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CONSERVATION MANAGEMENT OF THE FRESHWATER PEARL MUSSEL
Margaritifera margaritifera
Part 2: Water quality requirements

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DISCLAIMER

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Summary

The conservation of the freshwater pearl mussel *Margaritifera margaritifera* (L.) requires action to improve and maintain river quality conditions for this species. This includes controlling the physical effects that contribute to river bed deterioration, and the water quality parameters in which the mussels must live. For effective conservation, both aspects of river quality must be addressed. This volume deals with establishing the water quality parameters required for pearl mussels to live and reproduce effectively.

A survey of *Margaritifera margaritifera* was carried out at 526 sites in 149 Irish rivers. Comparisons were made between sites with and without mussels. A subset of 123 of these sites were statistically examined to look for correlations with 31 physical and chemical parameters. The historical water chemistry records of nine of these rivers were also examined.

Living populations of *M. margaritifera* were found in 49 sites on 28 out of the 149 rivers surveyed. Only 8 of these sites had very young mussels present. Conditions in rivers were generally good, with low numbers having silted conditions. Rivers with mussels had significantly more gravel, and less silt, erosion and canalisation. Sites with older mussels only had significantly more overhanging trees than sites with no mussels, and sites with young mussels present had significantly less algae than sites with no mussels.

Chi-square comparisons on the 123 sites tested showed additional significant associations between mussel rivers and certain stream orders, a short distance to the sea, the presence of a lake upstream, a small altitude drop from the source, a high Q-value, and low conductivity, pH, oxidised nitrogen and BOD values. Surrounding land use, and ortho-phosphate levels were also significantly different when rivers with different mussel status were compared.

Rivers with good populations of mussels had consistently lower ortho-phosphate and oxidised nitrogen levels than rivers with poor mussel populations in the historical water chemistry data comparisons.

Mussel populations with large numbers of individuals and juveniles occur more frequently in rivers with low nutrient levels and unsilted gravel. Stricter water quality standards are needed for waters where pearl mussels are to be conserved than are currently used for protecting salmonids.

Introduction

The aim of this work is to propose a set of water quality levels that reflect the minimum requirements that *Margaritifera margaritifera* require in order to reproduce effectively and to live for the duration of their normal lifespan.

Since 1987, pearl mussels populations or dead shells have been recorded from 129 10km squares in the Republic of Ireland (Moorkens, 1999). However, few of these populations are large, or have evidence of recent recruitment. *Margaritifera margaritifera* is classed as vulnerable on the IUCN red data list (Wells *et al.*, 1983). It is listed under Annex II and IV of the EU Habitats Directive and Appendix II of the Bern Convention and is protected under Statutory Instrument SI 112 of 1990 in Ireland (Wildlife Act, 1976).

The decline in pearl mussel populations may not be as a result of serious water quality reduction. It may reflect the very high quality of waters needed for this species. Long term trends show a continuing decline in the length of unpolluted water channel in Ireland, from 84% in 1971 to 57% in 1994, with a five-fold increase in the extent of slight pollution and a three-fold increase in moderate pollution (Environmental Protection Agency, 1999). It is therefore essential to the conservation of this species to establish the extent of the high water quality needed for pearl mussels while remedial action is still possible.

This volume is divided into two sections. The first section addresses the current legislation controlling Irish *Margaritifera* water quality. The second section provides the research background to proposals for new legislation based on work in the Republic of Ireland.

1. Current Water Quality Regulations

The pearl mussel, *Margaritifera margaritifera,* is found in a variety of Irish rivers, from the main channels of large water-courses to small streams in isolated areas. The legislation covering the quality of these waters derive from four main sets of regulations:

<u>E.C. (Quality of Salmonid Waters) Regulations, 1988 (S.I. 293 of 1988)</u>
This legislation prescribes quality standards for waters designated by local authorities to be of "Salmonid Quality". The regulations give effect to Directive 78/659/EEC on the quality of fresh waters needing protection or improvement in order to support fish life. The regulations allow for designation of the waters to which they apply, sampling programmes and methods of analysis and inspection. These are used by local authorities to determine compliance with the standards.

<u>Local Government (Water Pollution) Act, 1977</u>
This act includes a general prohibition against water pollution as well as provisions on licensing direct and indirect discharges, water quality standards and management plans. Orders under this act include procedures regarding the licensing of discharges to waters and sewers, including regulations regarding controls of chemical pollutants. Examples are the (Control of Cadmium Discharges) regulations (S.I. 294 of 1985), (Control of Hexachlorocyclohexane and Mercury Discharges) regulations (S.I. 55 of 1986), and more recently (Water quality standards for Phosphorus) regulations (S.I. 258 of 1998). The Phosphorus regulations are of particular importance to *Margaritifera*. They implement Directive 76/464/EEC (dangerous substances). They apply to all waters, not just those designated for conservation or salmonid quality. This directive is retrospective, i.e. water qualities in respect to Phosphorus should not have deteriorated since its implementation.

<u>E.C. (Quality of Water Intended for Human Consumption) Regulations, 1988 (S.I. 81 of 1988)</u>
These regulations set quality standards which must be met by all water supplies either intended for consumption or for use in the food and drinks industry.

<u>Waste Management Act, 1996</u>
This act has a number of sections that relate to management planning. Of particular importance is section 66, which deals with nutrient management planning and provides a legal framework for local authorities to deal with non-point sources of pollution.

There are various other regulations that either directly or indirectly affect water quality (Table 1.1). In looking at these legislative tools as a means of regulating pearl mussel rivers, two questions arise. Firstly, are pearl mussel rivers covered by these regulations, and secondly, are the water quality standards within these regulations sufficient for a healthy pearl mussel, i.e. a population able to recruit young mussels and live to an age appropriate to the life span of this species. In answer to the first question, all pearl mussel rivers must comply with the Local Government (Water Pollution) Act, 1977. Only those rivers designated as of Salmonid quality must comply with the E.C. (Quality of Salmonid Waters) Regulations, 1988 (S.I. 293 of 1988). These are mostly the main channels of larger catchments and would not include many *Margaritifera* populations. Some pearl mussel rivers would also be used as the source of drinking water supplies and would be covered by the E.C. (Quality of Water Intended for Human Consumption) Regulations, 1988 (S.I. 81 of 1988). Clearly, a Margaritiferid water quality standard would help to ensure an equivalence of responsibility for high water quality across all Margaritiferid designated rivers.

The second part of this report addresses the question as to whether the above water quality standards are sufficient for pearl mussel populations.

Table 1.1 Environmental Legislation directly or indirectly affecting Water Quality in Ireland.

Council of the European Community (1975) Surface Water Directive (75/440/EEC)
Council of the European Community (1976) Bathing Water Directive (76/160/EEC)
Council of the European Community (1976) Pollution caused by certain Dangerous Substances discharged into the aquatic environment of the Community Directive (76/464/EEC)
Council of the European Community (1978) Freshwater Fish Directive (78/659/EEC)
Council of the European Community (1979) Conservation of Wild Birds Directive (79/409/EEC)
Council of the European Community (1979) Methods of Analysis Directive (79/869/EEC)
Council of the European Community (1979) Shellfish Waters Directive (79/923/EEC)
Council of the European Community (1980) Drinking Water Directive (80/778/EEC)
Council of the European Community (1982) Mercury discharges from Chlor-Alkali industry Directive (82/176/EEC)
Council of the European Community (1983) Cadmium /Discharges Directive (83/513/EEC)
Council of the European Community (1984) Mercury discharges other than from Chlor-Alkali industry Directive (84/156/EEC)
Council of the European Community (1984) Hexachlorocyclohexane Directive (84/491/EEC)
Council of the European Community (1985 Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC)
Council of the European Community (1986) Protection of the Environment (Sewage sludge) (86/278/EEC)
Council of the European Community (1986) Limit values and quality objectives for discharges of certain Dangerous Substances Directive (86/280/EEC)
Council of the European Community (1991) Urban Waste Water Treatment Directive (91/271/EEC)
Council of the European Community (1991) Protection of Waters from Pollution by Nitrates Directive (91/676/EEC)
Council of the European Community (1992) Conservation of Natural Habitats and of Wild Fauna and Flora Directive (92/43/EEC)
Council of the European Community (1996) Inregrated Pollution Prevention and Control Directive (96/91/EEC)
Public Health (Ireland) Act, 1878
Local Government (Planning and Development) Acts, 1963 to 1993
Local Government (Water Pollution) Acts, 1977 and 1990
Environmental Protection Agency Act, 1992
Waste Management Act, 1996
Local Government (Water Pollution) (Control of Cadmium Discharges) Regulations (1985) S.I. No. 294 of 1985
Local Government (Water Pollution) (Control of Hexachlorocyclohexane and Mercury discharges) Regulations (1986) S.I. No. 55 of 1986
EC Quality of Water intended for Human Consumption Regulations (1988). S.I. No. 81 of 1988
EC Quality of Salmonid Waters Regulations (1988). S.I. No. 293 of 1988
Quality of Surface Water Intended for the abstraction of Drinking Water Regulations (1989). S.I. No. 294 of 1989

Quality of Bathing Water Regulations (1992). S.I. No. 155 of 1992
Local Government (Water Pollution) Regulations (1992) S.I. No. 271 of 1992
Local Government (Water Pollution) Reguations (1993) (Control of Aldrin, Dieldrin, Endrin, Isodrin, HCB, HCBD, and CHCl3 Discharges) S.I. No. 348 of 1993
EC Quality of Shellfish Waters Regulations (1994) S.I. 200 of 1994
Local Government (Water Pollution) Reguations (1994) (Control of Carbontetrachloride, DDT and Pentachlorophenol Discharges) S.I. No. 43 of 1994
Local Government (Water Pollution) Reguations (1994) (Control of EDC, TRI, PER and TCB Discharges) S.I. No. 245 of 1994
Environmental Protection Agency Act Regulations (1994) (Urban Waste Water Treatment) S.I. No. 419 of 1994
Quality of Bathing Water Regulations (1996). S.I. No. 230 of 1996
Waste Management (Use of Sewage Sludge in Agriculture). S.I. No. 148 of 1998
Local Government (Water Pollution) Act, 1977 (Water quality standards for Phosphorus). S.I. No. 258 of 1998

2. Assessment of Water Quality Requirements of Pearl Mussels based on Irish Studies

2.1 Introduction

In mainland European countries, *M. margaritifera* has declined (Dyk and Dykova, 1974; Wells *et al.*, 1983), with Bauer (1988) estimating a decline of over 90% this century in pearl mussels in Central Europe. Until this survey, there has been no evidence of decline of this species in the Republic of Ireland. In fact, Eugene Ross studied a range of populations of rivers in the west of Ireland in the early 1980's and found healthy populations (Ross, 1988). However, a recent survey of Northern Ireland found no juveniles and a probable lack of recruitment since the early 1980's (Mackie, 1992). The aim of this study was to survey as much of the country as possible to establish the general status of *M. margaritifera* in Ireland.

Decline of water quality has been implicated as the primary reason for the international decline of *M. margaritifera* (Wells *et al.*, 1983). Eutrophication was subsequently noted as the main problem (Bauer, 1988), and more recently, the impact of eutrophication on the quality of the substratum in which *Margaritifera* lives was highlighted (Buddensiek *et al.*, 1993). Thus water quality parameters for a range of rivers over the years are also included in this study.

2.2 Materials and Methods

A sample of rivers from 15 of the 26 counties in the Republic of Ireland were surveyed between 1990 and 1995. The remaining 11 counties lie on mainly calcareous rock and/or have little history of records for *M. margaritifera*. In all, 526 sites were surveyed on 149 rivers. Sampling was carried out by examining rivers at regular intervals, by wading in shallow areas, and snorkeling in deeper areas. If no mussels were found within 100 m in one hour, the site was deemed negative and the next site was examined. In sites where mussels were found, longer stretches (approximately one kilometre) were surveyed from the access point. Presence of dead shells, river bed substratum type, proximity to river bank, land use nearby, other species present, presence of macrophytes or filamentous algae, possible pollution sources, and sizes of mussels present were noted.

The ecology of populations containing young mussels and those with low numbers of adults only were compared for parametres directly or indirectly associated with water quality. For the 133 sites where data were available, 31 parameters were compared. Data on stream order, distance from sea, distance from source, presence of lake upstream, altitude, and altitude drop from source were all taken from 1/2" maps. Substrate type was categorised by observation as mainly bedrock, boulders, cobbles, gravel, or sand/silt. Presence of silt was positive if over 50% of the bed was covered in a layer of silt. Overhanging trees were positive for sites with more than 50% trees overhanging at least one bank. Sites were positive for eroded banks if more than 20% of one or both bank was visibly eroded. Agricultural practices were categorised by the most common use of land in the 50m from the bank. Human population living upstream was categorised, using maps, into either scattered dwellings only, one small village, or one or more towns upstream. Presence of filamentous algae was noted if 25% or more of the river bed was affected. Presence of *Ranunculus* or any macrophytes covering 50% or more of the river bed were noted. Levels of median and maximum conductivity, pH, ammonia, ortho-phosphate (reactive phosphorus, measured without pre-treatment), and oxidised nitrogen (sum of nitrate and nitrite) were compared to test both the normal levels for that river, and the highest, but as these are calculated from monthly samples, pollution incidents can be missed. Maximum temperature, BOD (Biochemical Oxygen Demand), and chloride were also compared, and maximum and minimum dissolved oxygen. The most recent Q-value (a macro-invertebrate water quality index ranging from Q1 (bad) to Q5 (good)) for each site was also compared. Test comparisons were made between rivers that had living mussels and no living mussels, and also between a subset of rivers having mussel records by comparing the status of mussels within these rivers. Pearson chi-square statistics were carried out for each parameter. This tested if the levels or presence/absence of parameters were the same in each river status category. Chi-squares were calculated by summing the squares of the differences between observed and expected counts using the JMP® software package. Correlations were also drawn using JMP®, using the equation for best fit in each case.

Finally, the role of declining water quality over time on mussel population size was assessed. Changes in nine pearl mussel rivers were studied by comparing the status of their mussel populations and the changes in their water chemistry since records began. Water chemistry records were taken from EPA data which includes water analysis since 1978 in some cases, in others 1988. Annual median and maximum levels of nutrients were calculated from monthly samples in most cases, but sometimes months are missed and there can be as low as seven samples per year (e.g. Owenriff, 1990). One site from each river was taken, where living pearl mussels were found over the previous four years. The sites at three of the rivers had good *M. margaritifera* populations with young mussels (5 years or younger). These were the Dereen (a tributary of the Slaney), the Mountain (a tributary of the Barrow) and the Owenriff (Corrib catchment). A river Nore site was included, and a river Slaney site, which had few, scattered adults only, comparable to the status of the hard water *durrovensis* population in the Nore. The Derry (a tributary of the Slaney) had very few adults, the Multeen (a Suir tributary) had only seven living mussels over a kilometre, and the Tar (a tributary of the Suir) and the Clodiagh (the Waterford Suir tributary) had only five and two living mussels respectively over a kilometre (Table 2.1).

2.3 Results

In all, 28 out of 149 rivers surveyed had populations of *M. margaritifera*, with 49 positive sites out of 526 (Fig. 2.1). These sites included some with old records for pearl mussels (18 rivers), and some new sites (10 rivers). It was found that 100% of sites with pearl mussels contained gravel (Table 2.2, Fig. 2.2). There was silt present at 336 sites (64%), and at 16 sites with mussels (33%). Filamentous algae was found at 235 sites (45%), with a lower percentage at sites with mussels (31%). Macrophytes were found at 144 sites (27%), with a higher percentage at sites with mussels (33%). Overhanging trees were found at 107 sites (20%), but at 47% of sites with mussels. Bank erosion was found at 136 sites (26%), and at 16% of mussel sites. Canalisation was evident at 130 sites (25%), but at only one mussel site.

Only 8 of the 32 positive sites had young mussels (5 years and under). Anecdotal evidence of pearl fishing was noted in 5 of these rivers. Two rivers were fished recently, which resulted in hundreds of dead mussels (the Leannan and Owenriff) according to local landowners. An attempt to fish the Bundorragha was curtailed recently by landowners, and the Newport and Glaskeelan rivers have been fished in the past, according to locals. There was a marked absence of silt, filamentous algae, macrophytes, bank erosion and canalisation in the best mussel sites. While habitat differences between sites with young mussels and sites with older mussels only were not significantly different (due to low numbers of young mussel sites), presence of silt, gravel, overhanging trees, erosion and canalisation were factors which significantly separated sites with and without mussels (Table 2.4). The best mussel sites had a significant lack of filamentous algae. There were a significantly higher number of trees overhanging sites with older mussels, but not with young mussels. The best mussel sites were in exposed sites, and where trees were present they did not shade the mussels.

A total of 123 of the above sites were examined statistically in more detail for a range of 31 parameters (Appendix 1). Five of these sites had young mussels and large populations, 3 had large populations of older mussels but no juveniles, 18 had low numbers of living adults, 9 had dead shells only and 88 had no evidence of pearl mussels.

Chi-square comparisons between all sites based on presence and absence of mussels showed significance for 15 of the 31 parameters (Table 2.5). If the same parameters are tested on the subset of rivers which have mussel records, and these rivers are categorised by mussel status (Table 2.6), there are 12 significant parameters (Table 2.7). Q- values were consistently high (Q 4-5 or Q5) in the best mussel rivers (Fig. 2.4) and conductivity was consistently low at the same sites (Fig. 2.5). PH values were higher in sites with low numbers or no mussels (Fig. 2.6), as were oxidised nitrogen (Fig. 2.7) and BOD values (Fig 2.8). Minimum dissolved oxygen values were higher in rivers with mussels than in those without (Fig. 2.9). The stream order of the best mussel rivers was between 2 and 4 (Fig. 2.10).

Comparing the historical water chemistry data for 9 rivers showed that maximum annual temperature has not steadily increased or decreased over the years but fluctuates as expected (Fig. 2.11). Median ortho-phosphate levels did increase in the 1980's in the Nore but have improved in recent years (Fig 2.12). The rivers with more favourable mussel populations (Owenriff, Mountain, Dereen) had consistently lower median ortho-phosphate levels, while those with severely depleted mussel numbers have had a number of elevated levels here. The same is true for maximum orthophosphate levels (Fig 2.13), with some of the more severely depleted mussel rivers including the Nore exceeding the EC salmonid river limit of 0.07 mg l^{-1} which exists to counter eutrophication (Table 2.10).

A similar pattern is observed in the median values for oxidised nitrogen (this is the total of nitrate and nitrite levels), with the Nore showing elevated levels in recent years, the Derry, Slaney and Clodiagh being worse and the Owenriff, Mountain, Dereen and in this case the Tar also being better (Fig 2.14). The graph of maximum oxidised nitrogen levels shows similar trends, the Nore showing a number of years of elevated levels (Fig 2.15), although not exceeding the 6 mg l^{-1} EC limit (this time for drinking purposes, not eutrophication) (Anon., 1985a).

The median ammonia levels fluctuated considerably, all median values being within the EC guideline limits of 0.16 mg l^{-1} for salmonid rivers (Fig 2.16). Maximum ammonia values in many rivers frequently showed levels exceeding this limit several times over the years (Fig 2.17). Revised limits of relevant nutrients are proposed based on levels found at viable populations in the study (Table 2.10).

4.4 Discussion

The survey of the 149 rivers above included a wide range of river types, from the short, isolated catchments in the west of the country to the larger catchments with numerous tributaries in the east of the country, along which large towns have built up. The results above confirm the difference in water and habitat quality of these rivers.

In the statistical analysis of the 123 sites categorised by 31 parameters (Appendix 1), the correlation of mussel rivers with high Q-values (Fig. 2.4) and low conductivity (Fig. 2.5), pH (Fig. 2.6), oxidised nitrogen (Fig. 2.7) and BOD (Fig 2.8) levels agrees with other workers conclusions that *M. margaritifera* needs high water quality (Bauer, 1983; Buddensiek *et al.*, 1993). The other significant parameters also confirm this, such as lack of macrophytes and siltation in mussel rivers with juveniles, both of which themselves occur in enriched rivers. The significant association of low distance to the sea shows that most mussel rivers in Ireland are away from the central plain, and in the more rural areas near the coast, which is also where the softer water occurs. The land in these areas is not as valuable for agriculture, and tends to be less fertilised or intensively farmed. The significant difference in altitude drop from the source (Table 2.5) is accounted for by mussels being found in mainly upland sites, again where agriculture has not inpinged on water quality. Presence of lakes upstream was significant for positive sites. A lake can act as a buffer against extreme high and low water flows. Young and Williams (1983) found torrential conditions caused mussels to be carried off downstream when placed in a river which had no lake upstream. This river was a tributary of one which had a lake upstream, and where mussels naturally occurred. Phytoplankton produced in the lake may be carried to the mussels as a food source, without the extremes of nutrients which would allow the growth of filamentous algae in the river below.

When only the rivers with mussel records are compared, those with large adult numbers and with juveniles present are significantly associated with low conductivity, low pH and low phosphate levels. Thus not only are mussels generally restricted to low pH and low conductivity rivers, the levels of these parameters in mussel rivers themselves is again significant. While low levels of oxidised nitrogen were needed for mussel rivers in general, the levels of phosphate become important if the population is to be viable. This agrees with the conclusion that Bauer (1988) reached that high nitrogen concentrations were associated with adult mussel mortality, and low phosphate levels with juvenile survival.

Sites with the best mussel populations were significantly nearer the sea, and nearer the source of rivers than poorer populations, thus typically being found in short rivers in rural areas in the west of Ireland, for the same reasons as mentioned before. They were also significantly associated with unfertilised, non-intensively farmed land. However, the best mussel populations were not at the extreme source of rivers, but were significantly associated with stream orders 2, 3 and 4 (Fig. 2.10). This reflects the need for certain levels of nutrients. Streams of larger order are considered autotrophic rather than heterotrophic (Anderson and Sedell, 1979). The better populations were again downstream of lakes. Siltation is found to be significantly associated with declining populations, again underlining the importance of eutrophication in the decline of Irish pearl mussels.

The comparison of nutrient levels over time was made to try to further predict nutrient needs of *Margaritifera*. The water quality data is limited in (i) only a small number of samples were taken (2 to 18 snapshot samples) per year and with flowing water many pollution incidents may be missed. In the cases where very few samples were taken, critical times of year where nutrients may be elevated could have been missed. (ii) Data does not go back far enough to establish levels that were present when *e.g.* the Nore had a healthy mussel population, so we cannot be certain whether the *durrovensis* population is more tolerant of nutrients than *M. margaritifera.* Given the sharp decline in the Nore population, it is unlikely that this species is any more tolerant than its soft water relative. The median levels of nutrients separated the three best mussel sites from the others. Median orthophosphate levels never exceeded 0.02 mg l^{-1}, median oxidised nitrogen levels never exceeded 1.5 mg l^{-1} and median annual ammonia levels never exceeded 0.06 mg l^{-1} in the top three populations.

The conditions of the best mussel sites suggest that these rivers have very little enrichment. As mussels are filter feeders from a very young age, some minimum levels of nutrients must be essential for their survival, and for the survival of their host salmonids. However, it is clear that further enrichment of the river beyond that which is necessary for food can only be detrimental to the viability of the population. Thus the notion that *M. margaritifera* thrives in slightly eutrophied water (Hrusca, 1995) has not been confirmed in this study. Indeed, the maintenance of low nutrient levels in pearl mussel SAC rivers is probably the most important conservation role of the responsible authorities.

The decline in mussel populations in salmonid waters questions the usefulness of the present EC guideline values as they appear to allow increasing eutrophication levels which will eventually interfere with salmonid populations, and are certainly inadequate in the protection of pearl mussels. The levels of nutrients measured at these sites (from local authority records) are lower in most cases than limits given by salmonid water regulations (Council of the European Communities, 1978) (Table 2.10). Thus keeping a river to salmonid quality may not be enough to maintain it as necessary for production of juvenile mussels. From the above study, the levels of nutrients needed for mussel recruitment are extrapolated, and used as a proposed new designation, i.e. rivers of margaritiferid quality.

Most important, of course, is the effect that nutrients have on the mussel microhabitat. Adult mussels are normally two thirds buried in the gravel or sand substrata. Because juveniles are completely buried for the first few years (Cranbrook, 1976) the water they filter is interstitial water rather than free running. Interstitial water can vary considerably over short distances and indeed depths. A study of mussel microhabitats in Germany concluded that young mussels survived best when interstitial water chemistry most closely resembled free running water nutrient levels (Buddensiek *et al.*, 1993). Thus the best substratum for young mussels is that which has a high rate of exchange with running water, which agrees with the habitat most used by mussels, namely clean gravel. If the gravel becomes clogged with filamentous algae or organic silt, water exchanged is reduced and microhabitats result. In some cases oxygen saturation can decrease from 100% to 20% at a depth of 9cm, pH can decrease to 3.8 or increase to 8.3 depending on the location, and ammonia can increase significantly at shallow depths (Buddensiek *et al.*, 1993).

In establishing the water quality required for healthy mussel populations, three essential points must be taken into consideration. Firstly, running water must be clean enough not to cause any direct stress on adult or juvenile mussels. Secondly, water quality must be high enough to ensure that eutrophication does not occur. Thirdly, siltation and algal growth must not be such so as to impair water flow through river bed gravel. Siltation may occur as a result of physical works upstream of the mussel population. Arterial drainage can change the erosion patterns of the water and subsequently the stability of the river bank downstream. Drainage of bogs result in silt deposits many miles downstream. Overgrazing or digging of trenches along slopes of river catchments, for example for afforestation, may lead to soil flow into the watercourses below. All physical causes of siltation must be stopped in *Margaritifera* rivers if river beds are to recover. These will be dealt with in a later publication. If this is successful, keeping water quality at the proposed *Margaritifera* standards should be sufficient for a healthy, reproducing pearl mussel population.

Table 2.1 Status of pearl mussels in nine rivers with historical water chemistry data.

River	Site	Grid Reference	Adult Numbers	Juvenile ages
Nore	Tallyho Bridge	S 424 761	Low and declining	None
Owenriff	U/s Oughterrard	M 073 422	Up to 100 / m^2	All ages
Dereen	Ford u/s Hacketstown	S 993 834	Up to 50 / m^2	Youngest approx. 3-5 yrs
Mountain	Rossdellig Bridge	S 772 515	Up to 50 / m^2	Youngest approx. 3-5 yrs
Slaney	New Bridge	S 898 597	Low (total of 30 found)	None
Derry	Clonegal	S 914 607	V. low (total of 9 found)	None
Multeen	Aughnagross Bridge	R 986 416	V. low (Total of 7 found)	None
Tar	Garrymore Bridge	R 986 153	V. low (Total of 5 found)	None
Clodiagh (W)	Lowry's Bridge	S 420 147	V. low (Total of 2 found)	None

Table 2.2 Analysis of characteristics of 526 sampling sites in *Margaritifera* survey. Characters are defined in Appendix 1.

	Total Sites		***Sites with mussels***		***Sites w/out mussels***		***χ^2 test between sites +/- mussels***
	No.	***(%)***	***No.***	***(%)***	***No.***	***(%)***	
Mussels present			49	9%	477	91	-
Silted Bed	336	64%	16	33%	320	67%	P<.01
Gravel in bed	146	28%	49	100%	97	20%	P<.005
Filamentous algae	235	45%	15	31%	220	46%	not significant
Macrophytes present	144	27%	16	33%	125	26%	not significant
Overhanging trees	107	20%	23	47%	137	29%	P<.005
Eroded banks	136	26%	8	16%	128	27%	not significant
Canalised	130	25%	1	2%	129	27%	P<.005

Table 2.3 Comparisons of sites with young mussels present and with older mussels only.

	Young mussels present		*Older mussels only*		*No mussels present*	
	No.	***%***	***No.***	***%***	***No.***	***%***
Total sites	8	2%	41	8%	477	90%
Silt present	0	0%	16	38%	320	67%
Filamentous algae	0	0%	16	38%	320	67%
Macrophytes present	0	0%	16	38%	128	27%
Overhanging trees	2	25%	21	50%	137	29%
Eroded banks	0	0%	8	19%	128	27%
Canalised river	0	0%	1	2%	129	27%

Table 2.4 Significance of χ^2 tests of parameters at all Irish sites.

* = P < 0.05   ** = P < 0.01   *** = P < 0.001

	Comparing sites with young mussels to sites with older mussels only	***Comparing sites with older mussels only to sites with no mussels***	***Comparing sites with young mussels to sites with no mussels***
Silt present	Not significant	*	*
Gravel present	Not significant	***	**
Filamentous algae present	Not significant	*	*
Macrophytes present	Not significant	Not significant	Not significant
Overhanging trees present	Not significant	**	Not significant
Eroded banks	Not significant	Not significant	Not significant
Canalised	Not significant	**	Not significant

Table 2.5. Significant parameters from chi-squared test of all rivers, comparing presence and absence of living mussels.

**** P<0.05   ** P<0.01   *** P<0.001***

Parameter	*Degrees of freedom*	*Chi-square*	*P > Chi-sq.*	*Significance*
Stream order	5	11.25	0.0467	*
Km to sea	1	12.38	0.0004	***
Km to source	1	0.48	0.4879	-
Substrate type	4	17.09	0.0019	***
Silt present	1	29.08	0.0000	***
Trees overhang	1	16.54	0.0000	***
Eroded banks	1	0.24	0.6265	-
Agriculture type	2	0.03	0.9848	-
Human populat.	2	2.89	0.2352	-
Lake upstream	1	6.56	0.0104	*
Altitude	1	2.01	0.1561	-
Alt. drop / source	1	4.09	0.0431	*
Fil Algae present	1	3.22	0.0723	-
Macrophytes	1	4.69	0.0304	*
Med. Conductivity	1	16.47	0.0000	***
Max. Conductivity	1	20.09	0.0000	***
Med. pH	1	16.37	0.0001	***
Max. pH	1	5.50	0.0190	*
Med. Amm.	1	0.57	0.4509	-
Max. Amm.	1	2.51	0.1129	-
Med. O-Phosphate	1	3.34	0.0678	-
Max. O-Phosphate	1	1.39	0.2390	-
Med. Ox-Nitrogen	1	6.99	0.0082	**
Max. Ox-Nitrogen	1	3.68	0.0550	-
Max. Temperature	1	2.07	0.1498	-
Q-Value	1	7.58	0.0059	**
Max. BOD	1	6.40	0.0114	*
Max. Chloride	1	3.17	0.0747	-
Min Diss. Ox.	1	3.63	0.0569	-
Max. Diss. Ox.	1	1.09	0.2964	-

Table 2.6. Five status divisions of rivers with mussel records.

Category	***Status***
1	Old records only, no mussels or shells found
2	Dead shells found
3	Small living adult population
4	Large living adult population, no juveniles
5	Large population of adults, juveniles present

Table 2.7. Significant parameters from chi-squared test of all rivers with pearl mussel records, comparing status of mussels.

**** P<0.05 ** P<0.01 *** P<0.001***

Parameter	*Degrees of freedom*	*Chi-square*	*Probability > Chi-sq.*	*Significance*
Stream order	4	21.32	0.0003	***
Km to sea	1	6.18	0.0129	*
Km to source	1	12.47	0.0004	***
Substrate type	3	5.28	0.0713	-
Silt present	1	9.47	0.0021	**
Trees overhang	1	7.05	0.0079	**
Eroded banks	1	2.32	0.1275	-
Agriculture type	2	9.06	0.0108	*
Human population	2	4.16	0.1248	-
Lake upstream	1	12.95	0.0003	***
Altitude	1	3.72	0.0537	-
Altitude drop from source	1	3.82	0.0506	-
Fil amentous algae present	1	1.47	0.2257	-
Macrophytes	1	0.22	0.6412	-
Median Conductivity	1	13.61	0.0002	***
Maximum Conductivity	1	15.55	0.0001	***
Median pH	1	12.92	0.0003	***
Maximum pH	1	7.32	0.0068	**
Median Ammonia	1	0.53	0.4658	-
Maximum Ammonia	1	1.08	0.2992	-
Median Ortho-Phosphate	1	4.06	0.0439	*
Maximum Ortho Phosphate	1	0.63	0.4267	-
Median Oxidised Nitrogen	1	3.17	0.0752	-
Maxum Oxidised Nitrogen	1	1.75	0.1858	-
Maximum Temperature	1	1.38	0.2401	-
Q-Value	1	1.03	0.3107	-
Maximum BOD	1	2.05	0.1525	-
Maximum Chloride	1	0.47	0.4930	-
Minimum Dissolved Oxygen	1	2.98	0.0842	-
Maximum DissolvedOxygen	1	1.49	0.2224	-

Table 2.8. Standards and recommendations for salmonid fishery waters from E.C. Directive on protection of salmonid fishery waters, some recent Irish data on reproducing Irish mussel rivers, and possible required levels for viable *Margaritifera* rivers based on these.

	Dissolved Oxygen %sat/ mg l^{-1} O_2	***B.O.D. mg l^{-1}***	***Total Ammonia mg l^{-1}***	***Oxidised Nitrogen mg l^{-1}***	***Ortho-phosphate mg l^{-1}***
E.C. guideline (Salmonid Regulations)	50% > 9 100% > 7	not > 3	not > 0.16	no standard	not > 0.07 (eutrophication)
E.C. mandatory (Salmonid Regulations	50% > 9	no standard	not > 0.8	no standard	no standard
An Foras Forbatha EQS*	99.9% > 4 95% > 6 50% > 9	95% not > 5 50% not > 3	95% not > 0.5	95% not > 11	95% not > 0.2 50% not > 0.1
Mountain river (most recent)	min 9	max 2.9	max 0.06 med 0.015	max 1.7 med 1.3	max 0.06 min 0.01
Dereen river (most recent)	min 9.7	max 2.4	max 0.1 min 0.02	max 1.1 med 0.89	max 0.06 med 0.02
Owenriff river (most recent)	min 9	max 3.0	max 0.095 min 0.04	max 0.13 med 0.04	max 0.008 med 0.005
Newport river (most recent)	min 9	max 3.0	max 0.07 med 0.03	max 0.19 med 0.09	max 0.04 med 0.005
Leannan river (most recent)	min 9.5	max 2.7	max 0.02 med 0.02	max 0.6 med 0.06	max 0.12 med 0.06
Proposed Margaritiferid river level	100% > 9 mandatory	not > 3 mandatory	not > 0.10 mandatory	not > 1.7 mandatory	not > 0.06 mandatory

* A complete list of EPA Environmental Quality Objectives and Environmental Quality Standards has been published (Environmental Protection Agency, 1997)

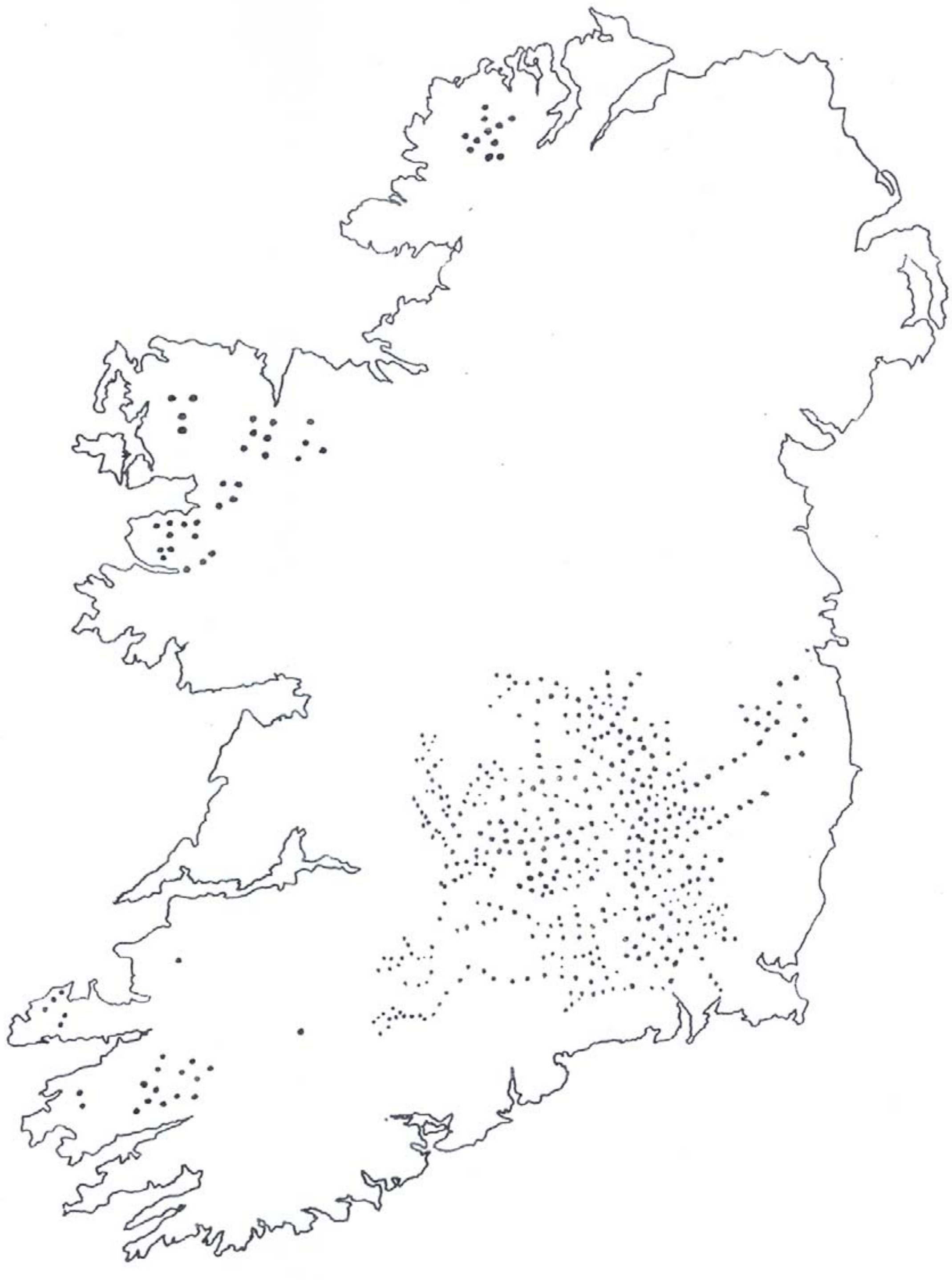

Figure 2.1 Map of Ireland showing sampling sites in *Margaritifera margaritifera* survey.

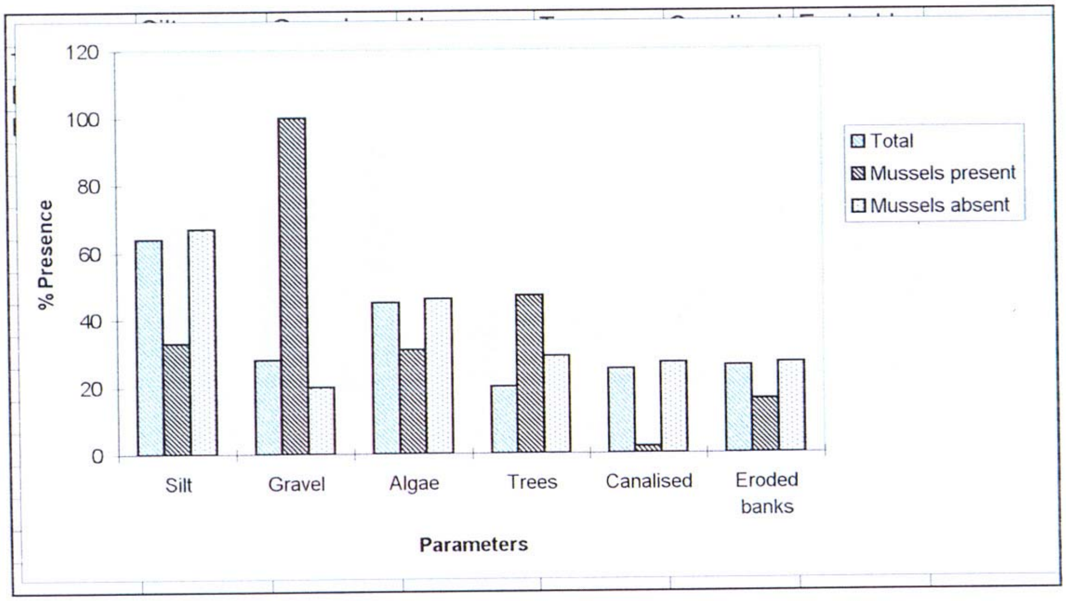

Fig. 2.2 Differences in percentage presence and absence of silt (in at least half of the river bed), gravel (in at least half of the river bed), filamentous algae (in noticeable quantities), overhanging trees (in at least half of one bank), canalisation and eroded banks (in at least half of the river bank) in all sites, sites with mussels present, and sites with mussels absent.

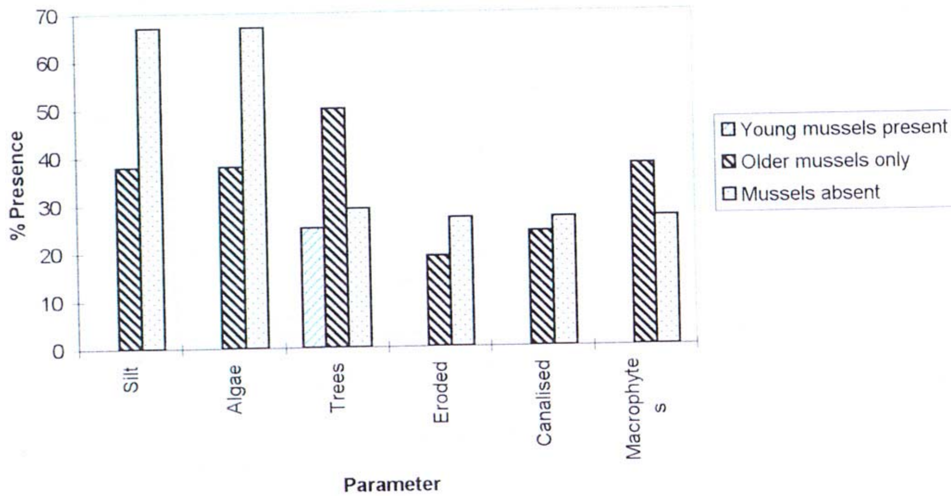

Fig. 2.3 Differences in percentage presence and absence of silt (in at least half of the river bed), gravel (in at least half of the river bed), filamentous algae (in noticeable quantities), overhanging trees (in at least half of one bank), erosion of at least 20% of river bank, canalisation and presence of macrophytes (in at least half of the river bank) in sites with young mussels, sites with older mussels only, and sites with mussels absent.

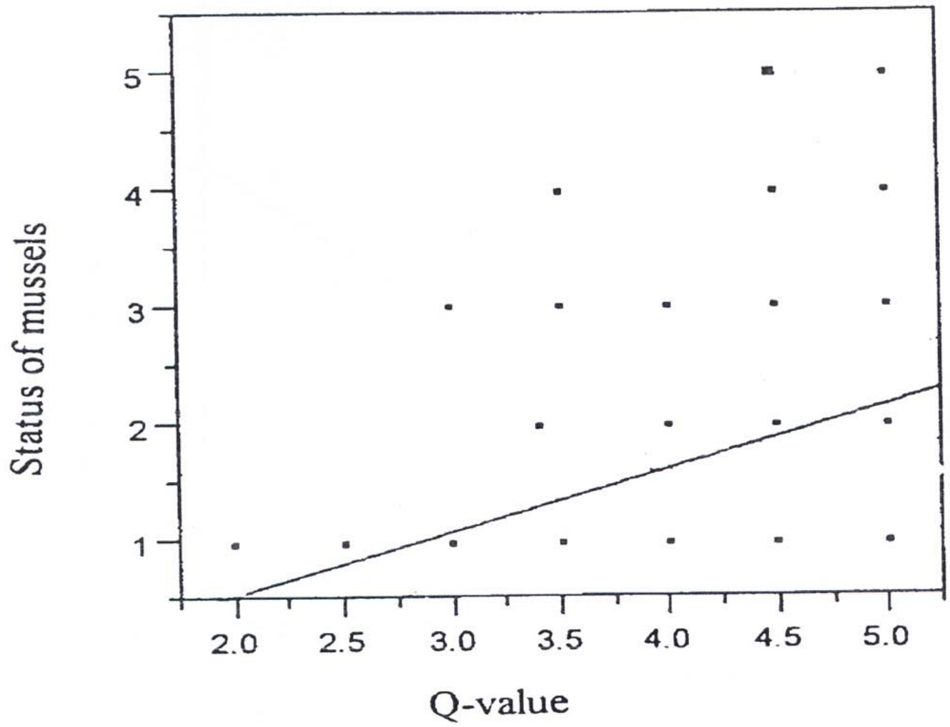

Fig. 2.4. Correlation of most recent Q-value (Q1 = poor quality, Q5 = good quality) and status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

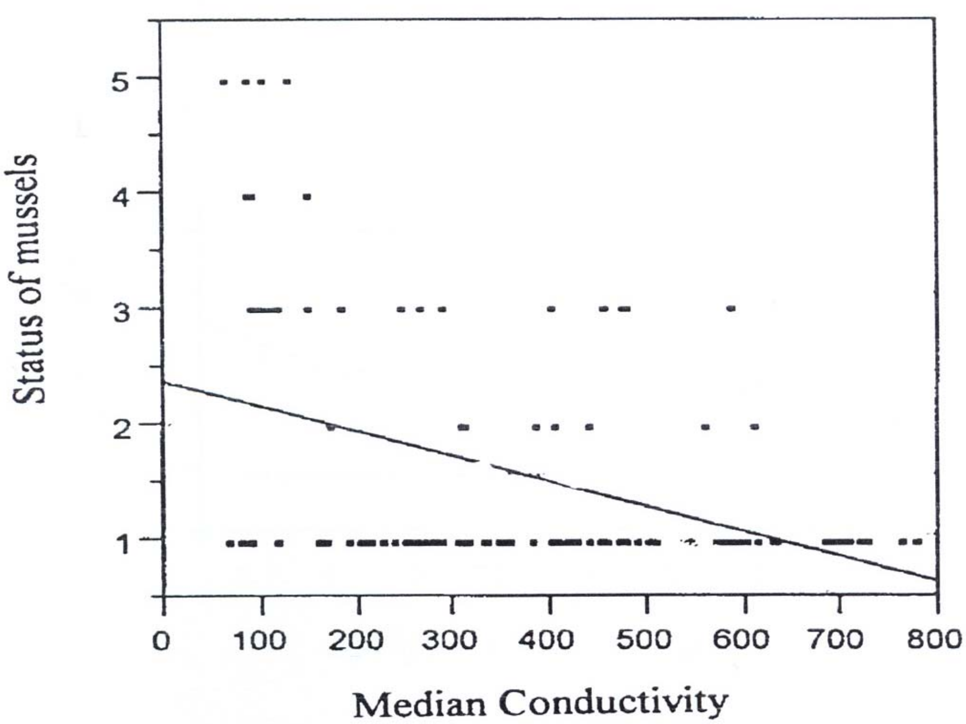

Fig. 2.5. Correlation of most recent annual median conductivity (µS/cm) with status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

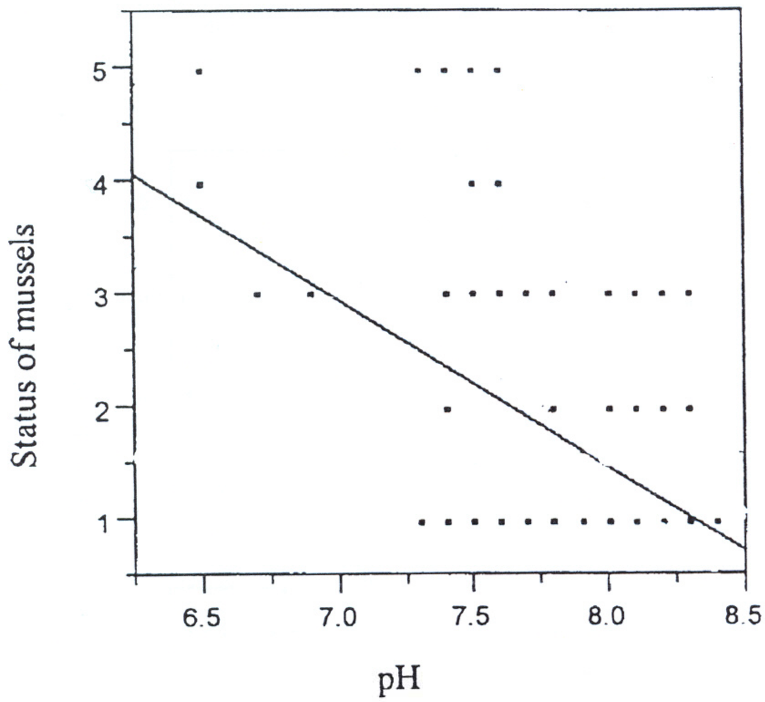

Fig. 2.6. Correlation of most recent maximum pH with status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

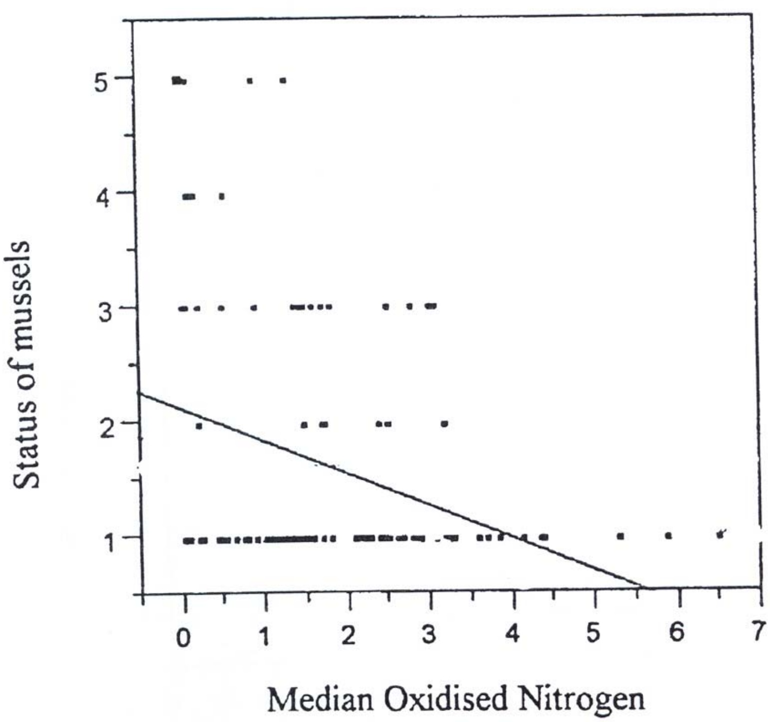

Fig. 2.7. Correlation of most recent annual median oxidised nitrogen with status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

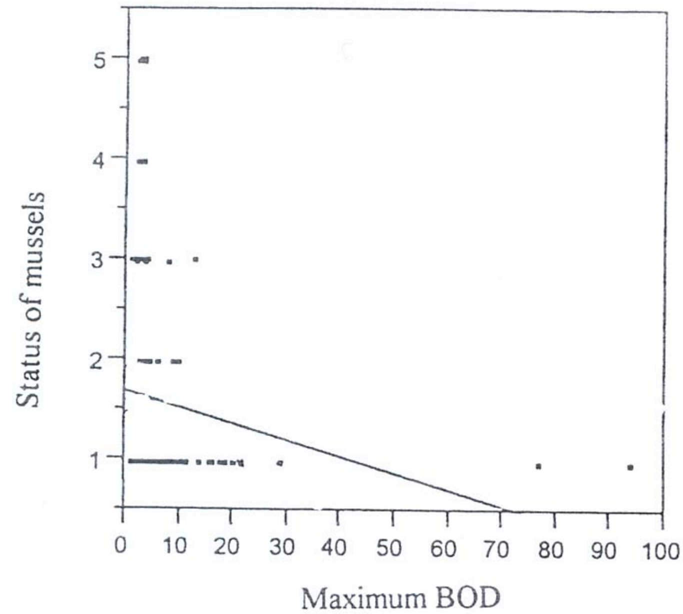

Fig. 2.8. Correlation of most recent annual maximum BOD with status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

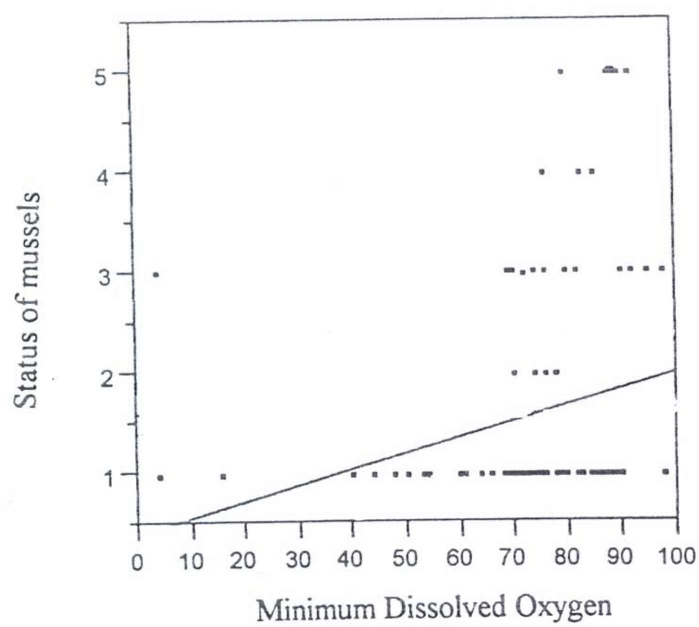

Fig. 2.9. Correlation of minimum dissolved oxygen with status of mussels in rivers (1 = no mussels, 5 = large population with juveniles).

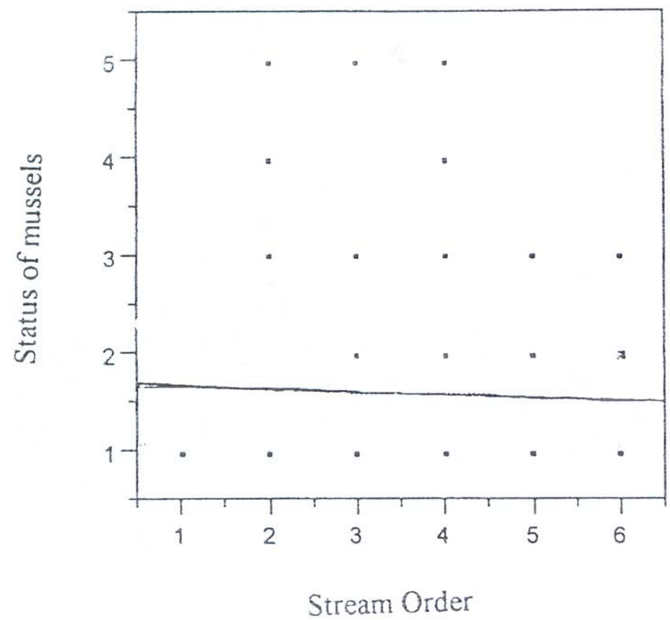

Fig. 2.10. Relationship between stream order and status of mussels in Ireland (1 = no mussels, 5 = large population with juveniles). Correlation is negligible, but the best mussel rivers are restricted to stream orders 2, 3 and 4.

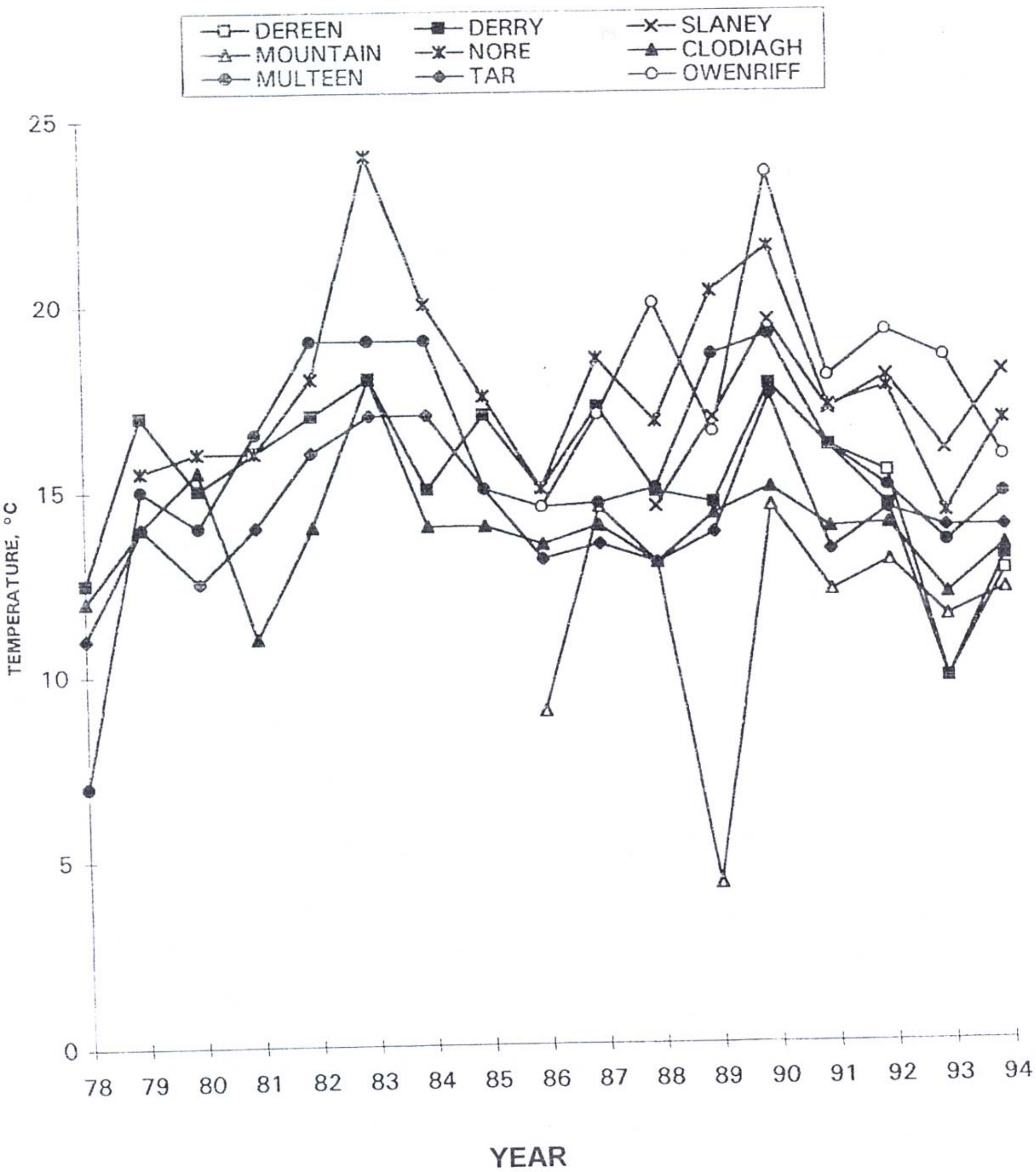

Fig. 2.11. Changes in maximum annual Temperature 1978 - 1994

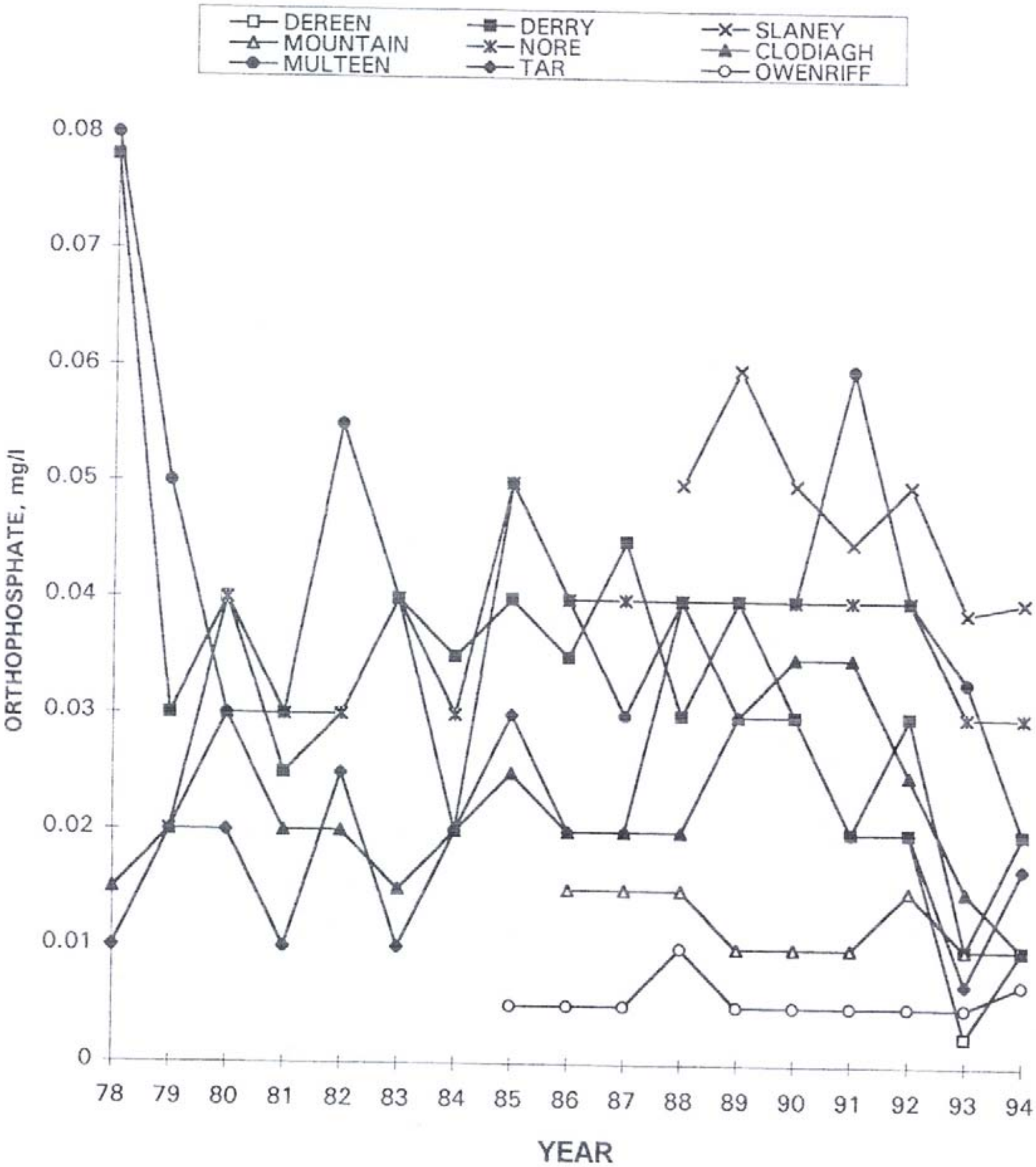

Fig. 2.12 Changes in median annual ortho-Phosphate 1978 - 1994

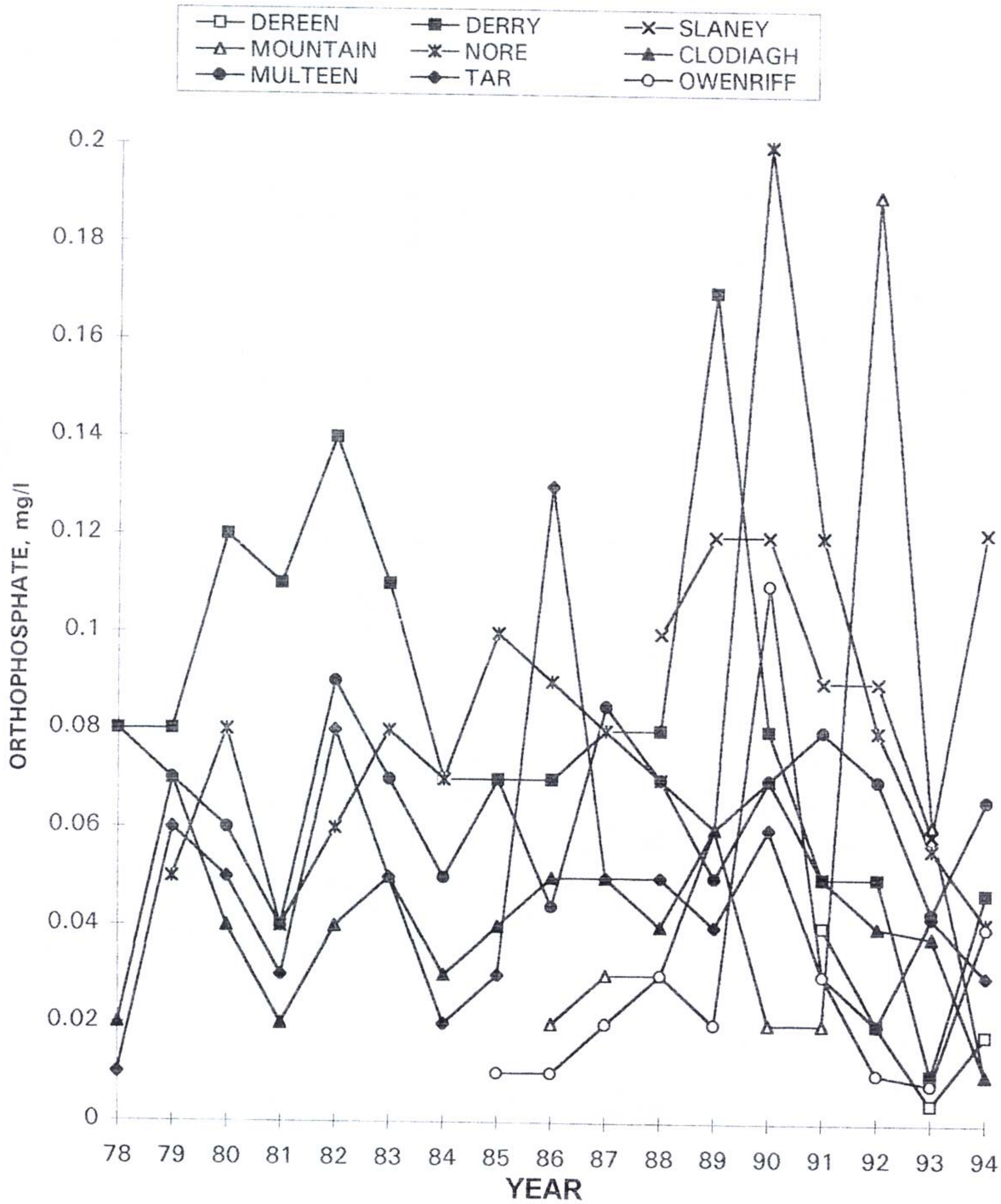

Fig. 2.13. Changes in maximum annual ortho-Phosphate 1978 - 1994

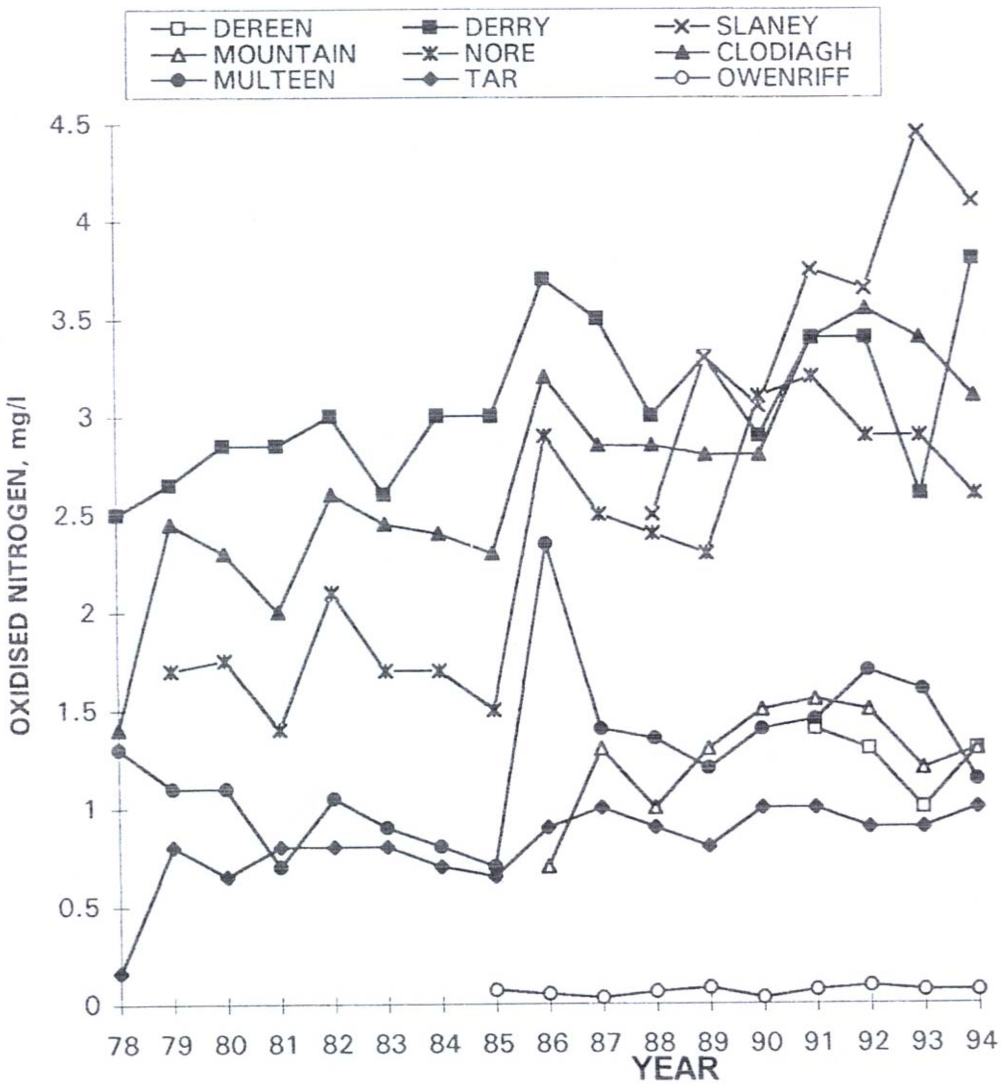

Fig. 2.14 Changes in median annual oxidised nitrogen 1978 - 1994

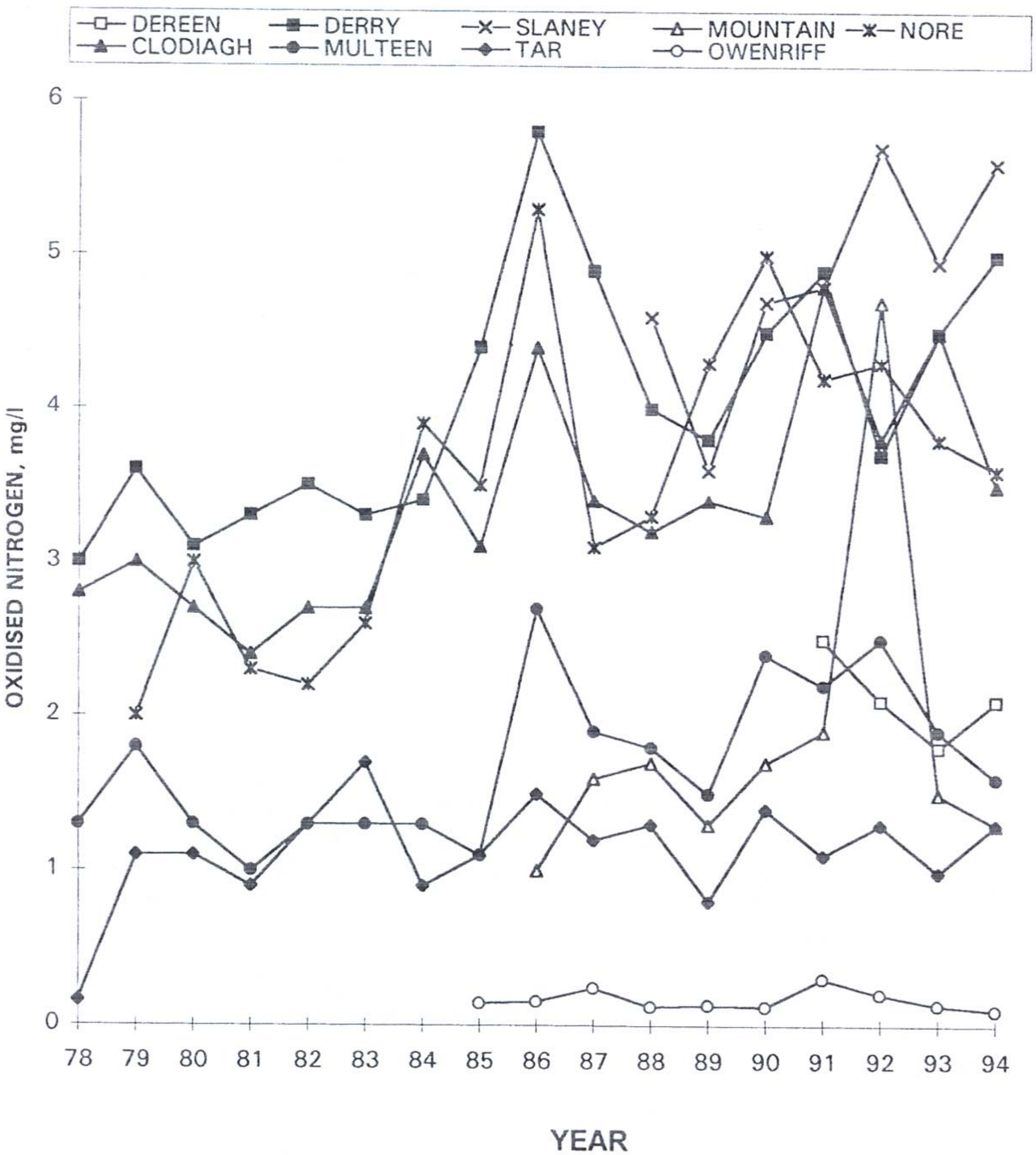

Fig. 2.15. Changes in maximum annual oxidised Nitrogen 1978 - 1994

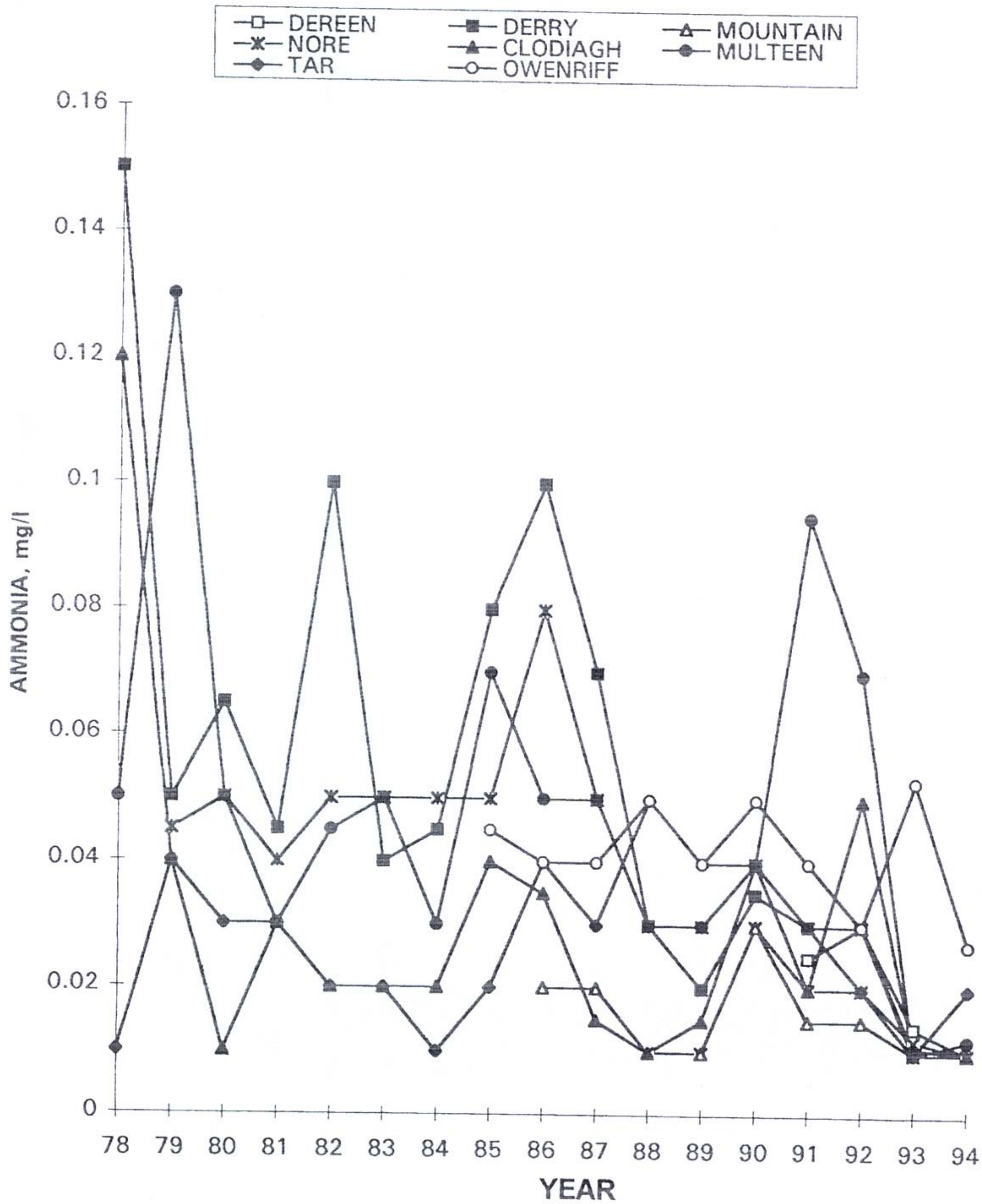

Fig. 2.16. Changes in median annual Ammonia 1978 - 1994

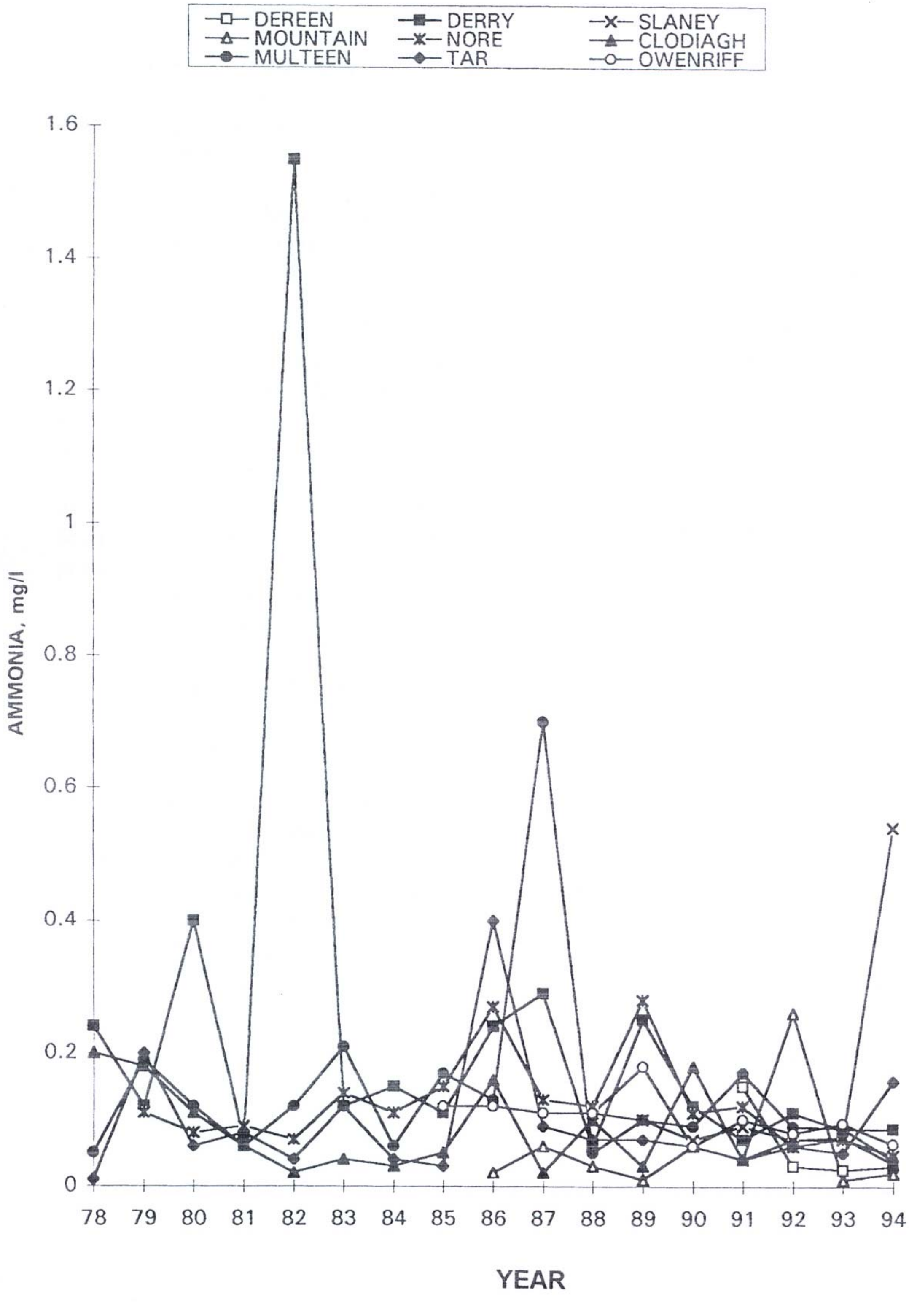

Fig. 2.17. Changes in maximum annual Ammonia 1978 - 1994

Conclusions

There are 85 parameters pertaining to water quality listed by Irish authorities (Flanagan, 1992), many of which are rare or heavy metals or compounds that are not normally a problem in areas with little industry. Nonetheless, there is little known about the effects of most of these compounds on pearl mussels. The effects of excess quantities of more common parameters (Table 3.1) are no longer speculative, unless water quality levels for these parameters are high enough, pearl mussels in a population will stop reproducing, decline in numbers and die out. Sources of pollution leading to increases of parameters such as nitrates and phosphates are often diffuse, and modern accepted policy is to manage water quality on a catchment-wide basis, thus addressing diffuse as well as point sources of pollution. Thus the time has come for authorities to be able to address the needs of this species. Required minimum water quality levels for *Margaritifera* rivers would be of immense value in focusing the many groups responsible for river management (Table 3.2) into working for pearl mussel conservation.

There have been a number of recent studies of pearl mussel rivers attempting to determine the minimum water quality requirements for a healthy pearl mussel population (Buddensiek, 1995; Valovirta, 1995; Lande and Lande, 1998; Ofenb¬ck et al., in press). Estimating these requirements is problematic, as in many cases mussel populations have declined, and records do not go back far enough to provide the data for when the populations were healthy. Even in good reproducing populations water quality may have declined, yet negative effects may not yet be visible due to a time lag between the cause and effect of decline. In these cases quality of water needed may be underestimated. It is also possible that many remaining reproducing mussel populations are in the most remote, unpolluted areas and that water quality there is somewhat higher than necessary. In some cases the number of measurements of parameters is low and the range of water quality levels may not have been established. In these cases quality of water needed may be overestimated. It is important to make the best possible estimate of *Margaritifera* requirements if they are to be implemented by river authorities. A form has been compiled in order to allow feedback from pearl mussel workers as to the appropriateness of the quality levels suggested (Table 3.3).

Table 3.1. Recently published levels for waters with living *Margaritifera* (not necessarily in good health).

	Dissolved Oxygen %sat/ mg l^{-1} O_2	PH	B.O.D. mg l^{-1}	Total Ammonia mg l^{-1}	Oxidised Nitrogen mg l^{-1}	Conductivity uS/cm	Ortho-phosphate mg l^{-1}
This study (reproducing populations) (Ireland)	Min 9 – 9.7	Min 6.5-7.6 Max 7.3-8.3	Max 2.4 – 3.0	Max 0.02-0.1 Med 0.015-0.03	Max 0.13-1.7 Med 0.04-1.3	Max 109-195 Med 65-129	Max 0.008-0.12 Med 0.005-0.06
Ziuganov et al., 1994 (Russia)	86 – 106 %	6.6-7.8	-	-	-	-	-
Buddensiek (1995) (Germany)	Mean 9.76	Mean 7.05	-	Mean 0.22	Mean 0.01	Mean 208	Mean 0.11
Valovirta (1995) (Finland)	-	6-7.5	-	-	-	-	-
Lande and Lande (1998) (Norway)	-	4.8-7.3	-	-	0.15-2.4	15.5 - 271	0.002-0.1
Ofenb¬ck et al. (in press) (Austria)	98 – 131%	6.8-7.5	-	<0.01-<0.01	0.9-1.4	91-110	0.009-0.014

Table 3.2 Authorities and Interest groups involved in Irish River Management.

Authority or Interest Group
Landowners
Local Authorities (County Councils)
Environmental Protection Agency
Central Fisheries Board
Regional Fisheries Boards
Office of Public Works
D ʃchas, The Heritage Service
Department of Environment
Department of the Marine
Department of Agriculture
Teagasc
Coillte
Regional Development Authorities (e.g. Shannon Development)
Community Development Groups (e.g. Chambers of Commerce)
Angling / Recreation Clubs
NGOs (Conservation groups)

Table 3.3 Feedback form for proposed minimum *Margaritifera* water quality standards. (Please photocopy and fill in any sections possible, and return to: ***Margaritifera* Standards, 40, Templeroan Avenue, Templeogue, Dublin 16, Ireland** or e-mail evelynmoorkens@eircom.net for e-format)

Water Quality Parameter	Proposed Minimum Standard	Feedback Comments
Aluminium mg/l	?	
Ammonia (mg/l N)	< 0.10	
Chloride mg/l Cl	?	
Conductivity µS/cm	<200	
Hardness mg/l CaCO3	?	
Heavy Metals mg/l	?	
Hydrocarbons mg/l	?	
Nitrate (Ox. Nitrogen) mg/l N	<1.7	
Nitrite mg/l N	?	
Organic Carbon mg/l C	?	
Oxygen Demand, Biochemical	<3	
Oxygen, Dissolved mg/l O2	>9	
Pesticides mg/l	?	
PH	<8.0, >6.3	
Phosphates (Ortho-P) mg/l P	<0.06	
Solids, Suspended mg/l dried	?	
Temperature °C	No artificial thermal changes	
Others….		

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Appendix 1. Physical and chemical data used in statistical analysis of sites.

Terms used:

O.S.: Ordnance Survey grid reference.

Stream Order: Number of sources joining the river by this site (including the main channel).

Distance/sea: Distance measured from site to sea in kilometres from 1/2'' map.

Distance/source: Distance measured from source to site in kilometres from 1/2'' map.

Substrate type: Main substrate covering over 50% of river bed, by observation; 1 = bedrock, 2 = boulders, 3 = cobbles, 4 = gravel, 5 = sand/silt.

Silt layer: (Yes/No) Presence of a layer of silt covering over 50% of river bed, by observation at site.

Trees overhang: (Yes/No) More than 50% of river site surveyed had trees overhanging water on one or both banks.

Eroded banks: (Yes/No) More than 20% of one or both banks visibly eroded by animals trampling or recent water undercutting.

Surrounding land use: Most common use of land in 50m from bank on either side of river. Unimproved = unfertilised grassland, bog or fen, Urban = roads, houses, yards, Cattle = cattle grazing, Sheep = sheep grazing, Fish farm = hatchery tanks and buildings.

Population upstream: F = few (scattered dwellings only), S = some (small village or individual dwellings for over 3km), M = many (town or more than 1 village upstream). Designations by observation and from maps.

Altitude: Altitude of site in metres, as taken from 1/2'' map.

Alt. drop: Drop in altitude from source to site in metres, as taken from 1/2'' map.

Fil. algae: Presence of filamentous algae in over 25% of river bed, by observation.

R. penn: Presence of *Ranunculus* or other macrophyte covering over 50% of river bed surveyed.

Conduct. Med: Most recent median annual conductivity (μS/cm). N.B. Most recent in all cases means either 1995 (from individual local authorities) or, where these were unavailable, 1990 (from most recently published Environmental Protection Agency data).

Conduct. Max: Most recent maximum annual conductivity (μS/cm).

pH med: Most recent annual median pH value (pH units).

pH max: Most recent annual maximum pH value (pH units).

Tot. Amm med: Most recent annual median total Ammonia value (mg/l N).

Tot. Amm max: Most recent annual maximum total Ammonia value (mg/l N).

O-Phosp med: Most recent annual median ortho-Phosphate value (mg/l P).

O-Phosp max: Most recent annual maximum ortho-Phosphate value (mg/l P).

Ox. Nit. med: Most recent annual median oxidised Nitrogen value (mg/l N).

Ox. Nit. max: Most recent annual maximum oxidised Nitrogen value (mg/l N).

Temp. max: Most recent annual maximum water temperature value (°C).

Q-Value: Most recent Q-value (range 1-5), calculated every 4 years.

BOD max: Most recent annual maximum biochemical oxygen demand (mg/l O_2).

Chloride max: Most recent annual maximum Chloride (mg/l Cl).

WQI min: Most recent annual minimum Water Quality Indicator value (range 0-100).

Diss. Ox. min: Most recent annual minimum dissolved oxygen value (% saturation).

Diss. Ox. max: Most recent annual maximum dissolved oxygen value (% saturation).