fig. 12.7).

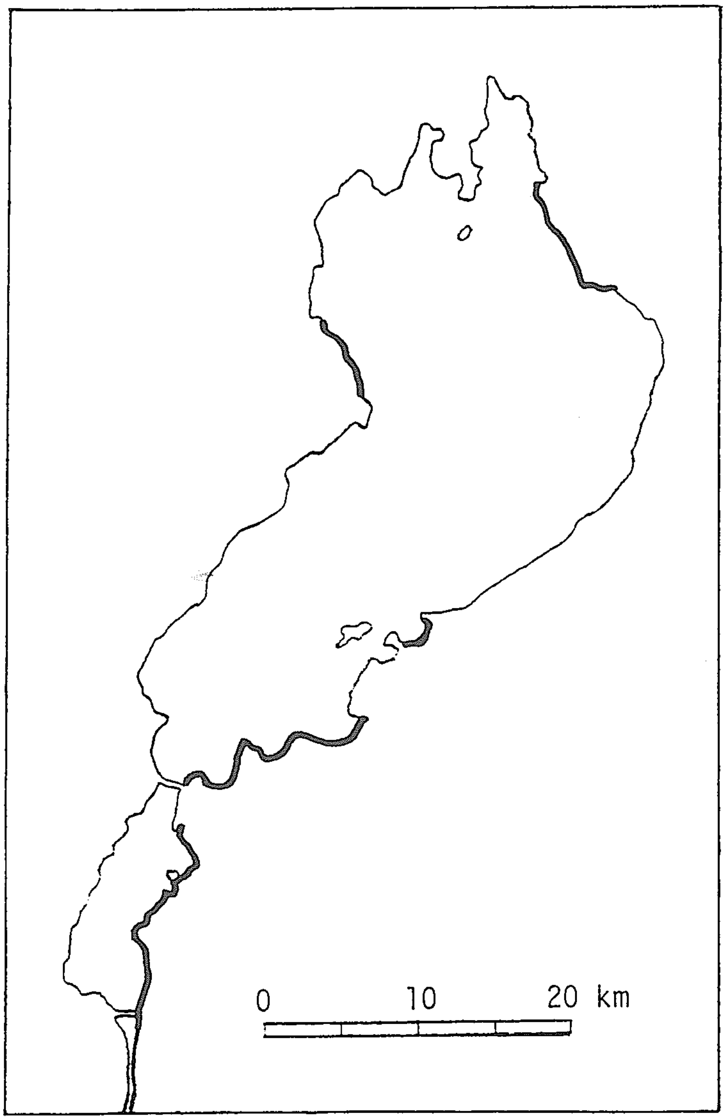

Fig. 12.7. Extension of lakeshore embankment (thick line) now almost completed.

All rivers and creeks are provided with gates at the bank intersections, which are closed at high lake water level while the excess river water is pumped out into the lake whenever necessary (Fig. 12.8).

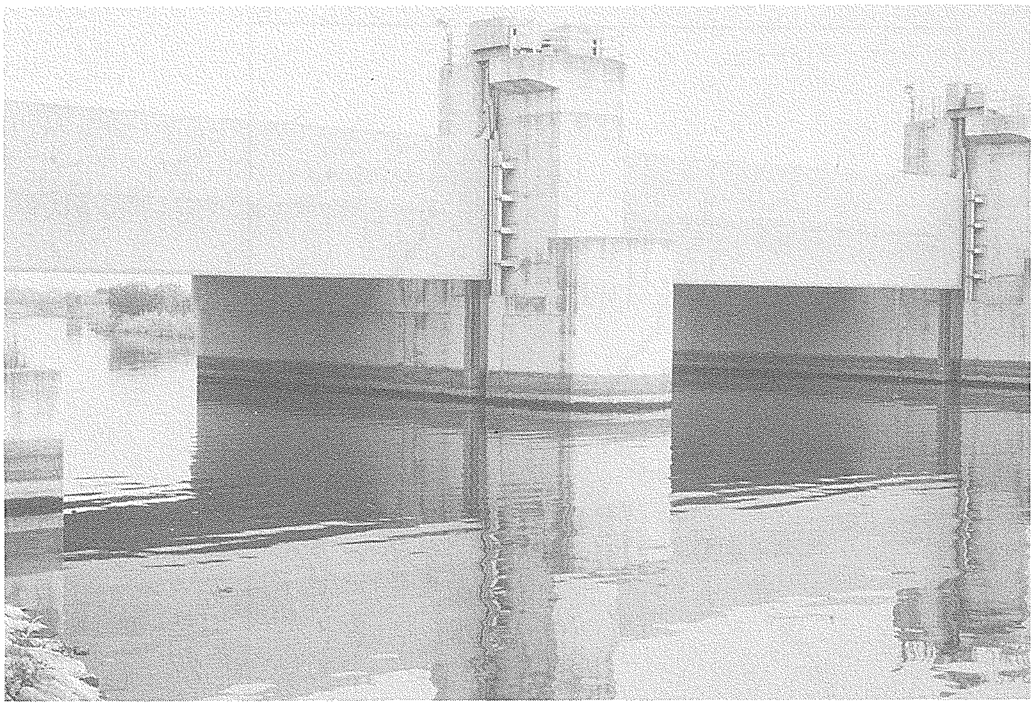

Fig. 12.8. Watergate at the mouth of an inflowing river.

The construction work sometimes resulted in the elimination of littoral wetland zone, causing the citizens' movement against the loss of natural ecotones and their functions. However, the undertaker now pays considerable attention, though still not totally satisfactory, to preserving or restoring emersed plant zone of reed, willow, etc., in front of the bank (Figs. 12.5 and 12.6).

12.4 LAKESHORE MANAGEMENT ON THE RIVER LAW

Management based on the River Law

River Law: This is a national law enacted in 1965, aiming at the integrated management of rivers for the purpose of preventing flood and other natural disasters. The law sets out to assure the rivers and maintain such functions as drainage, water supply, waterborne transportation, breeding of aquatic animals and plants, etc. For these purposes, the authorized river managers may construct necessary facilities (dams, banks, shore protection works, etc.), implement flood-control work plans, and regulate such activities which may cause flood damage within their respective river areas.

The rivers in this law include also public water areas which refer to lakes and man-made water areas for public use as reservoirs. Though rivers and lakes are conventionally distinguished, they are identified as "rivers" in this law, because of the similarities in their roles related to water use and flood control. The stagnant water in lakes originates from and returns into the flowing water of rivers and therefore the two types of inland water are treated as a continuous system.

River classes: Japanese rivers are classified into two categories: 1st class and 2nd class, by the law. The 1st class rivers are designated by the Minister of Construction as particularly important for land conservation and/or the national economy. Lake Biwa and the Seta River, with their 121 tributaries, belong to the category of first-class rivers.

Managing body and Managed area: The National Government represented by the Minister of Construction is responsible for the management of 1st class rivers. However, the Minister may specify certain sections of a 1st class river and delegate part of its management to the prefectural govenor concerned. In the case of Lake Biwa, the governor of Shiga Prefecture is entrusted by the Minister with the management of its water surface, and fulfulls his mission in consultation with the Ministry of Construction.

The area directly managed by the government is usually the narrow land within river banks, including the watercourse itself, dry river bed and the lands on which facilities necessary for management are built. Within this area, any kind of construction work or exclusive land use without the permission of the government agencies concerned is prohibited. The same concept also applies to lakes. Therefore, all shore areas of Lake Biwa, though very limited in their width, belong to and are managed by the government. No private beach exists, except those traditionally used by fishermen and residents, as community ports and anchorages, etc., are allowed.

Environment management scheme for the lake shore: The shore areas of Lake Biwa are classified into the following three zones according to the differences in the management of their environments (Fig. 12.9):

Zone I Shore areas where natural ecotones have been and will be preserved without artificial disturbance.

Zone II Areas, where natural landscape is basically protected, but which are used for nature-oriented recreational activities such as walking on nature trails, bird watching, cycling, swimming, sailing, camping, etc., with appropriate facilities.

Zone III Areas, where parks, open spaces for sports and festivals, fishing yeards, rest houses and similar facilities are arranged. Urbanized shores are also included in this zone.

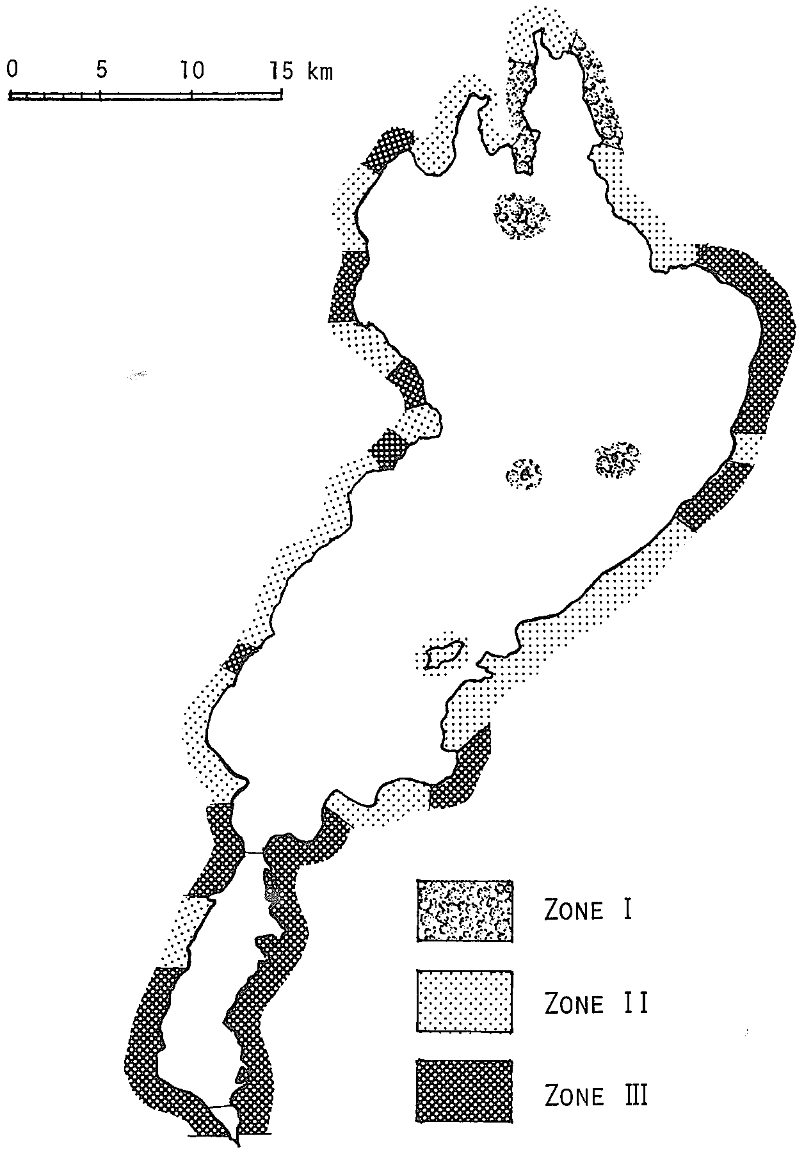

Fig. 12.9. Zoning of shorelines for the management by the government. See text for the description of the zones.

Legally, this zoning applies only to the narrow shore belt managed by the government, but it is expected to extend the same management principle to neighbouring areas through negotiations with various governmental and private sectors concerned.

Prefectural Landscape Ordinance

A landscape protection Ordinance entitled "The Ordinance for Protecting and creating Beautiful Landscape in Homeland Shiga" was enacted by the prefectural government in 1984 to preserve and restore the natural, rural and historical landscapes of Shiga which have long been familiar with the prefectural residents but are being repidly deteriorated into ugly disorder in the course of urbanization and industrial development. Since Lake Biwa is the nucleus of natural landscape in this prefecture, an emphasis is laid on the protection of landscape along its shore, where landscape formation areas - "including the special scenic zones" - are designated on the ordinance. The shore belt of 60 m width around the whole lake is also designated as the landscape formation area.

Those who wish to construct or remodel buildings or other structures, cut trees or bamboos, or change land-uses within a landscape formation area have to report to the governor in advance, and, if necessary, receive his guidance and/or advice so that the result of their action complies with the standards for the landscape formation specified for the area concerned. Similar guidance or advice may also be made to existing buildings, etc., if they are considered to be out of harmony with the surrounding landscape.

12.5 CONCLUDING REMARKS

Lakeshore protection, compared with the efforts made by the national and prefectural governments to maintain lake water quality against the progress of eutrophication has received less attention except from a flood control perspective. It has become increasingly recognized that littoral ecotones play an important role in sustaining the whole lake system and in ameliorating water quality, but the public at large are still little concerned about their conservation. As are the cases with other environmental issues in this country, the following two conditions make it difficult to improve the present situation.

1. The tightness and intensity of land use. Since only one-third of Japan's territory is topographically suitable for the residence and agricultural/industrial activities of its 122 million population, flat

lands are very tightly occupied, split into minute privately owned fractions, and characterized by extraordinary prices.

2. The Japanese public are still development-minded and oriented toward industrialization and urbanization, in spite of the great economic growth they have achieved. This is probably due, in part, to the rapidness of modernization process, which left the society still unprepared to a developmental capability, which is balanced with technological development.

Where the topography allows, agricultural and residential lands extend to the very margin of water of Lake Biwa. This is the reason why the shore belt under the direct government control or that designated as the landscape formation area is so limited in width. This also explains that the national government is so keen about flood control. As far as flood control works are concerned, the shore protection in lake Biwa is nearly complete, as stated above in relation to the Comprehensive Development Project. It may even seem excessive and ecologically unsound to the eyes of lake managers in other countries. The project has worked out during the height of Japan's economic growth with little concern about the resulting degradation of shore environments.

Although the construction work along the lakeshore was considerably modified in later years taking into consideration the protection of littoral ecotones, the changes it brought about are basically irreversible. The rest of the shoreline where banks were not built is, therefore, all the more valuable. Nevertheless, the recent projects for urban or tourist development are reluctantly paying attention to the loss of natural landscape and ecotones. Planners are too often not aware of the degradation of natural beauty they are going to bring about, and, even if they are landscape-concious, understand little about the ecological role of the natural shore systems. More concentrated efforts are therefore needed for publicizing the significance of ecological lakeshore management.

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