A simple key to canal water quality

using a biological technique

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SUMMARY

1. Sixty sites on canalised watercourses in the Thames, South-Western, Midlands and Yorkshire regions were sampled using the Chironomid Pupal Exuviae Technique.

2. Chironomid data were directly related to associated physical and chemical characteristics of each site.

3. Changes in abundance of chironomid taxa were significantly correlated with water quality, after accounting for geographical variation.

4. A 'non-expert' scoring system is proposed for assessing water quality in canals. Scores are attributed to widely distributed, frequently occurring and easily recognisable indicator taxa. A dichotomus key based on six of the these indicators is provided for classifying canal water quality.

INTRODUCTION

Biological assessment of water quality can require a variety of sampling equipment and methods, depending on the habitats under investigation. For example, a pond net could be suitable for sampling a riffle while a dredge may be most appropriate for a deep-water habitat. The use of more than one method of sampling to compare different habitats will confound the interpretation of data for water quality assessment.

During the early 1970's a biological sampling technique was developed which was considered applicable to all riverine habitats, from source to river mouth. The technique requires the collection of floating debris caught behind obstacles at the margins of rivers. Typically, this debris contains numerous skins (exuviae) cast-off by insect nymphs, larvae and pupae. Most numerous among these cast-offs are the pupal exuviae of Chironomidae (non-biting midges). There have been over 500 species of Chironomidae identified in Britain, this number is greater than the number of species of all other aquatic non-dipteran (true flies) families. Chironomids are often the most abundant macroinvertebrates in rivers. Despite a wide range of habitats, life-styles and water quality preferences, aquatic species of chironomid need to reach the water surface as pupae so that the adults can emerge. Chironomid pupal skins remain afloat for about two days before sinking and decomposition. Experiments have shown that pupal skins become caught behind obstacles in a river close to the point of adult emergence. The distance pupal skins travel depends on water current, channel width and straightness, wind direction and strength. For example, in a river of mean width 9m and surface current 30 m sec^{-1}, 90% of pupal exuviae travelled less than 200m. A random selection of pupal skins from debris collections at a river site should be representative of species emerging over the previous 48 hours from all available habitats a short distance upstream.

Chironomid larvae in British rivers typically take several weeks to several months to develop from the egg stage to become pupae, depending on species and water temperature. Many species have two generations a year but for some there could be five or more generations. The abundance and diversity of chironomid larvae provide the biologist with the potential to assess the effects of water and sediment quality integrated over several months. Sampling

chironomid larvae directly would invoke the problems of sampling different habitats, referred to in the first paragraph. The collection of pupal skins requires the same technique, irrespective of the type of waterbody.

The Chironomid Pupal Exuviae Technique (CPET) is most useful when it is necessary to assess water quality over a range of watercourses of different habitats or in water too deep for kick-netting or when semi-quantitative data are required. CPET would appear to be particularly suited to assess water quality in canals and canalised rivers. Many of these watercourses were excluded from the 1995 General Quality Assessment (GQA) because of the difficulty in obtaining representative biological samples. The aims of this report are firstly to provide a relative assessment of water quality in selected canals and canalised water courses. Secondly, this report provides a 'non-expert' system of assessing canal water quality which will reduce the time required in processing samples. Thirdly, it is hoped that other Agency biologists will try this system of assessment and report their findings and criticisms back to me.

SAMPLE SITES

Chironomid pupal skins have been collected from 60 sites within the Thames, South-Western, Midlands and Yorkshire regions of the Agency (Table 1). Sites in the Thames region were chosen for specific studies, unrelated to the aims of this report (eg. monitoring sewage effluent impacts for organic and inorganic enrichment). Table 1 records previous publications which have used these data. Data for the Taunton and Bridgwater Canal were provided by Dr R.S. Wilson while sites in other regions were chosen to extend the range of environmental variables studied (Fig. 1, Table 2).

METHODS

Chironomids

Each site was sampled at least three times, in different months between April and October of the same year (Table 1). Four sites on both the Wey navigation and the Oxford canal were

sampled in two separate surveys. At each site, floating debris was collected from several points, often behind lock gates, with a 250µm mesh net on an extendable light-weight pole. Samples were brought back to the laboratory and refloated in a bowl of water, stirred and subsampled randomly. The subsample was viewed under a low-power binocular microscope so that all the pupal skins were removed and identified, at least to generic level. Most samples were sorted until at least 200 skins were obtained, producing a minimum of 600 skins for a survey unless there were insufficient skins in a sample. Samples taken by Dr Wilson from the Oxford canal in 1991 and the Bridgwater-Taunton canal were sampled monthly.

Environmental data

As this was largely a retrospective analysis, selection of environmental data was determined by availability. Available physical measurements identified by the Freshwater Biological Association's River Classification Scheme as the best discriminators of macroinvertebrate distribution were selected for correlation with chironomid data. These were; latitude, longitude, mean air temperature, air temperature range, altitude, slope and discharge. Discharge at canal sites in the Thames region was based on nominal categories used for the 1990 GQA survey and in any case was based on data from feeder streams.

Chemical data were obtained from the Agency archive for the twelve month period ending on the month of the final pupal skin collection for each survey. Chemical data for canals outside the Thames region were kindly supplied by Matthew Sully (South Western), Brian Hemsley-Flint (Yorkshire), Shelley Howard and Peter Hufton (Midlands). The following measurements were used; mean pH, 90%ile BOD, 10%ile DO(%), 90%ile ammoniacal nitrogen, 90%ile TON, 90%ile chloride, 90%ile ortho-phosphate, mean hardness, 90%ile dissolved copper, 90%ile total zinc. Most sites were sampled monthly. Percentiles were calculated according to the formulae and presumed distributions of chemical data reported in the National Rivers Authority Water Quality Series Report no 19 "The Quality of Rivers and Canals in England and Wales 1990-92" p. 14.

Data analyses

Sample data for each site during a survey were amalgamated before analysis. This reduced variation due to seasonal differences in adult peak emergence periods between taxa. Taxa abundances were expressed as percentages of the total abundance to account for differences in sampling effort.

The first approach to interpreting biological data used an objective two-way classification (samples and taxa) called TWINSPAN. A quantitative classification was obtained by setting abundance cut-levels of 5%, 10%, 20% and 40%. With TWINSPAN, taxa can be identified which are indicative of the classes formed. Potentially, these indicators could be used in a dichotomous key for assessing water quality.

Biological variation among samples was directly related to a continuum of variation among physical and chemical data using Canonical Correspondence Analysis (CCA). CCA will order biological samples according to their taxa composition within the constraint of being linearly related, through multiple regression, to the supplied environmental data. With CCA it is possible to assess how much of the biological variation can be 'explained' by the known environmental variables and to determine which were the best correlated. Prior to CCA each environmental variable was tested for significance ($p \leq 0.05$) in explaining biological variation and redundant variables were removed. Variables were selected by forward stepwise regression and tested against the possibility of the relationship with biological data being random by running 99 Monte Carlo permutations of the data. Care was taken to avoid autocorrelation by restricting permutations within two blocks of sites such that no site had more than one sample in a block (see Oxford canal and Wey navigation). In addition to the original seven physical and ten chemical variables, synergistic interactions between hardness, dissolved copper and total zinc were also tested by forward selection. Monte Carlo permutations, restricted to the same blocks of sites, were also used to test the significance of each CCA axis. These multivariate techniques were provided by the program CANOCO version 3.1 using species scores that were weighted mean sample scores (scaling +2).

RESULTS

A total of 44,799 pupal skins from 95 taxa (after excluding taxa with abundance <0.1% of sample total) were identified from 68 amalgamated samples.

Classification

TWINSPAN classification was halted after four levels of division (Fig. 2). The first dichotomy primarily discriminated true canal sites from more riverine watercourses. On the left-hand branch are the lower Thames sites, navigation canals that communicate with their associated river regularly (Kennet and Avon, Wey and Lee, lower Stort) and the Salmon Brook above Deephams sewage effluent (which does not have vertical concrete banks like the downstream site). The Basingstoke canal is a true canal but its three sites have fallen across both halves. Chironomid taxa associated with samples on the left-hand branch included typically riverine *Rheocricotopus*, *Rheotanytarsus*, *Tanytarsus* and *Cardiocladius*.

Typical canal sites occupy the right-hand branch together with the disused Cromford canal which has effectively become a series of unlinked linear ponds. Samples from these sites were associated with lentic taxa, particularly from the tribe Chironomini, such as *Dicrotendipes notatus*, *D. nervosus*, *Parachironomus*, *Glyptotendipes* and *Chironomus*. The presence of any *Cricotopus (Isocladius)* species at abundances greater than 5% of the sample was sufficient to distinguish samples on the right half, except for the Cromford site. From an *a priori* view of relative water quality it was apparent that good and bad quality sites were found in both halves of the classification.

A classification of canal water quality based on TWINSPAN-derived indicator taxa would first discriminate between types of canalised watercourses before water quality could be assessed.

Ordination

Samples from Papercourt Lock (90 and 93) and Bowers Lock were omitted from Canonical

Correspondence Analysis (CCA) because of insufficient chemical data. Stepwise forward regression resulted in the elimination of air temperature range, dissolved oxygen, chloride and hardness from the suite of explanatory variables used in CCA. There was no synergistic interaction between metals and hardness. The remaining 13 environmental variables explained 40.5% of the biological variation. The first five CCA axes had a significant correlation between biological and environmental data ($p = 0.01, 0.01, 0.01, 0.01, 0.04$ respectively).

Among the first two CCA axes, samples were ordered along two diagonal gradients (Fig. 3). There was a gradient from cooler, higher, lentic, northern or western sites (top left) to warmer, low altitude, lotic, southern or eastern sites (bottom right). The other gradient ran from sites with low BOD and ammonia concentrations in the top right through to sites with high BOD and ammonia in the bottom left. The site at Cromford was an outlier at the top of the ordination diagram because it was associated with extreme zinc concentrations (see maximum in Table 2). Environmental variables at right-angles to each other are independent in their relationships to biological variation. The ordering of samples along the water quality gradient (BOD, ammonia, TON, ortho-P) was therefore independent of variation in chironomid composition related to geographical location (latitude, longitude, altitude). The analysis was re-run using latitude and longitude as covariables in a partial CCA (PCCA) so that biological variation independent of geographical location could be investigated. Following this procedure the primary axis of variation in chironomid taxa composition was strongly related to concentrations of BOD, ammonia and inorganic nutrients (Fig. 4). The relative order of samples along the first PCCA axis provided an objective assessment of relative water quality among the sites studied. This sequence was used as the basis for assessing canal water quality.

Water quality indicators

Two approaches to providing a non-expert 'rapid' assessment of canal quality were taken. The first approach used a scoring system, the second used a dichotomous key. Both approaches were derived from a two-way ordering of samples and taxa into their respective sequences provided by the first PCCA axis. A scoring system was obtained that would match the PCCA sequence, with the provisos that scoring taxa were easy to distinguish from other taxa, that

the three samples omitted from PCCA were reintroduced and that scoring taxa must occur in at least 10 of the 65 samples used for PCCA. The relative positions of samples from Cromford and Salmon Brook, downstream of Deephams STW, along PCCA axis 1 were also considered to be distorted. The extremely high zinc concentrations at Cromford determined its position in the PCCA biplot and not sanitary determinands, the sample was dominated by *Cricotopus (Cricotopus)* and *Procladius*. The site below Deephams STW was placed among the best water quality sites along PCCA axis 1. Both BOD and ammonia were measured on 11 occasions above and below Deephams STW during the qualifying period (Sept. '95 - Sept. '96). On two occasions BOD and ammonia were higher upstream than downstream of the effluent, however, automatic chemical monitoring stations (sampling every 15 minutes) conclusively show that ammonia concentrations were typically higher, and DO consistently lower, downstream of the effluent compared with upstream. Over 62% of the individuals identified from the downstream site of Deephams STW were *Cricotopus bicinctus*, a well-documented pollution-tolerant species. The ordering of samples in CCA/PCCA is equally influenced by the biological and environmental data. The BOD and ammonia concentrations measured by spot chemical sampling at Salmon Brook were not considered representative of the actual conditions experienced by the chironomid fauna. The positions of this site and *C. bicinctus* along PCCA axis 1 reflect these unrepresentative chemical data. A scoring system which downgraded the relative positions of these two sites in terms of water quality, particularly downstream of Deephams STW, was favoured.

With taxa and samples arranged according to PCCA axis 1 it was relatively easy to pick out taxa with proportional abundances increasing towards either end of the matrix. Originally, sixteen taxa were selected but these included species of the same genus. These indicator taxa were reduced to 12 by treating congenerics as one taxon. An exception was made for the species-abundant genus *Cricotopus*, the subgenera *Cricotopus* and *Isocladius* were retained because they are easy to distinguish. The system of scoring which best ranked samples according to water quality is reproduced in Table 3. Seven of the 12 indicators are pollution-tolerant and produce a positive score. Pollution-sensitive taxa have been given a negative score. Domination of a sample by one species is not considered indicative of good water quality, hence pollution-tolerant taxa receive higher scores if they are abundant whereas pollution-sensitive taxa do not receive more negative scores for being dominant. A simple

addition of indicator scores provides the pollution score for a sample, which may be negative if it came from a good quality water. A banding system is described in Table 3 which provides a descriptive classification of samples. The indicator taxa accounted for a minimum of 32.6% and a maximum of 94.7% of the individuals composing the 68 samples, with an average composition of 61.3%. A matrix of the indicator scores and water quality banding for each of the samples is provided in Table 4.

If it is only required to classify a sample according to the five quality bands, then a dichotomous key can be used which recognises only six of the indicator taxa (Fig. 5). This key correctly classified all 68 samples according to their banding in Table 4. The frequency of occurrence of these six indicator taxa among 68 samples were; *Potthastia* 27, *Tvetenia* 27, *Microtendipes* 51, *Tanytarsus* 64, *Parachironomus* 65 and *Cricotopus* (*C.*) 67.

RECOMMENDATIONS

This report is not intended to be used as a manual. By providing a system for assessing canal water quality that requires the recognition of a few distinctive taxa it is hoped that biologists will be supported in spending some time using the chironomid pupal exuviae technique. In 1996, Dr R.S. Wilson published a revised "A practical key to the genera of pupal exuviae of the British Chironomidae" (available from him at Mudgley Elms, Wedmore, Somerset BS28 4TH). This publication is not just a key but also a manual describing the sampling and laboratory procedures. This publication should be used to identify indicator organisms referred to in the last section, and most importantly to recognise a chironomid pupal skin from exuviae of other aquatic organisms so that percentage occurrences of indicator taxa are accurate.

Ideally, a site should be sampled at least three times between April and October and 200 chironomid pupal skins randomly subsampled on each occasion. For a quality assessment to be made, it is only necessary to record the numbers of each of the six taxa as a proportion of the total number of chironomid skins sorted . Photographs of distinguishing characteristics have been scanned onto Fig. 5 (with limited success) but reference to Dr Wilson's key is still recommended. Species of *Tanytarsus* are recognised by having a transparent abdomen with

paired longitudinal patches of points or spines and a toothed spur in the corner of the eighth tergite. Specimens of *Potthastia* are opaque brown while each anal lobe has 3 terminal macrosetae and an latero-apical projection covered in small teeth, there is no spur on the eighth tergite. *Microtendipes* have two conical projections on the head together with a thin anterior transverse band of spiny points on the tergites. There is a spur in each apical corner of the tergite VIII with 2-5 teeth, the innermost being the longest. *Tvetenia* has thoracic horns with a swollen base and long curved apical filament, there are paired spiny humps from the second or third tergite to the sixth and a row of small circular turbercles (pearl row) along the edge of the wing sheaths. *Parachironomus* lacks a spur on tergite VIII although there may be some small transparent spines, the thoracic horn is composed of a tuft of fine filaments, the abdomen is transparent with tergites having shagreen that becomes progressively stronger posteriorly, particularly on tergite VI. *Cricotopus* (*C.*) has anal lobes lacking a fringe of hairs but each lobe has three macrosetae (innermost may be reduced to a hair). The thoracic horn is a small simple tube, if there is any shagreen on the second tergite it will be restricted to the posterior half while shagreen on tergites III and IV do not extend more than three quarters of the segment width .

DISCUSSION

Although TWINSPAN classification did not provide a simple key to water quality it did reveal a biological basis for distinguishing true canals from more riverine watercourses. Nominal discharge categories used for CCA ordination, despite the subjective decisions required to derive these, were strongly correlated with chironomid taxa composition. Variation in discharge was apparently responsible for the primary division of biological data by TWINSPAN. TWINSPAN group 111 contained several of the BAD quality sites identified by PCCA. The indicator taxa distinguishing this group were also good indicators for the PCCA-derived scoring system. All these indicators were used for the scoring system except *Paratrichocladius rufiventris* which could be confused with other species.

Recognition of five bands of water quality was considered more robust than the use of the score itself. There are no absolute arbiters of water quality against which this assessment can be quantified. We might hope that monthly chemical sampling during working hours is

representative of water quality, at least relative to similar sampling regimes at other sites, but this is improbable. This is one of the major justifications for biological monitoring. New canal sites will be assessed using this scoring system but quantifying its accuracy will still involve a degree of subjective assessment. An objective measure of the success of this system will be the number of Agency biologists using CPET to assess canal water quality.

Among the present range of canals studied, the poorest quality sites were located downstream of sewage treatment works discharging directly to the canal. The poorest sites on the G.U.C. were downstream of Tring STW (dry weather flow 9,500m^3day^{-1}, population equivalent 11,500) and Berkhamsted STW (dwf 5,105m^3d^{-1}, p.e. 21,783), USBERK and DSBERK. Bad quality sites on the Oxford canal were downstream of Kidlington STW (dwf 12,600m^3day^{-1}, p.e. 12,000) during the surveys of 1991 and 1995; DSKIDSTW, USKING, USKG95, DSKING, DSKG95. Examples of larger STW's that did not have such deleterious effects on canal water quality were Maple Lodge (dwf 130,000m^3day^{-1}, p.e. 482,508) above COPP on the G.U.C. and Guildford (dwf 67,190, p.e. 74,250) above BOWERS on the Wey navigation. The effect of Maple Lodge effluent is ameliorated by the flow from the River Colne into the G.U.C. just upstream. Chemical data support the view that water quality is poorer in the G.U.C. downstream of Berkhamsted STW (90%ile BOD 10.8mgl^{-1}, 90%ile ammoniacal nitrogen 5.1mgl^{-1}) than downstream of Maple Lodge STW (90%ile BOD 7.1mgl^{-1}, 90%ile amm-N 4.6mgl^{-1}). The chemical quality below Maple Lodge STW is still poor and this is confirmed by the biological assessment for COPP (Table 4). Similarly the effect of Guildford STW on the Wey navigation is ameliorated by the discharge from the River Wey just upstream. Chemical data were not available for BOWERS but it was considered to be of FAIR water quality based on chironomid data.

The best quality canal sites were on the Kennet and Avon, which regularly communicates with the chalk river Kennet. This river was classified as VERY GOOD in the 1995 General Quality Assessment. The site at Crookham on the Basingstoke Canal was found to have the best water quality among 'true' canals. The canal is fed by the chalk-spring fed River Whitewater (also classed as VERY GOOD in the 1995 GQA) and sections of the canal are sites of special scientific interest . Canal sites beyond Thames region's boundaries did not provide more extreme examples of water quality, at least with respect to organic pollution.

The Cromford site, dominated by species of Cricotopus (*C.*) and Procladius, may represent a zinc-tolerant chironomid assemblage but more canal sites with high metal concentrations need investigating. This report will be seen by biologists in the regions represented here and their comments with respect to their own canals will be very welcome. The analysis of residual biological variation after accounting for geographical variation is believed to have been effective at removing regional bias in assessing water quality, at least for the canal sites investigated. The high frequency of occurrence of the recommended indicator taxa, and their high proportional abundance at these sites, should ensure that they can be effectively used to assess water quality at canal sites not yet investigated.

Table 1 Site information (3 pages)

Watercourse	Site name	Code	Date	Skins
River Lee/navigation	Kings weir	Kings 88	5-9/88	676
"	Enfield weir	Enf 88	"	675
"	Hackney Marshes	Hmar 88	"	639
Kennet & Avon canal	Ufton bridge	88 Ken 5	5-9/88	645
"	Burghfield	88 Ken 6	"	645
"	Above Thames	88 Ken 7	"	623
Wey navigation	Unstead lock	Unstead 90	6 -8/90	662
"	Peasmarsh	Peas 90	"	244
"	St. Catherines lock	StCath 90	"	638
"	Papercourt lock	Paper 90	"	666
"	Pyrford weir	Pyrfor 90	"	709
"	Parvis bridge	Parvis 90	"	653
"	Town lock	Town 90	"	639
Oxford canal	Baker's lock	Enslow	5-10/91	1061
"	Thrupp	Thrupp	"	834
"	Roundham lock	Round	"	1358
"	Kidlington lock	Kidling	"	1230
"	D/S Kidlington STW	DSKidSTW	"	1145
"	U/S Kings bridge	USKing	"	1060
"	D/S Kings bridge	DSKing	"	841
"	Wolvercote lock	Wolver	"	1157
Bridgewater-Taunton canal	Crossways Cross	Cross	4-10/91	1003
"	Huntworth Hunt	Hunt	"	778
Grand Union canal	Tring	Tring	6-9/92	612
"	U/S Berkhamsted STW	USBerk	"	657
"	D/S Berkhamsted STW	DSBerk	"	647
"	Springwell lock	Sprwell	"	632
"	Copper Mill lock	Copp	"	641
"	Horton bridge	Horton	"	319
"	Hanwell locks	Lock97	"	616
Wey navigation	Unstead lock	Unstead	6-9/93	625

Wey navigation	D/S Godalming STW	DSGodal	"	609
"	St Catherine's	StCath	"	640
"	Stoke lock	Stoke	"	619
"	Bowers lock	Bowers	"	712
"	Papercourt lock	Paper	"	656
"	Pyrford weir	Pyrford	"	662
Basingstoke canal	Brookwood lock 12	BasLK12	6-9/93	155
"	Deepcut lock 28	BasLK28	"	173
"	Crookham	Bascrook	"	508
River Thames	Hambledon lock	Hamble 93	6-9/93	664
"	Hurley lock	Hurley 93	"	567
"	Old Windsor lock	USWind 93	"	653
"	1 km D/S Windsor STW	DSWind 93	"	660
"	Molesey lock	ML 93	"	702
"	Teddington lock	TD 93	"	643
Oxford canal	Kidlington lock	Kid 95	6-9/95	633
"	U/S Kings bridge	USKG 95	"	438
"	D/S Kings bridge	DSKG 95	"	352
"	Wolvercote lock	Wolv 95	"	594
River Lee/Navigation	Fieldes Weir Lock	Leeusrm	5-9/96	640
"	Dobb's Weir	Ledsrm	"	660
Stort Navigation	U/S Rye Meads STW	Stusrm	"	652
"	Twyford Lock	USBS	"	475
"	Spellbrook Lock	DSBS	"	618
Salmon brook	U/S Deephams STW	USDeep	5-9/96	657
"	D/S	DSDeep	"	652
Leeds & Liverpool Canal	Canal Road, Leeds	Leeds	4-9/96	485
"	Dowley Gap Lock	Bingley	"	672
"	Eshton Road Lock	Gargrave	"	705
Aire & Calder Navigation	Woodlesford Lock	Woodles	"	658
"	Pollington Lock	Polling	"	645
Selby Canal	West Haddesley	Haddes	"	476

"	Brayton	Brayton	"	638
Chesterfield Canal	Bracebridge Lock	Worksop	"	.622
"	Whitsunday Pie Lock	Retford	"	653
Cromford Canal	Ripley	Ripley	"	253
"	Cromford	Cromford	"	668

Contributers:
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Row	VARIABLE	MEAN	STDEV	MINIMUM	MAXIMUM
1	LATITUDE	*	*	*	*
2	LONGITUDE	*	*	*	*
3	MEANTEMP	10.160	0.366	9.39	10.88
4	TEMPRANGE	13.210	0.352	11.95	13.68
5	ALTITUDE	41.415	27.618	5.00	130.00
6	SLOPE	1.189	1.179	0.10	5.00
7	DISCHARGE	4.554	2.062	1.00	9.00
8	pH	7.820	0.273	7.00	8.40
9	BOD	5.546	3.141	2.40	14.70
10	DO	62.538	21.749	7.00	92.00
11	AMM-N	0.797	1.259	0.00	5.06
12	TON	9.231	4.030	0.70	21.00
13	CHLORIDE	90.954	66.114	18.00	270.00
14	ortho-P	1.834	1.807	0.00	7.70
15	HARDNESS	287.585	79.343	109.00	494.00
16	COPPER	8.369	9.529	0.00	49.00
17	ZINC	46.923	131.185	9.00	1078.00

MTB > Table 2 Ranges of environmental variables (65 samples)

Table 3 **Water quality scoring system**

		Score
Parachironomous	≥40	5
	≥20	4
	≥10	3
	≥5	1
Glyptotendipes	≥10	2
	≥5	1
Chironomus	≥5	2
	≥2	1
Dicrotendipes	≥30	4
	≥15	3
	≥5	2
	≥2	1
Cricotopus(I)	≥50	5
	≥40	4
	≥20	3
	≥10	2
	≥5	1
Nanocladius	≥20	2
(excluding *balticus*)	≥5	1
Cricotopus (*C.*)	≥70	6
	≥50	5
	≥30	3
	≥20	2
	≥10	1

		Score
Tanytarsus	≥5	-2
Microtendipes	≥5	-1
Potthastia	≥1	-1
Tvetenia	≥1	-2
	≥0.1	-1
Epoicocladius	≥1	-2
	≥0.1	-1

Banding of total score	≥9	BAD
	≥5	POOR
	≥0	FAIR
	≥-4	GOOD
	≥-5	VERY GOOD

Table 4

Ranked quality assessment

Site/Taxon	PARACHM	GLYPPES	CHIRMUS	DICROPES	CRIC(I)	TANYSUS	MICRPES	NANOIUS	CRIC(C)	POTTTIA	TVETNIA	EPOI_FLA	Score	Site	Quality
88KEN6	0	0	0	0	0	-2	-1	0	1	-1	-2	-2	-7	88KEN6	V.GOOD
88KEN5	0	0	1	0	0	-2	-1	0	1	-1	-2	-1	-5	88KEN5	V.GOOD
BASCK	0	0	0	1	0	-2	0	0	0	0	-1	-1	-3	BASCRK	GOOD
UNSTEA90	0	0	0	0	0	-2	0	0	3	0	-2	-1	-2	UNSTEA90	GOOD
DSGODAL	0	0	1	0	0	-2	-1	0	3	0	-2	-1	-2	DSGODAL	GOOD
88KEN7	0	0	0	1	0	-2	0	1	2	-1	-2	-1	-2	88KEN7	GOOD
HURLEY93	0	0	0	0	0	-2	0	1	1	-1	-1	0	-2	HURLEY93	GOOD
PYRFORD	0	0	0	0	0	-2	0	1	1	0	-1	0	-1	PYRFORD	GOOD
CROSS	0	0	0	1	1	-2	-1	0	0	0	0	0	-1	CROSS	GOOD
StCATH	0	0	1	0	0	-2	-1	0	2	0	-1	0	-1	StCATH	GOOD
KINGS88	1	0	0	1	0	-2	0	0	1	0	-2	0	-1	KINGS88	GOOD
GARGRAV	0	0	0	0	0	-2	0	0	3	0	0	-1	0	GARGRAV	FAIR
UNSTEAD	0	0	0	0	0	-2	0	1	3	0	-2	0	0	UNSTEAD	FAIR
HUNT	0	0	1	1	1	-2	-1	0	0	0	0	0	0	HUNT	FAIR
HAMBLE93	1	0	0	0	0	-2	0	0	2	0	-1	0	0	HAMBLE93	FAIR
USWIND93	0	0	0	1	0	-2	0	0	2	0	-1	0	0	USWIND93	FAIR
BASLK12	0	1	2	0	0	-2	0	0	1	-1	0	0	1	BASLK12	FAIR
STUSRM	0	1	0	2	0	0	-1	0	0	0	-1	0	1	STUSRM	FAIR
WORKSOP	0	0	0	1	3	-2	0	0	0	0	-1	0	1	WORKSOP	FAIR
ENF88	1	0	0	0	0	-2	0	1	3	-1	0	-1	1	ENF88	FAIR
PAPER	0	0	0	0	0	-2	0	0	3	0	0	0	1	PAPER	FAIR
StCATH90	0	0	1	0	0	-2	0	0	3	-1	0	0	1	StCATH90	FAIR
LEDSRM	1	0	0	2	0	-2	0	0	1	0	-1	0	1	LEDSRM	FAIR
LEEUSRM	0	1	0	2	0	0	-1	0	0	0	0	0	2	LEEUSRM	FAIR
PEAS90	0	0	1	0	0	-2	0	0	3	0	0	0	2	PEAS90	FAIR
BOWERS	0	0	1	0	0	-2	0	0	3	0	0	0	2	BOWERS	FAIR
TRING	0	0	0	2	2	-2	0	0	0	0	0	0	2	TRING	FAIR
BASLK28	1	1	1	1	2	-2	-1	0	0	0	0	0	3	BASLK28	FAIR
PYRFOR90	0	0	1	1	2	-2	0	0	1	0	0	0	3	PYRFOR90	FAIR
PAPER90	1	0	1	2	0	-2	-1	0	2	0	0	0	3	PAPER90	FAIR
ML93	0	0	0	1	0	0	0	2	0	0	0	0	3	ML93	FAIR
BINGLEY	0	0	0	0	0	0	0	0	5	0	-2	0	3	BINGLEY	FAIR
DSWIND93	0	0	1	1	1	-2	0	2	1	0	-1	0	3	DSWIND93	FAIR
USDEEP	0	0	1	0	0	0	0	0	2	0	0	0	3	USDEEP	FAIR
PARVIS90	1	0	0	2	0	-2	0	0	2	0	0	0	3	PARVIS90	FAIR
ROUND	0	0	0	0	3	0	0	0	0	0	0	0	3	ROUND	FAIR
KID95	0	1	0	2	1	-2	0	1	1	0	0	0	4	KID95	FAIR
TOWN90	0	0	0	3	1	0	0	0	2	0	-2	0	4	TOWN90	FAIR
STOKE	0	0	0	1	0	0	-1	0	5	0	-1	0	4	STOKE	FAIR
TD93	0	0	0	2	1	-2	0	2	1	0	0	0	4	TD93	FAIR
CROMFORD	0	0	1	0	0	0	0	0	3	0	0	0	4	CROMFORD	FAIR
LEEDS	1	1	0	1	2	0	0	0	0	0	-1	0	4	LEEDS	FAIR
KIDLING	0	0	0	1	3	0	0	0	0	0	0	0	4	KIDLING	FAIR
RETFORD	0	0	0	1	3	0	0	0	0	0	0	0	4	RETFORD	FAIR
RIPLEY	1	0	2	1	1	0	0	0	0	0	0	0	5	RIPLEY	POOR
SPRWELL	1	2	0	1	1	0	0	0	0	0	0	0	5	SPRWELL	POOR
POLLING	0	0	0	0	5	0	0	0	0	0	0	0	5	POLLING	POOR
USBS	0	0	2	2	3	-2	0	0	0	0	0	0	5	USBS	POOR
ENSLOW	0	0	0	2	3	0	0	0	0	0	0	0	5	ENSLOW	POOR
THRUPP	0	2	0	0	4	0	0	0	0	0	0	0	6	THRUPP	POOR
HADDES	3	0	0	0	2	0	0	0	3	0	-2	0	6	HADDES	POOR
DSBS	1	0	1	2	2	0	0	0	0	0	0	0	6	DSBS	POOR
WOLVER	1	0	0	1	4	0	0	0	0	0	0	0	6	WOLVER	POOR
COPP	1	2	2	2	1	0	0	0	0	0	-1	0	7	COPP	POOR
BRAYTON	1	0	0	1	5	0	0	0	0	0	0	0	7	BRAYTON	POOR
HMAR88	0	0	0	0	0	0	0	1	6	0	0	0	7	HMAR88	POOR
LOCK97	0	2	1	2	3	0	0	0	0	0	0	0	8	LOCK97	POOR
WOODLES	3	0	0	0	3	0	0	0	2	0	0	0	8	WOODLES	POOR
HORTON	0	2	2	1	2	0	0	1	0	0	0	0	8	HORTON	POOR
WOLV95	3	2	0	2	2	0	0	0	0	0	-1	0	8	WOLV95	POOR
DSDEEP	0	0	1	2	1	0	0	0	6	0	0	0	10	DSDEEP	BAD
USKING	5	1	2	0	2	0	0	0	0	0	0	0	10	USKING	BAD
USKG95	3	2	1	2	2	0	0	0	0	0	0	0	10	USKG95	BAD
DSBERK	5	1	0	4	1	0	0	0	0	0	0	0	11	DSBERK	BAD
DSKG95	4	2	1	2	2	0	0	0	0	0	0	0	11	DSKG95	BAD
USBERK	4	2	1	2	2	0	0	0	0	0	0	0	11	USBERK	BAD
DSKIDSTW	5	2	2	0	3	0	0	0	0	0	0	0	12	DSKIDSTW	BAD
DSKING	5	2	2	0	3	0	0	0	0	0	0	0	12	DSKING	BAD

Fig. 1 Survey area

canalmap pre

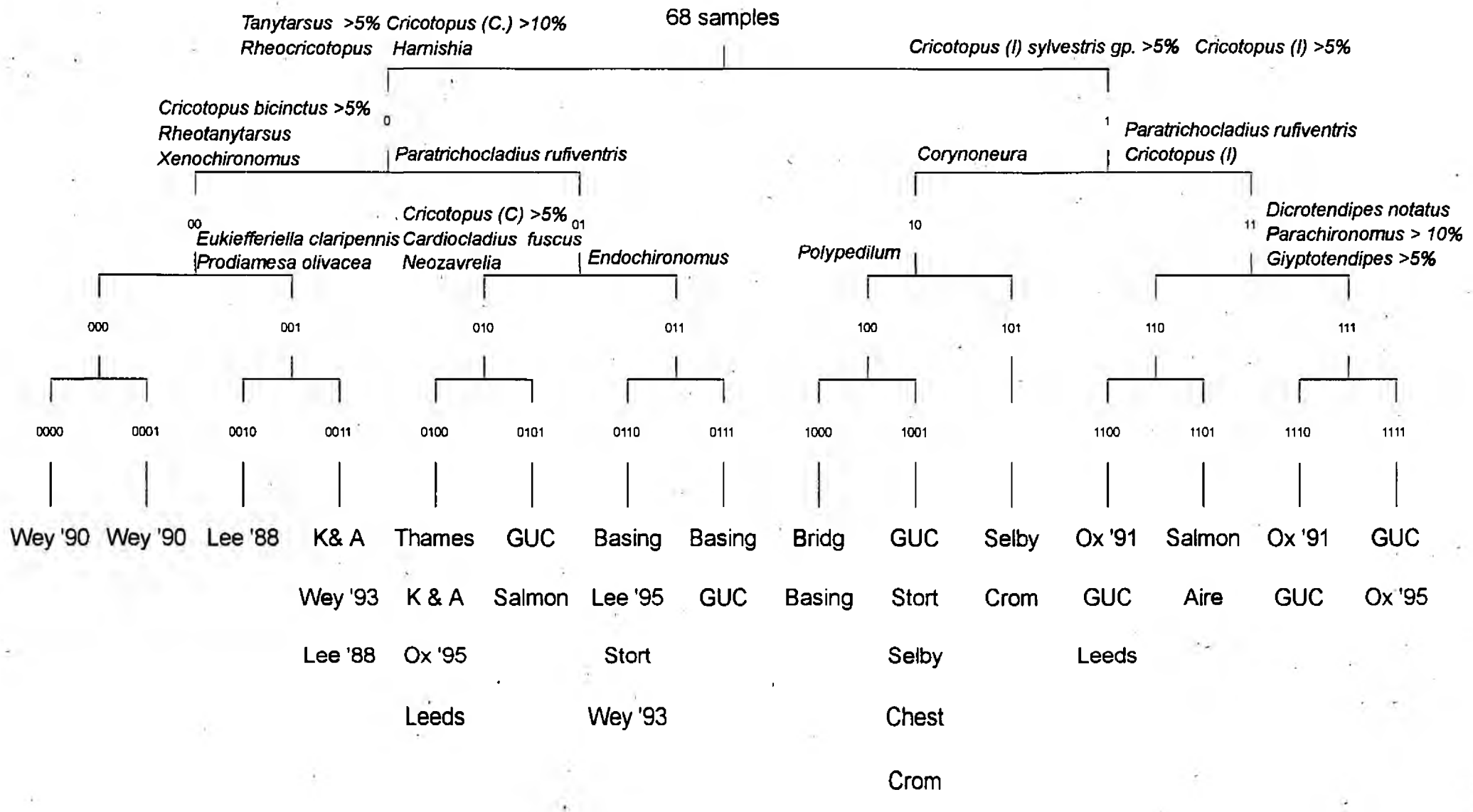
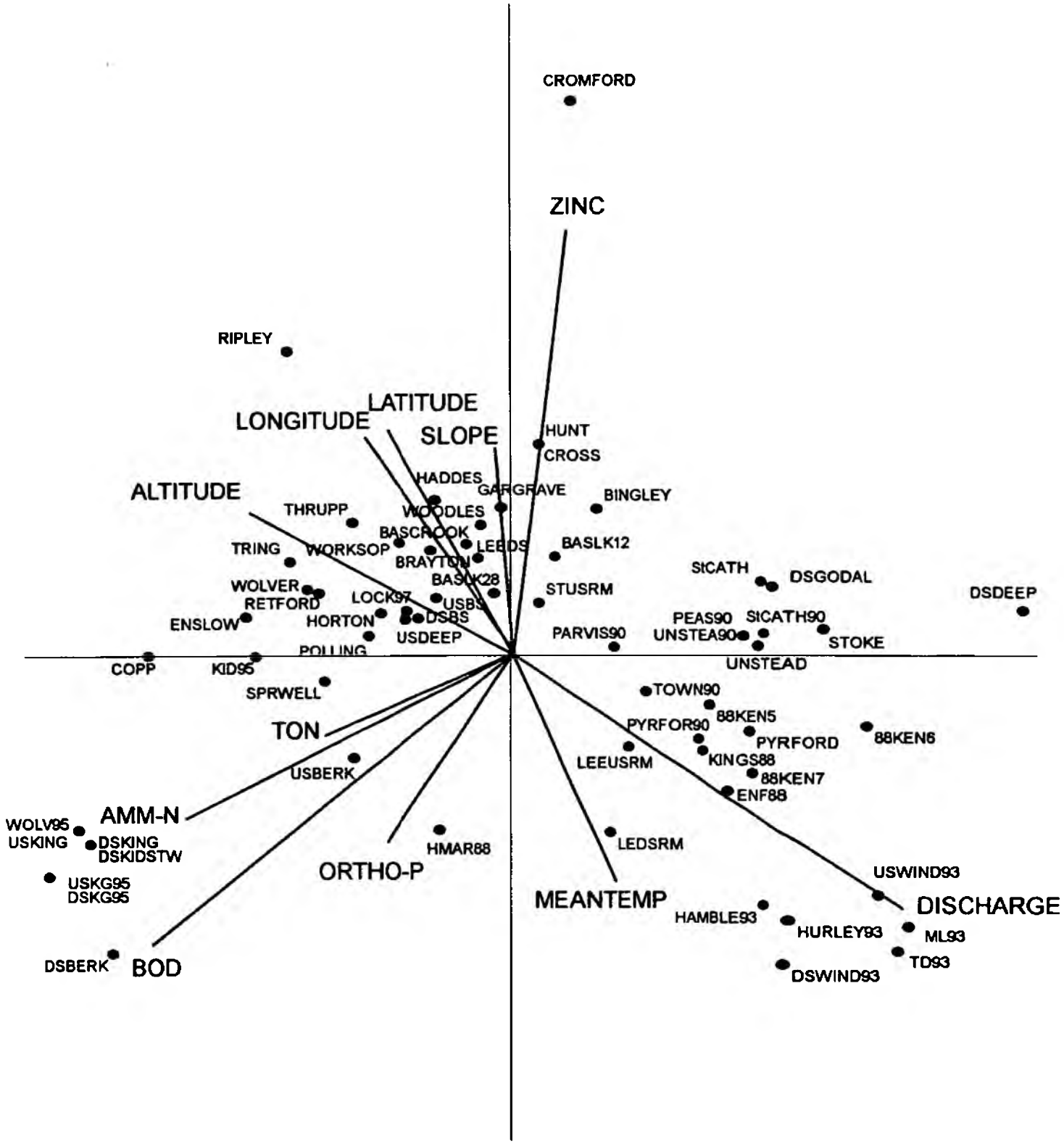


Fig. 2 TWINSPAN classification of chironomid data

(samples identified by canal)

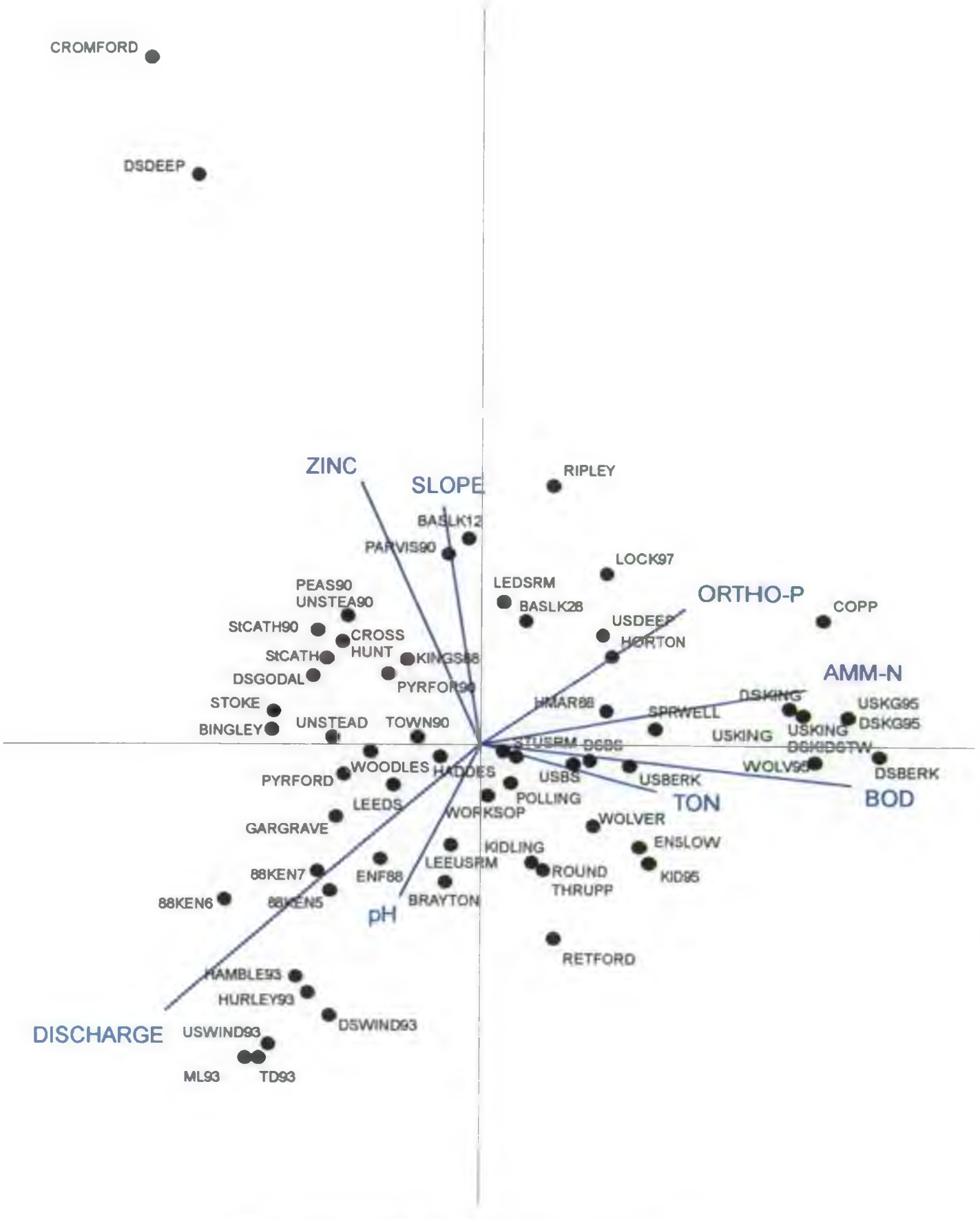
natwin.pre



minor environmental variables and some samples omitted

Fig. 3 CCA biplot of samples

natcca.pre



minor environmental variables and some samples omitted

Fig. 4 PCCA biplot of samples

natpcca pre

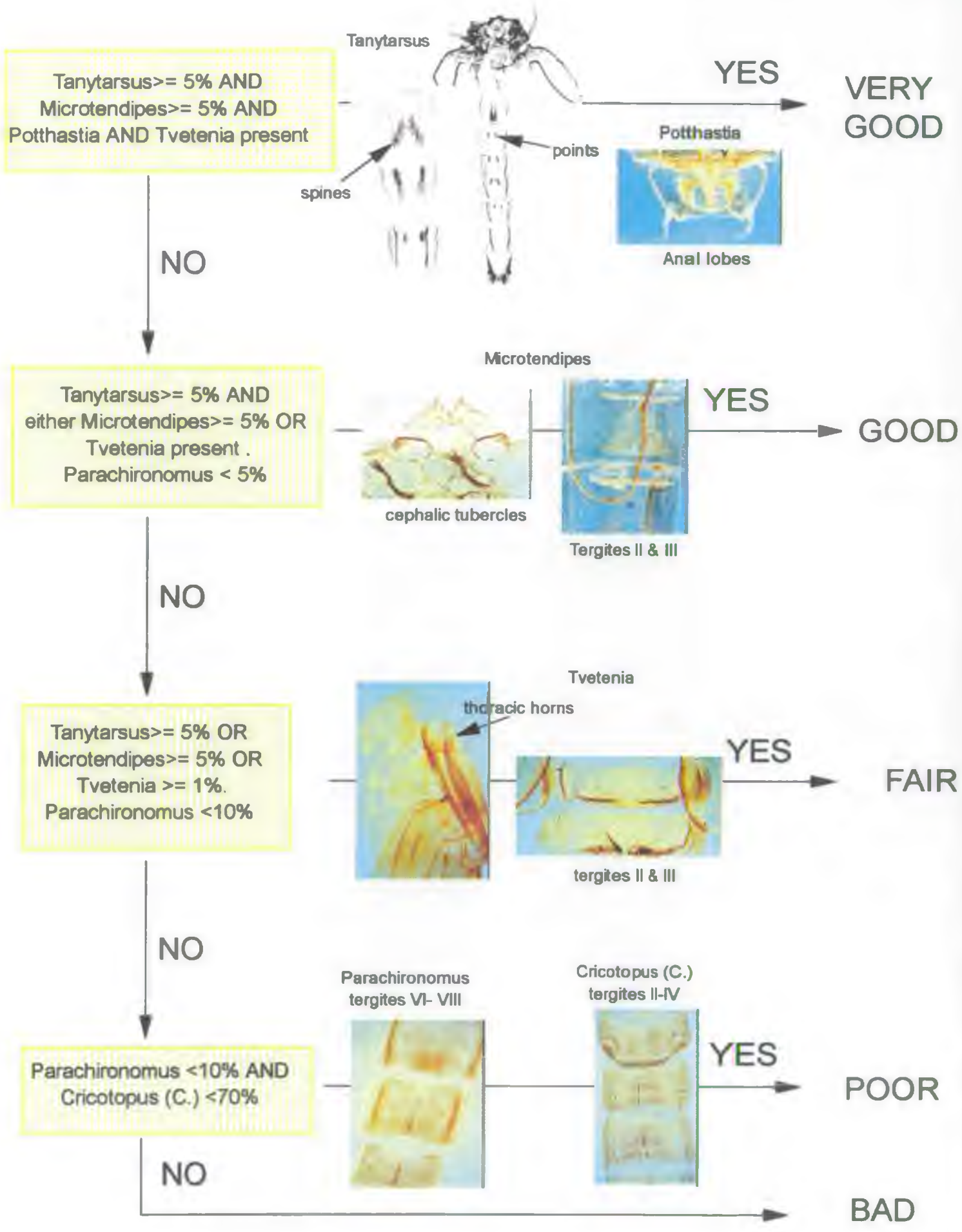


Fig. 5 Key to assess canal water quality