Project 001

Interim Report **R&D Project 001**

Sources of Farm Pollution and Impact on River Quality

WRc plc

April 1992

R&D 001/6/W

SOURCES OF FARM POLLUTION AND IMPACT ON RIVER QUALITY

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This report is the result of work jointly funded by the National Rivers Authority and the Scotland and Northern Ireland Forum for Environmental Research.

Dissemination status
Internal: Released to Regions
External: Restricted

Research contractor
This document was produced under R&D Contract 001 by:

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WRc Report No. NR 3063/4206

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EXECUTIVE SUMMARY

This project is concerned with providing the NRA and regulatory authorities in Scotland and Northern Ireland with practical tools for the assessment and control of organic pollution from livestock farming. Under the auspices of the NRA, the project has run from September 1989 and is due to be completed in September 1992. The emphasis of the work is on the use of biological monitoring techniques as a simple and rapid means of highlighting and assessing water quality problems. This report describes work undertaken between 1 October 1991 and 31 March 1992.

Nearly 150 sites, previously assessed in an extensive survey in West Wales, have been revisited using the biological indicator key approach developed under this project. The results are to be analysed to assess the efficacy of remedial measures on key polluting farms; however, owing to resourcing problems within the pollution control function, much necessary remedial work has not been undertaken. Samples are being processed to produce an indicator key for use in summer, to complement the spring key. The indicator key developed in NRA South West Region, to assess the usefulness of the approach in other regions, has been refined through the identification of macroinvertebrates down to genus or species level. The improved key appears to be more useful and it is recommended that future keys are similarly produced. The rapid appraisal technique is being tested in Yorkshire and North West regions, in high risk catchments selected using the computerised database on farm pollution risk developed under this project. Intensive chemical and biological monitoring of the Nant Pibwr, a stream known to have been polluted by yard drainage, revealed no major impact. This was thought to be due to the high dilution in the stream and successful remedial measures. Work has continued on monitoring salmonid recolonisation following acute farm pollution incidents.

KEY WORDS:

Farm, livestock, organic pollution, monitoring, indicator, invertebrates, water quality, salmonids.

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1. INTRODUCTION

The WRc farm pollution research programme was initiated in 1987 in response to widespread concern over the increasing number of farm pollution incidents. Studies initially concentrated on intensive monitoring of tributaries of the Eastern Cleddau, a catchment in West Wales, to investigate the impact of intensive dairy farming on river quality. Work undertaken in this catchment has been documented in Schofield (1988) and Schofield and Bascombe (1990).

The funding of the farm pollution programme was taken over by the NRA and SNIFFER in 1989, who have extended the scope of the work to provide nationally applicable tools for farm pollution assessment and control. The research is still targeted at the problems arising from organic farm wastes originating from livestock farming.

This report documents progress made under NRA Project Reference 001 (A3.001/A3.012) between October 1991 and March 1992. Previous work undertaken within this project has been reported in two earlier interim reports (Mainstone *et al* 1991; Rutt *et al* 1991).

2. PROJECT DESCRIPTION

2.1 Objectives

The overall objective of the work programme is:

To develop biological methods for the detection of organic pollution from farms and for assessing the effectiveness of remedial measures.

This overall objective has been broken down into the following specific objectives:

1. To identify through biological assessment the principal sources of organic pollution from farms and quantify their impact on water/biological quality and fishery status of receiving streams.

2. To identify farming practices causing pollution and assess the effectiveness of remedial measures using biological methods.

3. To develop a strategy within the NRA, using biological techniques, for the future monitoring and control of the farm pollution problem.

2.2 Work programme

There are a number of aspects to the programme of work, which can be summarised as below:

1. Literature review of farm pollution assessment and control;

2. National assessment of the farm pollution problem;

3. Development of rapid biological assessment techniques;

4. Detailed site investigations;

5. Implementation of remedial measures;

6. Salmonid recolonisation studies;

7. Slurry transport studies;

8. Biological recovery of streams using simulated pollution events.

A number of these topics have been reported in full in Mainstone *et al* (1991). Work has continued mainly on items (3), (4) and (6).

3. THE USE OF THE RAPID APPRAISAL METHOD IN WALES

3.1 Introduction

An earlier interim report (Mainstone *et al* 1991) detailed the development of an indicator key for use in the assessment and detection of organic pollution from agriculture in West Wales. The key is based upon assessment of the abundance of four invertebrate indicator taxa and sewage fungus cover. It is rapid in operation and is intended as a bankside means of rapidly pinpointing pollution sources, forming part of a coordinated pollution control programme (Seager *et al* in press).

As described in the last interim report (Rutt *et al* 1991), a large scale evaluation exercise was carried out in West Wales involving the sampling of 146 sites in fifteen catchments. As a result, 47 farms were highlighted as causing pollution and these were then reported to the NRA Agricultural Liaison Officer. He carried out a programme of farm visits aimed at identifying pollution sources and agreeing the necessary remedial measures with the farmers concerned.

Ninety-nine of the 146 sites were kick-sampled in July 1991 (Rutt *et al* 1991) to enable the development of a summer indicator key to compliment the winter/spring version.

3.2 Progress to date

3.2.1 Farm visits

The programme of farm visits began on 26 March 1991; however, initial progress was slow with only half of the farms visited by 30 August 1991. In view of the slow progress it was decided that the eight farms identified in the Millin Brook catchment would not be covered, and by 13 December 1991 all of the remaining 39 farms had been visited (Table 3.1). However, although remedial action had been agreed for all thirty farms where it was found to be necessary, work had only been completed at ten by 12 February 1992.

The 146 sites included in the initial survey were re-examined in February and March 1992 using the bankside indicator system. The results have yet to be analysed, but in view of the poor progress with remedial work on the farms it may be that significant improvements in biological quality will not be evident at many sites.

3.2.2 Summer indicator key

Of the 99 sites sampled in July 1991, 50 sites were selected so as to ensure a range of pollution impact and geographical area. To date 27 samples have been processed to species/genus level. The remaining samples will be processed in April 1992 and the data analysed by TWINSPAN classification to produce the required indicator key.

Table 3.1 Progress with programme of farm visits as of 12 February 1992

Figures on the left hand side of the slash refer to the number of farms found to have a definite discharge, figures to the right hand side refer to farms where pollution was possibly occurring.

	Polluting Farms (Definite/possible)	Number visited	Problems identified	Remedial Action agreed	Work carried out
AREA A					
1. Millin Brook	6/2	0/0	0/0	0/0	0/0
2. Fenton Brook	4/-	4/-	3/-	2/-	0/-
3. Cartlett Brook	2/-	2/-	2/-	2/-	2/-
4. Slade Brook	1/-	1/-	1/-	1/-	1/-
5. Rhydyfallen Stream	1/-	1/-	1/-	1/-	1/-
6. Llanycefn Brook	2/-	2/-	2/-	2/-	0/-
7. Nant Duad	4/5	4/5	3/2	3/2	0/0
AREA B					
8. Nant Cou	2/2	2/2	2/2	2/2	1/0
9. Nant Cwerchyr	1/1	1/1	1/0	1/-	1/-
10. Afon Peris	1/-	1/-	1/-	1/-	0/-
AREA C					
13. Nant Pibwr	3/1	3/1	2/0	2/-	0/-
14. Nant Rhydw	5/4	5/4	5/4	5/4	2/2
TOTAL	32/15	26/13	22/8	21/8	8/2
(cf. as at 30.08.91	32/15	18/6	15/2	8/1	0/1)

4. APPLICATION OF THE RAPID APPRAISAL METHOD IN NRA SOUTH WEST REGION

4.1 Introduction

The last interim report (Rutt *et al,* 1991) described the development of an indicator key for use in the rapid assessment of farm pollution in NRA South West Region. The methodology employed was similar to that used by Mainstone *et al,* (1991) to develop an indicator key for West Wales. TWINSPAN classification of the macroinvertebrate data was undertaken only at the 'family' level due to time constraints and it was recommended that further analysis should be carried out with taxa grouped at genus or species level. It was suggested that the greater taxonomic detail might yield a more discriminating key which would be more valuable in the pollution control strategy for which it was developed (Seager *et al* in Press).

4.2 Progress to date

4.2.1 Site selection

The site selection process and study area are fully described in Rutt *et al* (1991). Fifty-one sites within six catchments in Devon were selected (Figure 4.1) in accordance with criteria used in West Wales. Sites were selected so as to ensure a range of pollution impact, pollutant type and geographical location.

4.2.2 On site methods

Fieldwork was carried out between 25 February and 12 March 1992. The methodology was fully described in Rutt *et al* (1991) and followed that of Mainstone *et al* (1991). At each site a spot water sample was taken and macroinvertebrates were collected by means of a one minute kick sample from a suitable riffle. Details of stream width, substratum composition and sewage fungus cover were also recorded. Macroinvertebrate samples were processed as described in Rutt *et al* (1991) and Mainstone *et al* (1991).

4.2.3 Data analysis

Data analysis followed closely that described in Rutt *et al* (1991). The main difference was that macroinvertebrate taxa were grouped at species or genus level rather than at 'family' level for TWINSPAN classification and DECORANA ordination. Three missing samples omitted from the previous analysis had been located, allowing data from the full 51 sites to be employed.

The distributions of different invertebrate taxa between TWINSPAN groups was investigated using Chi-squared (X^2) tests. Analyses were carried out with due allowance for different levels of taxa abundance; e.g. *Baetis* spp. (2) indicated >9 individuals in the sample, whilst *Baetis* spp. (3) indicated >99 individuals.

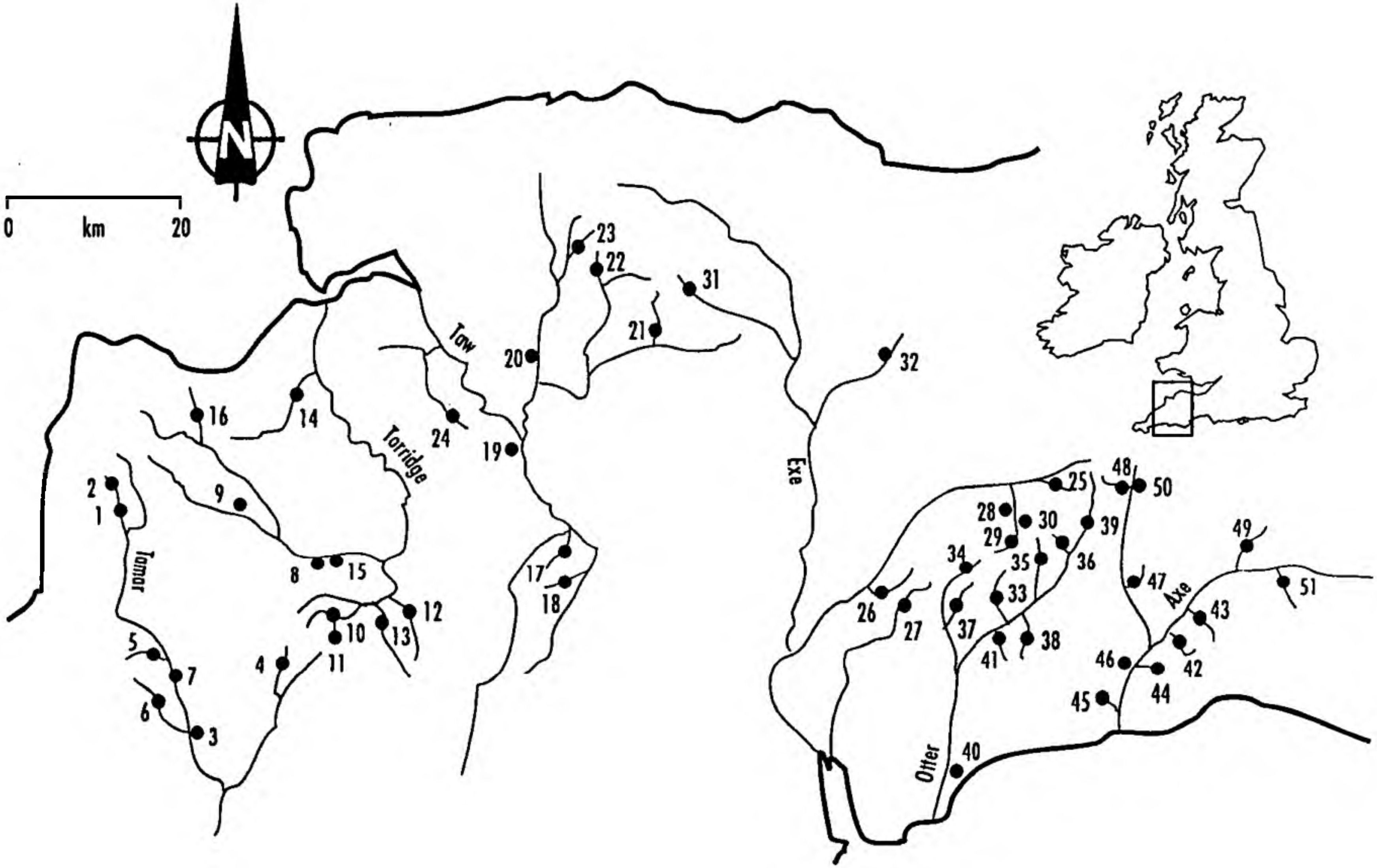


Figure 4.1 Map of Devon showing the 51 sites sampled and their relationship to major river systems

4.2.4 Pollution sources

Details of the status of each site showing some evidence of pollution were given to NRA pollution control staff, such that they could provide information on the pollution sources responsible either from existing records or investigation in the field. Such information is useful in validating the approach.

4.2.5 Results

Initial TWINSPAN classification of the macroinvertebrate data for the 51 sites produced an indicator key that incorporated taxa which were unsuitable for enumeration in bankside samples. These taxa were masked out as potential indicators in subsequent analyses. This process was repeated until an indicator key was derived which was suitable for use in the field (Figure 4.2). Taxa excluded were *Potamopyrgus jenkinsi, Ancylus fluviatilus, Erpobdella octoculata, Paraleptophlebia* spp, *Chloroperla* spp, Elminthidae and *Dicranota* spp.

Preliminary assessment of the stream groups suggested that the two groups to the left of the initial division were similar in biotic and physico-chemical terms. DECORANA reflected this similarity by marked overlap of the site groups in ordination space (Figure 4.3). These two groups were therefore combined so as to produce three groups (1, 2 and 3) in Figure 4.2.

There were highly significant differences between the three groups, in terms of the means of variables that might reflect the effects of farm pollution (Table 4.1, Figure 4.4). These were BMWP Score ($p < 0.001$), ASPT ($p < 0.001$), ammoniacal nitrogen ($p = 0.002$). There were no significant differences in BOD.

There were also significant differences for altitude ($p = 0.008$), conductivity ($p = 0.002$) and alkalinity ($p = 0.046$), but not for gradient, width, distance from source or pH (Table 4.1).

Analysis of the distribution of macroinvertebrate taxa between the three TWINSPAN groups by X^2 tests indicated that there were a number of taxa, in addition to the indicators, that showed a preference for the less polluted groups (1 and 2) (Table 4.2). These tended to be those of pollution sensitive stoneflies (*Protonemoura, Amphinemeura, Perlodes microcephala, Chloroperla, Bracyptera risi, Isoperla grammatica*), caddis (*Silo pallipes, Odontocerum albicorne,* Hydropsychidae, *Sericostoma personatum, Rhyacophila dorsalis*) and beetles (Elminthidae and Gyrinidae). There were a few pollution-tolerant taxa showing preference for the more polluted groups of sites (2 and 3) (Table 4.2). These included the leeches *Erpobdella octoculata* and *Glossiphonia complanata,* oligochaetes and *Asellus.*

In devising a flow chart for use in the field, it was thought desirable to include sewage fungus at a further stage in the system such that sites in Group 1 with some sewage fungus present (1a) can be distinguished from those without (Figure 4.5). Sites in Group 1b can be said to show evidence of mild organic input and could be investigated by surveying further upstream.

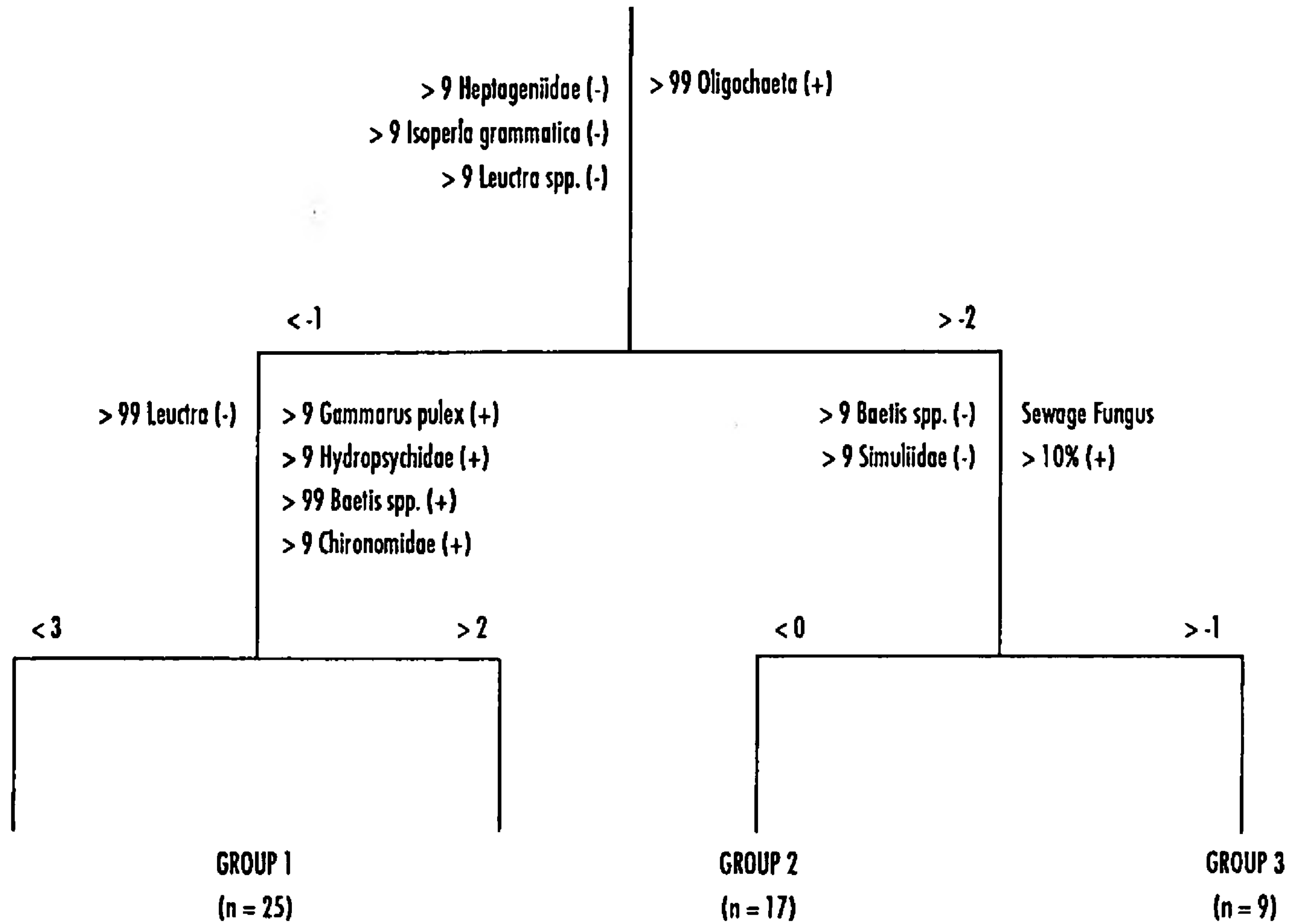


Figure 4.2 Indicator key for Devon derived from TWINSPAN analysis of macroinvertebrate data from 51 sites

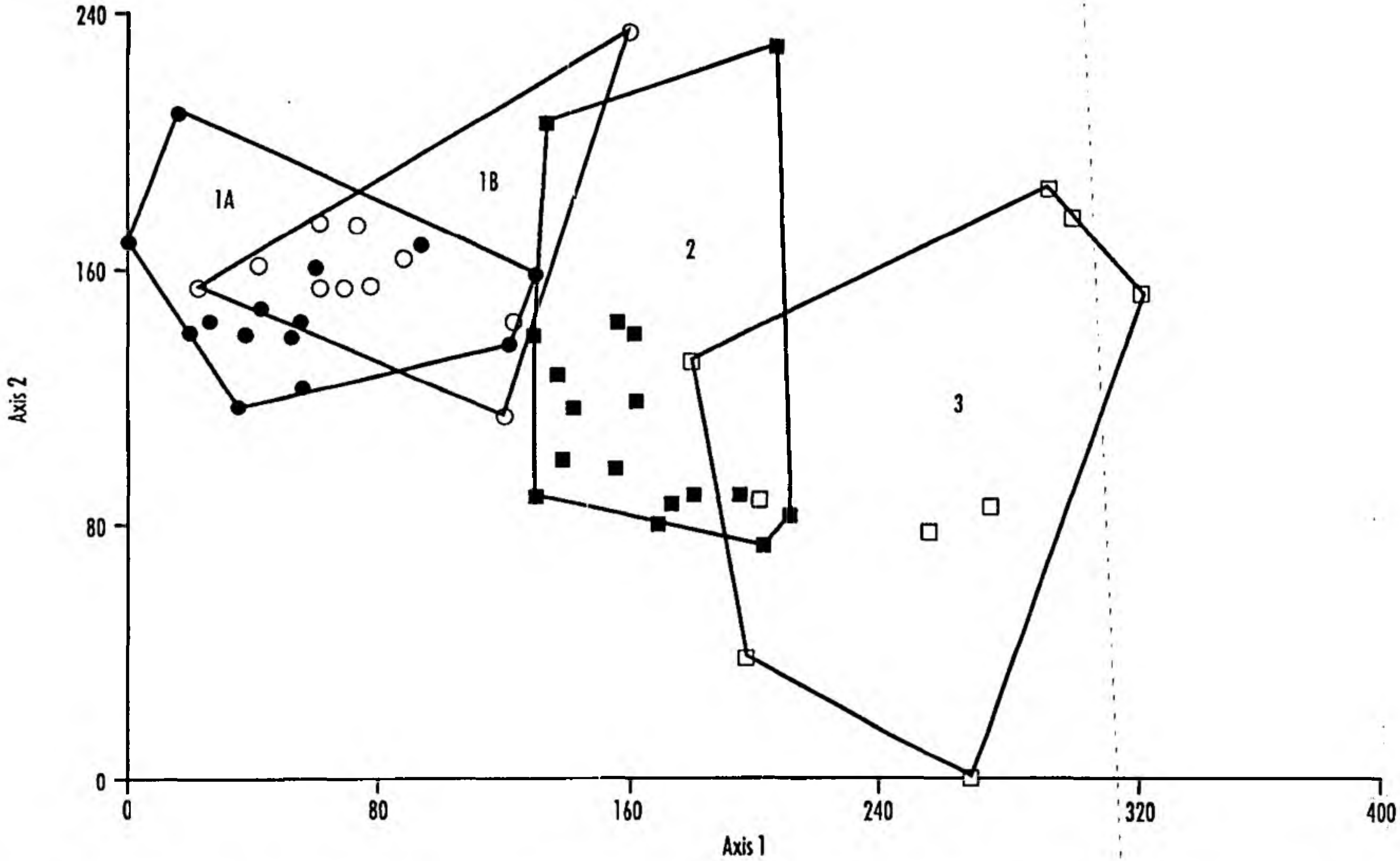


Figure 4.3 Ordination of 51 sites in Devon by DECORANA. Numbered polygons denote site groups generated by TWINSPAN

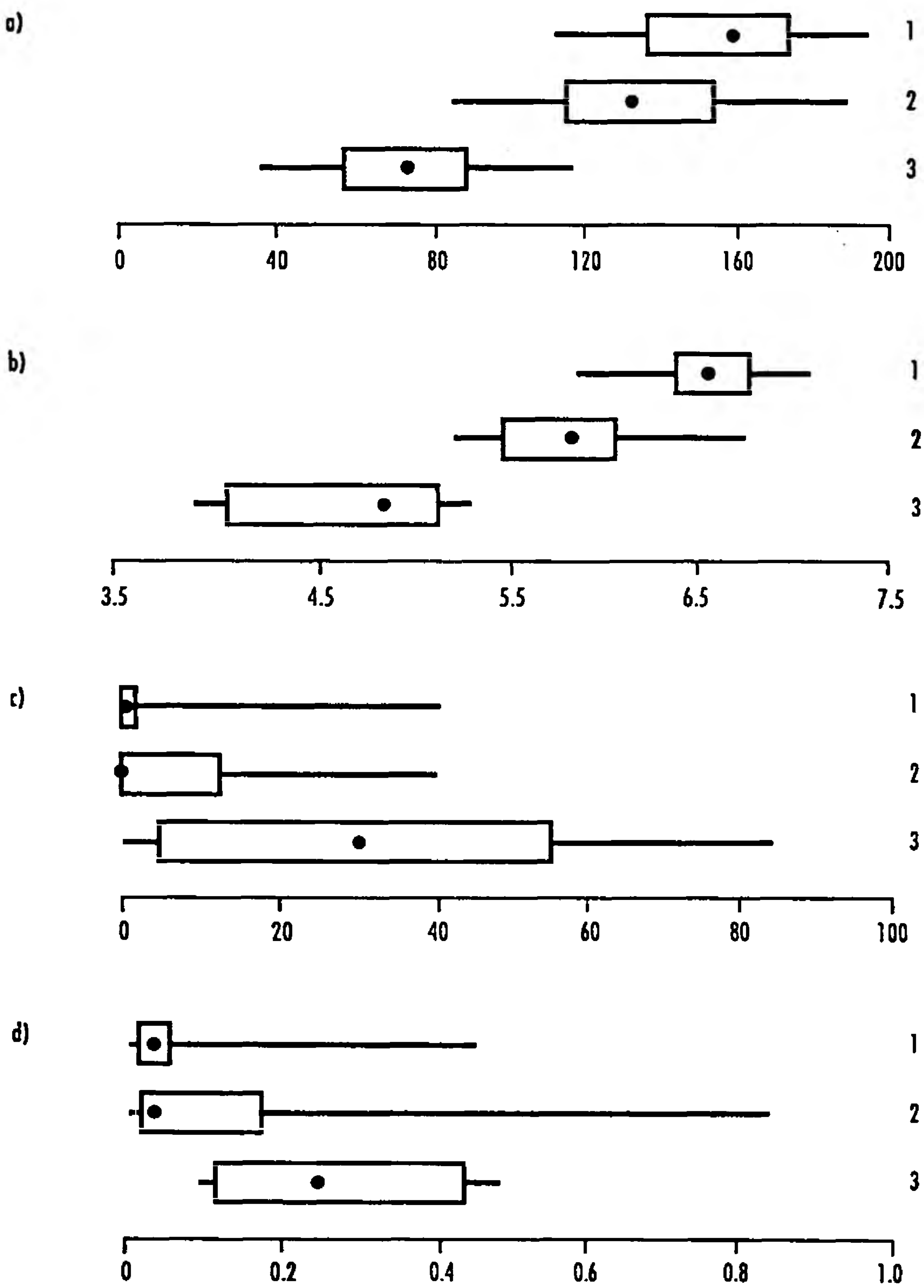


Figure 4.4 Distribution of a) BMWP score, b) ASPT, c) % sewage fungus cover and d) Ammoniacal Nitrogen (mg l^{-1}) concentration within TWINSPAN groups derived from the 51 sites in Devon

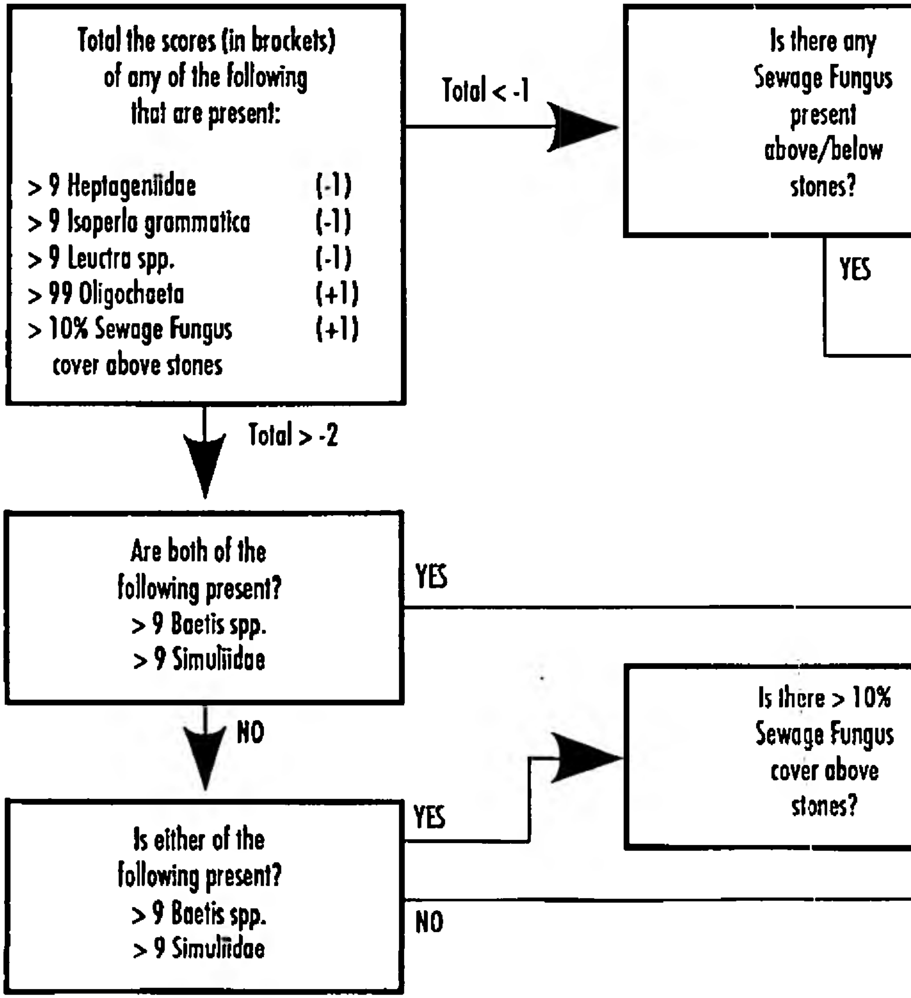


Figure 4.5 Indicator system for the rapid assessment of farm pollution in Devon

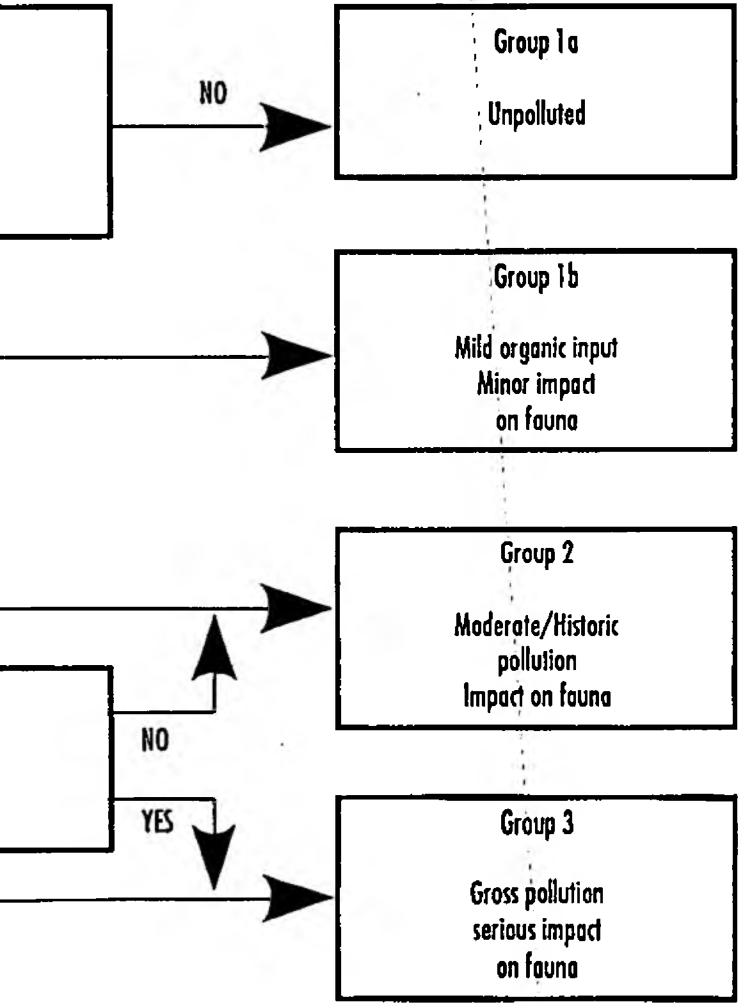

NO
Group 1a
Unpolluted
Group 1b
Mild organic input
Minor impact
on fauna
Group 2
Moderate/Historic
pollution
Impact on fauna
NO
YES
Group 3
Gross pollution
serious impact
on fauna

Table 4.1 Relationships between TWINSPAN groups and environmental and biotic variables

Variable (units)	Group 1	Group 2	Group 3	F	p
Pollution dependent variables					
BMWP	157 (135 - 178)	134 (108 - 159)	74 (51 - 98)	41.17	<0.001***
ASPT	6.6 (6.2 - 6.9)	5.8 (5.4 - 6.2)	4.6 (4.1 - 5.2)	84.16	<0.001***
BOD (mg l^{-1})	1.5 (0.3 - 2.6)	1.6 (0.4 - 2.8)	1.8 (0.7 - 3.0)	0.33	0.724
Ammoniacal N^{+} (mg l^{-1})	0.04 (0.01 - 0.10)	0.05 (0.01 - 0.2)	0.21 (0.1 - 0.4)	7.24	0.002**
Pollution independent					
Altitude (m)	134 (79 - 189)	102 (54 - 150)	72 (51 - 98)	5.35	0.008**
Gradient (%)$^{+}$	1.6 (1.1 - 2.4)	1.5 (0 - 2.3)	1.2 (0 - 3.3)	0.71	0.496
Width (m)	2.3 (1.4 - 3.1)	1.9 (1.3 - 2.4)	1.6 (0.9 - 2.3)	3.17	0.051
Distance from source (km)	2.9 (1.3 - 4.5)	2.5 (1.4 - 3.7)	2.9 (0.3 - 5.6)	0.25	0.779
pH	7.3 (6.9 - 7.8)	7.5 (7.1 - 7.8)	7.5 (7.2 - 7.7)	0.87	0.426
Conductivity (uScm^{-1})	190 (103 - 276)	252 (151 - 352)	327 (224 - 430)	6.99	0.002**
Alkalinity^{+} (mg l^{-1} $CaCO_3$)	26 (11 - 63)	39 (22 - 67)	53 (33 - 85)	3.31	0.046*
Mean substratum Class	2.7 (2.4 - 3.0)	2.9 (2.5 - 3.2)	2.8 (2.2 - 3.3)	1.15	0.326

NOTES $^{+}$ Denotes variables that were log-transformed prior to analysis. Group values are means with standard deviation range (+ or - 1 SD) in brackets.

F statistic (F) and probability (p) are from Analysis Of Variance. Asterisks indicate level of probability: * <0.05, ** <0.01, *** <0.001.

Table 4.2 Frequency of occurrence of selected invertebrate taxa in the three TWINSPAN groups

Taxon	Group 1 (n=25)	Group 2 (n=17)	Group 3 (n=9)	X^2	p
Taxa associated with Group 1					
Heptageniidae (2)	*****	*		29.3	<0.001
Heptageniidae (3)	***			22.1	<0.001
Brachyptera risi (2)	**	*		8.5	<0.02
Leuctra spp. (2)	***	*		10.6	<0.01
Perlodes microcephala	****	*		23.1	<0.001
Isoperla grammatica (2)	****	*		24.0	<0.001
Chloroperla spp.	*****	**		23.4	<0.001
Chloroperla spp. (2)	***	*		16.8	<0.001
Protonemoura spp.	**	*		7.1	<0.05
Amphinemeura sp.	***	*	*	12.1	<0.01
Odontocerum albicorne	**			11.4	<0.01
Taxa associated with Groups 1 and 2					
Ancylus fluviatilis	****	*****	**	9.2	<0.02
Ancylus fluviatilis (2)	**	***	*	7.9	<0.02
Heptageniidae	*****	*****		37.2	<0.001
Paraleptophlebia spp.	****	****	**	8.7	<0.02
Baetis spp. (2)	*****	*****	**	13.1	<0.01
Baetis spp. (3)	***	***		7.4	<0.05
Brachyptera risi	****	***	*	14.1	<0.001
Leuctra spp.	*****	****	*	23.4	<0.001
Isoperla grammatica	*****	****	*	21.9	<0.001
Gyrinidae	*****	***	*	15.2	<0.001
Elminthidae	*****	*****	***	11.3	<0.01
Elminthidae (2)	****	****	**	7.7	<0.05
Silo pallipes	**	*		6.5	<0.05
Sericostoma personatum	*****	***	**	13.6	<0.01
Sericostoma personatum (2)	**	*		6.5	<0.05
Rhyacophila dorsalis	*****	****		29.4	<0.001
Hydropsychidae	*****	****	***	8.8	<0.02
Hydropsychidae (2)	****	**		15.9	<0.001
Dicranota spp.	*****	*****	**	17.0	<0.001
Simuliidae (2)	*****	*****	***	6.2	<0.05
Wiedemania spp.	**	*		8.5	<0.02
Taxa associated with Group 2					
Habrophlebia fusca		***	*	13.1	<0.01
Psychodidae	*	***		7.6	<0.05

...../continued

Table 4.2 (continued)

Taxon	Group 1 (n=25)	Group 2 (n=17)	Group 3 (n=9)	X^2	p
Taxa associated with Groups 2 and 3					
Potamopyrgus jenkinsi	***	*****	****	9.0	<0.02
Pisidium spp.		**	**	9.9	<0.01
Oligochaeta (3)	*	***	**	13.1	<0.01
Glossiphonia complanata	*	****	***	15.3	<0.001
Asellus spp.	*	***	****	14.9	<0.001
Chironomidae (2)	****	*****	*****	8.4	<0.02
Taxa associated with Group 3					
Erpobdella octoculata	*	**	****	6.7	<0.05
Asellus spp. (2)	*	***		11.4	<0.01
Dytiscidae	*	*	***	13.1	<0.01
Taxa not showing association with Groups					
Polycelis spp.	**	***	***	2.1	NS
Polycelis spp. (2)	*	*	**	0.6	NS
Potamopyrgus					
Lymnaea peregra	*	**	*	4.9	NS
Pisidium spp.	***	****	*****	2.6	NS
Oligochaeta	*****	*****	*****	0.0	NS
Oligochaeta (2)	****	*****	*****	4.5	NS
Gammarus pulex	*****	*****	*****	2.1	NS
Gammarus pulex (2)	***	****	***	2.1	NS
Ephemera danica	***	***	**	1.8	NS
Paraleptophlebia (2)	**	**		4.4	NS
Caenis spp.	**	*	*	4.0	NS
Nemoura spp.	***	****	***	1.3	NS
Gyrinidae (2)	**	*		4.2	NS
Hydraena gracils	***	***	*	4.7	NS
Rhyacophila dorsalis (2)	**	**		4.4	NS
Agapetus spp.	**	*	*	0.8	NS
Plectocnemia sp.	***	***	*	3.7	NS
Limnephilidae	*****	*****	****	5.9	NS
Limnephilidae (2)	***	**	**	2.4	NS
Hydropsychidae (3)	*	*		3.4	NS
Dicranota spp. (2)	**	*		2.6	NS
Simuliidae (3)	*	**	**	3.2	NS
Chironomidae (3)	*	***	**	4.4	NS
Ceratopogonidae	*	***	**	3.5	NS
Chelifera spp.	*	**	**	2.0	NS

NOTES Asterisks indicate percentage occurrence:

* 1 - 20% of sites in group, ** 21 - 40%, *** 41 - 60%, **** 61 - 80%, ***** 81 - 100%. For certain taxa, abundance categories are treated as different taxa: i.e. (2) indicates >9 individuals in a 1 minute kick sample, (3) >99.

X^2 values and associated probabilities are given.

On this basis only 8 of the 25 sites in Group 1 could be placed into Group 1a, perhaps reflecting a persistent low level of organic pollution in these Devon catchments.

The information that could be provided by NRA pollution control staff about possible pollution sources was of variable quality. In some cases, recent site visits had been undertaken and detailed information was consequently available. For many sites in Groups 2 and 3, there were possible sources for observed impacts on the stream biota (Table 4.3).

4.2.6 Discussion

TWINSPAN classification was successful in defining three groups of sites with different biological status, as reflected in differences in BMWP scores, ASPT and ammoniacal nitrogen concentration. Group 1 sites generally had BMWP scores in excess of 140 and ASPT in excess of 6.4 and could be considered to represent largely unpolluted sites (Table 4.3, Figure 4.4). By contrast, Group 3 sites were the most polluted, with BMWP scores generally below 90, ASPT of all sites below 5.4 and frequently with substantial growths of sewage fungus. Group 2 sites were of intermediate pollution status, reflecting mild or perhaps historic pollution. There were significant differences between the three groups in altitude, conductivity and alkalinity but these are not thought to be major determinants of faunal composition in this study. The differences are likely to reflect the fact that unpolluted catchments tended to be at higher altitude and draining poorer soils where sheep farming rather than dairy farming is the commonest land use.

The indicator key generated by TWINSPAN incorporated taxa whose distribution and abundance have been shown to be influenced by organic pollution both by earlier work under this contract (Mainstone *et al* 1991; Rutt *et al* 1991) and by numerous other studies (e.g. Hynes 1960; Hawkes 1963). The mechanisms which may account for the absence of sensitive taxa from sites affected by organic pollution may involve both acute and chronic effects dependent on pollutant type. These relationships have been discussed more fully elsewhere (e.g. Rutt *et al* in preparation).

The TWINSPAN classification reported here was carried out at the 'species' or 'genus' level, in contrast to the 'family' level analysis of the same data reported previously (Rutt *et al* 1991). It would appear that the use of data at the 'species' level has produced a more discriminating analysis, with divisions more closely reflecting the effects of farm pollution. The indicators are very similar to those found previously and present comparably few problems for field identification. It is recommended that future developments of indicator keys should be based on species/genus level data which provide more information for the classification process. Unsuitable indicators can always be masked out of the analysis, which can be repeated until a practical system is obtained.

Biologists in NRA South-West Region received training in the use of the West Wales key and the earlier Devon system (Rutt *et al* 1991) in January 1992, and a trial of these methods was to be carried out in catchments in this region in late February 1992. If found to be successful, it is envisaged that the indicator approach may be adopted for larger scale surveys of farm pollution impact in this region in future years.

Table 4.3 Biological characteristics of stream sites in Devon arranged by pollution group, giving possible pollution sources

Site		Catchment	NGR	BMWP	ASPT	% fungus cover above	% fungus cover below	Possible sources of pollution
GROUP 1a								
21	Tributary of Yeo	Taw	SS792276	160	6.7	0	0	
22	Lyddicombe Bottom at Fyldon	Taw	SS738337	175	7.0	0	0	
23	Tributary of Bray at Holewater	Taw	SS705354	163	7.1	0	0	
31	Dane's Brook	Exe	SS819321	122	6.4	0	0	
39	Otter below Sweetlands Farm	Otter	ST216096	163	6.5	0	0	
44	Tributary of Axe below Trill	Axe	SY286959	174	6.4	0	0	
48	Yarty near Moorseek	Axe	ST245134	194	6.9	0	0	
49	Tributary of Axe at Chalkway	Axe	ST376075	134	6.7	0	0	
GROUP 1b								
4	Tributary in Witherdown Wood	Tamar	SX428953	129	6.8	40	20	No problem when site visited on 14.6.91
5	Tributary downstream of Ogbeare Hall	Tamar	SX308096	134	5.8	2	10	
7	Tributary North of Northcott Hamlet	Tamar	SX334934	153	6.7	2	2	
10	Tributary of Lew below Whiddon Farm	Torridge	SX479999	147	6.4	7	15	Dirty water runoff
11	Tributary of Lew East of Patchcott	Torridge	SX478994	150	6.3	5	10	Dirty water problem. LRI now installed.
12	Medland Brook near Northwood	Torridge	SS552002	141	6.7	0	2	
13	Tributary of Lew West of Westacott	Torridge	SS532002	112	6.6	1	1	
25	Tributary of Culm at Stapley	Exe	ST186134	144	6.6	0	<5	
28	Tributary of Madford near Abbey	Exe	ST141107	177	6.1	0	<5	Possible discharges from septic tanks.
30	Tributary of Madford D/S Gorwell	Exe	ST153094	186	6.9	0	5	
33	River Wolf at A373 road bridge	Otter	ST129022	162	6.5	1	15	Many historic problems in catchment
35	Tributary of Otter at Luppitt	Otter	ST173066	183	6.8	?	10	A few historic problems - none recently.
36	Tributary of Otter at Upottery	Otter	ST199078	160	6.4	0	5	S. fungus in trib. below Chapelhayes Farm
38	Tributary of Otter at Blannicombe	Otter	SY161985	160	7.0	5	5	
41	Gissage at Gittisham	Otter	ST135983	135	6.1	5	50	Yard runoff from several farms
42	Tributary of Axe at Sector	Axe	SY311982	172	6.6	1	3	Waste containment problems from 2 farms
47	Tributary of Yarty at confluence	Axe	ST259037	184	6.1	0	5	Very cloudy when sampled - no follow-up

...../continued

Table 4.3 (continued)

Site		Catchment	NGR	BMWP	ASPT	% fungus cover above	% fungus cover below	Possible sources of pollution
GROUP 2								
1	Lamberal Water below Forda	Tamar	ST274109	106	5.9	40	50	No problem noted by warden in May 1991
2	Lamberal Water near Broxwater	Tamar	SS267133	159	6.1	20	20	No problem noted by warden in May 1991
6	Tala Water near Boyton	Tamar	SX312919	189	6.8	2	5	
8	Tributary near Black Torrington	Torridge	SX463056	108	5.7	35	25	Dirty water overflow and domestic sewage
9	Tributary of Waldon	Torridge	SS389106	162	6.0	30	10	Inadequate waste containment
16	Tributary near Stroxworthy	Torridge	SS344198	150	6.3	1	0	Domestic sewage and dirty water
18	Gissage Lake	Taw	SS706037	124	5.9	5	25	Problem unknown, no follow-up.
19	Tributary below Churchlands Farm	Taw	SS660165	133	6.3	0	0	Problem unknown, no follow-up.
20	Tributary of Bray at Fullabrook	Taw	SS674257	85	5.3	0	3	
24	Tributary below Deptford Farm	Taw	SS598192	140	5.8	0	15	Dirty water problem - LRI. proposed
32	Tributary of Bathern D/S Raddington	Exe	ST011257	135	5.4	0	<5	No known problems, six farms upstream
34	Tributary of Otter at Broadhembury	Otter	ST101049	125	6.0	0	0	Historic problems, no recent reports
37	Tributary of Tale at Haskin's Farm	Otter	ST083027	125	5.4	0	0	
43	Tributary below Bagley Hill Farm	Axe	ST321010	162	5.8	0	5	Yard runoff - grant approved for LRI.
45	Tributary below Whitwell Farm	Axe	SY238925	110	5.5	0	<2	Yard runoff - LRI. installed
46	Tributary of Axe at Whitford	Axe	SY262956	141	5.2	<1	10	Yard runoff
50	Buckland Stream below Blindmoor	Axe	ST263136	120	5.7	0	0	Slurry containment problems at two farms
GROUP 3								
3	Small tributary near Crossgate	Tamar	SX346884	92	5.1	60	40	
14	Tributary of Yeo at Loosebam Bridge	Torridge	SS438217	58	5.3	10	15	Yard water and abuse of LRI system
15	Smithsland Stream below farm	Torridge	SS473059	83	5.2	30	20	Dirty water irrigation
17	Tributary of Taw at Aller Bridge	Taw	SS705067	35	3.9	85	90	Pig slurry and dirty water from dairy farm
26	River Weaver at B3181 Bridge	Exe	ST013033	116	4.8	*0	0	Suspect farm upstream
27	River Clyst North of Clyst Hydon	Exe	ST038019	56	4.0	10	75	Yard runoff problem and other possibles
29	Tributary of Madford nr Dunkerswell	Exe	ST149083	86	4.9	0	0	Immediately D/S Dunkerswell STW
40	Otterton Brook near North Star	Otter	SY087858	74	4.6	40	40	No file on stream, no reported pollution
51	Temple Brook at Greenham	Axe	ST410047	70	4.1	50	20	Intermittent discharge from large farm

* Sewage Fungus strands on vegetation only.

5. DETAILED SITE INVESTIGATIONS

5.1 Introduction

There is a need for intensive studies of the effects of particular farming practices on water quality and stream biota. Such studies can serve to identify which are the most damaging pollution sources affecting a stream system.

Intensive studies carried out under the current contract have been undertaken at polluting farms identified by more extensive surveys. A study at Pontfaen Brook, a tributary of the Gwaun in West Wales, was initiated in June 1990 following an extensive survey during the development of the rapid appraisal technique (Mainstone *et al* 1991). A second study took place in April - August 1991 in the Rhydw catchment (near Carmarthen), after a severely polluted tributary was identified during testing of the rapid appraisal methods (Rutt *et al* 1991). At Pontfaen Brook, the pollution was the result of a chronic leakage of silage effluent, whilst the tributary of the Rhydw was subject to daily inputs of parlour washings and to intermittent inputs of silage effluent whenever a reception pond overflowed following rainfall.

A third study was initiated to compliment the previous work, examining the effects of yard runoff on a water course. A suitable site was identified in the Pibwr catchment (south of Carmarthen) during the test of the rapid appraisal methods, and work began on 15 October 1991.

5.2 Study area

The Nant Pibwr rises at an altitude of 110 m some 8 km east of Carmarthen in West Wales. It flows parallel to the Afon Tywi before discharging to the Tywi estuary 2 km south of Carmarthen (Figure 5.1).

The Pibwr was one of the catchments selected for survey during a large scale evaluation of the rapid appraisal system developed to pinpoint polluting farms using biological techniques (Rutt *et al* 1991). During sampling on 13 February 1991, the pollution control officer responsible for the Pibwr catchment observed discharges from Penbontbren farm (SN450189), which were probably responsible for a reduction in biological quality downstream of the premises: the BMWP score below the farm was 75, compared with 112 above, and sewage fungus cover (above stones) was 60% downstream compared with no growth upstream.

The farm was visited by both the NRA Agricultural Liaison Officer and Graham Rutt on 15 May 1991. It was found to be in a poor state of management and three possible polluting discharges were discovered (Figure 5.1). Immediately upstream of the farm was a small stream which could be contaminated with slurry washed off the road during rainfall (Discharge 1). Further downstream was an input of parlour/dairy washings and yard runoff contaminated with diesel oil (Discharge 2). The most downstream discharge was yard washings which leaked from a heavily ponded yard between an earth-banked slurry lagoon and a solid manure store (Discharge 3).

5.3 Progress to date

5.3.1 Methods

Chemical monitoring began on 15 October 1991. Three pHOx 100 DPM continuous monitoring units were installed at sites A, B and C (Figure 5.1). Site A was a few metres upstream of Discharge 1 , site B was 60 m downstream of Discharge 3 whilst site C was some 300 m below site B. The meters were equipped to measure dissolved oxygen, temperature, pH, conductivity and ammonium (a close measure of total ammonia at moderate temperature and circumneutral pH). Data was recorded using Technolog NEWLOG data loggers set to record every fifteen minutes. A Casella rain gauge linked to a Technolog TINYLOG data recorder was situated adjacent to site C. This however, proved unreliable and rainfall data was obtained from an NRA rain gauge at Towy Castle (SN406142) some 6.5 km to the south-west. All the instruments were visited at weekly intervals for calibration and data retrieval. Monitoring ceased on 18 December 1991.

Weekly spot samples were taken at five different points: sites A, B and C, Discharge 1 and Discharge 2 (Figure 5.1). Discharge 3 was not monitored because it had ceased following remedial work carried out prior to the study. The samples were analysed at the NRA laboratory at Llanelli for a range of sanitary determinands such as BOD, dissolved oxygen, inorganic nutrients and Dissolved Organic Carbon (DOC).

Flow estimates were made below site A by measuring cross-sectional area and estimating current velocity.

Detailed visual estimations of the percentage cover of benthic growth (sewage fungus, algae, etc.) were made weekly at sites A, B and C, over ten contiguous 2 m sections of stream. In addition, five large stones at each site were examined for growth both on top and bottom surfaces. The character and extent of benthic growth downstream of Discharge 2 was also noted. Each week a sample of the growth from each site was collected for microscopic examination so as to identify and quantify the constituent organisms.

Three minute kick samples of the macroinvertebrate community were taken from riffles at sites A, B and C at the beginning of the study on 15 October 1991, on 12 November 1991 and at the end of the study on 18 December 1991. Samples were fixed at the laboratory in 4% formaldehyde solution and the invertebrates present were later identified to family level enabling the calculation of BMWP (Biological Monitoring Working Party) Scores and ASPT (Average Score Per Taxon).

The RIVPACS (River Invertebrate Prediction and Classification System) program was used to predict presence/absence of invertebrate families and BMWP Score and ASPT from environmental data (Cox *et al* 1991). The predictor variables used were distance from source, altitude, slope, width, depth, discharge category, chloride, hardness and substratum composition, and an autumn (September - January) only prediction option was employed. Only one prediction was performed as the three sites were close together and very homogeneous, having essentially the same environmental characteristics. Predicted families and biotic indices were compared with those actually observed. This technique was not used in the two previous intensive studies because the streams were too small, falling outside of the environmental range of the RIVPACS program.

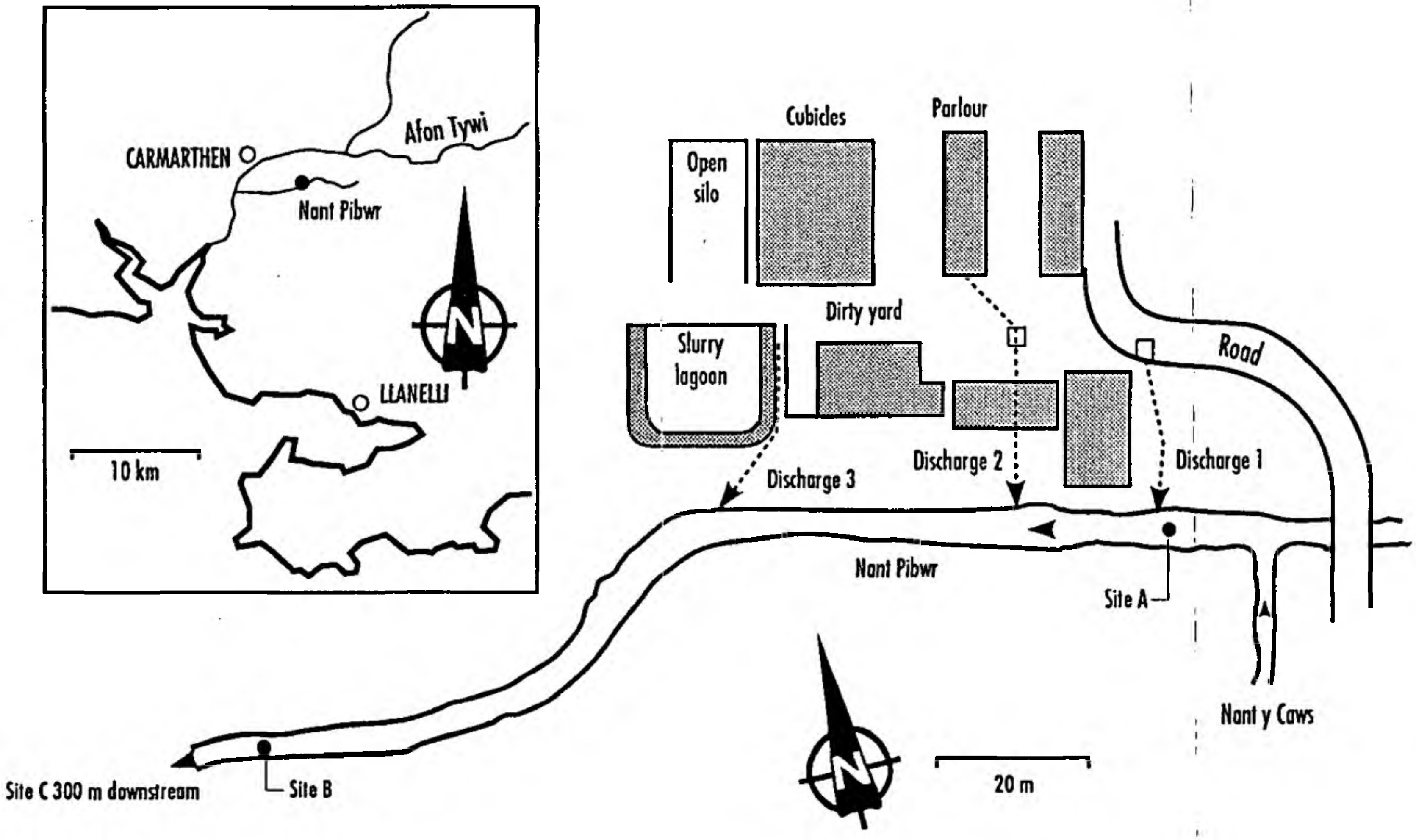


Figure 5.1 Diagram of the Nant Pibwr study area showing farm waste discharges and study sites. Inset shows the location of the Nant Pibwr in Southwest Wales

Quantitative electrofishing and HABSCORE assessment was undertaken on the Nant Pibwr in February 1992. However, the results have yet to be analysed.

5.3.2 Results

Water Chemistry

Data from spot samples and continuous monitors indicated that pH was generally in the range 7.0 - 8.0 at sites A, B and C. There were occasional depressions in pH down to 6.5 following prolonged rainfall but these levels are far above those known to adversely affect aquatic life.

Dissolved oxygen levels in spot samples from the three stream sites A, B and C showed a minimum recorded value of 9.8 mg l^{-1}, at site A (Figure 5.2). Discharge 2 showed much lower dissolved oxygen concentrations rarely exceeding 1.0 mg l^{-1}. Continuously monitored data showed consistently high dissolved oxygen concentrations at the three stream sites until the last two weeks of the study, when declines in oxygen concentration to below 6.0 mg l^{-1} were recorded at site A (Figure 5.3). Oxygen electrodes at sites B and C were not working correctly at this time so no comparative data was available.

Spot samples and continuous monitoring data indicated a baseline level of conductivity of 200 - 220 uScm^{-1} at all three stream sites. On one occasion conductivity decreased to around 120 uScm^{-1} corresponding to heavy rainfall and high flow. Peaks in conductivity were more common: on several occasions, all three stream sites showed conductivity peaks of 400 - 800 uS cm^{-1}, and on one occasion conductivity reached 1700 uScm^{-1} at all three sites.

Spot sample data indicated that ammoniacal nitrogen concentration rarely exceeded 0.1 mg l^{-1} N at any of the three stream sites (Figure 5.4). The highest value recorded was 0.17 mg l^{-1} N at site C, with a corresponding un-ionized ammonia concentration of 1.0 µg l^{-1}. Concentrations in Discharge 2 were much higher and generally in the range 10 - 20 mg l^{-1} N, with a maximum of 43 mg l^{-1} N of which the un-ionized ammonia component was 0.08 mg l^{-1} Figure 5.4). Continuously monitored levels of ammonium were below detection limits for all three stream sites for the majority of the study. An exception occurred at sites B and C on 15, 16 and 17 December 1991, when ammonium peaks were recorded corresponding to peaks in conductivity and rainfall (Figure 5.5). The largest peak occurred on 15 December with a maximum of 0.75 mg l^{-1} ammonium (0.004 mg l^{-1} un-ionized ammonia) and lasted for 10 hours (Figure 5.5). There was no ammonium recorded at site A at this time.

Spot sampling revealed that BOD at the three stream sites rarely exceeded 2.0 mg l^{-1} with BOD generally in the range 1 - 2 mg l^{-1} (Figure 5.6). The BOD of Discharge 1 was generally slightly higher than the stream sites but never exceeded 3.0 mg l^{-1}. The BOD of Discharge 2 was considerably higher than the other sites, being generally in the range 200 - 400 mg l^{-1} with a maximum in excess of 559 mg l^{-1} (Figure 5.6). Despite the high BOD of this discharge the input was relatively small compared to the size of the stream. The input was estimated to have a flow of 0.062 litres sec^{-1}, as compared with the 118 - 860 litres sec^{-1} recorded for the Pibwr (Figure 5.7), yielding a dilution factor of 1990 - 13 900. Taking the worst case scenario of the lowest dilution factor (1900) and the highest recorded BOD (559 mg l^{-1}), the BOD contribution of Discharge 2 to the Pibwr would be only 0.3 mg l^{-1}.

Benthic Growth

At site A, upstream of the farm discharges, there was no evidence of heterotrophic benthic growth at any time during the study. At sites B and C there was never any significant growth above stones but small patches of growth were often present below large stones. These growths were variable in composition but the major constituents were the colonial bacterium *Sphaerotilus natans*, iron bacteria and the sessile protozoan *Charchesium*.

The only significant growths of 'sewage fungus' were found in the mixing zone associated with Discharge 2. Here there were often thick growths of *Sphaerotilus* or Zoogloea in a tapering strip extending at most 0.5 - 1.0 m across the stream (stream width 3 - 4 m) and 3 - 12 m downstream. Growths of fungus were generally present below stones for a few metres beyond the limit of visible growth above stones.

Macroinvertebrate Populations

Examination of the macroinvertebrate data derived from kick sampling, including comparison of BMWP scores, ASPT values and abundances of the different families, revealed no clear pattern of differences between the three stream sites A, B and C (Table 5.1).

The observed taxa agreed quite closely with those predicted by RIVPACS. Of twenty families with greater than 40% predicted probability of occurrence, only six families were absent from all sites. Of these, three (Ephemeridae, Dytiscidae and Odontoceridae) are principally margin dwelling taxa and are less likely to occur in samples taken exclusively from riffles. Of the remaining three families (Planariidae, Goeridae and Chloroperlidae), the absence of Chloroperlidae is perhaps the most interesting as these were found to be present at three sites in the Pibwr catchment in February 1991, including site A. Predicted BMWP score and ASPT were 158 (confidence limits, 117 - 198) and 6.3 (confidence limits, 5.7 - 6.9). Thus observed BMWP scores (Table 5.1) were rather low by comparison, but generally lay within the confidence limits about the RIVPACS prediction. ASPT values were also relatively low and tended to lie below the lower confidence limit. Although differences in sampling methodology may account for some of the difference between observed and predicted biotic indices, there is perhaps some suggestion of low level perturbation of the fauna at all three sites.

5.3.3 Discussion

Data from both discrete and continuous monitoring suggested that during the course of the study, there was no marked reduction in the water quality of the Pibwr as a result of discharges of parlour/dairy washings and yard water from Penbontbren Farm. There was correspondingly little evidence of a biological impact attributable to the farm, except for localised growth of 'sewage fungus' in the mixing zone below the most polluting discharge.

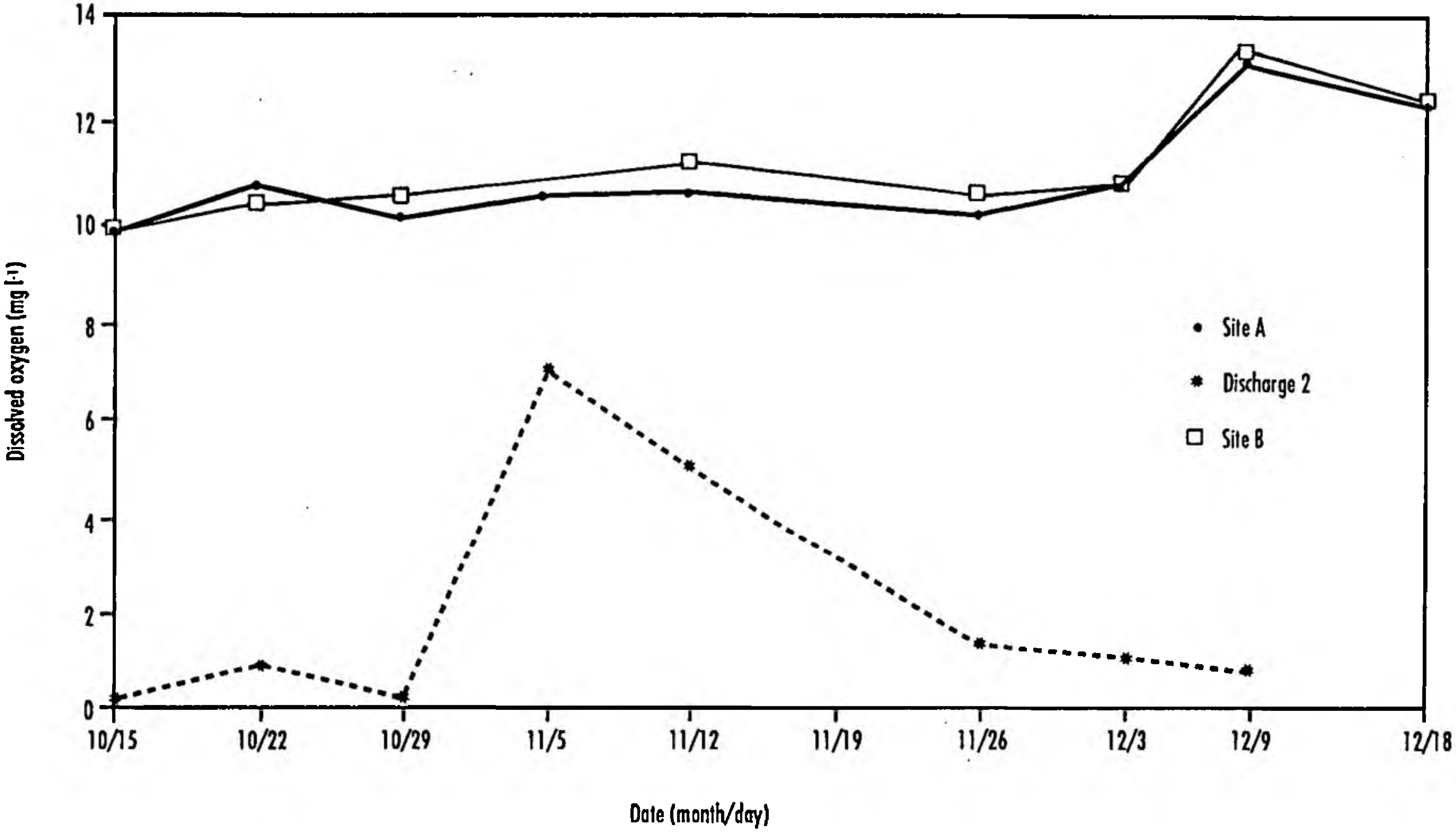


Figure 5.2 Dissolved oxygen levels in the Nant Pibwr from spot sampling between October 15 and December 18, 1991

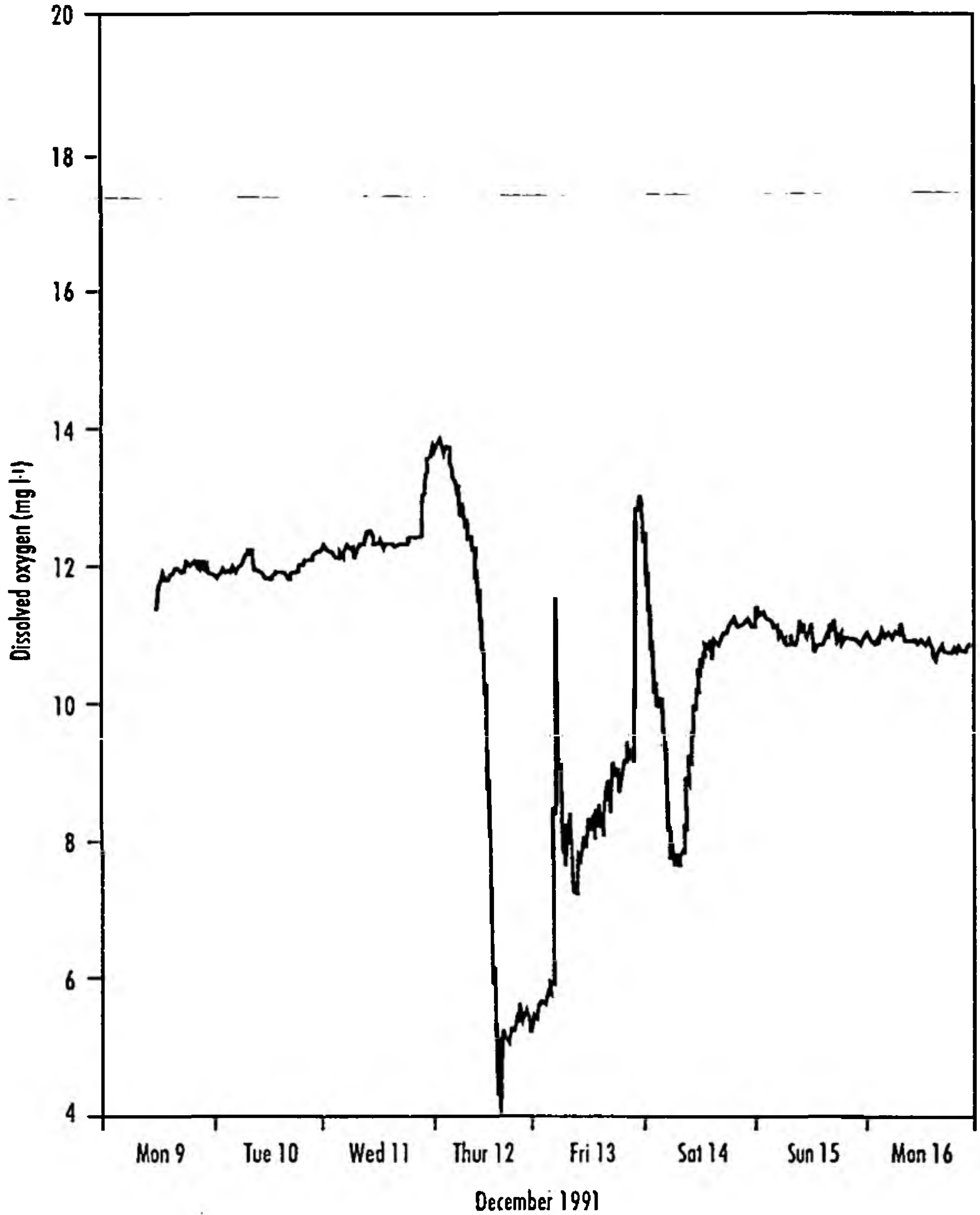


Figure 5.3 **Dissolved oxygen levels in the Nant Pibwr from continuous monitoring between December 10 and December 17, 1991**

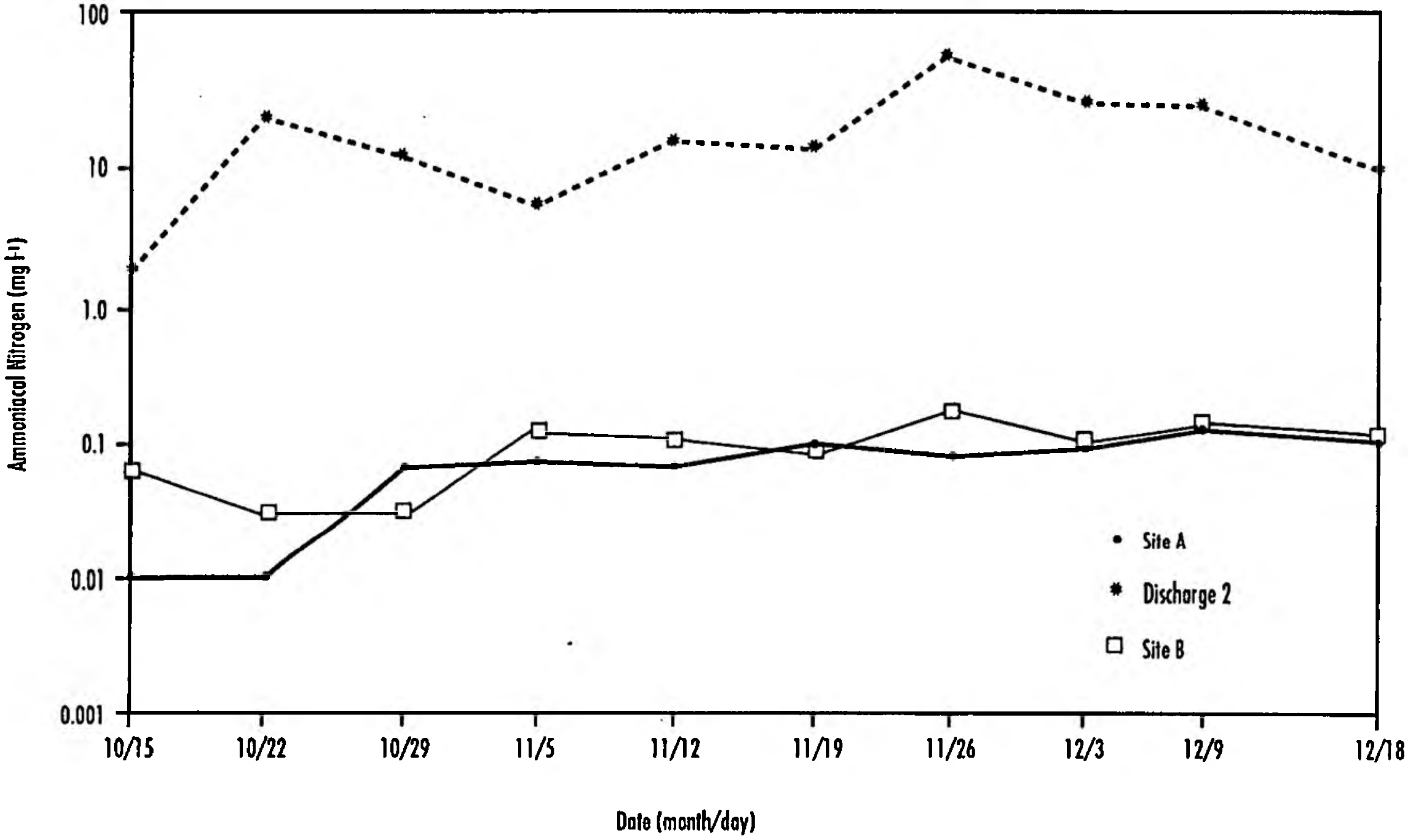


Figure 5.4 Ammoniacal Nitrogen levels in the Nant Pibwr from spot sampling between October 15 and December 18, 1991

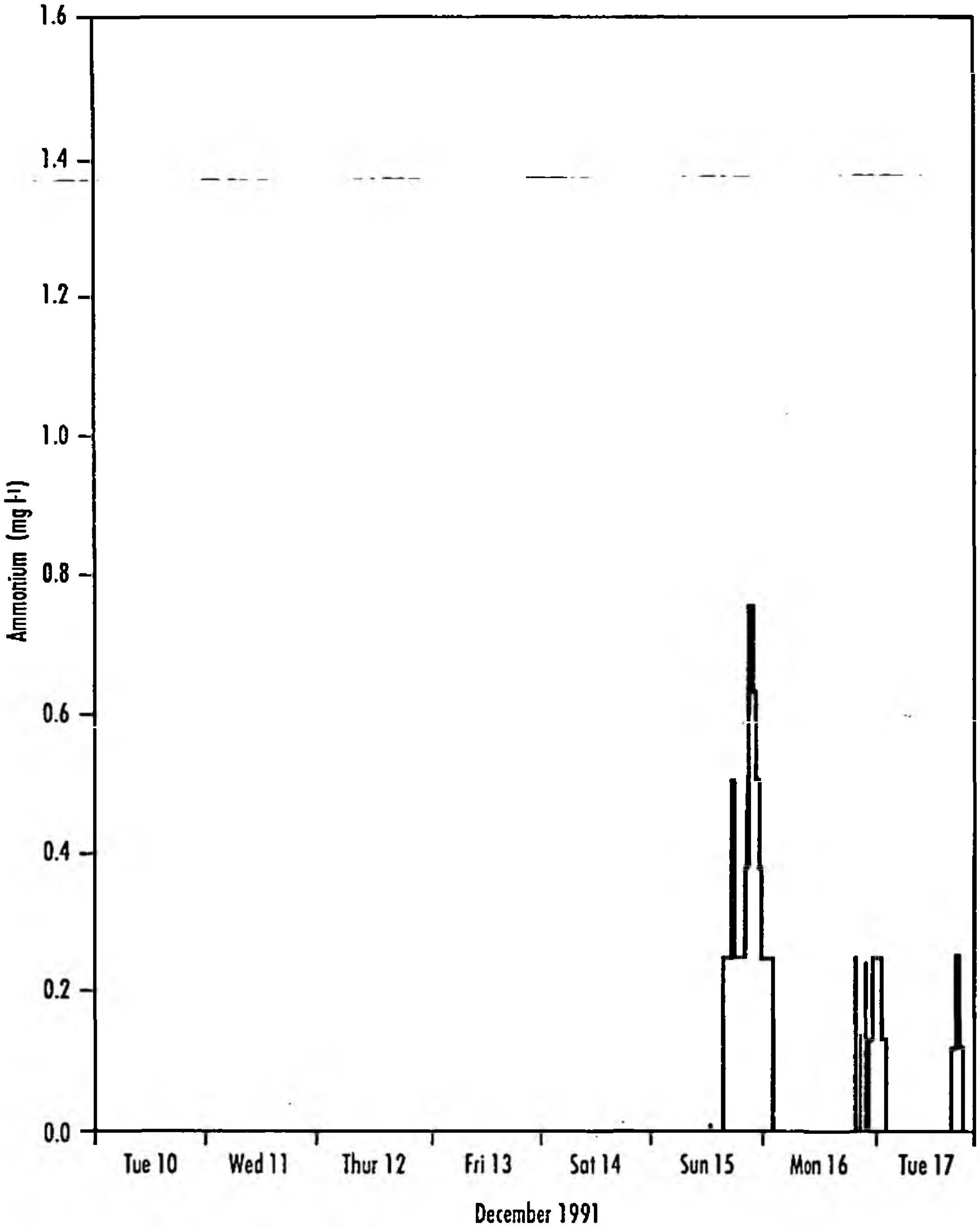


Figure 5.5 Ammonium ion concentrations in the Nant Pibwr at site B from continuous monitoring between December 10 and December 17, 1991

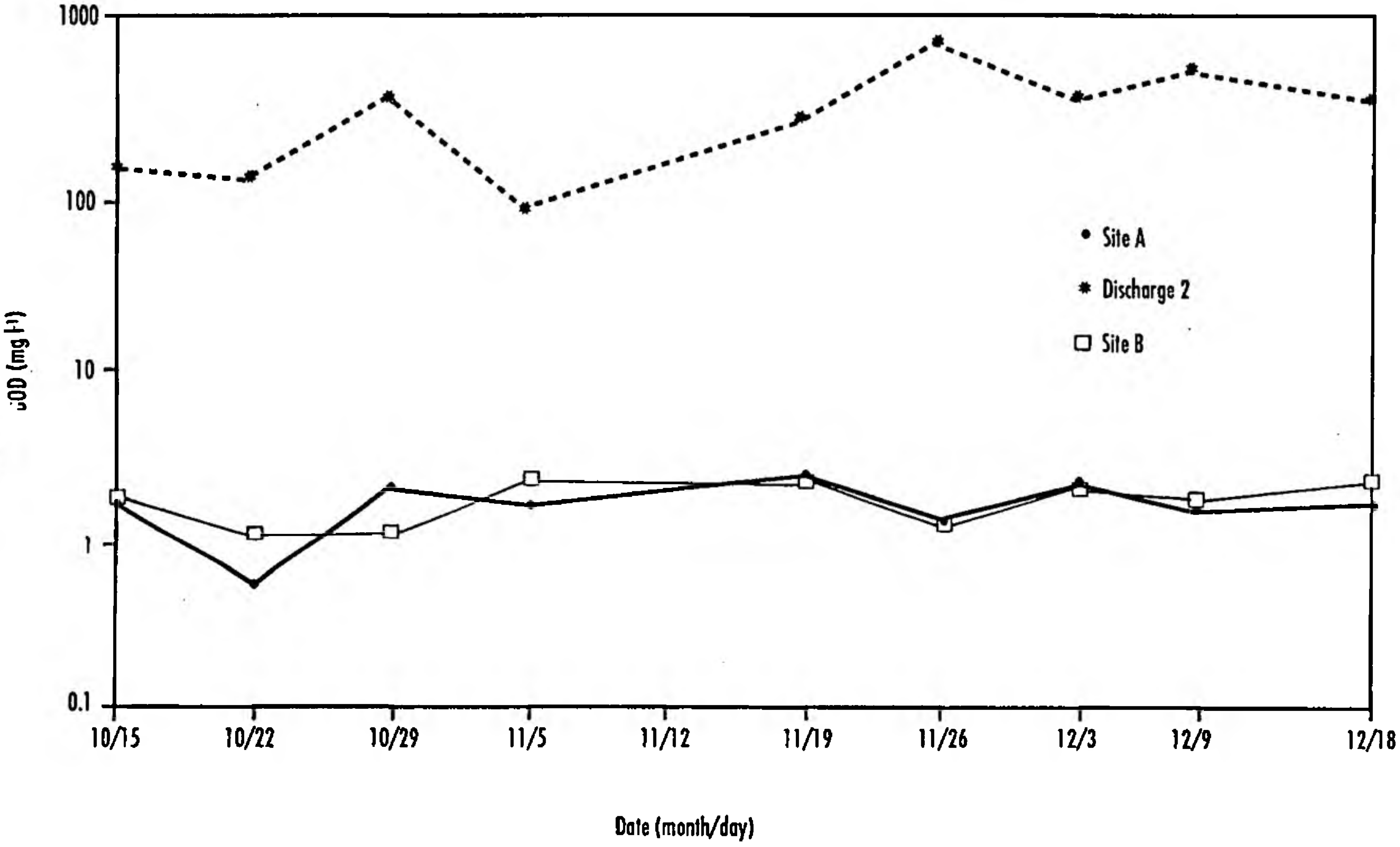


Figure 5.6 Biological Oxygen Demand (BOD) in the Nant Pibwr from spot sampling between October 15 and December 18, 1991

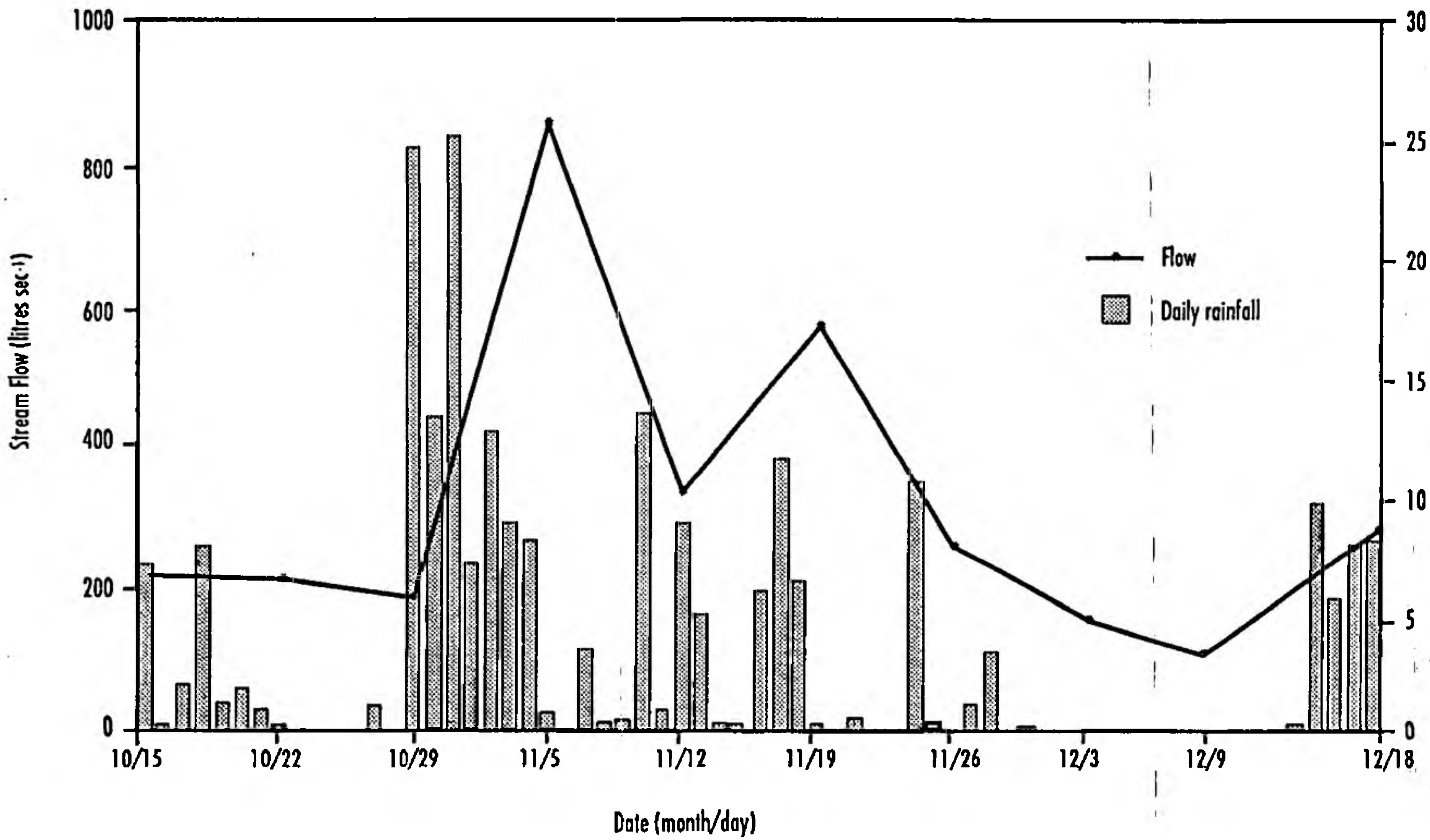


Figure 5.7 Stream Flow of the Pibwr below site A and daily rainfall between October 15 and December 18, 1991

Table 5.1 Invertebrate community analysis of sites on the Nant Pibwr

Taxa	Site A			Site B			Site C		
	Oct	Nov	Dec	Oct	Nov	Dec	Oct	Nov	Dec
Heptageniidae	2	2	1	2	2	2	1	2	1
Leptophlebiidae		1	1					1	
Taeniopterygidae						2			1
Leuctridae	1	2	1	1	1	1	1	1	1
Perlodidae	1	2	1	2	1	2	1	1	1
Sericostomatidae			1		1		1	1	
Caenidae		1							
Nemouridae	1	1	1	1	1	1	1		
Rhyacophilidae	1	1	1	1	1	1	1	1	1
Polycentropodidae	1	1	1	1			1	1	
Limnephilidae				1	1		1	1	
Ancylidae	1	1	1	2	1	2	2	1	1
Gammaridae	2	1	1	2	1	2	3	2	1
Gyrinidae	1	1	1	2	1	2	1	1	1
Hydrophilidae	2	1	1	2	1		1	1	1
Elminthidae	3	1	1	3	1	1	1	1	1
Hydropsychidae	1	1	1	1			1	1	1
Tipulidae	2	1	2	2	1	2	1	1	1
Simuliidae	2	2	1	2	1	1	1	1	1
Baetidae	2	2	3	2	2	3	2	2	1
Hydrobidae	2	1	2	3	1	2	4	4	3
Lymnaeidae				1	1				
Planorbidae		1					1	1	
Sphaeridae	1	1			1		2	2	1
Glossiphonidae	1	1		1	1		2	1	1
Erpobdellidae	1			1		1		1	1
Asellidae	1								1
Chironomidae		2	1	1	1	1	1	1	1
Oligochaeta	2	2	2	3	2	3	3	2	1
BMWP SCORE	113	129	123	129	107	102	122	132	118
ASPT	5.4	5.6	6.2	5.6	5.4	5.7	5.5	5.7	5.4

These results contrast with the severe impacts associated with farm effluents found in intensive studies carried out earlier in the contract period. A chronic discharge of silage effluent to Pontfaen Brook resulted in damaging growths of sewage fungus and severe disruption of the stream fauna (Mainstone et al 1991), whilst more intermittent discharges to a tributary of the Nant Rhydw produced a similar reduction in biological quality (Rutt *et al* 1991). The contrast may be partially explained by the much higher dilution capacity of the Pibwr, where measured flows during the study period were in the range 118 - 860 litres sec^{-1}, in contrast to 20 - 240 litres sec^{-1} for Pontfaen Brook and 10 - 70 litres sec^{-1} for the tributary of the Rhydw. Thus, although Discharge 2 had a consistently high BOD (200 - 400 mg l^{-1}), the BOD downstream did not reach the level of 2 - 3 mg l^{-1} required to promote significant growth of sewage fungus beyond the mixing zone (Quinn and McFarlane 1988; Mainstone *et al* 1991). Similarly, although the ammoniacal nitrogen concentration was relatively high (10 - 20 mg l^{-1}) in this discharge, the maximum recorded level of ammonium below the farm was only 0.75 mg l^{-1} (0.004 mg l^{-1} un-ionized ammonia). The value of un-ionized ammonia is six times lower than the EQS value of 0.025 mg l^{-1} recommended by WRc for the protection of freshwater salmonids (Seager *et al* 1988). This figure is based on the value quoted by Alabaster and Lloyd (1982), below which no adverse effects on salmonid fisheries are thought to occur.

The lack of observable impact can also be partly explained by improvements in the management of the farm between the initial visit to the site in February 1991 and the start of the intensive study. It is likely that the biological impact observed in February 1991 (see Section 5.2) was caused by a leakage of yard water which formerly bypassed the lagoon but has now been sealed following a visit by the NRA Agricultural Liaison Officer.

Despite a lack of impact attributable to the farm, there is some evidence to suggest that the Pibwr in the vicinity of Penbontbren is affected by organic pollution from unknown sources further upstream. The reductions in dissolved oxygen observed in mid December at site A were quite marked and the occurrence of intermittent episodes of this type may account for the disparity between observed and predicted biotic indices and the absence of certain riffle dwelling taxa which had a reasonable probability of occurrence. The peaks in conductivity recorded at all sites appeared to be rainfall-generated and may be the result of salt-contaminated runoff from the adjacent A40.

6. SALMONID RECOLONISATION STUDIES

6.1 Introduction

Following acute pollution events resulting in large scale fish mortalities, a series of electrofishing surveys were carried out on two streams in South West Wales. Previous results from this work have been reported in Schofield (1988), Schofield and Bascombe (1990) and Mainstone *et al* (1991). The objectives of the work are to assess the extent of damage to fish stocks and to monitor the rate of natural recovery. Such information will be of value to the NRA in relation to the restoration strategies adopted following fish mortality.

The two study streams are the Afon Fenni, a tributary of the River Taf, and the Deepford Brook, within a sub-catchment of the Eastern Cleddau. A slurry spill occurred on the Afon Fenni on 21 August 1989. It originated from Trehoose Farm (SN245249) and entered the stream in its upper reaches less than 1 km from source (Figure 6.1). Based on the recovery of corpses and historical data from previous surveys, it was estimated that a total of 9040 trout fry (*Salmo trutta* L.) and 5310 trout parr had been killed. 120 salmon parr (*Salmo salar* L.) were also thought to have been lost. A previous survey (NRA 1990) had found no salmon fry in the stream and so these were assumed absent at the time of the kill. As the polluting farm was located close to the stream source, and the total kill zone extended almost to its confluence with the River Taf (a distance of 10 km), the catchment's fish stock suffered a severe loss.

The Deepford Brook was subject to an input of cattle slurry on 28 April 1988. The spill originated from a collapsed slurry lagoon at North Lamborough Farm (SN165236) and entered the brook some 2 km from its source, via a drainage ditch (Figure 6.2). It was estimated that 2700 trout fry and 2780 trout parr were killed along with 480 salmon fry and 67 salmon parr. Stocks in the two main tributaries, the Churchill stream and the Cotland Brook, were unaffected by the pollution.

Restocking was withheld on the Deepford Brook and its tributaries and on the Afon Fenni, in order that salmonid recolonisation of the two streams could be studied under natural conditions.

6.2 Progress to date

6.2.1 Methods

Eight, easily accessible sites on the Afon Fenni, each of approximately 50 m length, were selected for electrofishing. They constituted 2.5% of the total stream length from its source to its confluence with the river Taf (Figure 6.1, Table 6.1). Following the mortality, an initial fishing of the stream took place on 25/26 August 1989. A second was carried out on 17/18 October 1990 and a third between 16 and 20 September 1991. In the last two surveys, a site of 85 m^2 in area was semi-quantitatively fished (i.e. a single electrofishing run with no stop nets) on a tributary near the top of the stream, in order to assess its potential as a source of colonists (T in Figure 6.1).

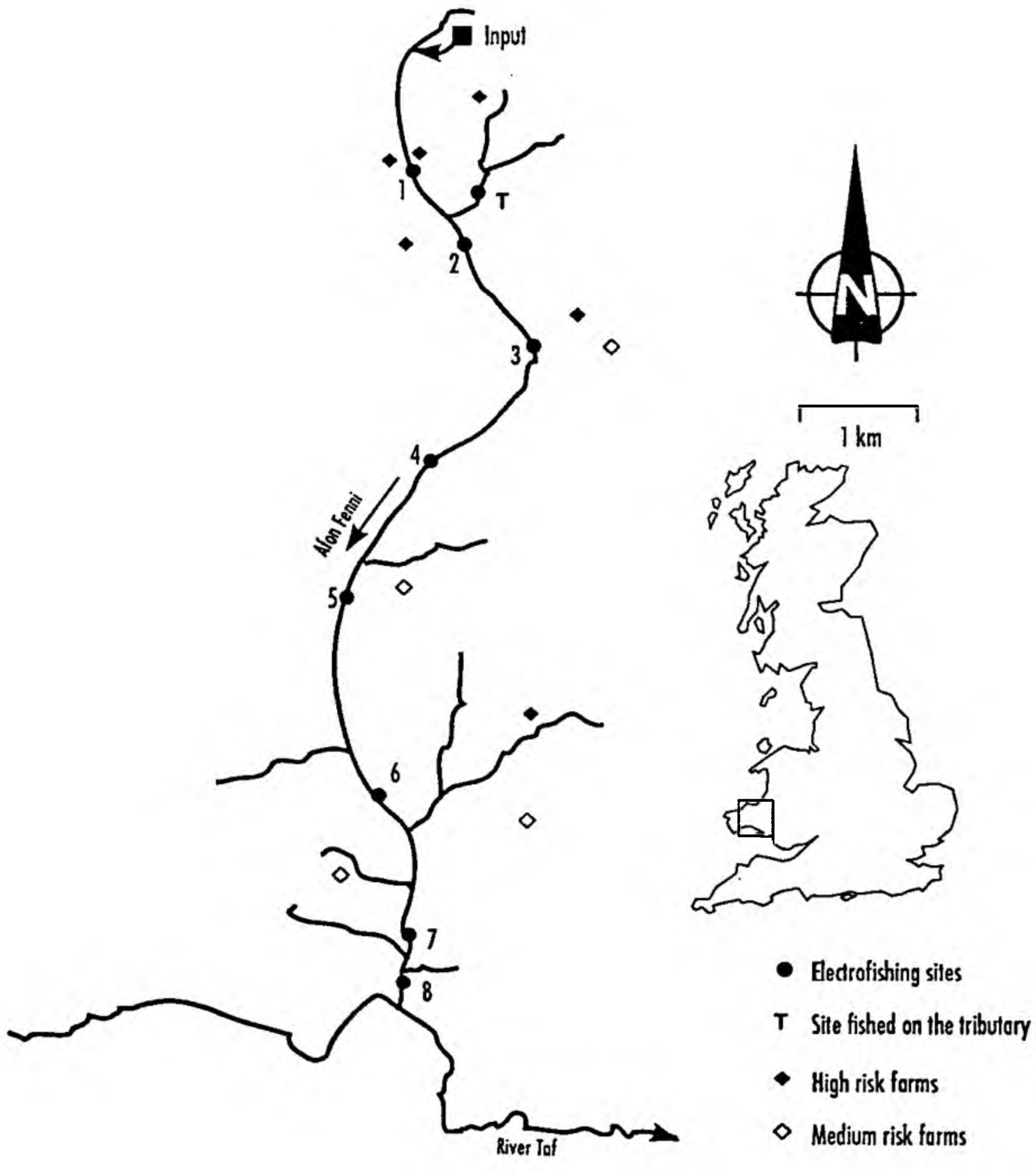


Figure 6.1 Location of electrofishing sites and farms at risk of polluting, on the Afon Fenni

Ten electrofishing sites were selected on the Deepford Brook and its tributaries. These were again each of approximately 50 m in length and also constituted 2.5% of the total length of the streams from their sources to the confluence with the Syfynwy (Figure 6.2, Table 6.2). The sites were initially fished on 5/6 May 1988. Successive surveys were undertaken on 19/20 September 1988, 22/23 August 1989, between 26 September and 4 October 1990 and between the 23 and 27 September 1991.

The first post-pollution survey on the Afon Fenni was carried out by NRA staff in rapid response to the pollution event, and was semi-quantitative. The results were adjusted so as to be comparable with quantitative data by dividing them by estimates of catch efficiency for each site, obtained from subsequent surveys. The remaining surveys on the Afon Fenni, and all those on the Deepford Brook, were quantitative; sites were enclosed by 1 cm mesh stop nets and two or three electrofishing runs performed to ensure catch depletion. Fork lengths, to the nearest 1 mm, of all salmonids caught were recorded and fry (0+) and parr (>0+) of both species were distinguished on the basis of length frequency data. Population estimates for the different age classes were calculated using the methods of Zippin (1956), or for two electrofishing runs, Seber and Le Crane (1967).

Table 6.1 Electrofishing sites on the Afon Fenni

Site	OSGR	Location	Width (m)	Gradient (m km^{-1})
1	SN241239	Afon Fenni 100 m downstream of Liechclawdd	1.9	20.0
2	SN245230	Afon Fenni at Maenoch	2.2	20.0
3	SN251220	Afon Fenni at Nantyreglwys Mill	2.9	13.3
4	SN241211	Afon Fenni at Rhydycaeshyd.	3.5	10.0
5	SN234199	Afon Fenni at Pistyll Gwyn	3.6	8.0
6	SN234184	Afon Fenni at Llwyncrwn	4.1	6.6
7	SN238169	Afon Fenni at Pont y Fenni	4.2	5.0
8	SN236163	Afon Fenni just above the confluence with the Taf	3.8	5.0

Historical data for sites 4 and 7 on the Afon Fenni, and site 3 on the Deepford Brook, were obtained from earlier work undertaken as part of NRA Welsh Region's salmonid monitoring programme (Welsh Water Authority 1988; NRA 1990).

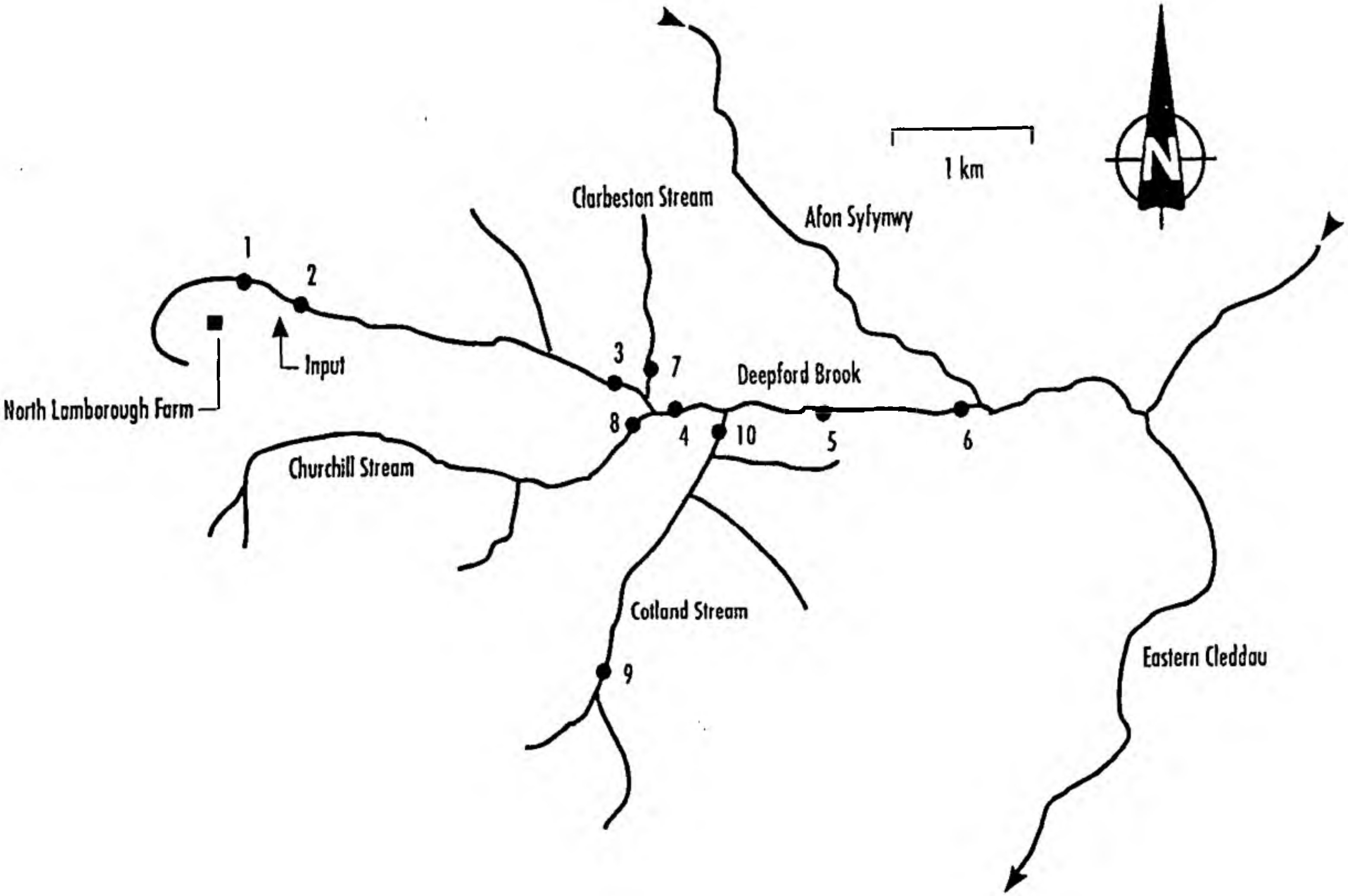


Figure 6.2 Electrofishing sites on the Deepford Brook and its tributaries

HABSCORE, developed by NRA Welsh region, is a multiple regression model designed to predict salmonid densities under given habitat conditions, assuming pristine water conditions (Milner *et al.* 1985; Milner and Wyatt 1991). Habitat assessment was undertaken during electrofishing in 1991. This involved making a detailed assessment of habitat characteristics at each site on the two streams and combining this with general information on the catchments obtained from 1:50000 Ordnance Survey maps. HABSCORE predicted salmonid densities for each site and compared them to those observed, indicating when the observed densities were significantly lower. The same sites were fished each year so the predictions could be compared with the observed densities from previous years, including those obtained from the regional salmonid monitoring programme (Welsh Water Authority 1988; NRA 1990).

6.2.2 Results

Afon Fenni

Following the pollution in 1989, trout fry were absent from all sites downstream of the input (Figure 6.3). In 1990 they were present at six of the eight sites. HABSCORE revealed that the densities at sites 2, 4, 5 and 6 were not significantly lower than would be expected for those sites under clean water conditions. In 1991 trout fry densities remained within predicted values at sites 4, 5 and 6; however, the density at site 2 fell from 14.8 100 m^{-2} in 1990 to 0.7 100 m^{-2} in 1991, and was significantly lower than predicted ($p < 0.01$). In 1990, nine trout fry were caught at the site on the tributary, but fry were absent in 1991.

Table 6.2 Electrofishing sites on the Deepford Brook and its tributaries

Site	OSGR	Location	Width (m)	Gradient (m km^{-1})
1	SM027206	Deepford Brook 50 m above effluent input	1.0	10.0
2	SM029205	Deepford Brook 50 m below effluent input	1.4	6.7
3	SM049200	Deepford Brook above road bridge	2.4	5.0
4	SM043198	Deepford Brook between Cotland Brook and Churchill Stream	2.5	4.4
5	SM060198	Deepford Brook at Drim Farm, below confluence of Cotland Brook	3.2	4.4
6	SM071199	Deepford Brook 50 m upstream of Syfynwy confluence	3.6	3.3
7*	SM050200	Clarbeston Stream at confluence with Deepford Brook	-	-
8	SM050198	Churchill Stream at Lower Lamborough	2.4	6.7
9	SM048184	Cotland Brook at Duckspool Farm	1.8	4.4
10	SM054197	Cotland Brook 200 m upstream of Deepford Brook	2.8	6.7

NOTES * This site has not been fished in recent years, but features in earlier reports. It is included here for reasons of continuity.

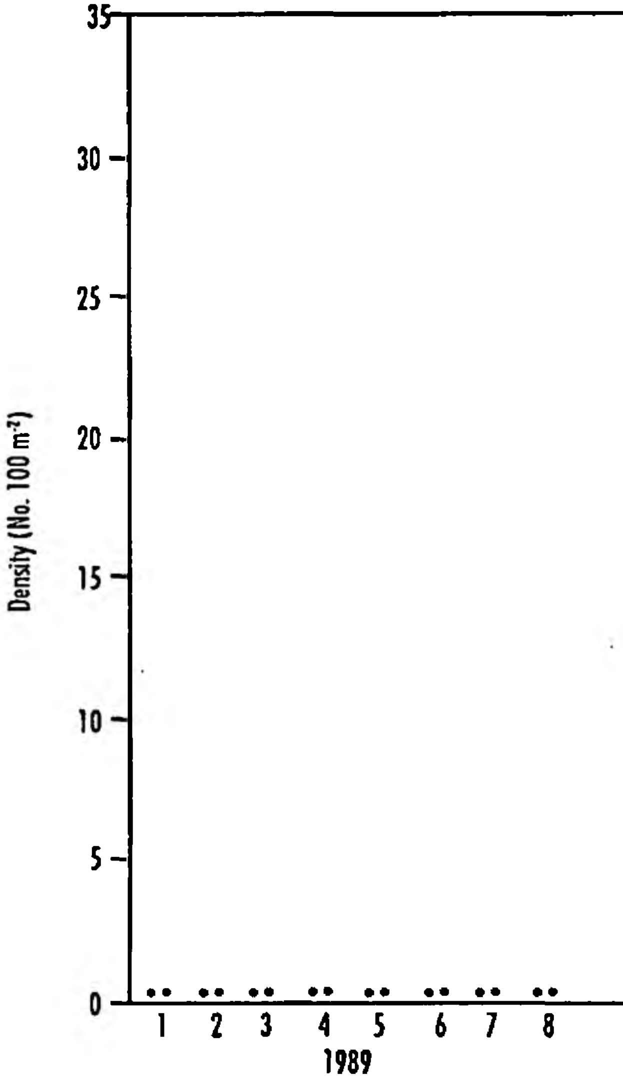
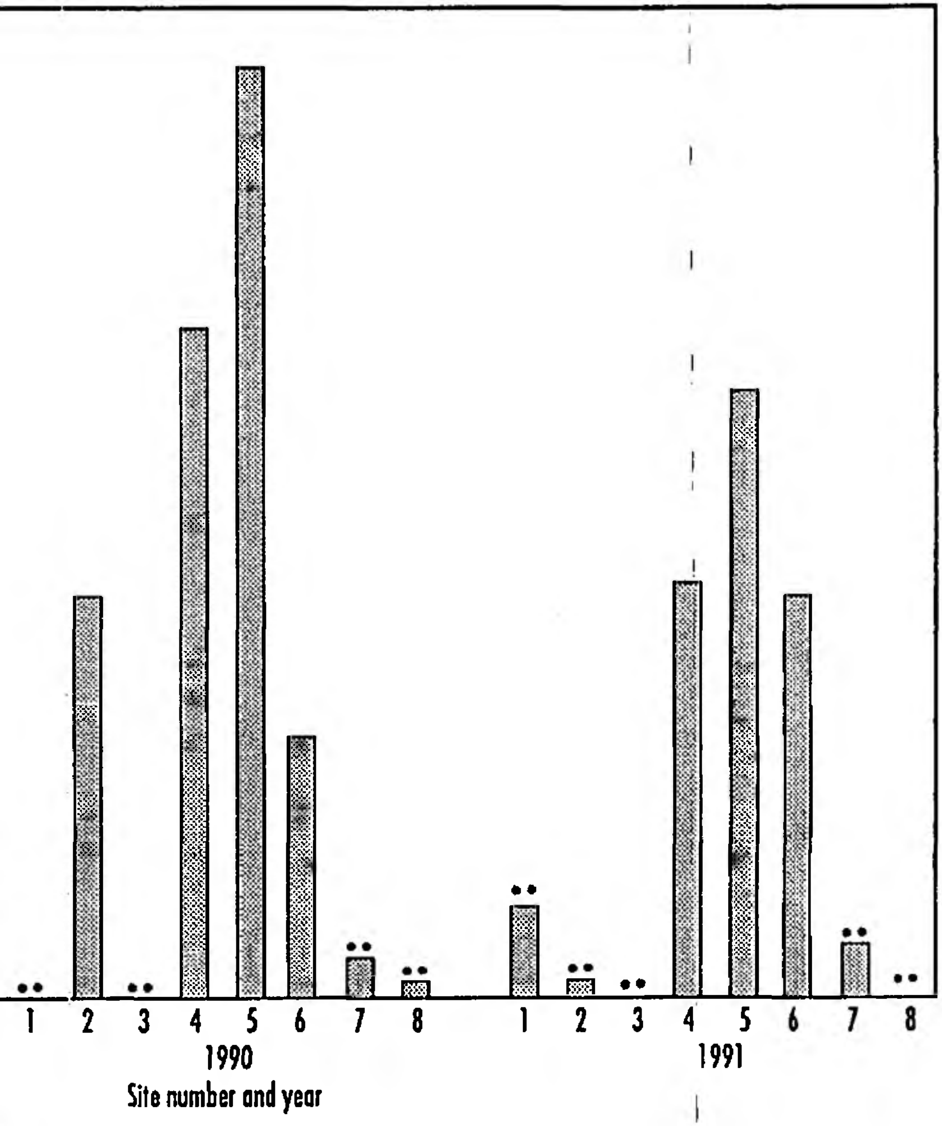


Figure 6.3 Density of trout fry (0+) at sites on the Afon Fenni. **:



: Significantly lower than predicted by HABSCORE (P< 0.01)

Historical data for the Afon Fenni were limited but were available for site 4 in 1986 and 1987 (Figure 6.4), and for site 7 in 1987 and in the summer of 1989, immediately before the pollution (Figure 6.5). At both sites, trout fry densities fluctuated widely in the years before the fish kill: from 4.1 100 m^{-2} in 1986 to 77.8 100 m^{-2} in 1987 at site 4, and from 11.2 100 m^{-2} in 1987 to 0 100 m^{-2} in 1989 at site 7. Fry densities are generally highly variable between years, and there is a large die-off through the first year of life that makes observed densities very dependent upon the timing of the survey. Nevertheless, fry densities appeared to have returned to pre-pollution levels at site 4 by 1990. At site 7 however, densities remained depressed and significantly lower than the HABSCORE prediction ($p < 0.01$) in both 1990 and 1991.

Immediately following the pollution, trout parr were present at sites 6, 7 and 8, with densities increasing with distance downstream (Figure 6.6). HABSCORE revealed that only the density at site 8 (9 100 m^{-2}) was not significantly lower than predicted. In 1990, trout parr were present at all sites apart from site 1, but only the density at site 4 (15.5 100 m^{-2}) was not significantly lower than predicted. In 1991, densities had increased at sites 4, 5, 7 and 8 such that none of these were significantly lower than predicted. Two trout parr were caught at the site on the tributary in 1990 but none in 1991.

Historical data for site 4 (Figure 6.4) showed trout parr density back to pre-pollution levels by 1990. Historical data for site 7 (Figure 6.5) showed a slower recovery with only the 1991 density comparable with pre-pollution densities.

With respect to salmon, fry were absent from all sites downstream of the input following the pollution in 1989 (Table 6.3). In 1990 they were present at sites 5, 6, 7 and 8, whilst in 1991 they were present at sites 7 and 8. At no time, even when fish were absent, did HABSCORE indicate that the observed densities were significantly lower than expected.

Table 6.3 Densities of salmon fry and parr (No. 100 m^{-2}) at sites on the Afon Fenni

	1989		1990		1991	
SITE	0+	>0+	0+	>0+	0+	>0+
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	1.0	0	0	0
6	0	0	1.1	0	0	0.5
7	0	0	19.8	0.8	0.9	3.7
8	0	0	4.6	0.63	3.5	3.6

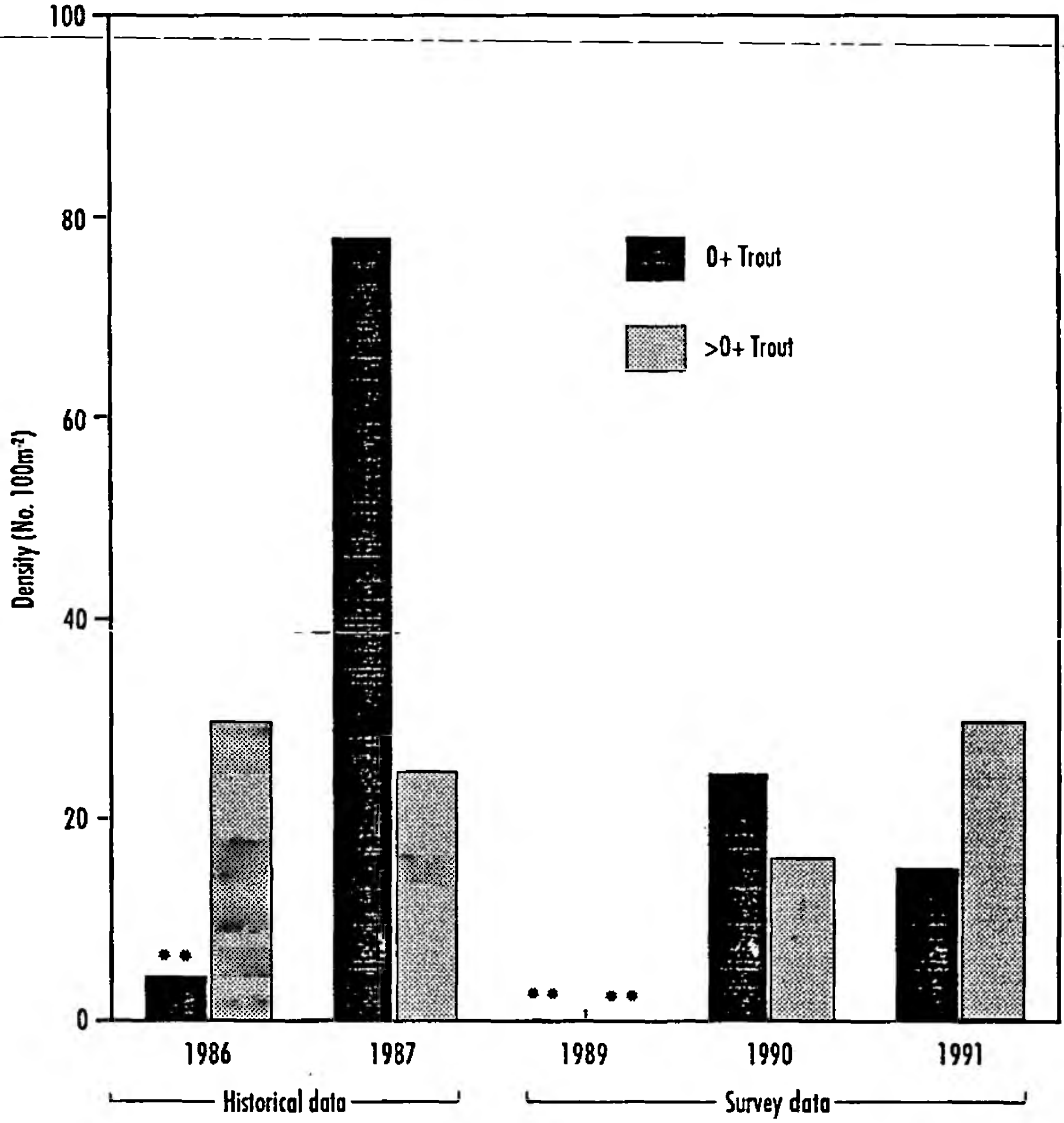


Figure 6.4 Comparison of historical data with survey data, for trout, at site 4 on the Afon Fenni.
**: Significantly lower than predicted by HABSCORE ($P< 0.01$)

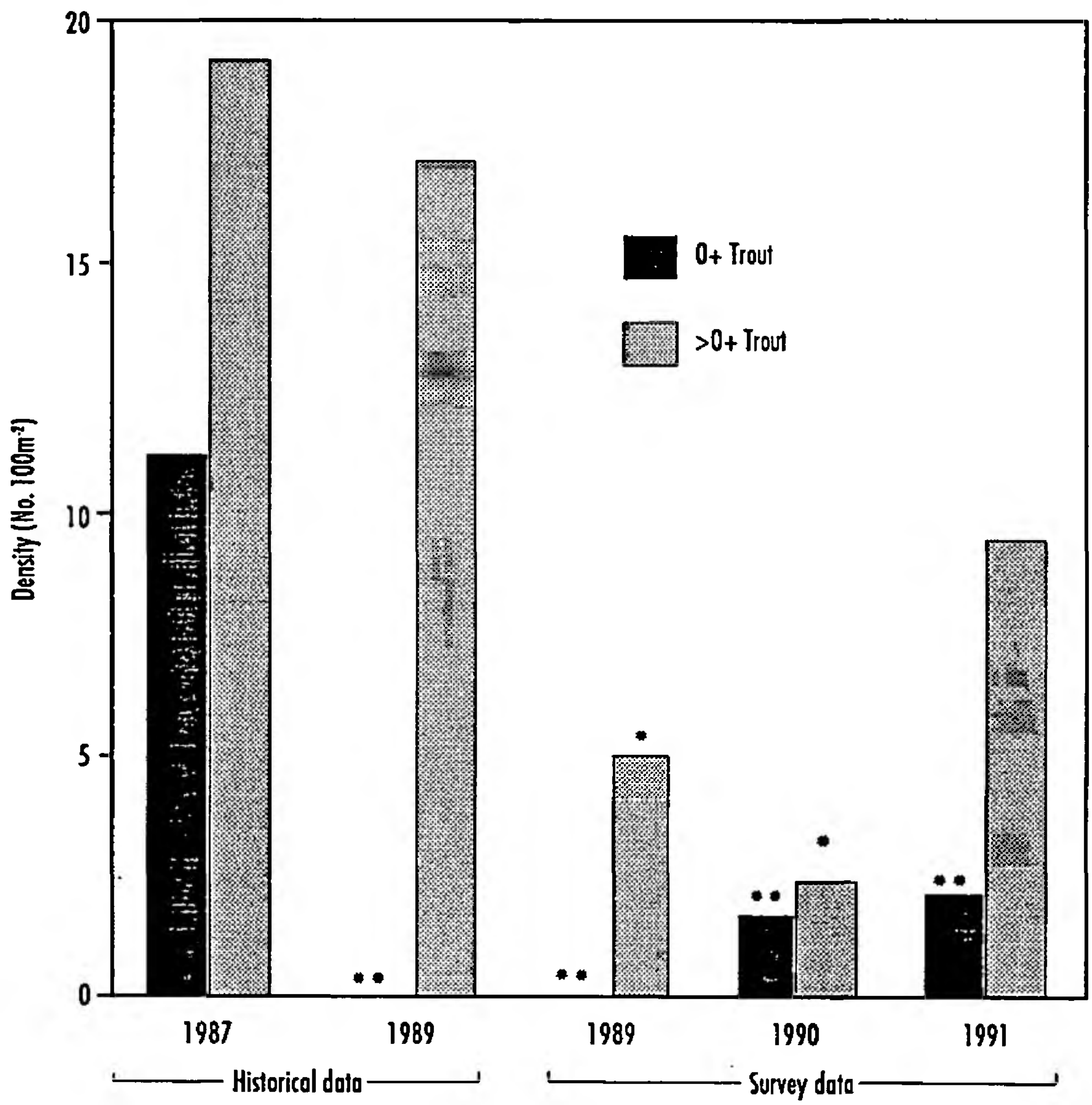


Figure 6.5 Comparison of historical data with survey data, for trout at site 7 on the Afon Fenni.
Asterisks indicate the significance of differences from HABSCORE predictions
** $p<0.01$; * $p<0.05$

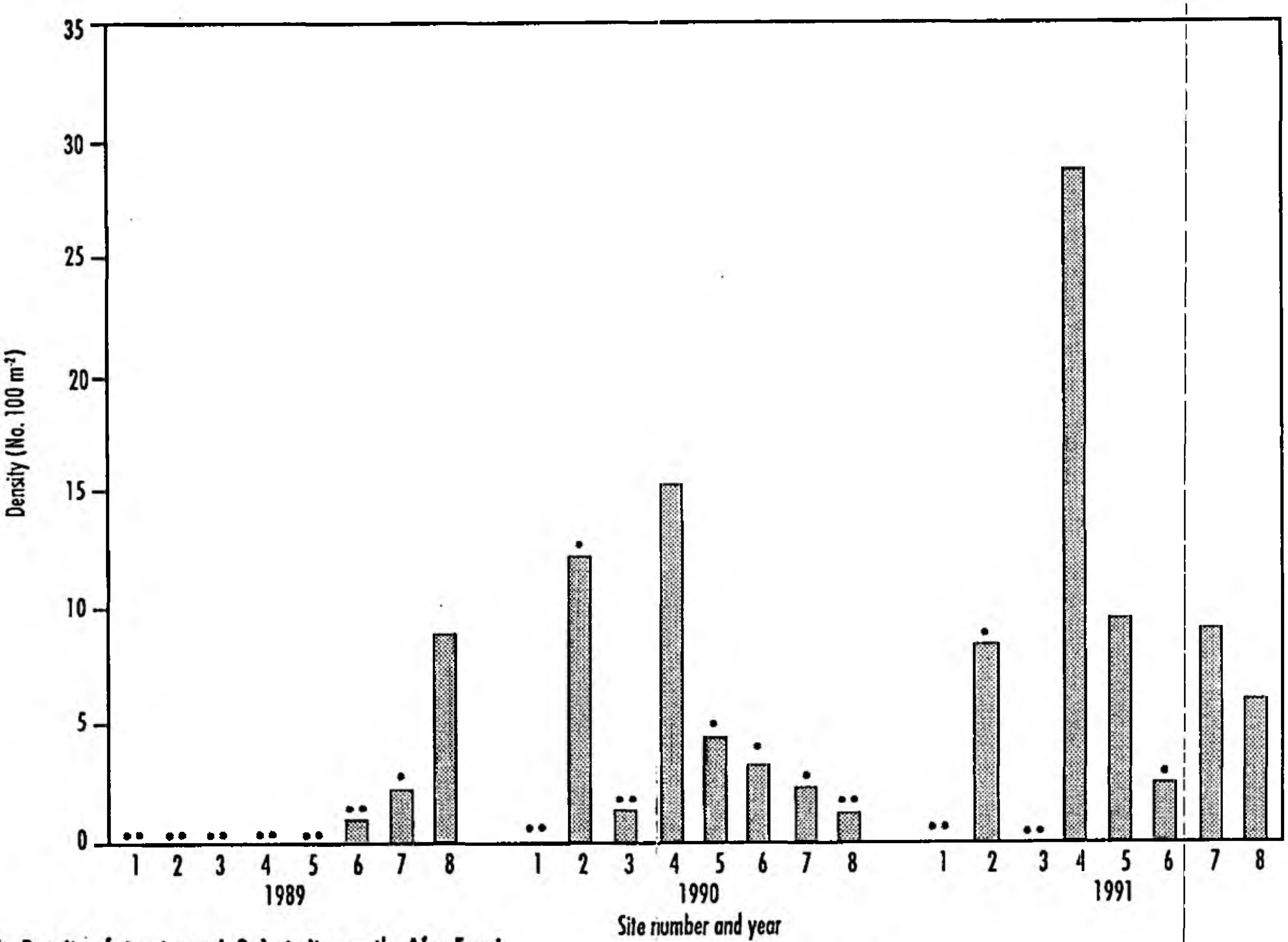


Figure 6.6 Density of trout parr (>0+) at sites on the Afon Fenni.
Asterisks indicate the significance of differences from HABSCORE predictions ** $p<0.01$; * $p<0.05$

In 1989, salmon parr were absent from all sites, whilst In 1990 they were present at sites 7 and 8 and in 1991 at sites 6, 7 and 8. HABSCORE revealed that only the absence of parr from site 6 was significantly lower than predicted ($p < 0.05$), in 1989 and 1990.

There were no historical data for salmon at site 4. Historical data for site 7 showed salmon fry to be absent in 1989, prior to the pollution, with salmon parr at a density of 3.3 100 m^{-2}. Fry and parr were present in both 1990 (20 and 1 100 m^{-2} respectively) and 1991 (4 and 1 100 m^{-2} respectively) at densities that were not significantly lower than HABSCORE predicted.

Deepford Brook

Following the pollution in May 1988, trout fry (0+) were absent from all sites below the pollution input (Figure 6.7). HABSCORE revealed that the absence of fry from these sites, and the small population that was present at site 1 (above the pollution input) were significantly lower than would be expected under clean water conditions. By September of the same year fry were present at all the sites, such that only the densities at those sites in the middle reach of the stream (3, 4, and 5) were significantly lower than HABSCORE predicted. Throughout the rest of the study trout fry densities remained significantly lower than expected at these middle sites, with the density at the bottom site (site 6) significantly lower in August 1989 and September 1990.

Historical data for site 3 (Figure 6.8) indicated that even before the pollution, trout fry density at this site was significantly lower than predicted.

Trout parr populations exhibited a more varied response than fry. They were absent from site 3 following the pollution in May 1988 and the densities at sites 2, 3 and 4 were significantly lower than HABSCORE predicted (Figure 6.9). The density at site 1, above the input, was also lower than predicted. The following year, trout parr had returned to site 3 but the densities at this and site 2 were still significantly lower than expected. In August 1989, the same was true at sites 1 and 4, and in September 1990 at sites 2, 3, 4, 5 and 6. In the final year of the study the densities at sites 1, 2, 4, and 5 were significantly lower than predicted. Historical data (Figure 6.8) suggested that trout parr populations at site 3 had returned to pre-pollution levels in August 1989, within 15 months of the pollution.

Data from the sites fished on the tributaries (Figures 6.10 and 6.11) showed that trout fry were absent from site 8, at the bottom of the Churchill Stream, during the final three years of the study. Parr, however were present at this site during all fishings and only at a density significantly lower than predicted in September 1991. At the bottom of the Cotland Brook (site 10), fry densities were significantly lower than predicted in May 1988 and September 1990 and 1991. Fry densities at site 9, near the top of Cotland Brook, were only significantly lower than predicted in September 1990. Trout parr density at site 9 was significantly lower than predicted during all fishings except September 1990.

Salmon fry were absent from all sites on the Deepford Brook in May 1988, immediately following the pollution (Table 6.4). In the remaining four surveys they were present only at site 6. At no time was the density of salmon fry significantly lower than that predicted by HABSCORE.

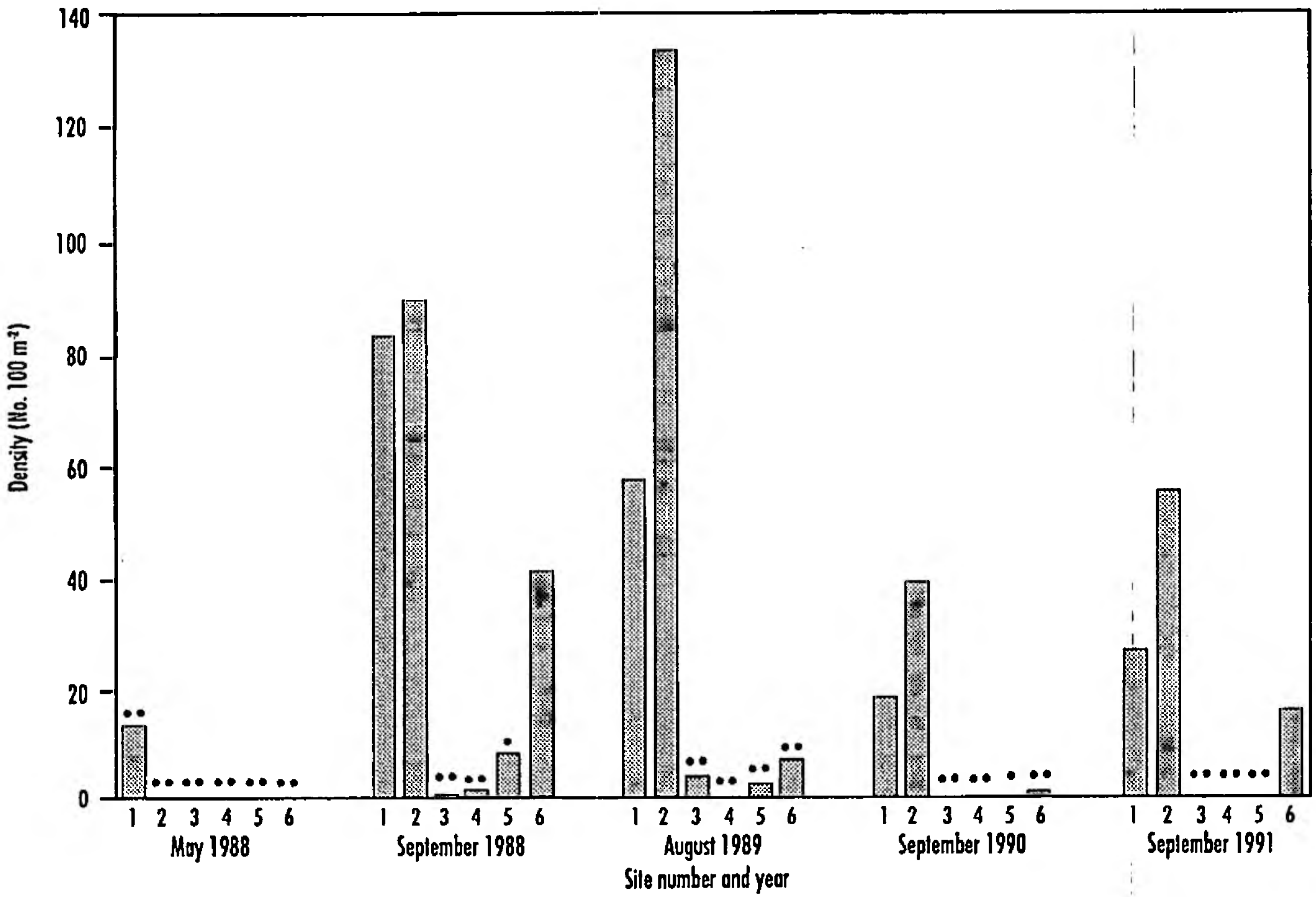


Figure 6.7 Density of trout fry (0+) at sites on the Deepford Brook.
Asterisks indicate the significance of differences from HABSCORE predictions ** $p<0.01$; * $p<0.05$; + indicates data unavailable

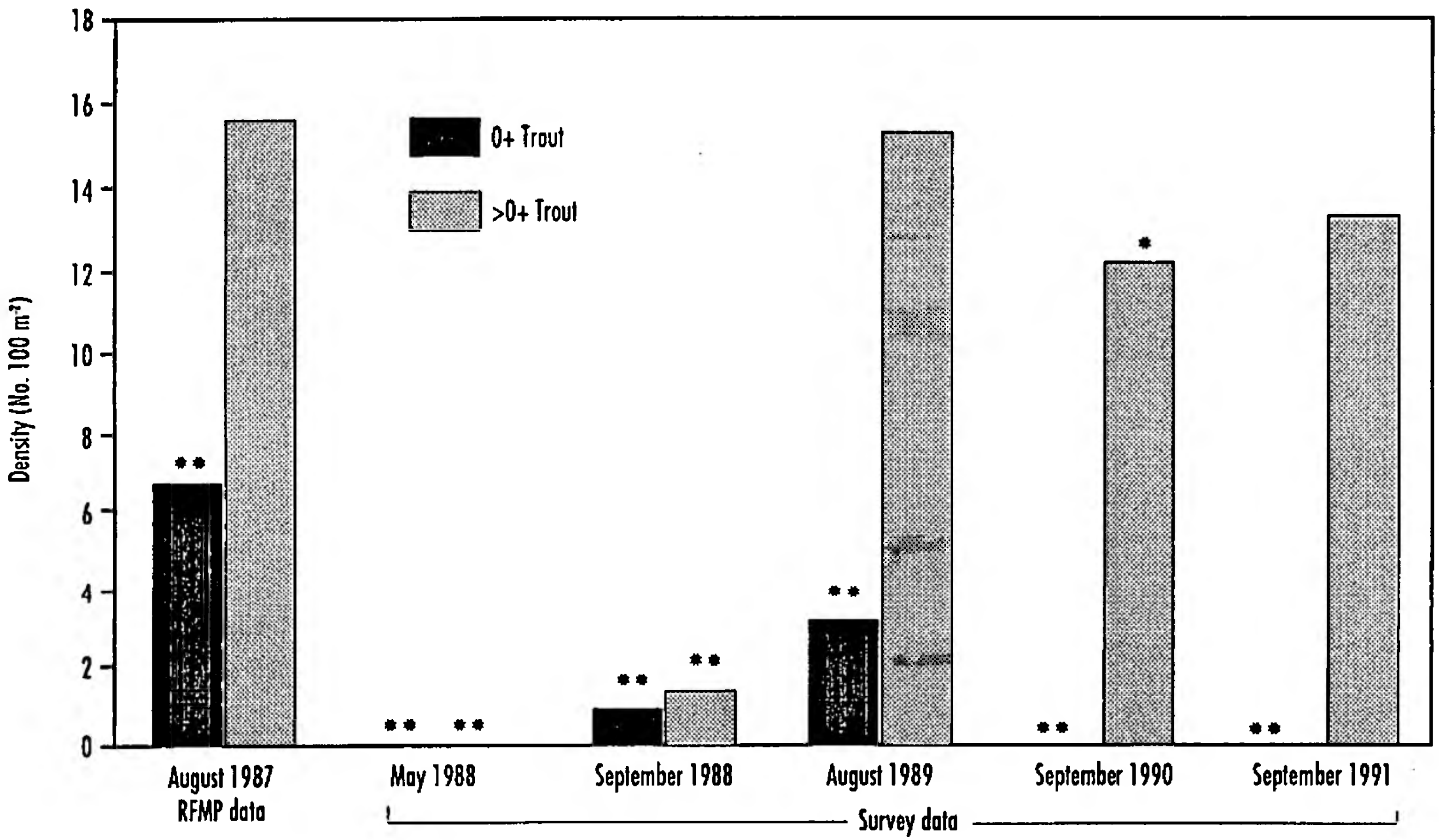


Figure 6.8 Comparison of historical data with survey data for trout, at site 3 on the Deepford Brook. Asterisks indicate the significance of differences from HABSCORE predictions ** p<0.01 ; * p<0.05

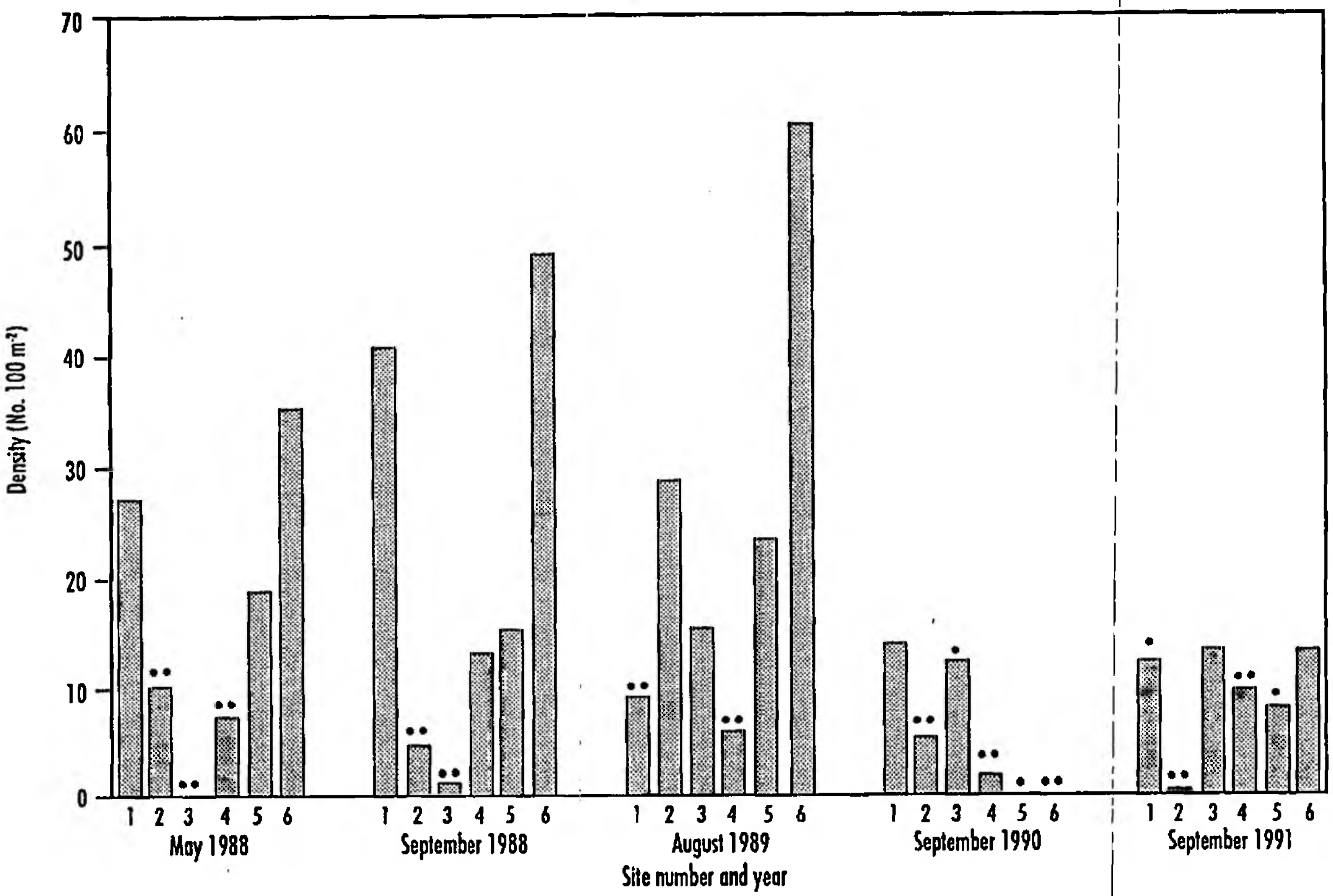


Figure 6.9 Density of trout parr (>0+) at sites on the Deepford Brook.
Asterisks indicate the significance of differences from HABSCORE predictions ** p<0.01 ; * p<0.05 ; + indicates data unavailable

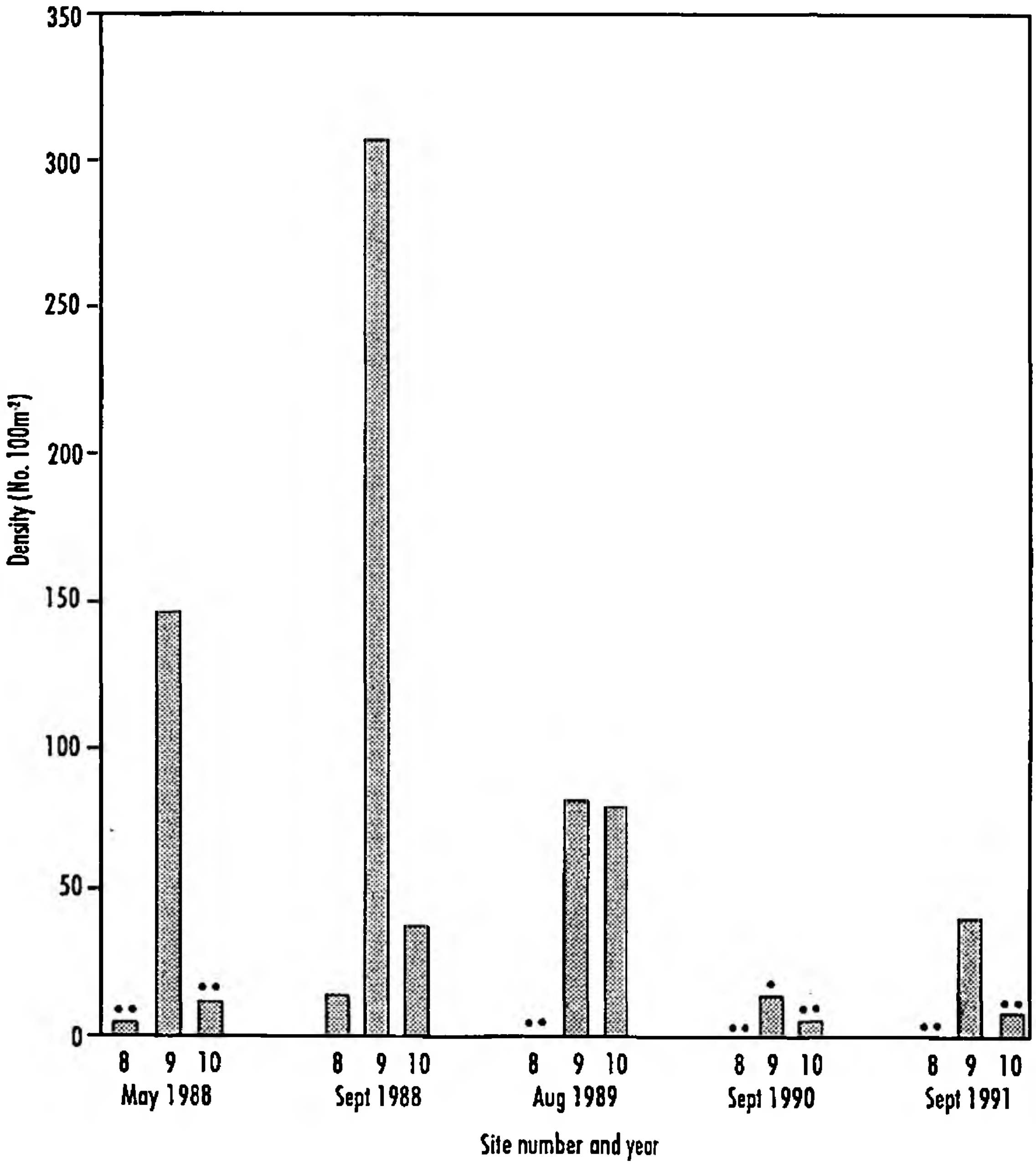


Figure 6.10 **Density of trout fry (0+) at sites on the tributaries of Deepford Brook. Asterisks indicate the significance of differences from HABSCORE predictions ** $p<0.01$; * $p<0.05$**

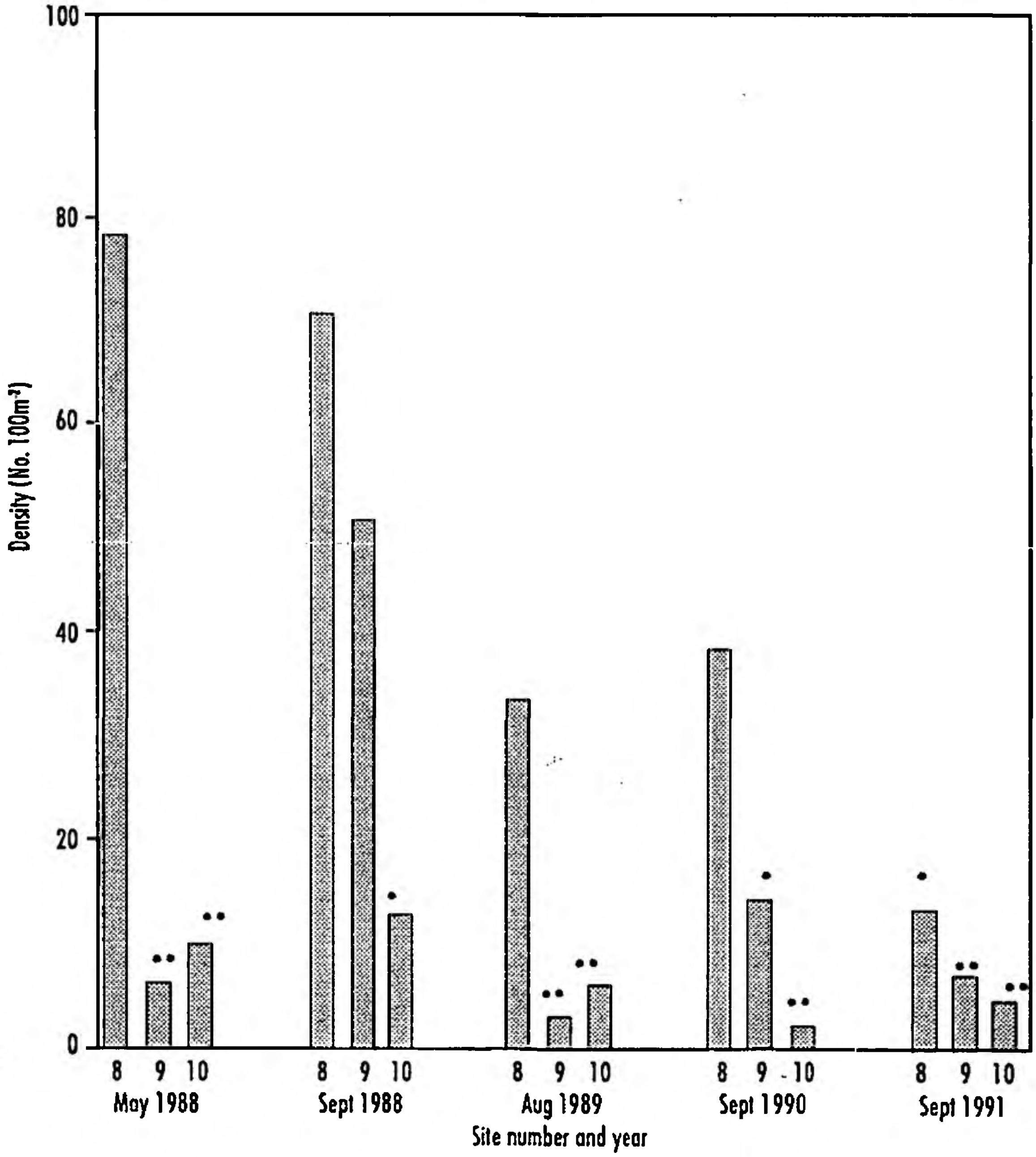


Figure 6.11 Density of trout parr (>0+) at sites on the tributaries of Deepford Brook. Asterisks indicate the significance of differences from HABSCORE predictions ** $p<0.01$; * $p<0.05$

Salmon parr were present at site 6 in all years, apart from September 1990 (Table 6.4). They were also present at site 4 in September 1988 and site 5 in September 1991. As with salmon fry, at no time were the densities significantly lower than those predicted by HABSCORE.

In the tributaries, fry were present at site 10 on the Cotland stream in September of 1990 and 1991. Salmon parr were present only at the very beginning of the study at site 8 on the Churchill Stream.

Table 6.4 Densities of salmon fry and parr (No. 100 m^{-2}) at sites on the Deepford Brook and its tributaries

Site	May 1988		Sept 1988		Aug 1989		Sept 1990		Sept 1991	
	0+	>0+	0+	>0+	0+	>0+	0+	>0+	0+	>0+
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	3.3	0	0	0	0	0	0
5	0	0	0	0	0	0	+	+	0	1.6
6	0	34	30.8	44.5	5.7	19.1	5.35	0	5.94	2.3
7	-	-	-	-	-	-	-	-	-	-
8	0	3	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0.7	0	0.8	0

+ Data unavailable.

6.2.3 Discussion

Trout

Both the Afon Fenni and the Deepford Brook showed the ability to recover to a certain degree following their fish mortalities. Recovery was much more marked in the Afon Fenni whose fish stocks had originally been the more seriously depleted.

Trout populations on the Afon Fenni had shown a substantial recovery within two years of the fish mortality. Comparison with HABSCORE predictions and historical data indicated that in the middle region of the stream, trout fry populations had recovered within a year of the fish mortality. Trout parr were slower to recover but numbers had reached predicted levels at most of the middle and lower sites within two years of the mortality. Redistribution within the stream and its tributaries would have been responsible for the parr populations in 1990, with recruitment from the previous years fry supplementing this in 1991.

In Deepford Brook, partial recovery of fry populations had occurred by September 1988. This had to be attributed to the redistribution of fry within the stream, as no restocking had been undertaken. Jorgensen and Berg (1991) showed that trout fry can move up and downstream up to a maximum distance of 600 m. The Deepford mortality occurred in May, before density-dependent mortality mechanisms would have had time to operate fully, and hence in the unaffected reaches of the catchment there would have been a high density of newly emerged fish available to recolonise (the significantly low density of fry at site 1 may have been due to difficulties in electrofishing the small, recently emerged fish, causing an underestimation of their numbers). Following this initial recolonisation, recovery appeared to cease and fry populations remained depressed at the lower sites throughout the rest of the study.

Trout parr on the Deepford Brook were thought to have recolonised site 2 immediately after the pollution, in the period before the first survey. Parr had returned to site 3 by September 1988. Further assessment of recovery was difficult as the densities fluctuated so much.

Previous work on salmonid recovery includes a study by Workman (1981) who looked at the recovery of trout in a stream in Montana, following chemical poisoning. The results suggested that it took 4 years and 3 spawning periods before the carrying capacity of the habitat had been attained over the affected reach of 35.6 km. More recent, unpublished, work includes a study by NRA Yorkshire Region who have been examining the recovery of trout stocks following a release of chlorine into Fossdale Beck, a tributary of the River Ure (NRA 1991a). Results showed that trout populations had largely re-established themselves within a normal life span (three to four years) in the study reach of 300 m. Both these studies differed from the Afon Fenni and the Deepford Brook in that they each had large unaffected upstream sections which provided a source of colonists.

Recovery of trout on the Afon Fenni may have been aided by the presence of sea trout, which were absent from the studies of Workman (1981) and NRA Yorkshire Region (1991a). They were also known to be present on the Deepford Brook but only at the lowest site, and are therefore likely to have contributed little to the overall recovery of the stream. Work by NRA Welsh Region on the River Teifi (NRA 1991b) showed that salmon populations recovered quicker than those of non-migratory trout. It was suggested that the migratory salmon were less susceptible to sudden pollution events in the streams where they spawned, than were the resident, native trout populations. Historically, redds excavated by migratory sea trout have been present on the Afon Fenni as far upstream as site 4. If migratory trout share the same ability to recover from this type of sudden pollution event as do salmon, it may help to explain the rapid recovery of juvenile trout in the middle and lower reaches of the Afon Fenni. It is also possible that a fall in trout density within the stream may occur in the future when fish that were killed in the mortality should have returned to spawn.

The low observed (compared to predicted) trout fry and parr densities in 1990 and 1991 at the upper sites on the Afon Fenni were most probably the result of further inputs of agricultural waste. From time to time during the survey the effects of chronic pollution were observed in the upper reaches of the stream. Sewage fungus cover of up to 30% was observed within the stream: at site 3 in spring 1990 (Mainstone *et al* 1991) and during electrofishing in 1991, and in the top tributary (T), considered to be a potential source of colonists. This may account for the absence of fish from this tributary and the reduction in the density of trout fry at site 2 in the final year of the survey. Indeed, there were 6 farms graded by pollution control as having either a high or medium pollution risks in the vicinity of these top sites (Figure 6.12). In contrast, there was only one such farm in the middle region of the stream, where sites 4, 5 and 6 were situated.

Recruitment of trout fry at the bottom sites on the Afon Fenni and at the middle and lower sites on the Deepford Brook was poor. Historical data from site 7 on the Afon Fenni indicated there was an adverse influence on populations at this site even before the fish mortality occurred. This may be a result of further inputs of agricultural pollution in the lower reaches. For example, in spring 1990 an overflowing slurry lagoon was observed discharging into the Churchill Stream (site 8), causing the growth of sewage fungus (Mainstone *et al* 1991); in addition, a ditch was observed during electrofishing in 1990, discharging slurry into Deepford Brook just below site 5.

Trout populations in the lower reaches of both streams may also be affected by siltation. Naismith and Wills (1991), working on the Torridge catchment in Devon, noted an elevated silt content in the spawning gravels of intensively farmed catchments with poor salmonid populations, and suggested that this was affecting egg and alevin survival. The lower reaches of the Afon Fenni were of a gentler gradient than its upper reaches and would have been more prone to siltation. The Deepford Brook, on the other hand, had an overall gentler gradient and silting would have been more pronounced over a greater proportion of its length (see Tables 6.1 and 6.2). This may help to explain why the recovery of trout populations on the Deepford Brook was not as good as on the Afon Fenni.

Salmon

The distribution of salmon in West Wales tends to be restricted to streams with a width greater than 3 - 4 m (Wightman 1989) and so the absence of salmon from the upper sites on both streams was not considered unusual (see Tables 6.1 and 6.2). On the Afon Fenni, fry and parr both returned to the bottom sites within a year of the pollution, indicating that some recovery had taken place. In 1991, results indicated further improvement in parr populations but the fry densities at the bottom sites had declined. Comparison with historical data for site 7 suggested that both fry and parr populations had recovered by 1990. On the Deepford Brook, salmon fry had returned to site 6 in the September following the mortality, again suggesting that some recovery had taken place. Accurate assessment of recovery of salmon on both streams was difficult as they were at the limit of their distribution and prone to large variations in density.

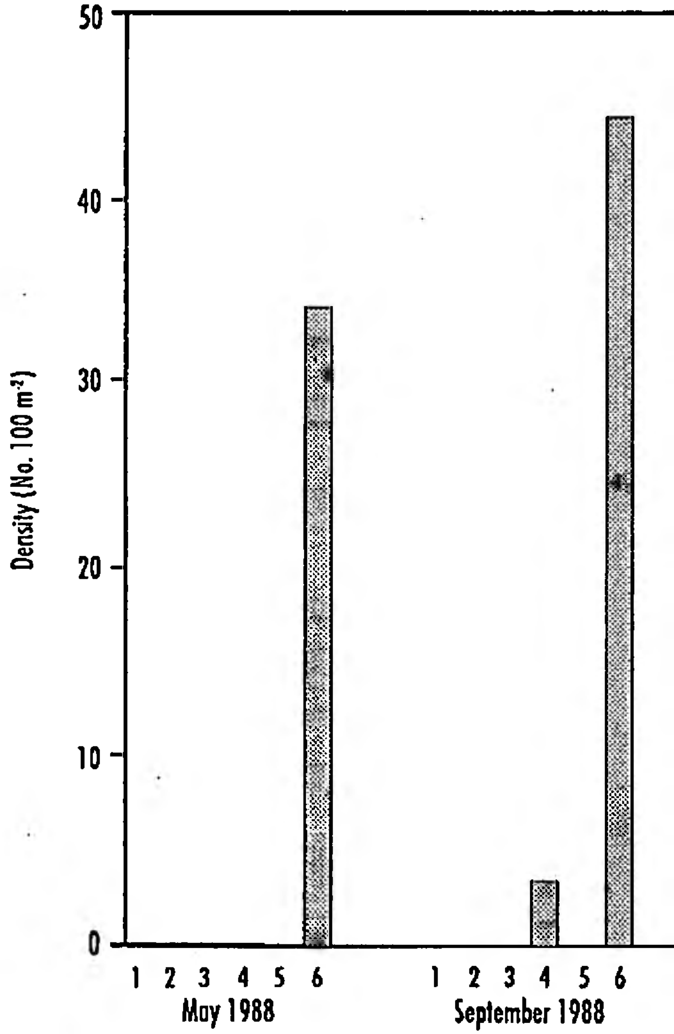
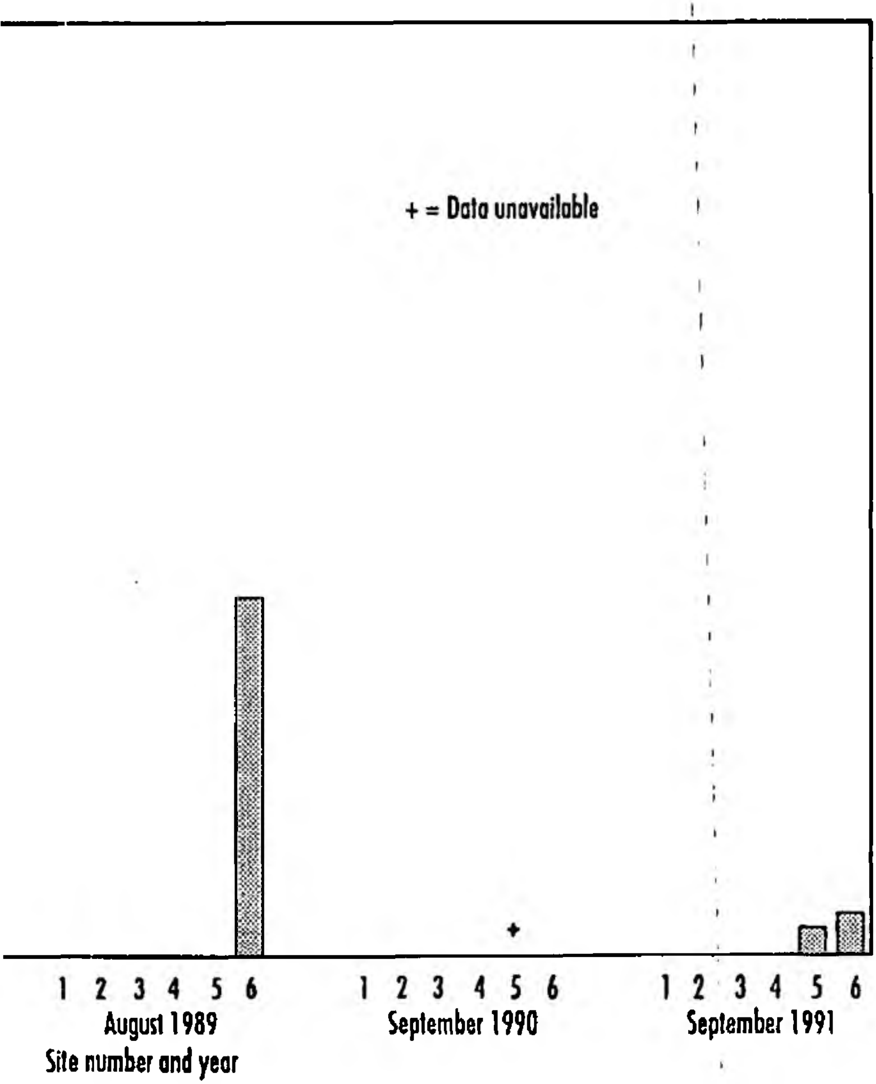


Figure 6.12 Density of salmon parr (0+) at sites on the Deepford Brook



+ = Data unavailable
+
1 2 3 4 5 6
August 1989
1 2 3 4 5 6
September 1990
1 2 3 4 5 6
September 1991
Site number and year

7. NATIONAL POLLUTION RISK DATABASE

7.1 Introduction

In order to place farm pollution in a wider context, a national assessment of the problem was undertaken during the early part of the project. This was reported in an earlier interim report (Mainstone *et al* 1991). Part of the assessment involved the development of a database of information relating to farm pollution risk, using Geographical Information System technology. Funds recently became available on a related NRA project (Project Ref. A17.007) for the database to be refined.

7.2 Progress

The combination of factors contributing to risk (livestock density, rainfall, soil permeability and topography) has been modified to produce a more realistic representation of farm pollution risk across the UK. The user interface has also been developed, such that all of the distribution maps on the database can now be displayed by the use of various menu options. Individual catchment cells (of which there are *ca.* 1000 covering the UK) can be interrogated for actual livestock numbers and values of other risk factors in the database. The refinements to the database will be reported in the final project report in September 1992.

8. FUTURE WORK

8.1 The use of the rapid appraisal methodology in Wales

The 15 catchments being studied in West Wales were revisited in February/March 1992 to assess the success of the farm visit programme using the rapid appraisal methodology. The samples taken will be processed and the results interpreted in the light of the remedial measures that have been implemented on polluting farms.

The remaining samples to be used for the development of the summer indicator key will be processed and the results analysed using TWINSPAN. The final key will be reported in the July progress meeting.

8.2 Intensive monitoring

Monitoring of the Nant Pibwr will be completed and the site decommissioned. No more new sites will be investigated.

8.3 Information collation and final report production

The results produced over the course of the study period will be drawn together and reported as a series of documents in September 1992. Outputs will include a manual for the development of indicator keys in other areas, and a field guide to the use of the rapid appraisal technique, aimed at non-biologists.

9. CONCLUSIONS TO DATE

9.1 The use of the rapid appraisal methodology in Wales

Progress with the programme of farm visits, necessary to the successful demonstration of the rapid appraisal approach, has been slow. As a consequence, the results of fieldwork undertaken in February and March, where 150 sites were revisited using the indicator key, may show little improvement in river quality.

9.2 Application in NRA South West Region

TWINSPAN classification of the macroinvertebrate data from Devon produced three site groups showing differences in variables which relate to organic pollution from farms.

The associated indicator key incorporated taxa whose distribution and abundance are considered to be affected by organic pollution.

The rapid appraisal system based on the TWINSPAN classification appears to be more discriminating than that reported previously when macroinvertebrate data at the 'family' level were analysed.

9.3 Intensive monitoring

A detailed investigation on the Pibwr catchment showed no major impact of dairying wastes from Penbontbren Farm on the water quality and invertebrate populations of the watercourse.

Growth of sewage fungus in the mixing zone below the most polluting discharge was the only observable effect.

The lack of impact probably relates to both the high dilution capacity of the Pibwr and remedial measures taken to stop a formerly serious input of yard water.

There is some evidence to suggest that this part of the Pibwr catchment is subject to organic pollution from sources further upstream.

9.4 Salmonid recovery studies

Small third order streams have an ability to recover, even from severe fish mortalities, providing that fish habitat has not been adversely affected.

The presence of migratory trout may have increased the rate of recovery at sites in the middle reaches of the Afon Fenni.

The upper reaches of the Afon Fenni appear to be suffering from continued inputs of farm pollution.

Silt content of spawning gravels may be having a detrimental effect on the survival of eggs and alevins in the lower reaches of the Afon Fenni and the middle and lower reaches of the Deepford Brook; further investigation, however, would be required to prove this relationship.

10. RECOMMENDATIONS TO DATE

10.1 The use of the rapid appraisal methodology in Wales

Sufficient resources must be made available for farm visits to ensure there are measurable improvements to be registered by the follow-up biological survey the following year.

10.2 Application in NRA South West Region

The future development of rapid appraisal methods by TWINSPAN classification should use macroinvertebrate data grouped at 'species/genus' level rather than at higher taxonomic levels.

The rapid appraisal methods developed under this contract should be given further trials to assess their applicability and usefulness in NRA South West Region.

10.3 Intensive monitoring

Possible sources of organic loading to the upper reaches of the Pibwr should receive further investigation.

10.4 Salmonid recovery studies

A further 1 - 2 years fishing should take place on the Afon Fenni, in order to further assess its recovery.

Electrofishing the Deepford Brook is unlikely to yield any new information and should be discontinued.

HABSCORE has proved to be a useful technique for assessing the recovery of salmonids and should be considered as an impact assessment tool in the event of future mortalities.

At the present time, restocking should not be undertaken on either stream. Effort would be better spent understanding the causes of poor trout densities, where they occur, and eliminating them. The upper reaches of the Afon Fenni would benefit from further biological monitoring, to assess the risk posed to the fishery by farms in the area. The potential problem of siltation in spawning gravels, in the lower reaches of the Afon Fenni and the middle and lower reaches of the Deepford Brook, should be investigated.

The effect that migratory trout have on recovery rate also merits further investigation.

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