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Land-use experiments in the Loch Laidon catchment: Second Report on stream water quality

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Executive Summary

1. This report presents data for the first two 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 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. In the second year of monitoring (1993), cattle were introduced to the experimental catchment over the summer grazing season. This was repeated in 1994.

4. To date, there is no clear evidence of chemical or biological change in the experimental burn which can be attributed to the introduction of cattle.

5. Elevated concentrations of certain chemical determinands in both catchments, coincident with the first grazing period, demonstrate the importance of the control in the assessment of cause and effect in the experimental catchment. 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 fully 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 reintroduction 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 two 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.

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 although the stock was 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 collected to date is not appropriate given the short period of study to date.

Results for water chemistry, monitored regularly since August 1992, are presented in time series graphs (Figures 3-11), with individual determinands for both burns plotted on the same axes. The summer grazing periods of 1993 and 1994 are indicated by arrows on the time axis which define when cattle were introduced (ON) and removed (OFF) from the experimental catchment. In order to relate the determinand concentrations of the experimental burn to the control burn, each figure includes a time series of the ratio of the former to the latter. These ratios provide some indication of the similarity of the chemistry of the two sites throughout the course of the experiment. However, caution should be exercised in their interpretation, especially given the short period of monitoring to date, and since physical differences between the two stream catchments, eg. catchment size, is likely to effect differences in response to rainfall and other climatic seasonal variables and thus influence the ratio.

Biological data is presented in similar format to the previous report.
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 for the control and experimental burns is presented for the periods 1/10/92 - 30/9/93 and 1/10/93 - 30/9/94 in Table 1. Variation in the principal determinands and their ratios are shown graphically in Figures 3-11.

Figure 3 demonstrates the close relationship between the temporal variation in acidity of the two burns. However, in almost all samples the pH of the control burn is slightly higher than that of the experimental burn. Interestingly, the only two samples where the experimental burn is less acid than the control were taken during periods of grazing. It is evident that the first of these was taken as both burns were recovering from low pH conditions. It is likely the ratio in this case simply reflects a shorter lag time of recovery of the more flashy experimental burn. However, the second of these samples, where the difference is more considerable, is more difficult to explain and a possible "grazing effect" cannot be ruled out. In addition, peaks are apparent in the ratios for alkalinity (Figure 4), calcium (Figure 6) and conductivity (Figure 5) during the two grazing periods, although the presence of an earlier peak (before the onset of grazing) in each case makes interpretation difficult at this stage. The period immediately before and during the first grazing period in Figure 4, demonstrates the importance of a control in this project; without reference to data from the control site the impact of grazing on the alkalinity of the experimental burn would have apparently been considerable.

The period of monitoring is currently too short to permit any detailed statistical examination of the significance of differences between sites or changes through time.

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 three years at the control burn and the last two years at the experimental burn.

Given the inherent seasonal and year to year variability of stream biota, it is inappropriate at this time to comment either on the significance of differences between the assemblages of the two burns or on the significance of any change in the flora of the experimental burn. The summary statistics show that the sample from the experimental burn contained 50% more diatom species in 1994 compared with the previous year. However this is at least partly accounted for by the larger sample size in the second year. The 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 very similar. A noticeable difference between 1993 and 1994 at the experimental site is the virtual disappearance of *Synedra minuscula*, a species which has remained common at the control site. This species is usually considered indicative of circumneutral (ie. close to pH 7) conditions. Further years of sampling are required before the significance of this apparent change can be evaluated.

Aquatic Macrophytes

The percentage macrophyte cover for a designated survey stretch of each burn is presented in Table 3. The similarity in the macrophyte flora of the two sites is clear although the total plant cover is considerably greater in the experimental burn. Filamentous algae, the presence of which is dependent on such factors as antecedent stream flow and time of year is much less abundant in 1994 at both sites. At the experimental site, the most noticeable differences in 1994 compared with 1993 concern the recording of the occurence of the ubiquitous, acid tolerant liverwort, *Scapania undulata* and an increase in the cover of *Juncus bulbosus*. Neither observations imply any change in water quality.

Macroinvertebrates

Macroinvertebrate data is presented in Table 4 and the summary statistics in Table 5. As in 1993, the macroinvertebrate population of the two burns in 1994 are similar in terms of both species representation and relative abundance. The most apparent difference between the two sites is the high abundance of two *Leptophlebia* (a genus of mayfly) species in the experimental burn which are absent from the control. There are no clear changes in the abundance of this group within the experimental burn, between years. The absence of plecopterans (stoneflies) of the family Leuctridae (a high scoring family in the BMWP system) largely accounts for the lower BMWP score at the experimental site in 1994. It should be noted that the BMWP score for the control site is also reduced in 1994.

Fish Populations

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 were very similar in 1993 and 1994. However, it appears that recruitment in the experimental burn was poorer in 1994 than in the previous year with only half the number of fish being caught. As with the other biological groups it is not yet possible to draw any conclusions on the possible effect of grazing on the trout population of the experimental burn.

Discussion

With only a single year of data available since the introduction of grazing it is too early to draw any significant conclusions from the grazing experiment. However, some observations can be made.

(1) The data reinforce the findings of the previous report that, despite some physical differences between the two burns, they exhibit very similar chemical and biological properties and similar seasonal variation in chemistry.

(2) The grazing period in the experimental burn catchment is relatively short and it seems unlikely, at least at such an early stage in the experiment, that the introduction of cattle will have a year round influence on the water chemistry of the burn. Any effect is likely to be ephemeral at first, and changes will be best detected by comparisons between the chemical regime of the burns immediately before and during the grazing period. Visual inspection of the time series graphs for pH, conductivity, calcium and alkalinity reveals a possible "during grazing" effect, in 1994 although this is based on one water sample only. No further significance can be placed on these observations at this time.

(3) For the most effective examination of trends in time series chemical data, water samples should be taken at a consistent interval, ideally on a monthly basis. In addition, more frequent sampling of both sites, over the period of grazing, would allow a greater insight into the immediate, short term impact of cattle.

(4) There is little evidence in the biological data of any significant change with time at either burn. A possible exception is the apparent reduction in newly recruited brown trout in the experimental burn in 1994. However, the difference in fish population estimates between years is well within the limits of annual variation observed in upland streams thought to be little affected by anthropogenic impacts (eg. see fish population data for Allt a'Mharcaidh (Monteith *et al.* 1994)).

(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 suphur emmisions 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.

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

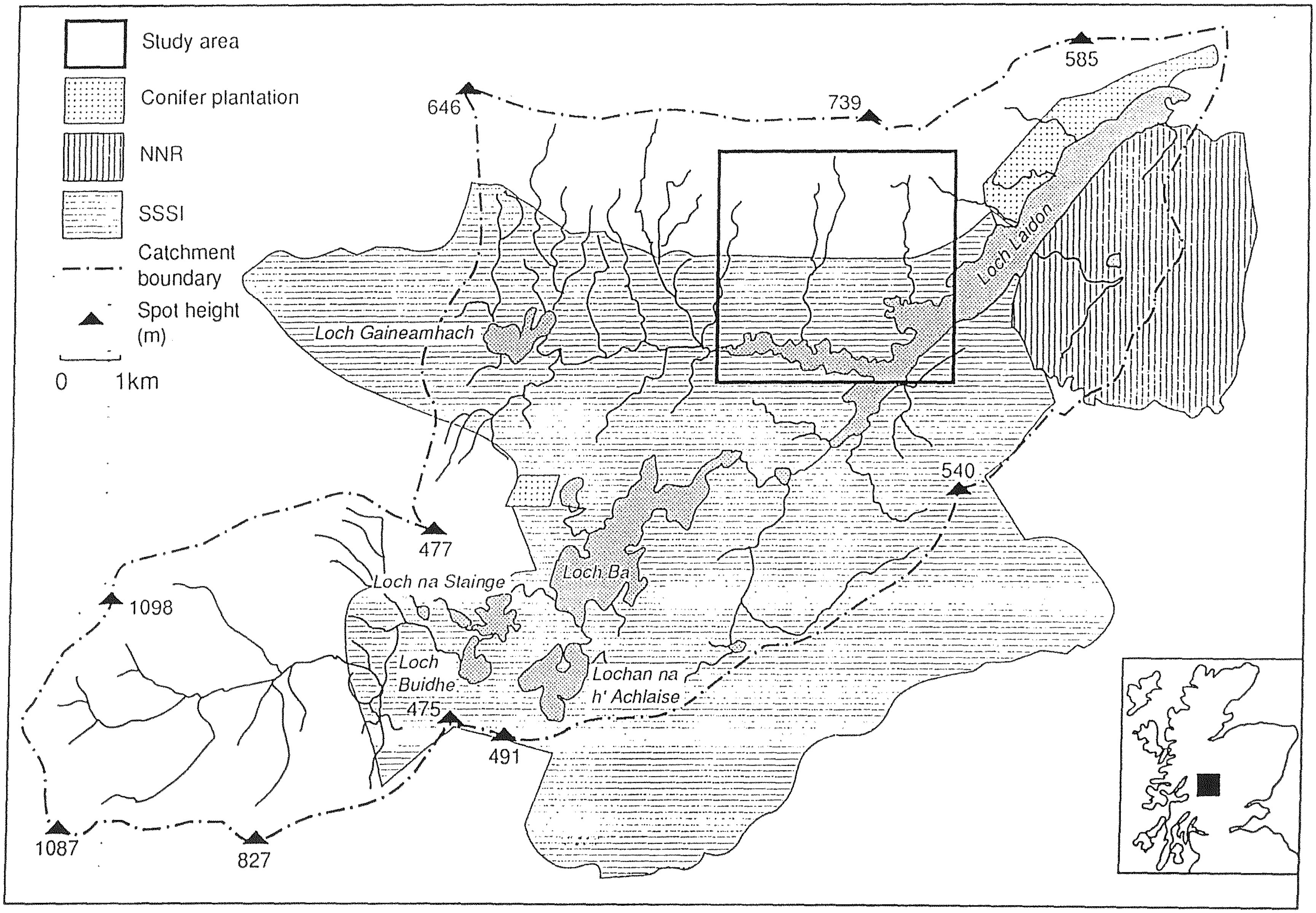

Figure 2: Loch Laidon study area

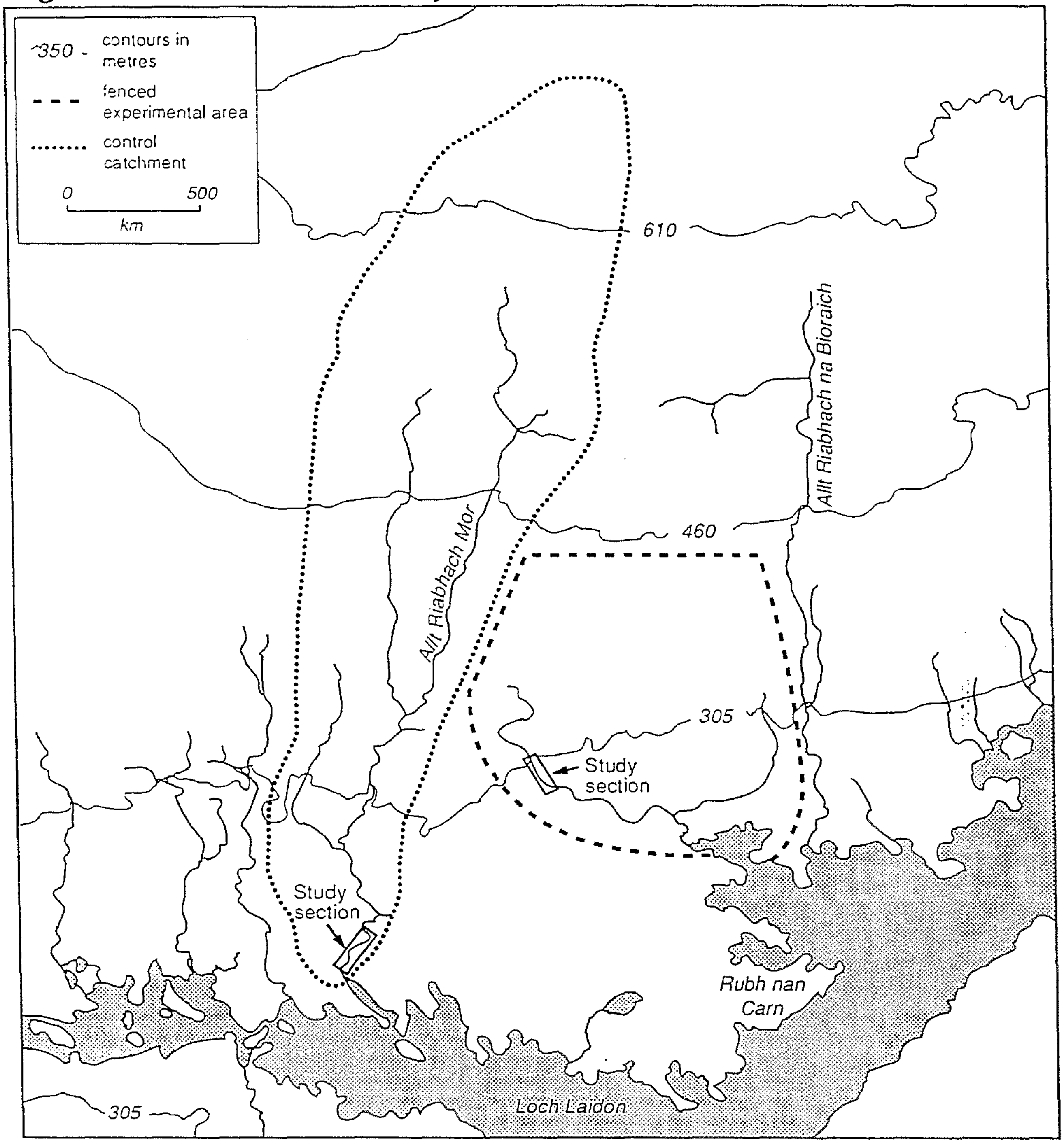

Figure 3 The ratio of H^+ concentration and the temporal variability of pH of spot samples from the experimental and control burns, and their H^+ ratio, August 1992 - September 1994.

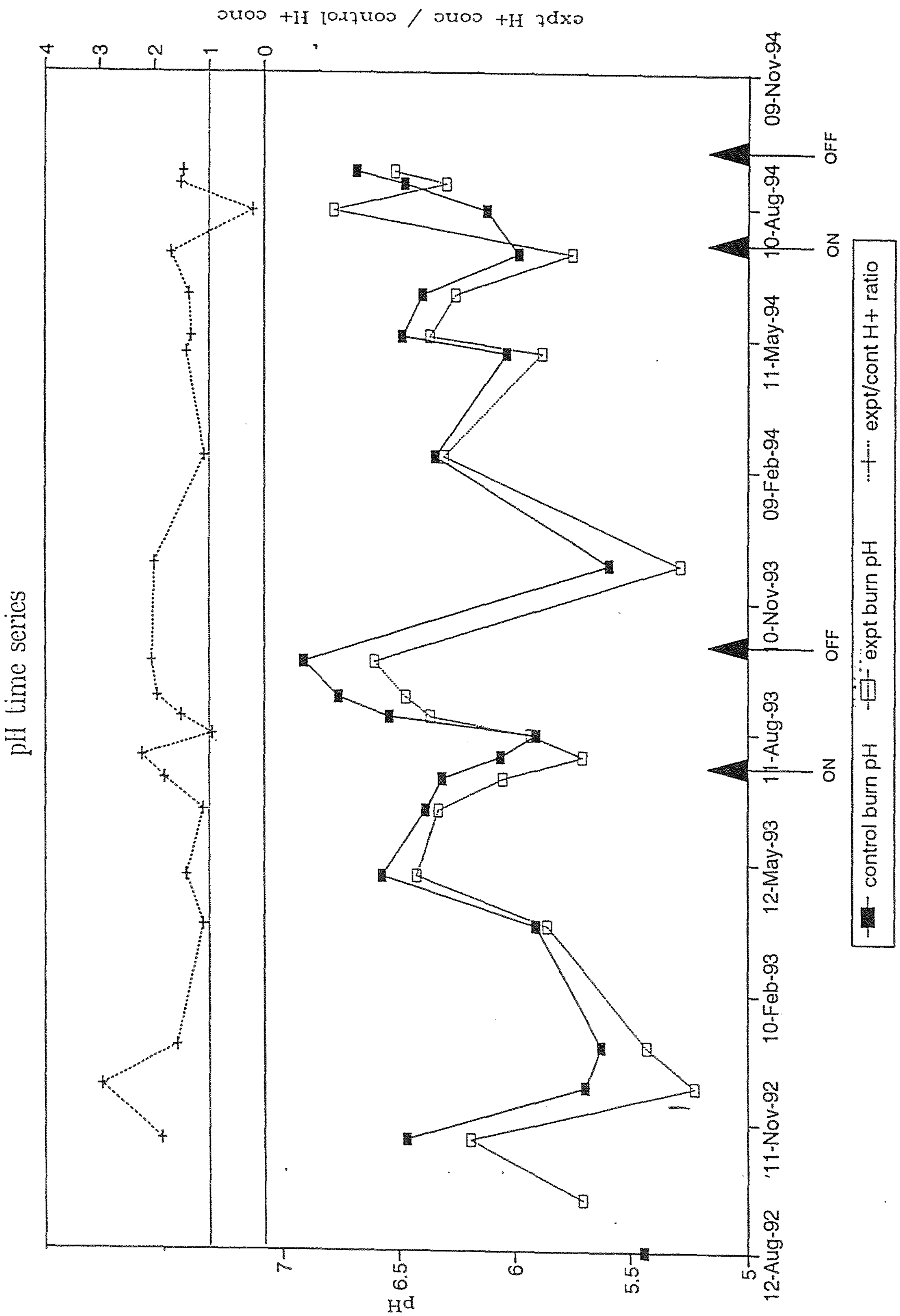

Figure 4 The ratio of alkalinity and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1993

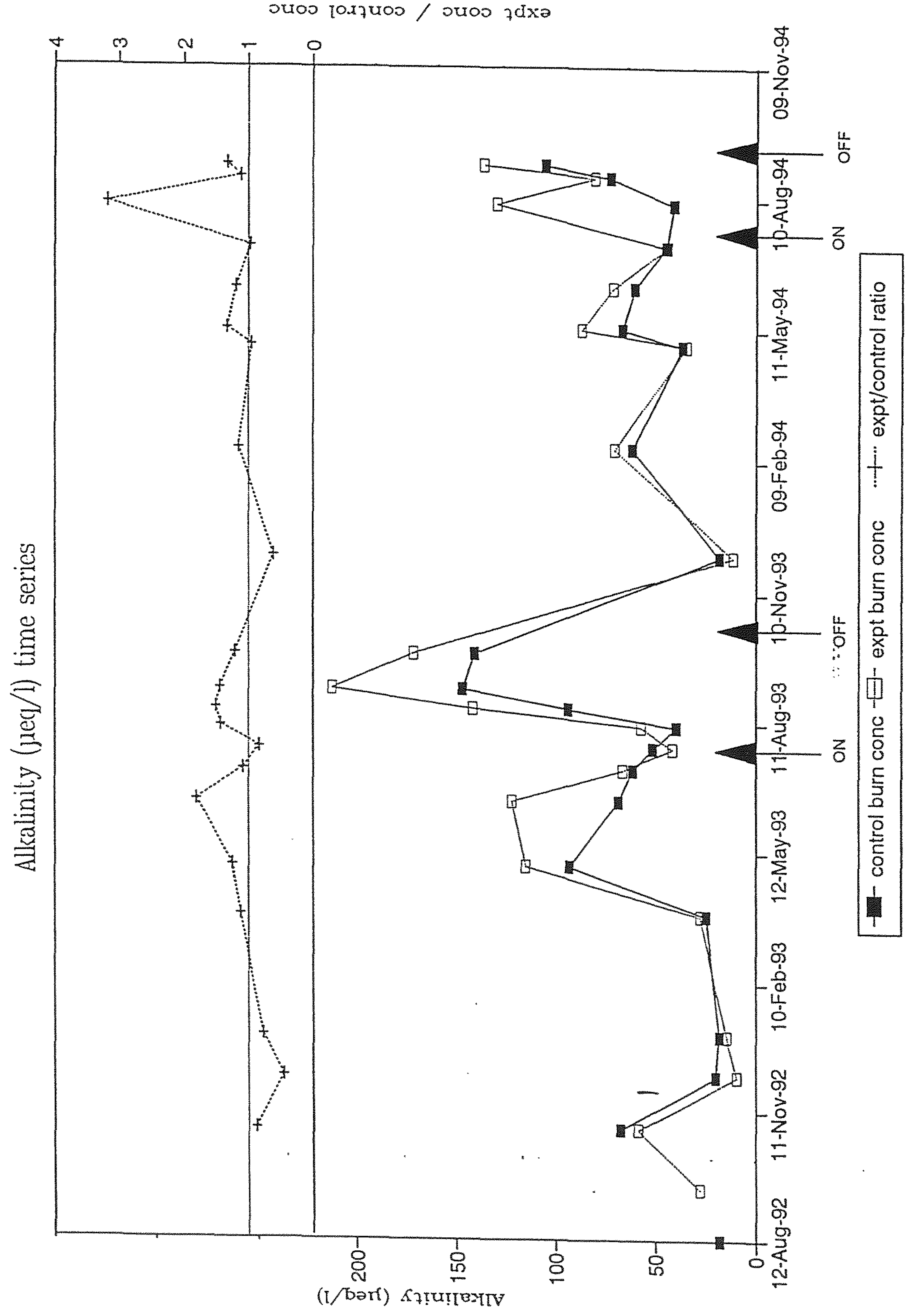

Figure 5 The ratio of conductivity and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994

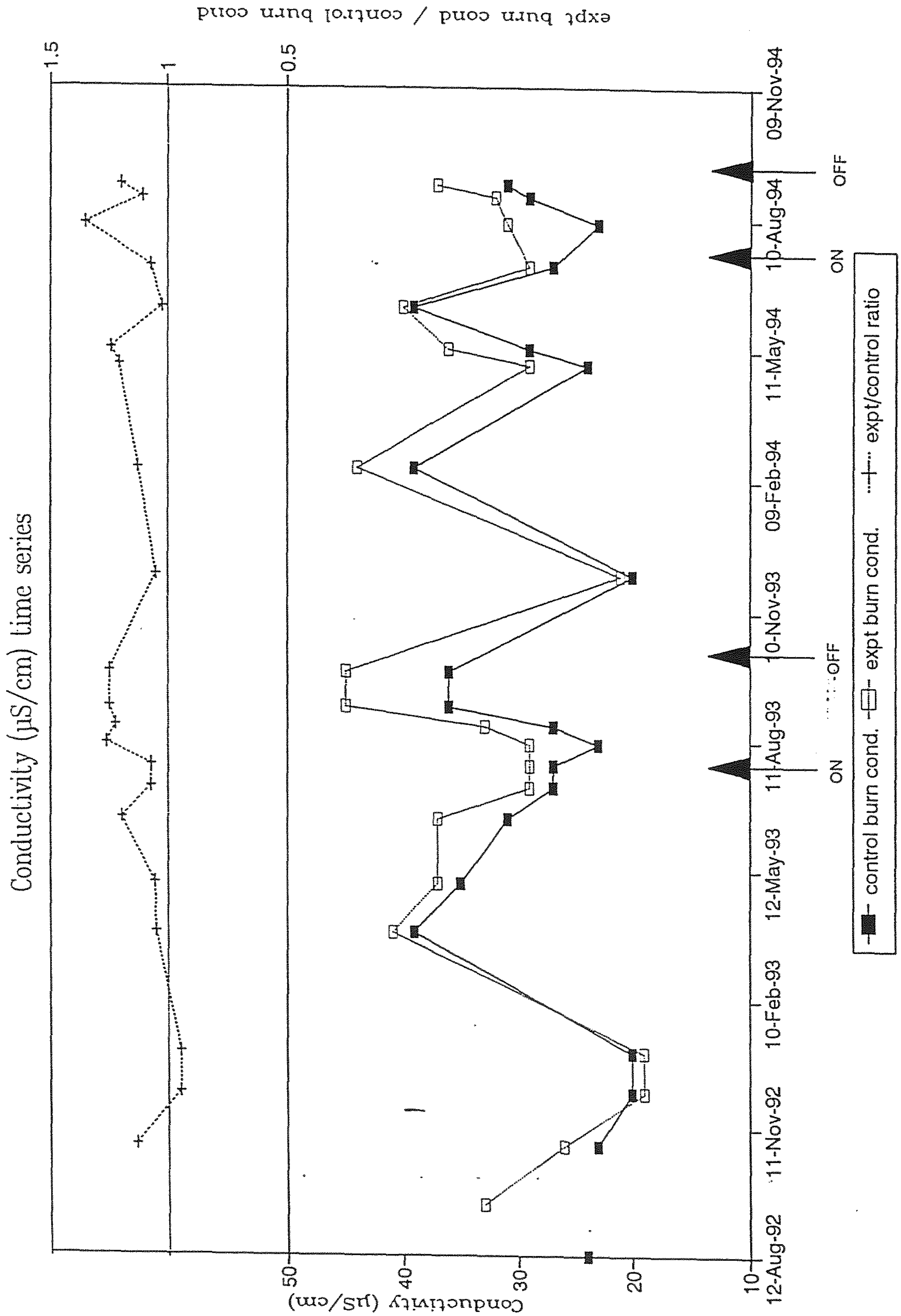

Figure 6 The ratio of calcium and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994

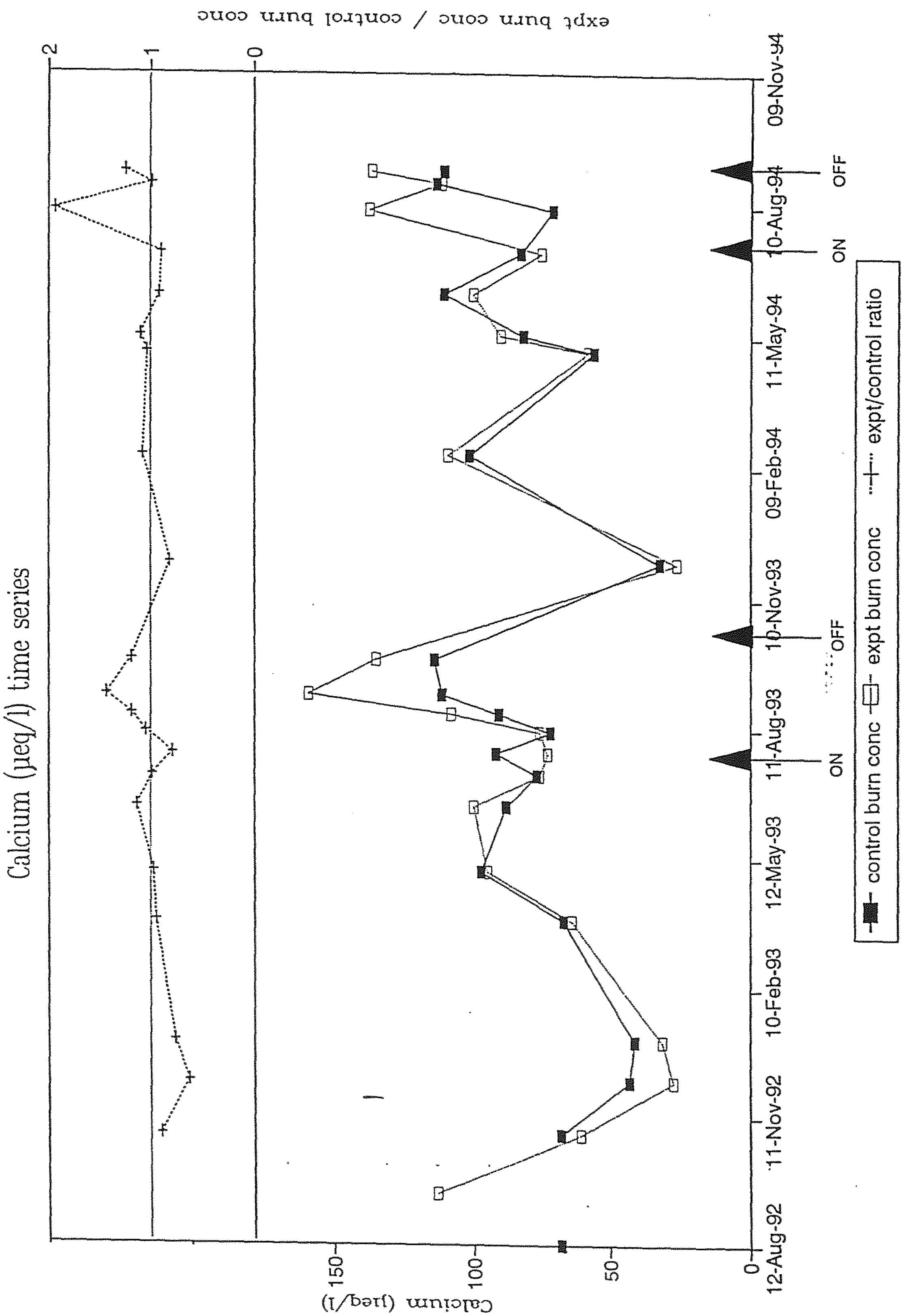

Figure 7 **The ratio of chloride and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994**

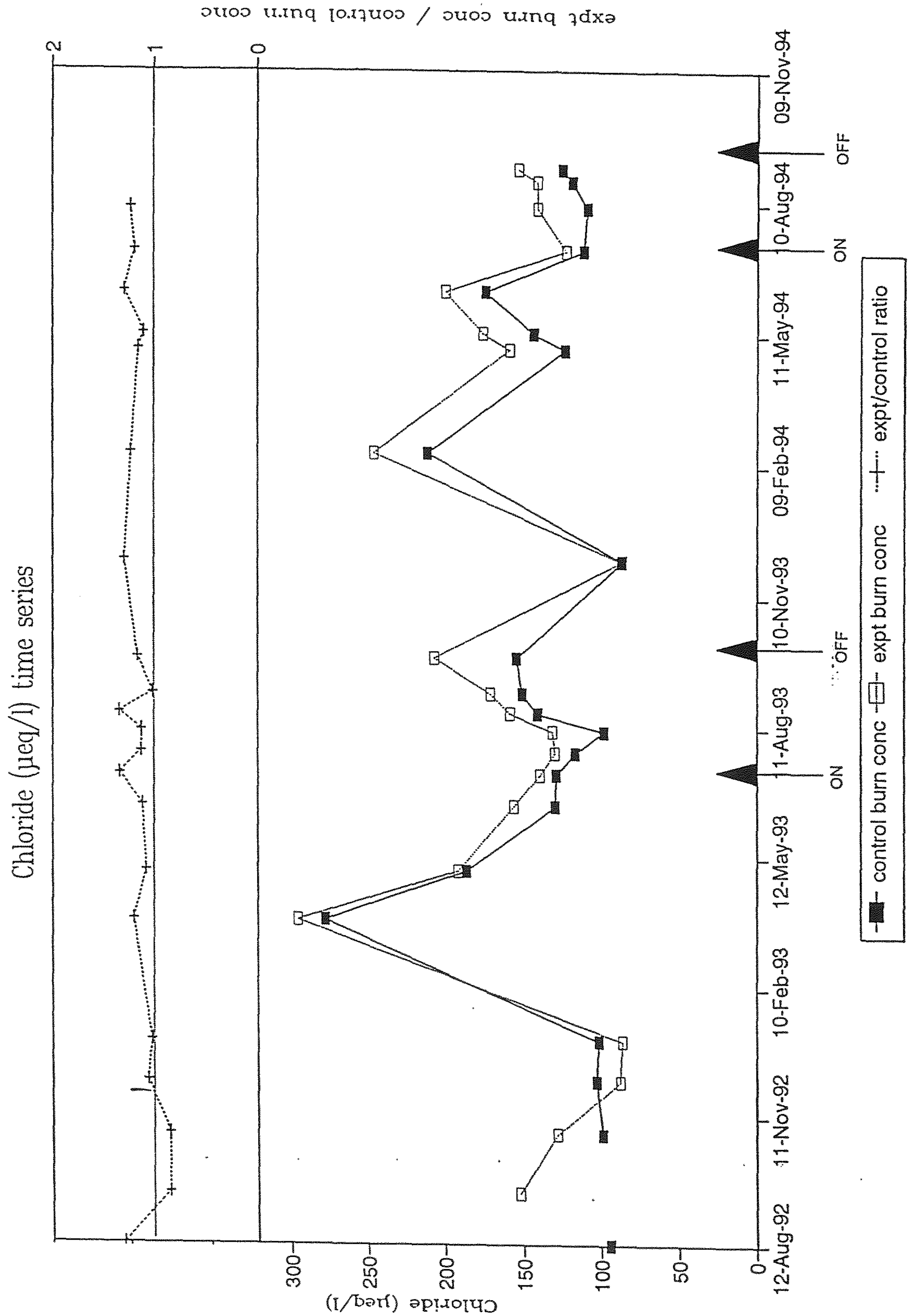

Figure 8 The ratio of sulphate and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994

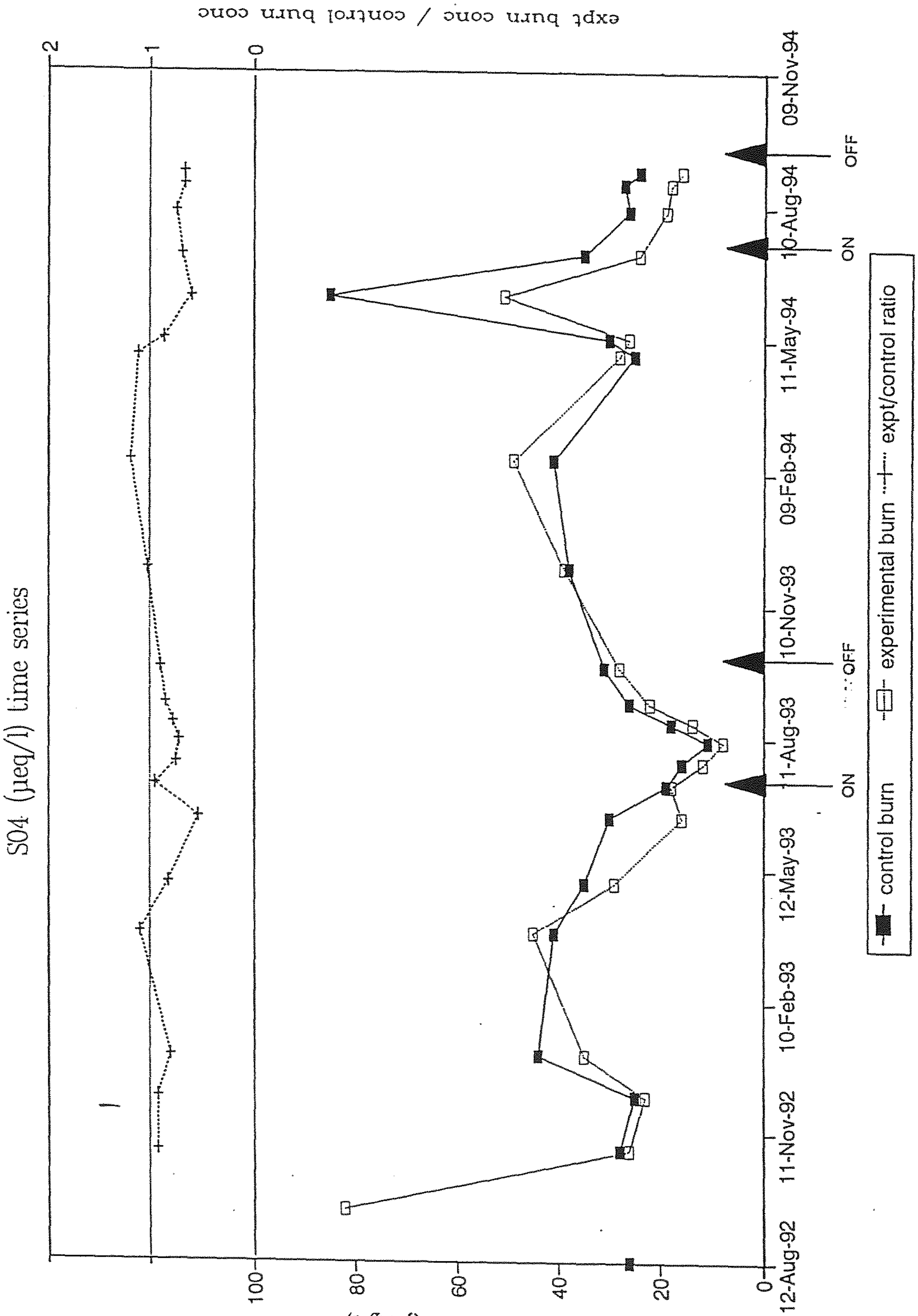

Figure 9 **The ratio of total monomeric aluminium and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994**

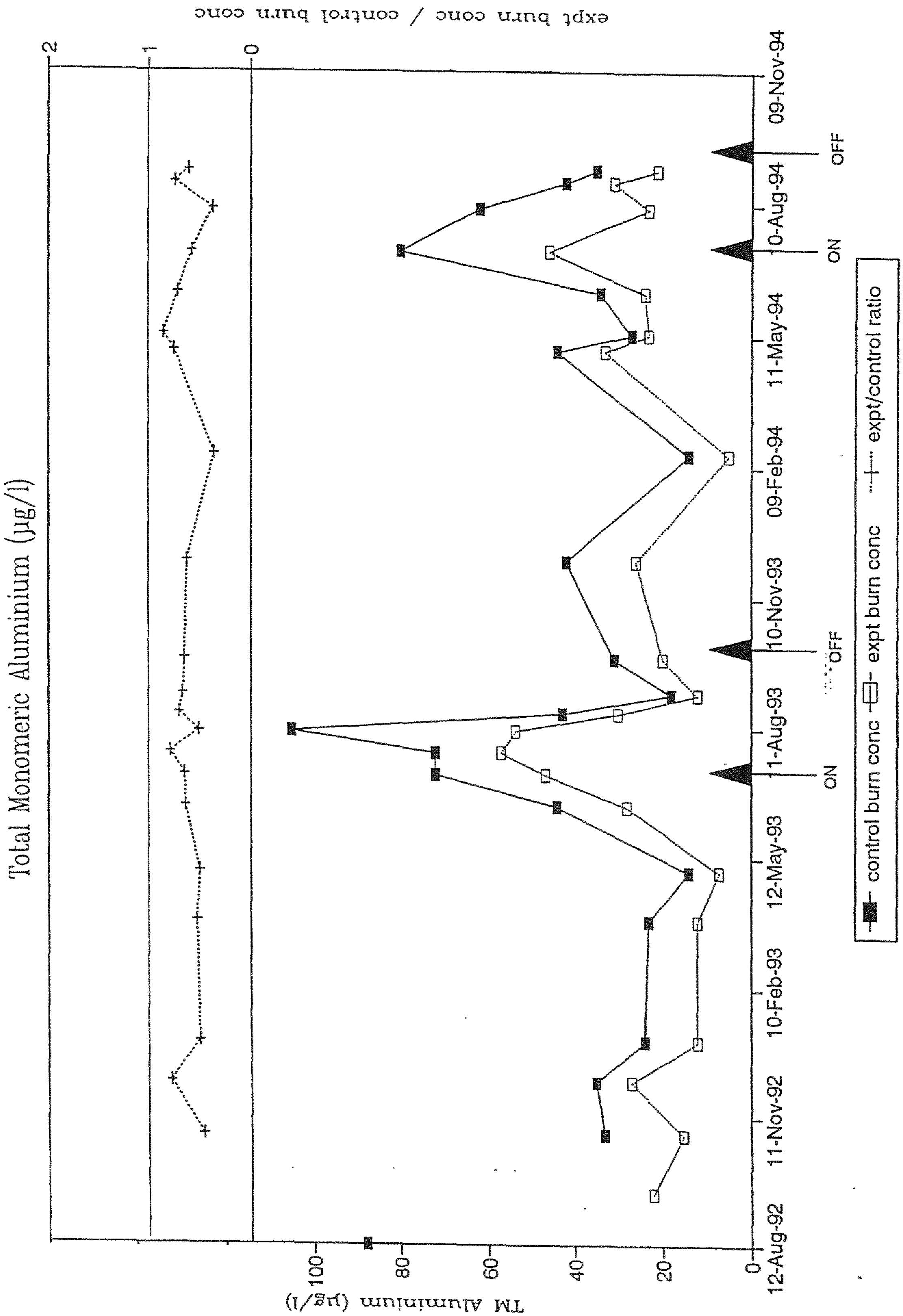

Figure 10 **The ratio of phosphate and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994**

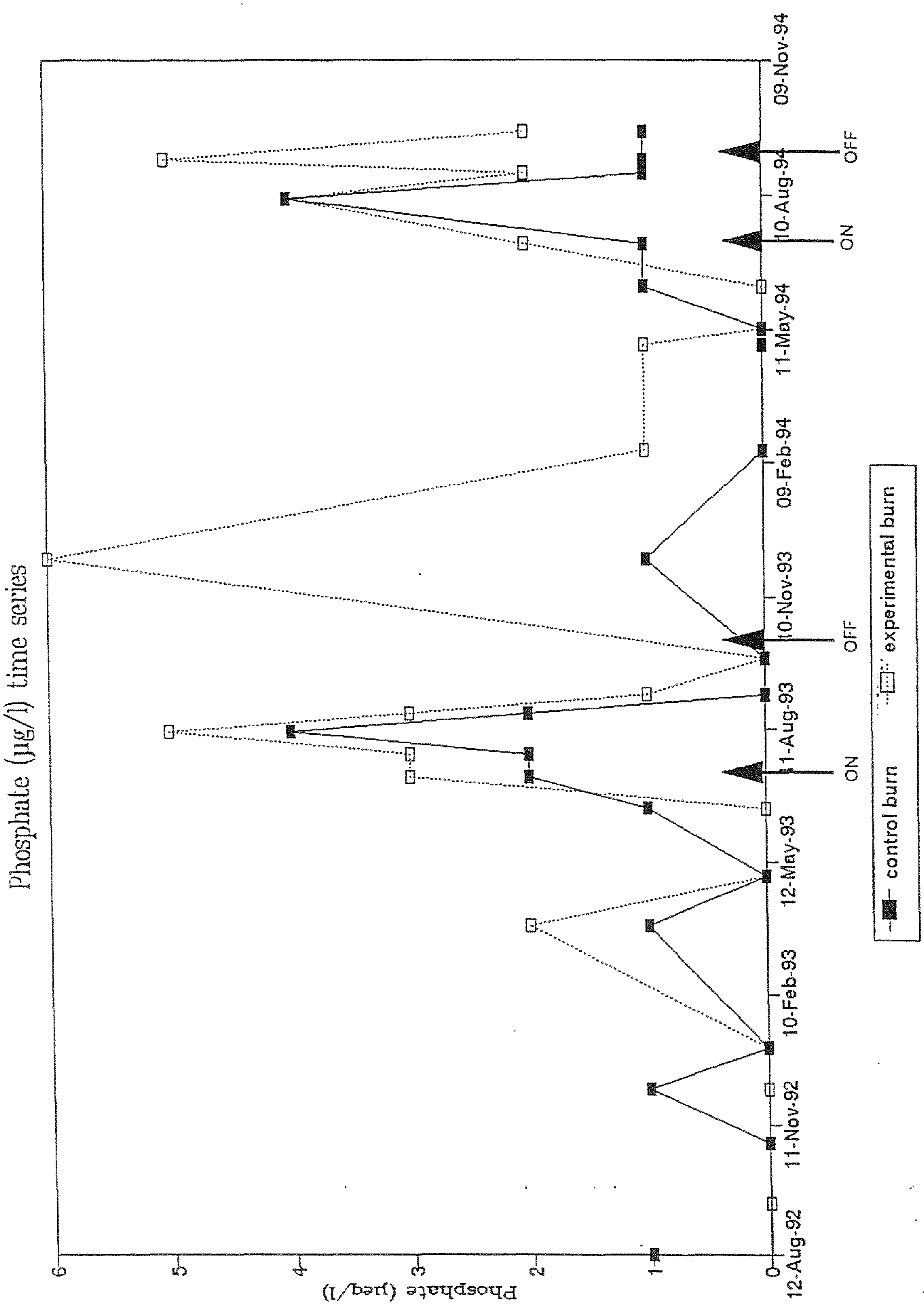

Figure 11 The ratio of Absorbance (250nm) and its temporal variability in spot samples from the experimental and control burns, August 1992 - September 1994

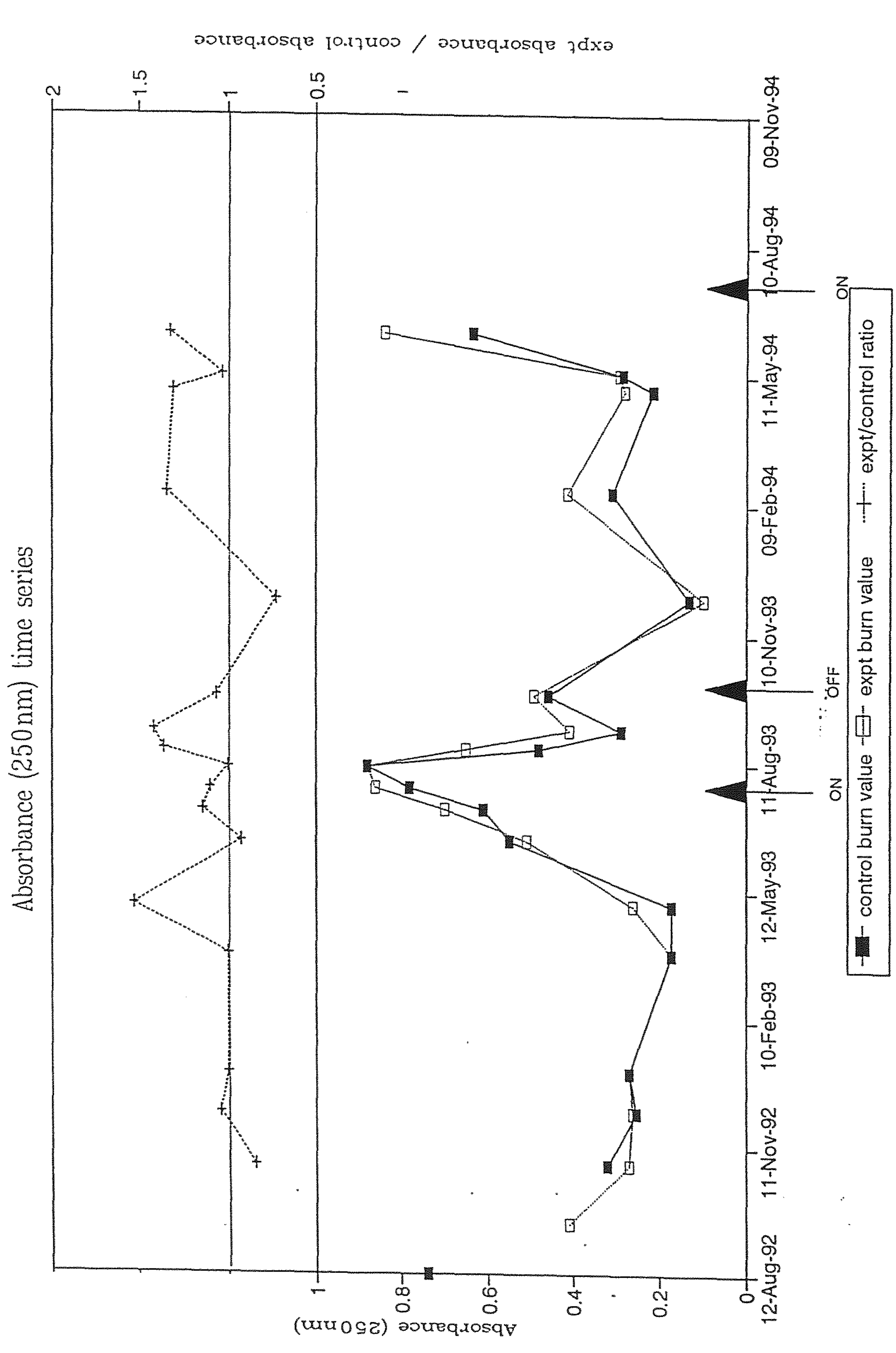

Table 1 Summary of chemical determinands

	Control burn						Experimental burn					
	1/10/92 - 30/9/93			1/10/93 - 30/9/94			1/10/92 - 30/9/93			1/10/93 - 30/9/94		
Determinand	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	5.84	5.23	6.60	5.92	5.29	6.78
Alk $\mu eq\ l^{-1}$	69	18	147	56	18	105	86	9	213	74	11	136
Cond $\mu S\ cm^{-1}$	28	20	39	29	20	39	33	19	45	33	21	44
Na $\mu eq\ l^{-1}$	143	104	203	158	99	210	169	93	230	188	105	243
K $\mu eq\ l^{-1}$	4.4	3.0	7.0	6.2	4.0	9.0	5.1	2.0	15.0	6.7	3.0	13.0
Mg $\mu eq\ l^{-1}$	37	17	47	51	25	68	43	14	68	61	24	81
Ca $\mu eq\ l^{-1}$	80	41	114	84	32	113	84	27	159	94	26	137
Cl $\mu eq\ l^{-1}$	141	98	278	133	86	211	157	86	296	158	87	246
NO_3 $\mu eq\ l^{-1}$	0.2	0.0	2.0	0.6	0.0	2.0	0.6	0.0	2.0	0.6	0.0	1.0
SO_4 $\mu eq\ l^{-1}$	27	11	44	37	24	85	23	8	45	30	17	51
PO_4 $\mu g\ l^{-1}$	1.1	0	4	1.0	0	4	1.4	0	5	2.3	0	6
TMAl $\mu g\ l^{-1}$	43	14	105	42	14	80	27	7	57	26	5	46
NLAl $\mu g\ l^{-1}$	37	9	92	39	14	80	24	5	54	23	5	45
LAl $\mu g\ l^{-1}$	6	0	29	4	0	8	2	0	9	3	0	7

For sampling period 1/10/92 - 30/9/93 N = 12 For sampling period 1/10/93 - 30/9/94 N = 9
Alk = Alkalinity ($CaCO_3$), Cond = Conductivity TMAl = Total monomeric Aluminium
NLAl = Non labile monomeric Aluminium LAl = Labile monomeric Aluminium

Table 2 Diatom taxon list, percentage frequency and summary statistics

TAXON	% abundance of taxa (> 1%)					
	Control burn			Expt burn		
	1992	1993	1994	1993	1994	
Brachysira brebissonii				1.3		1.
Brachysira vitrea 15.9	10.7	7.3	6.9	20.1	8.6	2
Cymbella lunata 1.5				1.6	1.0	
Eunotia curvata var. *curvata*					1.6	
Eunotia exigua var. *exigua* 2.0	2.7	1.6	4.5	3.1	3.4	1
Eunotia incisa 1.8	1.6	1.4	3.8	3.8	7.4	–
Eunotia naegelii		1.1		6.6	9.4	
Eunotia pectinalis var. *minor* 2.0	2.0		6.0	6.0	15.0	2
Eunotia rhomboidea			1.2		1.0	3
Eunotia sp.			1.2			1
Frustulia rhomboides var. *saxonica* 1.3	1.0			6.0	7.4	2
Frustulia rhomboides var. *viridula*					1.3	
Gomphonema gracile	1.5				1.2	
Gomphonema minutum	1.0					
Peronia fibula 4.7	2.7	1.2	2.4	22.3	15.6	8
Synedra minuscula 25.9	8.2	55.4	19.9	8.8		
Tabellaria flocculosa var. *flocculosa* 34.3	65.8	24.9	47.6	15.7	19.9	–
Achnanthes minutissima 1.28						1.5
SUMMARY STATISTICS						
Total count	983	1009	1047	320	672	
Total number of taxa	24	28	34	22	33	
Hill's N1	4.0	4.4	6.5	10.0	11.9	
Hill's N2	2.2	2.7	3.6	7.5	8.7	
Hill's E5	0.4	0.5	0.5	0.7	0.7	

Table 4 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 5 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 6 Aquatic macrophyte cover

Taxon	% cover of stream bed *				
	Control burn			Expt. burn	
	1992	1993	1994	1993	1994
Batrachospermum sp.	<0.1	0.7	<0.1	33.3	12.7
Marsupella emarginata var. *aquatica*	4.4	4.0	4.9	38.0	37.3
Scapania undulata	2.8	3.7	1.7	-	5.0
Racomitrium aciculare	0.3	<0.1	2.1	-	-
Juncus bulbosus var. *fluitans*	0.1	<0.1	-	2.6	9.0
TOTAL COVER (excluding filamentous algae)	7.6	8.4	8.7	73.9	64.0
Filamentous green algae	<0.1	10.7	<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 7 Fish population data for the experimental and control burns

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

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

Appendix 1 Water chemistry for 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

All units in µeq l^{-1} except pH, cond (conductivity µS cm^{-1}), Al-TM, Al-NL, AL-L and PO_4 (µg/l), TOC (Total Organic Carbon mg l^{-1}) and Abs-250 (absorbance at 250nm)

Appendix 1 continued

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

All units in μeq l^{-1} except pH, cond (conductivity μS cm^{-1}), Al-TM, Al-NL, AL-L and PO_4 (μg/l), TOC (Total Organic Carbon mg l^{-1}) and Abs-250 (absorbance at 250nm)

Appendix 2 Biology Sampling Dates

Sampling Year	1992*	1993	1994
Fish		29th September	27th September
Macroinvertebrates		3rd May	12th May
Epilithic diatoms	15th August	29th September	25th August
Aquatic macrophytes	15th August	29th September	25th August

* Control burn only sampled in 1992