MONITORING OF LAKE ECOSYSTEMS

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Abstract

The essential component of management strategies for the conservation of lake biota is a reasonably complete understanding of the factors and processes regulating the composition, organization and dynamics of the communities. One aspect of the habitat quality is the trophic state, which can be defined on the basis of, e.g. nutrient content, primary production or secondary production. Within the International Biological Programme the basic parameters of production, metabolism and energy flow in freshwaters and the controlling factors were studied. During the 1970s, an international OECD cooperative study on Eutrophication of Freshwaters was performed to explore the strengths and weaknesses of nutrient load assessment and to relate external nutrient loading to the trophic response of lakes. Within this context, a number of relationships between areal phosphorus load, lake phosphorus concentration and primary production as a function of morphological and hydrological lake characteristics were developed. As a result, a few dominant regulating factors have been identified and are still in use in monitoring programmes within the context of eutrophication. As an example of an Austrian case study, the limnological development of Neusiedler See is briefly described and discussed. The need for more quantitative information on biotic interactions and their changes in the context of lake management strategies, biomanipulation and lake conservation is put forward. Finally, the example of Seewinkel pinpoints the need for the determination of areal changes in the landscape, especially with regard to water and the land - water ecotone.

Herzig, A.: **Monitoring von Seen**

Jeder Maßnahmenkatalog, der zur Erhaltung der ökologischen Funktionsfähigkeit des Lebensraumes See beitragen soll, bedarf der Kenntnis über die Faktoren und Prozesse, die Zusammensetzung, Organisation und Dynamik der Lebensgemeinschaften steuern. Ein Kriterium der Beschreibung der Qualität eines Sees ist die Trophie, die aufgrund von Nährstoffgehalt, Primär- und/oder Sekundärproduktion bestimmt werden kann. Im Rahmen des Internationalen Biologischen Programmes wurden die Grundparameter der Produktion, des Stoffumsatzes und des Energieflusses und deren kontrollierende Faktoren bestimmt. DieOECD - Studie über die Eutrophierung von Binnengewässern hatte das Ziel, die Menge der externen Nährstoffzufuhr zur trophischen Reaktion des Sees in Beziehung zu bringen. Beziehungen zwischen Nährstoffzufuhr, Nährstoffkonzentration im See und Primärproduktion wurden als Funktion von morphologischen und hydrologischen Eigenschaften des Sees entwickelt. Einige steuernde Faktoren konnten identifiziert werden und sind bei der Kontrolle von Eutrophierungsprozessen noch immer in Anwendung. Anhand des Neusiedler Sees, dessen limnologische Entwicklung kurz beschrieben wird, kann der Bedarf an quantitativer Information über biotische Interaktionen und deren steten Wechsel im Zusammenhang mit Seenmanagement, Biomanipulation und Seenreinhaltung gezeigt werden. Schließlich läßt das Beispiel des burgenländischen Seewinkels erkennen, daß die quantitativen Veränderungen in einer Landschaft, vor allem in Bezug auf Wasserflächendargebot und Ausdehnung und Gestaltung der Land - Wasser - Ökotone, vermehrt erfaßt gehören.

Herzig, A.: **Monitorování jezerních ekosystémů**

Ochrana životní složky jezer se neobejde bez rozumné znalosti faktorů a procesů ovlivňujících složení, organizaci a dynamiku těchto společenstev. Jedním ze znaků kvality stanoviště je jeho trofick stav, jež může být definován na základě např. obsahu živin, primární a sekundární produkce. Základní produkční parametry, metabolismus a tok energie ve sladkovodních ekosystémech byl studován v rámci Mezinárodního biologického programu (IBP). Během 70-átých let byla vypracována mezinárodní OECD kooperační studie týkající se eutrofizace sladkých vod s cílem objevit silné a slabé stránky hodnocení zatížení vod živinami a zhodnotit vztah mezi přísunem živin a reakcí jezer. V rámci této studie bylo vypracováno množství vztahů mezi plošným přísunem fosforu, koncentrací fosforu v jezeře a primární produkcí jako funkce morfologických a hydrologických vlastností jezer. Bylo identifikováno několik dominantních regulačních faktorů, které jsou nadále používány k monitorování eutrofizace jezer. Studie z Rakouska popisuje limnologický vývoj Neusidlerského jezera a zdůrazňuje potřebu většího množství kvantitativních informací týkajících se biotických interakcí a jejich změn v souvislosti s různými strategiemi hospodaření na jezerech, biomanipulacemi a ochranou jezer. Na příkladu Seewinkel je zdůvodněna nutnost determinace změn v krajině, týkajících se zejména vody a ekotonů na rozhraní suchozemského a vodního prostředí.

INTRODUCTION

Management strategies for the conservation of the biota of lakes need an understanding of the factors and processes regulating the composition, organization, and dynamics of the communities. Within the biota habitat quality is influenced by natural environmental fluctuations, by direct impact by man (e.g. drainage, cutting littoral vegetation, shore line management for swimming and boating or fish stocking), as well as through the management of the catchment area. It were mainly human activities which created rapid and severe changes in the environment.

About 40 years ago the need for a better understanding of the environment as a basis for the rational management of natural resources resulted in the establishment of the International Biological Programme (IBP). It was the first occasion on which biologists throughout the world were challenged to work together for a common cause and for several years; in some occasions this was the beginning of a long-term investigation and/or monitoring; e.g. in Austria: Neusiedler See, Wörthersee, Ossiacher See, Millstätter See, Mondsee. The aim was to study the basic parameters of production, metabolism at all trophic levels and later also of energy flow, and to identify and understand the abiotic and biotic factors controlling these processes.

IBP results are summarized in a synthesis volume (LECREN & MCCONNELL, 1980) in which it is also tried to compare the various production data at the various trophic levels. IBP also provided some models to predict ecosystem change over time, the effects of physical variables on freshwater production and some of them have the potential for use as diagnostic tools for better understanding of the intricacies of aquatic ecosystems (STRAŠKRABA, 1980; WALTERS et al., 1980).

A survey of the existing literature on eutrophication processes published by the OECD (VOLLENWEIDER, 1970) formed the basis of an international cooperative study on Eutrophication of Freshwaters. These studies were performed to explore the strengths and weaknesses of nutrient load assessment and to relate external nutrient loading to the trophic responses of lakes. Among the nutrients, phosphorus is judged as the major element controlling eutrophication since it limits algal growth in most lakes. The programme covered approximately 200 natural and artificial lakes from all over the world.

What was analyzed within the context of these surveys (topics in bald print were of primary interest in most projects)?

* land use in the catchment area
* components of the water balance
* changes in lake morphometry (shore line development)
* **physico- chemical changes**
* **changes in loading** (mainly point sources)
* **changes in nutrient content** (nitrogen and phosphorus)
* **changes in biomass** (algae, zooplankton)
* **changes in productivity** (primary, secondary)
* changes in communities / populations (algae, zooplankton, fish)

Relationships between P- load, P- concentration, algal biomass (biovolume, chlorophyll a) and primary production, as a function of morphological and hydrological lake characteristics were developed. A number of models have been developed to study the relationship between nutrient loading, nutrient content and chemical and biological responses of lakes and reservoirs. Most models were empirical, while others were conceptual and based on a mass balance. The estimation of the trophic state of lakes and predictions on the effectiveness of measures taken to reduce eutrophication is done mainly on the basis of these models (e.g. VOLLENWEIDER, 1970, 1975, 1976; DILLON & RIGLER, 1974; RECKHOV & CHAPRA, 1979; FICKER, 1981).

Other relationships developed included e.g. turbidity index (HOYER & JONES, 1983), macrophyte density (CANFIELD et al., 1984), development of cyanobacteria (SMITH, 1985; SEIP & IBREKK, 1988), or fish yield (HANSON & LEGGET, 1982). Most frequently these relationships were based on multiple regression analysis. However, the applicability of these models is restricted to the water body they are derived from, very rarely an extrapolation to similar water bodies is possible.

In Austria another programme was initiated in 1974 - the Man and Biosphere programme (MaB) - which focused on the impact by man through tourism and agriculture (HERZIG, 1977). These studies included the role of non-point nutrient-sources in the eutrophication of lakes (LÖFFLER & NEWRKLA,1985).

Nevertheless, already during the International Biological Programme limnologists were aware of the need for a multi - nutrient limitation approach and the need of concentrating on theoretical aspects of the mechanisms of processes determining aquatic ecosystem reactions (STRAŠKRABA, 1980).

Furthermore the changes of the relationships within and between trophic levels need to be described quantitatively on the basis of short- and long-term investigations and laboratory experiments which is shown below for Neusiedler See.

The need for the determination of areal changes in the landscape with regard to water and land - water ecotone, applying a geographic information system (McGIS), is pinpointed by the example Seewinkel.

Case study - Neusiedler See (Fig.1)

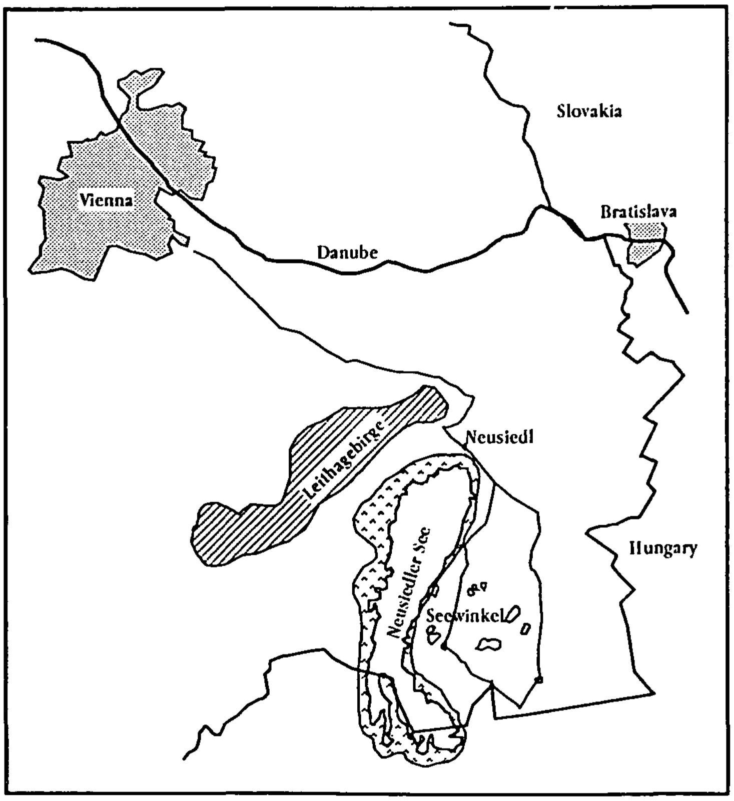


Fig. 1: Location of Neusiedler See and Seewinkel.

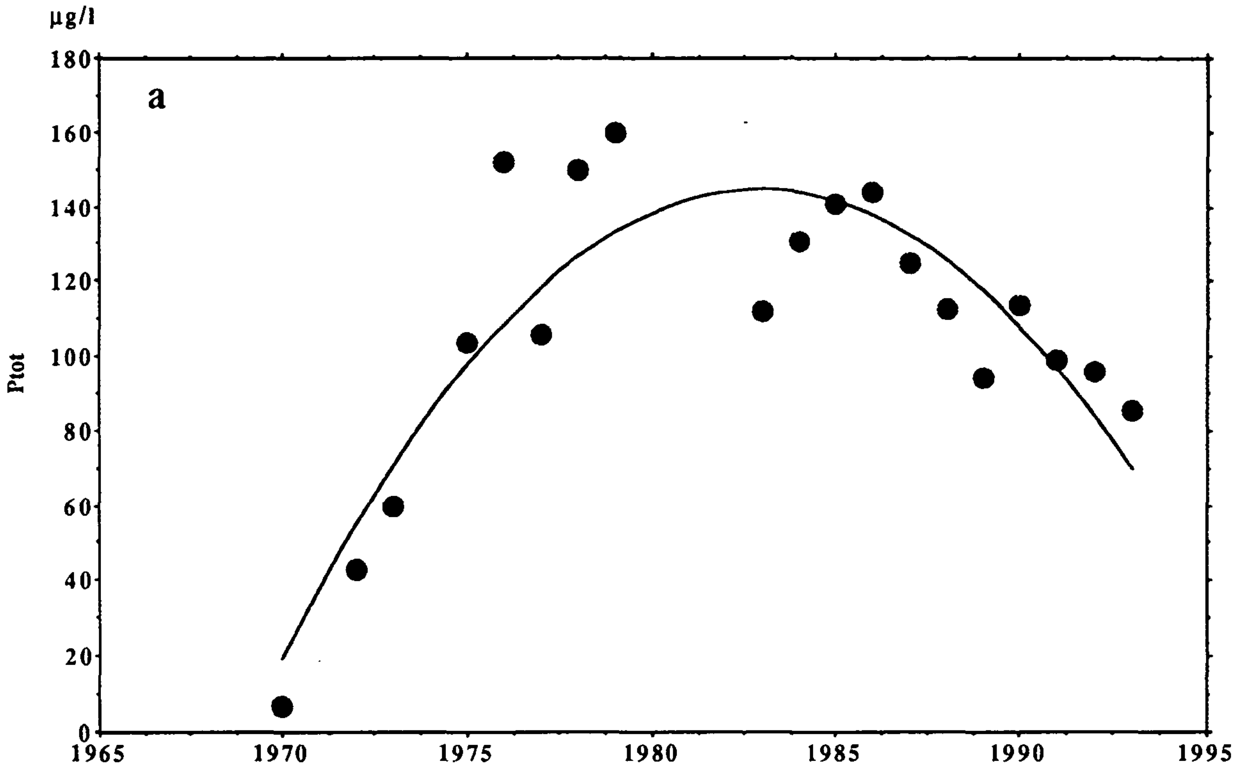


Fig. 2a : Long - term development of total phosphorus concentration (Ptot) (annual means).

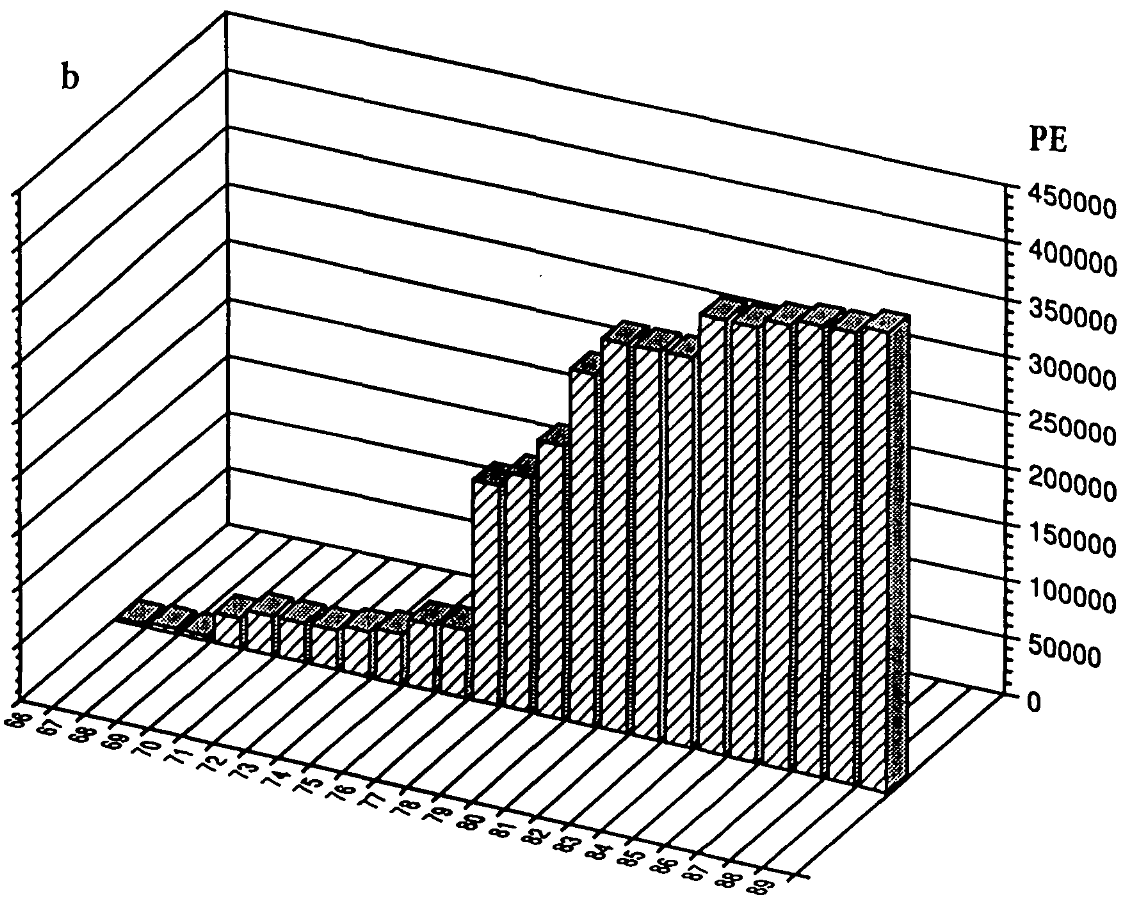


Fig. 2b: Development of sewage treatment plants and sewerage in the catchment area of Neusiedler See, expressed as population equivalents (PE).

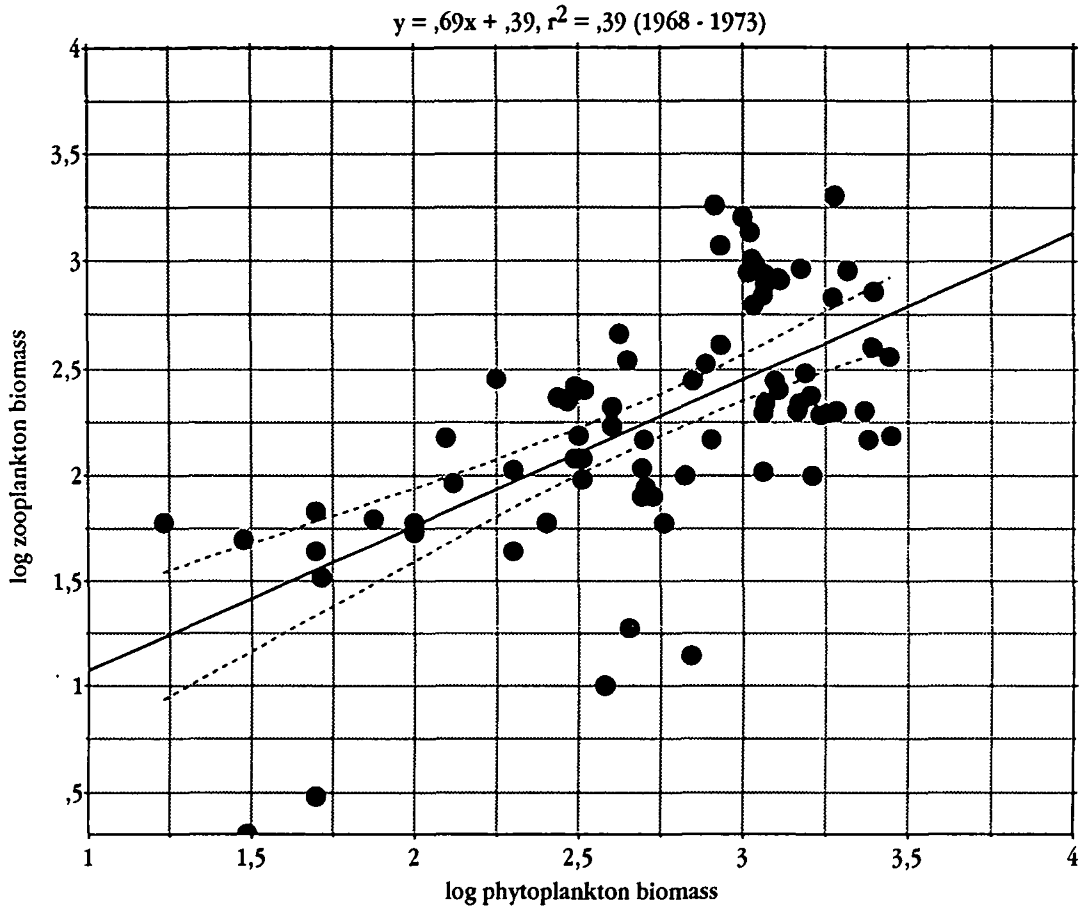


Fig. 3: Relationship between phytoplankton (mg wet weight x m^{-3}) (data - PADISAK pers. comm.) and zooplankton biomass (mg dry weight x m^{-3}), 1968 - 1973 (dotted lines: 95% confidence bands).

Limnological investigations were performed since the beginning of this century, mainly dealing with physical features (water level, wind, turbulences, temperature), plankton and fish. 1967 the first process orientated programme was initiated, investigating primary and secondary production and the factors controlling these processes (IBP). In continuation the changes in the trophic state, its implementation in the various trophic levels and the results of the measures taken to reduce the nutrient load and hence the degree of eutrophication were of interest. Beginning with 1987, metereological, physico - chemical and biological parameters are measured in the context of a monitoring programme of the Biological Station Illmitz. In addition laboratory experiments are performed to define the feeding capacity of juvenile and adult fish, as well as invertebrate predators. Since 1968 the lake underwent severe eutrophication. This is well described on the basis of the measurement of total phosphorus concentration (Ptot) (Fig.2a).

It becomes obvious that within 10 years (1970-1980) the annual mean Ptot increased from <10 µg x l^{-1} to >150 µg x l^{-1}. Later on the trend turned towards a steady decrease in Ptot values which continues until today. A comparison with the measures taken in the catchment area, i.e. well developed sewerage and sewage treatment plants of an appropriate dimension, clearly demonstrates the relationship between nutrient reduction in the catchment area through treatment and the nutrient concentration in the lake (Fig.2 a,b). Therefore the

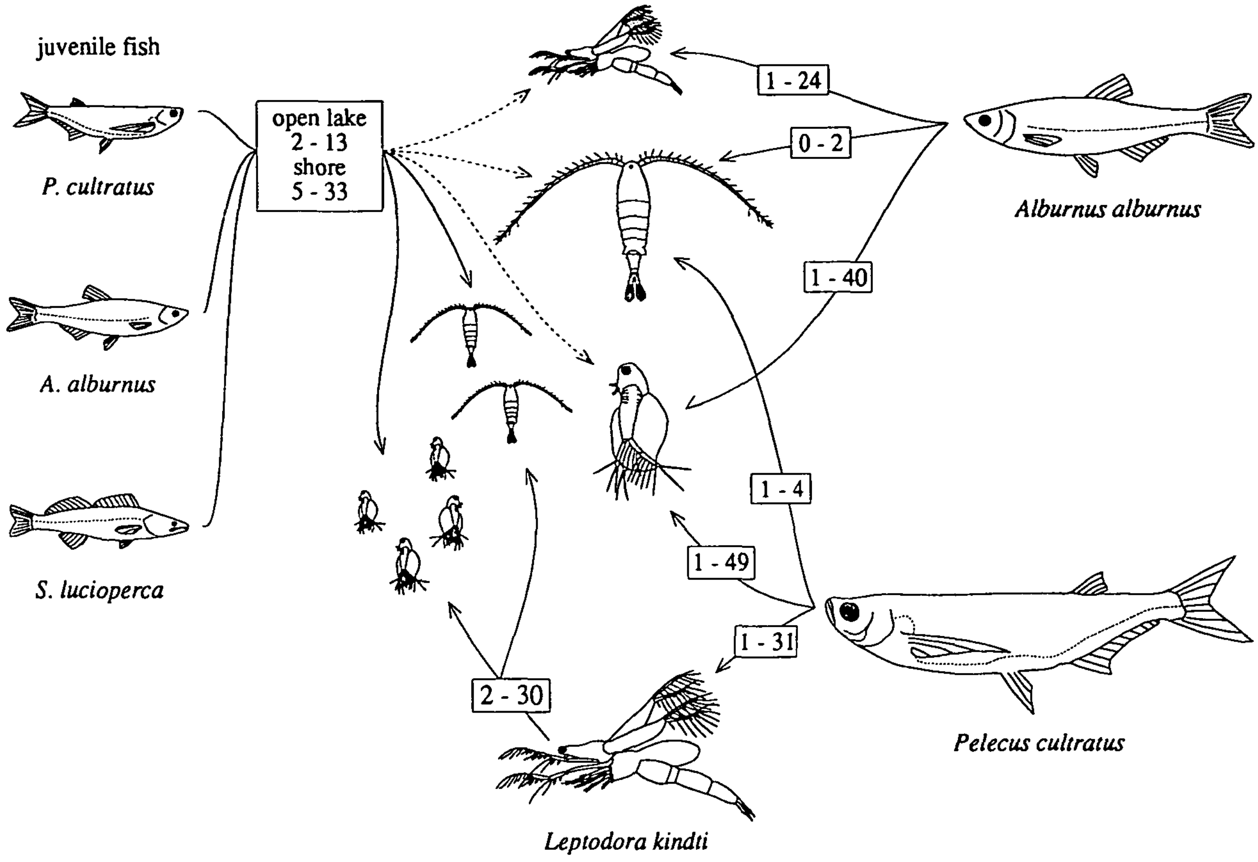


Fig. 4: Predator - prey relationships within the pelagic community of Neusiedler See (1990, 1991) (modified from HERZIG (1994)).

analysis of Ptot can be recommended for monitoring as it is a good indicator to check the effectiveness of rehabilitation and treatment work.

The increase in nutrients resulted in a higher phytoplankton biomass which led to an increase in zooplankton biomass. At the beginning of the period of eutrophication (1968 - 1973) this food - grazer relationship was well expressed and highly significant ($R^2 = 0.39$; $p < 0.0001$; $n = 81$) (Fig.3).

Later on this relationship was less pronounced. In an earlier paper abundance data, egg numbers, birth and death rate of the dominant zooplankton species, as well as food availability, water temperature and wind speed were subjected to a multiple regression analysis (HERZIG, 1994). The results revealed that especially for the summer months other factors than the ones mentioned above are responsible for the population development of the planktonic species. Predation is the most likely one (HERZIG, 1994).

Predators do have pronounced effects on their prey, on species succession and community structure. Planktivorous fish seem to be the most important predators in aquatic systems, but juvenile fish and invertebrates also need to be considered as efficient feeders and therefore as structuring elements of pelagic communities (HERZIG, 1994). As it is shown in Fig.3 the nutritive situation for the herbivorous zooplankton did improve and as a result its biomass did increase which again led to an enlarged stock of planktivorous fish.

According to AUER & HAIN (1992) juvenile fish occur in high enough densities to

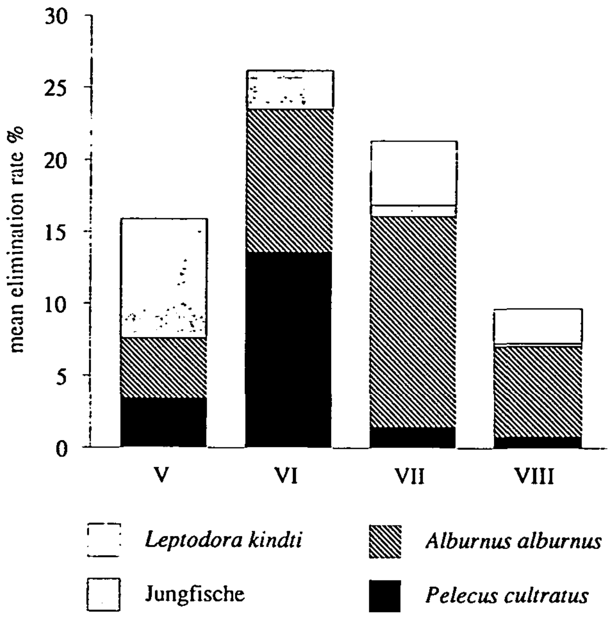


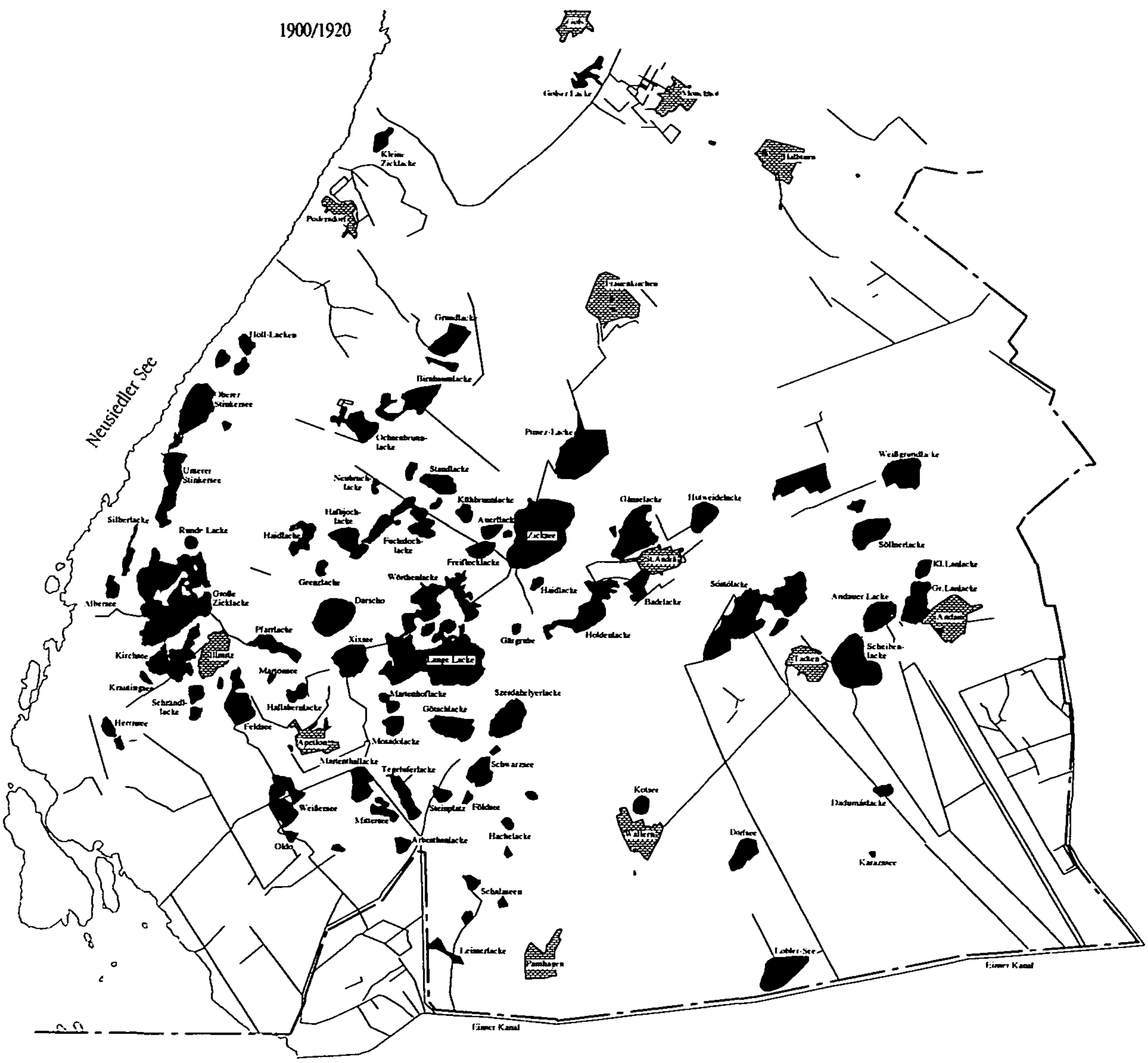
Fig. 5: Monthly mean of total predatory elimination by fish and *Leptodora* (modified from HERZIG (1994)).

create an impact on the zooplankton. In addition a very efficient invertebrate predator (*Leptodora kindti)* successfully invaded the lake and quickly developed high individual densities. To quantify the impact of the predators their densities were recorded and their feeding behaviour was described and the feeding capacity defined (HERZIG & AUER, 1990; HERZIG et al., 1993; HERZIG, 1994; TATRAI & HERZIG, 1994). According to the results obtained for two years (1990, 1991) juvenile and underyearling fish, fish older than 0+ and *Leptodora* do have a substantial impact on the zooplankton community, especially during summer, when most predators concentrate on one food item (*Diaphanosoma mongolianum*) (Fig.4). On a monthly average 8 - 27% of the zooplankton standing stock can be eliminated by all predators. The position of the dominant predator is changing throughout the year, beginning with juvenile fish, followed by the obligatory planktivores, and in August *Leptodora* also contributes a substantial amount to overall predation (Fig.5).

That means the phenology of predation needs careful attention in the discussion of species succession, community structure, rate of change, or in general in the context of ecosystem - based management (e.g. biomanipulation) and/or monitoring.

Case study - Seewinkel (Fig.1)

The Seewinkel, the region between Neusiedler See and the Hungarian border, is not only famous for its excellent wines, but even more from a scientific and natural conservationist point of view, for its numerous saline pans (Lacken). These pans are partly highly alkaline and are inhabited by a number of plants and animals adapted to these conditions. On the other hand, they are breeding grounds of bird species, like Avocet - *Recurvirostra avosetta*, Little Ringed Plover - *Charadrius dubius*, Lapwing - *Vanellus vanellus*, Redshank - *Tringa totanus* , and resting places for migratory ducks, geese, grebes and gulls.
This eminent wetland area is a Ramsar site since 1982 and hence the wise use of such a landscape is implemented. However, from the beginning of this century wide spread artificial draining (224 km drainage channels still exist today) took place which did withdraw the surface waters from that area very effectively and also lowered the water table in waterlogged soils. On the other hand, long-term extraction of groundwater for irrigation exceeded long-term recharge rates leading to regional groundwater over-exploitation.
Alltogether this management in the Seewinkel caused severe damage to the natural hydrological cycle and to the aquatic ecosystems. As it is shown in Fig.6 and Table 1, more than 100 pans can be recorded for the year 1900, and in 1993 only 36 are still existing. From 1900 to nowadays the water surface area was reduced by 74.6%. Of the 36 pans only 20 can be called healthy, undisturbed ecosystems. 11 are perturbated by drainage, digging into the groundwater, or fish culture, 5 are actually degraded.



1900/1920

Fig. 6: Seewinkel pans: situation 1900/1920 (drainage system: 1941) and 1993; solid lines - drainage system (documented in McGIS)

1993

Table 1: Long-term development of saline pans in the **Seewinkel** (analysis based on: map 1:75000, Györ, 1889; map ÖK 25V, revised 1987; GÜNTSCHL, 1942; KOPF, 1962; SUPPER, 1990). Calculation in McGIS.

	~1900	1941	1962	1993	
number of lakes	107	99	70	36	*
surface area (ha)	2974	2272	2102	755	**
cumulative losses (ha)		702	872	2219	
cumulative losses (% of 1900)		23,6	29,3	74,6	

* 20 lakes: ± healthy natural ecosystems, nevertheless all of them show a reduced open water area; average = 44% (range: 23,7% - 78,4%)
11 lakes: markedly perturbated ecosystems (perturbation: drainage, digging into the groundwater, used as fish pond)
5 lakes: ± degraded

** additionally 200 gravel pits and/or fish ponds exist; area = 98 ha

Drainage system: ~1940: 188,79 km
1993: 224,21 km

In parallel to the draining the agricultural area and the intensity of the management has been increased. Nowadays frequently wineyards directly border upon the water bodies. As a consequence, the nutrient content (phosphorus and nitrogen) of the water of the pans increased. METZ & FORRÓ (1989) reviewed the nutrient situation of the pans back to the 1940s. Beside their conclusion that more information is needed, a positive correlation between no buffering zone around the pan and more nutrients in the water was found, a statement which is in agreement with the investigations of KRACHLER (1992).
Obviously sociopolitical and socioeconomic motives and decisions led to this development. A cost - benefit analysis for drained systems and intensive agriculture versus loss of conservation, aestetic and recreational values never was performed, the values of the latter were generally disregarded. As it is stressed by MOSS (1992) in a general statement about land - use - policy, professional biologists have had little influence in the policy decisions taken in the management of waters; this field has been dominated by engineers.
Very recently measures are taken towards a catchment area based management of water. That means, controlled extraction of groundwater and inhibition or reduction of the outflow of surface waters from the area. In the future, the environment Seewinkel needs to be managed in landscape units, based on integrative hydrological, physico-chemical, biological and socio-economic assessments.

CONCLUSION

The idea that environmental management should be based on integrative assessments and should be ecosystem or landscape orientated is older than 20 years, but still it is very rarely tried to follow along these recommendations (SLOCOMBE, 1993). With respect to water this means that management and conservation needs an integrated land - use - policy. However, such a policy is not yet developed (MOSS, 1992) (cf. Seewinkel).

Increasingly, nature conservation, and especially with respect to wetlands, deals with islandlike, isolated areas which are subjected to internal and external threats.

Without knowledge about the functioning of the ecosystem no proper management can be implemented. Such an approach needs several new basic research (cf. SLOCOMBE, 1993):

*multidisciplinary data collection, including monitoring, on past and present system state, behaviour, and functioning;
*exploration of methods to organize, display, and illustrate the interrelationships of data collected, e.g. geographic information systems and computer simulations;
*exploration of methods of transdisciplinary synthesis of varied data, e.g. multipurpose, integrative targets and indicators.

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