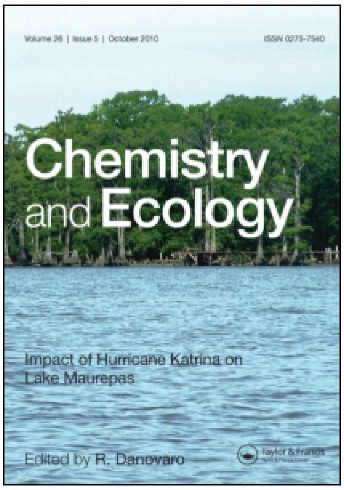

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THE BROWN TROUT POPULATION AT LOCH FLEET EIGHT YEARS AFTER LIMING

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At the start of the Loch Fleet Project in 1984, the Loch and the upper 7 km of its efferent stream were found to be devoid of trout (*Salmo trutta*) as a result of acidification. Following the liming treatments applied to the catchment, from 1986 the formerly toxic water quality conditions (pH ~ 4.5, calcium ~ 1 mg l^{-1}, elevated aluminium and heavy metal levels) were eliminated, and trout were reintroduced on two occasions, in 1987 and 1988. A total of 520 fish were stocked, at a combined density equivalent to 5.5 kg ha^{-1}. Surveys of the loch and stream populations were carried out annually until 1993 to monitor their development, using a range of techniques, including electrofishing, gill-netting, seine-netting, spawner trapping and mark-release recapture methods. Length and scale- analysis were used to investigate fish growth.

The trout population in Loch Fleet expanded rapidly as a result of natural spawning in the loch's main feeder stream, augmented by the use of an artificial spawning bed which was constructed at the loch outlet in 1990. In mid-1983 the stock density, estimated by mark-recapture census methods, had increased to 24.9 kg ha^{-1}. Poor recruitment in the years 1991–93, however, reduced the rate of expansion and resulted in a population comprising mainly older individuals. The poor recruitment in these years was not fully explained but was not caused by water quality and was most likely a result of fry washout by spring spates.

Fish growth rates were high initially and were estimated on the basis of the Elliott trout growth model to be optimal for the prevailing water temperature regime of the loch. By 1991, growth rates had fallen, probably as a result of competition for food, but showed signs of recovery towards the end of the study period in 1993, following the period of lower population densities of young fish.

Trout rapidly repopulated the loch's outlet stream after 1987 but have remained sparse and have shown no signs of spawning within most of the stream. Water analyses have shown that the liming of the Loch Fleet catchment has minimal impact on downstream waters when flows are high, so that potentially toxic acid episodes have not been prevented.

KEY WORDS: Brown trout, *Salmo trutta*, acidification, liming, fishery restoration, population census, growth rates, artificial spawning beds, spawning

INTRODUCTION

Up to the 1950's Loch Fleet contained a thriving population of brown trout (*Salmo trutta* L.), which was fished by angling enthusiasts and yielded an average of around 100 fish per year, of mean weight 0.5 kg. Shortly after this the fishery began to decline and, despite attempts to restock in 1960 (brown trout) and in 1965 (rainbow trout) no fish were caught after 1975. The Loch Fleet project began in 1984 (Howells and Dalziel, 1992) and the first two years of fishery work, prior to catchment liming, were spent investigating the causes of the decline and the means for remediation. The findings of this work have been reported by Turnpenny *et al.*(1988), who attributed the decline of fishery to recruitment failure, brought on by acidification and associated acute metal toxicity effects acting upon the early life stages of trout. This was shown by a series of live fish exposure trials, involving life stages from freshly fertilized eggs to yearling fish, held captive in a range of appropriate waters. A target water quality for restoration of a self sustaining fishery was defined as pH > 6.0 and calcium concentration > 2 mg l^{-1} (Turnpenny, Chapter 3 in Howells and Dalziel, 1992).

A number of more recent publications have documented the fishery investigations covering the period shortly after liming (Turnpenny, 1991; Turnpenny, Chapter 13 in Howells and Dalziel, 1992; Howells *et al.*, 1992). These describe: repetition of fish exposure trials, confirming that liming had eliminated acute toxicity to all the life stages of trout, from eggs to adults; restocking, whereby 520 trout of a mixture of three local stocks of a naturalistic age composition were introduced in 1987 and 1988; continuing studies of egg hatching rate and spawning success; finally, growth and dietary studies. All these investigations led to the conclusion that the fishery programme at Loch Fleet had succeeded in restoring a naturally spawning population, whose members were growing well for the type of water, and were in good health.

The present paper follows on from the previously reported studies, and covers fishery investigations from 1990, to the conclusion of the project in spring of 1994. In particular, it focuses on the status of the trout population in the 1993–94 period, almost eight years after the first lime applications took place on the catchment (1986), and looks back at its development since 1987; it also considers whether the progressive reacidification of the Loch and its feeder streams has given rise to any detectable deterioration of the brown trout population.

STUDY AREA

A full description of the study area is given in Howells and Dalziel (1992), and fish sampling sites are described by Turnpenny *et al.* (1988), hence only the essential points are mentioned here.

The Loch has several tiny feeder streams but only one, the Altiwhat, at the north-east corner of the Loch, is accessible by fish. It has a median flow of 0.05 $m^3 s^{-1}$ and an average slope of 15% over its fish-containing portion. Maximum width is barely 2 m. A water quality sampling point some 30 m upstream from its confluence with the Loch is known as site 7U.

The Loch itself has a surface area of 17 ha and is only a few metres deep over most of its area. It falls to a maximum depth of around 15 m towards the north-east. The substrate in this deep portion is of loose peat but elsewhere, is of rock or gravel composition, featuring many large boulders. Small, sandy beaches occur on parts of the western and south-western shores of the Loch.

The water chemistry of Loch since the application of various liming treatments has been monitored closely and is described elsewhere in more detail (Dalziel, this volume), especially with respect to reacidification. In spite of liming, the water chemistry has remained essentially characteristic of an oligotrophic lake, with calcium levels averaging less than 4 mg l^{-1} over the time since liming took place.

The invertebrate fauna of the Loch in the period post-liming was described by Battarbee *et al.* (Chapter 14 in Howells and Dalziel, 1992) and more recent studies have dealt with fish diet rather than direct sampling of the Loch's fauna.

METHODS

Fish Sampling

Loch Fleet Sampling by all methods other than spawner-trapping (see below) was carried out in late May to early June of each year.

Samples of fish were collected from Loch Fleet either by rod-and-line fishing (both fly and spinner) or by gill-netting. Seine-netting was also used to a limited extent. Rod and line fishing was carried out from the shore and by boat.

For gill-netting, nylon monofilament nets were used, ranging in mesh size from 19 mm to 54 mm (half-mesh). Each net was 20 m in length by 2.4 m deep. The nets were deployed in banks of two to ten nets, strung together in a continuous series with a randomized sequence of mesh sizes. The nets were lifted once or twice daily and fish were removed by cutting the meshes. In this way it was possible to rescue some of the more recently ensnared fish and later return them to the loch, the fish having suffered only minor scale loss. Seine-netting (1993 only) was carried out using a 30 m long × 2.4 m deep net, of mesh size 10 mm knot-to-knot. This was used on sandy bays on the southern and western margins of the loch.

Fish population surveys on stream sites The main population surveys on stream sites were carried out by electrofishing in late May and early June of each year. The standard sampling stations and quantitative sampling methodology are as described by Turnpenny *et al.* (1988). For each electrofishing run, all salmonid fish captured were counted and measured for length and weight.

Automated fish counting Electronic fish counting tunnels (Scottish HydroElectric Mk X resistivity) were located on the inlet and outlet streams, 50 m upstream and downstream of the Loch, respectively, from June 1989 onwards. These were set up to count fish of > 20 cm length. Dataloggers recorded the incidence, direction (up-or downstream) and date of new counts.

The outlet stream counter was located downstream of the artificial spawning bed, which lies between the counter and the loch outlet.

Trapping of spawners Prior to the installation of the fish counters and, later to validate the accuracy of the counters, spawner traps were installed adjacent to both counting locations. On the Altiwhat, an upstream fish trap was deployed, placed immediately upstream of the fish counting tunnel position. The trap was of a simple box-type, of dimensions 75 × 75 × 30 cm, with a downstream-opening, funnelled entrance and an opening lid. The trap was installed so as to provide a minimum water depth of 10 cm, which 30 to 40 adult fish were able to occupy overnight without any problem. The outlet trap was a Wolf-grid type attached to a small waterfall, in which fish were collected in a circular black tank and held in flowing water.

Owing to suspected problems of fish by-passing the Altiwhat trap and counter during spates in some years, prior to the 1992–93 spawning season a fence was constructed across the top of the counting tunnel. Construction was of galvanized angle iron, covered with plastic mesh of 6 mm-opening. The fence was arranged at an angle of 45° to the vertical, sloping downstream to encourage self-cleaning, with a top level 60 cm above the fish counter tunnel. The fence was extended to cut into both stream banks, making it impassable by fish, other than through the counting tunnel and trap.

Multiple accounting was avoided by clipping the adipose fin of each fish trapped, prior to release. Release was upstream of the fish trap on the Altiwhat, or back on to the spawning bed for fish caught at the loch outlet. Fin-clipped fish were recorded as recaptures.

Mark-Release-Recapture Population Estimation

In June 1993, a population census of the Loch was carried out using a mark-release-recapture technique. All live fish captured were fin marked with a Panjet® inoculator, using Alcian Blue 8GX dye (Hart and Pitcher, 1969). Marks present from earlier dates were also noted, in particular a batch of 165 spawners which were marked by an adipose fin clip in the previous November.

After completing these operations, the fish were held in a cage for the remainder of the day of capture to ensure that they were in good condition, and then returned to the loch. The fish were taken by boat and released at various points around the loch. An estimate of the size of the Loch Fleet brown trout population was made, following the method of Schumaker and Eschmeyer (1943), from captures and recaptures over 20 sampling dates. The method assumes no migration in or out of the system (confirmed by the fish-counters located at the Altiwhat and Loch outlet), 100% survival of the released fish (likely, as fish were released only if they were in good condition), and complete remixing of the fish into the population. The procedure of dispersing the fish around the Loch during release should have helped to achieve this.

Fish Measuring, weighing and Scale Sampling and Analysis

Prior to handling, fish were anaesthetized with MS222 (Sandoz Ltd) at a concentration of 1 in 16,000. They were then measured in length, from the tip of the snout to the end of the caudal peduncle (standard length, nearest 1 mm), and weighed (nearest 1 g). Condition factor (K) was calculated as: 100 × weight/standard length^3, where weight is in units of grams and standard length in cm. Around 20 scales were scraped from each fish, from an area just below the dorsal fin. These were placed in labelled plastic envelopes and retained for laboratory examination.

Scales were cleaned in 2% KOH and examined under transmitted light, using a microfiche projector. Age was determined from the number of annuli present, and the length was back-calculated to each annual growth check, after confirming that an isometric relationship existed between fish length and oral radius (Bengal and Tesch, 1978). Several scales from each fish were examined, the first three scales giving consistent results being selected for back-calculation. The results from the three scales were then averaged to give the final back-calculated lengths.

Egg Planting

Planting out of green eggs Prior to the establishment of a natural spawning run, eggs used for planting out were collected from trout trapped in the neighbouring Loch Dee catchment by the Forestry Commission. Subsequently, Altiwhat fish, collected by trapping, were used, except in the 1993-94 season, when no trapping took place and Loch Grannoch (in the adjacent catchment) stock were instead used. After fertilization, the eggs were counted out into batches of 50 or 100 and placed amongst gravel in Harris boxes (Harris, 1973). Up to 12 boxes each were planted in gravel beds of the Altiwhat (above site 7U) and the outlet spawning bed. Further boxes were held as controls at the Forestry Commission's Clatteringshaws hatchery.

Recovery and Examination of Eggs and Fry

Batches of eggs were recovered from the stream bed planting sites and hatchery controls in mid-April of each year, when they were expected to have hatched. The numbers of hatched fry, dead and unfertilized eggs were counted.

Construction of an Artificial Spawning Bed

An artificial spawing bed was constructed in early October 1990 at the outlet of Loch Fleet. The aim was to augment the spawning area in the Altiwhat, and to take advantage of the more stable water quality and flow regime created by the buffering effect of the Loch's volume (see Turnpenny, 1991). The stream at the outlet of the Loch flows for some 50 m length over smooth granite bedrock, with few pockets of gravel suitable for trout to spawn. To create the spawning bed, a small weir was first constructed at the downstream end of a run, some 30m below the Loch outlet. A piece of timber was fixed to the bedrock, transverse to the flow, and sealed using a plastic membrane weighted down with gravel. This was then backfilled level with 10 tonnes of washed pebbles (approximately 50 mm to 10 mm grading). A number of large boulders were placed at points on top of the bed to encourage downwelling of water into the gravel (Vaux, 1968).

RESULTS AND DISCUSSION

Changes in Population Size, Age Structure and Biomass

The trout stock intoduced in May 1987 and July 1988 comprised fish of various sizes and ages. The initial size structure is shown in Figure 1, and is followed through the years of the study in the lower histograms, based on sampling of the Loch only. Spawning commenced in 1987, and the first fry were detected in the spring of 1988, but remained in the streams surrounding the Loch, or were too small or too few to be caught by the methods used, until 1991. Up to that point, the fish caught were all of the initial stocking and were few in number. From 1991, catches increased markedly, comprising by this time, almost entirely naturally-spawned fish.

The sample data shown in Figure 1 are not readily adjustable for estimating catch-per-unit-effort (CPUE) and a better indication of the growth in population numbers following stocking is given by counts of spawners made from trapping and fish counter records for those years where they were available, and from the population

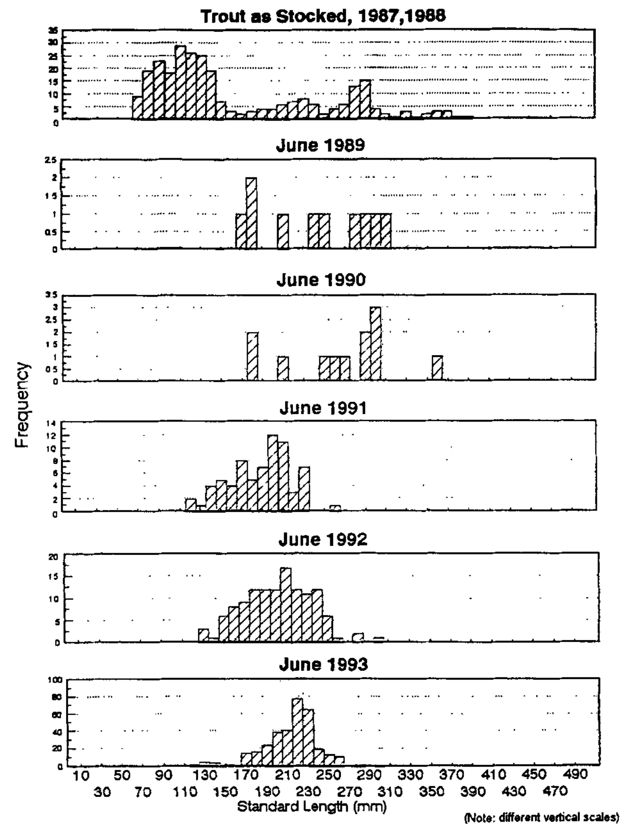

Figure 1 Changes in the length-frequency distributions of brown trout sampled from Loch Fleet after the 1987–88 stockings.

census made in June 1993. Table I shows the increase in spawning stock size, from 91 in 1987 (the number of age 2+ fish in the initial stocking), to 2,665 in 1993. The pattern shows an initial fall in numbers due to mortality up to 1989, followed by a rapid increase thereafter.

Table II shows the age distribution of trout in the Loch in June 1993, based on the results of scale reading. It reveals that 3+ age-group fish (the product of the 1989/90 spawning season) were predominant numerically outnumbering all other age groups combined. Trout densities (per ha) by age class are also shown, and biomass, based on the mean weight, for each age group. The standing crop of age classes 1+ to 4+ in June 1993 was estimated to be 423 kg in 17 ha, equivalent to 24.9 kg ha^{-1}. This compares with stocking rates of 3.2 kg ha^{-1} in 1987 plus 2.3 kg ha^{-1} in 1988, i.e. a four- to five-fold increase.

Growth and Condition

Growth and condition of trout in the Loch were measured to establish the adequacy of food resources and to compare the length-at-age with values measured for trout living in comparable, non-acidified upland lakes in Britain.

Table I The growth in brown trout spawning stock size, as estimated by different means, from the date of the first re-introduction of trout, up to the population census in June 1993.

Date of Sampling *Months*	*Year*	*Method of Sampling*	*Estimated Number of Spawners*
May	1987	(as stocked)	91
November	1987	Trapping	61
November	1988	Trapping	58
November	1989	Electronic counter	101
November	1990	Electronic counter	391
November	1991	Electronic counter	> 1000
November	1992	–	no count
June	1993	Mark-release-recapture	2,665

Note: For the 1987 and 1993 estimates, only fish of age 2+ and older have been included.

Table II Estimated age structure, population density and population biomass of brown trout in Loch Fleet in June 1993.

Fish Age	*Year Class*	*Estimated Number in Loch*	*Mean Weight* g	*Density* $n \cdot ha^{-1}$	*Biomass* $g \cdot ha^{-1}$
1+	1992	75	34	4.4	150
2+	1991	713	102	41.9	4,279
3+	1990	1445	170	85	14,451
4+	1989	507	202	29.8	6,021
TOTAL		2,740	–	161.1	24,901

The 1993 growth curve for brown trout in Loch Fleet is given Figure 2, based on back-calculated length-at-age data, derived from scale reading. Also shown are comparable curves from earlier years of the study, and scope of values reported from a sample of 18 other Scottish lochs (Frost and Brown, 1967). The data show that, after a drop in growth rates which occurred between the 1988–90 and 1992 surveys, growth rates of the age classes up to 2+ had recovered by 1993, though age 3+ and 4+ fish showed less improvement in growth. It is seen that all the curves fall near the centre of the range shown for the other Scottish lochs.

Condition factors measured each year since 1988 are shown in Table III. These indicate that the trout in Loch Fleet have maintained a more-or-less constant weight-for-length over the period since their reintroduction, with K-values mostly in the range 1.55-1.60. Deviations from this range in 1989 and 1990 are based on small sample sizes and are shown by the large standard deviations to be insignificantly different from other values ($p > 0.05$).

Turnpenny (1991) showed, using the Elliott (1975) growth model for trout, that for the 1988–90 period, the growth rates attained by trout in Loch Fleet reached the expected maximum for the temperature regime of the loch, indicating that food supply was not limiting. The subsequent decline in growth rates by 1992 suggests that, with the rapid

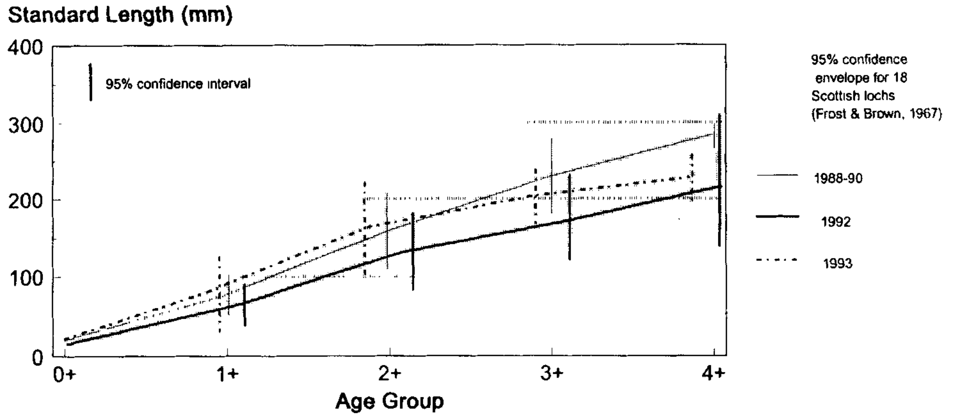

Figure 2 Back-calculated growth curves of brown trout in Loch Fleet for fish caught in 1989–90, 1992 and 1993. Comparative data are also shown for other Scottish upland lochs.

Table III Condition factors (K) of brown trout caught in Loch Fleet, June 1988–93.

Year	*Mean condition Factor, K*	*Standard Deviation*	*Number of Fish Sampled*
1988 (as stocked)	1.58	0.22	30
1989	1.71	0.35	15
1990	1.33	0.38	7
1991	1.50	0.10	70
1992	1.52	0.16	126
1993	1.55	0.14	272

expansion of the adult population over this period (Table I), food had become limiting. The return to optimal growth rates amongst the younger age classes by 1993 is taken to be a response to the poor representation of the 1991–92 year classes (Table II) and consequently reduced competition within the cohorts.

Egg Survival and Spawning Success

Egg planting experiments, carried out each year of the project, compare the survival rates to eyeing and hatching of freshly-fertilized ("green") eggs. As the salmonid egg stage is particularly sensitive to low pH, and the newly-hatched alevin to aluminium toxicity (Brown and Sadler, 1989), these experiments were designed to provide the first indications of reacidification effects in the Altiwhat. To complete the picture, electrofishing surveys were carried out in June of each year to determine fry densities in the Altiwhat.

Table IV summarizes this information for the years 1989–94, as available. It is seen that whilst overall hatching rates in the Altiwhat varied between 60 and 98%, these

Table IV June population densities of trout fry in the Altiwhat in the years 1989–93, with details of recorded spawning movements for the previous year, spring rainfall, egg survival estimates for artifically planted eggs, and Altiwhat pH levels (± values shown are standard deviations).

Year	*Spawners Counted*	*Fry Density* $n\,m^{-2}$		*Egg Survival to Hatching, %*			*pH Mean, Minimum*	*Mean,Minimum*	*Calcium* $mg\,l^{-1}$		*April + May Rainfall*
		Altiwhat	*outlet*	*Altiwhat*	*outlet*	*Hatchery*	*Altiwhat*	*outlet*	*Altiwhat*	*outlet*	*mm*
1989	57	13 ± 1.4	1.88 ± 0.94	81 ± 9	–	86 ± 7	6.76, 6.52	6.30, 5.97	4.7, 2.7	3.1, 2.4	137
1990	57	12 ± 1.5	0.48 ± 0.095		–	–	6.84, 6.04	6.17, 5.74	4.0, 2.6	3.1, 2.9	187
1991	320	6.0 ± 0.21	0.43 ± 0.091	98 ± 2.6	96 ± 2.6	96 ± 3	6.80, 5.85	6.07, 5.83	4.0, 2.5	2.9, 2.4	272
1992	>1000	0.8 ± 0.27	0 ± 0	80 ± 4.2	52.7 ± 17.2	81 ± 8.4	6.69, 5.95	5.91, 5.44	3.0, 1.4	2.4, 1.6	373
1993	Counter inoperative	1.7 ± 0.21	0 ± 0	60 ± 11	28.0 ± 13.4	60 ± 24	6.32, 5.61	5.67, 4.60	3.0, 1.0	2.4, 1.6	446
1994	Counter inoperative	–	–	85 ± 5	86.4 ± 9.6	59 ± 21	6.17, 5.83	–	–	–	–

values were not significantly different ($p < 0.05$) from control values for hatchery held eggs, and the variability is probably explained largely by variable fertilization rates.

In contrast to the sustained, high hatching rates of experimentally-held trout eggs, the early summer fry densities measured in the Altiwhat show a progressive decline, from two strong years in 1989 and 1990, to a moderate year in 1991 and poor years in 1992 and 1993.

Water quality data (Table IV) appear to rule out re-acidification as a possible cause of declining fry production. High spring rainfall in 1991 and 1992 (Table IV) is considered to be the most likely reason for recruitment failure in these years. The proposed mechanism is that high flows flushed fry out of the steep stream section into the Loch, where they would have become vulnerable to cannibalism by the now well established adult population. An alternative but untested hypothesis is that, with the expansion in the number of spawners from 1990, competition for spawning area became critical, leading to overcutting of redds or fry starvation. This type of spawner-recruit relationship is not unknown and is described by the "Ricker Curve" (Ricker, 1975). Thus, although recent surveys have revealed poor recruitment compared with that for earlier years of the Project, re-acidification has not been the cause, and recruitment could return to the higher levels found in 1989 and 1990. The fluctuations observed may be seen as evidence of the precarious existence of fish in upland waters, where it is not uncommon for one in two trout year-classes to fail (Turnpenny, 1990), or where the oscillations of a newly-established population are progressing towards a stable age structure.

The Artificial Spawning Bed

The spawning bed built at the outlet was used by loch trout immediately after construction in October 1990, and has been used in each season since. It was evident in the 1992/93 season, when the bed was observed over a two-week period in early November, that the area of the bed was fully utilized, with new redds being constructed each day during this period. This was confirmed by digging sample holes, which, in every case, revealed the presence of eggs.

Table IV gives the results of the measured survival rates to hatching of the artificially implanted eggs in the Altiwhat, Loch outlet and in the hatchery (control). Poor hatching rates relative to controls were seen in 1992 and 1993, but in 1994 were high (86%), comparable to those in the Altiwhat, and better than control values.

Results of electrofishing a 50 m length of the outlet stream around the spawning bed in early June (Table IV) show, surprisingly, a higher density of trout fry in 1989, before it was constructed, than in subsequent years. In 1990 and 1991, fry were recorded, albeit at lower densities than in the Altiwhat, but none were detected in 1992 and 1993. In these two years, the survival rates of artificially-implanted eggs were poor, suggesting that mortality of the naturally deposited eggs during the intra-gravel phase was a contributory cause but, as in the Altiwhat, high spring flows in these years would have flushed downstream many fry that did hatch sucessfully. In retrospect, although a few boulders were distributed over the surface of the artificial bed to encourage water exchange, little cover was provided for the newly-emerged fry and this aspect should not be overlooked in future schemes of this type.

The water quality data in Table IV reveal a declining trend in calcium and pH levels at the loch outlet over the period shown, with the mean pH falling below the project target level of 6.0 by 1992, though calcium levels remained above the target level of $2\,mg\,l^{-1}$ over the whole period. The high survival rate to hatching of artificially implanted eggs in the 1993/94 season indicates that water quality remained satisfactory.

Downstream Fish Populations

Whilst improving fish populations in the river draining the Loch was not an objective of the project, it was of interest to monitor any effects in the Little Water of Fleet. This stream is some 13 km in length, beyond which it joins the larger River Fleet, entering Wigtown Bay below Gatehouse of Fleet. The stream is naturally divided by a 5 m high waterfall (the Craigie Linn: OS NX 584 651) with a conifer-afforested portion draining the high altitude granitic part of the catchment, and a lower portion flowing through mainly agricultural pastureland, with a more basic greywacke and alluvial geology. Prior to liming and restocking of Loch Fleet, it had been shown that, whilst eels (*Anguilla anguilla*) were present throughout the river, trout were present upstream only as far as the Craigie Linn, considered to be impassable by trout in the upstream direction (Turnpenny *et al.*, 1988).

Following the re-introduction of trout to the Loch, the stream was resurveyed in 1989, and trout were now found throughout the river; an increase in trout population density in the lower reaches below the Craigie Linn was construed as possible evidence of a beneficial effect of liming the upper catchment (Turnpenny: Chapter 13 in Howells and Dalziel, 1992).

Figure 3 summarizes the population density values for these and subsequent years to 1993 along the whole of the Little Water of Fleet. It is clearly shown that whilst trout

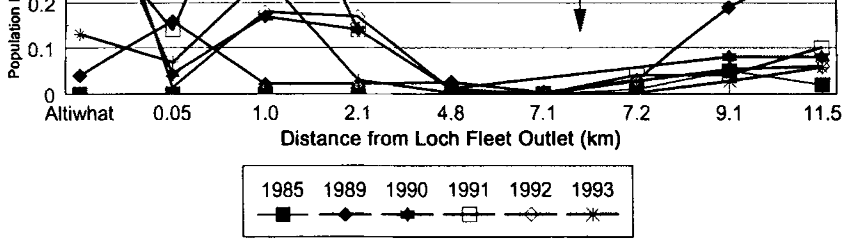

Figure 3 Population densities of age 1+ and older brown trout in the Altiwhat and Little Water of Fleet as estimated in 1985 and from 1989–93.

Table V Annual means and minima of pH and calcium concentration measured in water samples taken from the Little Water of Fleet, 2 km below the Loch Fleet outlet.

		1988	*1989*	*1990*	*1991*	*1992*	*1993*
pH	Mean	6.12	4.75	4.96	5.44	4.93	4.77
	Min	4.22	4.75	4.23	4.24	4.24	4.34
Calcium	Mean	2.40	2.5	2.20	2.30	1.92	2.11
$mg\,l^{-1}$	Min	1.50	2.5	1.60	1.50	1.00	1.90
	n	36	1	20	40	36	18

have maintained a presence in the upper part of the river, an effect which can be attributed directly to the intervention at Loch Fleet, any improvement in the reaches below the Craigie Linn has been modest, if at all significant.

None of the electrofishing surveys in the Little Water of Fleet revealed the presence of trout fry in the upper reaches, except in the upper few hundred metres around the loch outlet and artificial spawning bed. This is undoubtedly explained by the lack of fish present of spawning size. At Loch Fleet trout matured at round 175 mm standard length, whereas the maximum fish size found in the outlet stream was around 150 mm. Given the obvious downstream loss of fish from the loch to the river, it must be concluded that such fish either did not survive or else passed down to the lower reaches of the river.

Table V lists annual means and minima for pH and calcium, measured at a point 2 km below the loch outlet, from 1988 to 1993. The values show an overall acidifying trend with time in the stream, but reveal that even shortly after fish were stocked in the loch, minimum pH values in the outlet fell to well below 5.0, combined at times with calcium levels of less than 2 $mg\,l^{-1}$. Such conditions (pH 4.5, [Ca] 1 $mg\,l^{-1}$) in the Loch prior to liming proved lethal to trout (Turnpenny *et al.*, 1988). The susceptibility to acidification of this reach, even so close to the Loch, may be explained by the flow-buffering of the Loch whereby release of water from the outlet after heavy rainfall is relatively slow, whilst run-off from the catchment is very fast. Thus, the acidic run-off initially overwhelms the alkalinity of the issuing loch waters.

SUMMARY AND CONCLUSIONS

The brown trout population at Loch Fleet, and in its main inlet and outlet streams, has been monitored throughout the period since their stocking in 1987, 1988, when a total stock density equivalent to 5.5 $kg\,ha^{-1}$ was introduced.

Successful spawning was established in the season immediately following their introduction, and spawning has taken place annually ever since, either in the main feeder stream, the Altiwhat, or in a purpose-built spawning bed in the Loch outlet stream. This led to a rapid expansion of the population, which reached a standing crop density of 24.9 $kg\,ha^{-1}$ by mid–1993.

Growth of fish in the 1987–1990 period was estimated from the Elliott growth model to be optimal for the water temperature regime of the Loch, but had declined by 1992, probably as a result of overcrowding. Moderate to poor recruitment in the years 1991–93 reduced the overcrowding amongst younger age-classes, allowing growth to return to optimum by 1993. The reasons for the poor recruitment are not clear but it was not associated with measured toxic water conditions. More likely it was due to violent flows which occasionally occur in upland spawning streams, flushing out fry and rendering them vulnerable to predation or cannibalism. Alternatively, it may have been caused by internal population pressures, which serve to bring a newly established population to a stable age structure.

The influence of interventions at Loch Fleet on downstream water quality and fisheries has been limited. Although a long stretch of stream which was devoid of trout at the start of the project now has a limited trout population, it has not flourished and is subjected to repeated exposure to potentially toxic acid conditions.

The liming treatments applied to the Loch Fleet catchment have so far remained effective through nearly a decade, and look set to endure for some years. The Project is therefore deemed to have met its primary objective of establishing a self-sustaining trout population.

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