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LWRRDC Milestone Report 1: Temporal variability of macroinvertebrate communities in Australian streams.

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LWRRDC Milestone Report

Report 1, Project ARR1

Project title: Temporal variability of macroinvertebrate communities in Australian streams

Principal investigators: Dr Chris Humphrey, ***eriss***

Date of submission: December 1995

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3 Attachment 2

Humphrey, CL, Faith, DP & PL Dostine (1995). A long-term study of macroinvertebrate communities in the upper South Alligator River, NT: temporal variability. Presentation to Annual Conference of the Australian Society for Limnology, Jenolan Caves NSW, 18-20 September 1995.

LWRRDC Milestone Report

LWRRDC project reference no.: ARR1

Project title: Temporal variability of macroinvertebrate communities in Australian streams

Principal investigators: Dr Chris Humphrey, ERISS

Project duration: 1 January 1995 to 30 June 1997

Due date for milestone report: 31 December 1995

Project objectives

- Access long-term macroinvertebrate data-sets from selected (reference) streams across Australia. Where necessary, extend sampling in streams so that data-sets are sufficiently 'long-term' in nature as to allow long term comparisons to be made for relevant old data-sets.
- Measure 'persistence' of macroinvertebrate community composition using appropriate statistical analyses of the data.

Where lack of persistence is observed:

- Explore the implications of the results for MRH predictive modelling by assessing the degree of temporal variability in reference sites relative to classifications of related impacted sites.
- Where data-sets allow, seek environmental correlates that may account for any year-to-year variation in community composition and input these variables to the MRH predictive models.
- Make appropriate recommendations to the developers of MRH predictive models according to different climatic/hydrological regions of Australia.

Alteration to original objectives: Nil

Milestones and achievement criteria

<u>Milestone 1, 31 Dec 1995</u>

a) Liaise with owners of long-term sets of stream macroinvertebrate data and organise: data transfer, compilation and checking and/or additional sampling and/or sample processing as required.

b) Compile the seven year South Alligator River data set and perform preliminary analyses to a level required for ERISS Internal Reporting.

c) Instigate the extension of sampling of existing SAR sites for macroinvertebrates.

d) Compile data sets from different regions and conduct preliminary analysis of community persistence. This should include: an assessment of persistence through classification, rank correlation and dissimilarity measures; examination of the significance of excursions; an assessment of the influence of environmental variables on temporal variability.

e) Attend the second NRHP workshop (ca. May 1995): report on project scope and progress, and liaise with other project leaders of the NRHP commissioned study teams, notably Dr L Barmuta and Dr D Stockwell, to ensure that analysis methods allow adequate assessment of the impact of temporal variability in macroinvertebrate composition on the ability to construct predictive models.

<u>Achievement criteria</u>

a) Description of long-term data sets accessed and arrangements for data transfer/enhancement;

b) Summary of statistical methods used for analysis;

c) Results of preliminary analyses of long-term data sets and seven year South Alligator River data set;

d) Outcomes of project integration and communication activities conducted.

Achievement of milestone criteria 1

Description of long-term data sets accessed and arrangements for data transfer/enhancement

Access to a number of long-term data-sets has been sought from various custodians around Australia and some further sampling will be conducted in selected streams. A number of hydrological and climatic regimes is represented amongst these data sets:

Temperate streams:

- southwestern Australia, permanent and seasonally-flowing streams (custodian: P. Davies, published data, no funds provided for additional sampling);
- Tasmania, Musselboro and Coquet Creek catchments (P. Davies, funds provided for additional sampling);
- Victoria, Latrobe & Wimmera Rivers (Museum of Vic, Vic EPA, funds provided for additional sampling);
- NSW, Thredbo River [alpine] (R. Norris, no additional funds, data have been forwarded).

Arid/ semi-arid streams:

- SA, temporary streams and springs of the Flinders Ranges (A. Boulton, funds provided for additional sampling).

Subtropical/ tropical streams:

- southeastern (subtropical) QLD, Brisbane R. & Barker-Barambah Ck catchments (A. Arthington, funds provided for additional sampling);
- north (Wet tropical) QLD, Birthday & Yuccabine Cks (R. Pearson, funds provided for data collation);
- north (Dry tropical) WA, Pilbara streams (P. Davies, no additional funds);
- NT 'Top End' (Wet-Dry tropical), South Alligator R. (C. Humphrey, funds provided for additional sampling).

A broad coverage of 'bioregions' is present in the data sets requested for analysis. Apart from data from the South Alligator River (NT), only one other data set has been provided for analysis at this stage (Thredbo R., NSW). For most other data sets, funds have been requested for further sampling so as to allow long-term comparisons to be made for older data sets of irregular or discontinued time series. (Hence, data in complete 'analysable' form are mostly unavailable at present.) Arrangements have been made for most of the data from those streams for which further sampling has been/ is being conducted to be forwarded to the principal investigator throughout 1996.

Achievement of milestone criteria 2

Summary of statistical methods used for analysis

Analyses conducted on SAR data have included: (i) *Classification* using hierarchical techniques, and (ii) *Spearman rank correlation* using the rank order of abundance of taxa and, *(dis)similarity measures* using absolute abundance data, between any pair of years. Analyses so far have been conducted using relative abundance data. (Presence-absence data will be analysed in 1996.) 'Anomalous' years and hence lack of persistence are evident in misclassifications or absence of statistical significance in the Spearman rank correlations. Where there is lack of persistence in the data sets, implications of the results for MRH predictive modelling are to be explored by a third analytical approach, (iii) assessing the degree of temporal variability in the sites under investigation relative to *multivariate ordinations* of related impacted sites. Lack of constancy of communities would present a problem if, after the assessment, natural changes in community structure were of the same direction and magnitude as those in disturbed sites.

Achievement of milestone criteria 3

Results of preliminary analyses of long-term data sets and seven year South Alligator River data set

As stated above, only data from the SAR have been available for analysis to date. Early and late Dry season data (April/May and October repectively) from the 8 SAR sites and for the seven year period 1987-1993 are presented in Attachment 3. (This ERISS internal report contains full lists and counts of invertebrates to family-level and accompanying environmental data.) The analyses conducted on this data set provide a template from which analyses of other data sets will follow.

Results of analysis of SAR persistence in community structure show two community states for data gathered from 1987 to 1995: a 'high-flow' state (HFS) present from 1987-92 and a 'low-flow' state (LFS) present from 1993 to the present. The HFS communities are dominated by leptophlebiid mayflies whilst the LFS communities have low abundances of flow-dependent taxa (including leptophlebiids) and are dominated by elmid beetles. There is high persistence amongst samples from *within* HFS or LFS communities, but clear dichotomy between the groups in any analysis (Spearman rank correlation, dissimilarity measures, classification or ordination).

From ordinations conducted using data from both unpolluted/ mine-polluted portions of the adjacent Rockhole Mine Creek (RMC) and SAR data, post-1992/ pre-1993, it was shown that the magnitude of change occurring in the SAR post-1992 was even more severe than that occurring in polluted portions of RMC (see Attachment 2). Moreover the direction of change occurring in the SAR data was in the same direction as the pollution gradient in RMC. This would indicate that, in the absence of additional information, the change occurring in the SAR post-1992 could falsely be attributed to human impact.

Given such lack of persistence, a stated objective of the project is to seek environmental correlates that may account for any year-to-year variation in community structure and input these variables to the models. However, lags in response of organisms to natural (low flow) disturbances were observed in the SAR data and hence a data set of a decade or longer may be required to fully explain and account for such variation. Moreover, if switches between different community states are a response to stochastic features of the environment (possible in the SAR), community composition or structure might never be predicted.

Predictive modelling of such stream communities might still be possible, however, if models were simply constructed for different community 'states' such as runs of dry or wet years. More appropriate, would be the incorporation of data from spatial controls. For predictive modelling, regular sampling of reference sites over time could be undertaken to 'update' or 'adjust' models.

Full details of the results found to date are provided in the attachments.

Achievement of milestone criteria 4

Outcomes of project integration and communication activities conducted.

The most important consultations required for the current project are with project leaders of other NRHP-commissioned study teams, notably Drs Barmuta, Stockwell/ Faith and the consultant undertaking agency modelling, to ensure that analysis methods for model construction allow adequate assessment of the impact of temporal variability. This consultation has occurred by way of three NRHP fora in 1995 (workshops/ technical committee meetings). Project integration will be constrained, however, by unavoidable delays in acquiring long-term data sets that are needed to assess the extent of temporal variability. (As stated above, most of these data sets are still being gathered.) Nevertheless, there is acceptance that additional (flow) variables together with some regular sampling of reference sites over time may be required for more accurate modelling as a consequence of temporal variability arising from drought.

Variations required to future milestones

It is anticipated that no significant variations will be required to future milestones. On a minor note and as alluded to above, if lags are observed in the response of invertebrates to environmental conditions, modelling of such relationships may not be feasible with short-term (< 10 year) data sets. Statistical advice would be sought on this issue and advice heeded accordingly.

Financial issues

In October 1995, the NRHP Management Committee approved a request from the principal investigator for additional funds of $5,500 to support further data collection in streams of southeastern Queensland. Dr Angela Arthington, Griffith University, is organising collection and forwarding of these data. It is possible that further sampling could be undertaken in jarrah forest streams of southwestern WA in autumn 1996 to enhance an extensive data set gathered from 1984 to 1990 on behalf of the Water Authority of WA. The region is still experiencing a period in which flows in streams are at much lower levels than they were for the period in which the earlier data set was gathered. It is highly desirable that responses of invertebrates to the full variation in flow conditions is studied. A request may come to the NRHP management committee early in 1996 for co-funding (50:50) of further data collection with the WAWA (say $5,000 each for federal/ state funds).

Human resource issues

There are no human resource issues to raise.

Communication achievements

All communication has centred on NRHP fora, namely workshops and technical committee meetings.

Listing of attachments

Attachment 1

Humphrey, CL (1995). Temporal variability of macroinvertebrate communities in Australian streams: implications for the prediction and detection of environmental change. Report prepared for 2nd Annual Workshop of the National River Health Program, Canberra ACT, 23-24 May 1995

Attachment 2

Humphrey, CL, Faith, DP & PL Dostine (1995). A long-term study of macroinvertebrate communities in the upper South Alligator River, NT: temporal variability. Presentation to Annual Conference of the Australian Society for Limnology, Jenolan Caves NSW, 18-20 September 1995.

Attachment 3

Humphrey, CL, Dostine, PL, Klessa, BA, Walden DJ & AG Spiers (1995). Benthic macroinvertebrate communities in riffle substrates of the upper South Alligator River, NT. Phase 2 - Review of data from April/May and October samples 1987-1993. Internal Report 197, Supervising Scientist for the Alligator Rivers Region.

Other comments

Nil.

Summary

Temporal variability of stream macroinvertebrate communities is being investigated across a broad cross-section of climatic/ hydrological regimes in Australia. Data from only one long-term study, that of the upper South Alligator River (SAR) of wet-dry tropical Australia (NT),

has so far been analysed. Results show that there is lack of persistence in SAR macroinvertebrate communities as a result of medium-term (~5-year) shifts in the base (dry season) perennial flow. Two distinct community states have been observed, each characteristic of either 'high' base flow or 'low' base flow conditions. Flow-dependent taxa are in low abundances under 'low' base flow conditions and in high abundances at 'high' base flow conditions. In comparison with upstream undisturbed vs downstream mine-polluted sections of an adjacent stream in the SAR catchment, the change in community structure from high to lower base flows was of a greater magnitude. Moreover, the nature of the change in community response mimicked the pollution gradient evident in the mine-impacted stream.

Environmental correlates of these different community responses may be sought and included in MRHI models. However, attempts to model the relationship between community response and environmental conditions may be thwarted by lags in the response and by possible stochastic recolonisation of key taxa as flow returns from low to high base flow conditions. In support of the latter, inter-catchment differences (SAR vs Magela Creek) have been observed over time in responses of flow-dependent taxa.

Whilst it is possible that similar flow-varying responses are evident in stream communities from other 'bioregions' of Australia, such lack of persistence might be expected to be more pronounced in tropical streams where the short life cycles of resident insect larvae may lead to more dynamic responses to environmental disturbances. Provided that switches between different community states are reasonably predictable amongst catchments of a bioregion, those developing MRHI models have relatively simple (but not inexpensive) recourse to regular sampling of reference sites over time to 'update' or 'adjust' models should this be the case. It is worth noting that conditions of permanent stream flow are less common in the wet-dry tropics of Australia than seasonally-flowing conditions. There is literature available to show that, elsewhere, invertebrate communities of temporary streams may not be constant. However, in the wet-dry tropics at least, there is a lack of capricious flow-dependent taxa in seasonally-flowing portions of streams and this may, ironically enough, infer greater relative constancy to the resident faunas.

Further analyses are required whereby SAR data in both relative abundance and presence/absence form are classified together with other NT data being gathered by the lead agency. It is only in this context that the severity or otherwise of the lack of community persistence can be fully measured.

ATTACHMENT 1

Report prepared for 2nd Annual Workshop of the National River Health Program, Canberra ACT, 23-24 May 1995

Temporal variability of macroinvertebrate communities in Australian streams: implications for the prediction and detection of environmental change

C.L. Humphrey

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Report prepared for 2nd Annual Workshop of the National River Health Program, Canberra ACT, 23-24 May 1995

Temporal variability of macroinvertebrate communities in Australian streams: implications for the prediction and detection of environmental change.

C.L. Humphrey
Environmental Research Institute of the Supervising Scientist, Jabiru NT.

One of the potential problems associated with the predictive modelling of stream macroinvertebrate communities, the basis of the MRH protocol, is variability in community structure with time. Excessive temporal variability may result in statistical misclassifications of the biological data and, if changes in communities from year to year cannot be accounted for using environmental data, will result in models that fail to accurately predict invertebrate community composition or structure.

In Britain, some long-term studies have concluded that the degree of annual variation of the fauna was too slight to affect RIVPACS-type models. RIVPACS uses species composition data rather than relative abundance data and this makes the predictions more robust to year to year changes in communities. Finally, the authors of RIVPACS are no doubt confident that their measurements of environmental variables can pick up and account for any drift in the fauna. John Wright recently warned, however (AJE), that some small British streams could present problems in their stochastic recolonisation following a period of drying out.

In developing a RIVPACs-type predictive model for Australian stream communities, few potential problems with temporal variation would be anticipated: family-level identifications should lead to more robust models and, if the modelling is conducted on 2-3 years of data, recovery and accounting of the important faunal elements would be expected. Nevertheless, we should not be too complacent, especially as the issue of constancy and persistence of the invertebrate communities of Australian streams has not been well studied. There are a few issues that are of concern in this regard:

1) If family presence/absence data only were incorporated in the modelling, then very large natural changes in community composition would have to occur before problems arose in the models. These models, however, will not be particularly sensitive to human-related disturbance. Ideally, abundance data by way of relative values or rank family order, would be used in the modelling. However, while these models will be more sensitive to impact, they will also be more sensitive to temporal variation in invertebrate communities.

2) Apart from small streams in Britain, there is other literature available from the USA and Australia to show that where flow is seasonally-variable or unpredictable, the fauna may not be particularly constant and may be very responsive to droughts and floods - these features of streams and climate of course characterise the Australian continent.

3) In the Wet-Dry tropics of northern Australia (NT), ERISS workers have also found evidence of lack of temporal constancy in invertebrate communities from permanent sections of the South Alligator River.

Figure 1 shows the mean abundances of the major insect orders present over 8 years in four Surber samples at one of the 8 SAR sites. In the 7th year of sampling, in 1993, mayfly numbers were very low compared to abundances observed in previous years. Mayflies are normally the dominant insect order present in the samples with leptophlebiids the dominant family (Fig. 2). As shown in Figure 2, in 1993 the family is missing entirely, with only a slight recovery in 1994. Other taxa, though, appear to have benefited from the associated decline in the base flow in the river since 1987: especially caenids (Fig. 2), elmid beetles (Fig. 1), pyralids and hydroptilids (Fig.

3). However, the complete switch from high abundances of leptophlebiids to their complete absence between two successive years is particularly dramatic: if low flow is responsible, then there is a lagged response because 1993 was not even the driest year. R. Marchant (pers. comm.) noted that dynamic fluxes might be more evident amongst tropical invertebrate species with short life cycles. They could be very responsive to sub-optimal conditions.

Clearly classification and prediction using family abundance data could be fruitless unless the year to year variation can be explained by environmental factors. Long-term data-sets can prove invaluable in identifying explanatory variables of spatial and temporal variation; the SAR data-set has obvious relevance and value to MRH developments in northern Australia. So, to the project objectives:

- Firstly, access long-term data-sets from suitable reference streams across Australia. For some of these sites, sampling or sample processing will need to be extended so that data-sets are sufficiently 'long-term' in nature.
- With these data sets, measure 'persistence' of macroinvertebrate community structure using appropriate statistical analyses of the data.

Where lack of persistence is observed:

- Explore the implications of the result by assessing whether the anomalous data classify near or together with those from related disturbed sites.
- Seek environmental correlates that may account for any year-to-year variation in community structure and input these variables to the models.
- And finally, make appropriate recommendations according to different climatic/ hydrological regions of Australia.

Progress since commencement of the project (late December 1995)

Access to a number of long-term data-sets has been sought from various custodians around Australia and some further sampling will be conducted in selected streams. A number of hydrological and climatic regimes is represented amongst these data sets:

Temperate streams: southwestern Australia (published data); Tasmania; Victoria (Latrobe & Wimmera Rivers); NSW (Thredbo R. [alpine], Molonglo R.).

Arid/ semi-arid streams: Flinders Ranges.

Subtropical/ tropical streams: southeastern QLD; Wet tropical QLD (Yuccabine Ck); Wet-Dry tropical NT (South Alligator R.)

At this early stage of the project, some progress has been made is with the South Alligator River study. Invertebrates were sampled twice-yearly from 8 sites in the SAR from 1987-1991 to develop a monitoring program to assess impact of mining at Coronation Hill. Late Dry season samples have been processed, with species-level data analysed and published. Late Dry season samples from 1992, 1993 and 1994 were also gathered but only a limited number of samples has been processed. The aim is to process the backlog of samples, then sample twice yearly over the period 1994-1996 to derive a 10-year data-set for two seasons, early and late Dry seasons.

The degree of 'persistence' of macroinvertebrate community structure will be measured using: (i) Spearman rank correlation using the rank order of abundance of taxa and, (dis)similarity measures using absolute abundance data, between any pair of years; and (ii) classification using hierarchical techniques.

'Anomalous years will appear wherever there is absence of statistical significance in the Spearman rank correlations, or misclassifications. For one of the 8 sites, some limited family-level analyses have been performed for 8 years of data. For Spearman rank correlation, there is an absence of statistical significance for most comparisons involving 1993, this year clearly being very different (Table 1).

The analysis based on dissimilarity measures (Table 2) again shows high dissimilarity - arbitrarily defined here at values greater than 0.5 - wherever 1993 and 1994 data are compared with other years. No hierarchical classification has been attempted yet.

Clearly, there is lack of persistence in the data set and so the next step will be to explore the implications of the results for MRH predictive modelling by assessing the degree of temporal variability in the SAR sites relative to classifications/ ordinations of related impacted sites.

For the South Alligator River study, data from the adjacent Rockhole Mine Creek, polluted by acid mine drainage will be used for this assessment. Lack of constancy in SAR communities would clearly present a problem if, after the assessment, natural changes in community structure were of the same direction and magnitude as those in disturbed RMC sites.

If this analysis clearly showed, in the absence of further information, that the anomalous SAR data could easily have been interpreted as 'impacted', then environmental correlates would need to be sought to account for any year-to-year variation in community structure. These variables would then be fed into the MRH predictive models.

Again, for the SAR data, the biological and environmental data from the 8 sites and (say) first 8 years would be modelled. The model would then be tested and refined using the data of years 9 and 10. Some dynamic measure of stream discharge might well account for the SAR anomaly - though possible lags in response could mean that long time series are required to properly model the data.

This broad approach would be repeated if necessary for long-term data-sets from other locations in Australia.

From the above, appropriate recommendations would be made to the developers of the predictive models according to different climatic/ hydrological regions of Australia. For example:

(i) As discussed above, feedback to MRH of key explanatory variables (e.g. flow variables associated with floods, long-term drought).

(ii) Avoid sampling after known extreme events (Wright, 1995); or expend less sampling effort during 'problem' seasons.

(iii) Regular sampling of reference sites over time to 'update' or 'adjust' models.

(iv) Other approaches: BACIP and other repeated measures designs for monitoring river health.

Table 1: Significance of Spearman rank correlation R - values for pairwise comparisons of 8 years of family-level data from a site on the South Alligator River.

YEAR	1987	1988	1989	1990	1991	1992	1993
1988	* * *						
1989	* * *	* *					
1990	* * *	* *	* * *				
1991	* * *	* * *	* * *	* * *			
1992	* * *	* * *	* * *	* * *	* * *		
1993	NS	*	NS	NS	NS	*	
1994	* * *	* *	*	*	* * *	* * *	* * *

NS = not significant; * = P<0.05; * * = P<0.01; * * * = P<0.001.

Table 2: Dissimilarity values (Bray-Curtis) for pairwise comparisons of 8 years of family-level data (untransformed) from a site on the South Alligator River.

YEAR	1987	1988	1989	1990	1991	1992	1993
1988	0.395						
1989	0.388	0.439					
1990	0.327	0.485	0.123				
1991	0.175	0.377	0.249	0.244			
1992	0.194	0.473	0.286	0.239	0.184		
1993	0.421	0.464	***0.765***	***0.716***	***0.50***	***0.514***	
1994	***0.50***	***0.613***	***0.734***	***0.677***	***0.554***	***0.530***	0.406

Figure 1

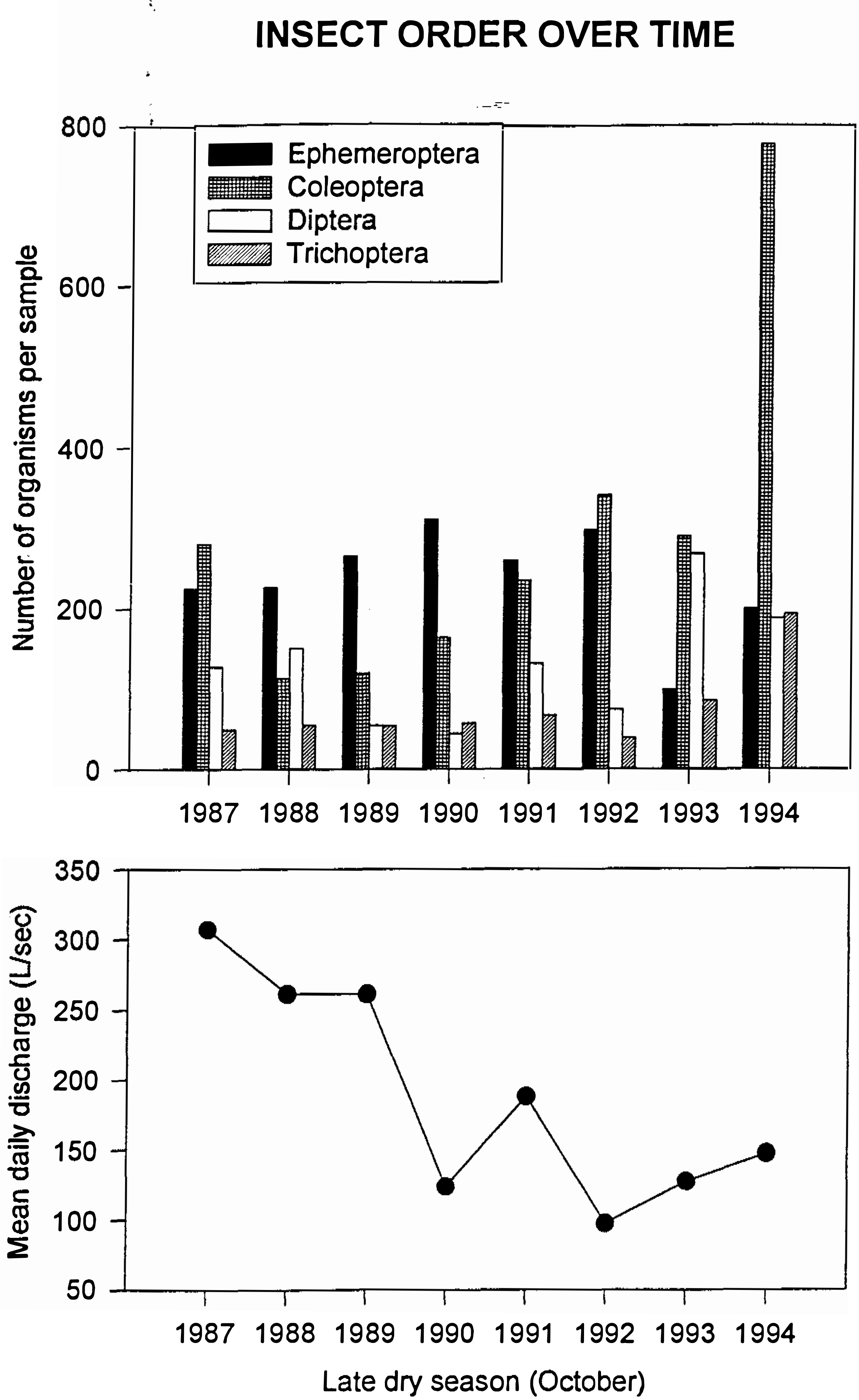

INSECT ORDER OVER TIME
Ephemeroptera
Coleoptera
Diptera
Trichoptera
Number of organisms per sample
0
200
400
600
800
1987 1988 1989 1990 1991 1992 1993 1994
Mean daily discharge (L/sec)
50
100
150
200
250
300
350
1987 1988 1989 1990 1991 1992 1993 1994
Late dry season (October)

Figure 2

MAYFLY FAMILIES OVER TIME

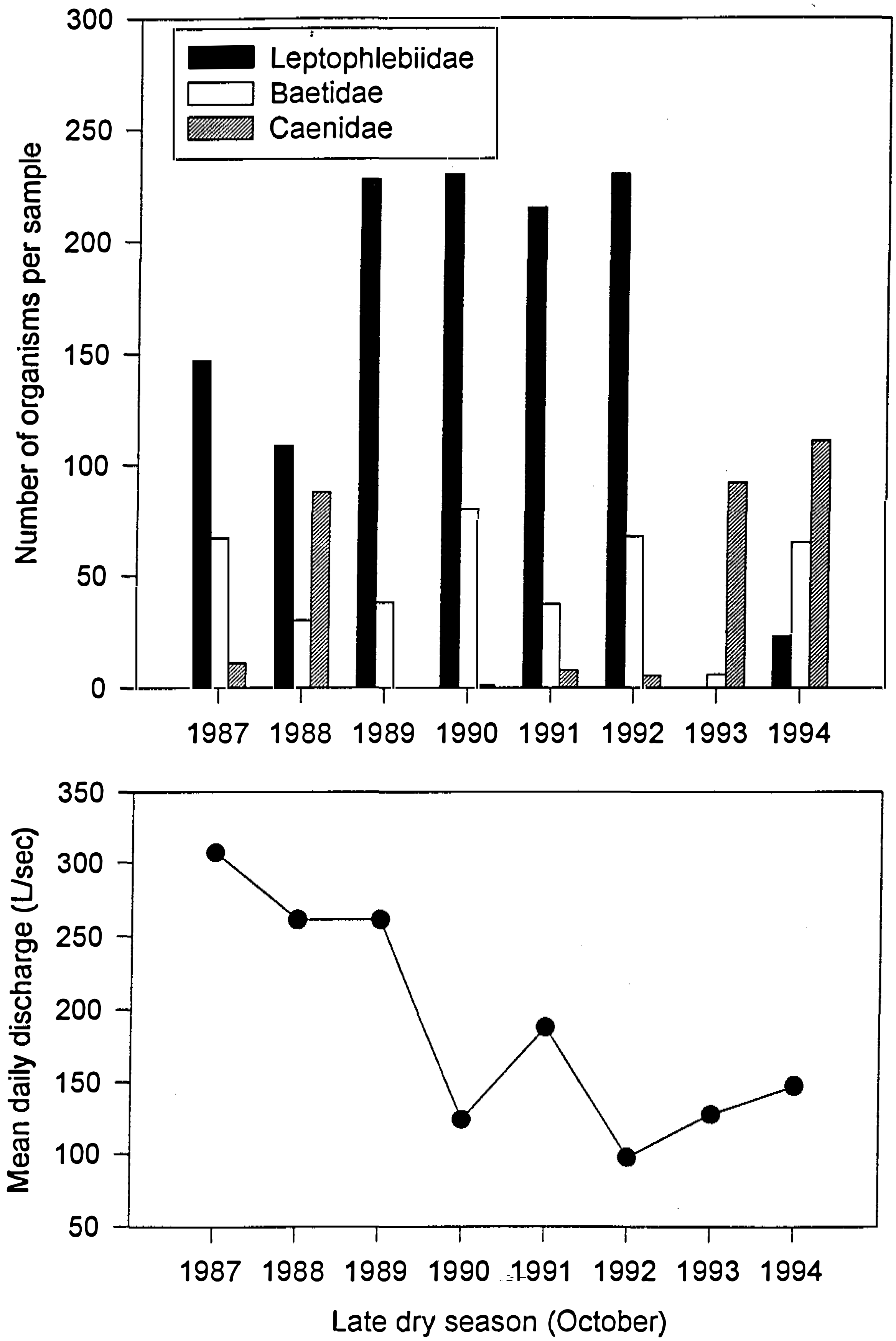
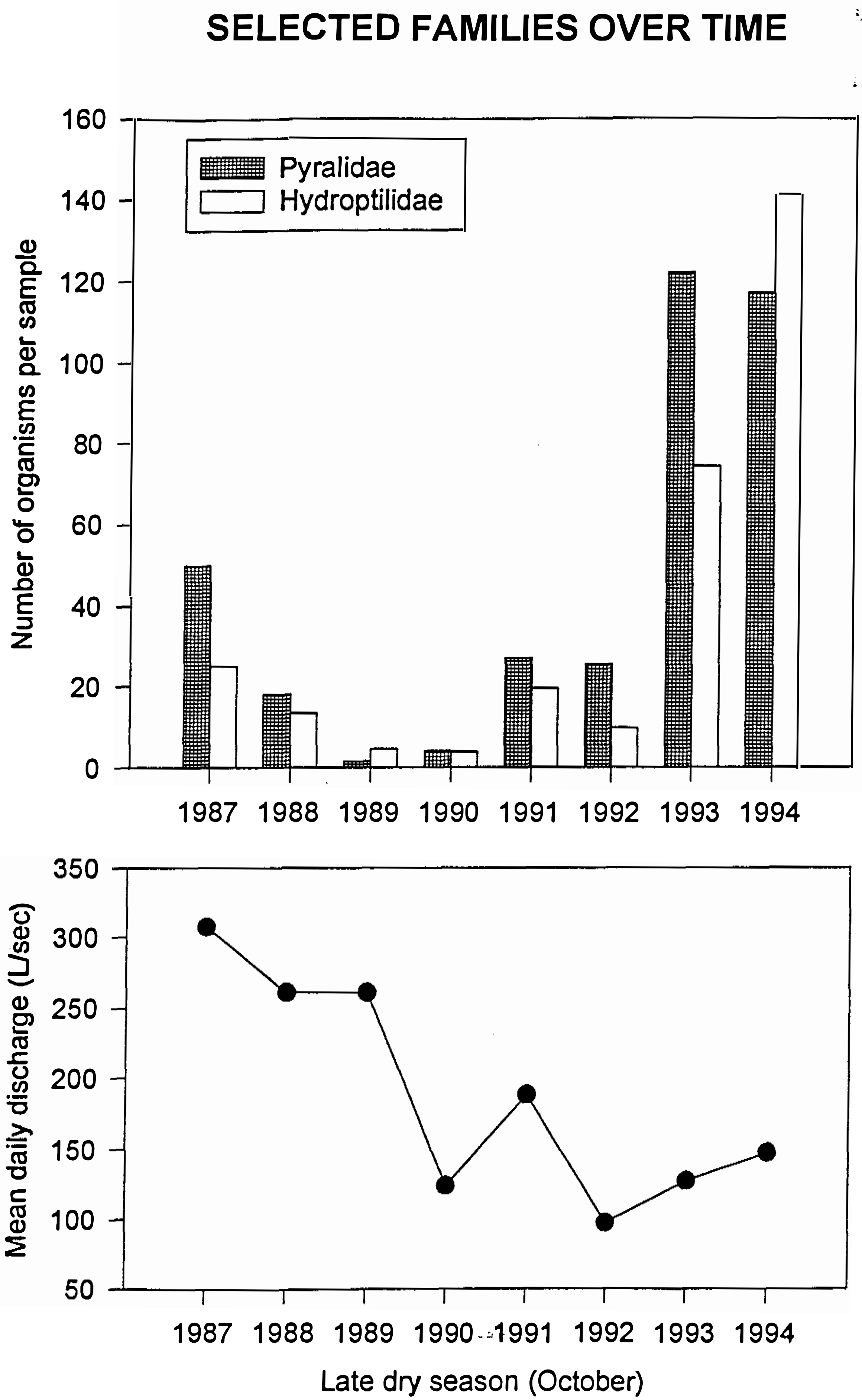


Figure 3


SELECTED FAMILIES OVER TIME
Pyralidae
Hydroptilidae
Number of organisms per sample
160
140
120
100
80
60
40
20
0
1987 1988 1989 1990 1991 1992 1993 1994
Mean daily discharge (L/sec)
350
300
250
200
150
100
50
1987 1988 1989 1990 1991 1992 1993 1994
Late dry season (October)

ATTACHMENT 2

Presentation to Annual Conference of the Australian Society for Limnology, Jenolan Caves NSW, 18-20 September 1995

A long-term study of macroinvertebrate communities in the upper South Alligator River, NT: temporal variability

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[2]Division of Wildlife and Ecology, CSIRO, PO Box 84, Lyneham ACT 2602;
[3]Conservation Commission of the NT, PO Box 496, Palmerston NT 0831.

Presentation to Annual Conference of the Australian Society for Limnology, Jenolan Caves NSW, 18-20 September 1995

A long-term study of macroinvertebrate communities in the upper South Alligator River, NT: temporal variability

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Abstract

A long-term study of macroinvertebrate communities in the upper South Alligator River (SAR) (NT) has been underway since October 1987. Samples from 8 sites in permanent sections of the river were gathered at bimonthly intervals for an initial 2 year period and twice yearly (early and late Dry seasons) thereafter to 1992. Further twice-yearly sampling and data analysis are being funded as part of the MRHI R&D program. The resulting 10-year data set will be used to assess the degree of temporal variability in these and related tropical invertebrate communities.

Temporal patterns in invertebrate communities of the SAR, within and amongst the 8 years of data, are described. The most significant observation to date occurred in the 7th year of sampling (1993) when leptophlebiid mayflies, until then the dominant insect family present in the river, were almost entirely missing. This and other alterations to the rank order abundance of invertebrate families continued into 1994 and appeared to be related to a progressive decline in the base flow of the river since 1987. Such lack of persistence is a problem for impact detection and assessment models with a predictive base, such as the MRHI. For the SAR data, the magnitude of change occurring post-1992 was at least as severe as that occurring in mine-polluted portions of an adjacent stream (Rockhole Mine Creek). To fully explain and account for such natural disturbances (by way of environmental variables), a data set of a decade or longer may be required. The implications of these results for predictive modelling and for alternative repeated-measures designs (BACIP) are discussed.

1. Introduction

Long-term data sets such as that from the SAR, have many virtues. One valuable attribute is in the ability to test assumptions behind broad-scale models for monitoring. Biological models used to detect human-related disturbance depend on a number of factors. For example, critical assumptions that must be met in BACIP designs, which use a form of temporal replication over a control and to-be-disturbed site, include the constancy of difference values derived between the two sites and independence of the temporal 'replicates' over time. For predictive models such as RIVPACS, there is a key assumption concerning the constancy of community composition or structure over time. If this constancy or persistence was not observed and if changes in communities from year to year cannot be accounted for using environmental data, then the models may fail in their classifications and predictions of invertebrate community composition or structure.

The issue of temporal persistence of stream invertebrate communities is not one that has been well investigated - primarily because there are few long-term data sets available from which to address the issue. There is some literature available from North America and Australia to show that where flow is seasonally-variable or unpredictable, the fauna may not be constant and may be very responsive to droughts and floods; such features of streams and climate of course characterise the Australian continent. Hence, this is an issue that needs to be closely investigated in relation to development of impact assessment models based on predictive modelling in Australia.

As part of the MRH Initiative, the ERISS has been contracted by LWRRDC to carry out an R&D project designed to assess the degree of temporal variability of macroinvertebrate communities in Australian streams and implications for predictive modelling. The SAR data set constitutes one of the streams under such investigation. Some background to the SAR study:

- Invertebrates from 8 sites in the SAR were sampled from 1987-1991 to develop a monitoring program to assess impact of mining at Coronation Hill. Sampling was conducted bimonthly over an initial 2-year period, then twice-yearly thereafter. Late Dry season samples from 1992, 1993 and 1994 have also been collected.
- Further twice-yearly sampling, sample processing and data analysis are being funded as part of the MRHI R&D program. The resulting 10-year data set will be used to assess the degree of temporal variability in these and related tropical invertebrate communities.

This paper will present results of preliminary analyses on temporal variability of macroinvertebrate communities in the SAR. Consistent with all MRHI protocols, the SAR analysis has been conducted using family-level data only.

2. Seasonal pattern of community structure

All sampling has been conducted in the permanent headwaters of the river. Flow is very predictable with high wet season flows expected between November and April, with a period of recessional flow occurring during the Dry season months from May to October (see Fig. 1).

Figure 1 shows the abundances of the major orders of invertebrates that occurred in riffle substrates from the bimonthly sampling that was conducted over the first 2 years of the study. Values are mean abundances per Surber replicate averaged over 8 sites (4 replicates per site). Also shown are mean daily discharge data for the months sampled. Seasonal dynamics of the invertebrate communities may be summarised:

- - The fauna was dominated in these 2 years by immature Ephemeroptera, followed by Coleoptera, Diptera and Trichoptera. (Leptophlebiid mayflies were by far the most dominant family in the river over this 2-year period.);

  - There was little in the way of seasonal changes in the rank order abundance of the different taxa;
- The fauna is very responsive to flow; there are low abundances during months of higher wet season flow, with increases over the dry season as flow subsides. Higher flows in 1989 resulted in more scouring and lower abundances over the ensuing dry season.
- Multivariate ordination demonstrated clearly the considerable variation in community structure during wet season months, but little variation during the period of recessional dry season flow (May-Oct). Community structure was very similar amongst years by the late dry season (Oct).

An SSH ordination of the bimonthly, family-level data are shown in Figure 2. The two year trajectories show annual cycles of wet season scouring and dry season recovery. From the ordination the following features are noteworthy: i) the broader trajectory in 1989 than in 1988 because of greater wet season discharges and scouring; and ii) there is greater variation (sample points more scattered) in the fauna in the months of wet season flow (Dec-May). From these results, the late dry season would be a preferred time to sample if comparable community structure was the target of the study, such as for monitoring - note that all October samples are positioned closely in the ordination (Fig. 2).

3. Interannual variation

Analyses hereafter are for late Dry season samples (October) from 8 or 9 years of sampling. Figure 3 shows the mean abundances of the major insect orders and dominant families present over 9 years of late Dry season sampling at the 8 sites. Also shown is the recessional or dry season flow volume in the river in the 5 months prior to sampling. Up to 1992, the fauna was dominated mainly by mayflies; some high chironomid numbers at a few lower sites in 1990 and 1991 influence the dipteran counts for the data shown here. From 1993 though, mayfly numbers have switched from a position of dominance to one of lower rank order. Looking at the mayfly data in more detail (Fig. 3): Leptophlebiids are normally the dominant family at this time of year; in fact up to 1993, this family was numerically the most abundant of the entire SAR fauna. As shown in Figure 3, in 1993 the family is missing entirely from the river, with only a slight recovery in 1994 and 1995. Baetid mayflies follow the same pattern of decline as leptophlebiids. Other taxa though appear to have benefited from the associated decline in the base flow in the river since 1987, including elmid beetles and caenid mayflies.

3.1 Persistence

The data for 2 or 3 sites in the vicinity of Coronation Hill were used to quantify the degree of persistence in the invertebrate fauna over 8 years of data (1987-94).

Firstly, ***Spearman rank correlation*** was performed using the rank order of abundance of taxa between any pair of years. 'Anomalous' years will appear wherever there is absence of statistical significance in the pairwise Spearman rank correlations. Table 1 shows results of data analysis for one of the sites. Typical of the pattern for other sites, there is an absence of statistical significance for most comparisons involving 1993 and 1994, these years clearly being very different from others, though they are similar to one another (Table 1).

Classification using hierarchical techniques can also be used to quantify the degree of persistence. This is particularly relevant to assessment of the RIVPACS-type approach because RIVPACS uses a classification system as the basis for the predictive model. Again, 'anomalous' years, and hence lack of persistence, will appear as misclassifications in the dendrogram. For this analysis, other than SAR late Dry season data, data from the early Dry season as well as those from the adjacent Rockhole Mine Creek (RMC), portions of which are polluted by acid mine drainage, are also included. These additional data can give any anomalous SAR data a better context to assess its severity. In the resulting UPGMA classification (Fig. 4), the data (not surprisingly,) split between SAR and RMC at the 2-group level; the fauna of the 2 streams - one permanently flowing, the other seasonally-flowing - differs somewhat. Nevertheless, the late Dry season data from the SAR from 1993-94 split from other late Dry season SAR data at a high level; early Dry season samples are intermediate in nature between the two groups of late Dry season samples. Note too, that the distinction between polluted and unpolluted sites in RMC is small compared with interannual variation in the SAR.

3.2 Implications of temporal variation for monitoring

The misclassification and 2-stream comparison (Fig. 4) was further explored using multivariate ordination. Lack of constancy in SAR communities would clearly present a problem if, after the assessment, natural changes in community structure were found to be of the same direction and magnitude as those in disturbed RMC sites. In this case and, in the absence of further information, we could falsely conclude that the anomalous SAR data indicated human impact.

The SSH ordination (Fig. 5) confirms the results of the classification in showing that the magnitude of change occurring in the SAR post-1992 was of a greater magnitude than that occurring between undisturbed and mine-polluted portions of RMC. Further though, the change is in the same *direction* as that between the two portions of RMC. 'Principal axis correlation' (PCC) was used to find which taxa were influencing magnitude and direction of the separated groups; correlation values of 0.8 or greater are shown here. As expected, there are groups of taxa simply separating the 2 streams; these taxa are common in one stream but are generally absent in the other. Also though, there are taxa common to both types of disturbance, low flow and mine pollution. Leptophlebiid and baetid mayflies and hydropsychid caddisfly larvae are particularly sensitive to the 2 types of disturbance, while caenids appear to be favoured by the altered conditions. Clearly, the gradient of disturbance in the SAR is the same as that in RMC and in the absence of further information, the result could falsely be ascribed to human impact.

Summarising some key issues with this observed lack of persistence in the SAR:

Factors contributing to low persistence in SAR fauna

- The Leptophlebiidae are mostly represented by just 2 dominant species. (Hence, any major shifts in abundance of these taxa will be reflected directly at the family level.)
- Dynamic fluxes might be expected to be more evident amongst tropical, flow-dependent taxa. These taxa, with short life cycles, could be very responsive to sub-optimal conditions and high seasonality in discharge.

Factors of interest in low persistence of invertebrate communities of the SAR

- For the data analysed, there was an absence of intermediate densities of leptophlebiids (i.e. "all or nothing"). The absence/low abundances of leptophlebiids is low-flow related: the disappearance of this family commenced at some downstream low-flow sites in 1990 but culminated in near-complete absence from 1993-95, even at upstream 'refuge' sites of high flow or in early dry season months of high flow.
- Ordinations conducted on all SAR data (Fig. 6) show two different community 'states': a 'high flow' state (sites where leptophlebiid densities are high), separated by 'low flow' state (sites without leptophlebiids and dominated by elmid beetles). The 'switch' from 'high flow' to 'low flow' state appears to be very abrupt
- The results of the present study may lead to generation of interesting hypotheses. For example, leptophlebiid presence/absence is influential in site classifications. Is the group more than just an indicator taxa for flow conditions, i.e. are leptophlebiids important in structuring SAR macroinvertebrate communities ('keystone' role)?
- There are lags in response of leptophlebiids to flow conditions. Loss of this family from the river occurred well after the 'driest' year (1992, Fig. 3). Moreover, a slow recovery to the 'high flow' state is evident in that despite higher recessional flows in 1994 and 1995, leptophlebiids have not reappeared (Fig. 3). Whilst lack of recovery in 1995 may have been exacerbated by very high flows in the preceding wet season, it is also likely that there is a stochastic element to the recovery process as well.
- Finally, it is quite possible that different community 'states' prevail over decadal time spans.

Following from this last dot point, Figure 7 shows recessional flow volumes for the SAR since records began in 1958. Across the base of the hydrograph a line is scored indicating a possible flow threshold below which leptophlebiids are essentially absent in the river. It is also assumed that recovery is not particularly rapid (see above) and that the 'odd' high-flow year amongst mostly low-flow years would be characterised by absence of leptophlebiids. If these assumptions are correct, then from 1958 to 1970, the river fauna was of a different state to that occurring from say the early 1970s to 1992. Thus, different community states may persist over long periods of time. If recovery from 'low flow' to 'high flow' state is somewhat stochastic, then even lags in community response might not be so predictable.

Such lack of persistence is a problem for impact detection and assessment models with a predictive base, such as the MRHI. An obvious need now, is to seek environmental correlates that may account for any year-to-year variation in community structure and input these variables to the models. Given the lags in response of organisms to natural disturbances though, a data set of a decade or longer may be required to fully explain and account for such variation (by way of environmental variables). As stated above, moreover, if stochastic processes determine switches between different community states, community composition or structure might never be predicted.

On a more optimistic level, however, models could simply be constructed for different community 'states' such as runs of dry or wet years. Even better, would be the incorporation of data from spatial controls. For predictive modelling, regular sampling of reference sites over time could be undertaken to 'update' or 'adjust' models. With judicious selection of sites, e.g. upstream and downstream of proposed developments, fall back to BACIP or other repeated measures designs for monitoring river health should be possible.

The authors have been monitoring community structure at 2 sites in the SAR either side of Coronation Hill (upstream /downstream) using a multivariate extension of the BACIP design. This design incorporates a form of temporal replication of 'difference' values derived between upstream control and downstream 'to-be-disturbed' sites. The multivariate extension of the design incorporates dissimilarity values as the measure of difference between the sites: a set of dissimilarity values is gathered in a pre-disturbance, baseline phase and again in a disturbance phase and the sets of values compared using a *t*-test for significance. The BACIP design and resulting test assume that the temporal difference values are independent and constant over time. For 5 years of species-level data from the river we have demonstrated *low* mean dissimilarity and *constancy* of the measure for the 2 sites either side of Coronation Hill. In ordination space, the sites effectively 'track' one another.

Extending this analysis to 8 years of family-level data for the same 2 sites (Fig. 8), it can be seen that despite large year to year variation of community structure, the 2 sites again track one another. Looking at the compositional distances between the 2 sites by linking the sites in ordination space (Fig. 9), it can be seen that the distances are reasonably constant - though, interestingly, not as constant as species-level data. The resulting mean dissimilarity is low at about 0.2 with a CV of about 20% (cf CV of about half this value for species-level data). Hence spatial comparisons are the obvious solution for monitoring wherever major temporal shifts in community structure are evident.

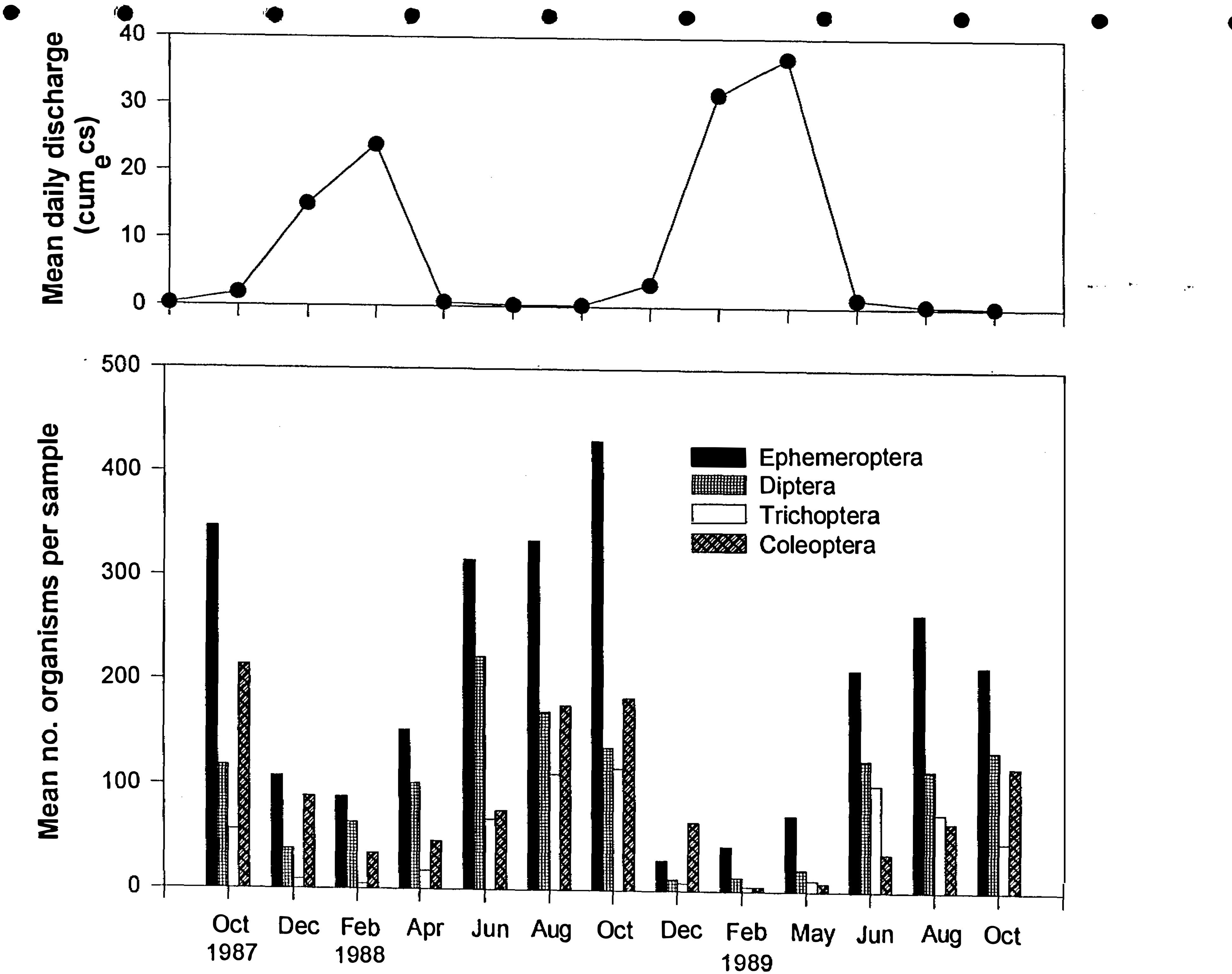

Mean daily discharge (cum_ecs)
40
30
20
10
0
Mean no. organisms per sample
500
400
300
200
100
0
Ephemeroptera
Diptera
Trichoptera
Coleoptera
Oct 1987
Dec
Feb 1988
Apr
Jun
Aug
Oct
Dec
Feb 1989
May
Jun
Aug
Oct

Figure 1

Figure 2

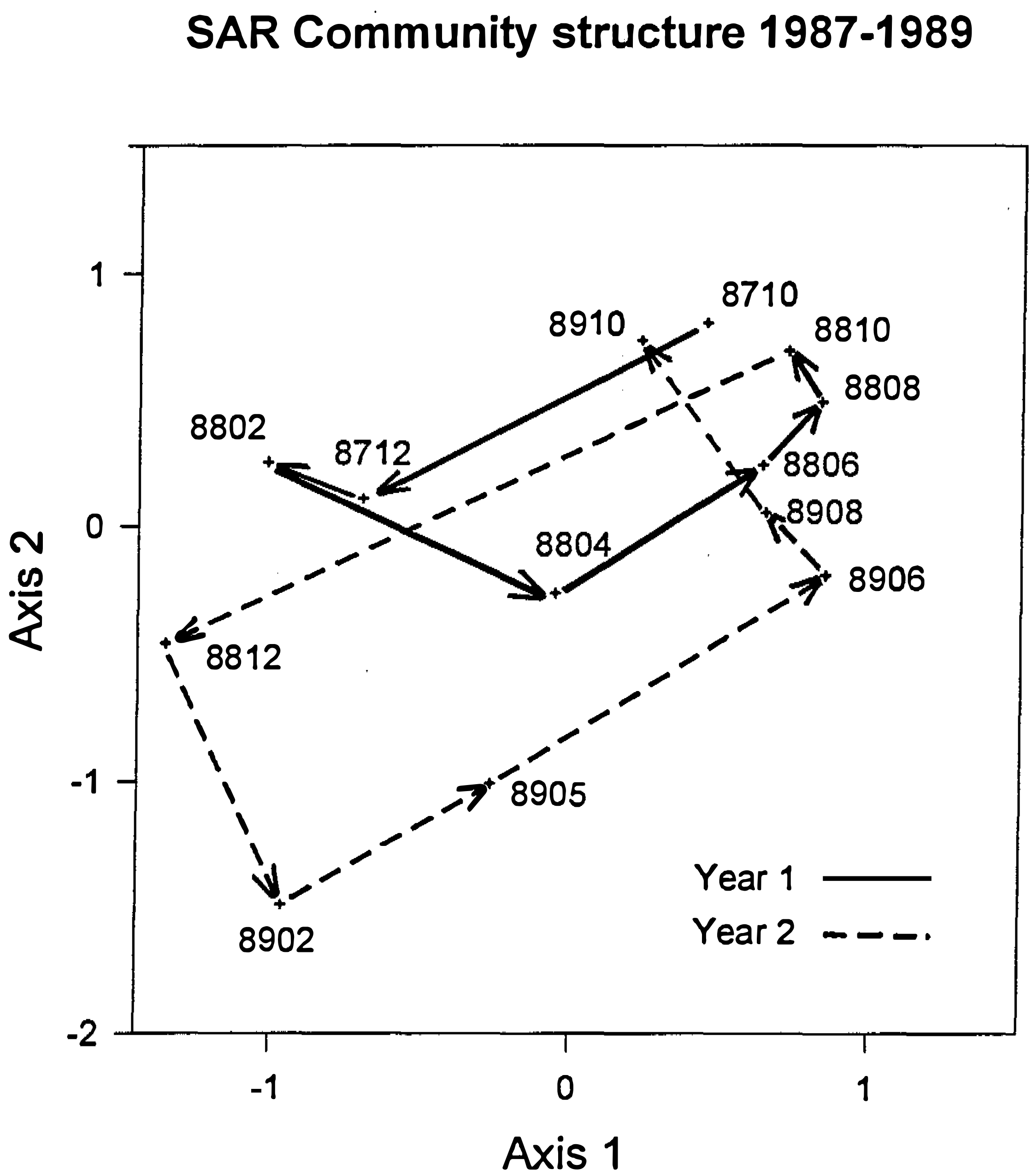
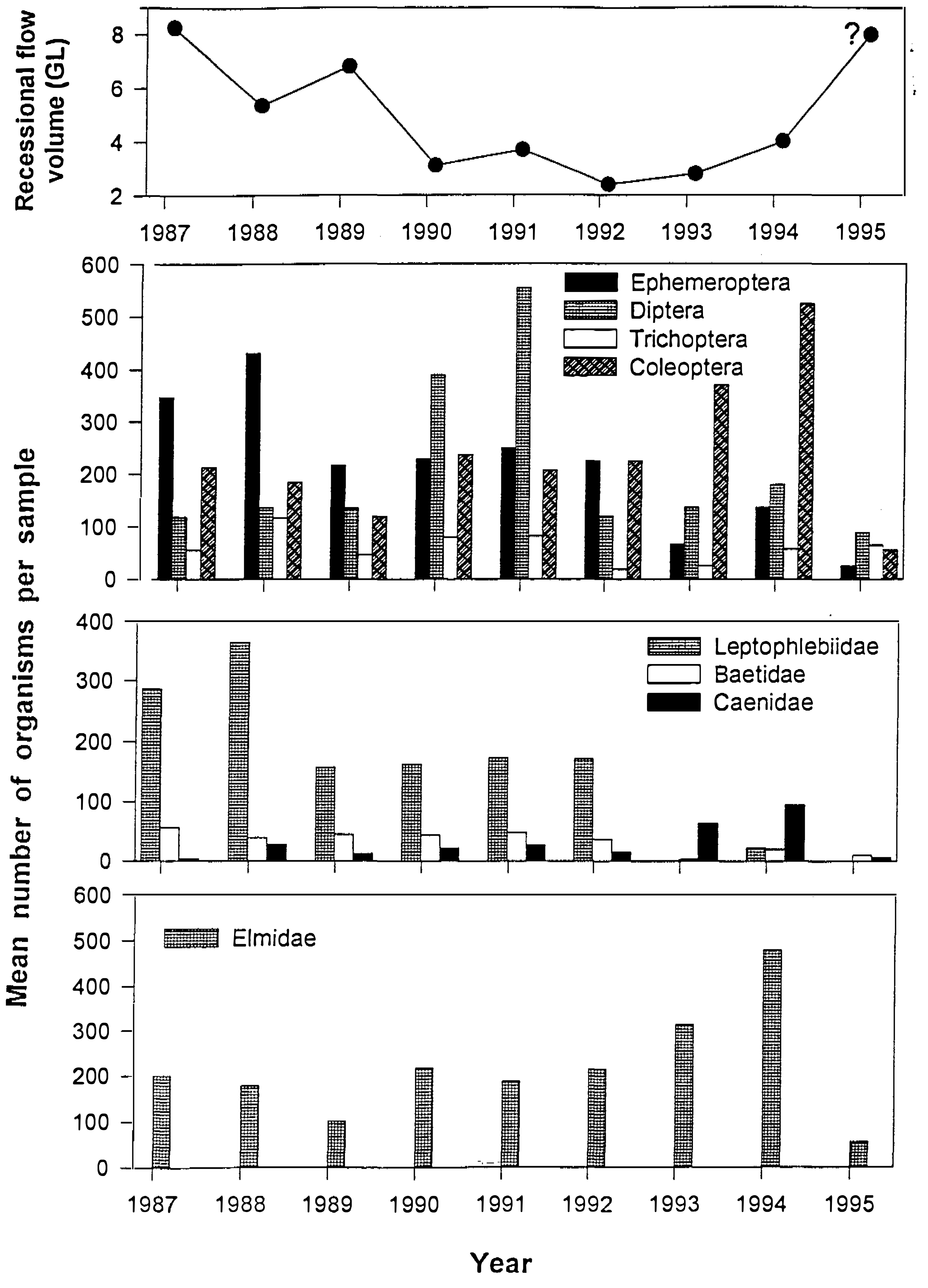

SAR Community structure 1987-1989
Axis 2
Axis 1
1
0
-1
-2
-1
0
1
8710
8910
8810
8808
8802
8712
8806
8908
8804
8906
8812
8905
8902
Year 1
Year 2

Figure 3



Recessional flow volume (GL)
8
6
4
2
?
1987
1988
1989
1990
1991
1992
1993
1994
1995
600
500
400
300
200
100
0
Ephemeroptera
Diptera
Trichoptera
Coleoptera
400
300
200
100
0
Leptophlebiidae
Baetidae
Caenidae
600
500
400
300
200
100
0
Elmidae
1987
1988
1989
1990
1991
1992
1993
1994
1995
Mean number of organisms per sample
Year

Table 1

Significance of Spearman rank correlation R - values for pairwise comparisons of 8 years of family-level data from a site on the South Alligator River.

YEAR	1987	1988	1989	1990	1991	1992	1993
1988	* * *						
1989	* * *	* * *					
1990	* * *	* * *	* * *				
1991	* * *	* * *	* * *	* * *			
1992	* * *	* *	* * *	* *	* * *		
1993	NS	NS	NS	NS	NS	NS	
1994	NS	NS	NS	NS	NS	NS	* * *

NS = not significant;

* * = P<0.01;

* * * = P<0.001.

Flexible UPGMA classification of 3 SAR sites (1987-94, twice-yearly) and 2 RMC sites (1991-93)

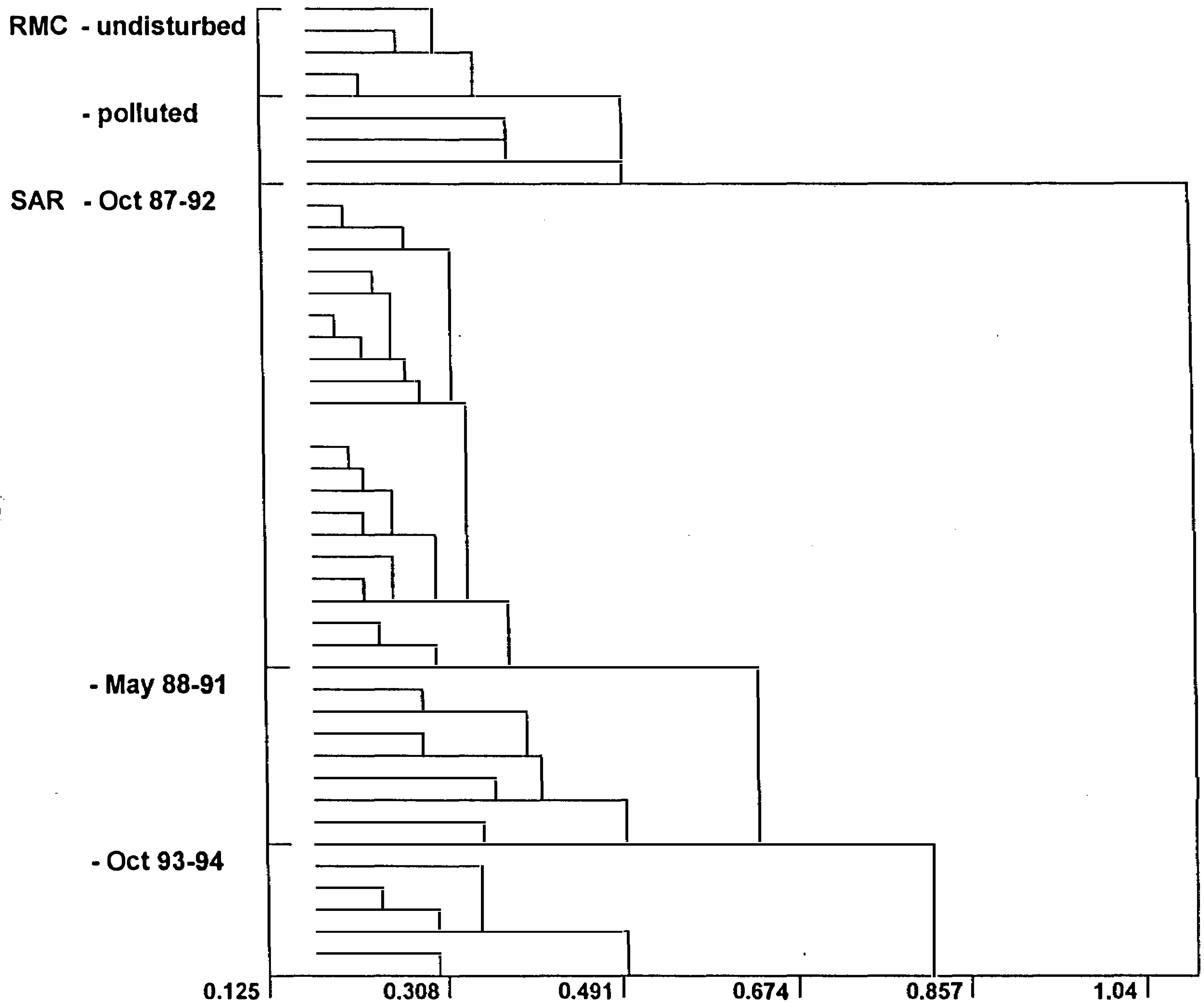


Figure 4

Figure 5

SSH Ordination of SAR (sites 2 and 3) and RMC (1991-93) data with PCC analysis

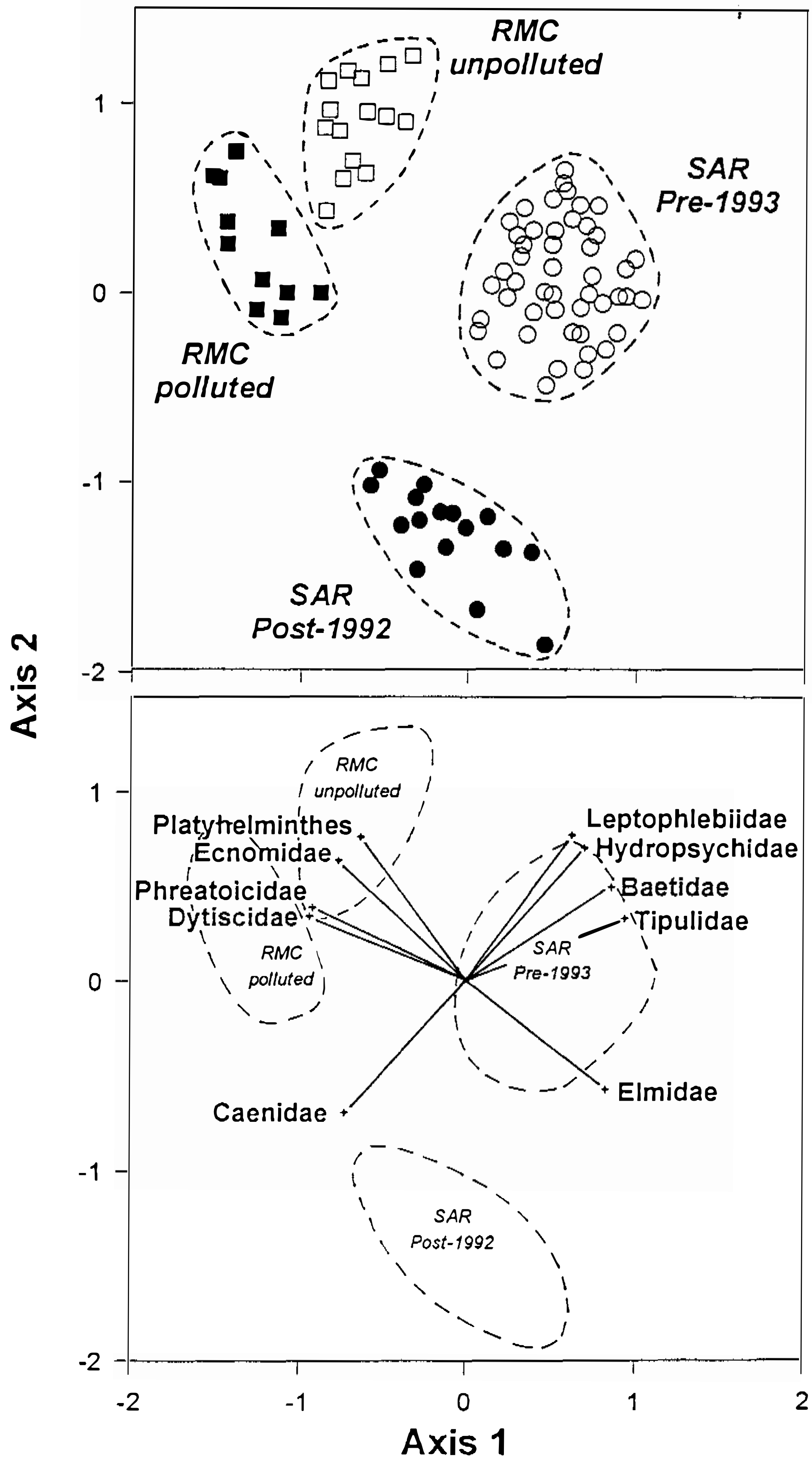
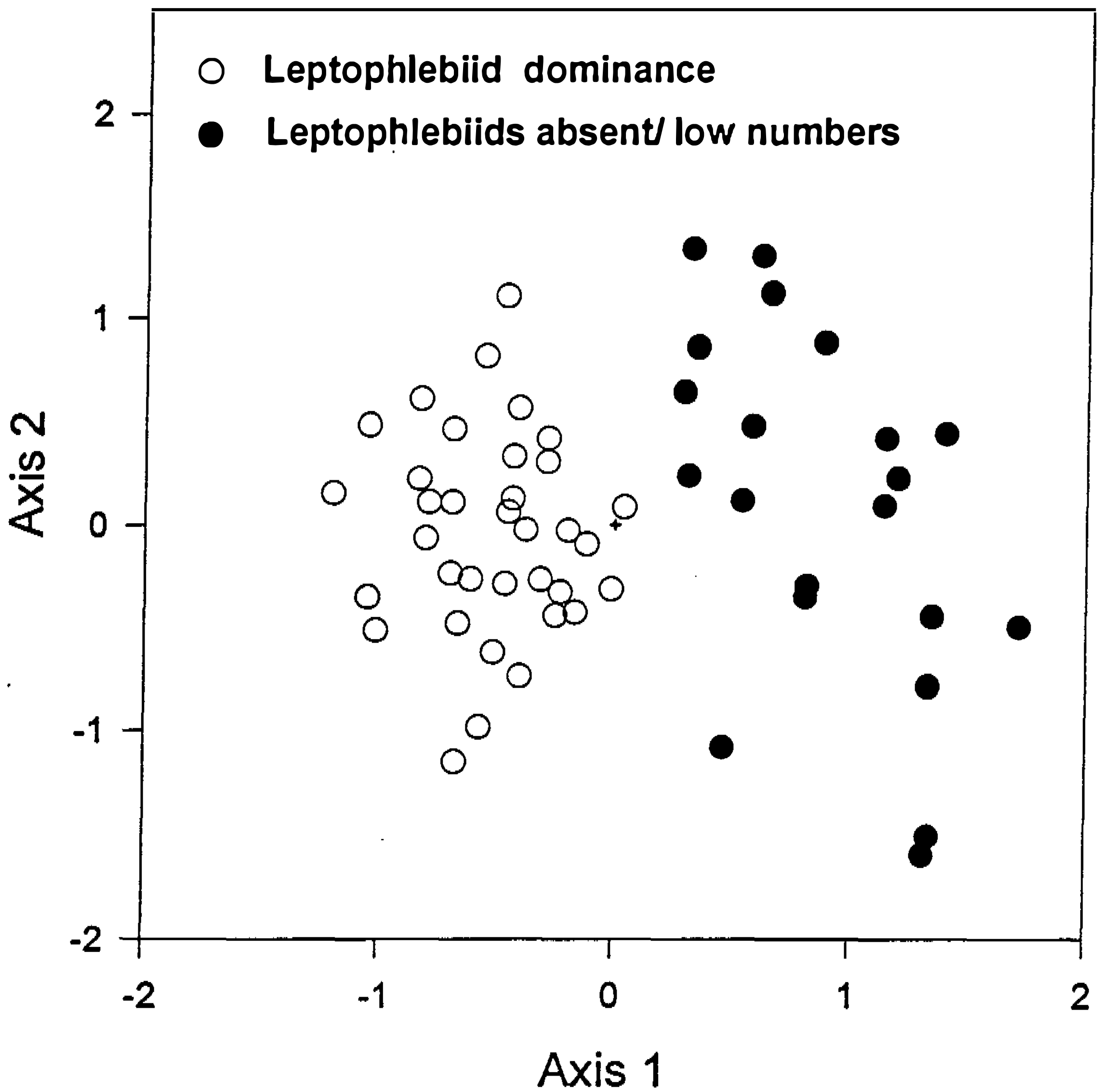


Figure 6.

SSH ordination of all SAR sites, 1987-1994



Possible dichotomy in SAR macroinvertebrate community structure over time

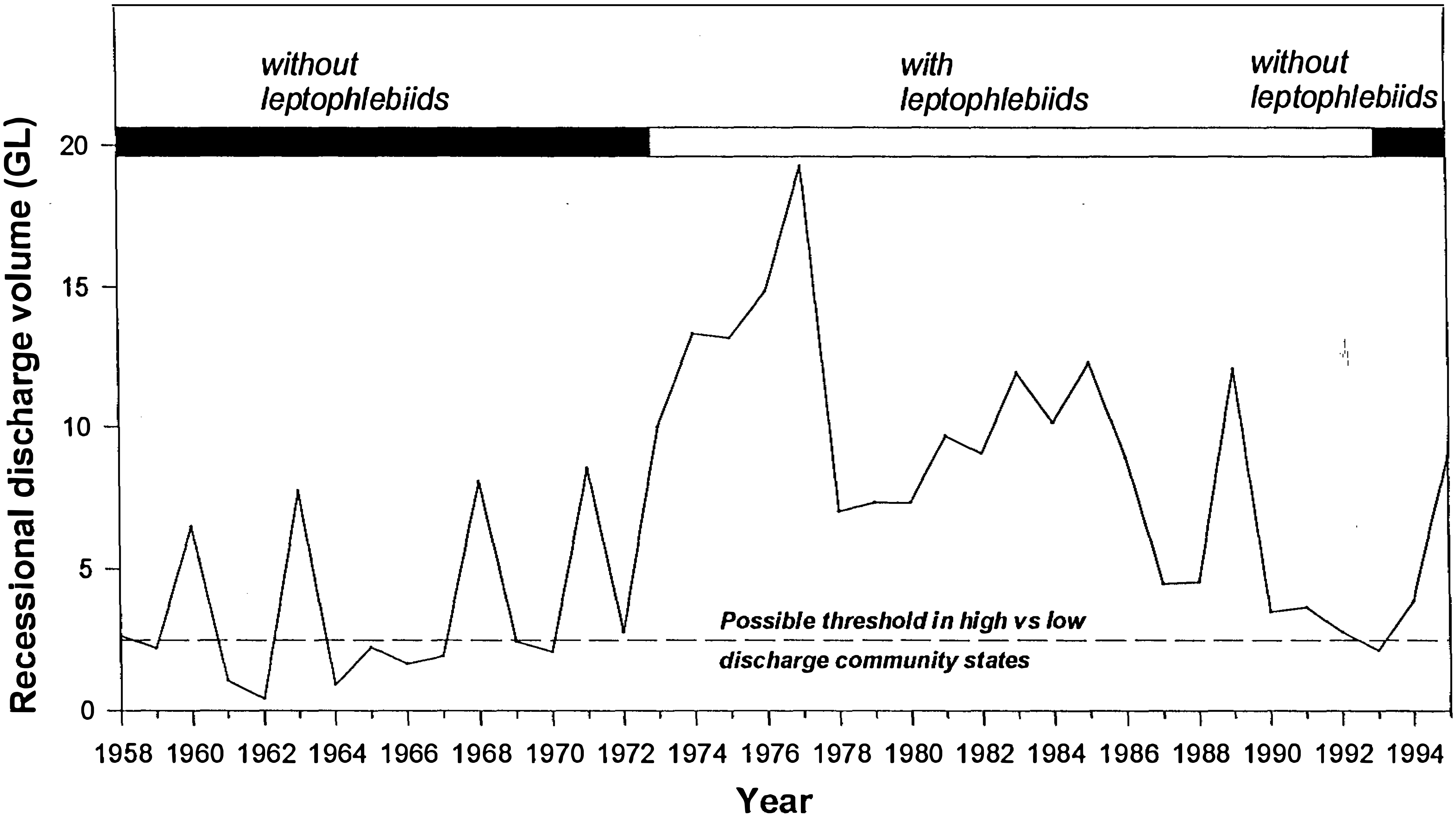


figure 7

Figure 8

Eight-year SSH ordination for SAR sites 2 and 3

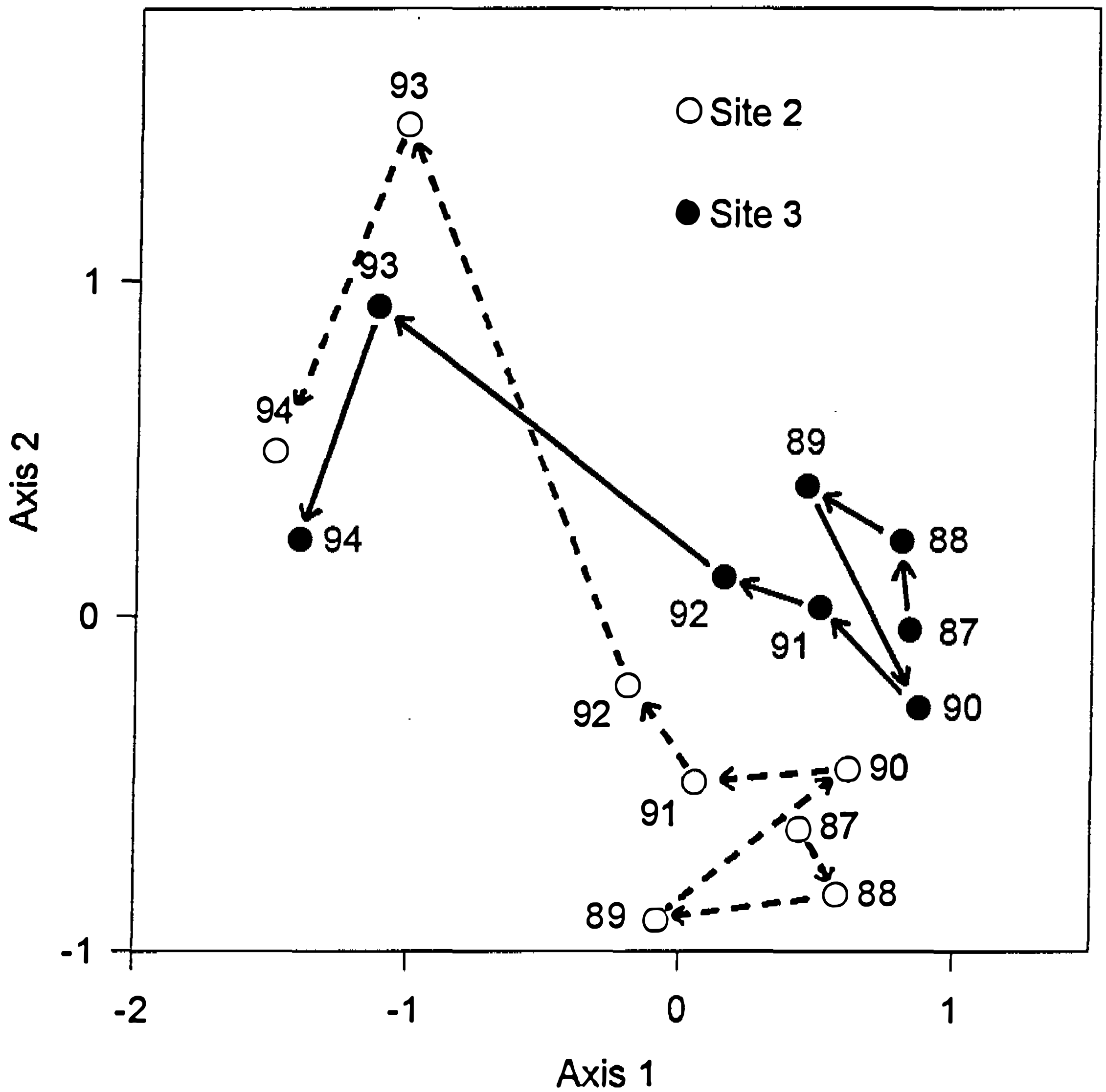


Figure 9

Compositional 'distances' between SAR sites 2 and 3 over years