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Land-use experiments in the Loch Laidon catchment

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Third 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 during the first three 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 in the Loch Laidon catchment have been monitored for chemistry and biology since August 1992. They possess similar chemical and biological characteristics typical of slightly acid, upland sites in Scotland, and as such they provide a suitable experimental/control pairing for land-use experiments.

3. A regime of summer grazing by cattle (July to September) in the experimental catchment was initiated in 1993 and is continuing.

4. Water chemistry results indicate slightly elevated levels of calcium, magnesium and conductivity in the experimental burn relative to the control burn during the months of summer grazing. Caution should be exercised in the interpretation of these results since the experimental plot is grazed over the same summer period each year and therefore potential differences in the seasonal hydrological response of the two burns and their catchments need to be taken into account. However there is no evidence of any significant difference in the relative flow regime of the two burns during the summer months compared to the rest of the year. It is recommended that monitoring of water chemistry should continue at both sites for at least two years following the final season of grazing so that the relationship of summer water chemistry between the two sites might be better understood.

5. Although usually slightly more acid, the pH of the experimental burn was greater than that of the control on four sampling dates. Three of these dates were during periods of grazing. However the pH of the experimental burn is not consistently elevated relative to that of the control during these periods.

6. To date, there is no evidence of any long term (ie. year round) change in water chemistry of either burn.

7. To date, there is little evidence of biological change in the experimental burn which can be attributed to the introduction of cattle. This is to be expected given the relatively modest evidence for any chemical change. However, the aquatic macrophyte data suggest that there has been a shift in the representation of the dominant liverwort species, in the experimental burn only, from *Marsupella emarginata* to *Scapania undulata*.

8. Given the inherent variability in the stream environment at a number of temporal scales, continued monitoring of the burns for a period of at least five years will be necessary for the effects of the experiments on water quality to be quantitatively evaluated.

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.

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 (eg. 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 upland cattle grazing. It is not clear what influence 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.

Two streams within the moorland catchment of Loch Laidon were selected for the purposes of the project in 1992. Allott *et al.* (1994) demonstrated that the two streams exhibited similar chemical and biological characteristics and were therefore suitable as a control/experimental pair. Cattle have now been introduced to the experimental catchment for three consecutive summer grazing seasons, and monitoring of chemistry and biology has continued as before.

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, macroinvertebrates, aquatic macrophytes and epilithic diatoms of the two burns. Dates of biological sampling are provided in Appendix 2. Macroinvertebrates were not sampled at either site in 1995 but sampling will resume this year.

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 was implemented in 1994 and 1995 although the stock has been reduced slightly to 15 cows, 15 calves and 1 bull.

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. Additionally, diversity indices have been used as measures of the species richness and evenness of the diatom and macroinvertebrate samples. Statistical analysis of temporal trends in the data is not appropriate at this stage given the short period of study to date.

Results for water chemistry are presented in full data format (Appendix 1), as summary statistics (Table 1), and as time series graphs (Figures 4-16) with individual determinands for both burns plotted on the same axes. 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 each time series, the relationship of determinand levels between the two burns is also plotted as a ratio, or, in the case of phosphate, nitrate and labile aluminium, for which several measurements were below detection limits, as the difference in concentration. The distribution of experimental / control ratio values, for many determinands, during (July - September) and between (October - June) grazing periods are contrasted in the form of Box and Whisker plots which represent median values and the interquartile range (Figure 15).

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.

Results

Water Chemistry

Summary water chemistry data for the control and experimental burns are presented as annual means, maxima and minima from October 1992 to September 1995, in Table 1. Variation in the principal determinands and their ratios are plotted in Figures 4-16.

Figures 4-16 demonstrate the continuing close relationship between the temporal variation in water chemistry of the two burns. However, the ratios of some determinands appear to deviate at a time of year coincident with periods of grazing. Most striking are the apparently enhanced levels of the cations calcium and magnesium (see ratios presented in Figures 7 and 8) in the experimental burn relative to the control during these periods. A similar, but not quite so pronounced, pattern is evident for conductivity and for alkalinity.

The distribution of experimental / control ratio values during grazing and non-grazing periods are compared using Box and Whisker Plots (Figure 17). These emphasise the difference in the experimental / control ratio between the two periods for calcium, magnesium and conductivity, for which the 25 and 75 percentiles during grazing periods exceed the median and upper limit respectively during non-grazing periods. The plots appear to confirm that the levels of these determinands in the experimental burn relative to the control burn are generally higher during grazing periods than at other times of year.

As was noted in the previous report, the experimental burn is slightly more acid than control on nearly all sample dates. The Box and Whisker plot for H^+ (Figure 17) demonstrates that, in general, the H^+ concentration ratio is marginally greater during grazing than non-grazing periods, ie. the experimental burn is usually slightly more acid relative to the control during grazing than non-grazing periods. However, on four sample dates the pH of the experimental burn is greater than the control (see Figure 4), and three of these are within grazing periods. Two of the dates (7/8/94 and 25/8/95) coincide with significant peaks in the experimental / control ratio for calcium, magnesium and alkalinity.

There is no indication to date of any sustained trends in chemistry data at either site.

However, a longer time-series is required before any statistics can be usefully applied. Analysis of monthly data for acid sensitive streams in the United Kingdom Acid Waters Monitoring Network (Patrick *et al.* 1995), where trends were identified at some sites, has shown that even for the determinand with the greatest gradient of change, six years of data are required to establish statistical significance at the 95% confidence level.

Epilithic Diatoms

Marked similarities in the epilithic diatom assemblages of the two burns prior to the onset of grazing have already been described by Allott *et al.* (1994). Table 2 presents data for the relative abundance of the more common taxa for the last four years at the control burn and the last three years at the experimental burn.

Given the inherent seasonal and year to year variability of stream biota, it is still not possible to draw firm conclusions on the data collated to date, either on differences between the assemblages of the two burns or on differences between years at either site. However, diversity indices indicate little change between years in the epilithic diatom diversity of either burn; the experimental burn continues to support a more diverse assemblage in terms of evenness of taxon representation although the total number of taxa found is similar. Diatom evidence for possible changes in the pH regime at the experimental site is difficult to interpret. The samples show a decrease both in the acidophilous species *Eunotia naegelii*, and in *Synedra minuscula*, a species usually considered indicative of circumneutral (ie. close to pH 7) conditions. The latter species has remained common at the control site. The 1995 sample at the experimental burn contained increased abundances of *Cymbella lunata* and *Frustulia rhomboides* var. *saxonica*, species with pH optima between those of *E. naegelii* and *S. minuscula*. Further years of sampling are required before the significance of these apparent differences can be evaluated.

Aquatic Macrophytes

The percentage submerged macrophyte cover for a designated survey stretch of each burn is presented in Table 5. The species representation for the two sites remains similar although the total cover of the experimental stretch is markedly greater. The water level of both burns was low during the 1995 survey, compared to previous years, and this could account for discrepancies in the estimates of relative percentage cover for individual species compared to previous years. The data suggest that, over the three years of sampling, *Scapania undulata* may be replacing another liverwort species, *Marsupella emarginata* var. *aquatica* in the experimental burn. The former species is common in a wide range of aquatic environments and is tolerant of poor water quality. Both species, however, are frequently observed in acid streams, and the environmental significance of a possible shift in their relative abundance is not clear. As with the other biological data, it is too early to evaluate the significance of any potential changes.

Macroinvertebrates

Macroinvertebrates were not sampled in 1995, but data for previous years are presented in Table 3 and the summary statistics in Table 4. A brief summary of this data is given in the previous report (Monteith *et al.* 1994). Sampling will resume at both sites this year.

Fish

The fish population data demonstrate that brown trout continue to spawn in both the control and the experimental burns (Table 6) . The density and age structure of the trout population of the control burn remain very similar from between years. There appears to be more year to year variability in the population of the experimental burn, but it is not possible at this stage to investigate the possibility of trends in the data.

Discussion

It is still not possible to draw firm conclusions from the data collected, regarding the effect of cattle grazing on stream water quality, given, (a) the short period of monitoring to date and (b) the absence of a suitably long period of chemical monitoring prior to the initial introduction of cattle at the experimental site. After only three years the biological data is particularly difficult to interpret since the frequency of sampling is low (annual), and since the degree of natural year to year variability is likely to be high in most cases. However, evidence of sustained biological change in the experimental burn is not expected at this stage given the absence of evidence for trends in the chemistry data.

Despite these points, the experiment has already yielded interesting results which are summarised below together with other observations and recommendations for future work.

(1) The general chemical and biological properties of the two sites and the timing of variation in water chemistry, remain similar.

(2) Although more data is required before statistically significant tests for trends in water chemistry can be applied, differences are apparent in the experimental / control ratio for calcium, magnesium, conductivity and possibly alkalinity between grazing and non-grazing periods. It is not yet possible to ascertain the cause of these effects since:

(i) grazing is implemented over the same period every year;
(ii) the summer grazing period (July - September) is, by definition, usually the warmest and often the driest time of year;
(iii) the experimental design did not include a "control" year, before cows were introduced for the first time, which would have allowed an examination of the year round relationship between the water chemistry of the two burns in the absence of grazing;
(iv) although stage board readings have been taken to coincide with the taking of most samples, the relationship between water depth and flow has not yet been established and therefore it is not possible to "flow-weight" the chemical data.

If, after a suitable number of years of sampling, there is no evidence of a temporal trend in the chemistry of the experimental site, it should be possible to examine the normal "non-grazed" relationship between the two sites by continuing to monitor them for two or more years after the cows have been removed. If, on the other hand, trends have been identified at the experimental site, this approach may be unsuitable. In this case, an alternative methodology would be to take water samples from both sites at a much finer temporal resolution (perhaps daily samples, taken with the aid of automatic water samplers) immediately prior and then during future grazing seasons, so that the relationship between the timing of introduction of cattle and possible responses in the experimental/control ratios could be examined in greater detail. However the problems of maintaining scientific apparatus within an enclosure of inquisitive animals should not be underestimated.

(3) We continue to recommend that water samples should be taken at a consistent interval that is no greater than monthly. This will allow the most rigorous statistics to be applied to time series chemistry data for the testing of trends.

(4) Although there is little evidence of significant changes in stream biology, it is possible that the relative composition of the liverwort flora of the experimental stream has changed since macrophyte surveys were first conducted at the experimental site in 1993. However, further years data will be required to verify this.

(5) The control burn continues to perform well as a control site. It possesses all the chemical and biological criteria required for compatibility with stream sites in the United Kingdom Acid Waters Monitoring Network, which assesses the effects of recently agreed cuts in sulphur emissions for the Department of the Environment. Given its geographical location this site is ideally placed to enhance the spatial coverage of the Network, should future funding become available.

Note on additional sampling locations

Since June 1995 the experimental plot area has been expanded. The east side of the fence has been moved further east to incorporate a second burn which has physical characteristics more similar to the control burn than the existing experimental burn.

Additional water samples are now being taken from the following sites.
These include:
(a) a second sampling location in the same stream system as the current experimental site;
(b) the second burn, newly incorporated within the enclosure;
(c) a lake littoral sampling location situated in a shallow bay which receives water from burns in the experimental enclosure; and,
(d) Loch Laidon outflow.

Data collated for these sites will be reported for the first time in the next report.

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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.

Flower, R.J., Battarbee, R.W., Natkanski, J., Rippey, B. & Appleby, P.G. (1988) The recent acidification of a large Scottish loch partly located within a National Nature Reserve and Site of Special Scientific Interest. *Journal of Applied Ecology* **25**, 715-724.

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Patrick, S.T., Waters, D,. Juggins, S. & Jenkins, A. (eds.) (1991) *The United Kingdom Acid Waters Monitoring Network. Site descriptions and methodology report.* ENSIS Ltd, London.

Patrick, S., Monteith, D.T. & Jenkins, A. (eds.) (1995) *UK Acid Waters Monitoring Network: The First Five Years. Analysis and Interpretation of results, April 1988 - March 1993.* A report for the Department of the Environment and the Department of the Environment (Northern Ireland). ENSIS Ltd, London

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

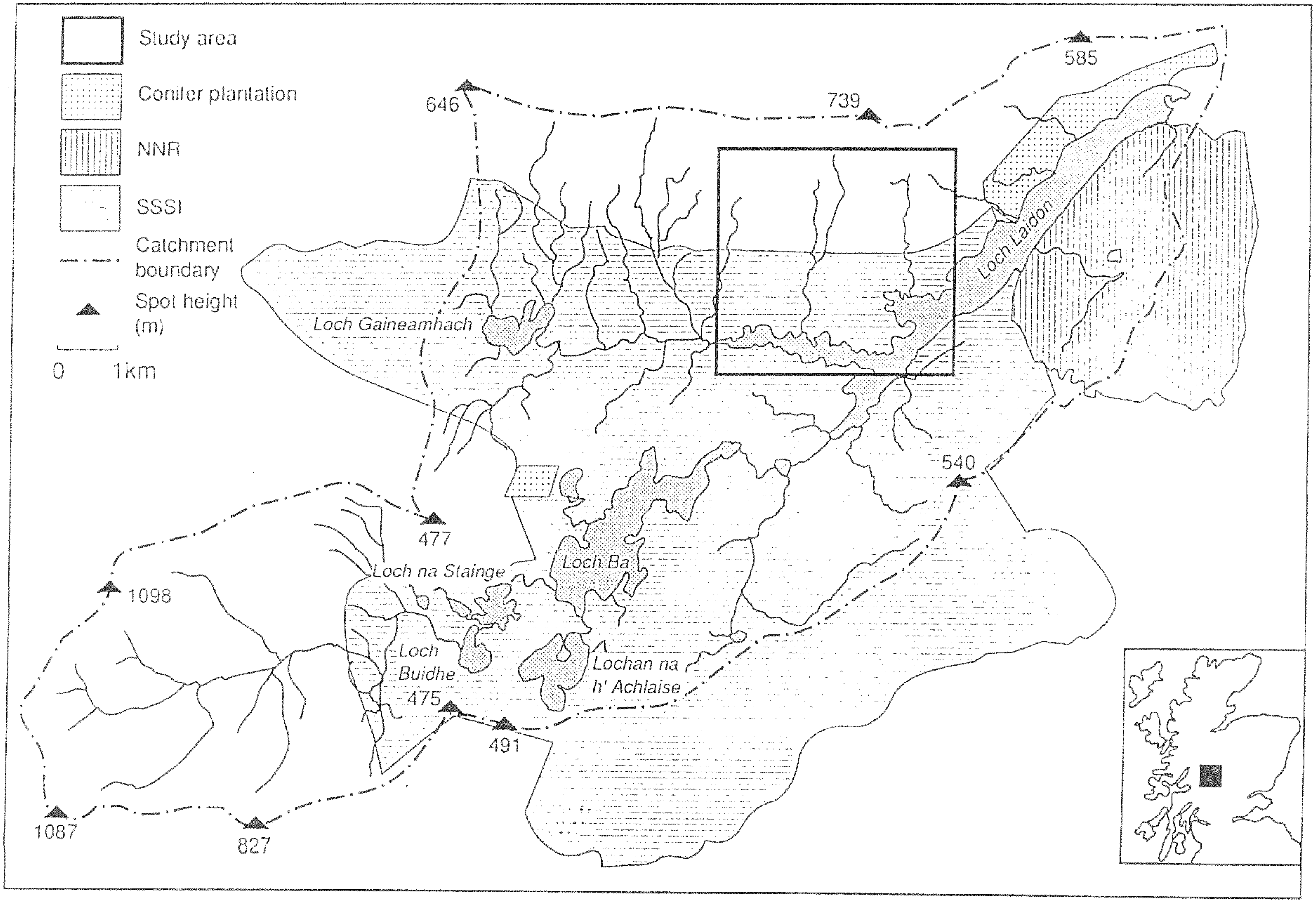

Figure 2: Loch Laidon study area

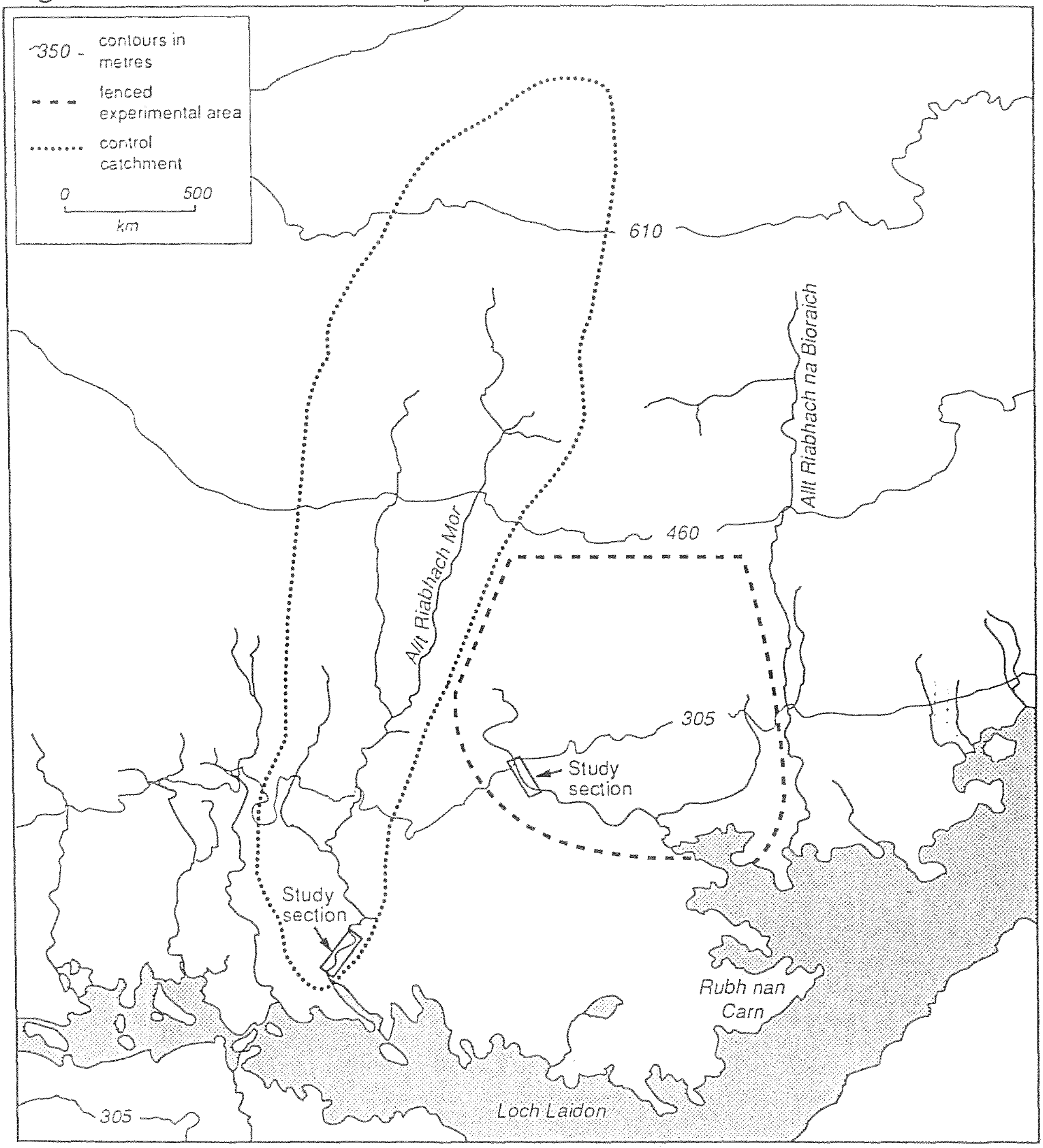

Figure 3 The difference in gauge height between the experimental and control burns and the temporal variability in actual gauge height, August 1992 - May 1996.

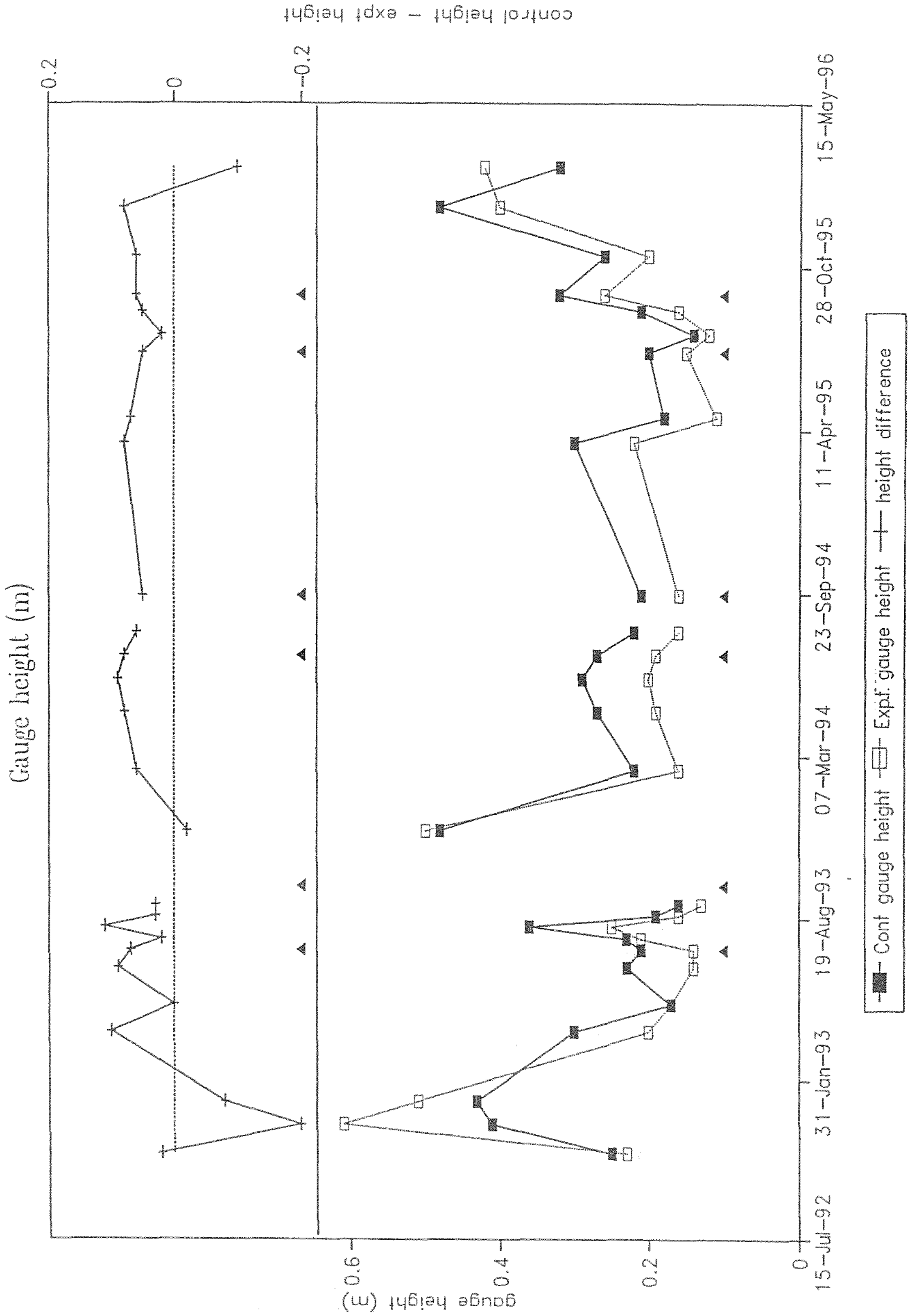

Figure 4 **The ratio of H^+ concentration and the temporal variability in pH of spot samples from the experimental and control burns, and their H^+ ratio, August 1992 - May 1996.**

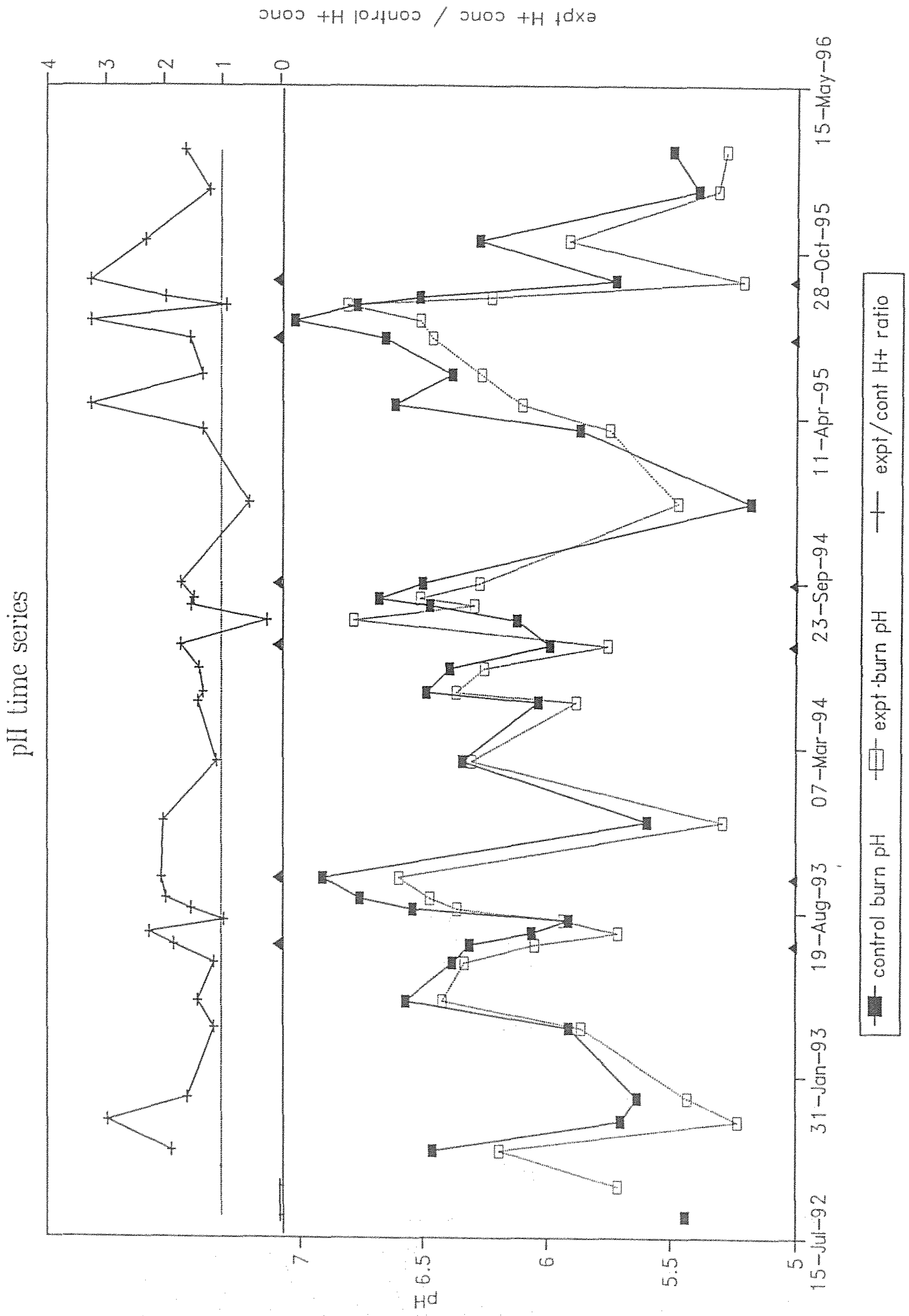

Figure 5 **The ratio of alkalinity and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

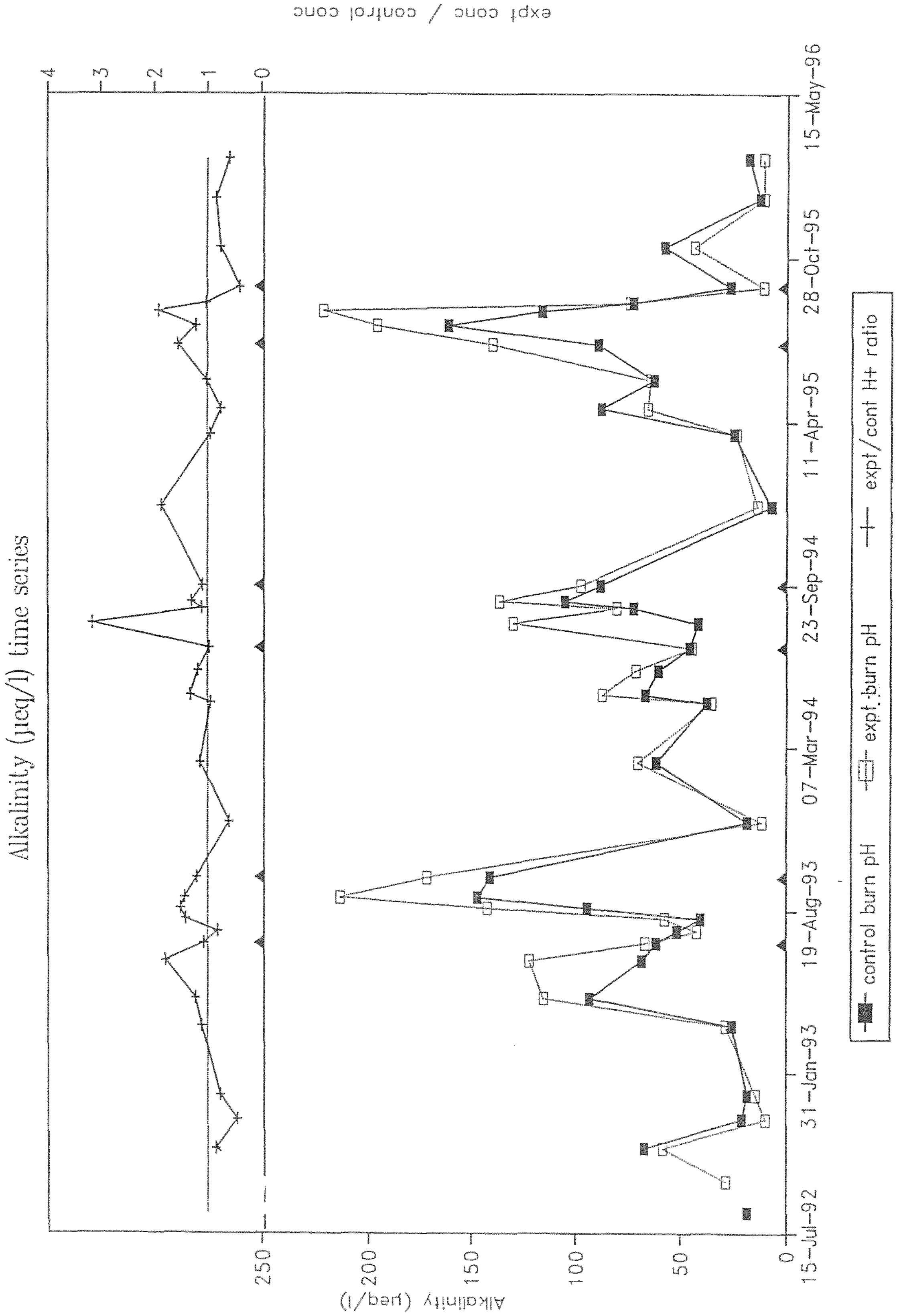

Figure 6 **The ratio of conductivity and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

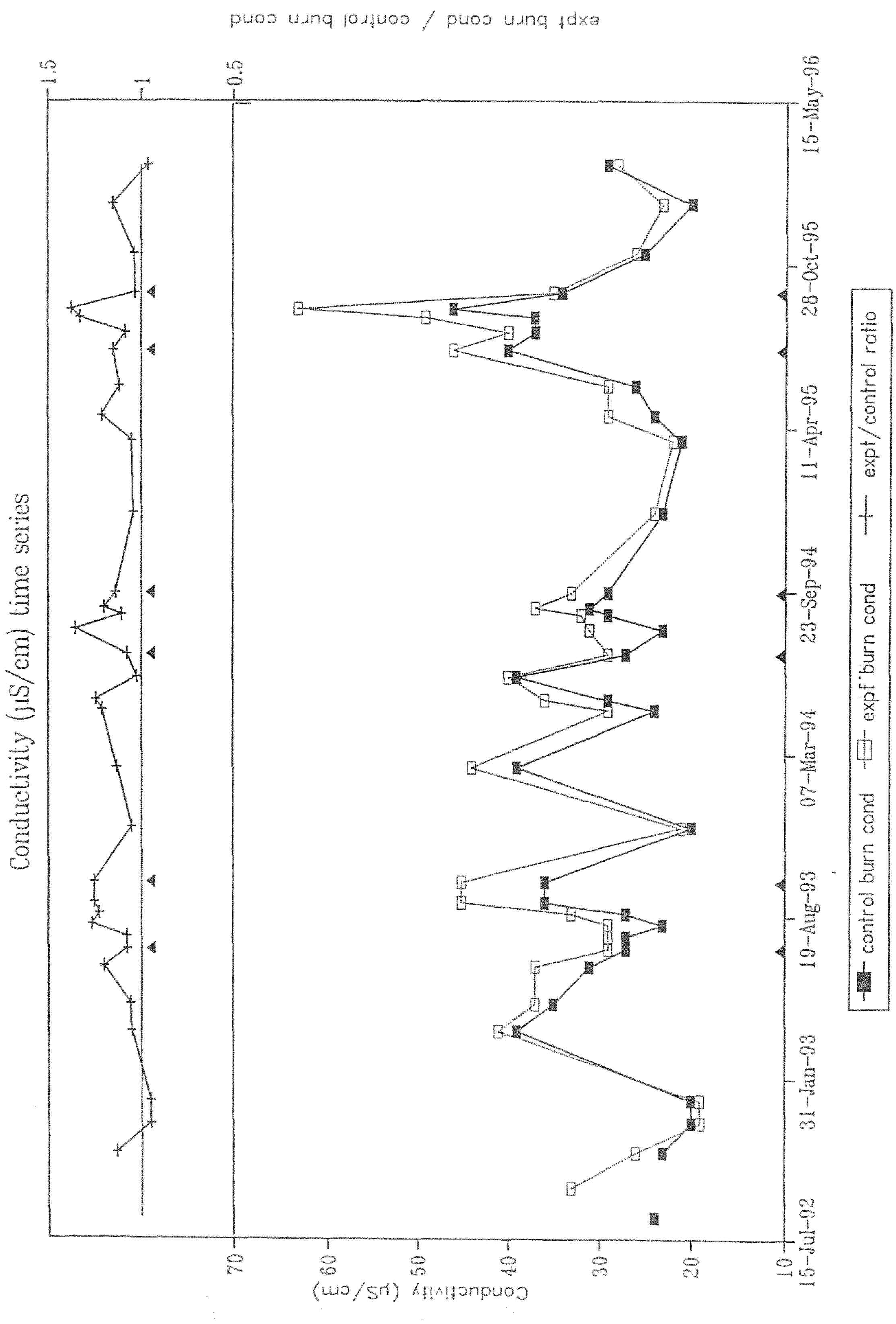

Figure 7 The ratio of calcium concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.

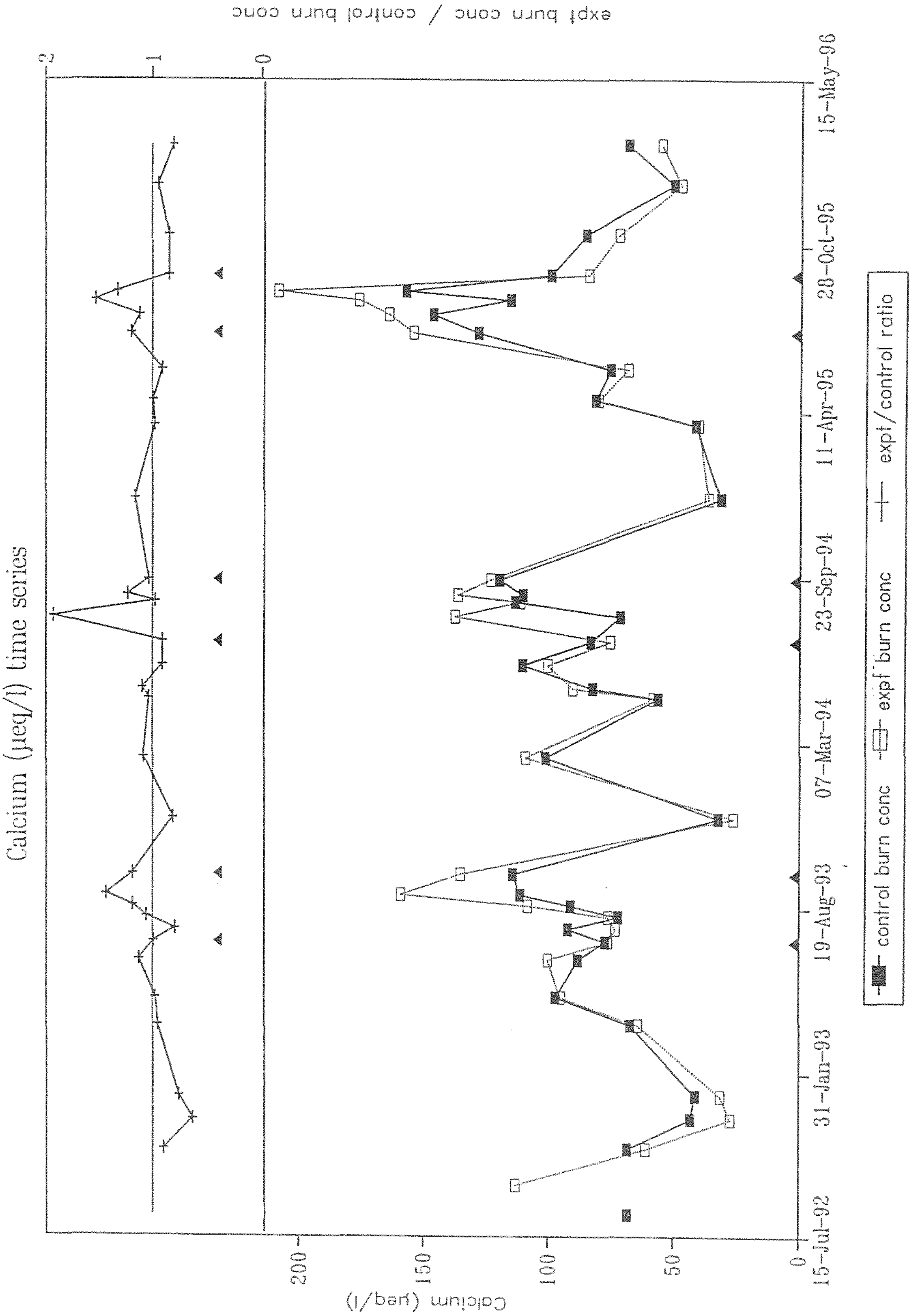

Figure 8 **The ratio of magnesium concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

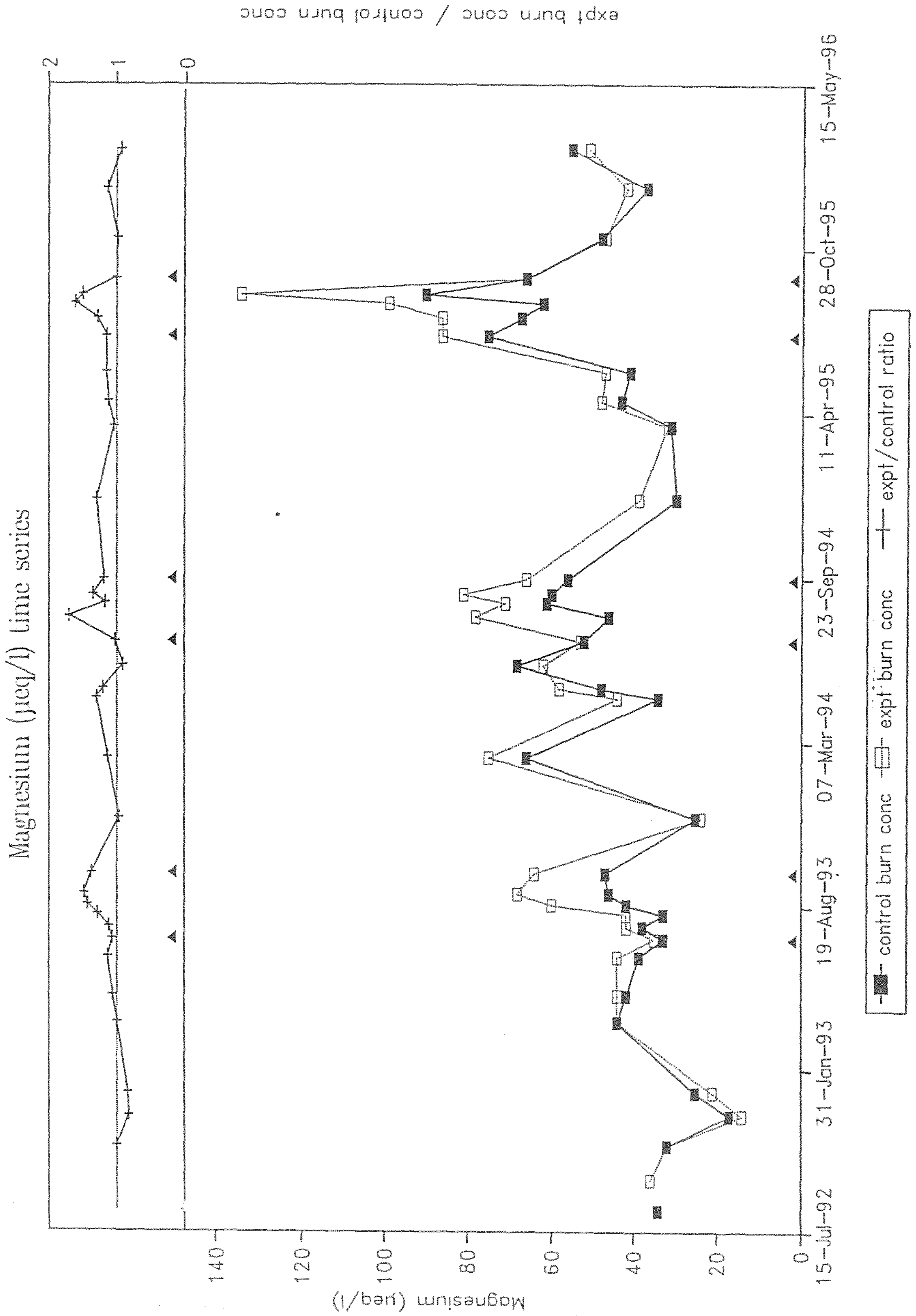

Figure 9 The ratio of potassium concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.

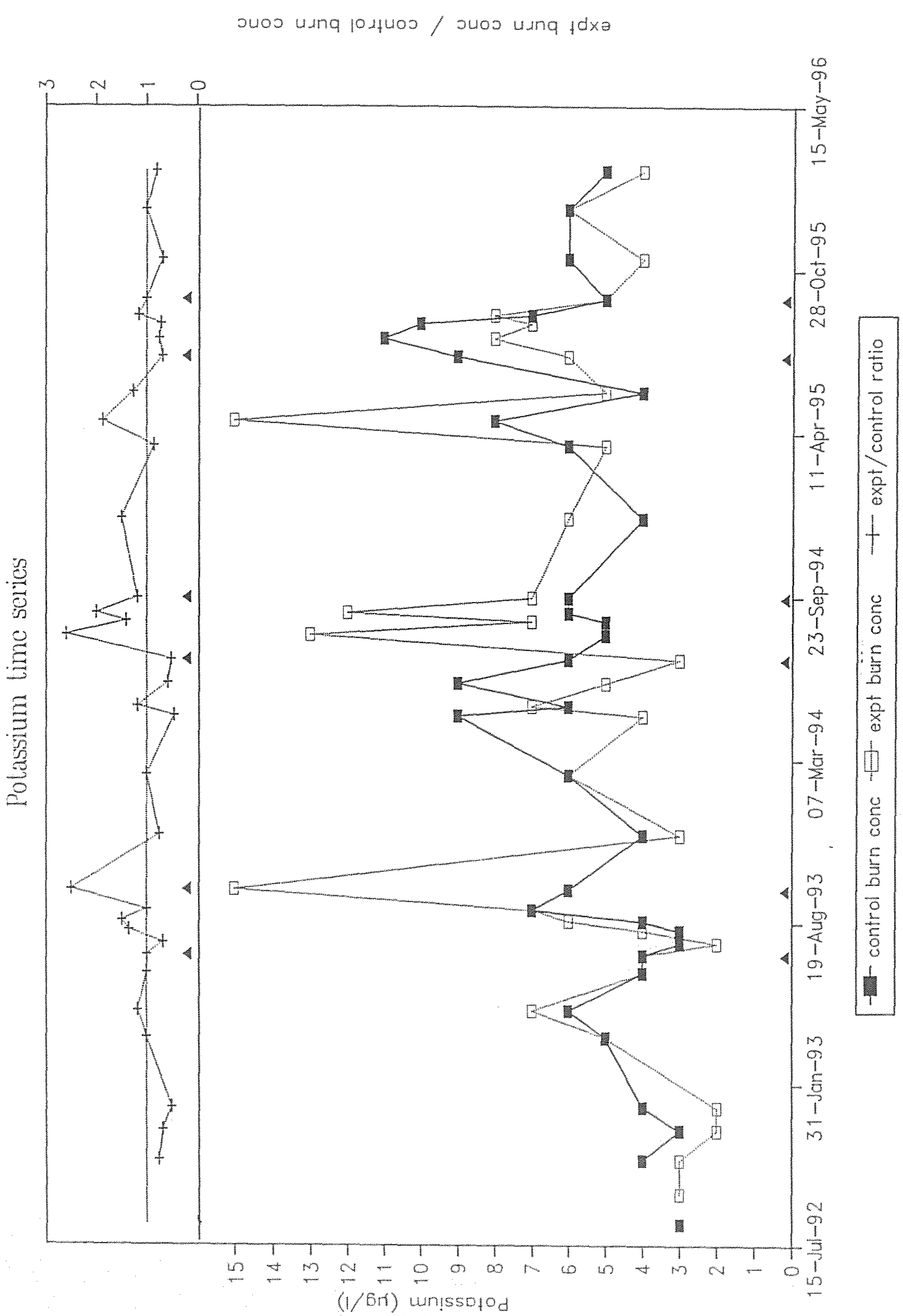

Figure 10 The ratio of chloride concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.

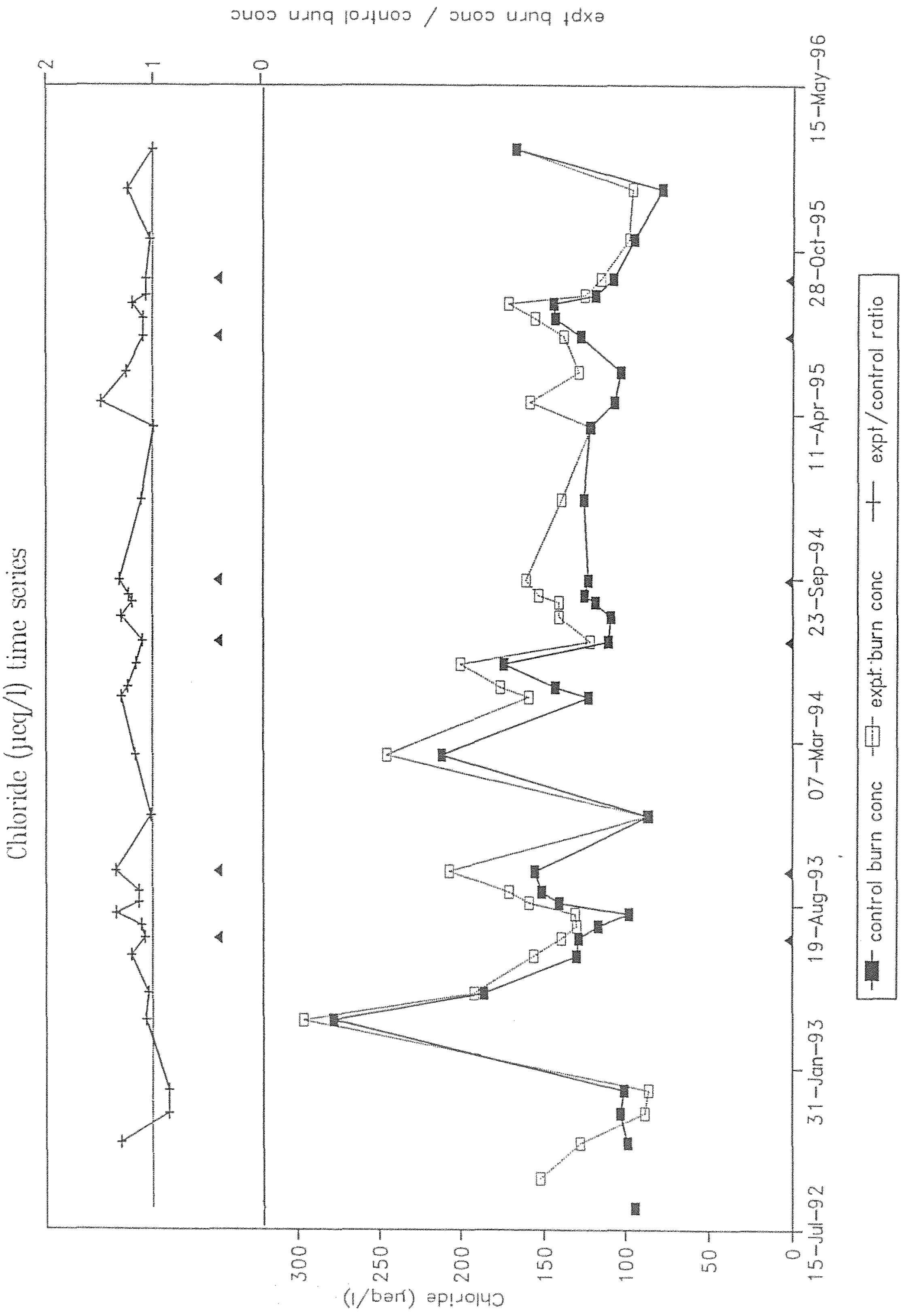

Figure 11 The ratio of sulphate concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.

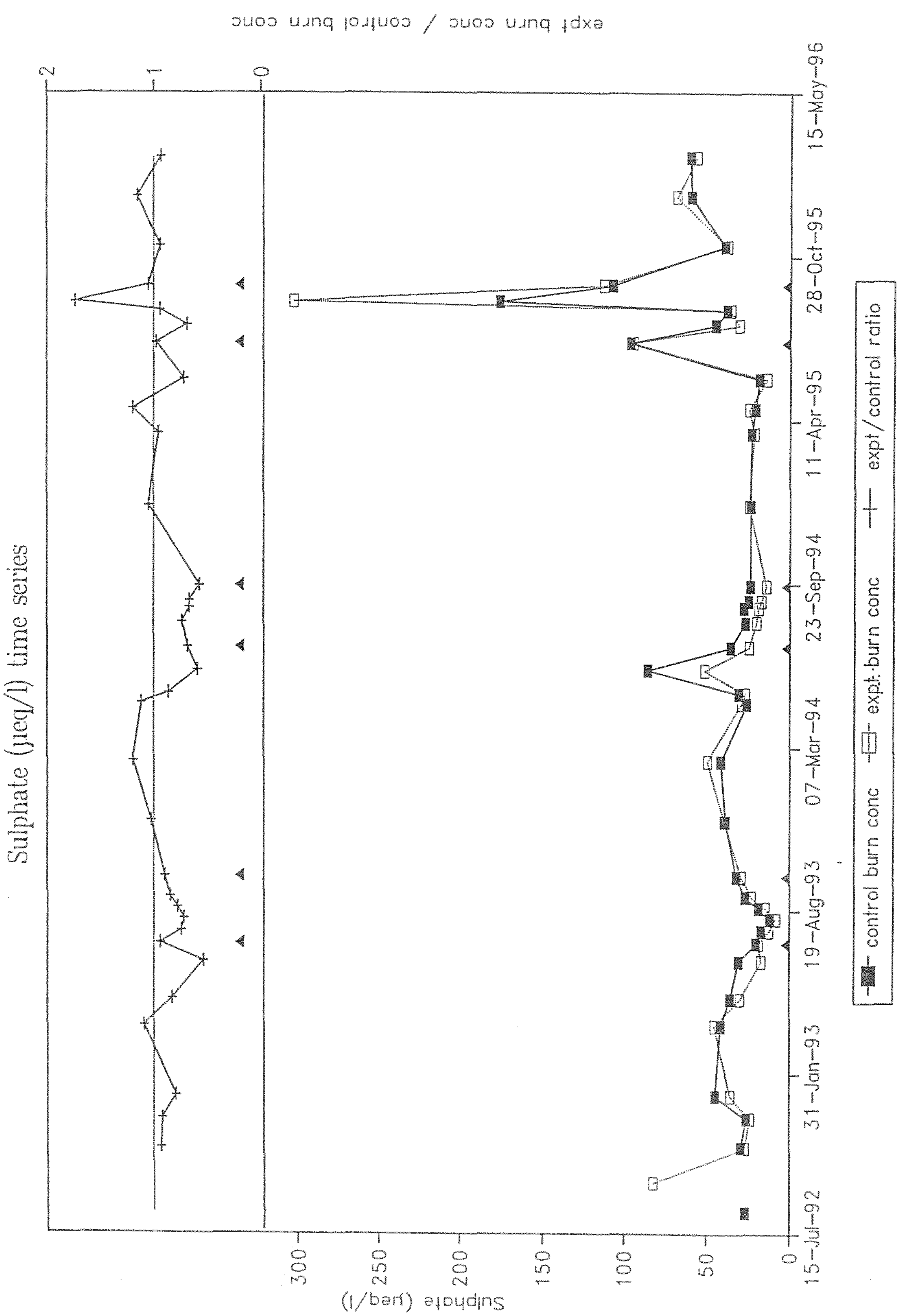

Figure 12 **The difference in nitrate concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

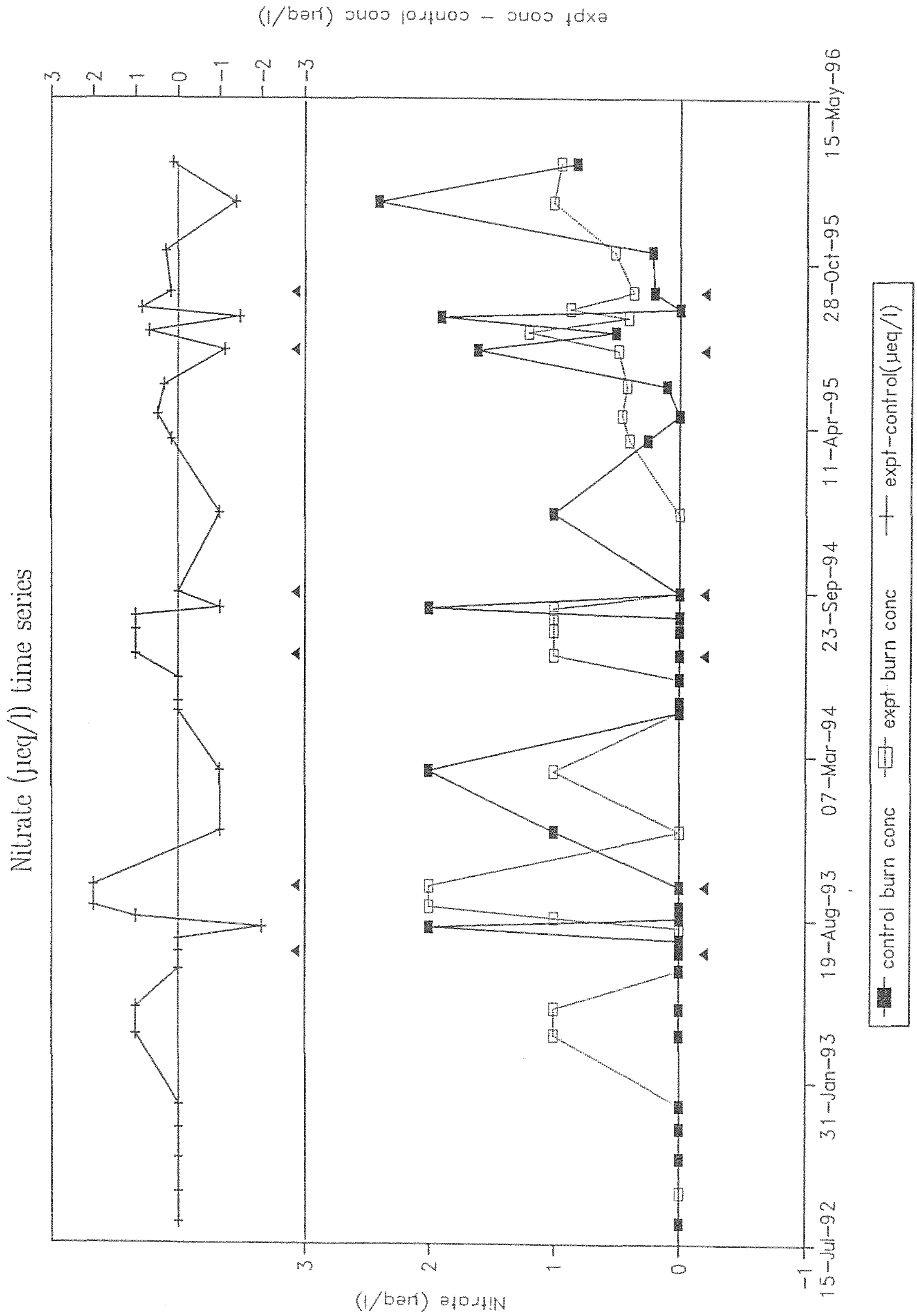

Figure 13 **The ratio of total monomeric aluminium concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

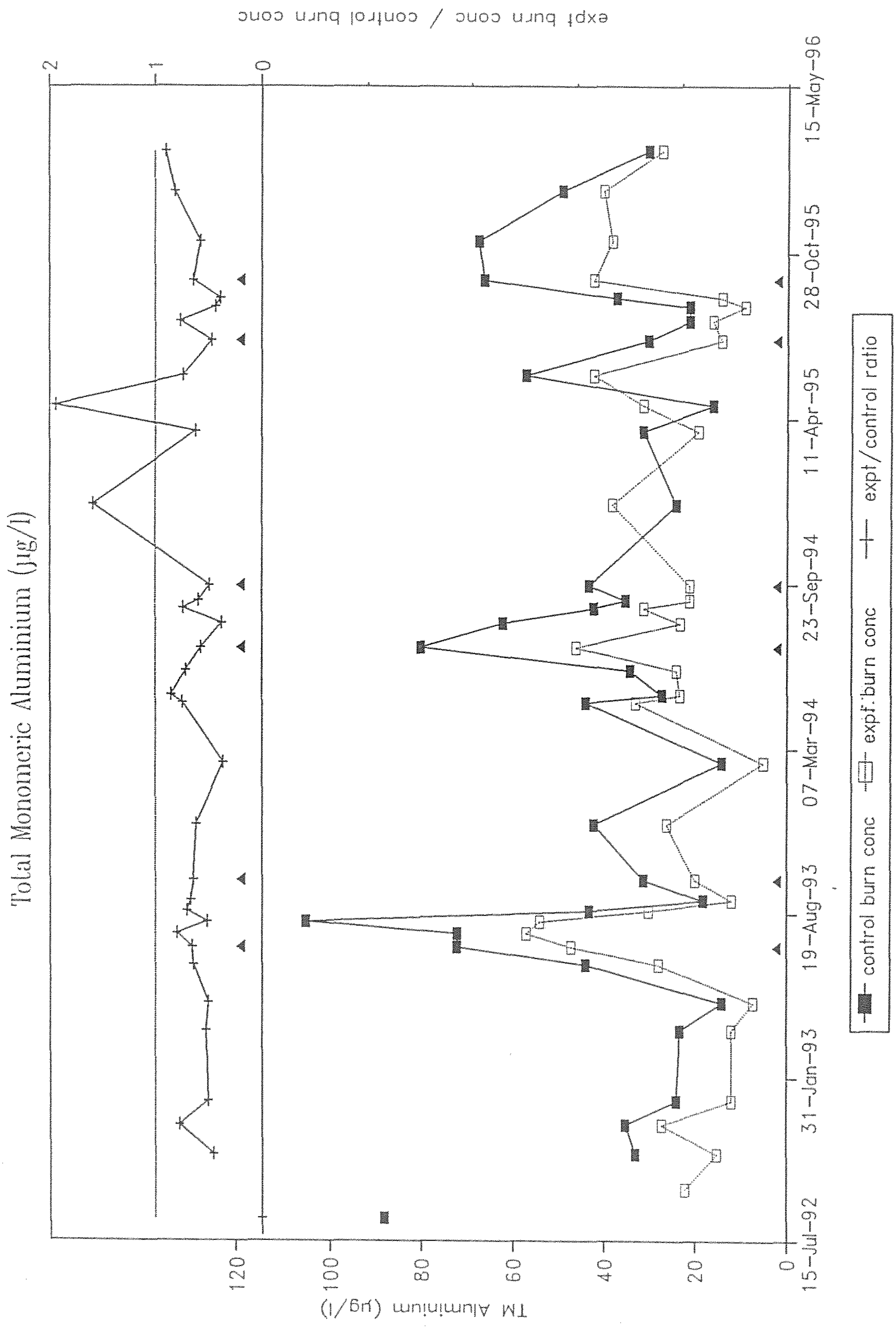

Figure 14 **The difference in labile aluminium concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

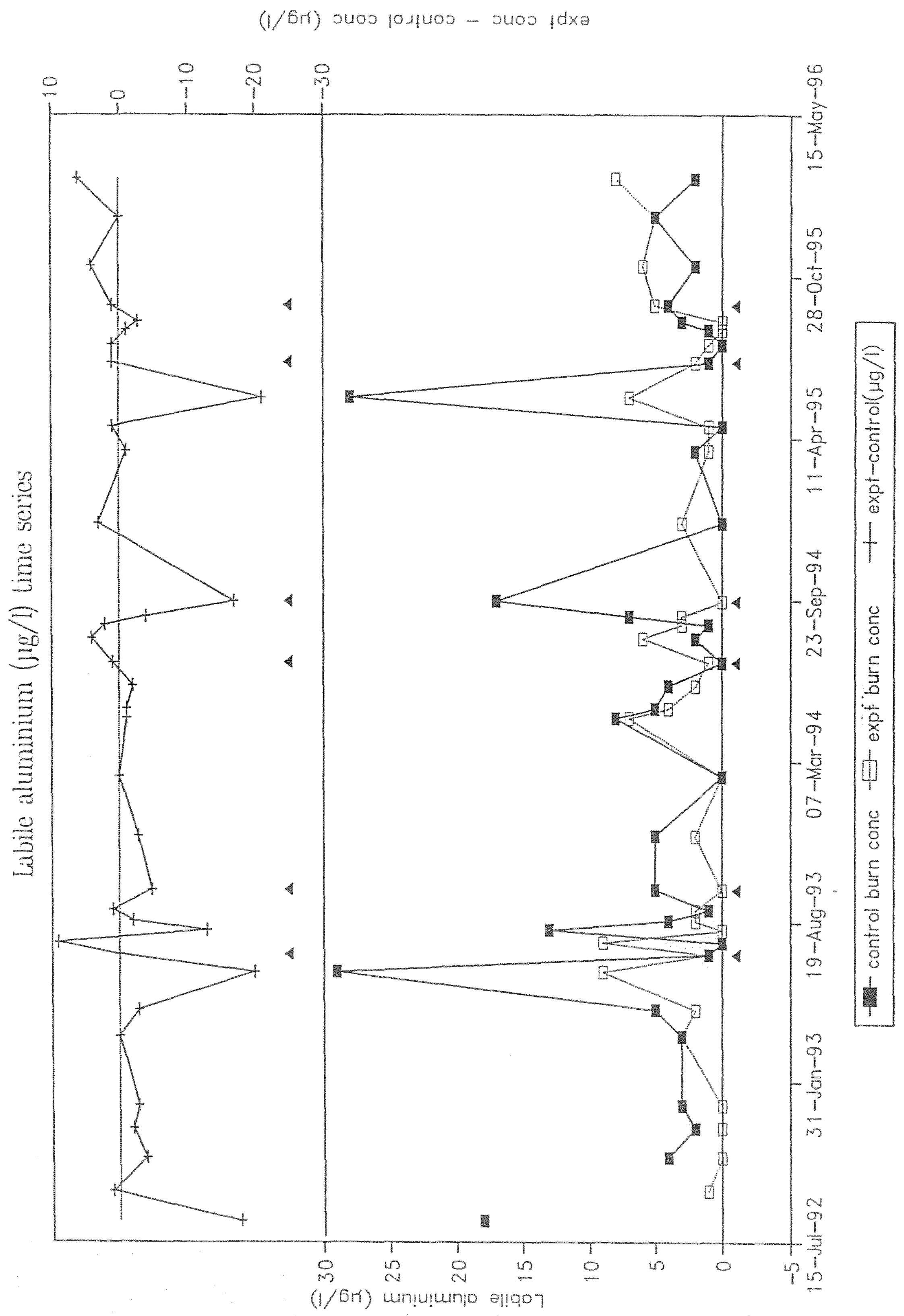

Figure 15 **The difference in phosphate concentration and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996**

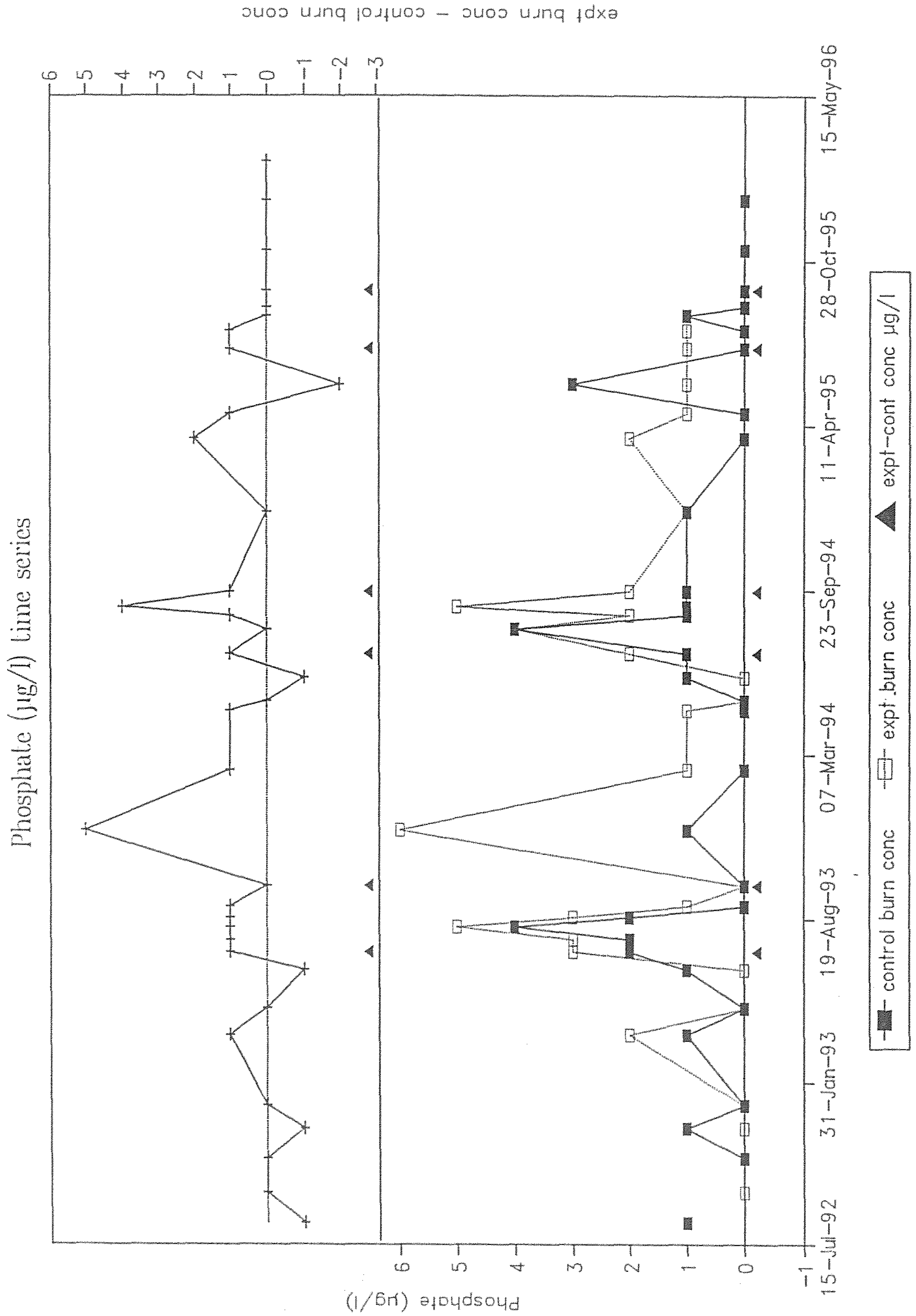

Figure 16 **The ratio of Absorbance (250nm) and its temporal variability in spot samples from the experimental and control burns, August 1992 - May 1996.**

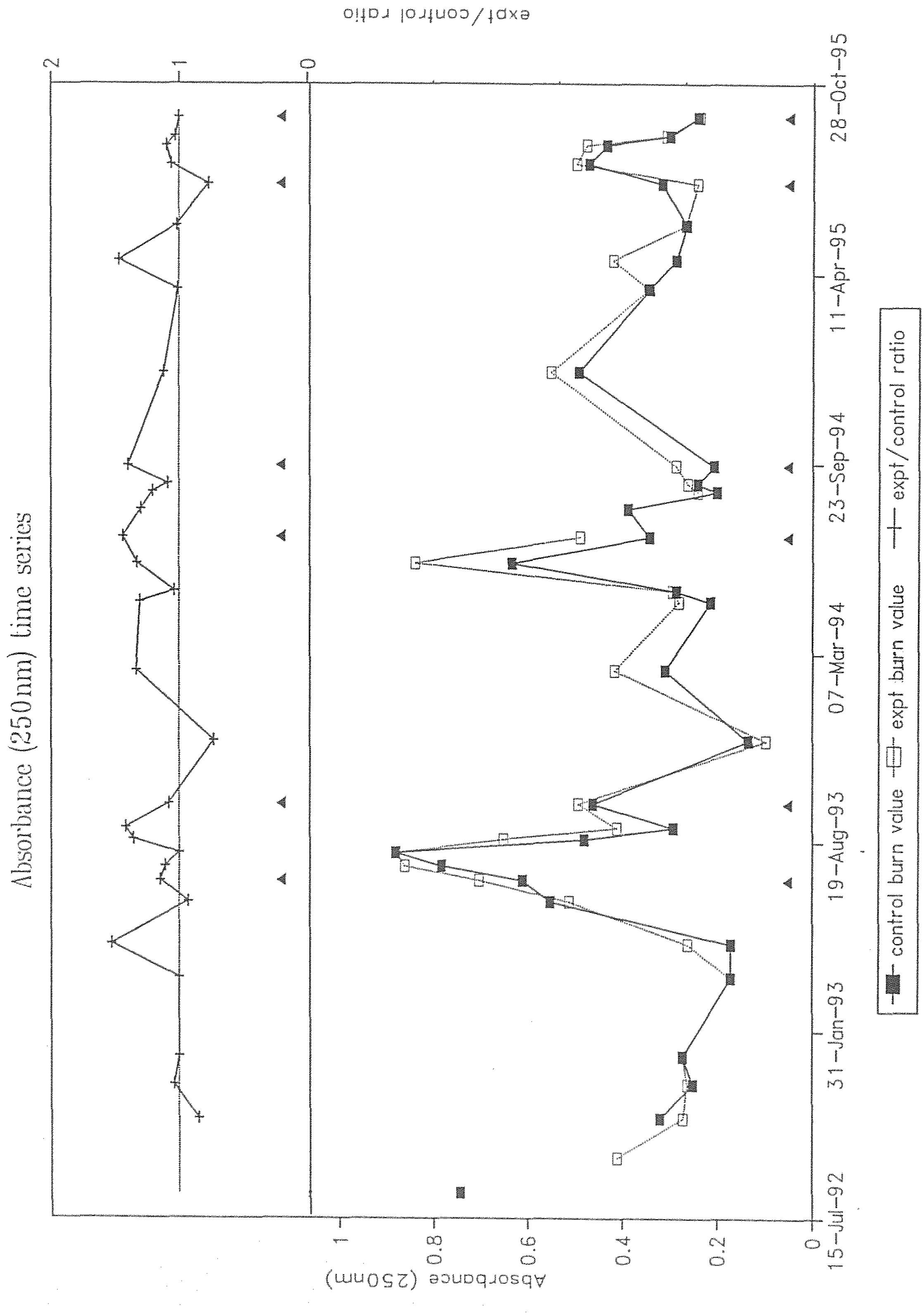

Figure 17 Box and Whisker Plots providing a comparison of the distribution of experimental / control ratio values between grazing (July - September) and non-grazing periods (October - June) for a number of determinands and for water depth (gauge height). The Plots present the median (centre line), interquartile range (upper and lower lines of box), 95% limits (outer lines) and outliers (circles)

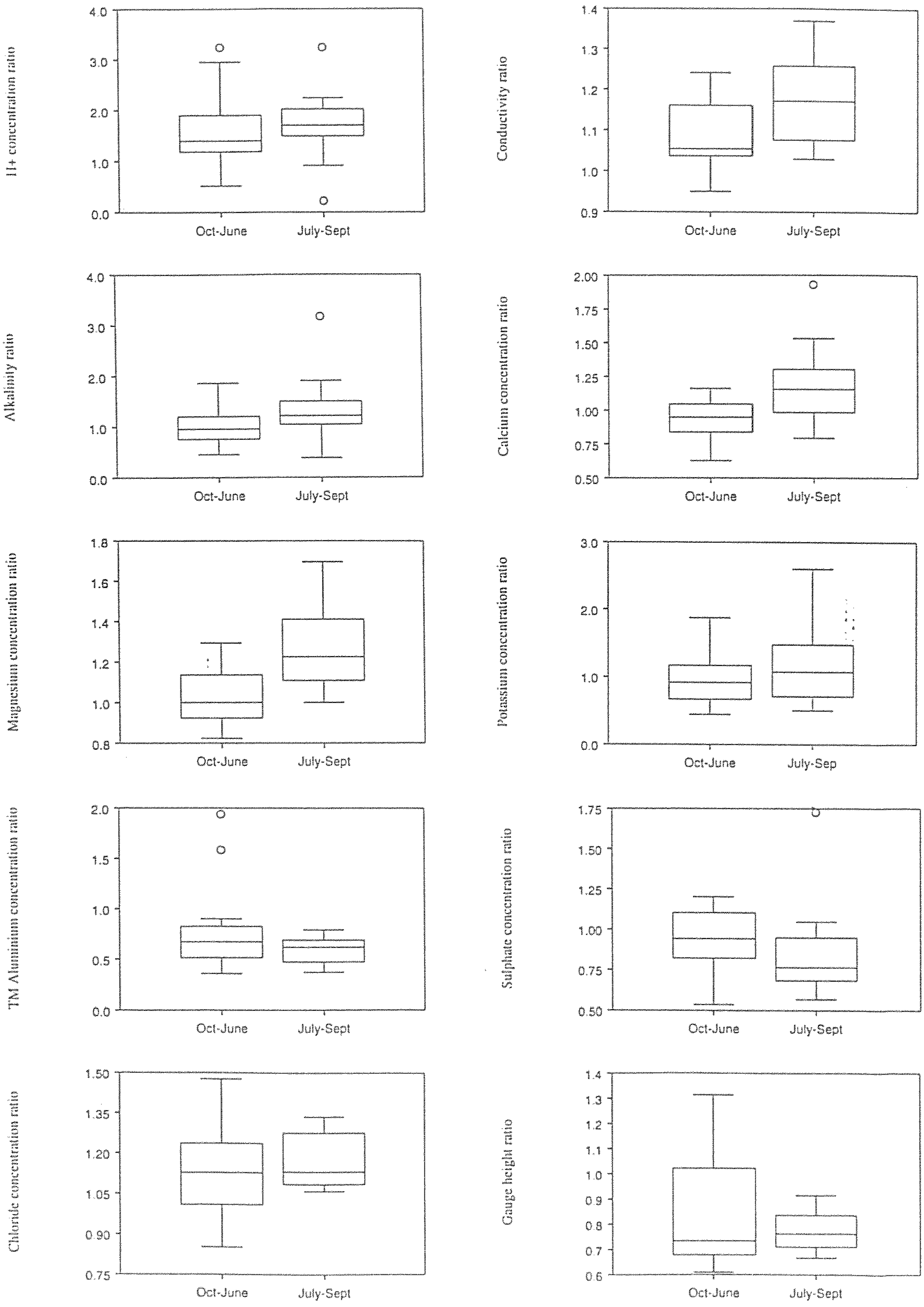

Table 1 Summary statistics of chemical determinands

	Control burn									Experimental burn								
	1/10/92 - 30/9/93			1/10/93 - 30/9/94			1/10/94 - 30/9/95			1/10/92 - 30/9/93			1/10/93 - 30/9/94			1/10/94 - 30/9/95		
Determinand	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
pH	6.09	6.05	6.91	6.11	6.16	6.68	5.90	5.18	7.02	5.84	5.23	6.60	5.92	5.29	6.78	5.80	5.21	5.80
Alk $\mu eq\ l^{-1}$	69	18	147	56	18	105	72	7	161	86	9	213	74	11	136	90	10	221
Cond $\mu S\ cm^{-1}$	28	20	39	29	20	39	32	21	46	33	19	45	33	21	44	38	22	63
Na $\mu eq\ l^{-1}$	143	104	203	158	99	210	156	108	195	169	93	230	188	105	243	183	125	239
K $\mu eq\ l^{-1}$	4.4	3.0	7.0	6.2	4.0	9.0	7.1	4	11	5.1	2.0	15.0	6.7	3.0	13.0	7.2	5	15
Mg $\mu eq\ l^{-1}$	37	17	47	51	25	68	56	30	90	43	14	68	61	24	81	71	32	134
Ca $\mu eq\ l^{-1}$	80	41	114	84	32	113	97	31	157	84	27	159	94	26	137	112	36	208
Cl $\mu eq\ l^{-1}$	141	98	278	133	86	211	122	103	144	157	86	296	158	87	246	139	115	171
NO_3 $\mu eq\ l^{-1}$	0.2	0.0	2.0	0.6	0.0	2.0	0.6	0.0	1.9	0.6	0.0	2.0	0.6	0.0	1.0	0.5	0.0	1.2
SO_4 $\mu eq\ l^{-1}$	27	11	44	37	24	85	60	18	175	23	8	45	30	17	51	73	13	302
PO_4 $\mu g\ l^{-1}$	1.1	0	4	1.0	0	4	0.6	0.0	3.0	1.4	0	5	2.3	0	6	0.9	0.0	2.0
TMAl $\mu g\ l^{-1}$	43	14	105	42	14	80	34	16	66	27	7	57	26	5	46	25	9	42
NLAl $\mu g\ l^{-1}$	37	9	92	39	14	80	29	16	62	24	5	54	23	5	45	23	9	37
LAl $\mu g\ l^{-1}$	6	0	29	4	0	8	4	0	28	2	0	9	3	0	7	2	0	7
Abs (250nm)	.43	.17	.88	.34	.13	.63	.31	.2	.49	.48	.17	.88	.41	.1	.84	.34	.24	.55

For sampling period 1/10/92 - 30/9/93 N = 12 For sampling period 1/10/93 - 30/9/94 N = 9 For sampling period 1/10/94 - 30/9/95 N = 9. Alk = Alkalinity ($CaCO^3$) Cond = Conductivity
TMAl = Total monomeric Aluminium NLAl = Non labile monomeric Aluminium LAl = Labile monomeric Aluminium Abs = absorbance at 25onm

Table 2 Diatom taxon list, percentage frequency and summary statistics

TAXON	% abundance of taxa (> 1%)						
	Control burn				Expt burn		
	1992	1993	1994	1995	1993	1994	1995
Achnanthes minutissima				1.3			1.5
Brachysira brebissonii					1.3		1.2
Brachysira vitrea	10.7	7.3	6.9	15.9	20.1	8.6	24.4
Cymbella lunata			4.5	1.5	1.6	1.0	6.1
Eunotia curvata			3.8			1.6	
Eunotia exigua	2.7	1.6	4.5	2.0	3.1	3.4	1.8
Eunotia incisa	1.6	1.4	3.8	1.8	3.8	7.4	7.9
Eunotia naegelii		1.1	1.2		6.6	9.4	
Eunotia pectinalis var. *minor*	2.0		6.0	2.0	6.0	15.0	2.7
Eunotia rhomboidea			1.2			1.0	3.1
Eunotia sp.			1.2				1.8
Frustulia rhomboides var. *saxonica*	1.0			1.3	6.0	7.4	20.1
Frustulia rhomboides var. *viridula*						1.3	
Gomphonema gracile	1.5					1.2	
Gomphonema minutum	1.0						
Peronia fibula	2.7	1.2	2.4	4.7	22.3	15.6	8.8
Synedra minuscula	8.2	55.4	19.9	25.9	8.8		-
Tabellaria flocculosa	65.8	24.9	47.6	34.3	15.7	19.9	7.9
SUMMARY STATISTICS							
Total count	983	1009	1047	1014	320	672	328
Total number of taxa	24	28	34	41	22	33	24
Hill's N1	4.0	4.4	6.5	7.9	10.0	11.9	10.8
Hill's N2	2.2	2.7	3.6	4.7	7.5	8.7	7.7
Hill's E5	0.4	0.5	0.5	0.7	0.7	0.7	0.7

Table 3 Macroinvertebrate taxon list and total abundance

TAXON	Control burn		Experimental burn	
	1993	1994	1993	1994
NEMATODA			2	
Pisidium sp.				1
OLIGOCHAETA	22	6	14	10
Ameletus inopinatus	11	4		
Baetis rhodani	5			
Baetis muticus	3	2	9	
Heptagenia lateralis	3	18		
Leptophlebia marginata			16	19
Leptophlebia vespertina			20	61
Amphinemura sulcicollis	168	32	20	1
Nemoura avicularis				2
Nemoura cambrica			2	
Leuctra inermis	41	6	1	
Leuctra hippopus		1		
Leuctra nigra			1	
Isoperla grammatica	106	4	7	
Siphonoperla torrentium	109	48	23	5
Pyrrhosoma nymphula			1	1
Cordulegaster boltonii			1	
Dytiscidae undet. (larvae)				1
Oreodytes rivalis		36		
Oreodytes sanmarkii	18			
Elmis aenea	17			
Limnius volckmari	129	16	2	5
Oulimnius tuberculatus	55	22	151	98
Rhyacophila dorsalis	1			
Plectrocnemia conspersa	6	1	13	9
Plectrocnemia geniculata		2		1
Polycentropus flavomaculatus		2	23	6
HYDROPTILIDAE			38	
Hydroptila sp.		2		
Oxyethira sp.		1		29
LIMNEPHILIDAE undet.	10	7	66	2
TIPULIDAE	2	1	1	
Dicranota sp.	8	2	6	2
CHIRONOMIDAE	26	17	56	86
SIMULIIDAE	23		2	
Simulium latipes				3

Table 4 Macroinvertebrate summary statistics

Statistics	Cont. burn		Expt. burn	
	1993	1994	1993	1994
Total count	768	231	477	231
Total number of taxa	24	22	25	20
E(100)	17	17	18	14
Hill's N1	11.5	11.9	11.3	7.9
Hill's N2	8.4	9.0	6.9	5.4
Hill's E5	0.71	0.73	0.57	0.64
BMWP score	110	99	108	83
ASPT	6.4	6.6	6.4	5.5

Table 5 Aquatic macrophyte cover

Taxon	% cover of stream bed *						
	Control burn				Expt. burn		
	1992	1993	1994	1995	1993	1994	1995
Batrachospermum sp.	<0.1	0.7	<0.1	-	33.3	12.7	54.2
Marsupella emarginata var. *aquatica*	4.4	4.0	4.9	0.4	38.0	37.3	9.4
Scapania undulata	2.8	3.7	1.7	0.9	-	5.0	21.7
Racomitrium aciculare	0.3	<0.1	2.1	0.4	-	-	-
Juncus bulbosus var. *fluitans*	0.1	<0.1	-	-	2.6	9.0	2.7
TOTAL COVER (excluding filamentous algae)	7.6	8.4	8.7	1.7	73.9	64.0	88.0
Filamentous green algae	<0.1	10.7	<0.1	0.1	68.0	<0.1	-

* Control burn survey stretch = 50m length
Experimental burn survey stretch = 20m length

nb. Filamentous algae tends to form ephemeral blooms covering the more permanent macrophyte species and therefore for the purposes of monitoring the consistency of plant cover is excluded from the estimate of Total Cover.

Table 6 Fish population data for the experimental and control burns

		Trout population density (nos. m^{-2})								
		1993			1994			1995		
Site	Area fished	age 0+	age >0+	Tot	age 0+	age >0+	Tot	age 0+	age >0+	Tot
Control	115 m^2	0.25	0.14	43	0.35	0.02	46	0.33	0.05	45
Expt	32 m^2	0.97	0.13	34	0.14	0.28	15	0.34	0.03	13

Tot = the total number of fish caught in the survey stretch

Appendix 1 Water chemistry for the experimental and control burns

Control burn chemistry data																		
Date	pH	Alk	Cond	Na	K	Mg	Ca	Cl	NO3	SO4	PO4	TP	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	0.46	6.7	
18-Feb-94	6.34	61	39	210	6	66	101	211	2	41	0	5	14	14	0	0.13		0
01-May-94	6.03	37	24	141	9	34	56	123	0	25	0	10	44	36	8	0.31	4.4	0
12-May-94	6.48	66	29	161	6	48	82	143	0	30	0		27	22	5	0.21	3.2	0
10-Jun-94	6.39	60	39	201	9	68	110	174	0	85	1		34	30	4	0.28		0
08-Jul-94	5.98	45	27	151	6	52	83	111	0	35	1		80	80	0	0.63		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		35	28	7			0

Control burn chemistry data (continued)																		
Date	pH	Alk	Cond	Na	K	Mg	Ca	Cl	NO3	SO4	PO4	TP	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
22-Sep-94	6.5	88	29	152	6	56	119	123	0.00	23	1		43	26	17	0.385	7.5	0
29-Dec-94	5.18	7	23	108	4	30	31	126	1.00	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
27-Apr-95	6.61	87	24	133	8	43	81	107	0.00	20	0	2.5	16	16	0	0.204	4.8	0
02-Jun-95	6.38	62	26	137	4	41	75	103	0.10	18	3	3.0	57	29	28	0.49	9.9	0
15-Jul-95	6.65	89	40	178	9	75	128	127	1.60	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	1.90	37	1	2.5	21	20	1	0.262	5.6	0
04-Sep-95	6.51	72	46	188	7	90	157	118	0.00	175	0	6.0	37	34	3	0.313	7.6	0
24-Sep-95	5.72	26	34	156	5	66	99	108	0.20	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	2.40	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

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

Experimental burn chemistry data																	
Date	pH	Alk	Cond	Na	K	Mg	Ca	Cl	NO3	SO4	PO4	TP	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	0.41		
30-Oct-92	6.19	58	26	130	3	32	61	128	0	26	0		15	15	0	0.27	4.4	
06-Dec-92	5.23	9	19	93	2	14	27	88	0	23	0		27	27	0	0.26	3.4	
04-Jan-93	5.43	14	19	98	2	21	31	86	0	35	0		12	12	0	0.27	3.8	
30-Mar-93	5.86	28	41	230	5	44	64	296	1	45	2		12	9	3	0.17	2.9	
03-May-93	6.42	115	37	204	7	44	95	192	1	29	0		7	5	2	0.26	4.2	
18-Jun-93	6.33	122	37	202	4	44	100	156	0	16	0	19	28	19	9	0.51	8.2	
10-Jul-93	6.05	66	29	164	4	35	76	139	0	18	3	22	47	46	1	0.7	9.5	
25-Jul-93	5.71	42	29	156	2	42	73	130	0	12	3		57	48	9	0.86	13	
09-Aug-93	5.93	57	29	151	4	42	76	131	0	8	5		54	54	0	0.88		
22-Aug-93	6.36	142	33	186	6	60	108	159	1	14	3		30	28	2	0.65		
04-Sep-93	6.47	213	45	210	7	68	159	171	2	22	1		12	10	2	0.41		
29-Sep-93	6.6	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	6.3	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	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		21	18	3			0

Experimental burn chemistry data (continued)																		
Date	pH	Alk	Cond	Na	K	Mg	Ca	Cl	NO3	SO4	PO4	TP	Al-TM	Al-NL	Al-L	Abs-250	TOC	NH4
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	0.00	24	1		38	35	3	0.238	4.6	0
27-Mar-95	5.74	23	22	129	5	32	40	121	0.40	21	2	2.5	19	18	1	0.26	5.3	0
27-Apr-95	6.1	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	1.20	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	0.80	302	0	6.0	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	1.00	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

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

Appendix 2 Biology Sampling Dates

Sampling Year	1992*	1993	1994	1995
Fish		29th Sept	27th Sept	27th Sept
Macroinvertebrates		3rd May	12th May	no sample
Epilithic diatoms	15th Aug	29th Sept	25th Aug	25th Aug
Aquatic macrophytes	15th Aug	29th Sept	25th Aug	25th Aug

* Control burn only sampled in 1992