THE PROBLEMS OF RESTORING LARGE, SHALLOW LAKES.

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ABSTRACT

The problems of restoring eutrophic, shallow lakes are discussed using examples from three lakes with different surface areas, e.g., L.Neagh (N. Ireland), L.Balaton (Hungary) and L.Suwa (Japan). The water quality in each lake has undergone marked deteriorations during this century and all of them were considered hypertrophic by the late 1970's. Improved sewage treatment was installed and although they all showed some initial recovery (max. chl a down by 25 - 33% by 1984), since then further improvement has been much slower. Two of the main reasons for this are internal recycling and the in-wash of nutrients from non-point sources. In considering the restoration plans for the three lakes, it is important to include inshore areas. Each of these lakes has been lowered and their annual water level fluctuations controlled. To highlight the major ecological problems associated with such changes, L.Neagh, which has a largely 'undeveloped' shoreline but where rare post-glacial habitats are endangered, is compared to L.Balaton, now one of Central Europe's most popular resorts.

Keywords - eutrophication, lake restoration, internal recycling, bioturbation, lake margins, water levels.

INTRODUCTION

For many local residents, the deterioration of a lake only becomes obvious with the appearance of unsightly algal blooms or fish kills. In some cases, the diversion or treatment of the excessive nutrients is sufficient to give an improvement (5). However, if the enrichment of a lake has been going on for a long while (1), then the lake may fail to respond as expected (e.g.,3,6,12,18,19). Three lakes that would fit into this 'difficult to recover' category are Lough Neagh (Northern Ireland)(11), L.Balaton (Hungary)(15,16) and L.Suwa (Japan)(19,20). They are all relatively shallow but large enough to make it prohibitively expensive to use internal techniques (such as sediment removal or biomanipulation, etc.), which have been successfully tried on a number of small lakes (2,3,6,12,18,21,24). It should be stressed, that even on small lakes, internal measures have only been successful if external measures (diversion or treatment) are also used to reduce the nutrient load (2,3,6,21).

The first part of this paper is concerned with the environmental processes, mainly at the sediment-water interface, that can delay or even prevent recovery of the water quality in shallow lakes. The second part of the paper concentrates on the changes that have occurred around the lake margins. All three lakes are similar in having had considerable reductions in water level in the last 100 to 150 years but this has led to different patterns of development along the shoreline. Restoration of lake margins is frequently overlooked but can be very cost-effective.

EUTROPHICATION IN THE THREE LAKES

Background

With increasing eutrophication, nutrients which would normally have become bound in a lake's sediment are recycled back into the water, thus maintaining nuisance algal populations. The degree of nutrient release from the sediments depends on the individual characteristics of each lake. In a review, Marsden (17) concludes that 'where lake phosphorus does not decrease as predicted, then the release of phosphorus from the sediment is implicated'. This applies to the three lakes compared in this paper - Lough Neagh (N.Ireland), Lake Balaton (Hungary), Lake Suwa (Japan). All have had some reduction in their external loading for about ten years but have shown only limited recovery (11,13,15,19,20). They form a natural grouping (Table I), as all three are eutrophic and normally have well-mixed water columns, although they do have occasional short periods of weak stratification. A key factor, common to all three, is that during high winds the majority of the lake bottom can become directly affected by wave action.

Table I. Characteristics of L.Suwa, from Okino and Kato (19), L.Neagh and L.Balaton, from Herodek et al.(15).

		L.Suwa	L.Neagh	L.Balaton
Surface Area	(km^2)	13.3	383	596
Mean depth	(m)	4.1	8.9	3.3
Max. depth	(m)	6.3	31.0	10.2
Mean Chl. a	($mg.m^{-2}$)	684	490	125
Flushing time	(yr)	0.11	1.3	4.7
Improvement of treatment		1979	1981	1982

Both L.Suwa and L.Neagh have relatively simple morphometric shapes but L.Balaton is more complex with four identifiable basins. L.Neagh is the only one that regularly remains ice free, having frozen only once (1947) this century. All three have long records of research, reflecting their importance in each country, and the stories of their eutrophication during the last two decades are summarised by Gibson (11) for L.Neagh, Herodek et al. (15,16) for L.Balaton and Okino and Kato (19,20) for L.Suwa. Also shown in Table I is the phytoplankton biomass expressed as the highest annual averages before the introduction of water treatment. The chlorophyll a is expressed per unit area (i.e., *concentration per unit volume multiplied by the mean depth*). Each lake has relatively high populations in their catchments, with approximately 200,000 around L.Suwa; 358,000 around L.Neagh; and 420,000 around L.Balaton (but an influx of nearly 2 million visitors each year). All three are typical of eutrophic lakes with phosphorus limitation dominating early in the year but nitrogen sometimes limiting later in the summer (11,13,15,19).

Pattern of recovery - nutrient reduction

Improved sewage treatment was started in all three lakes about the same time (Table I), with a gradual build-up to full effectiveness taking several years. By 1984, Suwa's P-loading was reduced by about 30% (19), in L.Neagh it was down by about 25 % (11) and in L.Balaton it was reduced by a third (15,16). So, all were relatively similar. Although this may seem a modest achievement, it should be put in context of a period of increasing P usage. For instance, in the L.Neagh catchment it increased from 0.6 to 1.6 g P per person per day from the beginning to the end of the decade (7). However, the overall reductions achieved at the sewage works were sufficient to ease the problems at the water extraction plants, which used to come under the greatest pressure in June and July when cyanobacterial crops were at their highest (11).

A major difficulty in reducing the P-loading further is that much of it comes from non-point sources (i.e., land-drainage, unsewered populations, etc) but Foy et al. (7) concluded for L.Neagh that if there was a 90% reduction in P at the 18 major sewage works then up to a 42% reduction in the loading might be achieved. By the end of the decade, this figure is being approached (Gibson, personal communication) and the lake does seem to be responding (Fig.1) but the decrease at the end of the eighties should be treated with some caution, as it is probably helped by climatic factors. The weather in these years was drier and warmer, similar to the mid 70's (10). At that time, the annual average phytoplankton biomass decreased (see Fig.1). This was against the trend of rising phosphorus usage just described. The reason

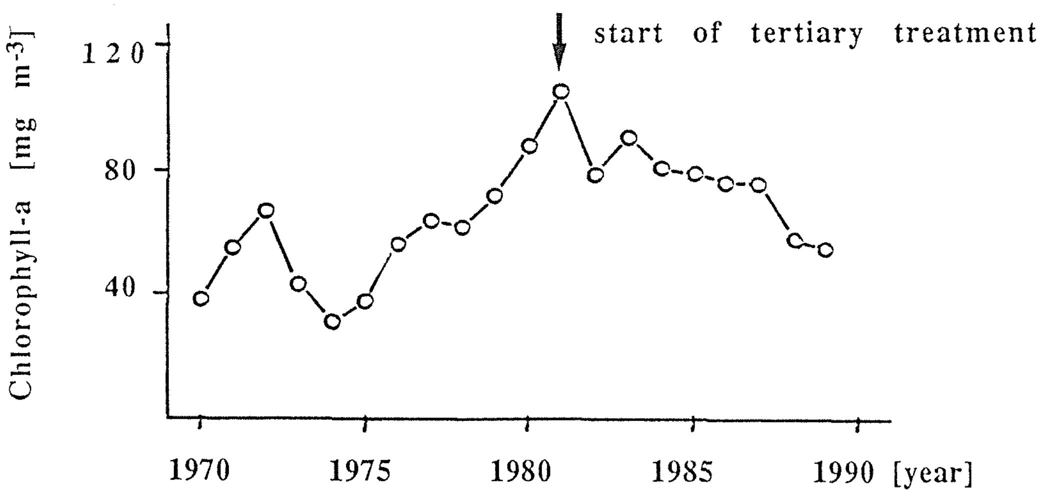

Fig.1. The annual average chlorophyll a concentration (mg m^{-3}) in L.Neagh from 1970 -1989. Data supplied by Dr.C.E.Gibson.

for this apparent paradox is because limitation of growth does not just involve phosphorus but also nitrogen, silica and light. Phosphorus, which mainly comes from sewage works, largely determines when and how high the main spring phytoplankton peak is, whereas nutrients that limit at other times, such as silica (spring diatoms,10) and nitrogen (in late summer,7), are derived more from land drainage (23). So, in drier years, there is less inwash of Si and N, and this reduces the annual average biomass used in Fig.1. Climatic variation also played a part in the pattern of recovery in L.Suwa, which had a summer typhoon in 1982 (19), and in L.Balaton in 1983 and 1985. Therefore, recovery programmes have to consider periods of time long enough to allow for such climatic perturbations.

Lack of recovery and events in the sediment

In deciding whether we can expect the underlying trend in improvement to continue, one of the major influences is the degree of internal recycling of nutrients. This is very much affected by events in the surface layers of the sediments (17). It is not necessary to have anoxic conditions to get release. In L.Suwa, Fukuhara (8,9) has shown that invertebrates are a major influence on nutrient release, utilising material buried down to over 30 cm below the sediment surface. In

L.Neagh the situation is similar, with chironomids (mainly detritivores, <u>C.anthracinus</u>) feeding to a depth of 10 cm and oligochaetes down to 30cm (see Fig.2). Their activity leads to a rapid depth dispersal of the diatoms sedimented after the spring growth period (Fig.2). They also help maintain a high redox potential, which favours high bacterial activity (Fig.2) and mineralisation. If this depth of activity is compared to the calculated accumulation rate of sediment in L.Neagh, which is about 1 cm per year (1), it becomes obvious that the balance is in favour of nutrients being recycled rather than being locked-up. In L.Balaton, where the top 8 cm of sediment are 'ecologically active', it has been calculated that this layer contains mobilizable phosphorus equivalent to 6-7 times the external load (14,15). Marsden (17) concludes that for lakes with a mean annual concentration of total phosphorus greater than 100 mg m^{-3} the sediment P release will compensate for reductions in external supply, unless the reductions are greater than 60%. Even then he quotes a number of examples that have failed. To get 60% reductions in these lakes, the difficult and costly problems of nutrients originating from non-point sources must be tackled.

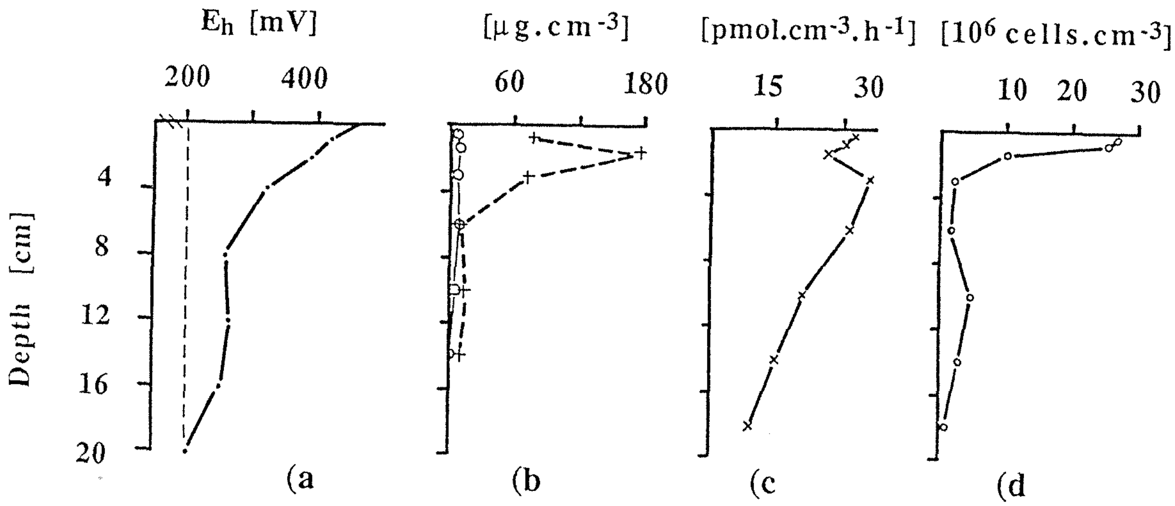

Fig.2. Depth distributions in the surface sediment layers of L.Neagh at 15m in April, after sedimentation of the spring diatom crop; a) redox (Eh), b) biomass, as dry weight, of oligochaetes (solid line) and chironomids (broken line), c) bacterial activity, as ^{3}H-thymidine uptake, d) live diatom cells, <u>Aulacoseira subarctica</u>.

RESTORATION OF LAKE MARGINS

Water level changes

One aspect, often overlooked, is the restoration of lake margins. In larger, shallow lakes a particular problem is that there would normally be large seasonal changes in water level. This is not often very easy to reconcile with modern human developments, especially if it involves frequent flooding. All three of the lakes discussed here have undergone drainage and lowering in the last 150 years. L.Suwa was reduced by 8.3% surface area in 1910. L.Neagh has had three lowerings, in the 1850's, 1930's and 1950's. The aims were to reclaim and improve drainage of agricultural land, as well as to prevent flooding and stabilise the water level. The normal summer level is now about 1.22m lower but the maximum level is about 3m down (cf. mean depth now 8.9m). However, most dramatic are the changes in L.Balaton. The lake area was one third larger in the seventeenth century (15) but the effect of drier climate and drainage work on the outlet (started in the 1850's) culminated in a drop of lake level of several metres, down to it's present mean depth of about 3m. The level is probably now 8m below it's maximum value in the 1500's but similar to what it was in Roman times. The aim of the engineering work, begun in the last century, was not just to lower the level but also to reduce the seasonal variation and prevent flooding. In both L.Balaton and L.Neagh, the variations in the 1800's were about 2.4m. Between 1978 and 1987 the engineering work on L.Balaton had made it possible to keep the level to an average of 31 cm, with only a few days below the specified minimum. In L.Neagh, the range is similar, except that during very wet weather the level may rise up to 0.75m above the minimum for several weeks.

Water level changes and the ecology of lakes

In L.Balaton, the first hydrographic surveys show that 250 years ago the shore was still undeveloped, with marshes of 200 km^2. After the water level changes in the second half of the nineteenth century, the exposed land was developed with railways, holiday homes and beaches but, crucially, without allowing for the effects of the changed hydrology of the lake. Problems of erosion started to arise, mainly on the sandy Southern shore, which has the most wave action. In some areas, with no reed protection, it eroded by 1.2m per year. Embankments were built in a very short time to protect the shore (Fig.3), as a result the total length of the open sandy beaches around the lake shrunk from about 75 km to less than 10 km by 1982 (27). The steep stone embankments, compared to shallow sloping sandy shores, changed the

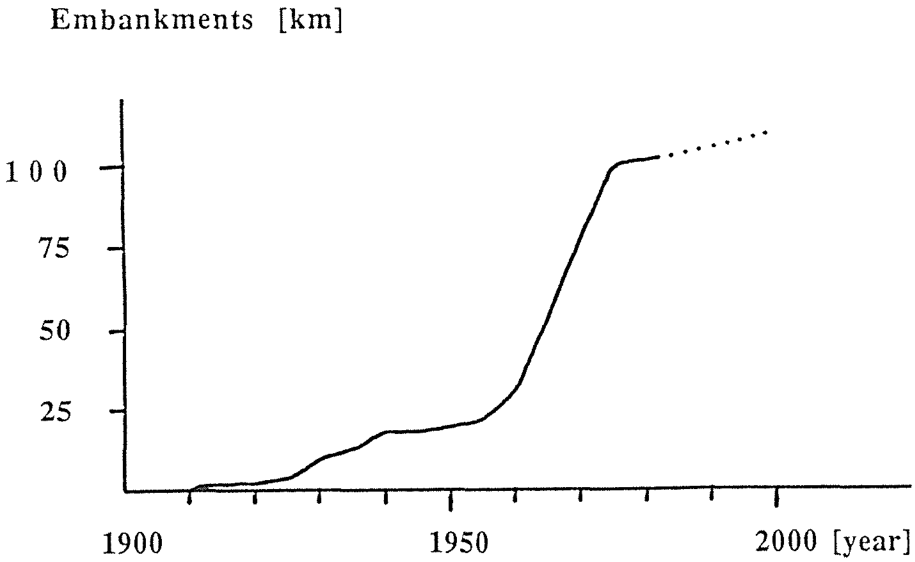

Fig.3. The increase of concrete embankments around L.Balaton between 1900 and 1982 (solid line), with the projected figures up to 2000 inserted as a dashed line.

energy dissipation patterns of the waves, resulting in major changes in sediment particle size and associated flora and fauna. Problems of erosion continued to occur because, with the stabilised water level, wave action became concentrated at particular points on the shore. In some cases, the embankments even became undermined and collapsed.

L.Neagh has similar sloping sandy shores around about one third of it's shoreline. These have a bar and trough system (4) with up to seven sand ridges (20cm high and 20m broad) running parallel to the shore for several kilometres. (The railway on Balaton was built on the inner most of the bars exposed by the lowering in the last century) The bars do not remain in one position but move when there is a combination of wave action and change in water level. The movement is offshore if the water level goes down and inshore if the water level goes up. In the bars in L.Neagh, benthic algae attached to the sand grains are buried up to 0.5m below the surface and can remain viable for over a year. One of the dominant species is the very rare diatom Cymbellonitzschia diluviana. It is probable that this is a habitat dating back to the last ice age (10,000 years ago). Associated with it are some of the earliest sites of human occupation in Ireland (26). Man used to move onto the exposed, dried-out sand banks near the outlet in summer and catch migratory fish species, such as eels and salmon in the narrow water channels. The present annual water fluctuations (about 0.75m) are just sufficient to maintain these bar systems, without causing major problems to other activities on the lake, and should be retained.

Water levels and the restoration of littoral areas

Experience in Sweden(3) has shown that recreating the original habitats when old lake levels are restored, is not easy, especially where there has been extensive growth of rooted vegetation. However, in all three lakes discussed here, the extent of development around the edges makes it unlikely that it will be possible either to raise the water levels or increase the annual fluctuations. L.Suwa is totally ringed by embankments, except where a short section has been removed, as an experiment in rehabilitation. In L.Balaton the stable water level is now the basis for an enormous tourist industry. The most that can be hoped for is that some water margin sites are set aside for conservation. More research needs to be done on the the interactions between inshore and offshore areas of lakes but recent studies are beginning to show how important littoral communities can be. For instance, in the shallow fen lakes of Eastern England, it has been found that algal biomass can be reduced, if sufficient artificial or natural refuge areas are provided to protect the zooplankton from fish predation (24). Of the three lakes, L.Suwa offers the best chance of this type of restoration, as it's shoreline is relatively large compared to it's volume A promising first step is the removal, in one small area, of the man-made embankments that encircle the lake. This is to try and recreate a more natural shoreline but to be of any real significance, there has to be a considerable improvement in light penetration to allow the macrophytes to grow.

Sakurai (22) has carried out a number of studies on the conservation and restoration of waterfronts in Japan and believes that for many lakes, where it is important to maintain a littoral plant community, a stabilised water level should be aimed for. However, there are exceptions, such as L.Neagh, where large annual lake level fluctuations, combined with frequent wave-action, have probably always reduced the importance of submerged macrophytes. In this case, the lake level changes, that would otherwise be so damaging, help the preservation of the mobile sand bank habitats which would have been familiar to hunter-gatherer man 8,000 years ago. He would also have been familiar with the shallow water diatomite deposits (Kieselguhr) that L.Neagh is so famous for but which are at present in great danger of being completely removed by commercial extraction and other developments.

In all cases, whether fluctuating water levels or not, more wetlands along the water margins (planted with endemic species) should be reintroduced (see Kis-Balaton, 15,16). Lough Neagh shoreline does not have the embankment problems of the others but it has lost the natural marshes and fen-carr associations, especially alder tree (Alnus) stands, around the edge of the lake. These were removed to try and give more agriculture land (largely grass for cattle grazing) but usually only gave very poor returns and could be relatively easily restored.

FINAL REMARKS

What do we want to restore lakes to?

All lakes go through an ageing process. We can only marvel at the perspicacity of the ancient Chinese and Japanese calligraphers who included the symbol for age in the character representing a lake. During the ageing of a lake, there are also likely to be long-term climate changes. On top of this, few lakes have escaped without man's intervention. For example, L.Neagh is probably now back to a water level similar to that after the last ice-age and L.Balaton to what it was in Roman times. Also, apart from changes to plant and animal communities from deteriorations in water quality, there have been species changes caused by introductions. For instance, L.Neagh has gained at least two invertebrate (Gammarus tigrinus and G.pulex) and two fish species (Rutilus rutilus and Perca fluviatilis). This in turn has led to changes in the wildfowl populations (25). Similar problems with introductions have arisen in L.Balaton, which has gained three fish species (eel, grass and silver carp). So, it is unlikely we can ever turn the clock back to some specific point in a lake's development.

Björk (3) has suggested that restoration means re-establishing environmental conditions that are acceptable and sustainable. Each lake is different and will need it's own solution. It is especially important to look at the whole lake catchment and to include the lake margins. Conservation areas must be large enough to enable the typical plant and animal communities of each particular lake to sustain themselves. This requires sensible management policies based on long-term monitoring programmes, such as those that have been carried out on these three lakes to date. The money needed to maintain such research is small when considered against the costs of restoration.

Restoration is not just for aesthetic reasons but can have important economic benefits. In L.Neagh, the present tertiary treatment largely pays for itself in reduced water purification costs. Also, it helps safeguard a £4 million per annum fishery (mainly eels, Anguilla anguilla). The tourism on L.Balaton is a major foreign currency earner, in a country restructuring its economy. Many of L.Suwa's problems can be traced to the rapid economic development from industries attracted into an area famed for its beauty (e.g., the painting of L.Suwa by Hokusai in his series of 36 views of Mt.Fuji). In conclusion, it is important that we should learn, from the problems of these three lakes, that recovery is far more difficult (and expensive) than prevention.

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