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Comprehensive approach to the rehabilitation and management of Vesijärvi, a lake in southern Finland

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The rehabilitation programme of Vesijärvi, a lake in southern Finland, was commenced in 1987. It has been carried out in three stages: (1) reduction of the external nutrient loading to the lowest possible level, (2) management of the foodweb structure to reduce internal nutrient loading, and (3) measures to maintain the rehabilitated state of the lake. The recovery of Vesijärvi has proven biomanipulation to be an applicable rehabilitation method for large lakes, too. The mechanism behind the recovery was linked to migrations of the dense roach (*Rutilus rutilus* L.) population that transferred nutrients from the littoral to pelagic zone. Biomanipulation decreased the migrating fish stock and diminished both input and availability of nutrients in pelagic water. Consequently, the productivity of planktonic algae and especially cyanobacteria decreased. To maintain the achieved state, local people have been encouraged to participate in lake and drainage area management. Participation of the key groups (fishermen and farmers) has been enhanced with computer simulation models, which have been used to demonstrate the effects of fisheries and farming practices on the lake. The yield-recruit model and the multispecies value-per-recruit model have helped fishermen in optimising the fisheries to a sustainable level. With the help of the GLEAMS model, farmers have been able to compare the nutrient-loading effects of different field-farming techniques and to choose the less-loading alternatives. The increased participation and cooperation of local people and authorities has been considered to keep the comprehensive management process on a sustainable basis.

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Introduction

Eutrophication is one of the major environmental problems confronting the world's lakes and reservoirs. Eutrophication, and the associated turbidity of water, is not only an aesthetic nuisance but also a health risk, since many blooming cyanobacteria species produce metabolites that are highly poisonous to animals and humans (Sivonen 1996, Falconer 1996). Consequently, during the last decades much effort has been directed world-wide to the development of various restoration and management measures in order to reduce anthropogenic fertilisation of aquatic ecosystems as well as to enhance the recovery of eutrophicated lakes and reservoirs.

Vesijärvi provides an excellent example of the difficulties and challenges faced in the rehabilitation of a large eutrophicated lake. Eutrophication of this originally clear-water lake commenced during the first decades of this century, primarily due to the increased industrial and sewage water discharges from the surrounding urban community (Keto 1982). Cyanobacterial blooms have been documented since 1928, especially in the 1960s and early 1970s (Hindersson 1933, Keto 1982). They prevailed despite the traditional restoration measures during the late 1970s and early 1980s which reduced the external nutrient loading to 0.15 g P m^{-2} a^{-1}, i.e. clearly below the critical level of 0.3 g P m^{-2} a^{-1} established by Vollenweider (1976) (Keto and Sammalkorpi 1988, Kairesalo *et al.* 1999).

The dense roach (*Rutilus rutilus* L.) stock was shown to have a major role in maintaining the high phytoplankton productivity and biomass in Vesijärvi (Horppila and Kairesalo 1990, 1992). Consequently, a biomanipulation programme, i.e. massive removal of roach by trawling, was carried out in 1989–93. This biomanipulation resulted in the collapse of cyanobacterial blooms and hence in increased transparency and quality of water (Kairesalo *et al.* 1999).

The aim of this paper is to summarise the main results of the rehabilitation and management process of the Enonselkä basin, the most eutrophic part of Vesijärvi from the 1960s to early 1990s. The ecological mechanisms behind the recovery of the lake basin are elucidated and discussed on the basis of the results of long-term monitoring of water quality and fish stocks. The integrated lake and drainage area management methods that were developed and tested during European Union LIFE project in 1995–98 are also presented and discussed. The comprehensive lake management scheme presented in this paper includes ecological, economical and sociological viewpoints, emphasising the role and commitment of the local people in the lake's management.

Materials and methods

Study area

Vesijärvi (Fig. 1) is a part of the Kymijoki watercourse in southern Finland, between the extensive Salpausselkä Eskers. The lake is characterised by a long retention time and a low number of islands. The hydrological characteristics of Vesijärvi are given in Table 1. The Enonselkä basin (area 26 km^2, mean depth 6.8 m), which was the main target of the rehabilitation and management measures, is situated at the southern part of Vesijärvi (Fig 1).

The drainage area of Vesijärvi is mainly covered by woodland, but the percentage of arable land is also quite high (Table 1). There are 283 farms in the study area and agriculture is a notable source of livelihood in the surrounding countryside. Three quarters of the human population in the drainage area (about 150 000) live in cities and villages.

Water quality and plankton samples

Water quality samples were collected from the deepest part of the Enonselkä basin, 5–11 times between May and October (1986–1997). Pooled samples were taken from surface water (0–5 m) with a Sormunen sampler (height 1 m, volume 7 l). Total phosphorus and nitrogen concentrations as well as phytoplankton biomass were analysed as described by Keto and Tallberg (2000).

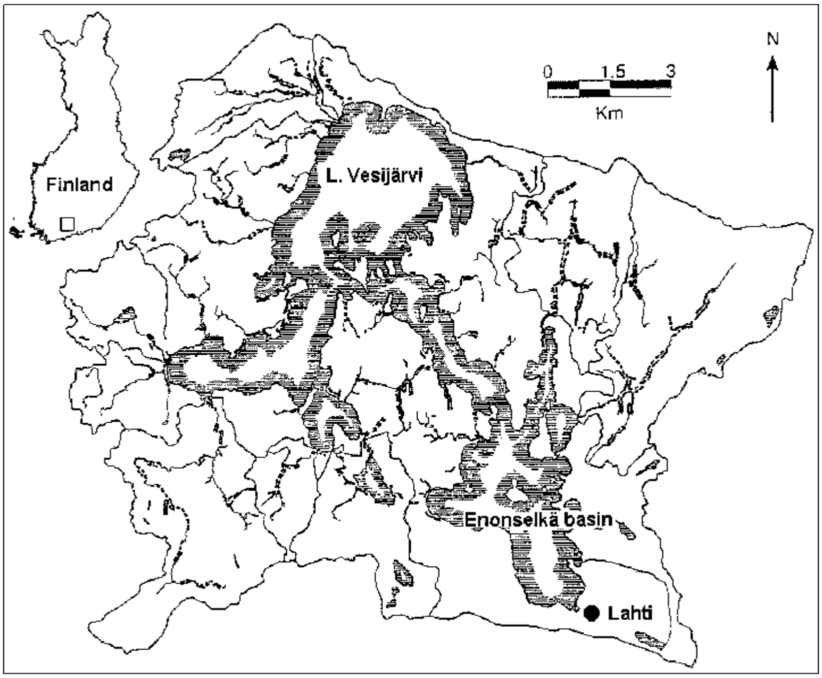

Fig. 1. Location of Vesijärvi and its drainage area.

Selection of the key groups in the comprehensive management scheme

The present comprehensive management of Vesijärvi is based on the view that local people have a central role in the sustainable development of a rehabilitated lake. The process began by determining the groups of people that have the key role in controlling nutrient loading into the lake.

Fishermen were chosen as a key group, because they are of major importance in controlling internal nutrient loading through regulating densities of roach and other planktivorous and benthivorous fish populations. Fishermen can improve the structure of the fish assemblage and the density of 'unwanted' fish populations either directly through fishing those species or indirectly by various practices that strengthen predatory fish stocks (Fig. 2). Farmers were chosen as the other key group in the management, since according to mass balance calculation, agriculture currently contributes the major part of the external nutrient load into Vesijärvi (Table 2).

Point-source loading information for the mass balance calculation was collected from the monitoring reports of the Health Control and Environmental Centre of the City of Lahti. The coefficients of Rekolainen *et al.* (1992) were used for calculations of diffuse nutrient loading from field farming. The nutrient loading from animal hus-

Table 1. Characteristics of Vesijärvi and its drainage area.

Vesijärvi	(109 km^2)	Drainage area	(515 km^2)
Mean discharge	3.9 $m^3 s^{-1}$	Water	21%
Mean retention time	5.4 a	Woodland	57%
Maximum depth	42 m	Arable land	17%
Mean depth	6 m	Settled area	3%
Shoreline	180 km	Wetland	2%

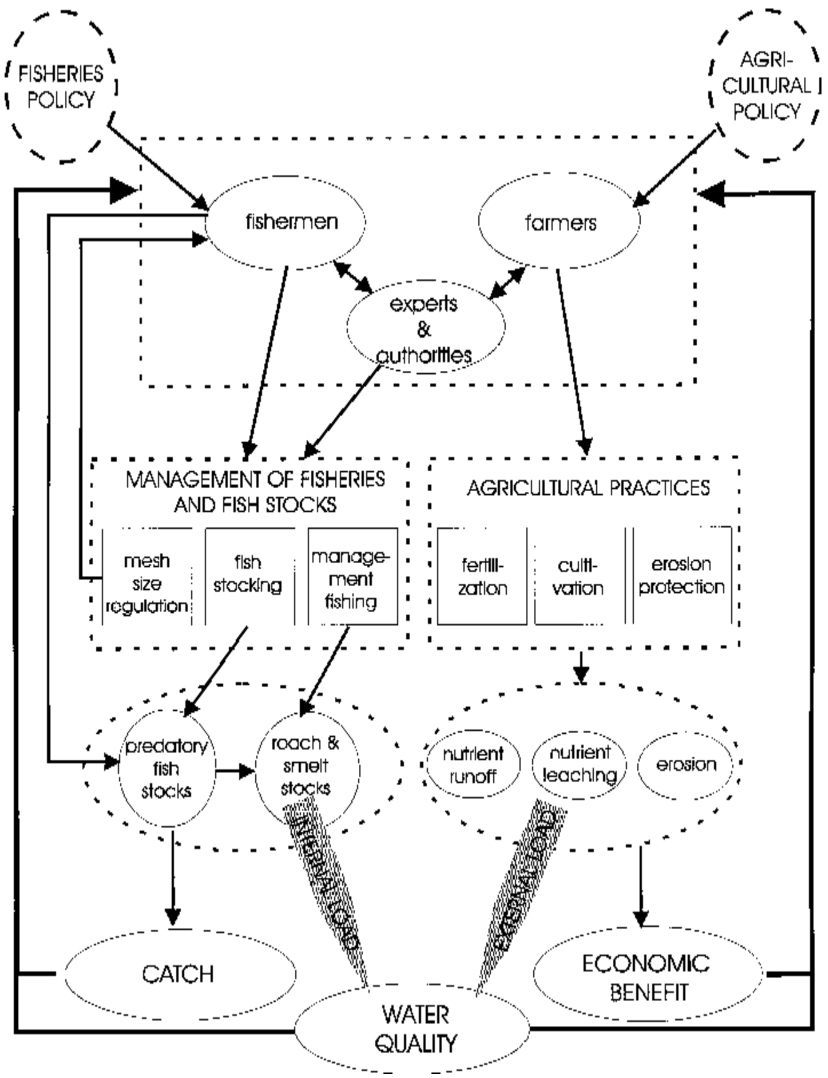

Fig. 2. Model for integrated management of lake and drainage area.

bandry was calculated according to Anonymous (1995) and loading from silage effluent according to Bilaletdin *et al.* (1992). Farm-scale information needed in the calculations was collected from the environmental management plans made for every farm in the area during 1993–1994 (Jatila 1994). The calculation of nutrient loading by forestry practices was based on the area of ditched regions and relevant loading coefficients (Anonymous 1995). The loading from scattered settlements and holiday cottages was calculated by using the number of residents and the loading coefficients of Rontu and Santala (1995). The data for atmospheric fallout calculation came from the meteorological observatory of the Lammi Biological station (40 km NW of Lahti). Natural nutrient leaching was calculated by using the average

Table 2. Proportions of the external nutrient loading sources within the drainage area of Vesijärvi.

	External phosphorus load (%)	External nitrogen load (%)
Point loading	< 1	< 1
Scattered settlements	25	6
Atmospheric fallout	10	20
Natural leaching	16	18
Forestry	< 1	< 1
Farming	49	56

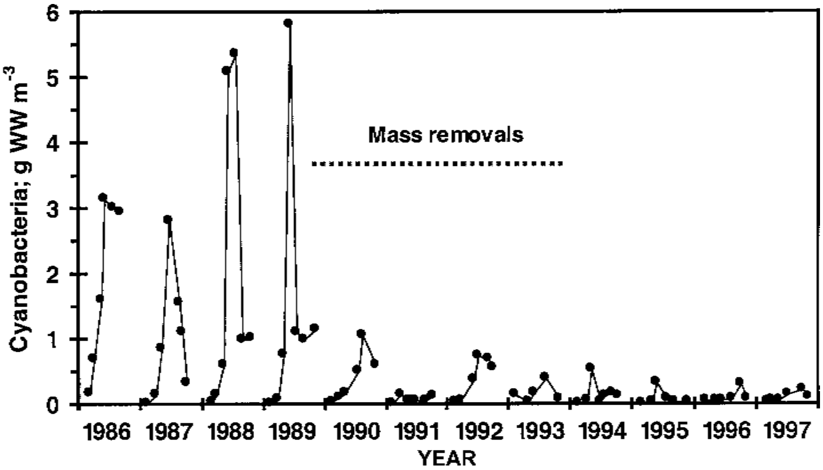

Fig. 3. Development of cyanobacterial biomasses in the Enonselkä basin during 1986–1997.

leaching values for southern Finland (Kauppi 1979).

Drainage area management methods

As foreseen by the drainage area management scheme, the co-operation with farmers started with semi-structured interviews to chart their views of the possibilities to diminish nutrient loading and of the prime obstacles involved. Another purpose of contacting the farmers was to distribute information and to generate new ideas concerning water protection on farms in general. Forty-five randomly chosen farmers of the 283 (16%) living in the drainage area of Vesijärvi were invited to interviews. Twenty-eight of them (i.e. 10% of all farmers in the study area) participated in the study.

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), a mathematical model developed by Knisel (1993), was used in this study for simulating and comparing the effects of various agricultural practices on nutrient losses from fields. The purpose of modelling was to help farmers to adopt lower-loading farming practices.

The GLEAMS simulation was made for 17 farms during the spring and summer of 1997. In terms of nutrient loading, every farmer chose potentially the most critical field for the simulation. The field data used in the simulation was collected in cooperation with the farmer. In the first simulation run, the nutrient losses for the cultivation practices at that time were estimated. Thereafter, simulations of alternative farming practices were run to compare their effects on nutrient loading. The main criterion in choosing the alternative farming practices was their environmental soundness according to recommendations made by the Ministry of Agriculture and Forestry (Korkman *et al.* 1993). For instance, simulation comparisons were made between conservation tillage and conventional tillage; tillage in spring instead of autumn; and growing perennial grasses instead of grain.

During the study the GLEAMS model was adapted to local conditions by re-defining some soil properties and by adding descriptions of local crop species to the model. The user-friendliness of the model was improved by preparing a Finnish-language manual and data-collecting sheets. Participated farmers and agricultural advisors were interviewed afterwards in order to evaluate the utility and applicability of the model.

Results

Water quality and cyanobacterial biomasses

In the Enonselkä basin, cyanobacterial biomass collapsed in 1990, one year after the first mass removals of roach, and since then has remained at low level (Fig. 3). The maximum summer biomass of cyanobacteria has declined approximately to one-tenth of the pre-biomanipulation level being now less than 0.5 g (wet weight) m^{-3}. No harmful

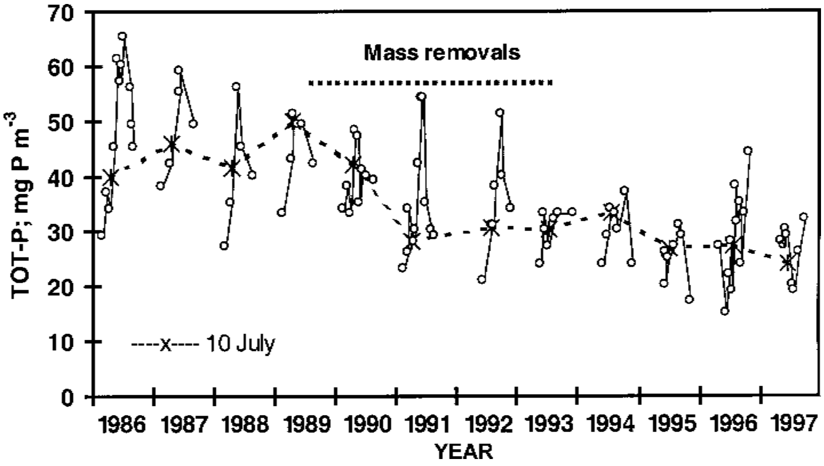

Fig. 4. Total phosphorus concentration and its seasonal variation in pelagic water in the Enonselkä basin in 1986–1997. The trend line illustrates the descending impact of roach removals on the pelagic phosphorus concentration (*see* text for further explanation).

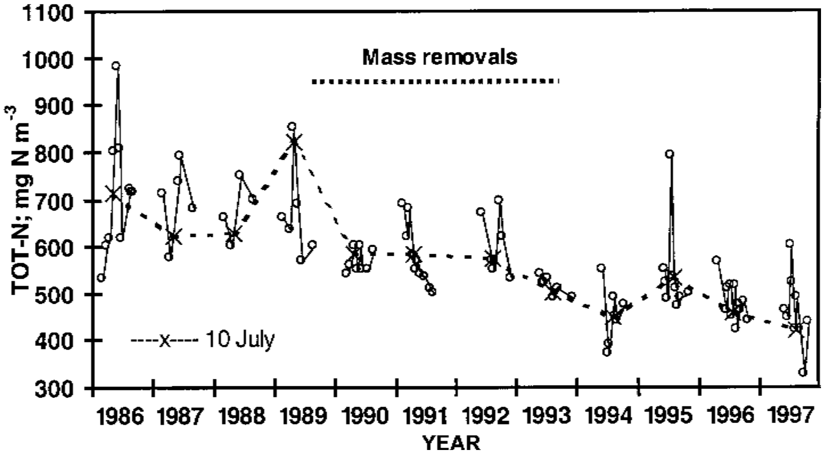

Fig. 5. Total nitrogen concentration and its seasonal variation in pelagic water in the Enonselkä basin in 1986–1997. The trend line illustrates the descending impact of roach removals on the pelagic nitrogen concentration (*see* text for further explanation).

cyanobacterial blooms occurred in the 1990s.

Since the start of biomanipulation, both phosphorus and nitrogen concentrations in surface water had a descending trend in early July (Figs. 4 and 5). Early July concentration of total phosphorus declined from 40–45 to 30 mg P m^{-3}. Late-summer phosphorus peaks that occurred in 1991, 1992 and 1996, followed periods of heavy winds that broke up the thermal stratification already in August, causing hypolimnetic phosphorus upwelling to surface water. These late summer nutrient pulses, however, did not lead to cyanobacterial blooming (Fig. 3).

Nitrogen concentration of early July decreased from 700–800 to 500 mg N m^{-3}. Before biomanipulation, the maxima of nitrogen concentration tend to appear in August (time of cyanobacterial blooming), whereas after the biomanipulation the highest concentrations were measured usually in June (except 1992).

There was a wide summertime fluctuation in the N:P ratio (Fig. 6). However, it seems that in the course and after the biomanipulation period the N:P ratio declined to a lower level than in earlier years. Summertime declines were especially steep in 1991, 1992 and 1996, when the ratio dropped to even below 10.

Drainage area management

The GLEAMS simulation results showed that in half of the cases the alternative farming practice that was supposed to be environmentally sound, did not diminish the phosphorus or nitrogen load from the simulated field (Table 3). Soil erosion

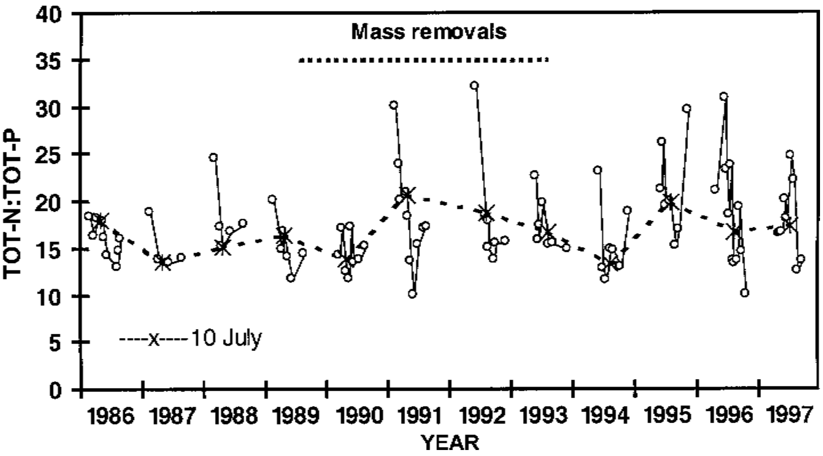

Fig. 6. N:P ratio in pelagic water in the Enonselkä basin in 1986–1997. The trend line illustrates the situation in early July, right after the yearly migration of roach (*Rutilus rutilus* L.) from littoral to pelagic area. (For N:P ratio, six sampling dates were omitted since they had results only of one of the nutrients, P or N.)

reduced in only 52% of the simulated fields as a consequence of alternative farming practices. However, in the fields where the model predicted decreased loading due to alternative farming practices, the average reduction was 29% (10–30 kg ha^{-1}) in nitrate loading, 31% (1–16 kg ha^{-1}) in phosphate loading and 45% (10–46 000 kg ha^{-1}) in eroded soil mass.

Discussion

Ecological mechanisms of the recovery

Vesijärvi was successfully rehabilitated during 1987–1994. The biomanipulation programme (1989–1993) included mass removals of roach and smelt (*Osmerus eperlanus* L.), predatory fish stockings and fishery restrictions (Peltonen and Horppila 1992, Horppila and Peltonen 1994). The cyanobacterial biomass collapsed already after the first biomanipulation year and has remained at low levels (Fig. 3).

Knowledge of the ecological mechanisms behind the lake recovery is essential for directing the management measures after rehabilitation. Biomanipulation was originally based on the idea that when the numbers of planktivorous fish are reduced, the density of large-sized cladoceran zooplankton increases, and due to their grazing on planktonic algae the turbidity of water decreases (Shapiro *et al.* 1975). In Vesijärvi, the species and

Table 3. The effect of replacing the present agricultural practices with supposedly environmentally better practices (Korkman *et al.* 1993) on nutrient loading according to GLEAMS simulations ($n = 17$).

Route of the nutrient loss	Decreased (% of all cases)	Increased (% of all cases)	No change (% of all cases)
Surface runoff			
Phosphorus	26	61	13
Nitrogen	57	35	8
Leaching			
Phosphorus	13	13	74
Nitrogen	17	74	9
Eroded matter			
Phosphorus	52	35	13
Nitrogen	61	26	13
Total loss			
Phosphorus	52	43	5
Nitrogen	22	70	8

the size distribution of the cladoceran populations did not change during or after biomanipulation (Hansson *et al.* 1998, Kairesalo *et al*. 1999). In fact, the cladoceran production and biomass declined concomitantly with those of phytoplankton (Kairesalo *et al*. 1999). This indicates that the mechanisms behind the cyanobacterial reduction in Vesijärvi were more related to nutrient dynamics driven by benthivorous fish (bottom-up regulation by fish) than to the changes in zooplankton grazing pressure (Horppila *et al.* 1998, Kairesalo *et al.* 1999).

Water quality results show that the pelagic nutrient dynamics clearly changed during and after biomanipulation (Figs. 4 and 5). The decrease of phosphorus and nitrogen concentrations in early July can be explained by a reduction in the migrating fish population. In early summer after spawning, adult roach (> 3 yr. old) migrated from the littoral to the pelagic area (Peltonen and Horppila 1992, Horppila *et al.* 1996). A dense roach stock could significantly increase the concentrations and recycling of the nutrients in pelagic water. Horppila (1998) estimated that the phosphorus excreted by the dense pelagic roach stock (before biomanipulation) corresponded to 18% of the annual external phosphorus loading, and the maximum phosphorus supply into ambient water was 0.4 mg P $m^{-2}d^{-1}$. As a result of biomanipulation this phosphorus supply declined to one-fifth of the previous level.

It has been shown in many studies that considerable reduction of benthivorous and omnivorous fish can lead to improvement in water quality without significant changes in cladoceran populations (Tátrai *et al.* 1990, Van Donk *et al.* 1990, McQueen *et al.* 1992). The results of Vesijärvi indicate that the internal nutrient loading by fish (transport and excretion) played a key role in maintaining the summertime dominance of the cyanobacteria in the pelagic water. The mass removals of the migrating roach population diminished especially the internal nutrient load of phosphorus, but perhaps also the availability of ammonium which favours the development of non-nitrogen-fixing cyanobacteria (Hyenstrand *et al.* 1998), and thereby led to the restructuring of the pelagic phytoplankton (Liukkonen *et al.* 1997, Keto and Tallberg 2000).

High summertime N:P ratios in the surface water indicate that primarily phosphorus was the limiting nutrient for algal growth in the Enonselkä water. No clear change, however, could be observed after the mass removals of fish even though enclosure experiments in Vesijärvi showed that roach density was inversely related to the N:P ratio in water (Keto *et al.* 1992).

Nevertheless, the decline in the N:P ratio has become more pronounced after the onset of biomanipulation. At lowest, the ratio declined close to or even below 10 (1991, 1996) indicating that then nitrogen rather than phosphorus might be the limiting nutrient in the Enonselkä water. The lowest measured N:P ratios coincided with the wind-induced upwellings of hypolimnetic phosphorus in late summers, but due to the concomitant decline of water temperature no clear enhancement of cyanobacterial growth was observed (Kairesalo *et al*. 1999).

Lake management prospects

After the biomanipulation project the roach stock has been kept at low density through management fishing with fyke nets and seines (J. Ruuhijärvi unpubl.). Although the present fishing activity is probably high enough to control the roach stock (Horppila and Peltonen 1994) and the large stocking programme of pikeperch during 1984–1991 has produced a naturally reproducing stock (Peltonen *et al.* 1996), there remains a need to strengthen the predatory fish stocks.

Firstly, the large pikeperch stocking programme was not fully successful because cyprinid fish played only a minor role in the diet of pikeperch. The stockings also increased subsistence gill net fishing, which limited the number of large pikeperch feeding on adult roach in the pelagic areas. Similar reports have also been made for Köyliönjärvi in South-western Finland (Salonen *et al.* 1996). In Lake Mendota, USA, sportfishing has decreased the predation on planktivorous fish despite intensive walleye (*Stizostedion vitreum* Mitchill) stockings and minimum size limits for catchable fish (Johnson and Staggs 1992, Johnson *et al.* 1996).

Secondly, managing fisheries (e.g. by placing restrictions on gear) is costless whereas management fishing, despite being partly carried out by voluntary fishermen, is quite costly. A dense pikeperch stock is also of major importance in controlling the smelt stock, which is not controlled by present management fishing. Smelt stock recovery to the pre-biomanipulation level might have undesirable effects on the water quality.

The experiences from Vesijärvi showed that it is essential to take into account the behaviour of the fishermen if the stocks of predatory fish are to be improved. It is also probable that if fishermen's opinions are taken into account, their motivation to participate in other lake management activities will improve. Because fishermen generally oppose all kinds of fishing restrictions, it would have been practically impossible to get them involved in the management scheme if the only purpose had been to control the 'unwanted' (coarse) fish stocks. Consensus on appropriate management actions was difficult to achieve until the overfishing problem was demonstrated with an interactive computer model to the representatives of the Vesijärvi Fishery Area. After that, mesh sizes between 22–50 mm (knot to knot) were forbidden in the Enonselkä basin. This restriction will probably increase the average pikeperch yield and the predation on roach and smelt stocks. However, it is only a small step towards the optimum mesh size. The yield-recruit model (Y/R model) (Kairesalo *et al*. 1998) and diet studies (Peltonen *et al.* 1996) suggest that the mesh size of 50 mm is still too small in order to maximise either the yield or the predation effect.

The LIFE project of Vesijärvi has developed a new management model (multispecies value-per-recruit model) for subsistence fishery in the Enonselkä basin. The aim of the model is to determine the optimal minimum limit for the mesh size of gill nets, and identify optimal stocking species that would succeed in maximising the utility (i.e. pleasure) of fishermen. The model is based on a presumption that the traditionally used average yield is not an appropriate optimisation objective for all subsistence fishermen. In the model, the value functions for each species determined by personal, interactive interviews are linked to size- and age-structured Y/R models. More detailed model descriptions are found in Kairesalo *et al.* (1998).

Computer modelling in diminishing drainage area nutrient loading

The GLEAMS model was tested and developed to help farmers to compare the effects of different agricultural practices on nutrient loading. Simulation results pointed out which practices generated lower nutrient loadings and thus the farmer could decide whether it would be profitable to choose an alternative farming practice or continue with the present one.

The simulation results indicate that one set of unambiguous, environmentally sound farming instructions cannot be given for all farms or fields. The practices that decreased the nutrient load in one field might increase it on another field. The results of the field studies of Turtola and Puustinen (1998) in South-western Finland are similar to the GLEAMS simulation results: the effect of supposedly environmentally sound no-tillage technique on nutrient loading can vary remarkably on different fields. Patni *et al.* (1998) compared groundwater nitrogen concentrations under conventional and conservation tillage in Canada. The changes in concentrations were explained more adequately by spatial differences of the study area than by the tilling method. These results emphasise the importance of farm-level planning in finding the right farming practices. Simulation models like GLEAMS can serve as a tool in comparing the effects of different farming methods and in finding environmentally efficacious practices for different fields.

The GLEAMS is intended for use by agricultural advisors in co-operation with farmers partly because of its complexity, but also because its use is supposed to improve communication between farmers and the authorities in the drainage area. The aim is to transfer the emphasis of environmental decision-making gradually from governmental regulatory measures to the farm level so that farmers will rely more and more on their own initiative in keeping the agricultural practices environmentally sound. Increased information and participation of the farmers in environmental decision-making are thus seen as prerequisites for optimising environmentally sound drainage-area management.

Most farmers (57% of the interviewed) regarded the GLEAMS model as usable for comparing the superiority of different agricultural practices. However, only few farmers changed the farming practices on the basis of the modelling results, since in most cases the cost of changing a current practice would have been too high. The interviewed agricultural advisors also regarded the GLEAMS model as suitable for advising purposes. However, they also concluded that the most restrictive factors in implementing the changes in farming practices are economic rather than knowledge-dependent.

Field-level simulation models like GLEAMS can also be seen as an instrument for the development of agricultural policy. They make it possible to determine the exact nutrient loads from a single farm and consequently they help in allocating national and EU environmental subsidies. Knowing the nutrient loads of individual farms also makes it possible to get rid of the term diffuse loading and the farms can be treated as point sources. This will help in water protection planning and in focusing the measures on those farms that produce the highest loads.

When considering wider use of the GLEAMS model its reliability still needs further improvement. The preceding version of GLEAMS (CREAMS, developed by Knisel (1980)) was adapted to Finnish conditions by Rekolainen and Posch (1993). Also Siimes and Yli-Halla (1996) applied the GLEAMS model in Finland. They found that the model overestimates phosphorus loads at high fertilisation levels and underestimates them at low fertilisation levels. The GLEAMS was also proved to underestimate nitrate losses because of deficiencies in calculations of denitrification in the soil (Marchetti *et al.* 1997, Yoon *et al.* 1997).

The GLEAMS model as such cannot yet simulate the real loading effect of a farm on the water body. The model calculates the nutrient effluent from the simulated field into an adjacent ditch but does not take into account the distance between the ditch and watershed. Combining the distance factor with a loading model is one of the most significant development needs when studying the real effects of farming on water bodies in catchment scale. The distance problem was studied by Håkanson *et al.* (1990), who developed a drainage area zonation method that quantifies the influences of distance and other drainage area characteristics on nutrient drifting.

Comprehensive management

Conventional restoration measures had reduced the external nutrient load of Vesijärvi remarkably in the 1970s and 1980s, but the recovery of the lake took place only during and after the biomanipulation period (Kairesalo *et al.* 1999). Thus, to sustain the recovery, it was necessary to pay attention to the ecological and socio-economic mechanisms behind both the external and the internal nutrient loadings. Therefore, the integration of lake management with measures of drainage area management was seen to be of crucial importance.

The first requirement was to determine the approach to be used in the integrated management. A traditional approach would have been to restrict nutrient loading from the drainage area through regulatory means or sanctions, and to organise the lake management activities solely by authoritative measures. However, this was seen as an expensive and not a very sustainable approach. Instead, it was realised that the future of Vesijärvi depends significantly on the commitment of the local people living in the drainage area to the management process.

The participatory role of the local people was studied on the basis of action research. Action research is purposely multi-diciplinary and eclectic. Consequently, the models produced by it do not imply that it is possible to point out some definitive and universal lines of action. Methods and techniques must be tailored separately to each case (Greenwood *et al.* 1993). According to this approach people and their organisations should not only be consulted but they should also be involved in action together with experts and authorities (Schneider and Libercier 1995). The purpose of this kind of collaboration is to provide a higher degree of self-determination and self-development capability of local people (Elden and Chisholm 1993).

With the management of a rehabilitated lake and its drainage area the focus of activity transfers from ecological measures carried out by experts and authorities to co-operation between them and the local people. Local people have an essential role in connecting human action to various ecological aspects that affect water quality. On the other hand, the maintenance of good water quality increases the value and utility of the lake (Fig. 2).

Conclusions

The recovery of the eutrophicated Vesijärvi took place in three stages. The first stage was the reduction of external point source and diffuse loading to as low a level as possible. This stage can also be called the 'hard-technology' or 'engineering stage', and it required more economic input than the other two stages. However, the decrease in external loading did not alone lead to immediate recovery of the lake.

At the second stage, recovery of the lake ecosystem was enhanced through ecologically sustainable biomanipulation ('ecological, scientist & manager stage'). Total biomass and species composition of fish communities in Vesijärvi changed during the long eutrophication process. In particular, benthivorous cyprinid fish increased in abundance, causing remarkable internal nutrient loading. Determining the distortion in the fish community and correcting it by tailored methods played a crucial role in diminishing the internal nutrient loading at the second stage. Consequently, the planktonic cyanobacterial biomass collapsed and has remained low for already nine years. These results indicate that biomanipulation is an applicable rehabilitation method also in large lakes.

At the third stage of management, the participation and commitment of the lake-users and residents are necessary in maintaining the achieved results ('sustainable, layman & authority stage'). After the second stage, conditions for the growth and recruitment of coarse fish populations become better, and therefore additional fishing ('management fishing'), stocking of predatory fish and management of subsistence fisheries are necessary to maintain the achieved fish population densities. In addition, the activities in the drainage area need to be controlled to keep the external loading at its achieved level. Computer models are seen as relevant tools in demonstrating the effects of local activities (i.e. farming practices, fisheries restrictions) on the lake. These models improve the farm-level and fishery area decision-making processes and, at the same time, increase the interaction between authorities and locals interests.

Lake management measures at the third stage can be implemented mainly through voluntary work by local people in collaboration with experts and authorities. Sustainable drainage area management in agricultural areas may, however, require cost-sharing between farmers and the wider community because the reduction of nutrient loading often causes excessive costs for individual farmers. Computer modelling provides a tool for targeting grants or subsidies in environmentally problematic agricultural areas. Rehabilitation and management increase the economic and recreational value of the lake and promote the commitment of people so that management can become a continuous, sustainable process.

Comprehensive lake management is a multidisciplinary process involving both natural and human sciences. The approach is challenging because the research methods and theoretical backgrounds are traditionally different. Natural sciences are mainly based on quantitative approach, whereas human sciences often have a qualitative approach. A comprehensive and sustainable approach to lake management thus requires wide expertise including ecological, economical and sociological disciplines.

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