Chapter (non-refereed)

Maitland, P.S.. 1987 The status of fish in streams associated with lochs vulnerable to acid deposition in Scotland. In: Maitland, P.S.; Lyle, A.A.; Campbell, R.N.B., (eds.) *Acidification and fish in Scottish lochs.* Grange-over-Sands, Institute of Terrestrial Ecology, 54-63.

Appendix 4

The status of fish in streams associated with lochs vulnerable to acid deposition in Scotland

P S MAITLAND

Summary
Fish in the inflow and outflow streams of 63 Scottish lochs were sampled by electro-fishing; 50 of these lochs had granite catchments, whereas the catchments of the other 13 'control' lochs were of other types of bedrock. Seven species of fish were found in the streams concerned, but only one of these—brown trout (*Salmo trutta*)—was common. Some 33% of the loch inflows and 32% of the outflows were apparently fishless. The majority of these sites were shown to be acidified according to the acidification curve of Henriksen (1979). Many of the other granite sites and virtually all the 'control' sites had fish in the streams (usually in both inflow and outflow). In most cases, several year classes were present—although 0+ fish always dominated. Most of the streams where the absence of fish appeared to be associated with acidification occur in south-west Scotland.

1 Introduction
Following the evidence from Scandinavia and North America of extinctions of fish populations in numerous acidified lakes (Almer 1974; Harvey 1975; Wright & Snekvic 1978; Overrein *et al.* 1980; Haines 1981; Harvey & Lee 1982; Johnson 1982; Muniz & Leivestad 1982; Schofield 1982), considerable concern has been expressed about the status of fish in Scottish lochs and streams in relation to the known high levels of acid deposition here (United Kingdom Review Group on Acid Rain 1983; Cape *et al.* 1984; Watt Committee on Energy 1984).

The dominant fish in the majority of these lochs is the brown trout (*Salmo trutta*), and special attention was given to this species during this study. Because it has an ecological requirement for running water, both for spawning and for nursery grounds, the populations of fish in the inflowing and outflowing streams of the lochs selected for study were examined wherever possible. Such streams are known to be vulnerable to acid pulses under certain weather conditions (Bjarnborg 1983).

Attention within the project has been centred on lochs whose basins and catchments lie on granite bedrock—much of the current evidence suggests that these are likely to be the most vulnerable sites to acidic deposition from the atmosphere. From a comprehensive study of the 1:50000 OS maps and equivalent geological maps, it was possible to identify all the granite lochs in Scotland. Groups of these granite lochs in different parts of the country were chosen for field study and, in addition, a nearby 'control' loch (whose catchment lies on non-granitic rocks) was selected for each group. Only lochs which had at least one associated stream shown on the map were included in the study.

2 Methods
Eighty-three lochs were visited during 1984 and 1985. At each loch, the major inflowing stream and the outflow were sampled for fish by means of a portable back-pack electric fishing machine ('Safari 100' Electro Fisher). This machine was normally used to fish upstream from a suitable point for a standard period of time, and the length and width of the stream so sampled were noted (Plate 1). All fish caught were identified, measured for length and returned to the stream alive. Fishing time was kept relatively short (usually 10–20 minutes) in order to minimize use of electricity, because some sites were over 10 km uphill from the nearest vehicle access and all equipment had to be carried there.

For a variety of reasons, it was not possible to sample streams at all 83 loch sites. Several had no permanent inflow large enough to hold fish, a few had no outflow, or both were completely silted or dried up (Plate 2). Fishing conditions were variable and occasionally difficult due to bad light, high flows, overhanging vegetation, etc, and the data cannot be regarded as quantitative.

3 Results
3.1 General
Of the 83 sites involved in the study, it was possible to obtain data on the fish in 58 inflowing streams and 63 outflowing ones. Only 4 sites had no inflow or outflow of any kind, and at several others the small size of the stream (from which, however, water samples could be taken) or its nature (restricted access for fish, siltation, etc) virtually precluded fish surviving there.

3.2 Species
A list of species collected during the entire study (Table 1) shows that 3 of the total of 10 involved (arctic charr, roach and perch) were never found in streams. Of the others, Atlantic salmon, pike and nine-spined stickleback were uncommon. By far the most widespread fish were brown trout (64.5% of the sites

Plate 1. Sampling for trout and other small fish in the outflow from Loch Gaineamhach on the Moor of Rannoch (Photograph K H Morris)

studied). Eels (22.6%), three-spined stickleback (12.9%) and minnows (4.8%) were less common, but occasionally abundant. Eleven (17.8%) of the sites fished apparently had no fish of any kind present in either the inflow or the outflow.

3.3 Fish communities

Nineteen (33%) of the loch inflows which were studied apparently contained no fish. Of the others, 29 (50%) contained brown trout only, 8 (14%) brown trout and at least one other species, and 2 (3%) contained no brown trout but at least one other species.

Twenty (32%) of the loch outflows apparently contained no fish. Of the others, 17 (27%) contained brown trout only, 14 (22%) brown trout and at least one other species, and 12 (19%) no brown trout but at least one other species.

3.4 Site characteristics

The distribution of the pH and calcium values of the waters studied in relation to the curve of Henriksen (1979) indicates that many of them appear to be acidified (Figures 1 & 2). Of the 19 fishless inflows found, 17 (89%) lie above the curve and only 2 (11%) below it. Similarly, with the 20 fishless outflows, 17 (85%) lie above the curve and only 3 (15%) below it. The absence of fish in these streams, therefore, may well be associated with the acidified conditions there.

Table 1. Summary of all data on fish species from inflows to and outflows from loch sites

Fish species	Number of sites	% total sites
Atlantic salmon (*Salmo salar*)	1	1.6
Brown trout (*Salmo trutta*)	40	64.5
Arctic charr (*Salvelinus alpinus*)	0	0
Pike (*Esox lucius*)	1	1.6
Minnow (*Phoxinus phoxinus*)	3	4.8
Roach (*Rutilus rutilus*)	0	0
Eel (*Anguilla anguilla*)	14	22.6
Three-spined stickleback (*Gasterosteus aculeatus*)	8	12.9
Nine-spined stickleback (*Pungitius pungitius*)	1	1.6
Perch (*Perca fluviatilis*)	0	0
Sites with no fish	11	17.8

Plate 2. The dried up outflow from Loch Beanaidh in Strathspey. At sites like this it was not possible to fish or to take water samples from either inflow or outflow during dry weather (Photograph A A Lyle)

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Of the 10 fishless lochs for which inflow and outflow fish data are available, it should be noted that fish were found in 3 of the streams involved. However, in all 3 of these cases the fish concerned were eels which occurred only in the outflows. No fish were ever found in the inflows of these fishless lochs and trout were always absent from associated streams. The pH and calcium characteristics of almost all these sites are low (Figures 1 & 2).

The majority of the sites studied (Table 2) had fish in the loch and in its associated pair of streams. Chemical conditions were apparently acceptable in these situations and in only 3 (6%) of the streams was the pH below 5.0. In those situations where fish were absent from an inflow or an outflow, conditions were usually poorer and the pH was below 5.0 in 6 (23%) of them (Figure 3).

A particularly interesting situation was found at Loch Grannoch in Galloway. This large loch once maintained an important sport fishery for brown trout and one of the few populations of arctic charr in south-west Scotland. Over the last 3 decades the fishery has deteriorated and virtually ceased, and arctic charr have apparently become extinct. Much of the catchment of the loch has been afforested over this period. There are still some brown trout in the system, however, and it appears that they are being maintained by recruitment from the main inflow stream, where young fish were found on several occasions during this study and whose pH is normally around 6.0. In contrast, the outflow (which must reflect much of the chemistry of the loch) is fishless and acid, often with a pH below 5.0. Unfortunately, the catchment of the main inflowing stream has itself recently been afforested and it seems likely that this will follow the fate of the rest of the system and brown trout will disappear completely.

3.5 Stream populations

As indicated above, the data on the numbers of fish in streams were obtained in a standard way but were not really quantitative. When standardized, the numbers of trout found in a standard area of stream bear little relation to the numbers of adults found in standard netting in the loch (Figure 4), although most lochs with trout did have young in the inflow or outflow or both.

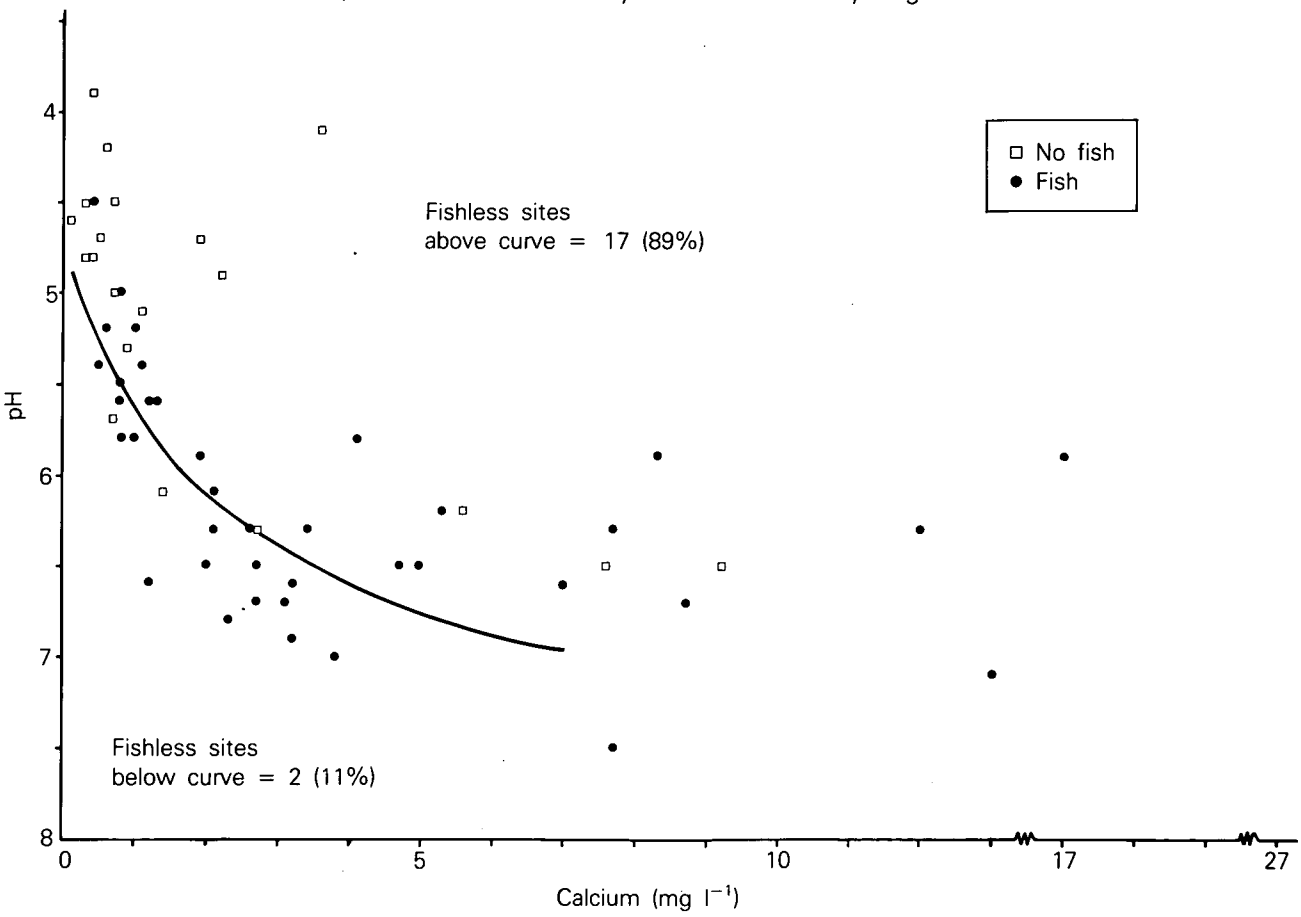

Figure 1. The distribution of pH and calcium plots for all inflow streams fished during this study

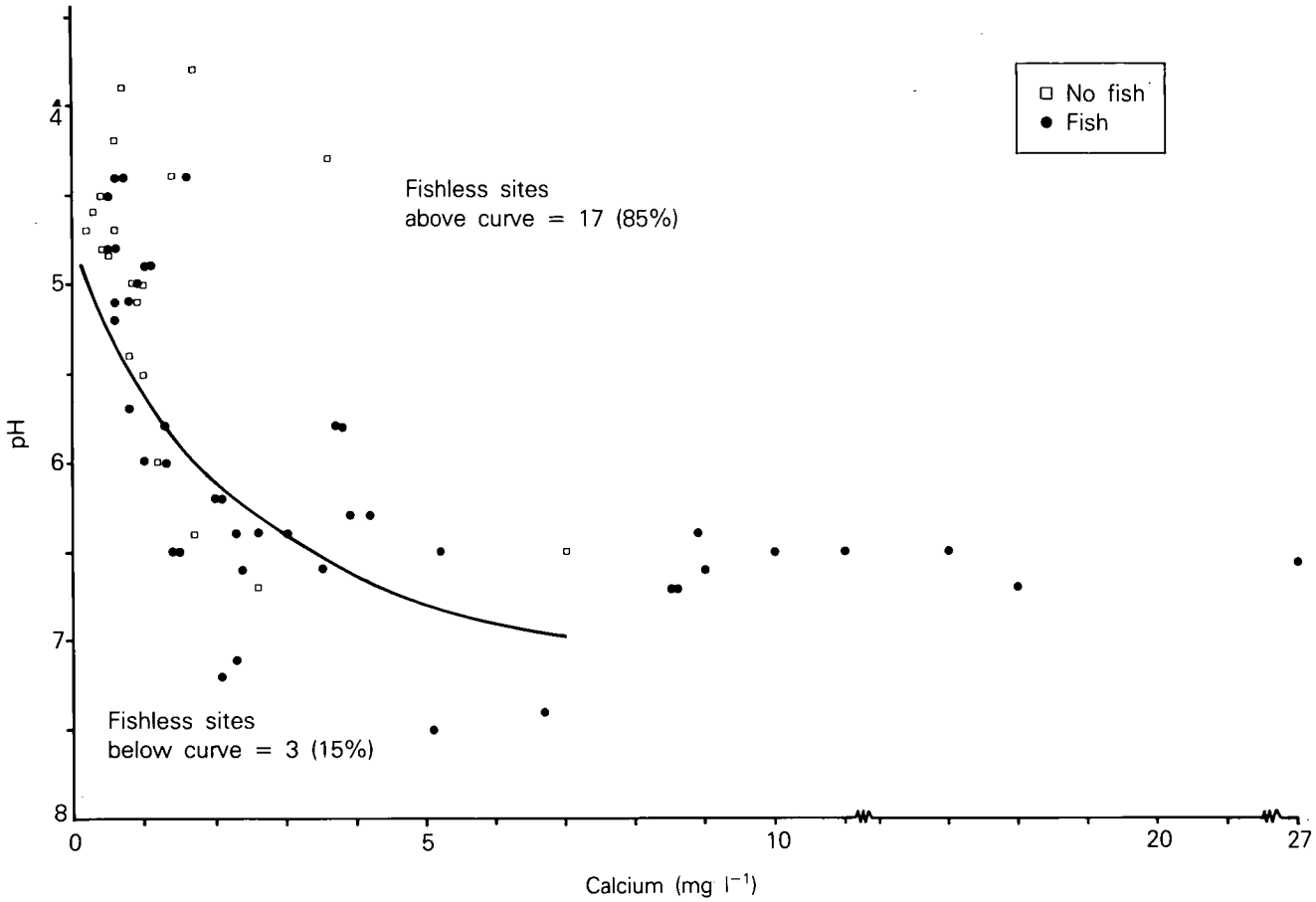

Figure 2. The distribution of pH and calcium plots for all outflow streams fished during this study

Table 2. The numbers of young trout in each 0.5 cm length group at the sites investigated during the study. Some sites (—) were not fished

Loch number	0		1		2		3		4		5		6		7		8		9		10		11+
1	—	—	—	—	1	2	1	3	7	—	—	—	—	—	—	—	1	1	2	1	3	1	2
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	10	36	8	10	—	—	—	1	—	—	—	—	1	1	1	2	—	—	1
4	—	—	—	—	—	2	8	3	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—
5	—	—	—	—	—	—	1	2	1	—	—	—	2	—	1	3	2	—	—	—	1	1	1
6	—	—	—	—	—	—	4	1	1	2	—	2	—	—	—	1	1	—	—	—	—	—	1
7	—	—	—	—	—	1	1	1	—	—	—	2	—	—	—	—	1	2	—	—	—	—	—
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	1	1	—	1	2	—	1	1
10	—	—	—	—	—	—	3	13	8	2	—	—	—	—	1	—	1	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	1	—	1	1
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	3
14	—	—	—	—	—	—	—	6	20	8	—	—	2	—	2	4	3	—	1	1	2	—	2
15	—	—	—	—	—	—	1	6	7	3	5	1	—	—	—	—	2	1	—	—	—	—	—
16	—	—	—	—	—	—	—	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	2	13	25	6	2	—	—	—	—	1	1	1	—	—	—	—
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22	—	—	—	—	—	—	—	1	3	9	13	6	5	3	1	—	—	1	—	3	—	1	—
23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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25	—	—	—	—	—	—	—	—	—	—	—	4	4	1	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	1	2	1	1	1	2	4	—	—	—	—	—	—	1	—	—
27	—	—	—	—	—	—	—	—	—	—	—	—	1	4	1	—	—	—	—	—	—	1	2
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	—	4	—	1
29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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39	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	—	—	—	—	6	10	7	—	—	—	—	—	—	—	1	1	1	1	—	1	—	—	1
41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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43	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
44	—	—	—	—	—	1	9	7	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	1	14	10	7	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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54	—	—	—	—	—	1	2	2	—	1	3	1	—	—	2	—	—	—	—	1	2	—	—
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78	—	—	—	—	—	—	—	—	—	—	—	—	3	1	3	1	—	—	—	—	—	—	2
79	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—
81	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
82	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
83	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Because of the differences in the years and seasons of sampling, the relative sizes of trout in the various streams are not of too great comparative significance. However, the size distribution within streams is of interest in relation to acidification and the suggestion that whole year clases can be removed by one acidic episode (Beamish *et al.* 1975; Frenette & Dodson 1984; Henriksen *et al.* 1984). As is normal in nursery streams, especially small ones, most streams were dominated by 0+ fish though other year classes were usually present too. However, only in a few places were older fish present in significant numbers.

Of the 63 sites where stream fish were sampled, 25 had no trout, 9 had one year class only, 9 had 2 year classes, 13 had 3 year classes and 7 had 4 year classes. The presence of year classes was estimated from an analysis of the length/frequency data available. The great majority of the sites with several year classes were between pH 5.5–7.0 and 1–10 mg l^{-1} calcium (see Brown & Sadler 1981; Brown 1982).

4 Discussion

The results lead to the conclusion that, as in some parts of Wales (Stoner *et al.* 1984), fishless conditions in a number of streams in Scotland are associated with acidification (Plate 3) and that the majority of such sites are found in south-west Scotland (cf Wright & Henriksen 1980). Fish data for lochs and at least one associated stream are available for 63 sites. Of this

Plate 3. The inflow burn to Loch Neldricken in Galloway was once probably an important spawning and nursery stream for the brown trout in this loch, which is now acidified and fishless (Photograph A A Lyle)

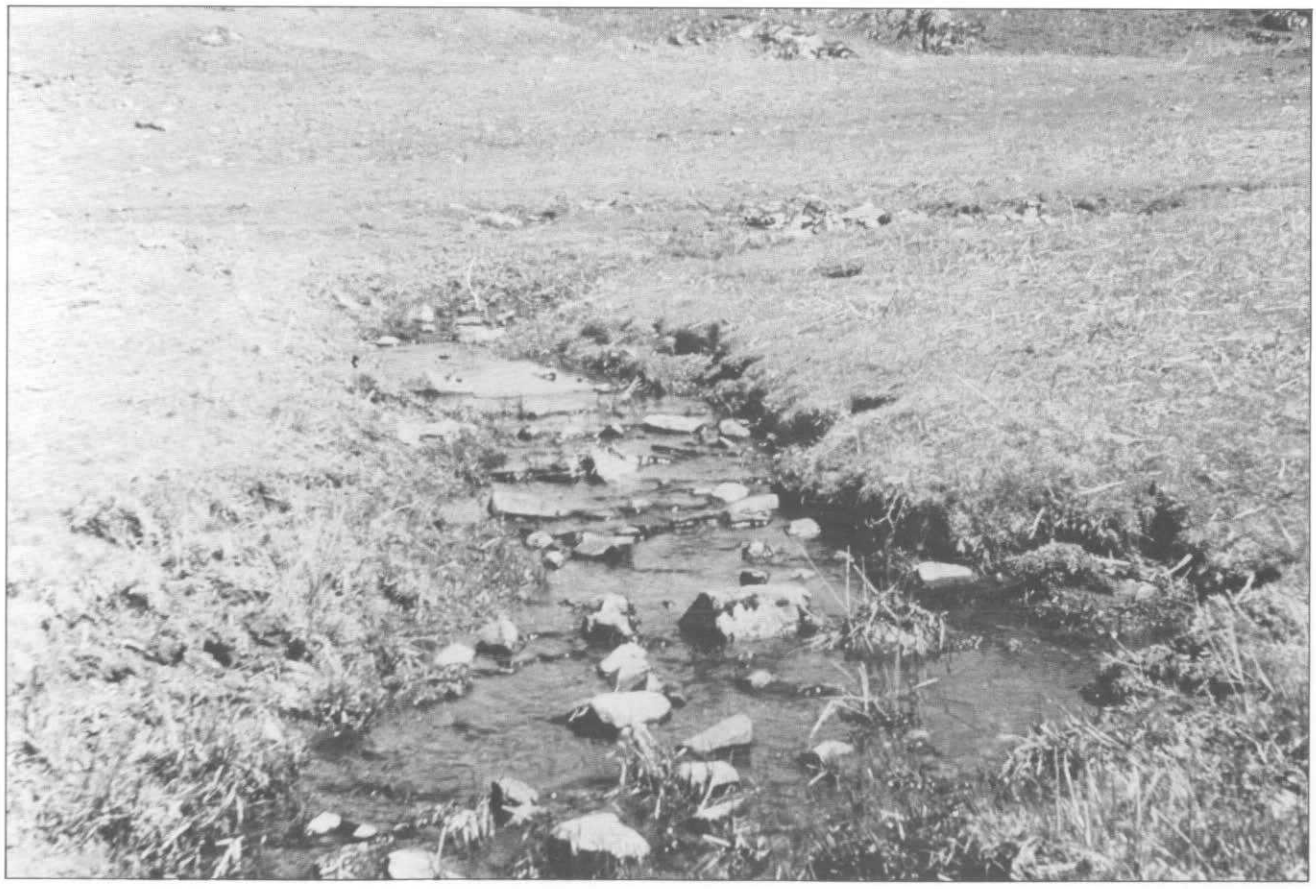

Plate 4. The inflow burn to Fellcroft Loch in Galloway, one of the 'control' lochs off the granite blocks. This burn is not acidified and is used by both brown trout and minnows from the loch as a spawning and nursery area (Photograph P S Maitland)

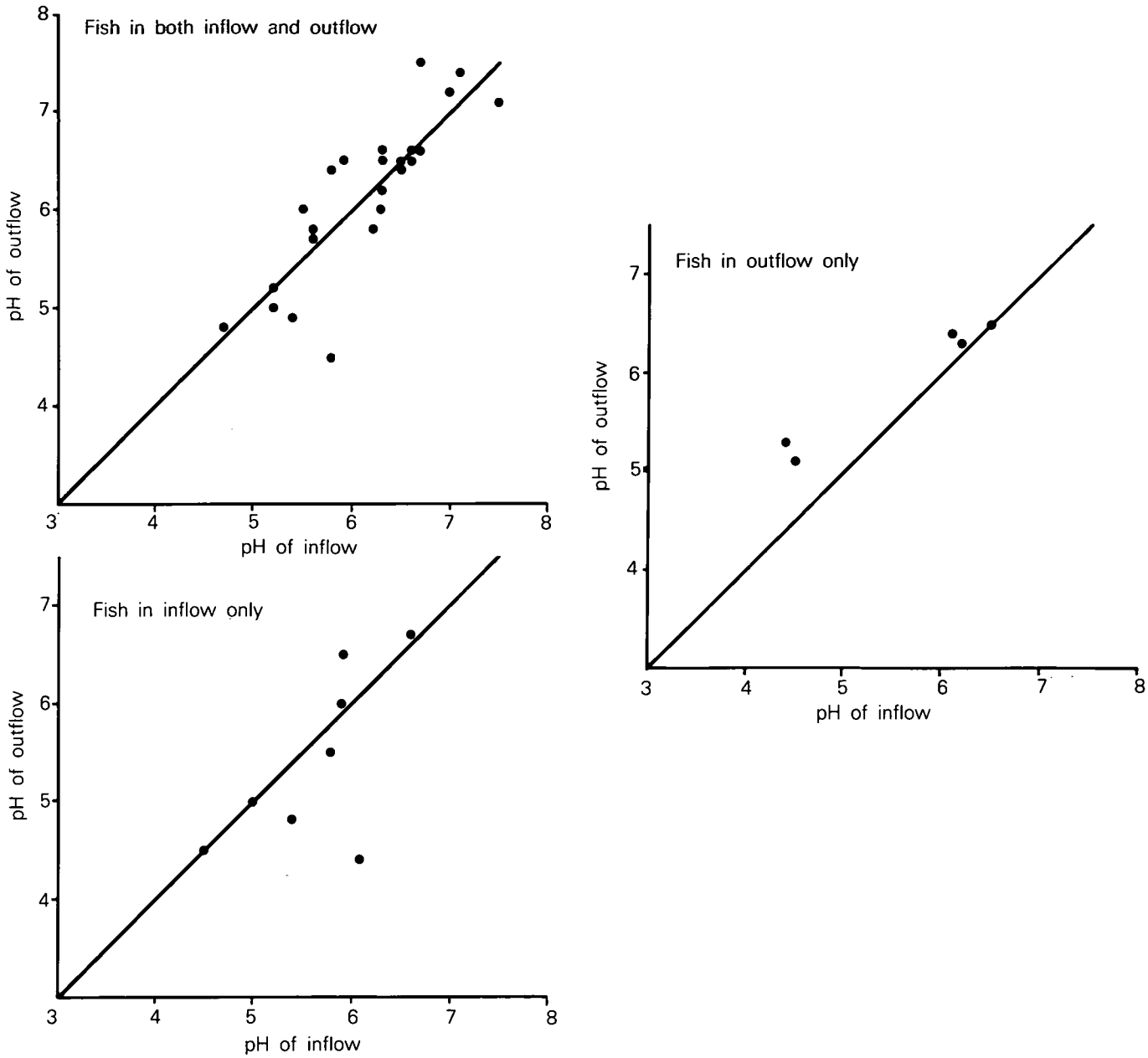

Figure 3. The occurrence of juvenile brown trout in streams in relation to the pH of inflows and outflows

number, 13 are 'control' sites (ie their catchments are not on granite bedrock but they are near sites whose catchments lie entirely on granite). All of these control sites have fish in the loch and usually at least one associated stream (Plate 4). In 3 cases (17%), fish were not found in streams associated with control sites.

Of the 48 lochs lying on granite and regarded as vulnerable, 7 have no fish in the loch or its streams, 3 of the lochs are fishless but have eels in the outflows, and one site has fish in the loch but none in the streams. Thus, 11 of the granite lochs (23%) have no trout in associated streams. Although some of these streams may have been infuenced by afforestation (Harriman & Morrison 1980, 1981, 1982), many had totally unafforested catchments.

As far as geography is concerned, the great majority of these fishless streams were found in south-west Scotland (cf Battarbee 1984), where a number of waters are known to be undergoing acidification (Burns *et al.* 1984). Only occasionally were fish absent from streams in other parts of the country.

Apart from systems from which fish have already disappeared, it is clear that some further extinctions are likely. Again, many of these will be in the Galloway area, and Loch Grannoch and perhaps the Lochs of Glenhead can be cited as examples. Thus, the next 2 decades are likely to see virtually all the lochs and streams on the granites of Doon and Cairnsmore fishless, unless conditions are alleviated. Even large lochs lying only partly on these granites may be in difficulty, and research by the author is in progress on Loch Doon, which contains the only known remaining population of arctic charr in south-west Scotland, to determine the status and likely future of this important system.

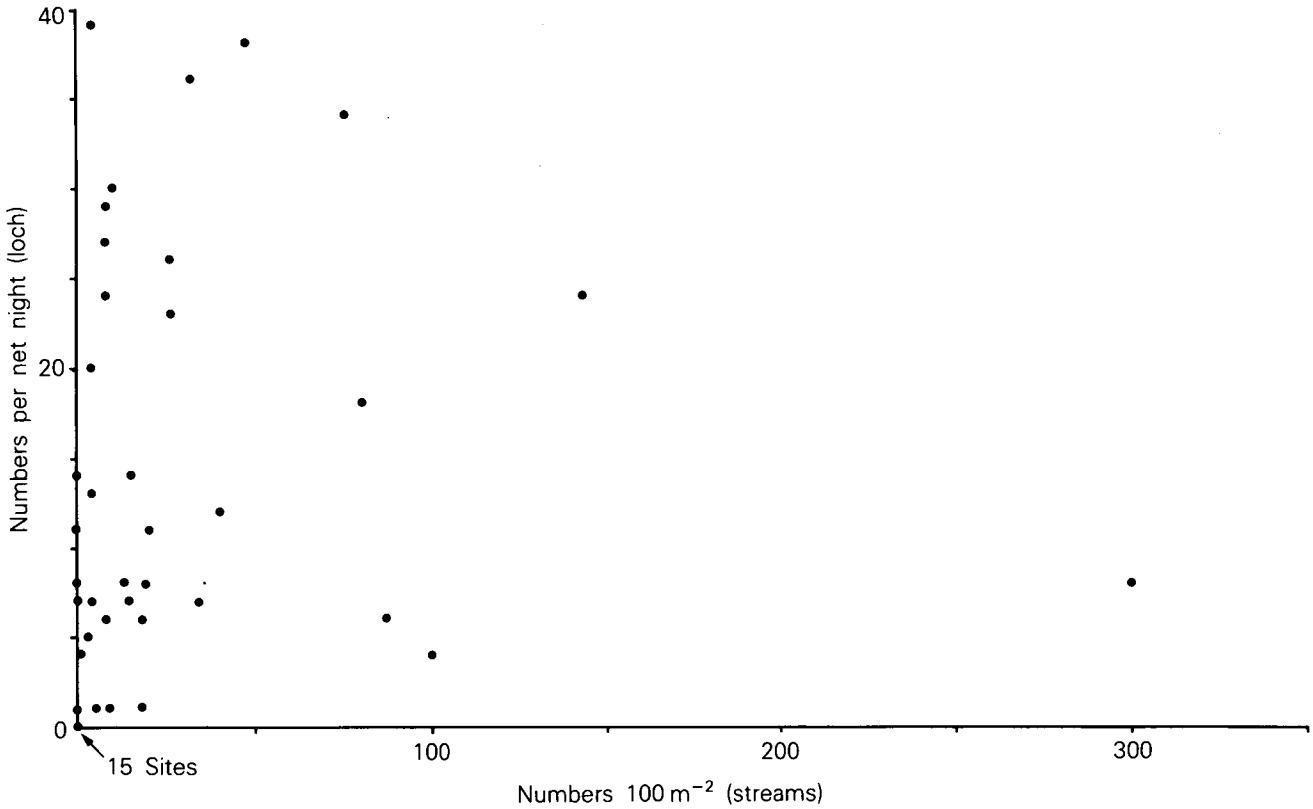

Figure 4. Plots of standardized catches of adult brown trout gill netted in lochs (numbers/net/night) and juvenile fish electric fished in the burns associated with each loch (mean values 100 m^{-2} in inflow and outflow)

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