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Keeping pristine lakes clean: Loughs Conn and Mask, western Ireland

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Abstract

The large western Irish lakes are natural salmonid lakes and a unique ecological resource. Lough Mask (82 km^2) and Lough Conn (50 km^2), Co. Mayo, are among the finest, natural, wild brown trout fisheries in Europe. Recently, however, threats have arisen to water quality in Lough Conn as a result of agricultural intensification. A doubling of phosphorus (P) inputs to Lough Conn for the period 1980 to 1990 caused a number of ecological changes such as an apparent increase in littoral algal production; while arctic charr (*Salvelinus alpinus* L.) have also disappeared from the lake over the same period of time. The changes in Lough Conn appear to represent an early phase in the eutrophication process. The western Irish lakes represent a super-sensitive ecological category requiring particularly strict catchment controls in order to protect the diversity of native flora and fauna including unusual glacial relict species and the unique genetic strains of fish which are present. Catchment management committees were established in order to study and reverse the perceived early-stage eutrophication problem in Lough Conn and in order to prevent the occurrence of similar problems in the case of Lough Mask. These committees have a sectoral basis covering: agriculture, local authority functions (sewage, rural septic tanks, planning and environmental control), forestry, peat harvesting and drainage works, as well as having representation from the fisheries boards and the Environmental Protection Agency (EPA). Management of these relatively pristine lakes is perhaps a more difficult problem than that of cleaning up an obviously degraded resource. This is especially so since they are located in regions which are economically underdeveloped and where a real need exists to improve economic returns from farming, tourism and industry in the catchments. The importance of developing a sustainable, ecologically-based management strategy which will maintain existing high quality lakes into the next century with their irreplaceable genetic and ecological resources intact cannot be over-emphasised. The challenge is to devise refined management strategies which will eliminate nutrient wastage to waters and yet allow an appropriate level of sustainable development in the area. The management of Lough Conn and Lough Mask is described in some detail concentrating in particular on the efforts to reduce phosphorus loss from agriculture in the catchment but also emphasising the importance of a multi-sectoral approach to phosphorus load reduction.

Introduction

The large western lakes in Ireland are among the most important natural wild brown trout fisheries in Europe. In addition to their importance as angling lakes, they hold important populations of glacial relict species such as *Mysis relicta* (Lovén). Some of the more important lakes are characterised in Table 1. Lough Corrib in County Galway together with Lough Conn, and Lough Mask in County Mayo are the main western lakes which with their sister lakes, Cullin, Carra and Nafooey cover a surface area in total of some 330 km^2. Lough Melvin in Leitrim, Lough Arrow in Sligo and the Killarney Lakes, in particular Lough Leane, are also grouped under the general category of ‘western lakes’ for the purposes of this paper. In total these lakes comprise a large proportion of standing waters in the Republic of Ireland. Loughs Conn, Mask and Corrib are situated where the Carboniferous limestone of the Central Plain meets the harder more resistant siliceous rocks (granite, gneiss and schist) of the Connaught Uplands. Lough Leane in Kerry has a similar meeting of old red sandstone and granite. Lough Melvin in Leitrim/Donegal/Fermanagh is located on limestone bedrock. Lough Arrow, Co. Sligo is also situated on limestone with significant karst areas in the catchment. Limestone solution may have played some part in the formation of Lough Conn, Mask and Corrib, but their relatively great depth and position astride the major geological boundary suggests that selective glacial erosion by the Connemara ice-sheet may be the principal factor in the formation of these lakes.

This paper concentrates in particular on the management of Lough Mask (82 km^2) and Lough Conn (50 km^2), two of the largest lakes in this western group of lakes (Figures 1a, b). Recent, quite subtle water quality problems in Lough Conn are outlined and the approach taken to management of these problems is discussed. Preventative management has been initiated in the case of Lough Mask which is the most pristine of the western lakes group. Ecological management of fish populations is undertaken on an ongoing basis by the Central and Regional Fisheries Boards since the early 1960s. Both lakes are also important as a source of high quality drinking water for towns and rural communities in their catchments. The most pressing water management issue in respect of these lakes is that of controlling phosphorus inputs. Approaches to reducing the phosphorus load to the lakes are discussed and prospects for the future management of the lakes based on ecological principles are considered.

Lough Conn discharges southward through Lough Cullin to the River Moy. Typical runoff from Lough Conn's total catchment area of 414 km^2 averages approximately 12 m^3 s^{-1}. The River Moy/Lough Conn system was subjected to arterial drainage in the 1960s with a significant lowering in the level of Lough Conn such that the original shoreline and littoral regions are now quite different to that which evolved naturally following the lake's formation. Occasionally the flow at Pontoon bridge between the two lakes is reversed and enriched water of higher ionic content moves from Lough Cullin into Lough Conn – generally following periods of heavy rainfall in the southern part of the catchment but perhaps also during periods of strong southerly winds when a wind-driven current occurs.

Lough Mask, situated upstream of the Lough Corrib catchment, receives drainage from Lough Carra (a highly calcareous system) and discharges principally through underground channels, through karst limestone, to Lough Corrib. A canal at Cong was excavated between 1848 and 1854 to link Loughs Corrib and Mask. The canal was never completed, however, due to a combination of economic and engineering circumstances. Today the channel is dry over much of its length during the summer months as the canal was never staunched to prevent water flowing into the underlying caverns (Delany, 1988). It is necessary to rescue trout from isolated pools along the 6.5 km channel as levels fall each year. Lough Corrib tributaries were subject to modern arterial drainage – the River Clare and tributaries in the period 1954–1962 and the Black and Headford region between 1967 and 1973. Arterial drainage was also carried out in the Carra/Mask catchment between 1979 and 1985.

Irish water quality management generally is guided by the principle that Irish waters are inherently salmonid due to climatic and biogeographical factors. Thus, salmonid criteria are generally applied to rivers and lakes. While the fish and associated ecological communities of salmonid waters are intrinsically important, the use of salmonid criteria which imply strict standards and highest quality waters has a range of added benefits in that:

1. all amenity uses are ensured if the salmonid criteria are met; and
2. the treatment requirements for drinking water and industrial abstraction are significantly less than they are for water from eutrophic sources.

Fish populations

Table 1 lists the fish species found in Lough Mask and Lough Conn, and compares them with a number of the other large western Irish lakes. These lakes are all important salmonid lakes and continue to support natural indigenous fish stocks dating from the Ice Age. These systems are ideally suited to the proliferation and propagation of salmonid species. The lakes are well supplied with natural, fast-flowing tributaries which for the most part are clean and unpolluted providing ample spawning and nursery areas for salmonids. Such nursery and spawning rivers yield up to 0.1 salmon parr per m^2 (O'Grady, pers. comm.). Because of the insular location and oceanic influence on the climate, water temperatures normally fluctuate between 4 and 21°C. Ice cover is rare, except for Lough Carra adjoining Lough Mask where substantial ice cover can occur occasionally, e.g., the winter of 1982/1983. The lakes are relatively shallow, expansive sheets of water exposed to turbulent mixing with mainly erosive stony shores.

Both Lough Conn and Lough Mask hold large stocks of wild brown trout (*Salmo trutta* L.). The latter

Table 1. Location, morphology and fish species present in some large western Irish lakes

Lake	OS Reference	Area (ha)	Max Depth(m)	Altitude (m)	Trophic status	Fish species
Arrow	G 79 13	1264	28	55.2	Mesotrophic	3,5,6,9
Carra	G 17 74	1620	20	20.4	Mesotrophic	3,5,6
Conn	G 18 13	5211	40	12.5	Mesotrophic	1,3,[4],5,6,8*,
Corrib	M 27 33	16841	50	8.8	Oligotrophic/ Mesotrophic	1, 2, 3, [4], 5, 6, +7, 8,9
Leane	V 93 88	2000	67	19.8	Mesotrophic	1, 2∗, 3, 4, 6, 7*, 10, 11
Mask	M 11 62	8294	58	20.7	Oligotrophic/ Mesotrophic	3, 4, 5, 6, +7*
Melvin	G 90 52	2125	45	21.3	Mesotrophic	1, 2, 3, 4∗, 6, 8

Key to fish species:
1 = Salmon, *Salmo salar* L.; **(2)** = Sea Trout,*Salmo trutta* L.;
(3) = Brown Trout, *Salmo trutta* L.; **(4)** = Arctic Charr, *Salvelinus alpinus* L.;
(5) = Pike, *Esox lucius* L.; **(6)** = Perch, *Perca fluviatilis* L.; **(7)** = Roach,*Rutilus rutilus* L.;
(8) = Rudd,*Scardinius erythrophthalmus* L.; **(9)** = Bream,*Abramis brama* L.;
(10) = Tench, *Tinca tinca* L.; **11** = Shad, *Alosa fallax killarnensis* (Lacepede).
+7 = present since 1977. **[4]** = no longer present. * occasional encounter only.
Note: Eels, Minnows, Three- and Ten-spined Sticklebacks are present in all these lakes.

water contains several brown trout sub-populations: including the large ferox trout which feed on other fish and 'Gillaroo' which feed primarily on molluscs. These varieties also occur in Lough Melvin where they have been shown to be genetically distinct (Ferguson & Mason, 1981). The relatively rich feeding conditions in these predominantly limestone lakes allows trout to grow to substantial sizes in comparison with the stunted fish characteristic of oligotrophic mountain lakes in regions of igneous bedrock geology (Kennedy & Fitzmaurice, 1971). Lough Conn has an Atlantic salmon run (*Salmo salar* L.) but L. Mask is isolated by its underground outflow which links it to Lough Corrib and, therefore, does not have a migratory salmon run. In the past both lakes have also had significant arctic charr populations (*Salvelinus alpinus* L.). Maitland & Campbell (1992) note that it is unusual for charr to occur in relatively productive lakes such as the large Irish lakes. Lough Conn, however, suffered a dramatic collapse of its charr population in the late 1980s (O'Grady, 1992) due perhaps to early-stage eutrophication impacts (McGarrigle et al., 1993). Similarly, recent stock surveys of Lough Corrib suggest that the charr population of Lough Corrib has suffered a similar decline within the past decade (O'Grady, pers. comm.). Lough Mask, however, still holds a large stock of charr (O'Grady, pers. comm.).

Kennedy & Fitzmaurice (1971) reported ferox trout eating other trout in Lough Conn in the winter of 1968/1969 but their occurence is thought to have been related to a shortage of food following the lowering of the lake. Lough Conn is regularly fished for salmon using trolled baits; and ferox trout, if present, would be captured using this method also (Tolan, pers. comm.).

Both Lough Conn and Lough Mask also have populations of introduced pike (*Esox lucius* L.), which in Irish is called *an gall iasc* or 'the foreign fish'. Coarse fish species such as perch (*Perca fluviatilis* L.) and rudd (*Scardinius erythrophthalmus* L.) occur in some of the lakes listed in Table 1 and roach (*Rutilus rutilus* L.) were recently introduced into the Lough Corrib and Lough Mask catchments. The unique combination of species makes these lakes particularly important in European terms.

Other ecological features of the western Irish lakes

The open water of these lakes is moderately hard with relatively low colour and good transparency (Flanagan & Toner, 1975). The isolated projection to the southwest of Lough Mask (known locally as 'Upper Mask') and a similar north western extension of Lough Corrib contain low ionic water draining from the siliceous mountainous formations adjoining this area of the lakes. This part of Lough Corrib is an area of special scientific interest because the aquatic floral assemblages exhibit special features which are pecu-

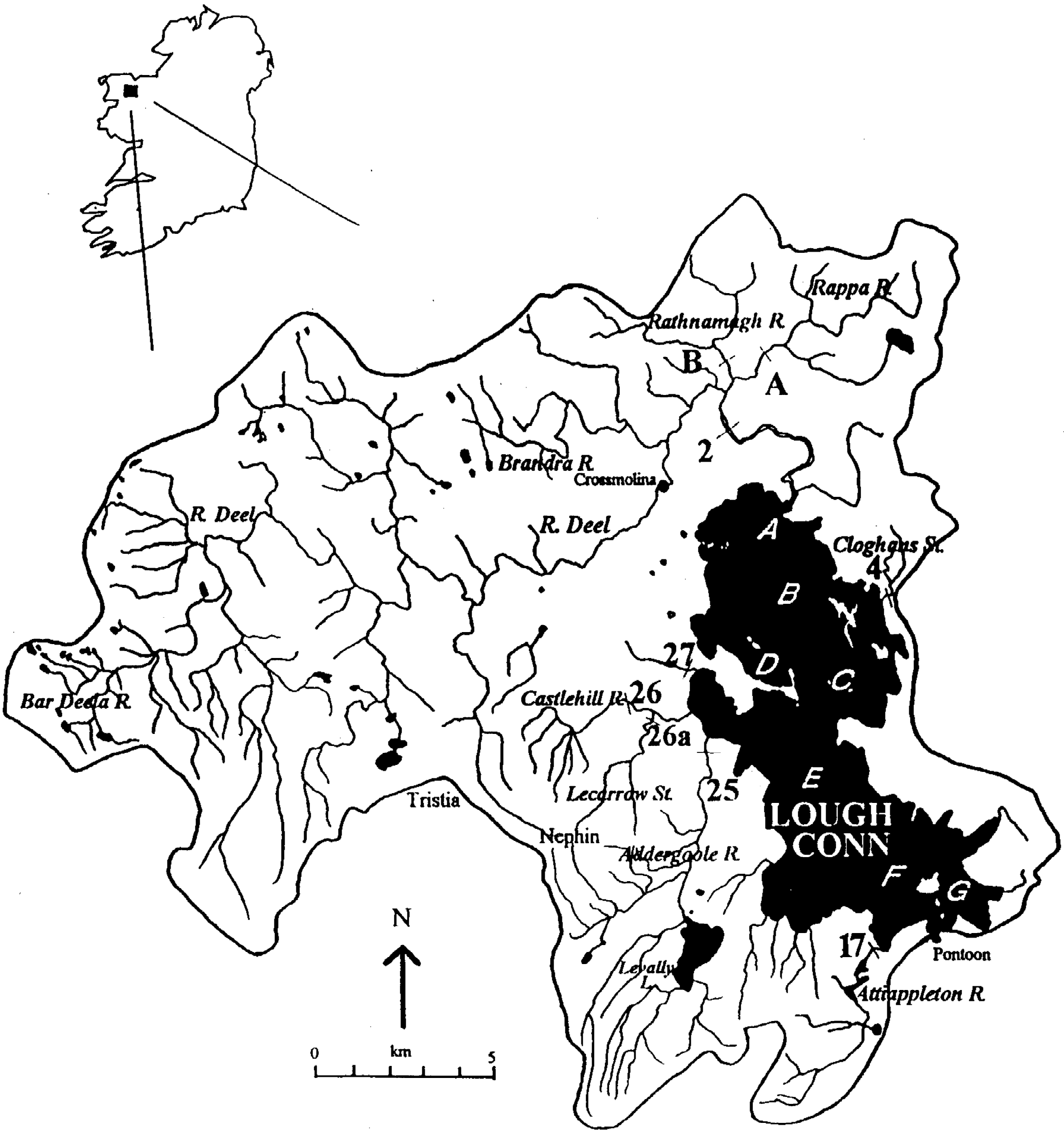

Figure 1. (a) Map of Lough Conn showing main tributaries and phosphorus loading sample stations.

liarly Irish: in particular, the occurrence of *Eriocaulon septangulare* With. and *Najas flexilis* Rostk & Schmidt (Krause & King, 1994). These authors describe these species as being widely distributed in North America and *Najas* is also widely distributed in Ireland, but usually in more enriched waters, while *Eriocaulon* is well distributed but largely confined to Connemara. Elsewhere in Europe, both species have a limited occurrence in Scotland, with *Najas* also recorded from Russia. *Eriocaulan septangulare* also occurs in 'Upper Mask' (King, unpublished data).

Stoneworts (charophytes) are widely distributed in Loughs Corrib and Mask with the densest communities occurring on the eastern embayments where they extend to depths of 6.0 m. One species, *Chara desmacantha* J. Gr. & B.W., grows to 20 to 35 cm and overwinters successfully as green plants. The species is largely confined to Ireland, Scotland and England. In locations where it occurs on the Continent the plants

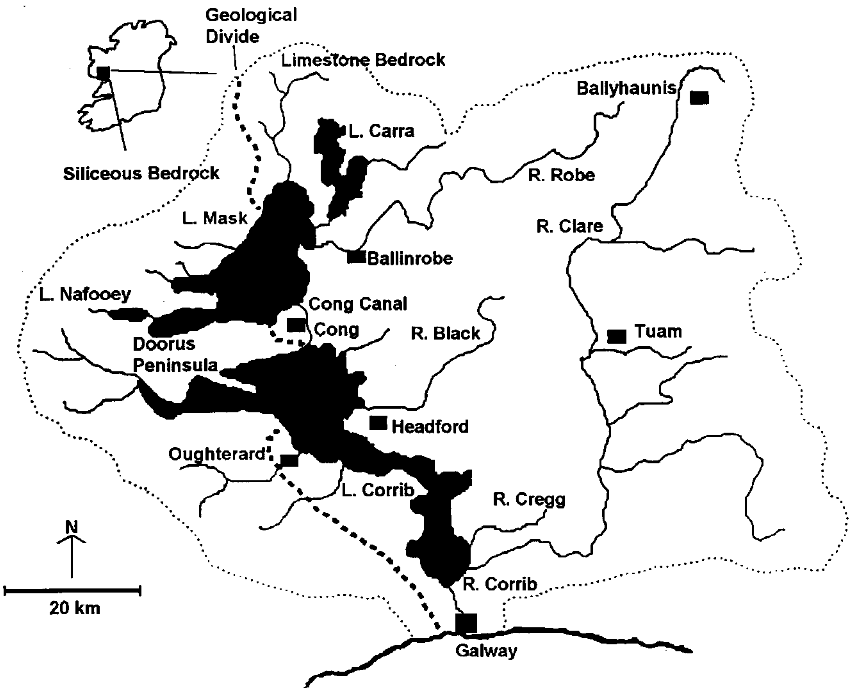

Figure 1. (b) Map of Lough Mask and Lough Corrib system showing main tributaries and east-west geological divide.

are stunted due to climatic factors there preventing overwintering of green apical buds (Krause & King, 1994). This species also occurs in Lough Conn, but the charophytes are more localised there, being confined to sheltered bays (Cloghans Bay and Pratt's Bay) with sparse cover in sheltered locations near Pontoon at the southern end of Lough Conn (Champ & King, 1988).

The western lakes are also noteworthy in that they have a number of unusual macroinvertebrate species; the glacial relict *Mysis relicta* Lovén occurs in Lough Corrib, *Niphargus kochianus irlandicus* Schellenberg, a sightless cave dwelling amphipod has been reported from deep water in Lough Mask (Gledhill et al., 1993) and *Gammarus tigrinus* Sexton has been recorded in Lough Conn O'Grady (pers. comm.). The interesting glacial relict chironomid species, *Corynocera ambigua* (Zetterstedt), has been recorded in Lough Corrib and perhaps may occur in others of the western lakes also (Murray & Ashe, 1983).

The large lakes along the western seaboard, therefore, possess unique ecological communities as evidenced by the flora, macroinvertebrate fauna and fish. Ferguson (1986) dealing with the genetic divergence of genetically isolated 'island' populations of brown trout in Lough Melvin states "The salmonid fishes are amongst the most native and unique components of the Irish fauna. They have been around for 10 000 years and in some cases are found nowhere else in Western Europe".

Water quality status of Lough Conn and Lough Mask

In terms of trophic status, Lough Conn is mesotrophic but with eutrophic tendencies in its North Basin in recent years; while Lough Mask remains on the oligotrophic/mesotrophic boundary. Table 2 gives the typical range of annual mean values for total phosphorus (TP), chlorophyll and Secchi disk. Figure 2 illustrates annual mean TP and chlorophyll values in Lough Conn over the 20 year period 1975–1995 and Figure 3 illustrates annual mean TP and chlorophyll levels for Lough Mask for the period 1976–1995.

Lough Conn

The arctic charr population of Lough Conn suffered a dramatic crash in numbers in the late 1980s and the species is now believed to be virtually extinct in the lake (O'Grady, 1992; McGarrigle et al., 1993). As stratification rarely lasts for more than a few weeks

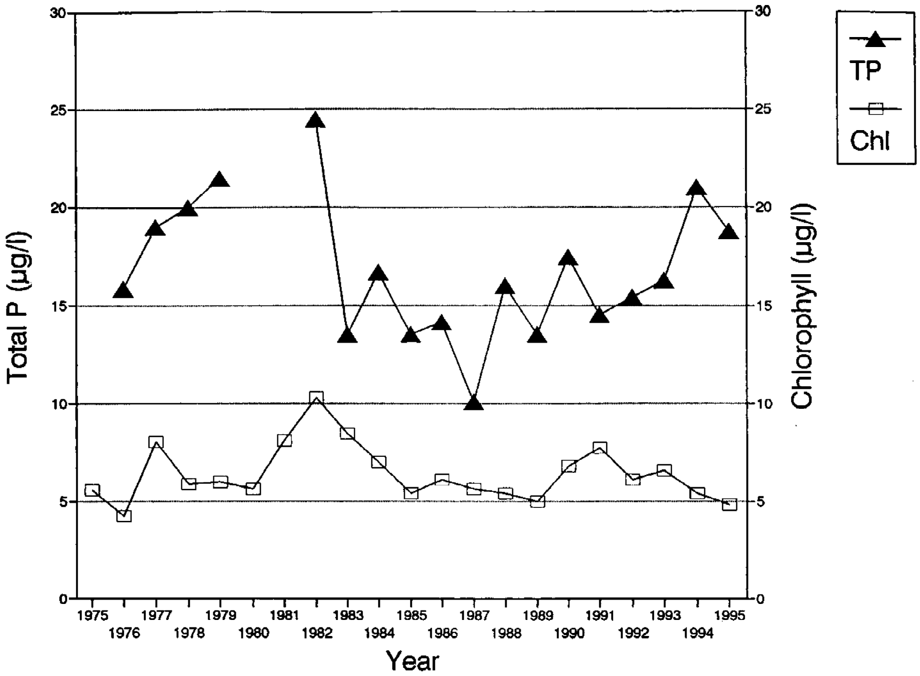

Figure 2. Lough Conn mean annual chlorophyll and total phosphorus 1975–1995

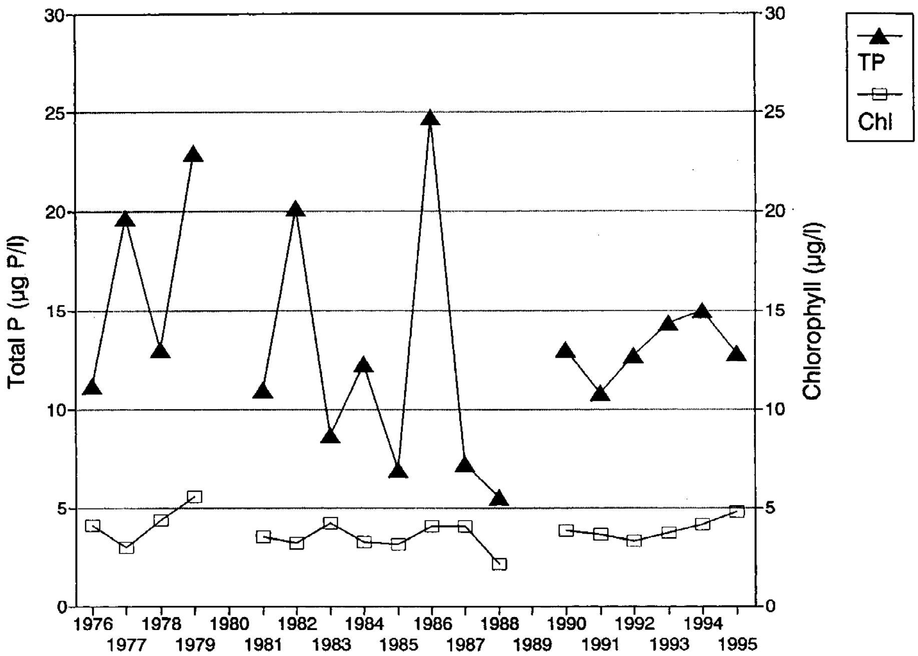

Figure 3. Lough Mask annual mean chlorophyll and total phosphorus 1976–1995

at most, even in the calmest of years, classic hypolimnetic oxygen depletion does not occur. Thus, the loss of charr could not be attributed to hypolimnetic oxygen depletion. Nevertheless, the possibility that eutrophication was responsible for the loss of arctic charr in Lough Conn led to an intensive study to quantify the phosphorus (P) loading to the lake. Monthly open lake monitoring carried over the period 1975–1992 by the Central Fisheries Board did not at the time show any statistically significant trends in chlorophyll, Secchi disk or in the nutrient chemistry of Lough Conn (see Figure 2 for annual mean total phosphorus and chlorophyll). There did, however, appear to be a significant increase in the frequency and intensity of littoral algal growths and accumulations of *Anabaena* (cyanobacteria). These signs, together with the fact that in the Spring of 1990 gill nets placed in the lake overnight became clogged with algae were taken to indicate a change in the ecology of the lake. Significant deposits of senescent *Oscillatoria* combined with filaments of *Mougeotia* were noted on stony littoral areas which would have previously been suitable for charr spawning. It is hypothesised that this may have been implicated in the charr's demise as Baroudy (1995) points out that charr eggs may be particularly sensitive to adverse conditions.

Lough Conn had been reported as mesotrophic since the 1950s, with algal types and abundance indicating mesotrophic conditions e.g. Macan & Lund (1954), Round & Brook (1959), Flanagan & Toner (1975), Champ (1977), Toner et al. (1986) and Clabby et al. (1992). West & West (1906), however, surveying the algae in late August 1904, found dominant algal types which suggested that Lough Conn was oligotrophic or at least oligo-mesotrophic at the time. The suggestion of a change in trophic status is also supported by Murray (1980) who, on the basis of a paleolimnological investigation, suggested that the lake had undergone accelerated eutrophication particularly since the 1960s as evidenced by increasing level of algal pigments in the upper sedimentary layers deposited since the 1960s. In these studies the arterial drainage programme of the 1960s is clearly evident in the sedimentary record as sharp peaks in sodium, iron and manganese levels in cores from the lake. A more detailed study of phosphorus inputs to Lough Conn had been carried out over the period 1979–1982

Table 2. Trophic characteristics of Lough Conn and Lough Mask

	Mask	Conn
Total P (μg P l^{-1})	8–25	9–44
Chlorophyll (μg l^{-1})	0.9–10.3	2.0–13.6
Secchi Disk (m)	3.7–6.1	1.2–3.6

covering all the major inflowing streams to the lake (An Foras Forbartha, unpublished data). This study was one of a series of studies on the trophic status of Irish lakes and it provided a good baseline for a repeat survey carried out in the early 1990s (McGarrigle et al., 1993). This latter survey revealed a striking change in the phosphorus runoff pattern in some of the larger tributaries of Lough Conn. In the 1979–1982 survey in-stream phosphorus concentration was not correlated with rainfall or streamflow in any of Lough Conn's tributaries. In the 1990–1991 survey, however, a strong positive correlation was found between rainfall or streamflow and in-stream unfiltered molybdate reactive phosphate (MRP) in two of the lake's largest tributaries: the River Deel (246 km^2) and in the Addergoole River (40 km^2) (Figure 1). Not all streams exhibited this change suggesting that a real change had occurred in some areas of the catchment and that the difference in runoff pattern was not simply an artefact due to methodological or climatic differences.

The pattern of increasing phosphorus concentration in rivers was taken as an indication of non-point source runoff from agricultural sources which is quite episodic in nature. The implications of this type of episodic increase in phosphorus concentrations during rainfall events is quite important when calculating phosphorus loading to the lake, as there is a multiplier effect between increasing hydraulic load and simultaneously increasing phosphorus concentration. Thus, in the 1990–1991 period the highest concentrations occurred at times of highest flow; whereas 10 years previously there would not have been any increase in concentration during a wet weather event. This meant that the pattern of phosphorus loading to Lough Conn had undergone a remarkable change in quite a short period. In fact the investigation suggested that the loading of TP to Lough Conn had approximately doubled from 18 to 35 t P ann^{-1} in the period between 1980 and 1990 (McGarrigle et al., 1993). The 'natural' background loading of phosphorus to the lake was expected to be of the order to 9 t P assuming a reasonably high specific runoff value of 0.25 kg P ha^{-1} ann^{-1}. This is a typical export figure for some of the cleaner stream sub-catchments of Lough Conn but nevertheless, still significantly greater than the export coefficients noted in the western Lough Mask streams, for example. Thus, the load to the lake was already quite high in 1980 at double this estimated background figure. Follow-up studies since the initial Lough Conn Report in 1993 (McGarrigle et al., 1993) confirm the strong positive correlation

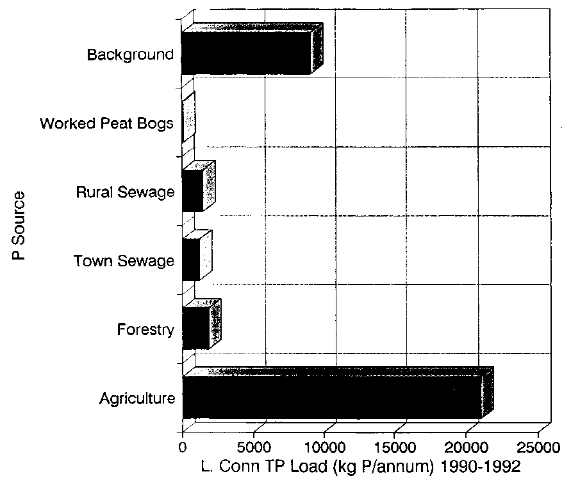

Figure 4. Sectoral breakdown of annual phosphorus load to Lough Conn in the period 1990–1993.

between in-stream phosphorus concentration and rainfall or streamflow. Using autosamplers, taking up to 8 samples per day in selected sub-catchments, it has been possible to demonstrate that there is an underlying, highly predictable, component of phosphorus loading which is dependent on rainfall amounts or streamflow. This predictable proportion can be as high as 90% of the total export from some small catchments (McGarrigle et al., 1997).

Total phosphorus loading from each of the major phosphorus sources in the Lough Conn catchment is illustrated in Figure 4. The manner in which this budget was established is discussed in detail in McGarrigle et al. (1993). The major component of the phosphorus budget is agricultural and as many of the other phosphorus sources, such as town sewage, have not changed very much over the 10-year period, the increase in phosphorus load was believed to be largely agricultural in origin. This is not unexpected, however, as major changes in agricultural practices have occurred in the west of Ireland consequent on European Union Common Agricultural Policy and linked Irish Government policies. This has resulted in a move away from traditional extensive type farming (i.e. grazing, hay making and outwintering of cattle) towards intensive fertilisation and silage making, with winter housing of cattle and spreading of animal manures.

The increased phosphorus load may now be affecting in-lake TP as there is an apparent increase from 1985 to 1995 whereas in the early 1990s a statistically significant pattern was not evident (Figure 2). Open lake chlorophyll values, however, do not yet show an upward trend. The lake sampling programme was primarily a monthly, two location mid-lake sampling programme. In view of the episodic nature of the phosphorus inputs it is possible that this programme may miss such peak values. The inflowing streams were sampled on a weekly basis and even then, many of the peak-flow, high concentrations were missed due to the episodic nature of the inputs. Unweighted MRP concentrations in the Deel River, for example, increased only slightly from 19 to 25 μg l^{-1} P (P<0.05) over the period 1980 to 1990; whereas the flow-weighted concentration doubled in the same period. Thus, it is not unexpected that the monthly open lake sampling programme could miss many of the high TP values. Rapid sedimentation may also be partly responsible for the lack of an apparent increase in mid-lake concentration. The upper, North Basin of Lough Conn is large but quite shallow (2161 ha and 4.4 m mean depth) such that there is plenty of contact between water and sediments and ample opportunity for sedimentation processes to rapidly reduce the inflowing phosphorus concentration. Occasionally, however, very high TP values have been observed following heavy rainfall. A period of intense rainfall occurred in late May and early June in 1993. Following this on 10 June 1993, a TP value of 135 μgl^{-1} P was observed in the lower Deel River and a corresponding mid-lake TP value of 53.5μgl^{-1} P in the North Basin. A chlorophyll peak of 17.8 μgl^{-1} was also measured on the same day in the North Basin. In comparison, a South Basin TP value of 14.6 μgl^{-1} P was recorded on the same day. It is possible that these events which are short-lived, but nevertheless accounting for a disproportionately high percentage of the annual phosphorus load, are not adequately represented in the normal monthly sampling programme. What was quite noticeable (and perhaps more so in retrospect) was the occurrence of winter shoreline blooms or, more correctly, algal accumulations following wet weather events. In Lough Conn these accumulations along shorelines are almost invariably dominated by the cyanobacterial genus *Anabaena* which is positively buoyant and cannot hold its position during calm conditions. In the autumn of 1995, for example, following a long dry summer the first heavy rains brought a series of shoreline blooms during calm weather following the initial wet spell. These shoreline accumulations can occur throughout the winter months. The frequency and intensity of cyanobacterial blooms (*Anabaena* and *Oscillatoria*) may be quite an important phenomenon in these large lakes, perhaps even with regard to their impact on the early life stages of the *Salvelinus alpinus* which spawn in the gravel areas of the shallows.

Lough Mask

Figure 3 illustrates the annual mean TP and chlorophyll levels in Lough Mask over the period 1976–1995. It can be seen that Lough Mask is on the oligo-mesotrophic boundary on the basis of the OECD fixed boundary system (OECD, 1982). Recent fish stock surveys show that it still has a large arctic charr population and while brown trout numbers have dropped, this is believed to be due to a combination of pike predation and recruitment problems due to pollution of some of the smaller streams in the River Robe catchment especially (O'Grady, pers. comm.). In general the ecological quality of the lake is of a very high standard. In view of the problems with Lough Conn, however, a very conservative approach is being taken to the issue of ecological quality in Lough Mask. Lough Mask is the 'jewel in the crown' of the western Irish lakes and it is important that it is maintained in top quality condition.

A TP load measurement programme was put in place in December 1995 with daily autosampling of two of the major tributaries (River Robe and River Owenbrin) supplemented by a weekly grab sample from each of the other important tributaries. Only preliminary results are available from this survey but it has demonstrated that the River Robe contributes a disproportionately high fraction of the TP input to the lake (preliminary findings suggest 85% of the total load). A new phosphorus removal plant came into operation at Ballinrobe Town (population equivalent 5000) near the mouth of the River Robe in early 1996 and this will reduce the annual phosphorus loading to the lake by at least 3 t P per annum. Winter loading of agricultural phosphorus is also a problem in this catchment and a diffuse runoff pattern similar to some of the Lough Conn streams is evident in the upper Robe catchment where there are no industrial or municipal discharges. In national surveys the River Robe has been classified as eutrophic in recent years on the basis of results of routine ecological assessments and physico-chemical surveys (e.g. Bowman et al., 1996; McGarrigle et al., 1996). On the western side of the catchment there has been a problem with overgrazing by sheep on the upland bog and moorland regions of the Partry Mountains. The Owenbrin catchment is affected in this manner, but the overgrazing does not appear to have had any significant effect on the total phosphorus concentrations in the river, as total phosphorus levels are very low throughout the year ($<10\ \mu g l^{-1}$ P). Some afforestation has taken place in the catchment particularly in the last 15 years but forest cover accounted for less than 3% of the total catchment area in 1990.

Lake catchment management strategies

Lough Conn

A Lough Conn Management Committee was convened by Mayo County Council in 1992 as a result of the perceived water quality problem in the lake. The Committee has representatives from all the major bodies which are likely to have an impact on the lake as well as the regulatory agencies. Included are the local authority, Mayo County Council, the convenor of the Committee; Coillte, the state forestry company; Bord na Móna, the state peat harvesting company; the state's farm advisory service, Teagasc; the Farm Development Service of the Department of Agriculture, Food and Forestry; the Central and North Western Regional Fisheries Boards, the fisheries managers who also represent the anglers; and the Environmental Protection Agency. While there is potential for conflict due to the diverse interests of the bodies involved, the Committee has been highly successful in obtaining agreement among the participants regarding management strategies and tactics. The fundamental guideline was that all sectors were required to reduce their phosphorus inputs to the lake. Thus, even those responsible for relatively small proportions of the lake's overall phosphorus loading had to demonstrate some progress was being made towards reducing this loading. This approach makes it more acceptable for the larger contributors, especially the agricultural sector, to introduce more wide-ranging programmes for phosphorus reduction. It was felt to be important that the local authority, in particular, should be seen to be reducing the municipal sewage phosphorus loading as a gesture of 'good faith', so to speak, in order to encourage farmers to participate in the phosphorus reduction programme. The Committee's technical report which outlined the nature of the Lough Conn problem, also agreed a wide ranging series of management recommendations aimed at halving the phosphorus load to the lake (McGarrigle et al., 1993). These were divided up on a sectoral basis covering agriculture, forestry, town sewage, rural sewage and peat harvesting. A series of recommendations for further research into the particular problems of these relatively pristine western lakes was also drawn up.

The following sections outline the principal recommendations of the Lough Conn Report in each of the sectors relevant in the Lough Conn catchment.

Agriculture

In the mid- to late 1980s, EU-funded agricultural improvement schemes in the catchment led to the installation of many new cattle housing units in the Lough Conn Catchment with concomitant slurry storage facilities. Much of this was aimed at general farmyard pollution problems. However, new problems arose due to the consequent increase in land application of slurry in the autumn and a build up of soil phosphorus levels caused by increased use of phosphorus fertiliser. The recommendations, therefore, emphasised the need for further environmental improvements and farm nutrient management measures.

Advice and education

A specific educational campaign for farmers in the catchment was recommended to increase their awareness of the water quality problems caused in the lake by agriculture and to make them more aware of the practical solutions that are available. This includes the commissioning of videos and booklets/leaflets, evening classes, demonstrations and public meetings, and covering topics such as nutrient management planning (NMP) concepts, timing and rate of nutrient applications, slurry spreader calibration to ensure target applications are achieved and quality control of slurry storage systems to minimise dilution with waters. Significant progress has been made in raising local awareness of these topics.

Nutrient Management Planning (NMP)

An important recommendation was for the introduction of an NMP service for farmers in the catchment which will assist them in ‘fine tuning’ their nutrient application rates on a field-by-field basis. The objective of NMP on the farm is to maximise the efficiency of crop uptake of applied nutrients from either artificial fertilisers or animal manures. This can be achieved by applying the nutrients at the required rate and at the correct time. This simultaneously achieves a reduction in nutrient wastage to waters, effecting an improvement in water quality.

The rate of nutrient application is determined by the crop to be grown (e.g. grass for silage or grazing) and soil fertility levels (i.e. the lower the soil fertility the higher the nutrient requirement). NMP focuses attention on the importance of soil and slurry testing in determining the crop’s nutrient requirements and in establishing the nutrients present in organic ‘wastes’. The fertiliser value of the nutrients in animal manures is often discounted by farmers. As a consequence the full complement of artificial fertilisers may be applied following slurry applications – resulting in excessive nutrients being applied. The fertiliser value of the applied animal manures must be emphasised and due account taken of this contribution to the crop’s requirement. NMP emphasises this concept by recommending appropriate application rates for slurries and ‘top up’ fertiliser application rates on a field-by-field basis, taking soil fertility, slurry nutrient content and crop characteristics into consideration. The objective is to reduce to a minimum the quantity of nutrients which might be washed off the land. NMP also reminds farmers of the savings that can be made by putting a monetary value on the nutrient content of animal manures. NMP has since been incorporated into national policy measures as part of the REPS programme and the Waste Act.

Slurry application

Recommendations were made for calibration of vacuum tankers to ensure that the target slurry application rates are achieved. Similarly, slurry application equipment and methods were recommended including buffer zones near watercourses and ensuring that sufficient vacuum tankers were available to farmers in the catchment in order to provide maximum flexibility with respect to weather conditions.

Nutrient applications should be made during the growing season and not in late autumn/winter – e.g. slurry should be spread on silage ground, ideally after the first and second cut silage. A co-ordinated and targeted campaign was recommended to convince farmers that fertiliser and slurry applications prior to a heavy rainfall event, increases the risk of nutrient runoff and results in an increased pollution risk and a loss of expensive nutrients. In general, there is a strongly held belief among farmers in the region that rain is required following nutrient applications to ‘wash’ them into the soil. In a high rainfall area, like the Lough Conn Catchment, this practice of waiting for rain prior to the animal manure application may be a very important factor which increases the risk of phosphorus runoff. Changes have since occurred in the slurry spreading practices used in the catchment with, for example, slurry spreading immediately after silage cutting now being quite a common practice.

Control of dirty water

Dirty or soiled water from farmyards is a significant source of nutrient loss from agriculture. Control of dirty water from farmyards can only be achieved on an individual farm basis as the appropriate controls (volume reduction, storage and land spreading options) require farm-specific data. The Committee recommended the provision of grants to assist farmers to install efficient, cost-effective control systems for dirty water.

Cattle access to streams

The fencing of stream and river banks was recommended in order to control animal access, to create buffer strips and riparian corridors. A small number of cattle standing in a stream can cause severe disruption. Deposition of dung and urine can result in an increased nutrient load to the lake as well as a significant BOD loading to the stream itself. In addition, grazing and trampling of bankside vegetation causes destabilisation of river banks.

EU Agri-environmental programme

In advance of the introduction of the EU Agri-Environmental Programme a series of suggestions were made which the Committee hoped would be incorporated into the Irish Government's Rural Environmental Protection Scheme (REPS). These recommendations were again aimed at reducing phosphorus losses from agriculture to water and they covered grant-aid for machinery, for NMP, soil testing and reduction in the use of artificial fertiliser. Assistance for streambank fencing was also recommended and for the creation of buffer strips along rivers and streams. Programmes were also recommended for the redirection of farm building roof water away from cattle yards, thereby minimising slurry dilution, controlling dirty water and for general improvement of slurry storage facilities. Many of these recommendations were actually incorporated into the REPS programme for Irish farmers which was introduced in 1994. After a slow uptake initially, approximately 30% of farms in certain key catchments are now participating in the REPS programme and obtaining financial support for the type of nutrient loss reduction practices outlined above. The nature of the REPs programme means, however, that it is more attractive to less intensive farmers. Intensive farmers who would be required to reduce their nutrient inputs to participate in REPS are slower to become involved.

Research needs

Recommendations were also made for research programmes related to agricultural impacts in particular: research into the precise forms of phosphate runoff which are causing problems – e.g. to quantify the relative importance of runoff from fields vs. farm- yards and of slurries vs. artificial fertiliser. Research was also recommended into the use of vegetated buffer strips and silt/nutrient traps as a means of reducing nutrient runoff from diffuse agricultural sources under Irish conditions. Similarly, areas such as research aimed at further refinement of the timing and methodology of slurry and fertiliser application in the Lough Conn, catchment were mentioned in the context of research into diffuse agricultural runoff.

Forestry

A number of recommendations were made aimed at controlling the loss of phosphorus from forestry. While previously most attention in Ireland was directed towards the acidification impacts of forestry in poorly buffered regions, the western lakes committees were concerned at the possibility of phosphorus leaching from forestry in upland bog areas. Thus, recommendations covered areas such as minimisation of phosphate leaching by following correct procedures in ground preparation and fertilisation, e.g. Fishery and Forestry Guidelines (Coillte/CFB, 1990). Ground preparation in all circumstances within the catchment should be by mounding and it was recommended that double mould-board mole ploughing should be discontinued. Fertiliser should be spread before turning the sod so that the fertiliser is trapped beneath the sod at the beginning in order to reduce the likelihood of leaching. Aerial fertilisation of trees should not be allowed within the catchment. Reduction of the likelihood of phosphate leaching from peaty soil should be an important management criterion. It was also recommended that large-scale planting of conifers in blanket peat areas should not take place. It was recommended that the lower size threshold of 200 ha for mandatory forestry Environmental Impact Statements should be eliminated altogether such that all forestry developments would require EISs. (In fact, this size limit was reduced to 70 ha by the Department of Agriculture, Forestry and Food in 1996). An emphasis was also placed on the importance of monitoring of phosphorus leachate from coniferous plantations within the catchment – especially in the 4 to 5-year period immediately following planting and fertilisation. Similarly, it was felt that the impact of clear-felling on erosion and leaching and phosphorus transport should be carefully monitored in the catchment. The hydraulic implications of large-scale drainage of blanket and raised bog areas for forestry (and peat production) also requires study. On a related matter it was felt that an assessment should be made of the potential long–term hydrological impacts of mature canopies – evapotranspiration, water retention (possibly with a reduced or rainfall regime under a global warming scenario).

Municipal sewage treatment

Upgrading of the secondary treatment capacity of the Crossmolina works was regarded as an important step as the existing secondary treatment plant is overloaded and phosphate removal is required in order to reduce the output of phosphorus from the town to the lake (population equivalent 1100). In the summer months phosphate values are routinely measured downstream of the STW which are some 10–100 times the level required to limit eutrophication. Phosphate stripping at a 90% removal rate would reduce the contribution from Crossmolina to approximately 125 kg phosphorus per annum and make a substantial contribution to reducing the overall load to Lough Conn. It was also recommended that an educational programme to encourage the use of phosphate-free and low phosphate detergents in the Crossmolina area be undertaken as inevitably it will take some time before a new sewage treatment plant could be constructed and brought on line. Low phosphate detergents have become quite popular with a market share of approximately 40% even in the absence of bye-laws to prohibit the sale of high phosphate detergents.

Hotels and institutions

With respect to point sources, such as hotels and institutions located near Lough Conn, it was recommended that the phosphorus loading to the lake from these institutions should be quantified, and targets set for reducing their individual phosphorus contributions. Phosphate-free detergents should be encouraged for dishwashers and laundry in these hotels and institutions.

Rural septic tanks

Domestic septic tanks are known to cause significant problems to surface waters in waterlogged areas or to groundwater in areas with thin soil overburden layers. A series of recommendations were made aimed at minimising the contribution from this source. Strict planning controls are required for individual houses adjacent to the lake. Groups of houses with septic tanks should be actively discouraged within 400 m of the lake. A number of other recommendations such as improved maintenance of septic tanks were also included in the Committee’s recommendations. Mayo County Council subsequently made a number of changes in their planning regulations implementing many of these suggestions.

Peat harvesting

In general terms it is recommended that every effort should be made to minimise the release of both particulate and dissolved humic substances from the commercial bogs in the catchment. Improved design and location and maintenance of settling ponds may be required particularly in order to avoid the flushing out of already settled material in wet weather. The area of silt ponds in use was doubled following the Committee’s recommendations.

General research and monitoring recommendations

The Lough Conn report demonstrated the value of baseline surveys and ongoing lake water quality surveys. Without the previous survey in 1979–1982 it would not have been possible to gauge the extent of the change which occurred in the late 1980s and early 1990s. A number of gaps are apparent, however, in our knowledge of the lake. In particular it appears that the mid-lake sampling programme may need to be supplemented or intensified in order to detect the subtle early-stage eutrophication changes which the lake was undergoing. In the case of Lough Conn it was recommended that greater emphasis be placed on the assessment of the shallow littoral areas of the lake in order to obtain a better understanding of the nature of the algal blooms that occurred in these areas. Regular mapping of the lake’s rooted vegetation was also required. Intensive lake sampling should be undertaken following rainfall events. Modelling of the phosphorus pathways through the lake itself should be undertaken – with particular emphasis on phosphorus sedimentation processes, the uptake of phosphorus by phytoplankton and rooted vegetation and the role of humic substances in transporting P.

The Lough Conn investigations highlighted the need for a broadly-based ecological approach to the assessment of lakes and in particular the western lakes which are relatively pristine. This would include an assessment scheme which would include surveys of the extent of littoral vegetation, frequency of shoreline blooms and algal accumulations, and surveys of benthic invertebrates, zooplankton and phytoplankton species and assessment of fish populations. While Irish rivers are regularly assessed both in terms of their water chemistry and biology, Irish lakes have not received adequate coverage in the past – due to the large numbers of lakes (over 5500) and the limited resources available.

Since the publication of the Lough Conn Report, however, a range of lake-related research projects have been supported by the Irish Environmental Protection Agency with European Regional Development Fund (ERDF) funding. The projects included research to develop an ecological 'early warning' system to detect early stage eutrophication problems in the western lakes concentrating particularly on the littoral zone of the large western lakes. Another project is developing an ecological assessment methodology for lakes more generally which will be capable of filling the requirements of the Draft Directive on the Ecological Quality of Surface Waters as well as predicting state change within individual lakes. A third project is refining remote sensing chlorophyll detection algorithms for Irish lakes and developing techniques for aquatic vegetation mapping and catchment land use mapping. A fourth research project is developing catchment models predicting phosphorus losses to water from soils based on soil phosphorus burden, soil type, rainfall amounts, slope, etc. These projects are also charged with producing a common geographical information system (GIS) for Irish lakes which will combine data sets from all of the projects. Many hundreds of lakes and their catchments have been surveyed and assessed in the course of these and other lake research projects which are currently being funded.

Management of Lough Mask

Following the experience with Lough Conn a catchment management committee was set up for Lough Mask and more intensive monitoring programme was started in order to provide a solid basis for management recommendations. Rather than waiting for the results of such monitoring to be completed, however, it was decided that relevant recommendations from the Lough Conn catchment should be put in place for the Lough Mask catchment immediately. This approach was agreed in view of the perceived urgency of the need to protect these important lakes, and in view of the results obtained for Lough Conn which is a neighbouring catchment with similar land use practices. In catchment management terms the Lough Conn recommendations were generally desirable and uncontroversial; such that they should be more widely implemented in any case.

In addition to the Lough Mask Committee, a separate programme under the EU Tourism Angling Measure for Ireland is in place aimed at improving and maintaining the fish stocks of the Lough Mask and Lough Corrib catchments. This programme also has a water quality element which is carried out in liaison with the Lough Mask Committee. Ecological management of fish populations is part of this programme and it includes stream habitat rehabilitation (especially following arterial drainage programmes) in order to maximise salmonid spawning, nursery and holding areas over the full life cycle of salmonid fish. Management of introduced species such as pike, which are salmonid predators, also forms part of this programme and fish population assessments have recently been completed for Lough Mask and Lough Corrib (O'Grady, *pers. comm.*). Measures to prevent the introduction of alien species are also in place nationally, as well as controls on the movement of fish between water bodies.

Farm surveys

In both the Lough Conn and the Lough Mask catchments the intensive phosphorus loading surveys carried out identified regions in the catchments which were responsible for a large proportion of the phosphorus exported. These were predominantly the more intensive agricultural regions with the main activities being grassland dairy and beef farming. Farms in these areas were targeted for a blanket survey in order to build up a picture of the phosphorus budget for the agricultural sector in defined sub-catchments. Voluntary co-operation was received from virtually all farms approached and detailed individual farm questionnaires were completed covering details such as animal numbers, artificial fertiliser usage, foodstuffs usage, the area devoted to growing silage on the farm, the area used for grazing of animals, the volume of tanks used for slurry and soiled water containment. Soil phosphorus levels are also recorded where available. The general condition of the farmyards and of their overall pollution risk is also assessed. The data gathered were incorporated into a catchment GIS.

Large catchments such as Lough Conn and Lough Mask (combined area of almost 1500 km^2) at first sight present a major logistics problem in carrying out farm surveys and in pinpointing pollution sources, especially diffuse sources, as there are many thousands of farms in the catchments. The detailed surveys of phosphorus loading from subcatchments demonstrated that there are localised 'hot spots' which are responsible for a large fraction of the phosphorus exported from the catchment. This concept leads to the possibility that limited subcatchments can be targeted for intensive surveying and pollution control measures in order to maximise the return on effort invested. Two approaches have proved useful in the case of these western lakes. First, the use of the GIS-based CORINE land use map for Ireland enables all areas of more intensive grassland agriculture to be pinpointed on a map. Areas of 'improved pasture' in particular tend to coincide with the more intensively farmed areas with higher soil phosphorus burdens, for example. The second technique in use is the rapid ecological screening of streams in a catchment using the national Quality Rating or 'Q-Value' System (Flanagan & Toner, 1972). This entails surveying streams which are smaller than those normally included in national river surveys. Rapid surveys allow colour-coded GIS maps to be prepared which highlight the polluted streams in the catchment. Overlaying the two sets of maps and placing the polluted streams over the intensively farmed regions gives an initial set of priority regions for immediate attention. This region of overlap will comprise quite a small proportion of the total catchment area and thus, allow surveys which are more manageable in that they include hundreds of farms rather than many thousands. It is hoped to refine this system further by producing a more detailed phosphorus loss model which takes a wider range of driving forces into account – this is currently the subject of an EPA funded research programme as mentioned above. This should also help to further narrow down the main sources of diffuse agricultural phosphorus loss in a catchment. Significant reductions in phosphorus losses can be achieved by the use of farm surveys followed up by advice and encouragement to use NMP on farms and, if necessary, legal action to prevent unnecessary phosphorus losses from farmyards and fields. It is concluded that reducing agricultural phosphorus losses to water can be a manageable proposition by pinpointing the catchment's most likely 'hot spots' for phosphorus loss and then targeting the farms in these relatively limited regions.

The follow-up programme deals with farms which were obviously causing water quality problems due to either direct farmyard losses or to field surface and subsurface runoff. Initially general pollution control advice is given and warnings regarding the likelihood of legal action if a major improvement is not apparent in subsequent inspections. Failure to make the required improvements results in the farmer being issued with a 'Section 12' Notice under the Water Pollution Act which requires specified changes or improvements to be made on the farm. Legal proceedings follow subsequently if this formal legal notice is not complied with. Another recent introduction in Irish environmental law (Waste Act) is the facility to allow local authorities to require farmers to prepare nutrient management plans in order to control the nutrient fluxes on farms and thus to reduce nutrient losses to water. The Fisheries Boards may also prosecute polluters under the Irish Fisheries Acts.

Conclusion

The large western Irish lakes are important in the wider European context and not solely in the Irish context. Ecological management is crucial for the future well being and ecological health of these lakes. The current management strategy has placed strong emphasis on the need to reduce the phosphorus loadings to these lakes. The management teams now in place for Lough Conn and Lough Mask have worked well in this context and in future the same committees should be capable of tackling other ecological problems such as overgrazing which is a major issue in parts of these catchments at present. Similarly, problems which are less pressing at the moment but which may become more important in future – climate change impacts, shoreline aesthetics, alien species introductions and the like – can be tackled by multi-agency committees of the type now in place for Lough Conn and Lough Mask.

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