Chapter (non-refereed)

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Appendix 5

Tail deformities in brown trout from acid and acidified lochs in Scotland

R N B CAMPBELL

Summary
Most old records of tail deformities in brown trout proved to be from lochs which are now acidified and fishless. Examination of trout from other lochs which are thought to be acidified but still have some trout revealed significant deformities in the tails of some of these fish too. The relevance of these findings to the acidification of Scottish lochs is discussed.

1 Introduction
In 1871, a 'tailless' brown trout (*Salmo trutta*) from the island of Islay in Scotland was exhibited at a meeting of the British Association for the Advancement of Science (Peach 1872). The caudal rays of this fish anastomosed towards the end, giving the tail a rounded appearance, hence the name (Plate 1). Similarly deformed trout were reported from Loch Enoch (Plate 2) in Galloway (Traquair 1882) and later from various streams in the central belt of Scotland (Traquair 1892). The identical nature of the deformity reported from both Islay and Galloway was noted by Traquair (1892), but at the time, though it was felt that the cause of the deformities was pollution, at least for those examples from industrial areas, this hypothesis could not explain the island and upland examples.

A further Galloway example was reported in 1927, from Loch Narroch, which is only 2 km from Loch Enoch (MacDonald 1927), and another from Loch Fleet in 1948 (Williams 1948). At present, Lochs Enoch, Narroch and Fleet are fishless (Maitland *et al.* 1986), and on the acidification curve of Henriksen (1979) are acidified. The question, therefore, arose as to whether these deformities were early indicators of acidification

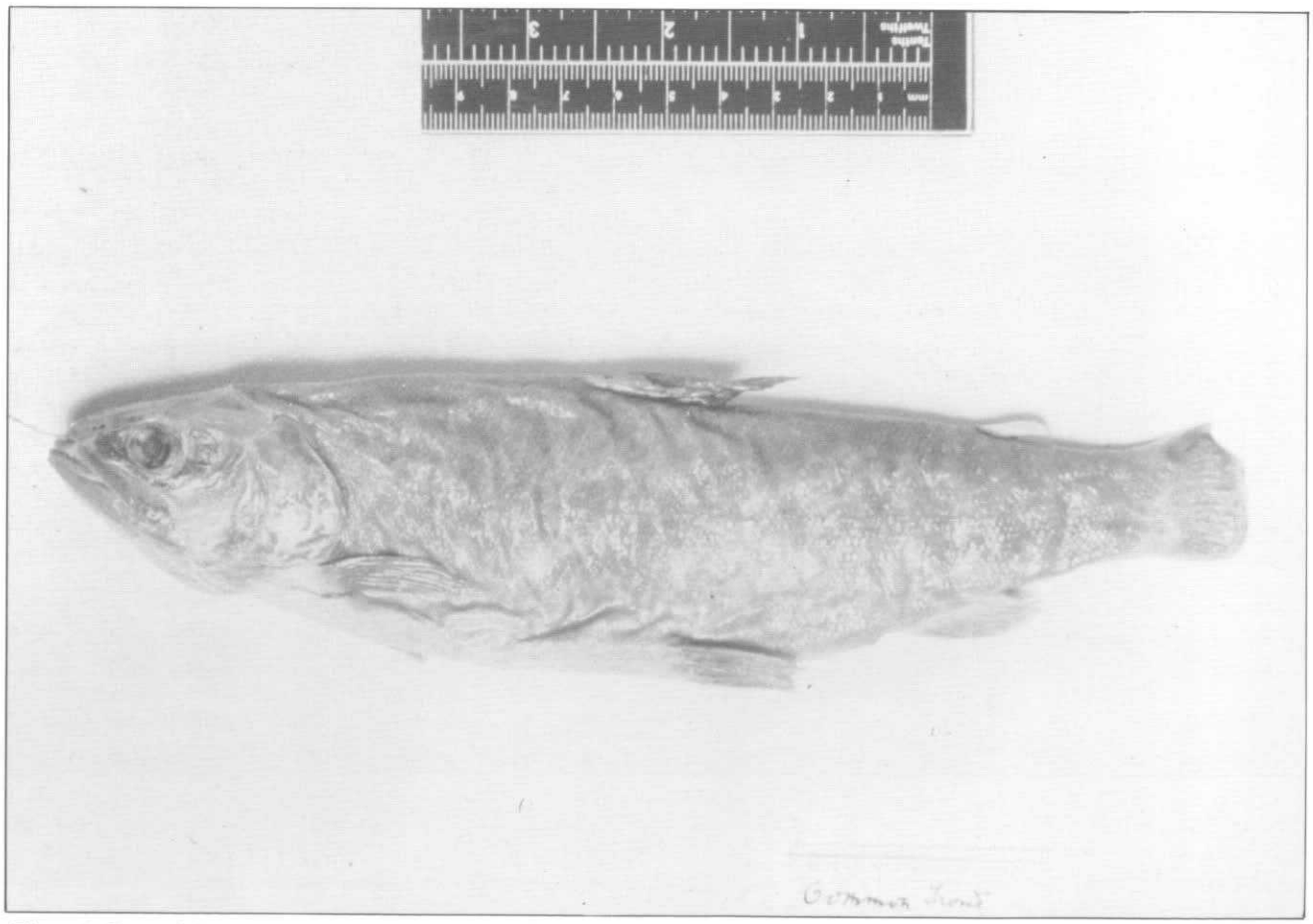

Plate 1. One of the earliest tailless trout recorded. A specimen from Loch nam Maorachan (now called Loch nam Manaichean on Islay, which is held in the Royal Scottish Museum in Edinburgh. This loch is now fishless (Photograph Royal Museums of Scotland)

Plate 2. Loch Enoch in Galloway where tailless trout were recorded by Traquair in 1882. The fishing guide of this period stated that catches of 4–5 dozen trout were common at this time. The loch is now fishless (Photograph P S Maitland)

affecting the fish, either through increased acidity itself or associated aluminium toxicity.

The possible connection between fish deformities and acidification was not one of the original objectives of the programme to investigate the status of fish populations in Scottish lochs in relation to acidification (Maitland *et al.* 1986), although the story of the 'tailless trout' of Loch Enoch (already identified as acidified by previous researchers) was well known in Scottish limnology. The decision to investigate this particular topic was taken only after reference to similarly deformed trout having occurred in Loch Fleet (also identified as acidified) was found in unpublished angling records. Fortunately, this information was noted before the first fish caught during the Scottish survey were processed, so it was possible to examine them for deformities, even though they had been caught before this topic became part of the programme. As these deformities had also been reported from Islay (as well as Galloway), it was decided to include several lochs there in the survey, even though these lochs were not on granite bedrock, the original criterion for selection.

2 Methods

During the processing of brown trout caught during the survey, each was examined for deformities of the caudal fin rays. The descriptions used to define the typical deformity seen in the past were those of Traquair (1892), based on a thorough examination of fish from both Islay and Galloway. Essentially, the deformity of interest is a waviness and clumping of the fin rays of the dorsal and/or ventral edges of the caudal fin. Some of the fish recorded last century had such a strong degree of distortion that the whole tail had a rounded-off appearance, which gave rise to the names of 'tailless' or 'dock-tailed' trout. It is clear from the literature that these were exaggerated exceptions and that milder distortions of the caudal fin rays were commoner.

Drawings and dissections of the various types of deformity are shown in Traquair (1892). When deformed tails were found in the present study, they were first photographed on the whole fish and then removed and preserved. Some tails were also X-rayed at the Royal Museum of Scotland in Edinburgh, where some of the original specimens from Islay are still preserved. In most cases, the commonest type of deformity was a linear waviness in the rays, and a rounded appearance was found only in a few fish

3 Results

The present chemical nature of the lochs concerned has been discussed by Maitland *et al.* (1986).

3.1 General

Of 34 relevant lochs sampled in different parts of Scotland, 3 produced brown trout which had deformed tails: one loch was on Islay, the other 2 were in Galloway (Table 1). The lochs previously recorded as having such fish were all found to be fishless now—the loch on Islay that produced the first records of deformity has been included in Table 2 for interest, despite having a Hazen value of 100, which is at the limit set here for working with the acidification curve of Henriksen (1979).

All the lochs which produced deformed fish were acidified on the criterion of this acidification curve, as were all those lochs from which deformed trout had been reported in the past. No examples of the deformity were found in unacidified lochs. These results are summarized in Figure 1, which indicates that the number of fish caught per night decreases as lochs become more acid, and that, as catches become very small, both the number of lochs that have lost trout and the proportion of deformed fish increase.

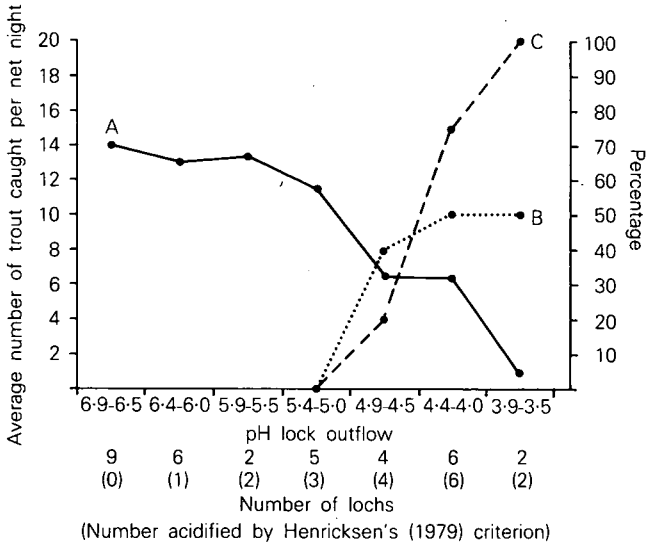

Figure 1. The relationship between loch acidity and: A, gill net catches of trout; B, the percentage of lochs with extinct populations; C, the percentage of deformed fish in the catches. NB The calculation of average catches per net night excluded zero catches from lochs with extinct populations

3.2 Islay

Two lochs were netted here: Loch nam Manaichean (which was called Loch nam Maoachan when the deformed trout in it were originally reported) and Loch nam Breac, 0.5 km to the north and at a slightly lower altitude.

Loch nam Manaichean was found to be fishless. Peach (1872) reported that all trout caught in this loch over the previous 30 years had had deformed tails and that such fish were not found in any nearby loch, or indeed in any other loch on the island. Thompson (1872) stated that the nearby Loch nam Breac 'abounds in small trout having the usually formed homocercal caudal fins'. In August 1985, however, 10 out of the 13 brown trout caught in this loch had deformed tails, the nature of which is well seen on X-rays of the fins. The Hazen values for these lochs indicate that the surrounding peat is the probable source of their acidity.

Local information indicated that 2 other lochs on Islay, the Leorin Lochs, had lost trout populations known to have been present in the 1930s. These lochs were not netted during this study, but chemical samples indicated that they are very acidic (pH 3.8) and peat stained (Hazen>250).

3.3 Galloway

Loch Enoch and 7 neighbouring lochs were netted during the present survey. Loch Enoch had had a good reputation as a trout fishery last century, but by 1883 was regarded as having few fish and was only visited by anglers wishing to catch the 'tailless trout' for

Table 1. Lochs in which brown trout with deformed tails were found during this study

Loch	Catch		Date	Chemistry	
	Deformed	Total	1985	pH	Hazen
Round Loch of Glenhead	1	1	May	3.7	15
Loch Harrow	2	10	May	4.7	5
Loch nam Breac	10	13	Aug	4.0	85

Table 2. Lochs from which brown trout with deformed tails have been recorded in the past

Loch	Catch	Date	First reference to deformed fish	Chemistry	
				pH	Hazen
Loch Enoch	0	Oct '84	Traquair 1882	4.6	5
Loch Narroch	0	May '85	MacDonald 1927	3.5	10
Loch Fleet	0	Apr '84	Williams 1948	4.4	20
Loch nam Manaichean	0	Aug '85	Peach 1872	3.9	100

which it had become famous (MacDonald 1927). The trout seem to have become extinct by 1890 at the latest, and when netted in October 1984 none were found. The nearest lochs, at a slightly lower altitude, Neldricken, Valley and Narroch, were also found to be fishless. In 1913, a trout with a deformed tail was caught in Loch Narroch, and in 1927 it was said of this loch '..the trout are becoming tailless and I hear have, within recent years, become so scarce that it is quite possible they may entirely disappear' (MacDonald 1927).

The Glenhead Lochs were netted in April 1985 and fish were found in both. The Round Loch of Glenhead yielded only one trout which had a deformed tail (Plate 3), but the Long Loch of Glenhead produced 11 trout and one minnow (*Phoxinus phoxinus*) none of which showed deformities. McDonald (1927) stated that he had fished the Round Loch of Glenhead many times and had caught many fish there, none of which were deformed. The lowest altitude lochs in this area that were netted, the Long and Round Lochs of the Dungeon, both produced trout in October 1984 and no records are known of there ever having been deformed fish in either of them. The histories and status of trout populations in these lochs are shown in Figure 2.

Loch Fleet was netted in April 1984 and found to be fishless. Angling records showed the trout here to have become extinct in the 1960s. Deformed fish, called 'half-tailed trout' were caught here in 1947 and 1948 (O Williams, unpublished angling diaries), and, interestingly, were described as being 'typically hard fighting half-tailed trout', which may indicate that the deformity is not too much of a disadvantage.

Loch Harrow does not lie on granite and was one of the 'control' lochs in this study. However, it is an acid loch and much of its catchment is now afforested. When netted in April 1985, 2 out of the 10 trout caught had deformed tails.

4 Discussion

After these deformities were reported, a number of theories were put forward as to the cause. The examples from industrialized areas were attributed to water pollution (Traquair 1892), but it was felt that this could not be the cause on an Hebridean island or in the upland areas of Galloway, where Loch Enoch was described as being '. . . away from every possible source of contamination . . .' (MacDonald 1927). Analyses were made of water from both Loch nam Manaichean and Loch Enoch and no pollutants were found, the very purity of the waters giving rise to a theory that the deformities were due to calcium deficiency and were, in fact, a form of 'rickets' (Traquair 1892). However, as was pointed out at the time, such an explanation would not account for the lowland polluted waters.

Other theories of mechanical damage or damage by other fish were easily refuted by examination of the deformed tails, which showed that the fin rays, though abnormal, were entire, unabraded and unbitten (Traquair 1892). The cause remained a mystery at the time, essentially because of the assumption that such island and upland lochs were beyond the reach of any form of pollution. In recent years, the discovery of just how far aerial pollution can travel has shown this assumption to be wrong, and the evidence from diatom cores is that Loch Enoch was beginning to acidify as early as the 1840s (Battarbee 1984). MacDo-

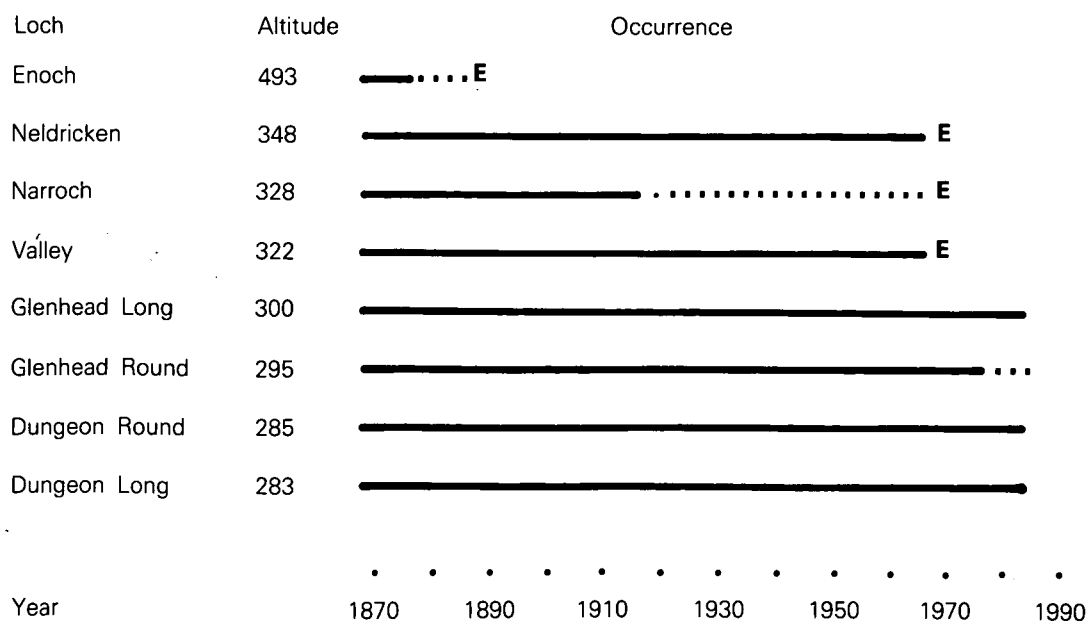

Figure 2. Records of appearance of brown trout with deformed tails (....) and their later extinction (E) in some lochs on the Doon granite block in Galloway. All dates are approximate

nald (1927) was prescient in being concerned at the 'public health' implications of the extinction of fish in such a remote place as Loch Enoch, but was unable to suggest any actual cause.

Deformities of fish due to water pollution are now well known in both fresh (Slooff 1982) and salt (Bengtsson 1985) water, and have now been particularly linked to acidification in North America, the sources of acidity being either mining operations (Mount 1973) or acid rain (Beamish *et al.* 1975; Fraser & Harvey 1982). It is not known whether the tail deformity apparently related to acidification in Scotland is produced during the egg or larval stages only, or whether it can be induced at any age whilst the fish is growing. Daye and Garside (1980) did hatch salmonid eggs at various acidities but did not rear any of the young concerned. Slooff (1982), working on bream (*Abramis brama*) in the polluted River Rhine, found that the most prevalent deformities, such as deformed fins, were most frequently seen in older fish.

In the Loch Enoch area, where there is a good altitudinal sequence of lochs identified as being acidified both by this study and others (Battarbee 1984), the fact that the occurrence of deformities precedes extinctions in relation to altitude is of interest. In Norway, the experience is that the effects of acidification are first apparent in the highest hill lochs where catchments are small and soils are thin (Leivestad *et al.* 1976). The chronological and altitudinal sequence of deformities and extinctions in Scottish lochs agrees with this evidence (Figure 2).

On Islay, the loch which originally produced the deformed fish (Loch nam Manaichean) is the highest on the island, and the one from which fish were taken during this study (Plate 4) is only slightly lower. Even here, therefore, the sequence of the deformity suggests that aerial pollution rather than acidity from the surrounding peatland may be the cause.

Thus there is strong circumstantial evidence that, before populations of brown trout become extinct because of acidification, a characteristic deformity (Plate 5) of the caudal fin rays often appears. Direct proof can only be obtained through experimental rearing of fish in acidified waters, but the historical evidence in Scotland is that, every time that this deformity has been reported from a loch, it has been followed by the extinction of the fish population itself. The clear water lochs in which this sequence has occurred are all now identifiable as acidified on the criteria of Henriksen (1979). The situation on Islay is complicated by organic acidity in the lochs there, but the fact that the phenomenon occurred first in the

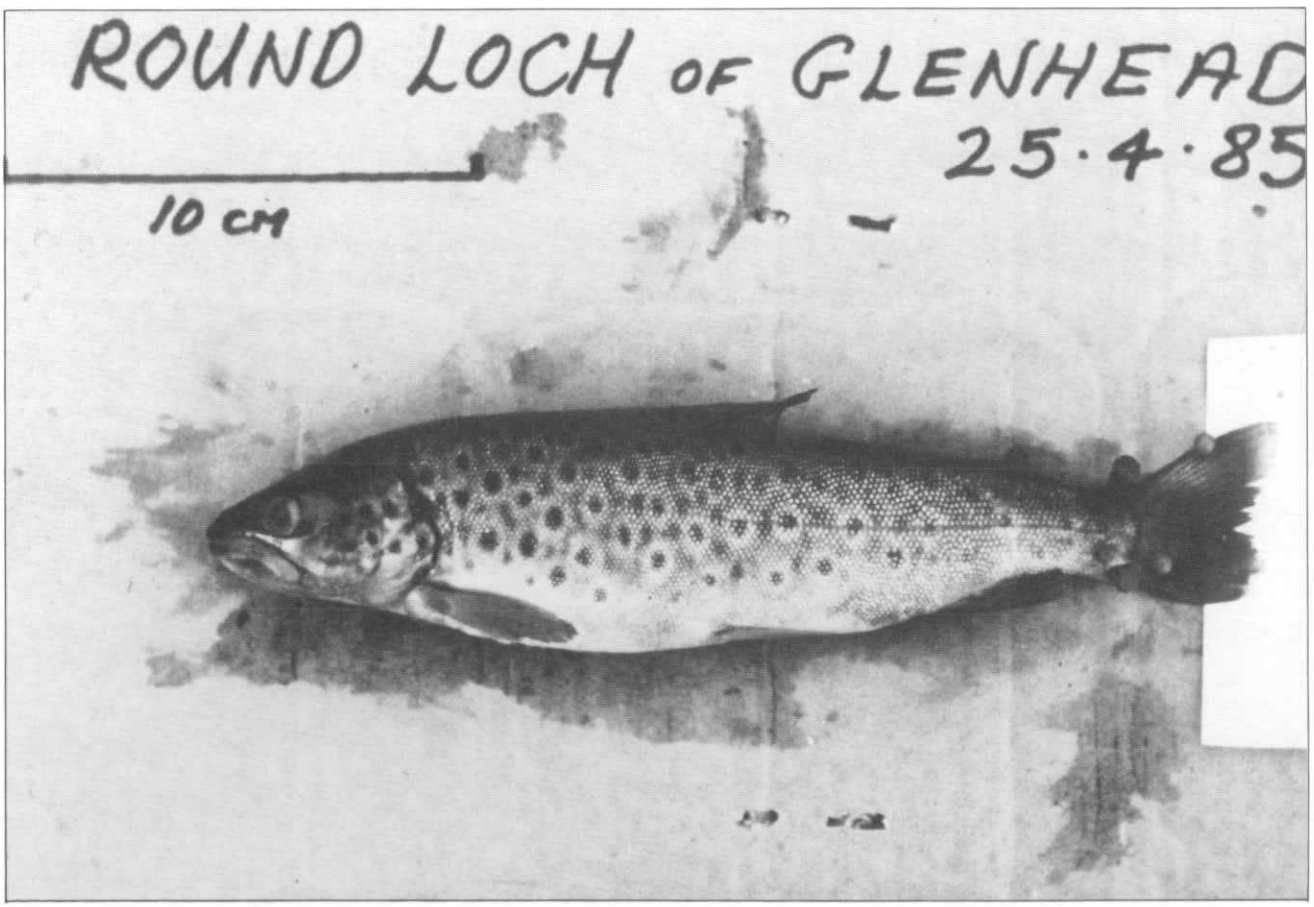

Plate 3. Brown trout with a deformed tail from the Round Loch of Glenhead in Galloway (April 1985). This loch is near several others which are now fishless. Earlier this century MacDonald (1927) stated that no deformed fish were known from this loch (Photograph R N B Campbell)

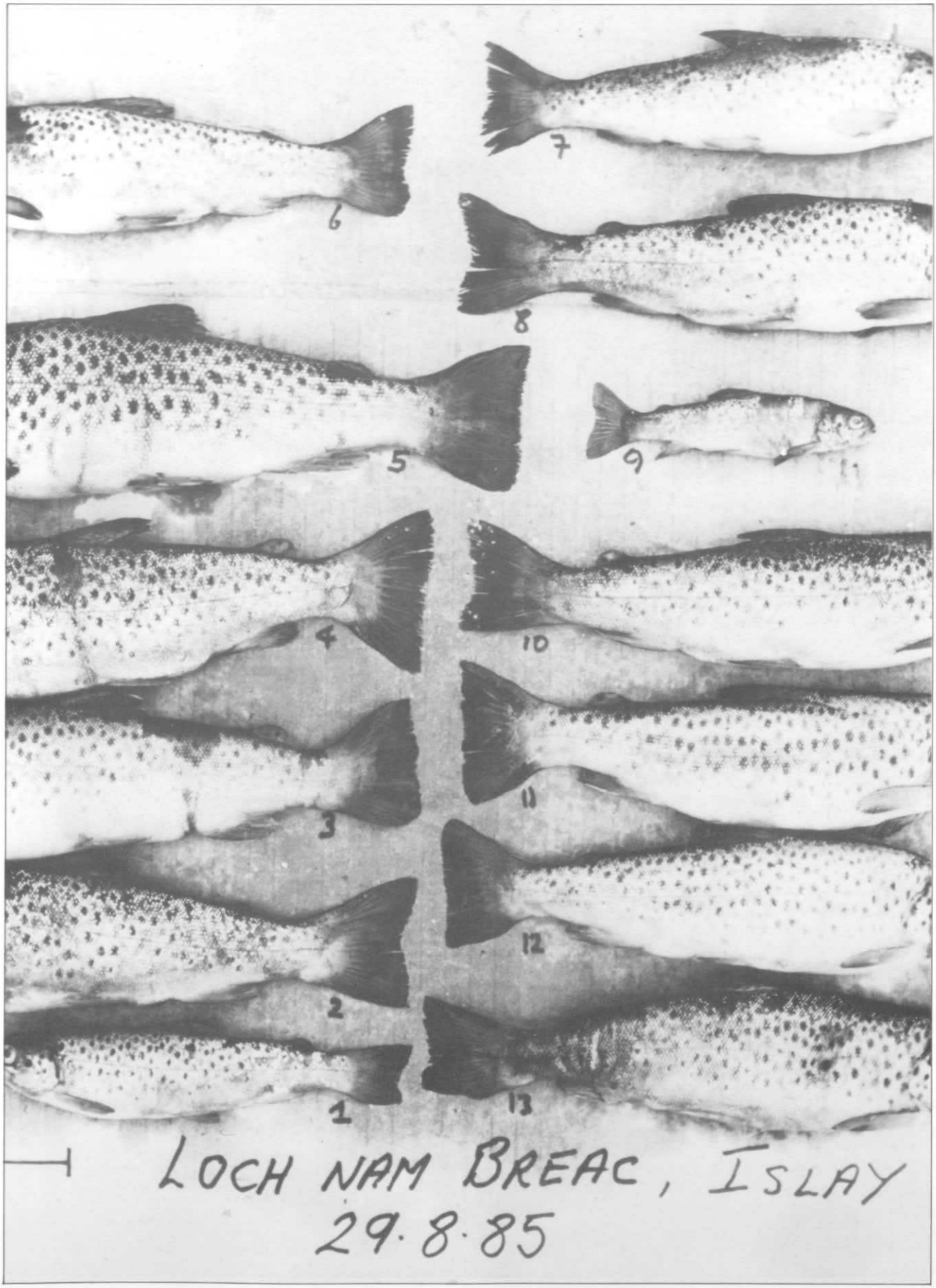

Plate 4. Tails of brown trout from Loch nam Breac on Islay, caught in August 1985. All but 3 have some deformity, but last century it was stated (Thompson 1872) that no deformed fish had ever been taken from this loch, whilst every year for 30 years most of the trout from the nearby Loch nam Maorachan had had deformed tails (Photograph R N B Campbell)

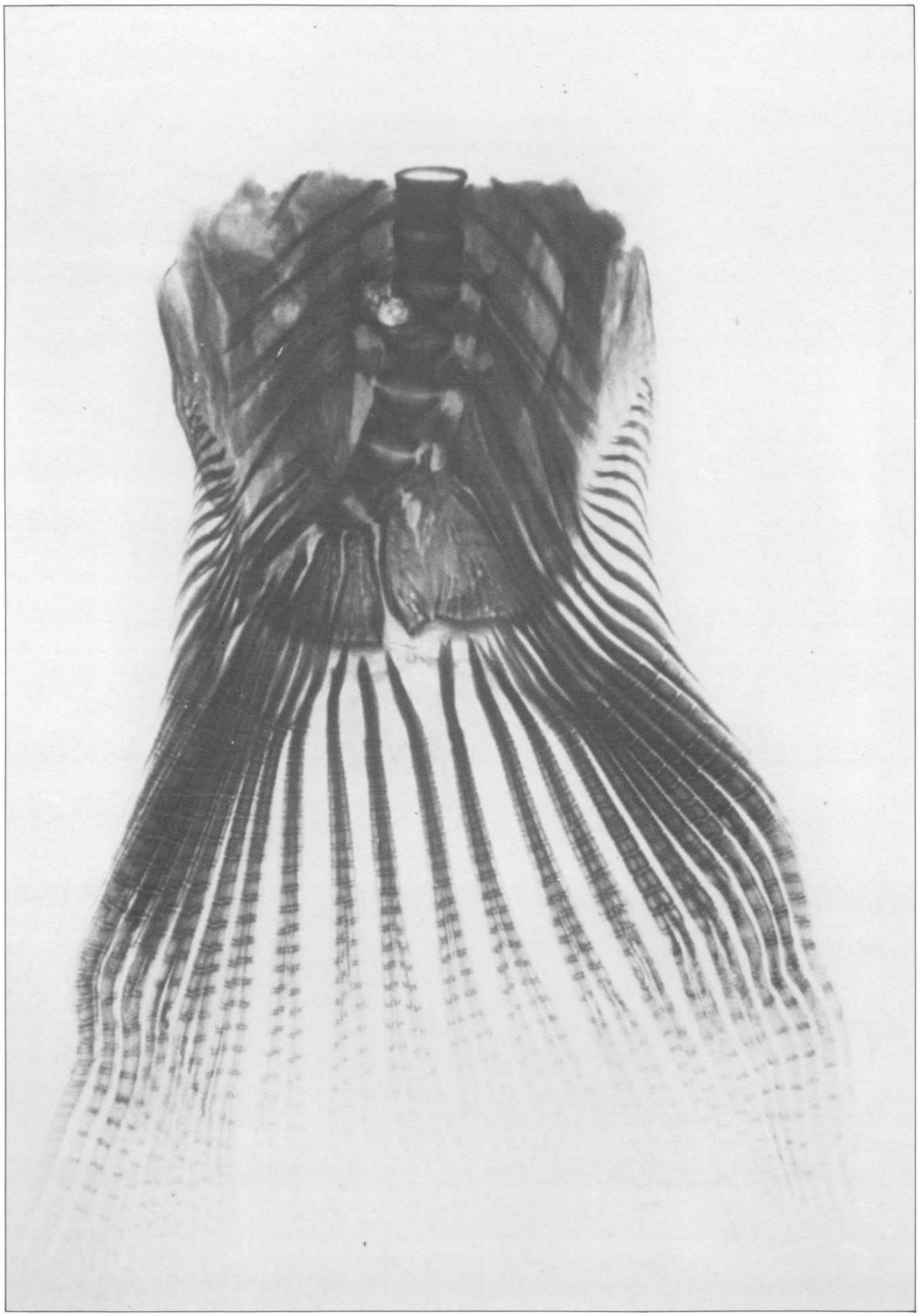

Plate 5. An X-ray of the deformed tail of a brown trout from Loch nam Breac on Islay (Number 12 in Plate 4) (Photograph Royal Museums of Scotland)

highest loch on the island, as it did first in the highest loch in Galloway, is suggestive of an air pollution effect.

These early deformed fish from Islay and Galloway may therefore have been the first ever indicators of man-made acidification of fresh waters in the British Isles, and the occurrence of similar deformities to-day may be a useful early sign of the process starting in other waters.

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