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Land-Use Experiments in the Loch Laidon Catchment: Fourth report on Stream Water Quality to the Rannoch Trust and Scottish Natural Heritage

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Executive Summary

1. This report summarises data collated over the first four years of monitoring stream water quality in part of the Loch Laidon catchment. The work is being undertaken as part of the land-use experiments instigated by the Rannoch Trust.

2. Two study burns, an experimental site (cattle grazed during summer) and a control, have been monitored for chemistry and biology since August 1992. To date there is no evidence of any 'grazing effect' on the water chemistry of the experimental burn during periods of grazing and there is no indication of a changing water chemistry relationship between the experimental and control burn with time. There is also no evidence of biological change in the experimental burn which can be unequivocally attributed to cattle grazing.

3. Since the instigation of the experiment it has become clear that, despite generally close chemical and biological similarities, slight seasonal differences in water chemistry between the control and experimental burn are apparent which are probably due to differences in hydrological characteristics. Detection of a response which could be directly attributable to grazing is therefore difficult. In addition there had only been a short pre-grazing monitoring period for the experimental burn and therefore the 'normal' seasonal relationship between the two burns, before the onset of the experiment, is not known. Monitoring of a third burn (Tigh na Cruaiche), physically more similar to the control site, was instigated in 1995. It is intended that cattle will be introduced to this catchment in approximately three years time.

4. The Tigh na Cruaiche burn shows closer chemical similarity to the control than the experimental burn, particularly during the summer, and this probably reflects more comparable hydrological characteristics. The Tigh na Cruaiche burn also exhibits similar trout population structure and epilithic diatom and macroinvertebrate communities to the control burn, although the aquatic macrophyte cover is relatively poor. With the possible exception of the latter biological group, this site is suited to provide an experimental/control comparison in the near future.

5. Given the inherent variability in the stream environment at a number of temporal scales, it is important to continue monitoring the Tigh na Cruaiche burn for a further year or more before and five years after the introduction of summer grazing to allow the quantitative asseessment of the influence of grazing.

6. Data for the control burn is gathered following similar protocols to those used on the United Kingdom Acid Waters Monitoring Network and as such this site has the potential to be used as a 'secondary site' to enhance the Network's spatial coverage.

1 Introduction

The background to the Loch Laidon Catchment land-use experiment is provided by Allott *et al.* (1994). The work, instigated by the Rannoch Trust, seeks to explore the impact of cattle grazing on the terrestrial and bordering aquatic environment and it is the latter component of the project which is reported here. Annual reports on stream water quality work have been published by Monteith *et al.* (1995) and Monteith (1996).

Although the acidification of aquatic systems in areas with acid sensitive geologies, such as those within the Loch Laidon catchment, has been clearly linked to acid atmospheric deposition (e.g. Flower *et al.* 1988), the importance of changing agricultural practices in influencing the aquatic environment in such regions is poorly understood. In modern times one notable change in land use has been the cessation of traditional cattle grazing. It is not clear what effect cattle grazing has on local surface water quality and to what extent the re-introduction of this practice may be to the benefit or detriment of freshwater ecosystems.

The previous reports detail the early stages of the land-use / freshwaters experiment. The main finding of the last report was that there had been elevated levels of calcium, magnesium and conductivity in the experimental burn relative to those in the control burn during periods of summer grazing. However, it was not possible to attribute this to a direct grazing effect since the two burns differ hydrologically and possibly will show relative differences in seasonal chemical characteristics. The larger control burn draws on a catchment of considerably greater relief (see Figure 2) and is on a steeper gradient than the experimental burn. These physical differences will influence hydrological pathways, and could lead to a significant difference in the extent to which precipitation interacts with the lower mineral soil horizons of the two catchments. The differences are probably least apparent during winter months when soils are relatively saturated and the pathway into both burns is dominated by surface run-off and flow through the upper soil horizons. During dry periods in summer, which coincide with the period of grazing, the experimental burn is likely to be more influenced by mineral enriched baseflow than the control. Unfortunately, monitoring of water chemistry of the experimental burn only commenced a few months prior to the introduction of cattle for the first time. Consequently it was not possible to gauge the 'normal' seasonal relationship between the experimental and control before the grazing regime began.

Concern has also been expressed that the location of the sampling point on the experimental burn was too high to represent the entire grazing area and therefore a second sampling station closer to the shore of Loch Laidon is now in operation. However, for the reasons given above a new burn, the Allt Riabhach na Bioraich (referred to here as the Tigh na Cruaiche), which is physically more similar to the control, has been introduced to the experiment. Presently, the Tigh na Cruaiche catchment is free of cattle and it is intended to monitor this site for approximately four years prior to their introduction.

In this report we present the most recent time series data for the original experimental / control pair and in addition we present data from the more recently monitored lower sampling station on the experimental burn and examine the chemical and biological suitability of the Tigh na Cruaiche burn as a future experimental site.

2 Methodology

The methodology of sampling and analysis follows that of Allott *et al.* (1994). This includes frequent (approximately monthly) spot chemistry sampling and annual biological surveys to determine the status of fish, aquatic macrophytes and epilithic diatoms. Macroinvertebrates were not sampled in 1995. Dates of biological sampling are provided in Appendix 4.

Cattle (16 cows, 16 calves and 1 bull), were introduced to the experimental plot on the 11th July and removed on the 30th September 1993. The same grazing period has been implemented in subsequent years, although the stock was reduced slightly by 1 cow and 1 calf in 1994.

Since the summer of 1995 additional spot chemistry samples have been taken from four additional locations which are as follows.

1. a lower station on the experimental burn
2. an upper station on the Tigh na Cruaiche burn (Allt Riabhach na Bioraich)
3. a lower station on the Tigh na Cruaiche burn (Allt Riabhach na Bioraich)
4. Loch Laidon outflow

The Tigh na Cruaiche burn has also been sampled for epilithic diatoms, fish and aquatic macrophytes since 1996, following existing protocols.

3 Data Analysis and Presentation

Data are transferred to a central database at the Environmental Change Research Centre and for this report are presented as raw data, graphs (for chemistry) and summary statistics. Statistical analysis of temporal trends in the data is not appropriate at this stage given the short period of the study to date.

In this report water chemistry results are presented graphically in three sections (Figures 3.1 - 5.6)

- in Figures 3.1 - 3.4 we present a comparison of time series data from the control and original experimental sampling station (upper experimental station) for a few key determinands from January 1993 to March 1997. This represents the longest time series comparison available;

- in Figures 4.1 - 4.4 we present time series data from the control and the two stations on the experimental burn from the summer of 1995 to March 1997. This allows an evaluation of the relative sensitivity of the original experimental site and the more recently monitored lower experimental site in the detection of potential 'grazing effects';

- in Figures 5.1 - 5.6 we present a comparison of time series data from the control, original experimental site and the lower Tigh na Cruaiche burn station, from the summer of 1995 to March 1997 to examine the suitability of the latter as a future experimental site.

Biological data is presented in the same format as in previous reports for specific stretches of the control, experimental and Tigh na Cruaiche burn.

Results for water chemistry are also presented in full data format (Appendices 1-3) and as summary statistics (Table 1). In Figures 3.1 - 3.4 the summer grazing periods are indicated by pairs of arrow heads which define when cattle were introduced and removed each year from the experimental catchment. In these time series, the relationship of determinand levels between the two burns is also plotted as a ratio.

Biological data is presented in the same format as in the previous reports. No data is available for macroinvertebrates for 1995.

The following diversity indices have been used for diatoms and macroinvertebrates:
Hill's N1 approximates to the number of *abundant* species in the sample.
Hill's N2 approximates to the number of *very abundant* species in the sample
Hill's E5 is a measure of the evenness of species occurrences in a sample. E5 approaches zero as a single species becomes more dominant in the community.
E(100) predicts the expected number of taxa in a sample of 100 individuals.
In addition, for invertebrates, the following indices have been applied:
BMWP is a scoring system for macroinvertebrates based on values of 1 to 10 given to each taxonomic family. It provides an indication of water quality; eg. those families which are very sensitive to organic pollution score 10, worms score 1.
ASPT is the Average Score per Taxon, based on the BMWP score divided by the number of taxa in the sample. A range of 6.3 to 6.7 is typical for a diverse fauna.

4 Results

4.1 Water chemistry

4.1.1 Comparison of the control and original experimental burn station

Figures 3.1 - 3.4 demonstrate the relationship between the water chemistry of the control and experimental burn from January 1993 to March 1997. The general similarities between the two sites referred to in previous reports are still evident. As in previous years, several determinands, particularly conductivity and base cations, are elevated in the experimental burn samples relative to the burn control during the summer grazing period, indicated by peaks in the experimental : control ratio. However it is now clear that these peaks are not confined solely to periods of grazing. Elevated levels in the experimental : control ratio are also seen during the spring of 1996 and appear to coincide with periods of relatively low flow. This provides further evidence that the observed peaks in the experimental : control ratio over the period of study result primarily from hydrological differences between burns as discussed in the introduction. It also underlines the problem of detecting any summer grazing 'signal' in the experimental burn. There is no apparent trend in the experimental : control ratio of any determinand over the full course of the experiment. This suggests that cattle have had no year - round or cumulative effect on the water chemistry of the experimental burn to date.

4.1.2 Comparison of the two stations on the experimental burn and the control burn

Monitoring of the upper site on the experimental burn commenced earlier (1993) than the lower site (1995). The upper station was selected to best represent the biological sampling stretch while the lower station probably provides a better integrated sample of catchment processes. Figures 4.1 - 4.4 provide examples of the chemical relationship between the two stations on the experimental burn and the control burn from July 1995 to March 1997. Such comparisons may help to determine whether the lower experimental station is better situated to detect a 'grazing response' than the original station. The two stations on the experimental burn show very similar values for alkalinity and pH over this period. During summer grazing, cation concentrations and conductivity are relatively high at the lower experimental station, however similar effects are apparent earlier in the year and probably reflect periods of low flow as discussed in section 4.1.1. It is therefore likely that the lower station on the experimental burn provides an even poorer comparison with the control site, since experimental : control differences appear to be even more influenced by hydrological differences than the original pairing. We recommend however that monitoring of this site continues for at least a further year before its performance is more rigorously assessed.

4.1.3 Comparison of water chemistry of the Tigh na Cruaiche with the original experimental and control stations

A comparison of water chemistry of the Tigh na Cruaiche with the original experimental and control stations is provided in Figures 5.1 - 5.6. Most importantly, the water chemistry of the Tigh na Cruaiche shows no evidence of departure from that of the control site during the summer months, and this suggests the two sites have similar seasonal hydrological characteristics. These data demonstrate a close year - round similarity in water chemistry between the Tigh na Cruaiche and control burns and highlight the suitability of the latter in a future experimental / control pairing.

4.2 Biology

4.2.1 Epilithic diatoms

Epilithic diatom data for the control, experimental and Tigh na Cruaiche burns are presented in Table 2. Data for the control and experimental burn demonstrate the considerable inter-sample variability which often characterises upland flowing waters. This reflects the rapid response in epilithic diatom communities to temporal fluctuations in the stream environment and highlights the problems encountered in making 'between site' comparisons. There is evidence of a shift to less acid conditions in 1995 and 1996 at both the control and experimental site. Both sites show a decline in the acidophilous species *Tabellaria flocculosa* in the past two years. In the control burn this is balanced by an increased representation of *Synedra minuscula* whilst in the experimental burn there are increases in *Brachysira vitrea* and *Achnanthes minutissima.*

The shift in both burns to a less acid assemblage is reflected in the water chemistry which, for example, shows prolonged periods of elevated alkalinity throughout the summer of 1995 and 1996. In the previous two years the summer peaks in alkalinity occur later in the summer and are of shorter duration.

The Tigh na Cruaiche burn shows many similarities to the control burn, with comparable proportions of *Brachsira vitrea*, *Eunotia curvata*, *Eunotia incisa*, *Gomphonema gracile* and *Peronia fibula*. However, the dominant taxa in the two burns is different; the Tigh na Cruiaiche is dominated by *Tabellaria flocculosa*, while the control is dominated by *Synedra minuscula.* Both species are indicative of acid conditions but the former is generally characteristic of waters of lower pH.

4.2.2 Macro-invertebrates

A summary of data collected for all sites is provided in Table 3. In the 1996 samples from the control burn contained a similar number of the more abundant species (as reflected in the scores for N1 and N2, Table 4) to previous years and the overall representation of species was similar to the species lists of 1993 and 1994. Likewise there appears to be little variation in the BMWP and ASPT scores between years at this site.

The experimental site exhibits greater variability between years. Despite a generally similar species assemblage, the BWMP score for the experimental site appears to have declined since 1993 when it was at a similar level to the control. The BWMP score was developed primarily as an indicator of organic pollution in streams and a decrease in its value, if deemed significant, infers a deterioration in water quality. The change at this site may be due to organic inputs which would limit the occurence of some (high scoring) mayfly and stonefly nymphs, found in the other two streams on the same day. However, it is possible that the small area of stream bed which is suitable for invertebrate sampling has been affected by previous sampling and that the habitat for these species has been reduced. It is difficult to make many direct comparisons of the macroinvertebrate population of the experimental and control burn as the two sites are physically so different.

The Tigh na Cruaiche burn has a more limited range of taxa than the control burn. However, like it, it includes the stonefly species mentioned above which prefer waters with lower levels of organic matter. The species assemblage at this site bears closer similarity to the control site than the experimental site.

4.2.3 Aquatic macrophytes

Aquatic macrophyte data for the three burns is summarised in Table 5. Although the control and experimental burn are both characterised by similar aquatic bryophytes indicative of acid waters it is difficult to make comparisons in terms of cover estimates as the two sites are physically so different. There is no evidence of any clear change in the species composition of either site.

The selected stretch of the Cruaiche burn has very little macrophyte cover and this is almost entirely composed of *Scapania undulata*, an acid tolerant liverwort which is common in both other burns. The sparse macrophyte cover probably reflects a water course of greater flow energy at times of high flow than the moderately covered control burn, rather than any difference in water chemistry between the two sites.

4.2 4 Fish

The fish density data (Table 6) demonstrate the considerable year to year variability which is typically observed in upland stream systems. All three streams exhibit similar population densities although the density of fish greater than 1 year old in the experimental burn has been very low over the past two years. It is not possible to infer from the limited data set to date whether this represents a decline in the older trout population at this site or whether this is within the bounds of natural variation.

5 Discussion

The four year period of study covered in this report is still too short to draw conclusions on the impact of cattle grazing on the experimental burn. To date there is little evidence that cattle grazing has had any effect. However, it has become increasingly clear that the differing physical characteristics of the control and experimental burn are a weakness in the experimental design and it will be difficult to assess the importance of grazing at the experimental site should any environmental change occur. The reasons for this have been covered elsewhere in this report but can be summarised as follows:

- Although similar in winter, differences are apparent in the summer water chemistry of the control and experimental burn. In particular, levels of conductivity and base cations in the experimental burn are often elevated relative to the control during the summer. This is most likely to be due to hydrological differences between burns since a similar relationship has also been observed during dry periods outside the summer grazing season.

- The chemistry and biology of the experimental burn was not monitored for a sufficient period before the first year of grazing to allow an assessment of the 'normal' relationship between it and the control burn.

- Physical differences between the control and experimental burns lead to problems in the interpretation of the biological differences. The differing nature of the substrate, open water stretches and the bank structure are likely to influence the diatom, aquatic macrophyte and macroinvertebrate species assemblages and the density of trout.

Despite the differences in hydrology and habitat it should be possible to identify gross, long term changes in the experimental burn which are independent of changes in deposition chemistry or climate, by the analysis and comparison of time trends in the chemical and biological data for this site and the control. However, given the evidence from this report , it is apparent that examination of changes in the ratio of chemical determinands of the two sites on a seasonal scale (as presented in Figures 3.1 -3.4) is perhaps an inappropriate technique for the identification of a 'grazing effect'.

The Tigh na Cruaiche burn is better suited as a comparison to the control burn both in terms of chemistry and biology. Perhaps most importantly, the relationship of conductivity and the concentration of base cations at the two sites remains similar throughout the year and this suggests that the hydrological regime at the two sites is similar. There are some biological differences between the sites. The sparse aquatic bryophyte cover suggests that the stream bed may be subject to more vigorous scouring action during storm events than the control and the epilithic diatoms indicate that the Tigh na Cruaiche may be a slightly more acid environment, although there is no indication of this from the water chemistry analysed to date. Although water chemistry samples are being collected from two points on the Tigh na Cruaiche burn, only data from the lower site has been analysed in this report. Once a further two or more years of data has been collected, to allow us to better understand the Tigh na Cruaiche environment, it will be possible to use this as a second experimental site by introducing summer cattle grazing to its catchment.

Water samples are now also being collected from the outflow of Loch Laidon, while sediment traps have been installed in the lake to provide a record of the most recently deposited diatoms and carbonaceous particles. Data from this work in conjunction with evidence from a recent sediment core pH reconstruction (Flower *et al.* 1996) will allow a continuing evaluation of the acidification status of the loch at a time when industrial emissions of sulphur in the UK are declining and sulphur deposition is expected to decrease.

References

Allott, T.E.H., Monteith, D.T., Harriman, R., Morrison, B.R.S, Collen, P. & Patrick, S.T. (1994). Land-use experiments in the Loch Laidon Catchment: First Report on Stream Water Quality. Environmental Change Research Centre, University College London, Research Report No. 5.

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Figure I: The Loch Laidon catchment indicating the boundaries of Rannoch Moor NNR and SSSI

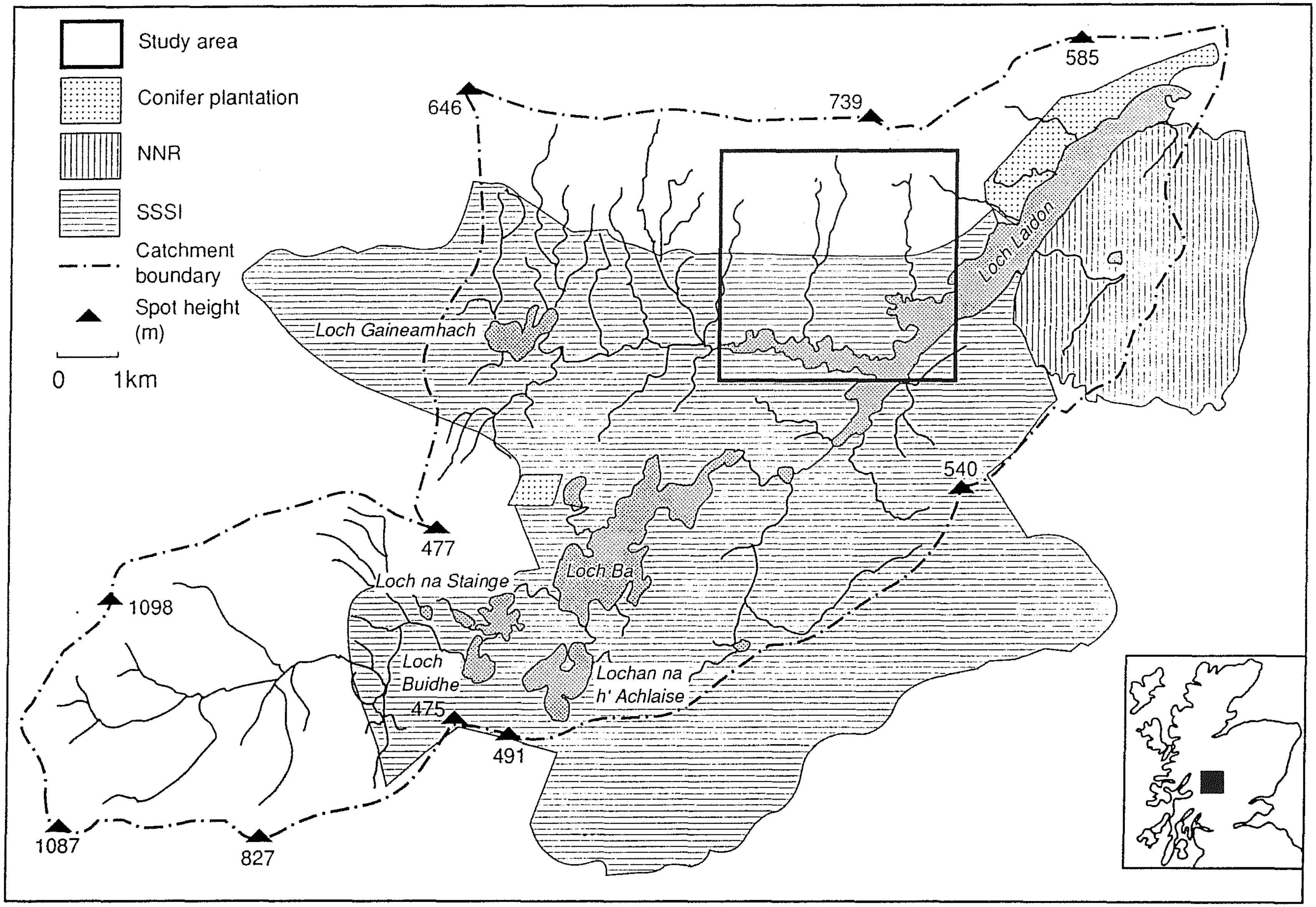

Figure 2: Loch Laidon study area

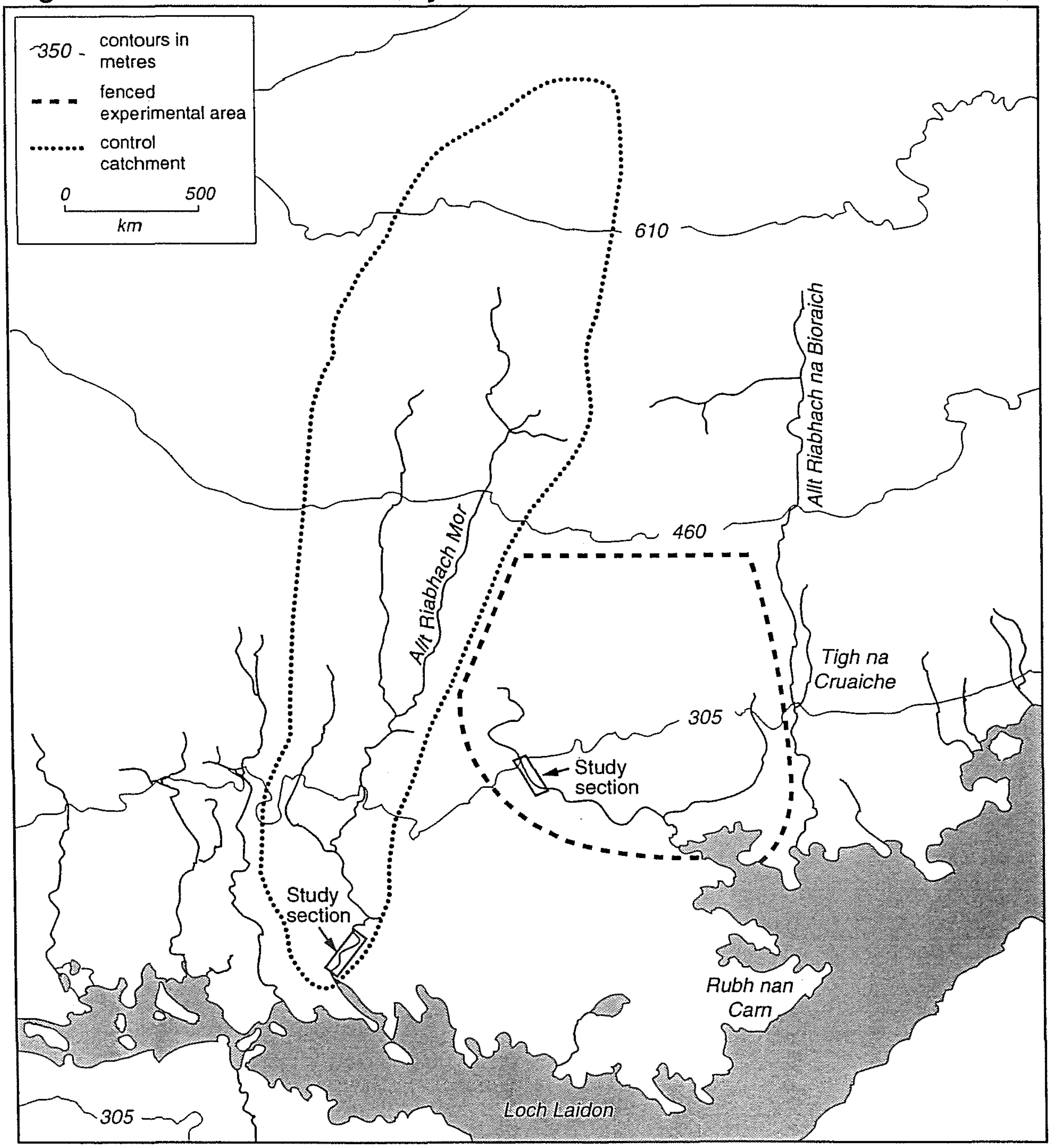

Figure 3.1 The ratio of alkalinity and its temporal variability in spot samples from the experimental and control burns, August 1992 - March 1997

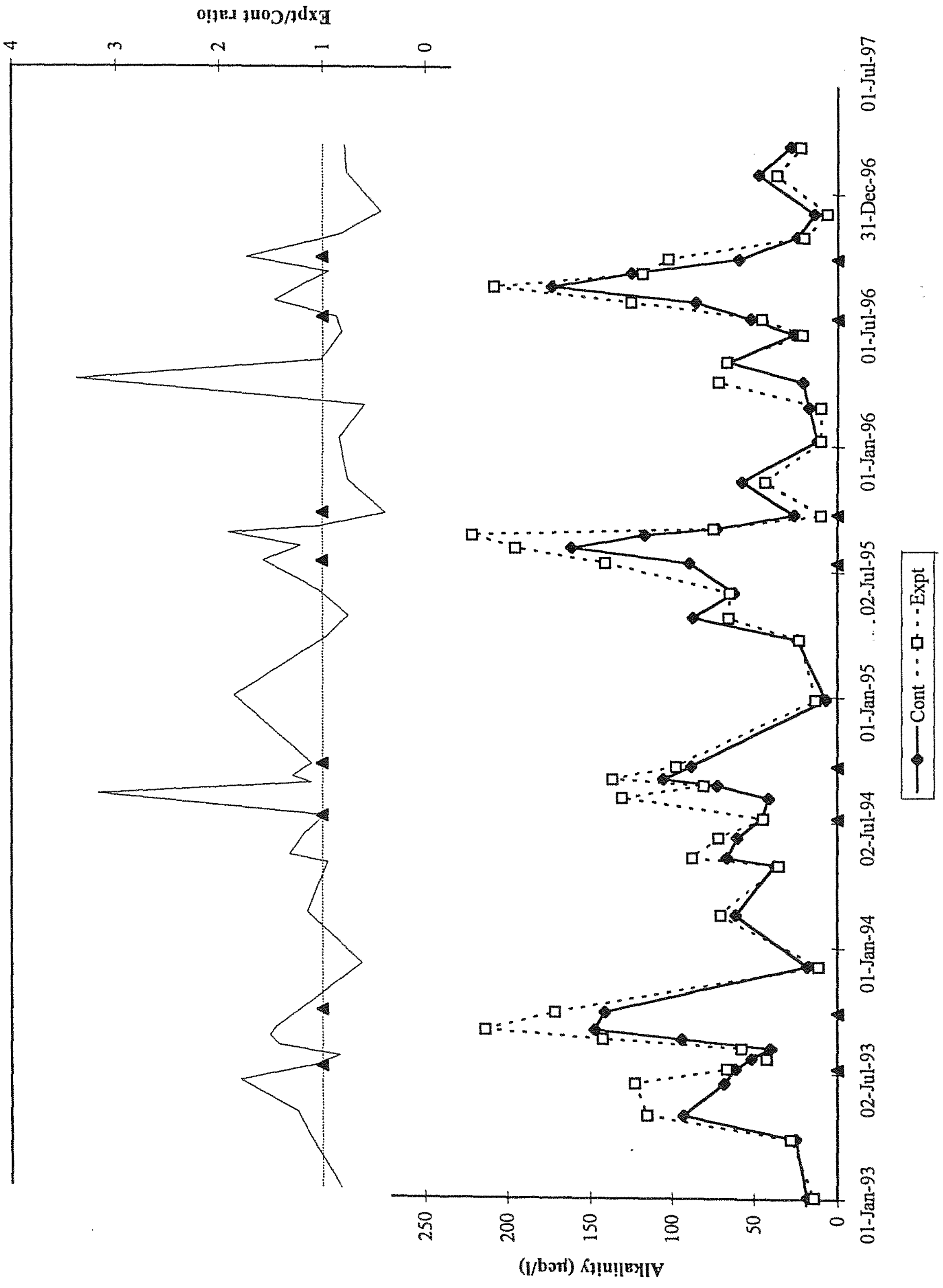

Figure 3.2 The ratio of H+ concentratio and the temporal variability in pH of spot samples from the experimental and control burns, August 1992 - March 1997

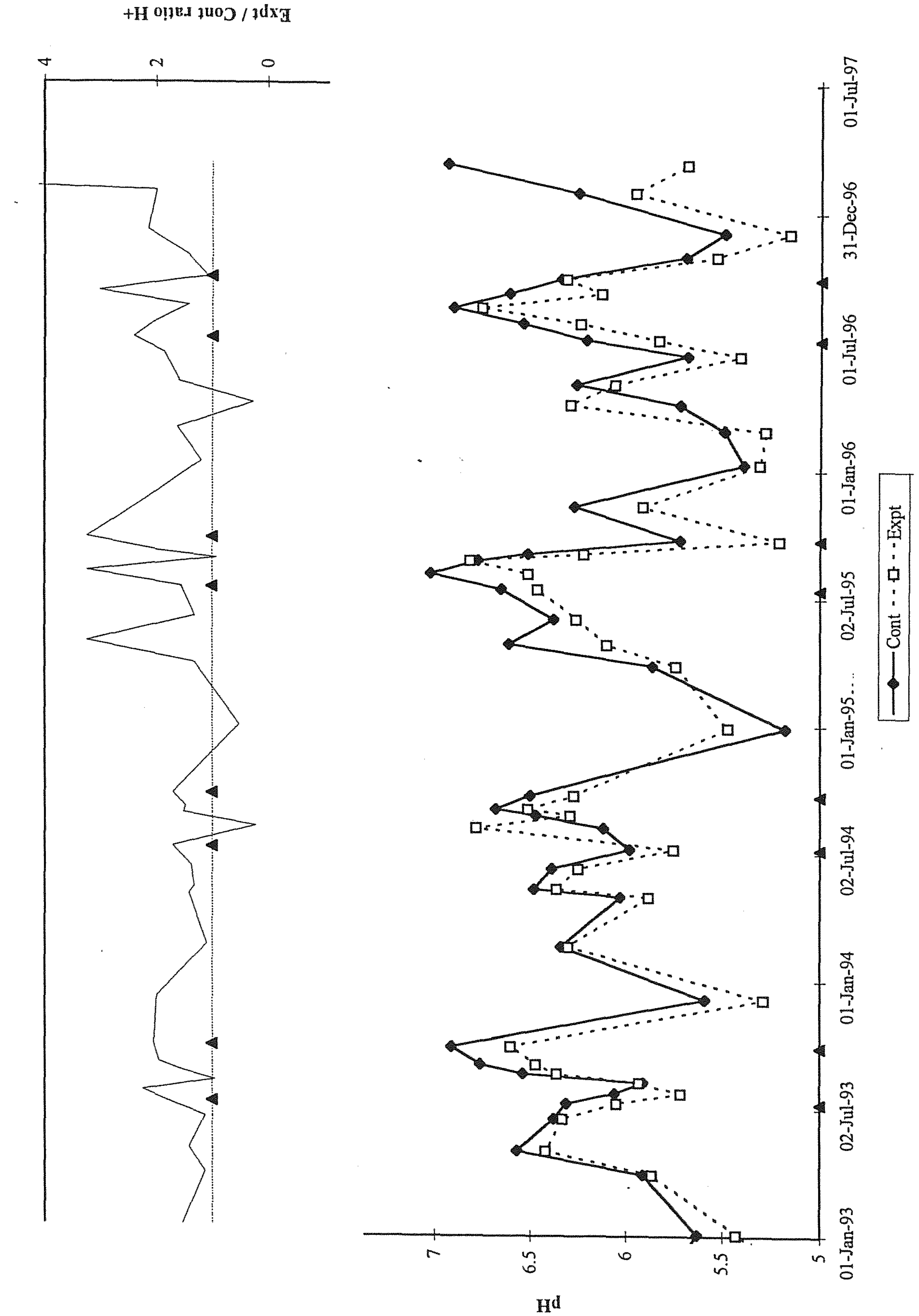

Figure 3.3 The ratio of calcium and its temporal variability in spot samples from the experimental and control burns, August 1992 - March 1997

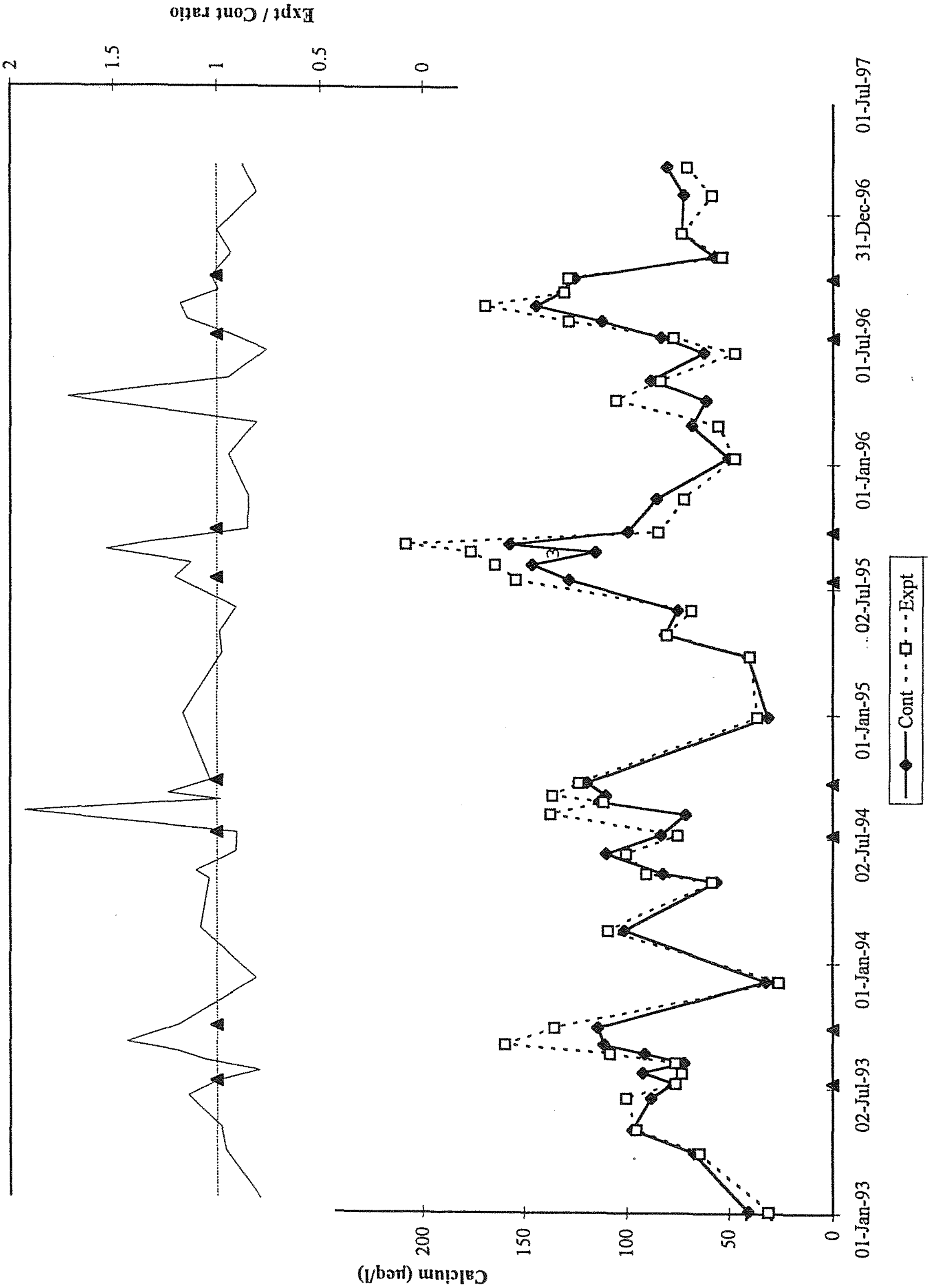

Figure 3.4 The ratio of conductivity and its temporal variability in spot samples from the experimental and control burns, August 1992 - March 1997

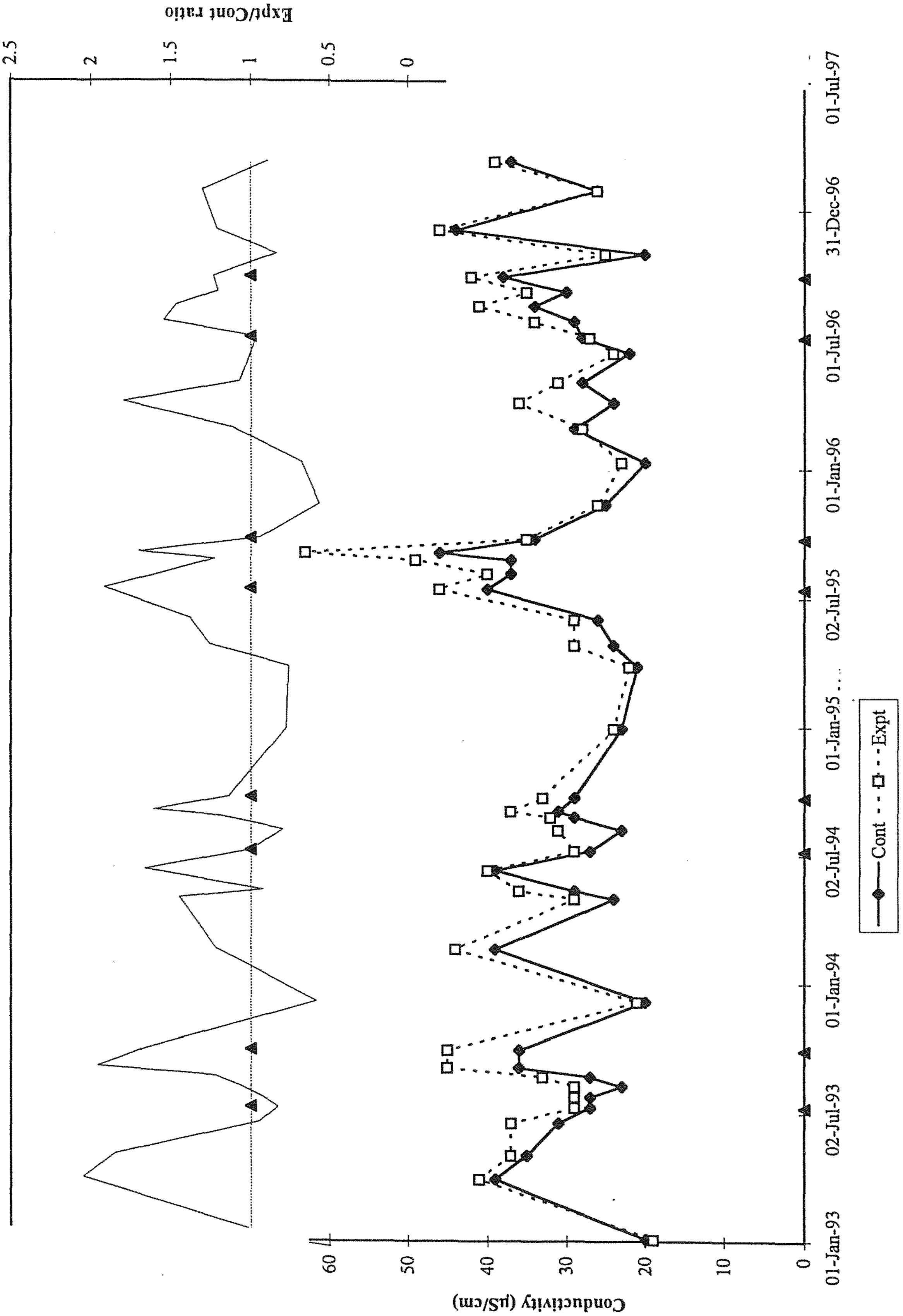

Figure 4.1 Alkalinity of spot samples taken from the upper and lower stations on the experimental burn and from the control burn, July 1995 - March 1997

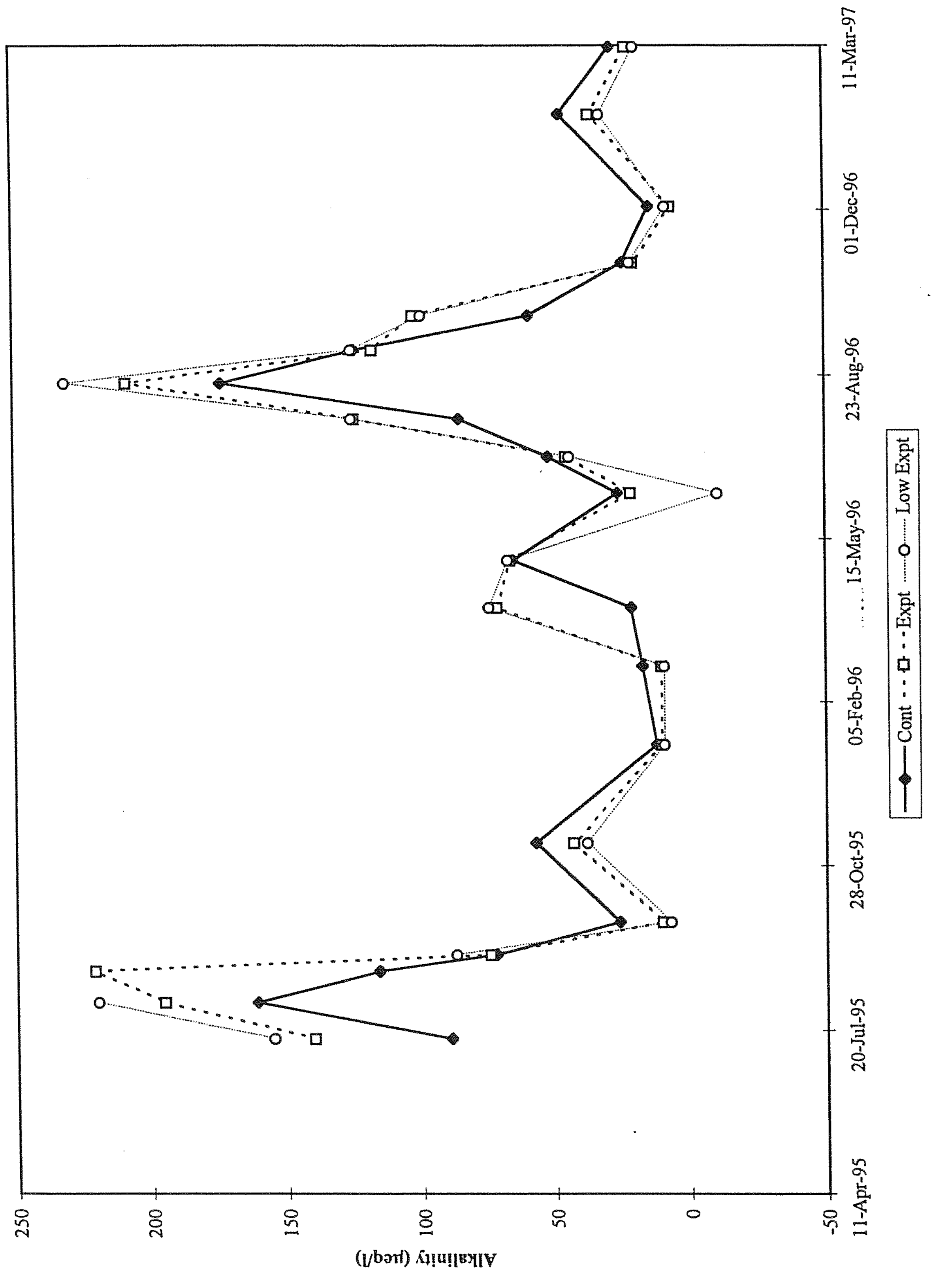

Figure 4.2 pH of spot samples taken from the upper and lower stations on the experimental burn and from the control burn, July 1995 - March 1997

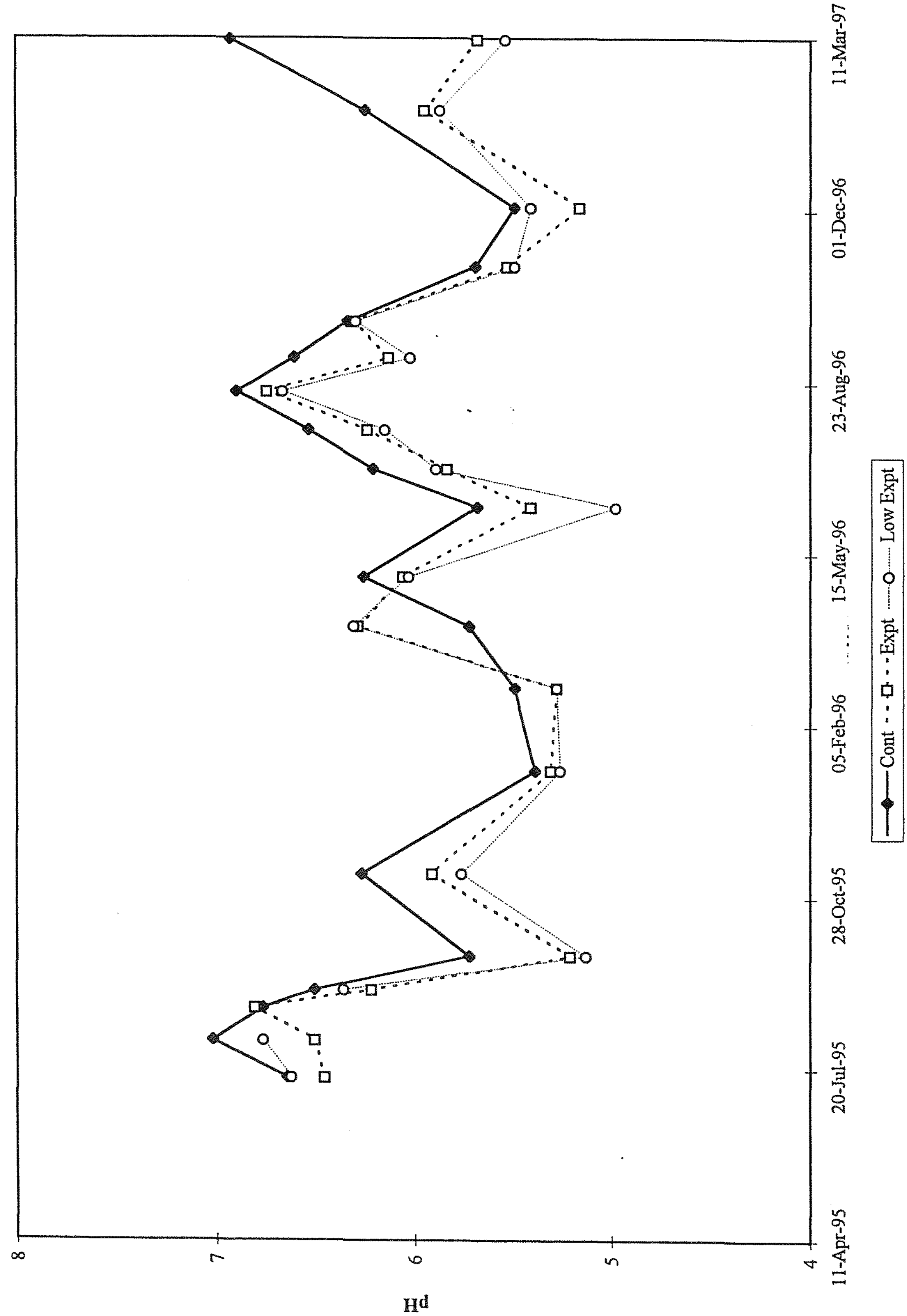

Figure 4.3 Calcium concentration of spot samples taken from the upper and lower stations on the experimental burn and from the control burn, July 1995 - March 1997

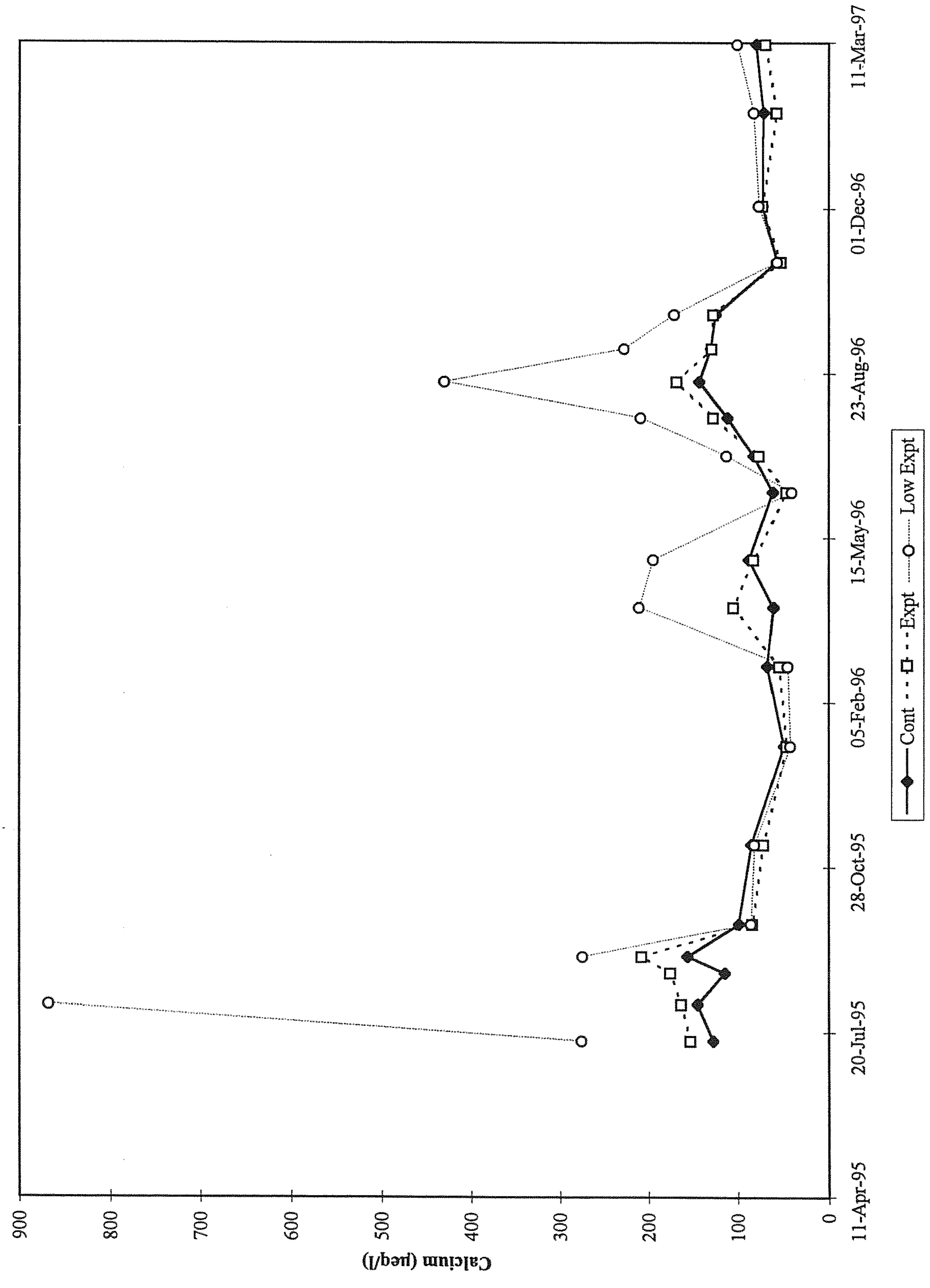

Figure 4.4 Conductivity of spot samples taken from the upper and lower stations on the experimental burn and from the control burn, July 1995 - March 1997

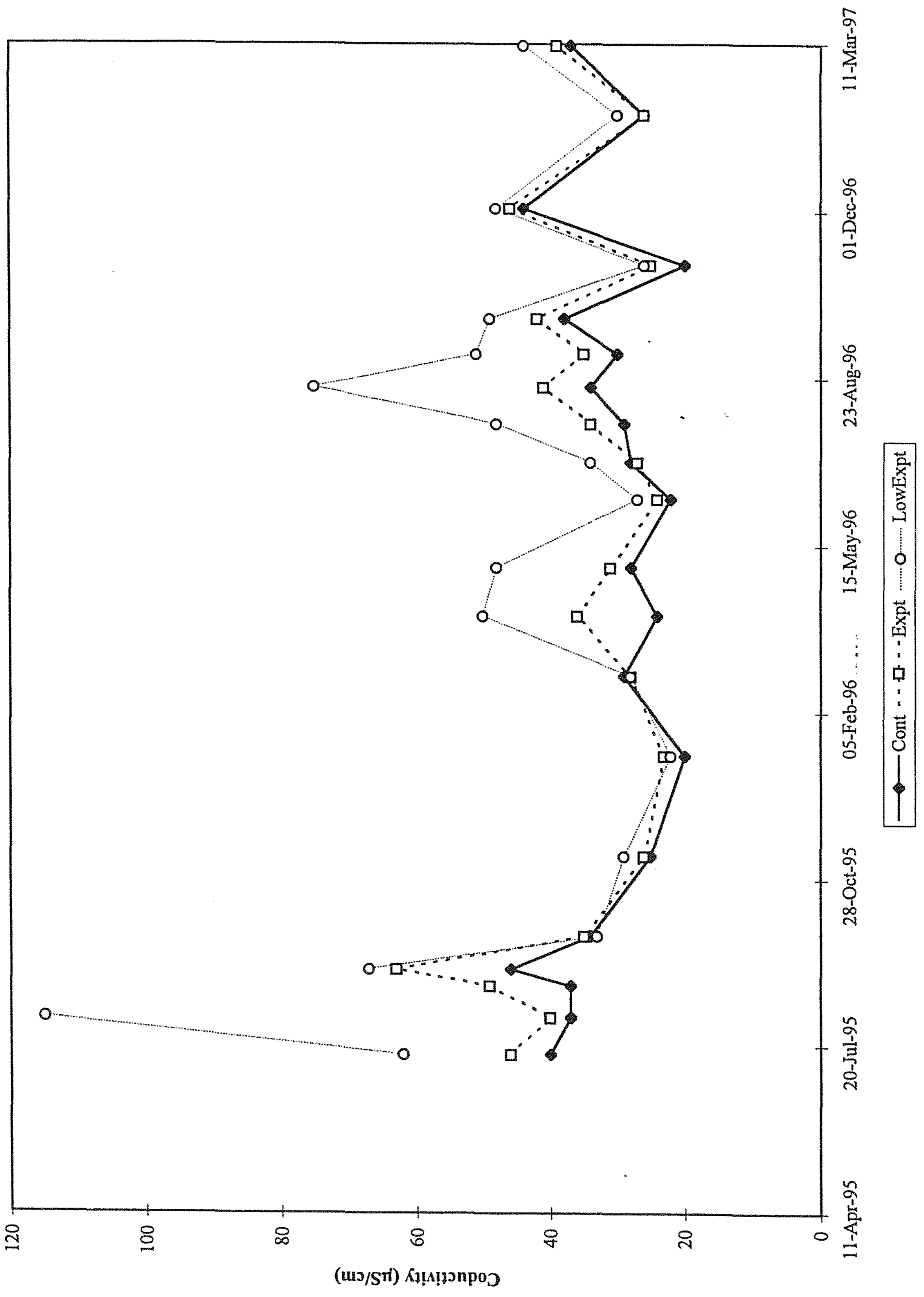

Figure 5.1 Alkalinity of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

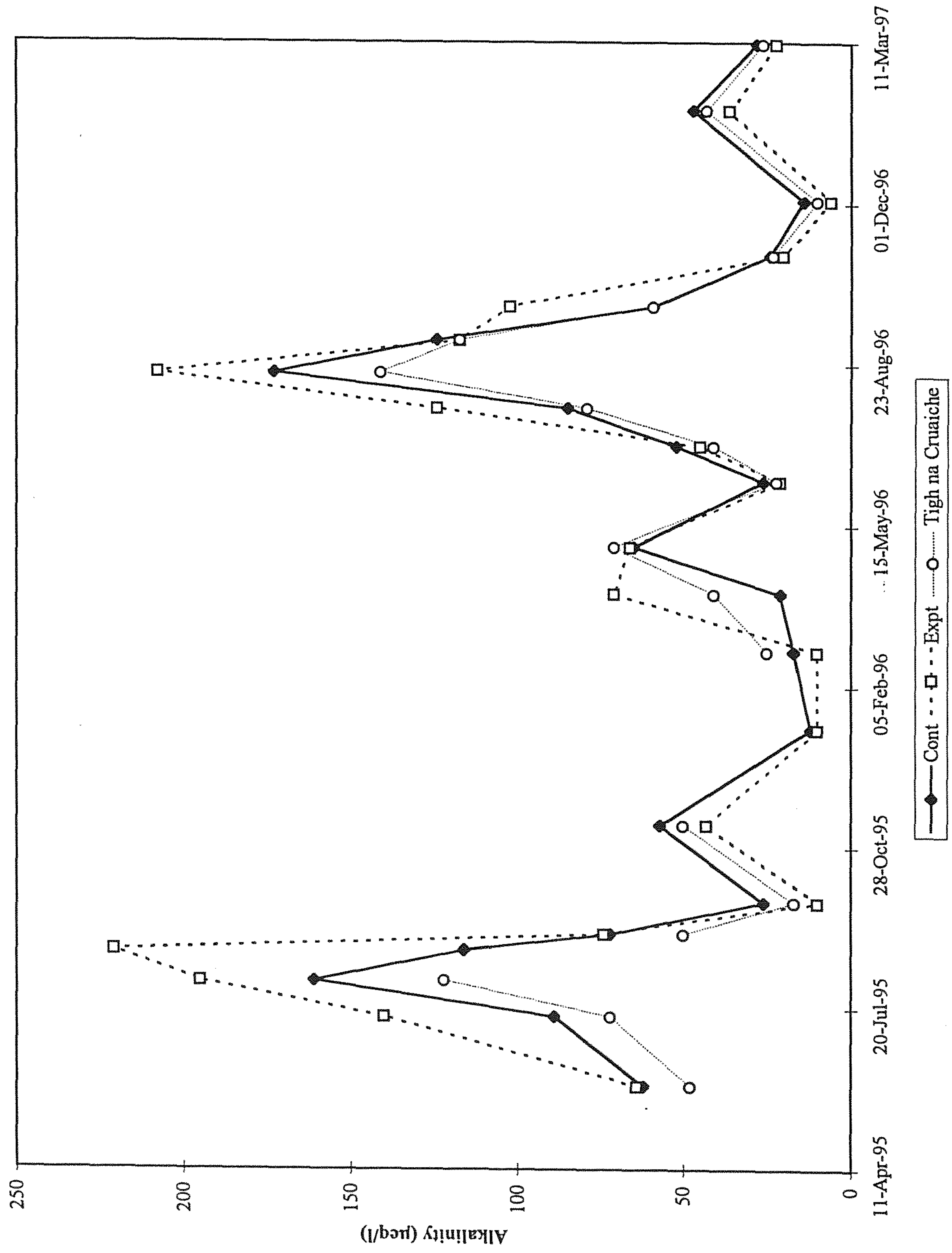

Figure 5.2 pH of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

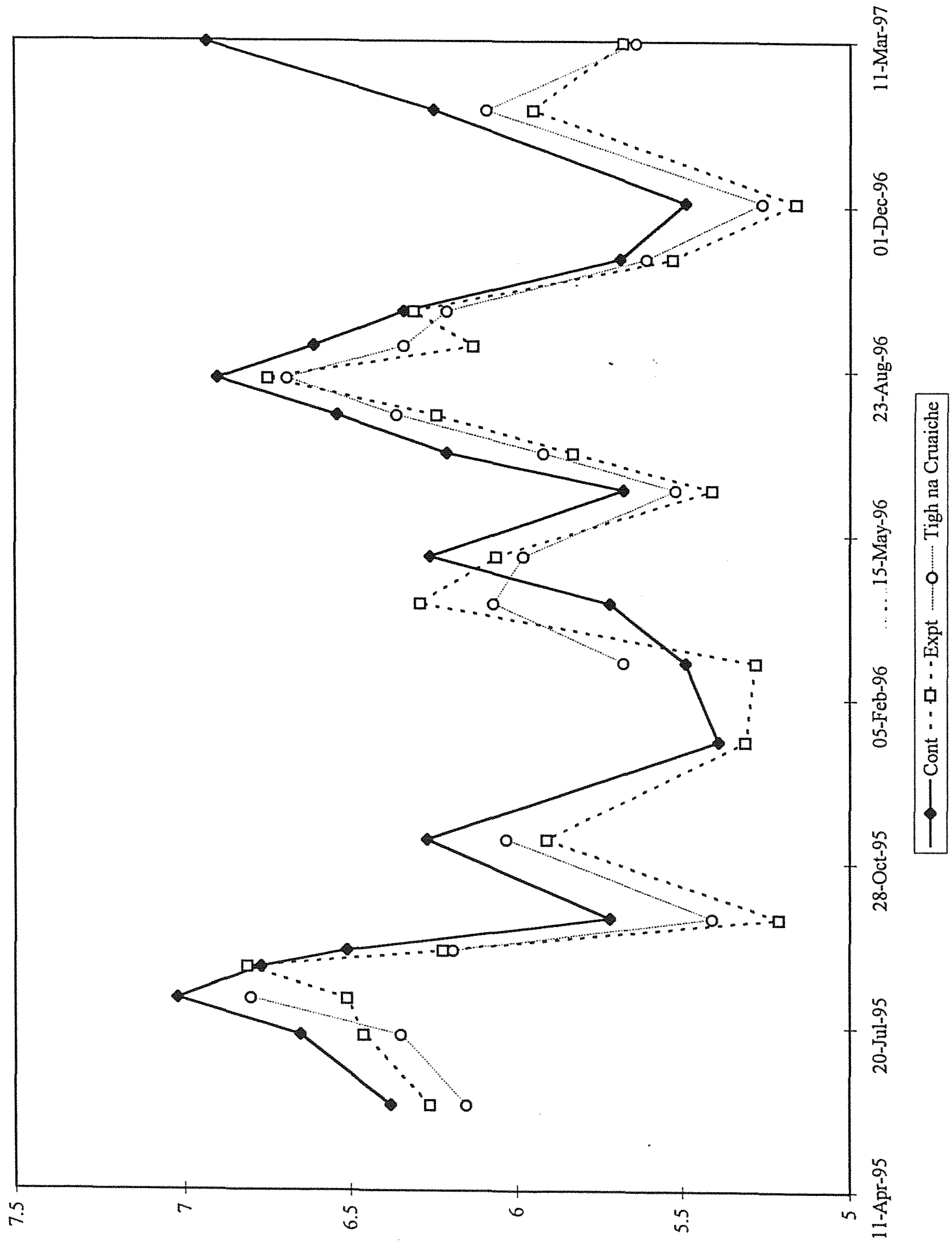

Figure 5.3 Calcium concentration of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

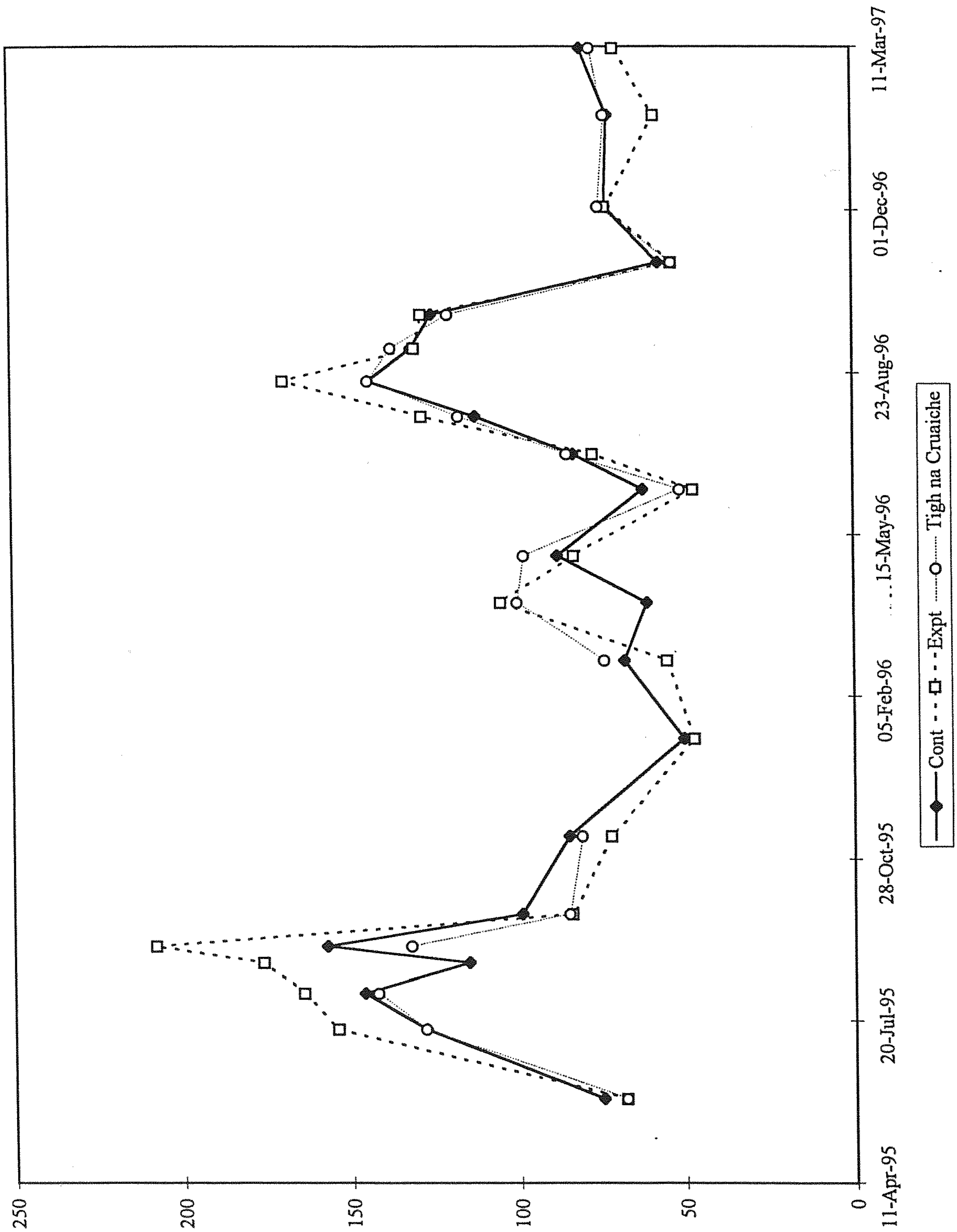

Figure 5.4 Conductivity of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

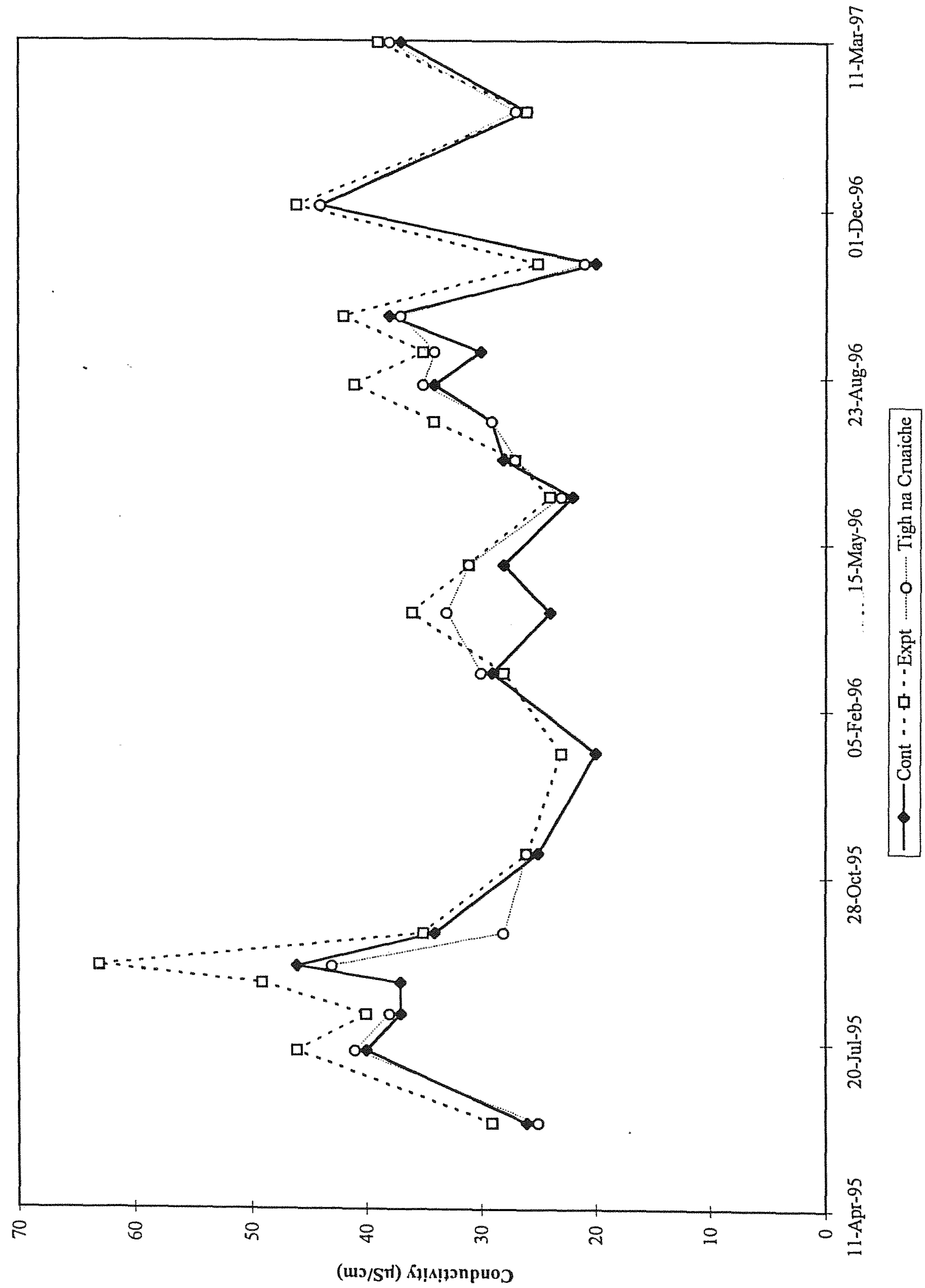

Figure 5.5 Nitrate concentration of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

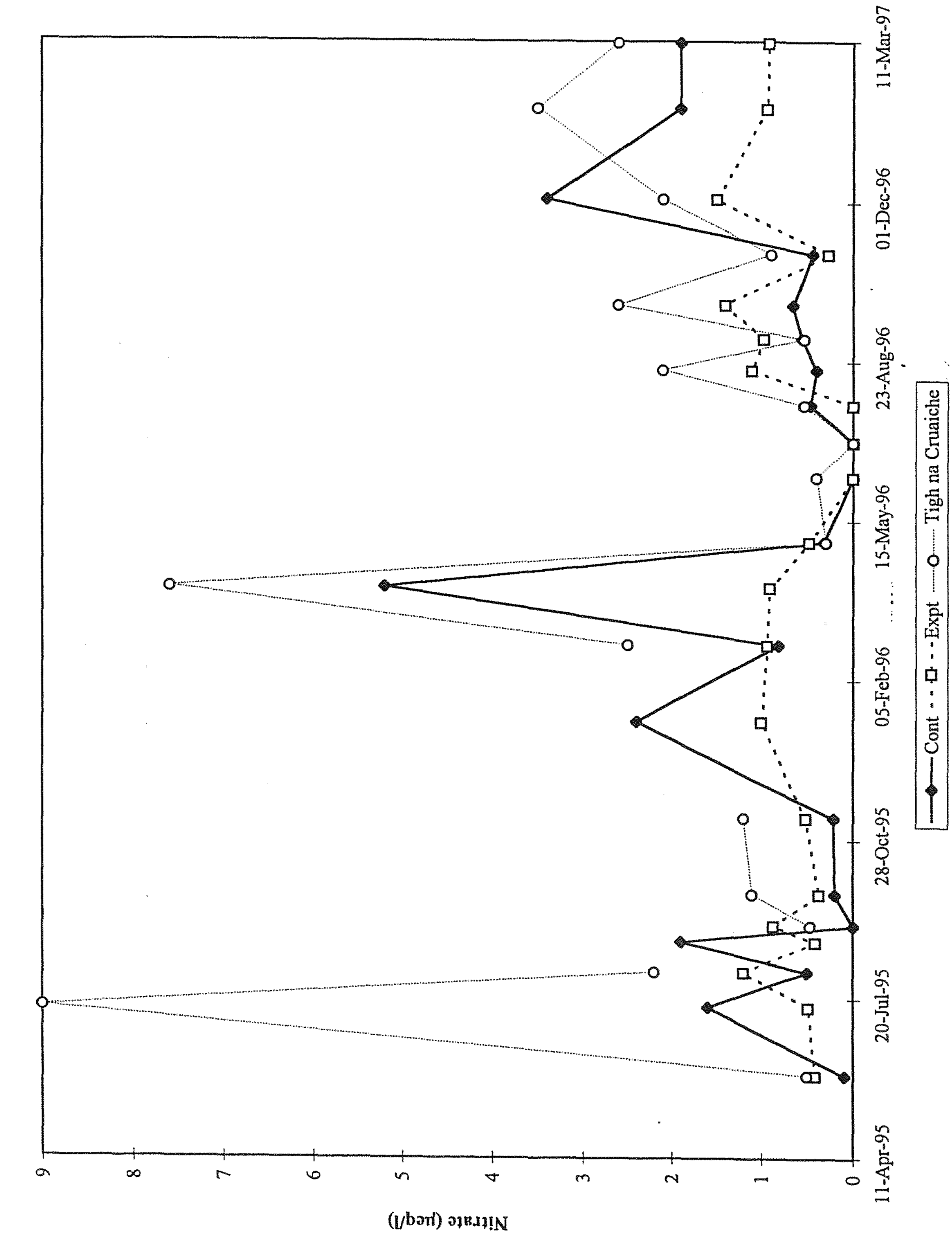

Figure 5.6 Labile aluminium concentration of spot samples taken from the control, experimental and Tigh na Cruaiche burns, July 1995 - March 1997

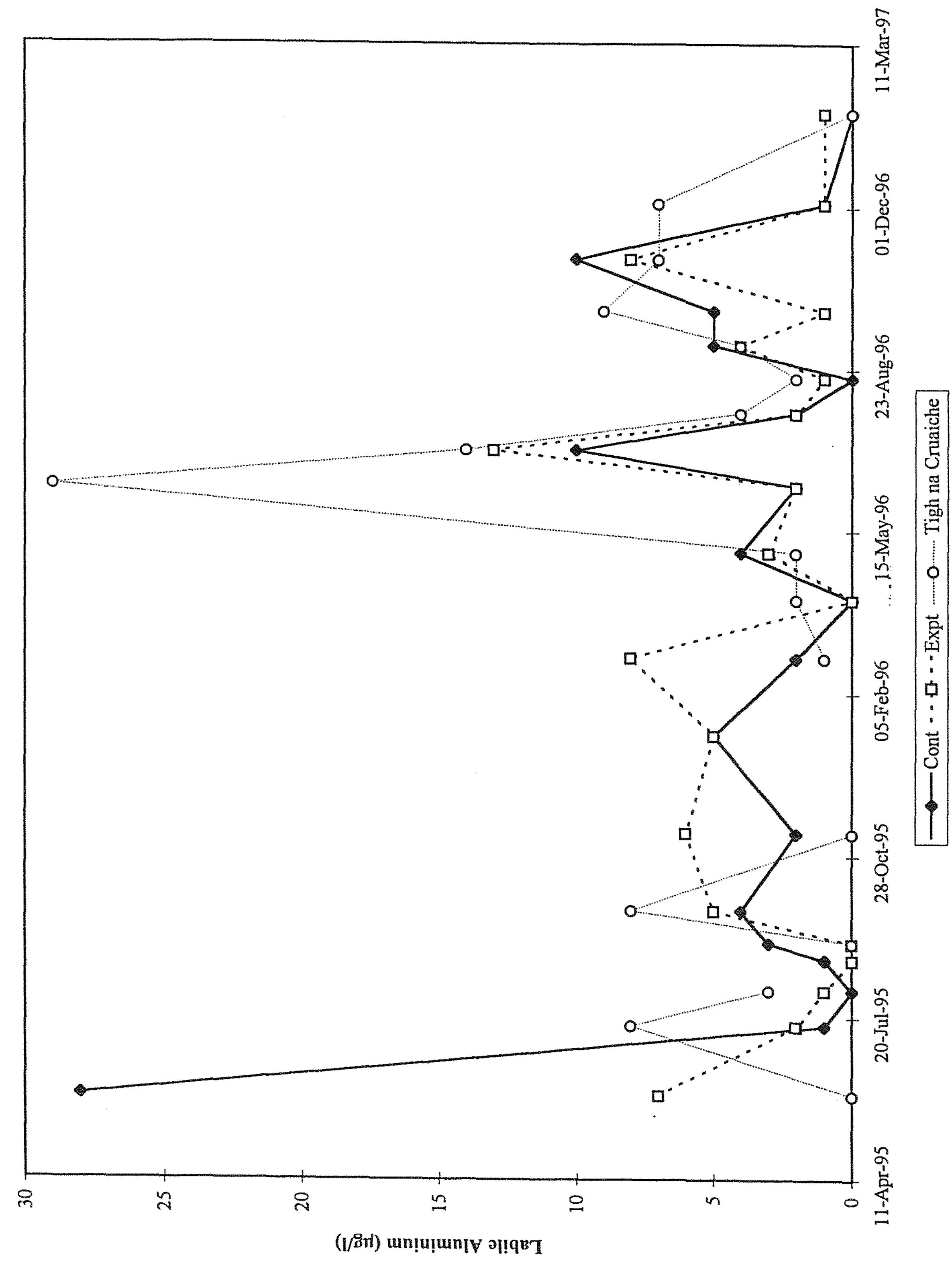

Table 1 **Summary statistics of selected chemical determinands for individual years at the control (cont), experimental (expt) and Tigh na Cruaiche (TnC) burns**

	pH			Alkalinity (μeq l^{-1})			Conductivity (μS cm^{-1})			Nitrate (μeq l^{-1})			Sulphate (μeq l^{-1})			Total Phosphorus (μgl^{-1})			Labile aluminium (μgl^{-1})		
Site	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max
Cont1993	6.23	5.59	6.91	68.7	18	147	29.2	20	39	0.3	0	2	28	11	44	23	19	26	6.3	0	29
Cont1994	6.22	5.18	6.68	58.2	7	105	29.3	23	39	0.5	0	2	34	23	85	19	2.5	58	4.4	0	17
Cont1995	6.42	5.72	7.02	77.1	24	161	32.2	21	46	0.5	0	1.9	62	18	175	3	2.5	6	4.6	0	28
Cont1996	6.03	5.39	6.90	56.0	12	173	28.8	20	44	1.2	0	5.2	41	18	62	3	2.5	10	3.8	0	10
Expt1993	6.04	5.29	6.60	89.2	11	213	33.2	19	45	0.6	0	2	24	8	45	21	19	22	2.7	0	9
Expt1994	6.19	5.47	6.78	76.3	13	136	33.5	24	44	0.5	0	1	27	13	51	19	0	60	2.9	0	7
Expt1995	6.14	5.21	6.81	92.8	10	221	37.7	22	63	0.6	0.4	1.2	74	13	302	3	2.5	6	2.6	0	7
Expt1996	5.86	5.16	6.75	66.7	6	208	32.7	23	46	0.7	0	1.5	37	16	75	3	2.5	3	4.0	0	13
TnC1995	6.16	5.41	6.80	59.8	17	122	33.5	25	43	2.4	0.5	9	84	26	156	3	2.5	6	3.2	0	8
TnC1996	5.97	5.26	6.69	57.2	10	141	31.3	21	44	1.8	0	7.6	47	22	88	3	2.5	4	7.4	1	29

Cont = Control burn   Expt = Experimental burn   TnC = Tigh na Cruaiche burn

Table 2 **Diatom taxon list (% frequency of taxa > 1.0%)**

Taxon	% abundance of taxa (all taxa > 1% in any one sample recorded - '+' = species present at < 1%)									
	Control Burn					Experimental Burn				Tigh na Cruaiche
	1992	1993	1994	1995	1996	1993	1994	1995	1996	1996
Achnanthes minutissima	+	+	+	1.3	1.0	+	+	1.5	26.9	+
Achnanthes saxonica	+	+	+	+				+		
Brachysira brebissonii	+		+	+	+	1.3	+	1.2		+
Brachysira vitrea	1 .7	7.3	6.9	15.9	1 .8	2 .1	8.6	24.4	25.4	4.7
Cymbella lunata	+	+	+	1.5	+	1.6	1.0	6.1	2.4	+
Cymbella microcephala									8.9	
Eunotia curvata	+	+	+	+	1.6	+	1.6	+		3.8
Eunotia exigua	2.7	1.6	4.5	2.0	1.3	3.1	3.4	1.8	+	+
Eunotia incisa	1.6	1.4	3.8	1.8	+	3.8	7.4	7.9	+	1.1
Eunotia naegelii		1.1	+	+	+	6.6	9.4	7.6	2.1	3.2
Eunotia pectinalis var. *minor*	+	+	6.0	+	+	+	+	2.7	+	+
Eunotia rhomboidea	+	+	1.1	1.1	+	+	1.0	3.0	+	+
Eunotia sp.	+	+	1.2	+	+	+	+	1.8	+	+
Frustulia rhomboides var. *saxonica*	1.0	+	+	1.3	+	6.0	7.4	2 .1	4.9	+
Frustulia rhomboides var. *viridula*	+	+	+	+		+	1.3	+	+	
Gomphonema gracile	1.5	+	+	+	1.0		1.2		1.4	1.4
Gomphonema minutum	1.0	+								
Peronia fibula	2.7	1.2	2.4	4.7	2.8	22.3	15.6	8.8	3.2	8.3
Synedra minuscula	8.2	55.4	19.9	25.9	46.8	8.8	+	+	6.4	2.1
Tabellaria flocculosa	65.8	24.9	47.6	34.3	29.1	15.7	19.9	7.9	9.8	71.4

Table 3 Macroinvertebrate taxon list and total abundance

TAXON	Cont 93	Cont 94	Cont 96		Exp 93	Exp 94	Exp 96		Tigh na Cruaiche 96
NEMATODA			1		2		1		1
Pisidium sp.						1			
OLIGOCHAETA	22	6	8		14	10	26		12
Ameletus inopinatus	11	4							
Baetis sp.						1			
Baetis rhodani	5		7						
Siphlonurus lacustris							35		17
Baetis muticus	3	2	3		9		3		
Heptagenia lateralis	3	18	11						2
Leptophlebia marginata			1		16	19	6		
Leptophlebia vespertina					20	61	9		5
Amphinemura sulcicollis	168	32	27		20	1	2		9
Nemoura avicularis						2			
Nemoura cambrica					2		1		
Leuctra inermis	41	6	1		1				
Leuctra hippopus		1							
Leuctra nigra					1				
Isoperla grammatica	106	4	8		7				3
Chloroperla torrentium			54						7
Siphonoperla torrentium	109	48			23	5			
Pyrrhosoma nymphula					1	1			
Cordulegaster boltonii					1				
Dytiscidae undet. (larvae)						1			1
Oreodytes rivalis		36							
Oreodytes sanmarkii	18		7						1
Elmis aenea	17		1						
Limnius volckmari	129	16	46		2	5			3
Oulimnius tuberculatus	55	22	21		151	98	19		9
Anacaena globulus							1		
Rhyacophila dorsalis	1		1						
Plectrocnemia conspersa	6	1	5		13	9	9		11
Plectrocnemia geniculata		2				1			
Polycentropus flavomaculatus		2	3		23	6	6		1
Halesus radiatus							6		
HYDROPTILIDAE					38				
Hydroptila sp.		2					1		
Oxyethira sp.		1				29			
LIMNEPHILIDAE undet.	10	7	6		66	2	7		6
TIPULIDAE	2	1			1				
Dicranota sp.	8	2	3		6	2	1		7
CHIRONOMIDAE	26	17	28		56	86	104		14
SIMULIIDAE	23		1		2		1		
Simulium latipes						3			

Table 4 Macroinvertebrate summary statistics

	Control				Experimental				Tigh na Cruaiche
	1993	1994	1996		1993	1994	1996		1996
Total count	768	231	256		477	231	247		109
Total number of taxa	24	22	27		25	20	20		17
E(100)	17	17	18		18	14	14		16
Hill's N1	11.5	11.9	12.8		11.3	7.9	7.7		12.6
Hill's N2	8.4	9.0	9.0		6.9	5.4	4.6		11.9
Hill's E5	0.71	0.73	0.68		0.57	0.64	0.54		0.94
BMWP score	110	99	125		108	83	82		89
ASPT	6.4	6.6	6.6		6.4	5.5	5.9		6.9

Table 5 Aquatic macrophyte cover

	Control						Experimental					Tigh na Cruaiche
	1992	1993	1994	1995	1996		1993	1994	1995	1996		1996
Batrachospermum sp.	<0.1	0.7	<0.1	-	<0.1		33.3	12.7	54.2	32.8		-
Marsupella emarginata var. *aquatica*	4.4	4.0	4.9	0.4	1.5		38.0	37.3	9.4	27.4		<0.1
Scapania undulata	2.8	3.7	1.7	0.9	2.0		-	5.0	21.7	12.0		0.4
Racomitrium aciculare	0.3	<0.1	2.1	0.4	<0.1		-	-	-	-		-
Juncus bulbosus var. *fluitans*	0.1	<0.1	-	-	-		2.6	9.0	2.7	6.6		-
TOTAL COVER (excluding filamentous algae)	7.6	8.4	8.7	1.7	3.5		73.9	64.0	88.0	78.8		-
Filamentous green algae	<0.1	10.7	<0.1	0.1	<0.1		68.0	<0.1	-	-		0.4

nb . Control and Tigh na Cruaiche burn sampling stretch = 50m length
Experimental burn sampling stretch = 20m length

Table 6 Fish population data

Site	Year	Area fished (m^2)	Density (no. m^{-2})	
			age 0+	age >0+
Control	1993	115	0.25	0.14
Control	1994	115	0.35	0.02
Control	1995	118	0.33	0.05
Control	1996	87	1.51	0.26
Experimental	1993	32	0.97	0.13
Experimental	1994	32	0.14	0.28
Experimental	1995	36	0.34	0.03
Experimental	1996	38	0.63	0.24
Tigh na Cruaiche	1996	57	0.63	0.24

Appendix 1 Water chemistry for the control burn August 1992 - March 1997

Date	PH	Alk	Cond	Na	K	Mg	Ca	Cl	NO3	SO4	PO4	Tot-P	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
12-Aug-92	5.44	18	24	106	3	34	68	94	0	26	1		88	70	18	0.74		
30-Oct-92	6.46	67	23	112	4	32	68	99	0	28	0		33	29	4	0.32	5	
06-Dec-92	5.7	20	20	104	3	17	43	103	0	25	1		35	33	2	0.25	3.5	
04-Jan-93	5.63	18	20	105	4	25	41	101	0	44	0		24	21	3	0.27	3.8	
30-Mar-93	5.91	25	39	203	5	44	67	278	0	41	1		23	20	3	0.17	3.1	
03-May-93	6.57	93	35	177	6	42	97	186	0	35	0		14	9	5	0.17	3.3	
18-Jun-93	6.38	68	31	145	4	39	88	130	0	30	1	19	44	15	29	0.55	9.4	
10-Jul-93	6.31	61	27	141	4	33	77	129	0	19	2	26	72	71	1	0.61	9.1	
25-Jul-93	6.06	51	27	134	3	38	92	117	0	16	2		72	72	0	0.78	11	
09-Aug-93	5.91	40	23	114	3	33	72	98	2	11	4		105	92	13	0.88		
22-Aug-93	6.54	94	27	148	4	42	91	141	0	18	2		43	39	4	0.48		
04-Sep-93	6.76	147	36	168	7	46	111	151	0	26	0		18	17	1	0.29		
29-Sep-93	6.91	141	36	161	6	47	114	155	0	31	0		31	26	5			
06-Dec-93	5.59	18	20	99	4	25	32	86	1	38	1		42	37	5	0.459	6.7	
18-Feb-94	6.34	61	39	210	6	66	101	211	2	41	0	5	14	14	0	0.132		0
01-May-94	6.03	37	24	141	9	34	56	123	0	25	0	10	44	36	8	0.309	4.4	0
12-May-94	6.48	66	29	161	6	48	82	143	0	30	0		27	22	5	0.213	3.2	0
10-Jun-94	6.39	60	39	201	9	68	110	174	0	85	1		34	30	4	0.283		0
08-Jul-94	5.98	45	27	151	6	52	83	111	0	35	1		80	80	0	0.632		0
07-Aug-94	6.12	41	23	140	5	46	71	109	0	26	4	58	62	60	2			0
25-Aug-94	6.47	72	29	152	5	61	113	118	0	27	1		42	41	1			0
03-Sep-94	6.68	105	31	163	6	60	110	125	2	24	1	2.5	35	28	7	0.339	5.5	0
22-Sep-94	6.5	88	29	152	6	56	119	123	0	23	1		43	26	17	0.385	7.5	0
29-Dec-94	5.18	7	23	108	4	30	31	126	1	23	1		24	24	0	0.198	4	0
27-Mar-95	5.86	24	21	121	6	31	41	122	0.25	22	0	2.5	31	29	2	0.239	4.8	0

Appendix 1 -continued Water chemistry for the control burn August 1992 - March 1997																	
Date	PH	Alk	Cond	Na	K	Mg	Ca	Cl	NO_3	SO_4	PO_4	Tot-P	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
27-Apr-95	6.61	87	24	133	8	43	81	107	0	20	0	2.5	16	16	0	0.204	4.8	0
02-Jun-95	6.38	62	26	137	4	41	75	103	0.1	18	3	3	57	29	28	0.49	9.9	0
15-Jul-95	6.65	89	40	178	9	75	128	127	1.6	96	0	2.5	30	29	1	0.34	8.9	0
06-Aug-95	7.02	161	37	195	11	67	146	143	0.51	44	0		21	21	0	0.285	6	0
25-Aug-95	6.77	116	37	186	10	62	115	144	1.9	37	1	2.5	21	20	1	0.262	5.6	0
04-Sep-95	6.51	72	46	188	7	90	157	118	0	175	0	6	37	34	3	0.313	7.6	0
24-Sep-95	5.72	26	34	156	5	66	99	108	0.2	107	0		66	62	4	0.469	11	0
11-Nov-95	6.27	57	25	124	6	48	85	95	0.22	39	0	2.5	67	65	2	0.43	8.7	0
10-Jan-96	5.39	12	20	100	6	37	50	78	2.4	59	0	2.5	49	44	5	0.297	6.6	3
27-Feb-96	5.49	17	29	152	5	55	68	166	0.82	60			30	28	2	0.238		0
03-Apr-96	5.72	21	24	124	6	39	61	112	5.2	49	1	2.5	28	28	0	0.243	5.3	3
02-May-96	6.26	65	28	136	5	50	88	113	0.32	49	0	2.5	34	30	4	0.251	5.1	0
12-Jun-96	5.68	26	22	109	2	38	62	88	0	21	3	10	72	70	2	0.586	11.3	0
04-Jul-96	6.21	52	28	131	4	49	83	93	0	47	2	2.5	58	48	10	0.513	13.9	0
27-Jul-96	6.54	85	29	143	5	61	112	102	0.47	31	1	2.5	50	48	2	0.551	11	0
18-Aug-96	6.9	173	34	160	7	69	144	110	0.4	26	0	2.5	24	24	0	0.386	7.7	0
07-Sep-96	6.61	124	30	159	7	71	131	114	0.56	24	1	2.5	36	31	5	0.496	10	0
28-Sep-96	6.34	59	38	164	9	74	125	163	0.66	62	0	2.5	63	58	5	0.486	11.2	0
30-Oct-96	5.69	24	20	94	7	37	57	79	0.44	18	4		79	69	10	0.564	11	0
03-Dec-96	5.49	14	44	219	7	67	73	296	3.4	40	0	2.5	39	38	1	0.165	4	3
28-Jan-97	6.25	47	26	128	5	42	72	102	1.9	43	0	2.5	40	40	0	0.301	6.2	2
10-Mar-97	6.93	28	37	190	7	57	80	228	1.9	41	0							0

All units in $\mu eq\ l^{-1}$ except: pH, Cond (conductivity $\mu S\ cm^{-1}$); Al-TM (Total monomeric aluminium,) Al-NL (Non labile aluminium), Al-L (Labile aluminium), TP (Total Phosphorus) and PO_4 in $\mu g\ l^{-1}$; TOC (total organic carbon in $mg\ l^{-1}$) and Abs-250 (Absorbance at 250nm).

Appendix 2 Water chemistry for the experimental burn August 1992 - March 1997

Date	PH	Alk	Cond	Na	K	Mg	Ca	Cl	NO_3	SO_4	PO_4	Tot-P	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
18-Sep-92	5.71	28	33	136	3	36	113	152	0	82	0		22	21	1	0.410		
30-Oct-92	6.19	58	26	130	3	32	61	128	0	26	0		15	15	0	0.270	4.4	
06-Dec-92	5.23	9	19	93	2	14	27	88	0	23	0		27	27	0	0.260	3.4	
04-Jan-93	5.43	14	19	98	2	21	31	86	0	35	0		12	12	0	0.270	3.8	
30-Mar-93	5.86	28	41	230	5	44	64	296	1	45	2		12	9	3	0.170	2.9	
03-May-93	6.42	115	37	204	7	44	95	192	1	29	0		7	5	2	0.260	4.2	
18-Jun-93	6.33	122	37	202	4	44	100	156	0	16	0	19	28	19	9	0.510	8.2	
10-Jul-93	6.05	66	29	164	4	35	76	139	0	18	3	22	47	46	1	0.700	9.5	
25-Jul-93	5.71	42	29	156	2	42	73	130	0	12	3		57	48	9	0.860	13.0	
09-Aug-93	5.93	57	29	151	4	42	76	131	0	8	5		54	54	0	0.880		
22-Aug-93	6.36	142	33	186	6	60	108	159	1	14	3		30	28	2	0.650		
04-Sep-93	6.47	213	45	210	7	68	159	171	2	22	1		12	10	2	0.410		
29-Sep-93	6.60	171	45	209	15	64	135	207	2	28	0		20	20	0			
06-Dec-93	5.29	11	21	105	3	24	26	87	0	39	6		26	24	2	0.492	6.8	
18-Feb-94	6.30	70	44	243	6	75	109	246	1	49	1	0	5	5	0	0.096		0
01-May-94	5.88	35	29	183	4	44	58	159	0	28	1	13	33	26	7	0.414	5.4	0
12-May-94	6.36	87	36	202	7	58	90	176	0	26	0		23	19	4	0.279	5.0	7
10-Jun-94	6.25	71	40	224	5	62	100	200	0	51	0		24	22	2	0.292		0
08-Jul-94	5.75	44	29	178	3	53	75	122	1	24	2		46	45	1	0.836		0
07-Aug-94	6.78	130	31	181	13	78	137	141	1	19	4	60	23	17	6			0
25-Aug-94	6.29	80	32	177	7	71	111	141	1	18	2		31	28	3			0
03-Sep-94	6.51	136	37	200	12	81	136	153	1	16	5	2.5	21	18	3	0.488	7.6	0
22-Sep-94	6.27	97	33	186	7	66	123	160	0	13	2		21	21	0		7.3	0
29-Dec-94	5.47	13	24	125	6	39	36	139	0	24	1		38	35	3	0.238	4.6	0
27-Mar-95	5.74	23	22	129	5	32	40	121	0.4	21	2	2.5	19	18	1	0.260	5.3	0

Appendix 2 continued. Water chemistry for the experimental burn August 1992 - March 1997																	
Date	PH	Alk	Cond	Na	K	Mg	Ca	Cl	NO_3	SO_4	PO_4	Tot-P	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
27-Apr-95	6.10	65	29	168	15	48	80	158	0.46	24	1	2.5	31	30	1	0.284	6.6	0
02-Jun-95	6.26	64	29	169	5	47	68	129	0.42	13	1	2.5	42	35	7	0.548	11.0	0
15-Jul-95	6.46	140	46	202	6	86	154	138	0.49	94	1	2.5	14	12	2	0.343	8.5	0
06-Aug-95	6.51	195	40	219	8	86	164	155	1.2	30	1		16	15	1	0.417	8.6	0
25-Aug-95	6.81	221	49	225	7	99	176	171	0.41	35	1	2.5	9	9	0	0.266	6.1	0
04-Sep-95	6.22	74	63	239	8	134	208	125	0.87	302	0	6	14	14	0	0.239	6.8	0
24-Sep-95	5.21	10	35	167	5	66	84	115	0.37	112	0		42	37	5	0.494	12.0	0
11-Nov-95	5.91	43	26	139	4	47	72	98	0.52	37	0	2.5	38	32	6	0.473	8.7	0
10-Jan-96	5.31	10	23	126	6	42	47	96	1	68	0	2.5	40	35	5	0.305	6.6	2
27-Feb-96	5.28	10	28	152	4	51	55	166	0.94	56			27	19	8	0.237		0
03-Apr-96	6.29	71	36	189	12	62	105	172	0.91	75	1	2.5	15	15	0	0.170	4.7	4
02-May-96	6.06	66	31	159	6	51	83	132	0.48	44	0	2.5	24	21	3	0.311	6.5	2
12-Jun-96	5.41	21	24	127	2	36	47	103	0	17	3	3	43	41	2	0.627	12.6	0
04-Jul-96	5.83	45	27	144	3	51	77	104	0	32	1	2.5	36	23	13	0.586	19.8	0
27-Jul-96	6.24	124	34	168	4	71	128	122	0	19	2	2.5	22	20	2	0.520	12.7	0
18-Aug-96	6.75	208	41	198	7	89	169	140	1.1	20	1	2.5	15	14	1	0.464	9.7	0
07-Sep-96	6.13	117	35	174	9	78	130	136	0.98	16	2	2.5	31	27	4	0.677	14.0	0
28-Sep-96	6.31	102	42	194	9	78	128	183	1.4	42	1	2.5	19	18	1	0.372	9.3	0
30-Oct-96	5.53	20	25	118	10	41	53	112	0.27	20	2		54	46	8	0.505	10.0	0
03-Dec-96	5.16	6	46	227	7	72	73	305	1.5	40	0	2.5	26	25	1	0.166	3.9	0
28-Jan-97	5.95	36	26	142	4	39	58	106	0.94	43	0	2.5	27	26	1	0.371	7.4	2
10-Mar-97	5.68	22	39	204	6	57	70	241	0.92	38	0							0

All units in μeq l^{-1} except: pH, Cond (conductivity μS cm^{-1}); Al-TM (Total monomeric aluminium,) Al-NL (Non labile aluminium), Al-L (Labile aluminium), TP (Total Phosphorus) and PO_4 in μg l^{-1}; TOC (total organic carbon in mg l^{-1}) and Abs-250 (Absorbance at 250nm).

Appendix 3 Water chemistry for the Tigh na Cruaich burn June 1995 - March 1997

Date	PH	Alk	Cond	Na	K	Mg	Ca	Cl	NO_3	SO_4	PO_4	Tot-P	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH_4
02-Jun-95	6.15	48	25	137	5	41	68	109	0.51	26	0	2.5	53	53	0	0.431	8.8	0
15-Jul-95	6.35	72	41	175	9	76	128	121	9.0	104	0	2.5	38	30	8	0.436	11.0	0
06-Aug-95	6.80	122	38	207	13	65	142	148	2.2	80	1		18	15	3	0.287	6.6	0
04-Sep-95	6.19	50	43	182	9	84	132	118	0.5	156	0	6.0	39	39	0	0.347	8.5	0
24-Sep-95	5.41	17	28	150	6	63	85	107	1.1	96	0		74	66	8	0.517	13.0	0
11-Nov-95	6.03	50	26	130	6	47	81	94	1.2	43	1	2.5	65	65	0	0.411	7.9	0
27-Feb-96	5.68	25	30	155	5	55	74	166	2.5	64			30	29	1	0.213		1
03-Apr-96	6.07	41	33	153	12	59	100	135	7.6	88	0	2.5	31	29	2	0.194	4.6	6
02-May-96	5.98	71	31	139	6	48	98	115	0.3	60	0	2.5	34	32	2	0.241	4.8	0
12-Jun-96	5.52	22	23	115	3	37	51	91	0.4	23	3	4.0	69	40	29	0.563	6.7	0
04-Jul-96	5.92	41	27	130	4	49	85	96	0.0	46	0	2.5	61	47	14	0.553	23.0	0
27-Jul-96	6.36	79	29	140	5	57	117	100	0.5	34	1	2.5	46	42	4	0.532	10.7	0
18-Aug-96	6.69	141	35	158	7	62	144	108	2.1	39	2	2.5	26	24	2	0.398	8.0	0
07-Sep-96	6.34	117	34	162	11	65	137	117	0.5	40	2	2.5	39	35	4	0.485	10.2	0
28-Sep-96	6.21	59	37	169	10	74	120	174	2.6	57	1	2.5	55	46	9	0.484	10.9	0
30-Oct-96	5.61	23	21	97	7	36	53	80	0.9	22	1		97	90	7	0.525	10	0
03-Dec-96	5.26	10	44	218	8	71	75	293	2.1	42	0	2.5	42	35	7	0.160	3.7	0
28-Jan-97	6.09	43	27	129	6	41	73	104	3.5	49	4	6	45	45	0	0.305	6.0	2
10-Mar-97	5.64	26	38	184	9	56	77	218	2.6	46	1							0

All units in μeq l^{-1} except: pH, Cond (conductivity μS cm^{-1}); Al-TM (Total monomeric aluminium,) Al-NL (Non labile aluminium), Al-L (Labile aluminium), TP (Total Phosphorus) and PO_4 in μg l^{-1}; TOC (total organic carbon in mg l^{-1}) and Abs-250 (Absorbance at 250nm).

Appendix 4 Biology Sampling Dates

Sampling Year	1992*	1993	1994	1995	1996
fish		29th Sept	27th Sept	27th Sept	24th Sept
macroinvertebrates		3rd May	12th May	no sample	15th May
epilithic diatoms	15th Aug	29th Sept	25th Aug	25th Aug	28th Aug
aquatic macrophytes	15th Aug	29th Sept	25th Aug	25th Aug	28th Aug

* Only Control burn sampled in 1992