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RIVER MINING:

ECOLOGICAL EFFECTS OF RIVER MINING

Economic Minerals and Geochemical Baseline Programme
British Geological Survey Commissioned Report CR/03/162N

WRc-NSF

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/03/162N

River Mining: assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica.

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Front cover

Turbid conditions in the Rio Minho, Jamaica caused by instream mining and processing of sand and gravel.

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Preface

Throughout the developing world river sand and gravel is widely exploited as aggregate for construction. Aggregate is often mined directly from the river channel as well as from floodplain and adjacent river terrace deposits. Depending on the geological setting, in-stream mining can create serious environmental impacts, particularly if the river being mined is erosional. The impacts of such mining on farmland, river stability, flood risk, road and bridge structures and ecology are typically severe. The environmental degradation may make it difficult to provide for the basic needs (water, food, fuelwood, communications) of communities naturally located in the river valleys.

Despite the importance of this extractive industry in most developing countries, the details of its economic and environmental geology are not fully understood and therefore do not adequately inform existing regulatory strategies. The main problem is therefore a need to strengthen the general approach to planning and managing these resources. Compounding the problem is the upsurge of illegal extractions along many river systems. There is therefore a need to foster public awareness and community stewardship of the resource.

The project 'Effective Development of River Mining' aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. This project (Project R7814) has been funded by the UK's Department for International Development (DFID) as part of their Knowledge and Research (KAR) programme. This programme constitutes a key element in the UK's provision of aid and assistance to less developed nations. The project started in October 2000 and terminates late in 2004.

Specific objectives of the project include:

- Resource exploration and resource mapping at the project's field study sites (Rio Minho and Yallahs rivers in Jamaica)
- Analysis of technical and economic issues in aggregate mining, particularly river mining
- Determination and evaluation of the environmental impacts of river mining
- Evaluation of social/community issues in the context of river mining
- Investigation of alternative land and marine aggregate resources
- Review of the regulatory and management framework dealing with river mining; establishment of guidelines for managing these resources and development of a code of practice for sustainable sand and gravel mining.

The 'Effective Development of River Mining' project is multidisciplinary, involving a team of UK specialists. It has been led by a team at the British Geological Survey comprising David Harrison, Andrew Bloodworth, Ellie Steadman, Steven Mathers and Andrew Farrant. The other UK-based collaborators are Professor Peter Scott and John Eyre from the Camborne School of Mines (University of Exeter), Dr Magnus Macfarlane and Dr Paul Mitchell from the Corporate Citizenship Unit at the University of Warwick, Steven Fidgett from Alliance Environment and Planning Ltd and Dr Jason Weeks from WRc-NSF Ltd. The research project is generic and applicable to developing countries worldwide, but field studies of selected river systems have been carried out in Jamaica and review studies have been undertaken in Costa Rica. Key participants in these countries have included Carlton Baxter, Coy Roache and Larry Henry (Mines and Geology Division, Ministry of Land and Environment, Jamaica), Paul Manning (formerly Mines and Geology Division, Ministry of Land and Environment, Jamaica) and Fernando Alvarado (Instituto Costarricense de Electricidad, Costa Rica).

The authors would like to thank the many organisations in Jamaica and Costa Rica who have contributed to the project. In addition to the collection of data, many individuals have freely given their time and advice and provided the local knowledge so important to the field investigations.

This report forms one of a series of Technical Project Output Reports listed below:

- *Geology and resources of the lower Rio Minho and Yallahs Fan-delta, Jamaica, 2003*. AR Farrant, SJ Mathers and DJ Harrison, British Geological Survey.
- *Aggregate production and supply in developing countries with particular reference to Jamaica, 2003*. PW Scott, JM Eyre (Camborne School of Mines), DJ Harrison and EJ Steadman, British Geological Survey.
- *Assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica, 2003.* J Weeks, I Sims, C Lawson (WRc-NSF Ltd) and DJ Harrison, British Geological Survey.
- *Scoping and assessment of the environmental and social impacts of river mining in Jamaica, 2003*. M Macfarlane and P Mitchell, Warwick Business School, University of Warwick.
- *Alternative sources of aggregates, 2003*. DJ Harrison and EJ Steadman, British Geological Survey.

Alluvial mining of aggregates in Costa Rica, 2003. Fernando Alvarado-Villalón (Costa Rican Institute of Electricity), DJ Harrison and EJ Steadman, British Geological Survey.

- *Planning guidelines for management of river mining, 2003*. S Fidgett, Alliance Environment and Planning Ltd.

Details of how to obtain these reports and more information about the 'Effective Development of River Mining' project can be obtained from contacting the Project Manager, David Harrison at the British Geological Survey, Keyworth, Nottingham, UK, email: djha@bgs.ac.uk

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We are grateful to all everyone who assisted us either in the field or facilitated the logistics of the work programme particularly the various Jamaican Ministries involved and the University of the West Indies.

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This report is one of a series of Technical Reports on alluvial mining of sand and gravel aggregate in developing countries, most of which relate to Jamaica (see Preface for details). They are the output from the 'Effective Development of River Mining' project which aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. The work was carried out under the Department for International Development Knowledge and Research programme, as part of the British Government's programme of aid to developing countries. The project was undertaken in collaboration with key organisations in Jamaica and Costa Rica, who provided field guidance and local support.

The key objective of this part of the River Mining project was to investigate the effects of sand and gravel mining activities at the rivers Yallahs and the Rio Minho in Jamaica using indices of biological diversity. This study examined the ecological impacts of aggregate abstraction and sediment redistribution in the two rivers. In each river there are a series of depositional and removal processes operating in close proximity. The extraction of river sediments and the associated redistribution of sediment and the ecological disturbance resulting from such activities in rivers is generally considered injurious to the overall aquatic (riverine) habitat and the biota therein.

The research results show major disturbances (both an increase and decrease) to the overall biodiversity of the benthic macroinvertebrate fauna at both rivers as one moves downstream. The greatest change in faunal assemblage occurs in the immediate vicinity and immediately downstream of gravel mining localities. Biological (in terms of species completeness) recovery from these activities is slow following the catastrophic removal of the stream bed, which results in massive habitat loss for the benthic fauna. Recolonisation of these disturbed habitats is also slow, resulting in areas of very low diversity. A serious stressor to these rivers would appear to be the removal of benthic sediments (gravel/ sand) from the watercourse.

Further longer-term studies, more data collection (or possibly a re-analysis of the data already held by various departments or by members of staff at the University of the West Indies) from a larger number of impacted rivers, and enhanced dialogue with both stakeholders and decision makers are needed to demonstrate the extent and longer-term impacts of river mining activities.

1. Introduction

1.1. ECOLOGICAL IMPACTS RESULTING FROM SAND AND GRAVEL ABSTRACTION IN RIVERS

This study examines the impacts of sediments, sediment abstraction and sediment redistribution in two rivers in Jamaica; where there are a series of depositional and removal processes operating in close proximity. It is important to consider the increased disturbance of the bottom and suspended sediments of mined rivers at all levels of the ecosystem from simple algae to fish and the need to understand both direct (impacts on the organisms) and indirect effects (impacts on their habitat).

The disturbance of bottom sediments in rivers is generally considered injurious to the aquatic habitat and biota therein. In terms of the actual physical disruption of the substratum, as overall stream bed stability decreases, there tends to be a corresponding decrease in species number (Robinson & Minshall, 1986; Death & Winterbourn, 1995). However the response of the aquatic fauna varies with the intensity and the frequency of the bed disturbance produced by sand and gravel mining. Frequent disturbances on a large scale will lead to a maintainance of low species diversity (Scrimgeour & Winterbourn, 1989). However it is important to note that as long as the bed disturbance (gravel mining) is occurring with the same intensity at regular intervals, adaptation of the fauna will occur, resulting in a speedy recovery (Lake et al, 1989).

Gravel mining, in addition to the direct physical disturbance of the habitat, often produces long range impacts on communities downstream which are not in the immediate sphere of activity. This is as a result of the increase in suspended sediments produced by mining activity. The impact of suspended solids on benthic fauna has long been studied. High levels of turbidity (Chutter, 1969) as well as siltation (Nuttall & Bielby, 1973) are known to have negative effects on species diversity. This underscores the importance of analyzing not just the benthic fauna but the abiotic conditions present.

Fish are particularly sensitive to the impacts of gravel abstraction (mining). Salmonids (salmon and trout) require freshwater stream gravels for spawning. The female digs a depression in the gravel stream forcing fine gravel particles into the current, which carries them downstream. This exposes some of the interstitial fine sediment within the gravel which is similarly washed away. The female deposits the eggs within the depression (pit) and the attending male releases milt over them. The female then loosens fine gravel immediately upstream, which the currents carry downstream to cover the eggs. The eggs remain in the completed redd (nest) for a period of weeks or months, depending on water temperature. The embryos depend upon a flow of water through the gravel to supply them with oxygen and to remove metabolic wastes. After hatching, the alevins (fry) continue to live within the gravel for a period of time, then wriggle through to the gravel surface, where they emerge to begin their lives as free-swimming fish.

In general, the literature suggests that interstitial sediments finer than about 1 mm, reduce the permeability of the gravel and can impair the inter-gravel water flow needed to provide oxygen and remove metabolic wastes from fish embryos, while sediments in the 1-10 mm size range have been implicated in blocking inter-gravel pores. In the latter case, the embryos can successfully hatch into alevins (fry), but they are unable to migrate upwards through the gravel. For a gravel deposit to be useable for spawning by fish, the fish must be capable of lifting the gravel from the bed to create a redd, a requirement that imposes an upper limit on the size of the framework grains of the gravel. While salmonids use a wide range of gravel sizes for spawning, it is possible to define an envelope curve relating median size of spawning gravel used to the fish length. In general, fish can spawn in gravels with a median diameter up to about 10% of their body length.

Much of the literature on the implication of gravels on spawning has been oriented to finding a single index that can capture all the necessary characteristics relevant to fish spawning success and various measurements can provide some indication of the resultant perturbation from, for example, gravel mining leading to poor spawning success. However, it is often not so possible to predict the extent of disruptive effects of gravel mining to an acceptable degree of accuracy by extrapolation from abiotic sampling, i.e. simple physical or chemical measurements. For example, the bioavailability of and toxicity of aluminium and lead to invertebrates in acidified freshwaters is extremely difficult to predict and will be largely dependent on the biological species present. There are several factors which complicate the relationship including temperature fluctuations, interactions with other pollutants, soil input to the river system and sediment types, rainfall, and of particular importance, pH.

Considerable differences in the extent of effects of gravel mining on stream biological communities and on the subsequent accumulation of pollutants and or other anthropomorphic disturbances, may be exhibited by species which are closely related taxonomically. Furthermore, the concentrations of a pollutant in individuals of a species at a particular site may exhibit differences due to genetic variability, feeding behaviour and physiological and reproduction status and not simply as a result of physical disturbance through gravel mining.

Even when all known sources of biological variability have been eliminated or taken into account, a very high degree of unexplained residual variability in community structure may persist between individual organisms in the same population. One way around the problems encountered when one attempts to interpret the significance of levels of disturbance in biotic or abiotic samples is to use a system of biological monitoring involving either survey techniques (as undertaken in this work) or bioassays deployed into the river system to measure direct impacts.

Biological assessments are therefore holistic evaluations of the condition of water-bodies using biological surveys and other direct measurements of resident biological organisms (macroinvertebrates, fish, and plants). The results from such biological assessments are used to answer the question of whether such water-bodies can continue to support the survival and reproduction of desirable fish and other aquatic macroinvertebrate species. Biological surveys integrate and assess the effects of all the activities impacting on the river or water body of concern be it sediment removal, or contaminant orientated and also allow some cumulative assessment of events over time.

One of the major advantages of the bioassessment protocol is the integrated nature of the assessment, comparing all features of the habitat (e.g., physical structure, flow regime), water quality and biological measures with empirically defined reference conditions (via actual reference sites, historical data, and/or modelling or extrapolation) and all impacts influencing it. Reference conditions are best established through systematic monitoring of actual sites that represent the natural range of variation in "minimally" disturbed water chemistry, habitat, and biological conditions and are typically selected upstream (i.e. non-impacted areas of the water body). The biological sampling framework can be enhanced by the development of an empirical relationship between habitat quality and biological condition (i.e. the expected community structure) that is refined for a given situation (in this case impacts from gravel abstraction). However, this method is data hungry and it is unlikely that we would be able to undertake such an assessment. As additional information is obtained from systematic monitoring of potentially impacted and site-specific control sites within Jamaica, then the predictive power of such an empirical relationship is enhanced and one day may be used routinely for stream quality monitoring in Jamaica. Once the relationship between habitat quality and biological potential is understood, the water quality impacts of gravel mining can be objectively discriminated from other habitat effects (such as storm events), and control and rehabilitation efforts can be focused on the most important sources of impairment.

1.2. ADVANTAGES OF BIOSURVEY TECHNIQUES

The water quality-based approach to impact assessment requires various types of data. **Biosurvey techniques** are best used for detecting effects (impacts) on aquatic life through changes in their biological community and assessing their relative severity. For example, the accidental spillage of a chemical into a water body will result in the loss of key species. The degree of loss (number) and the nature of the loss (species affected) will determine the severity of the spillage. Once an impairment is detected, however, additional ecological data, such as chemical and biological (toxicity) testing is helpful to identify the causative agent (i.e. what was the chemical, how toxic is it, how persistent is it?) its source (will it happen again?), and to implement appropriate mitigation (e.g. in this example, remove source, build a barrier). Integrating information from these data types as well as from habitat assessments, hydrological investigations, and knowledge of land use is helpful to provide a comprehensive diagnostic assessment of riverine impacts. In our study we are concerned with the impacts and negative effects (if any) of gravel mining on water quality and habitat for river dwelling species. The methods applied to the routine assessment of contaminant impact are the same that will be deployed here for the assessment of community impacts resultant of river mining. Some of the advantages of using biosurveys for this type of monitoring are:

Biological communities reflect overall ecological integrity (i.e., chemical, physical, and biological integrity). Therefore, biosurvey results directly assess the status of a water body irrespective of the cause of any perturbation (contaminant influx, gravel abstraction etc.).

Biological communities integrate the effects of different stressors and thus provide a broad measure of their cumulative impact irrespective of the stressor.

Communities integrate the stresses (subsequent impacts) over time and provide an ecological measure of fluctuating environmental conditions (or differing, successive impacts of gravel abstraction).

Routine monitoring of biological communities can be relatively inexpensive.

The status of biological communities is of direct interest to the public as a measure of a healthy environment.

Where criteria for specific ambient impacts do not exist (e.g., non-point-source impacts that degrade habitat, or even point-source impacts as in this study), biological communities may be the only practical means of evaluation as we have no starting point.

Biosurvey methods have a long-standing history of use as "before and after" monitors to assess the impacts of various processes. In our case upstream/downstream of gravel abstraction areas. However, the intermediate steps in management and control, i.e., identifying causes and limiting sources, require integrating information of various types; chemical, physical, toxicological, and/or biosurvey data. These data are needed to:

Identify the specific stress agents causing impact: It is necessary for us to determine if the process of gravel abstraction is having a specific stress and therefore causing an impact. This may be a relatively simple task; but, given the array of potential pollutants resulting from the process and the physical and mechanical disturbances (and their possible combinations – e.g. flooding, drought), it is likely to be both difficult and costly to identify the single causative agent of gravel abstraction. In situations where habitat degradation is prevalent, a combination of biosurvey and physical habitat assessment is most useful (as in this study).

Identify and limit the specific sources of these agents: Although typically biosurveys can be used to help locate the likely origins of impact, chemical analyses and/or bioassays and toxicity tests are helpful to confirm the point sources (or indeed disprove them). This study has an obvious focus (the areas of gravel abstraction) and so the origin of impact is prevalent. However, what is not known is whether the impact is direct (as a result of the physical removal of the gravels) or indirect (as a secondary feature of the gravel removal that may at first appear to be disconnected to the activity).

Effective implementation of the water quality-based approach requires that various monitoring techniques be considered over time and within a larger context of water resource management in Jamaica. Both biological and chemical methods play critical roles in any successful water management and effective control programme. They should be considered complementary rather than mutually exclusive approaches that will enhance overall programme effectiveness if adopted and used appropriately in Jamaica.

1.3. BIOLOGICAL MONITORING USING SURVEY TECHNIQUES TO ASSESS IMPACTS OF GRAVEL/ SAND ABSTRACTION

There are several approaches to the biological monitoring of mans impacts (via sand and gravel mining) on a river or stream. Along any particular impact gradient (a gradient results downstream (and sometimes, although rarely, upstream) from the point of influence, in this case the abstraction of gravel and sands from the river bed, or adjacent area), there will be changes in the abundance of species due to different levels of response to this activity. An organism in an impacted site must either tolerate the stressor, move to an area with a lower stress, or die. The most frequent response of a community is that some species increase in abundance, others (usually the majority) decrease in abundance and populations of others remain stable. The patterns of species abundance's reflect effects of the stressor integrated over time and are used widely to monitor effects of impacts on biological communities.

The most obvious biological effect of a stressor is the absence of species from a habitat in which they would normally be common. This is most apparent in heavily impacted rivers, for example, where raw sewage is discharged close to the source of the effluent, very few organisms manage to survive. Those that do survive often exploit the lack of competition and reach very high population densities (for example tubificid worms).

In Europe, more information has been gathered on the flora and fauna of un-impacted "reference" sites, and it has become easier to recognise more subtle effects of stressor change. Many researchers have analysed communities of organisms (mostly benthic invertebrates) to assess the degree of pollution of freshwater ecosystems (however, the same techniques apply to assess the influence of other stressors, not just pollution). The main approaches that have been adopted have been reviewed in a booklet (British Ecological Society, 1990), and are;

the **biotic** approach, based on the differential sensitivities of species to change; and

the **diversity** approach, based on changes in community diversity.

The most frequently used European *biotic* indices have been the Trent Biotic Index (TBI), Chandler Biotic Score (CBS) and Biological Monitoring Working Party (BMWP). All three are based largely on presumed relative tolerances of macro-invertebrates to organic pollution but lend themselves to assessing general stressor impacts on a river. The BMWP requires only family level identification.

In the field sampling will result in the provision of data enabling the derivation of a BMWP score. This score system was devised by the Biological Monitoring Working Party for the 1980 Water Quality Survey of England and Wales. It is, however, a generally accepted way of assessing water quality. A score is allocated to each invertebrate taxon found in a sample, based on its relative sensitivity to pollution. For example, most mayfly nymphs and caddis larvae score ten, water beetles five, molluscs three and worms one. The final score is derived from summing the scores from each taxon found in the sample. The number of taxa found describes the richness of the macroinvertebrate population. Higher numbers indicating a healthy environment. In addition, the Average Score per Taxon (ASPT) may be calculated. This is simply the BMWP score divided by the number of scoring taxa, and represents the "average sensitivity" of the taxa found. It can offer a more reliable index than the score as it is less dependent on sampling effort or the absence/presence of a rare species (often caused by a minor habitat difference). Scores and ASTPs greater than 100 and 4.00, respectively generally indicate good water quality. As a crude guide, a BMWP score of say 200 and an ASPT above 6.00 are exceptional.

However, one fault with the BMWP score is the difficulty in distinguishing the effects of pollution from the effects of natural factors such as changing river sediments or flow rates. One of the major disadvantages of the BMWP method is that it is not clear how diversity responds to pollution exposure (i.e. causation). For example, diversity of plankton reduces continuously with organic enrichment but for benthic invertebrates, the response is "bell-shaped" with the greater diversity at intermediate pollution levels. To overcome this issue it is important to use biological surveys in combination with both *in situ* and laboratory studies which can provide additional information on the reasons for changes in the diversity and abundance of species.

The major problem, however, when attempting to apply such a diversity approach in a Jamaican river system is the uncertainty associated with the correct identification of the different taxonomic groups to Genus or sub-family level and furthermore the lack of "undisturbed" reference sites with which to compare new benthic data with. Therefore this study utilises benthic sampling procedures in combination with computer calculations of biodiversity for each of the rivers sampled. The key advantages of benthic sampling are highlighted below;

Macroinvertebrate assemblages are good indicators of localised conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well-suited for assessing site-specific impacts (upstream-downstream studies).

Macroinvertebrates integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately one year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.

Degraded conditions can often be detected by an experienced biologist with only a cursory examination of the benthic macroinvertebrate assemblage. Macro-invertebrates are relatively easy to identify to family; many "intolerant" taxa can be identified to lower taxonomic levels with ease.

Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and stressor tolerances, thus providing strong information for interpreting cumulative effects.

Sampling is relatively easy, requires few people and inexpensive equipment, and has minimal detrimental effect on the resident biota.

Benthic macroinvertebrates serve as a primary food source for fish, including many recreationally and commercially important species.

Benthic macroinvertebrates are abundant in most streams. Many small streams (1st and 2nd order), which naturally support a diverse macroinvertebrate fauna, only support a limited fish fauna.

The key objective of this study therefore is to investigate the effects of river mining activities at two Jamaican rivers, the Yallahs and the Rio Minho using biological diversity indices.

2. Study Sites

2.1. THE SAMPLE LOCALITIES

Two rivers were sampled, the Yallahs River (Figure 1) and the lower Rio Minho (Figure 2). The Yallahs River drains the southern flank of the Blue Mountains to the east of Kingston, where it flows through the mountains at Easington bridge to a lobate fan-delta covering 10.5 square km. The Rio Minho rises in the karstic central highlands and flows south via May Pen to the sea near Alley. Farrant and others, (2003) have described the sedimentology, geology and resources of these rivers in more detail. The Yallahs fan-delta is the site of major sand and gravel extraction, and there is also evidence of gravel removal in the lower reaches around Easington. Much of the Rio Minho, especially in the Vere Plains, has been extensively mined for aggregate.

Figure 1 Sampling sites in the Yallahs river

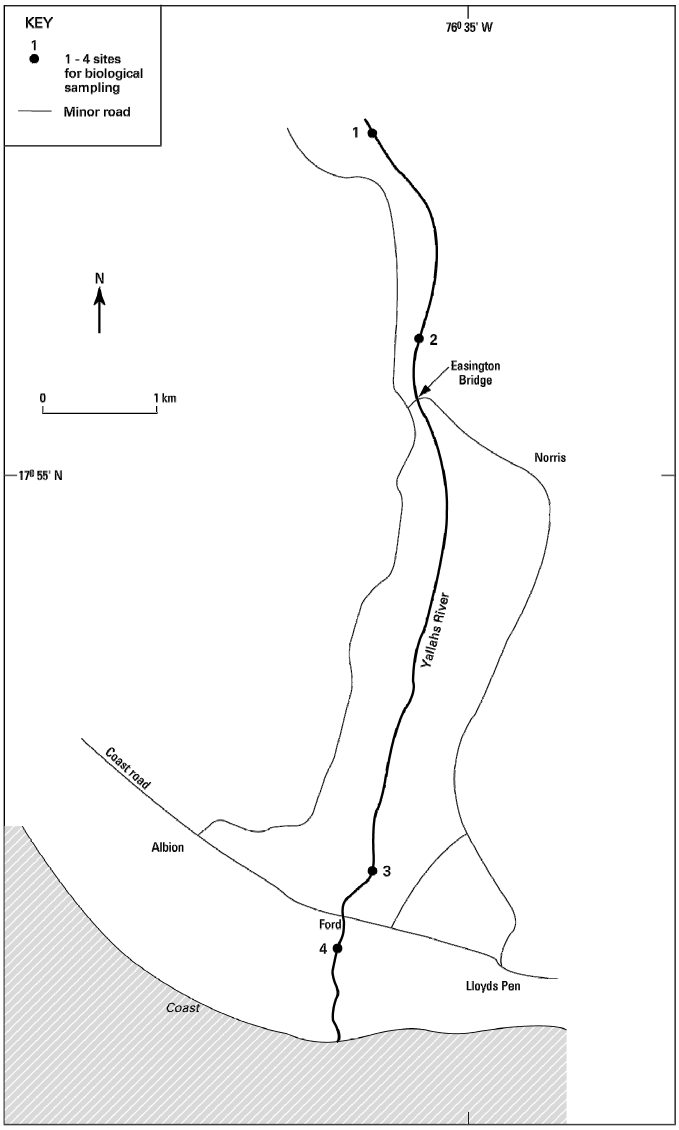
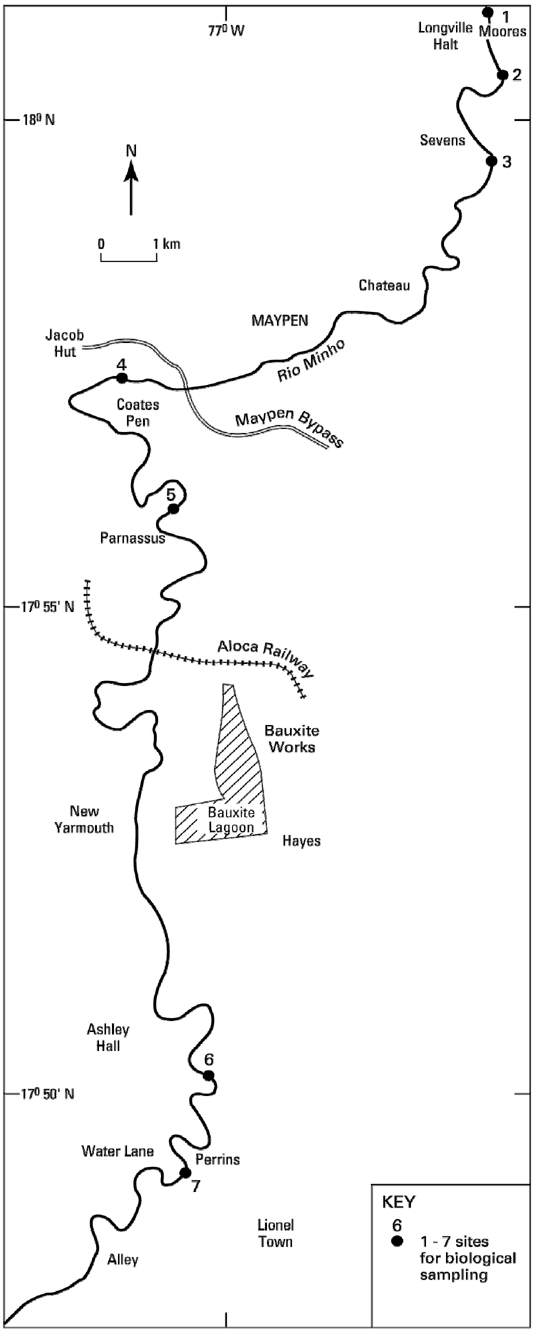


Figure 2 Sampling sites in the River Minho



2.2. SITE SELECTION

Site selection along the two rivers for biological assessment and monitoring was targeted to enable the identification of problems and sensitive waters resulting from sand and gravel extraction. Therefore, sampling sites were selected based on known existing problems i.e. the presence of river mining activities identified in previous visits to the rivers. This method therefore provides assessments of individual sites or stream reaches only.

To evaluate meaningfully "biological condition" in a targeted design, sampling locations must be similar enough to have similar biological expectations, which, in turn, provides a basis for comparison of impairment. The goal of an assessment is to evaluate the effects of water chemistry impacted by sediments and, therefore, comparable physical habitats were sampled at all stations, otherwise, the differences in the biology attributable to a degraded habitat will be difficult to separate from those resulting from other stressors. Availability of appropriate habitat at each sampling location was established during a preliminary reconnaissance. In evaluations where several stations on a water body are compared, the station with the greatest habitat constraints (in terms of productive habitat availability) was noted. The station with the least number of productive habitats available will often determine the type of habitat to be sampled at all sample stations.

Tables 1 and 2 describe in detail the sites, their locations and numerous other biological and physical information. In total four points were sampled along the Yallahs river and seven along the Rio Minho; sites were selected upstream and downstream of mining activity and on the basis of accessibility.

Table 1 Showing the physical, chemical and geographical parameters measured for each of the sites sampled along the Yallahs River

	YALLAHS RIVER SAMPLING SITES (arranged from upstream to downstream)			
Physical / chemical characteristics	**Site 1** **(1 km North of North Easington)**	**Site 2** **(North Easington)**	**Site 3** **(1 km North of road causeway)**	**Site 4** **(500m immediately South of road causeway)**
Stream width (m)	16	15	20	10-50
Mean depth (m)	0.5	0.3	0.2-1.0	0.2-0.5
Channel type	Natural	Natural heavily scoured	Natural	Natural
Bottom type	Hard - sand/ gravel	Hard – sand/ gravel	Hard – sand/ gravel	Hard – sand/ gravel
Immediate upstream habit	Similar non-disturbed	Similar, non-disturbed	(see site 2)	Mined, severe erosion, downstream of road crossing
Location of samples	Riffle samples throughout/ along edge	Along edge	Throughout area	Throughout area
Proportion of habitats sampled*	3X3 min kick samples 1 min search	3X3 min kick samples 1 min search	3X3 min kick samples 1 min search	3X3 min kick samples 1 min search
Description of riparian zone (looking downstream)	10 m wide, sand large boulders, stony	Near, 20 meters wide, (left bank) rock face (right bank)	Near, rock, spoil, gravel (right bank), shrubs, tress (left bank)	Worked gravel and mine spoils, screened material and wastes
PH	-	8.4	-	-
Conductivity us	-	315	-	-
Temp C	27.4	20.5	-	-
Recent weather	Dry	Wet overnight	Wet overnight	Wet overnight

Continued on next page

Table 1 continued

	YALLAHS RIVER SAMPLING SITES (arranged from upstream to downstream)			
Physical / chemical characteristics	**Site 1** **(1 km North of North Easington)**	**Site 2** **(North Easington)**	**Site 3** **(1 km North of road causeway)**	**Site 4** **(500m immediately South of road causeway)**
Channel modification	Natural, long runs, bends infrequent	Natural, long runs	Modified channel with bends, stream meanders within straight channel	Modified channel with no bends
Instream habitat (number of ecotypes present)	50% coverage 1-2 types	50% coverage, 1-2- types present	3-4 types present <50% dominated by one type	1-2 types, <50% coverage
Pools	Rare/absent	Rare/ absent	Shallow/ rare	Shallow pools
Bank stability	Very unstable	Very unstable, > 10% of the bank shows signs of erosion	Very unstable, many banks eroded, >40% banks show signs of erosion	Very unstable, much erosion along both banks, >50% of the bank shows erosion
Bank Vegetation type	Dominant shrubs	No vegetation	Dominated by non-vegetation, rock, soil, bulkhead	Dominated by non-vegetation, rock, gravel mining spoil
Shading	<25% water surface shaded	25-90% water surface shaded	<25% of water surface shaded	<25% shading of water surface
Riparian zone width	Evidence of human activity within 6 m (domestic, sanitation, hygiene)	Evidence of human activity within 6 m (mine related)	Evidence of human activity (clothes washing)	Evidence of human activity within 6 m of bank (mine activities)
Proximity of gravel mining	Non-evident	Adjacent	Adjacent (some historic spoil dumps and screening)	Adjacent (active mine workings)
Other		1.5 km downstream of site 1	Immediately upstream of the road causeway	500m downstream of the road causeway

*Where possible, sampling took place in riffles

Table 2 Showing the physical, chemical and geographical parameters measured for each of the sites sampled along the Rio Minho River

	Rio Minho sampling sites			
Physical/ chemical characteristics	**Site 1 (Moores)**	**Site 2 (Longville)**	**Site 3* (Chandlers Pen)**	**Site 4 (Coates Pen)**
Stream width (m)	3	12	12	21
Mean depth (m)	0.3	0.25	0.25	0.30
Channel type	Natural	Natural	Natural	Natural
Bottom type	Hard – sand/ gravel	Hard – gravel/ sand	Hard – gravel/ sand	Hard – gravel/ sand
Immediate upstream habit	Similar	Similar	Similar	Similar
Location of samples	Throughout area	Throughout	Throughout	Throughout
Proportion of habitats sampled	3x3 min kick samples 1 min search	3x3 min kick samples 1 min search	3x3 min kick samples 1 min search	3X3 min kick samples 1 min search
Description of riparian zone (looking downstream) **LB – left bank** **RB right bank**	LB - steep, shrubby RB - grass, gravel bank, shrub	LB - gravel bank, in front of shrubs, evidence of an abstraction point RB - shrubby, steep, undercut	LB – grass, gravel, shrub and road RB – steep, shrubby	LB/ RB - flood plain, gravel workings, no vegetation
pH	9.0	9.1	9.1	9.1
Conductivity us	610	481	558	510
Temp C	25.9	25.8	26.3	27.7
Recent weather	Hot/ dry	Hot/ dry	Hot/ dry	Hot/ dry
Channel modification	Natural channel, good diversity of bends and runs	Natural	Natural	Natural
Instream habitat (ecotypes)	3-4 types present >50% coverage	3-4 types present, <50% coverage	3-4 types present, > 50% coverage	1-2 types present, >50% coverage
Pools	Deep and shallow	Deep and shallow	Deep and shallow	Deep and shallow
Bank stability	Very stable, no evidence of erosion or bank failure	Moderately unstable, 5-10% of bank shows signs of active erosion	Moderately stable, areas of erosion healed over	Moderately stable
Bank Vegetation type	Dominated by shrubs	Shrubs, grass	Shrub or non-vegetation	Dominant vegetation grass and herbaceous plants
Shading	<25% water surface	<25% water surface	<25% water surface	<25% of water surface shaded
Riparian zone width	No evidence of human activity within 12 m	Evidence of former human activity within 6 m	Evidence of human activity within 6 m	No evidence of human activity within 6 m of sampling area
Proximity of gravel mining	None	Minor gravel abstraction point		

*known as Site 1 in a similar study by Christine Lawson Continued on next page

Table 2 continued

	Rio Minho Sampling sites		
	Site 5 **(Parnassus)**	**Site 6** **(Ashley Hall)**	**Site 7** **(Quarry, Perrins)**
Stream width (m)	20	10	70
Mean depth (m)	0.80	0.75	0.30
Channel type	Natural	Natural	Modified
Bottom type	Hard – gravel/ sand	Hard – gravel/ sand	Hard – gravel/sand
Immediate upstream habit	Similar	Floodplain	Wide floodplain
Location of samples	Throughout	Throughout	Throughout
Proportion of habitats sampled	3X3 min kick samples 1 min search	3X3 min kick samples 1 min search	3X3 min kick samples 1 min search
Description of riparian zone (looking downstream) **LB – left bank** **RB right bank**	LB/RB, immediate grass shrub moving out into sugar cane fields	LB/RB – grass banks, agricultural fields	LB/RB quarry
pH	8.5	8.6	8.6
Conductivity us	607	702	818
Temp C	26.0	25.7	29.0
Recent weather	Bright/ dry	Bright/hot/dry	Sunny/dry
Channel modification	Natural	Natural	Modified due to quarrying activities
Instream habitat (ecotypes)	3-4 types present, <50% coverage	1-2 types present, > 50% coverage	1-2 types present, > 50% coverage
Pools	Rare or absent	Shallow and abundant	Shallow and abundant
Bank stability	Very stable, no evidence of erosion or bank failure	Very stable no evidence of erosion	Moderately stable, areas of erosion healed over
Bank Vegetation type	Dominant vegetation is grass and herbaceous plants	Dominant vegetation is grass and herbaceous plants	Crops at distance
Shading	<25% of water surface shaded	<25% of water surface shaded	<25% of water surface shaded
Riparian zone width	No evidence of human activity within 18 m	No evidence of human activity within 12 m	Evidence of human activity within 6 m
Proximity of gravel mining		Former mine spoil deposits	Former mining/quarry area

3. Materials and Methods

3.1. PHYSICOCHEMICAL SAMPLING

Water was collected from each site and kept refrigerated until returned to the UK where it was analysed at BGS using ICP-AES techniques for selected heavy metals (Cu, Zn, As, Cd, Pb) and a GC-MS (Gas chromatography with mass spectrometry) profile for organic compounds.

3.2. BENTHIC MACROINVERTEBRATE SURVEY

A survey was carried out at each of the identified sites with appropriate upstream (or often downstream) control sites depending on extraction activity along the river course.

The data from the field surveys at each site was used to indicate generic changes in biodiversity at each locality i.e. which taxonomic groups/families or species are consistently missing at the downstream compared to their upstream location.

Much of the sampling methodology conforms to the extensive detail presented in Murray-Bligh et al. (1997) on procedures for collecting and sampling macroinvertebrate samples. Samples were taken using a standard FBA (Freshwater Biological Association) pattern long-handle pond-net with a 1mm mesh. At each sampling site, three, three-minute kick samples were taken (the time included only the time spent sampling, not for example, time spent moving around the site). Kick sampling was carried out as follows: with the net resting on the bottom of the stream at right angles to the current; the substratum was vigorously disturbed by kicking with the heel of a boot to dislodge the benthic fauna within it to a depth of about 10 cm into the net. Large stones were moved by hand when they could not be lifted by foot. A further one minute search took place for animals attached to the underside of rocks or other locations within each sampling location. Specimens from all searches/kick samples were pooled and after the removal of large stones, stored in large water-filled containers prior to sorting and preservation. Subsequently the samples were sorted from the associated debris and stored in alcohol at 4°C.

Upon return to the UK, the samples were separated into their representative taxonomic groups and efforts to identify all the aquatic macroinvertebrates made. The key taxonomic guides and reference works consulted for taxonomic determinations were Brinkhurst (1971); Thorp and Covich (2001); Donnelly (1970); Hinton (1971); Stone (1969); Travers (1938) and Wallace et al. (1990).

Checksheets detailed in Figures 3 and 4 were used to record details of each sampling site from where each faunal collection was made. A quality procedure was followed such that all samples could be traced back to their origin and all samples have been archived for future reference. Some will be lodged with the British Museum of Natural History, South Kensington, London, UK.

3.3. STATISTICAL ANALYSIS

3.3.1. Biodiversity Statistics

It is well known to experts in the field that there is no single species diversity index that could be said to be superior for all circumstances, or give a comprehensive picture of species ‘richness’ or ‘diversity’ within or between samples. For this reason the use of a range of single figure diversity indices was adopted and these were calculated using a software package called BioDiversity Professional Beta (McAleece, 1997) (developed and supplied by the Natural History Museum and The Scottish Association for Marine Science). The following biodiversity measurements were undertaken for this study using this programme.

Single figure (i.e. univariate) numerical measures of diversity which incorporate species richness and equitability (i.e. evenness) were calculated for each of the samples from each river system. Different priorities in the reconciliation of the two factors have led to the invention of a variety of indices which are optimised in different ways and hence have different merits. No one descriptor could be said to be superior for all circumstances. A family of related indices, including k-dominance, Berger-Parker, H', Simpson's index, and a simple count of the number of species, are known as intrinsic diversity.

The **Shannon** H' is an information statistic used as a diversity index and is probably the nearest thing to a common standard and is used in these studies. It is notoriously sample-size dependent and tends to be weighted slightly towards species richness. Shannon is one of the family of intrinsic diversity indices.

The following biodiversity indices were measured for the river systems examined in this study.

Berger-Parker

This is a simple intrinsic diversity index based on the proportional importance of the most abundant species. It is equitability biased and so surprisingly effective.

Rarefaction

This describes the expected numbers of species when plotted against number of individuals on the x axis. This plot provides a measure of species diversity which is robust to sample size effects, permitting comparison between communities where, for example, densities of animals are very different. Steeper curves indicate more diverse communities.

Beta Calculations

Defined as the turnover of species between localities (or habitats), used here for calculations based on comparison between samples.

SHE

SHE analysis examines the relationship between S (species richness), H (information) and E (eveness) in the samples. This is useful for testing whether the data resembles a log-normal, a log-series or MacArthur's broken stick. This is probably the most effective practical method for testing for 'goodness-of-fit' to these stochastic models. It has further uses in finding ecotones.

The output shows a spreadsheet and plot of S, H and E for all samples.

Species Richness

Methods for estimating the number of species in a population (from a sampling point) are termed species richness analysis which randomly pools the samples and examines how specific indicators accumulate as the samples are pooled. This command plots a graph of the selected indicator against the number of pooled samples.

Species

Plots number of new species accumulating as the samples are pooled. This is the traditional taxonomist's collector's curve. When asymptote is reached all the species in a region have been collected and no further sampling is required.

Individuals

Plots the number of individuals accumulating as the samples are pooled. Note that if the samples are truly replicated a straight line should be produced; a noticeable kink suggests that some sort of ecotone line has been crossed.

Species distribution

Chi-squared tests are used to measure patchiness in species populations or in whole communities (i.e. whether the organisms are distributed randomly through the samples or aggregated or uniformly distributed). The whole community analysis can also be used to assess whether individual species are randomly distributed with respect to each other, or aggregated together or aggregated in different samples.

Multivariate

These techniques allow simultaneous analysis of more than one independent variable. They are used here for ordination and clustering techniques. These are powerful descriptive methods which can suggest correlations between biodiversity patterns and potential causes but cannot resolve cause and effect.

Cluster

This method classifies objects judged to be similar according to distance or similarity measures. Data can be quantitative or presence/absence. Bray-Curtis similarity using Group-Average clustering gives a useful hierarchy of clusters.

Principal components

This is a means of displaying the relative effects of the most important sources of variation. Values are derived from Eigenvalues. Points are plotted in space with each character being represented on an axis at right angles to all other axes. The objective is to describe a matrix of data by reducing the dimensions. It finds uncorrelated linear combinations of the original variables with maximal variance. PCA is designed for continuous data and for data well summarised by variances and covariances. It is not good at discovering non-linear relationships.

Principal Components is a good choice for linking environmental variables to an ordination of samples.

Figure 3 Example of the type of data collected in the field for each site assessed. The data collected from this habitat assessment forms are compiled in Tables 1 and 2.

Habitat Assessment Field Data Sheet
(MACS Workgroup Method - USEPA 1997)

Survey No: ____________ Date: ____________ Rater(s): ______________ Basin: ________________

Station ID/location: ____

	Excellent	Good	Fair	Poor
1. **Channel Modification**	natural channel, bends frequent, good diversity of runs and bends 20-16	natural channel, long runs, bends infrequent 15-11	modified channel with bends, OR stream meanders within straight channel 10-6	modified channel with no bends 5-0
2. **Instream Habitat** snags vegetated banks undercut banks macrophytes riffles	3-4 types present > 50 % coverage 20-16	3-4 types present < 50 % coverage 15-11	1-2 types present > 50 % coverage 10-6	1-2 types present < 50 % coverage 5-0
3. **Pools** abundant: >5 /100m shallow: >1 ft deep: 2-3 ft (> prevailing depth)	deep and shallow pools present and pools are abundant 20-16	deep and shallow pools present and pools are rare, OR stream is uniformly deep 15-11	all pools shallow and pools are abundant 10-6	all pools are shallow and rare, or pools are absent 5-0
4. **Bank Stability** (⇒ while facing downstream)	very stable, no evidence of erosion or bank failure left 10-9 right 10-9	moderately stable, areas of erosion healed over 8-6 8-6	moderately unstable, 5-10% of the bank shows signs of active erosion 5-3 5-3	very unstable, many eroded areas along both runs and bends; > 10% of the bank shows signs of erosion 2-0 2-0
5. **Bank Vegetative Type** (⇒ while facing downstream)	dominant vegetation is shrubs left 10-9 right 10-9	dominant vegetation is trees 8-6 8-6	dominant vegetation is grass and herbaceous plants (briars) 5-3 5-3	stream bank dominated by non-vegetation (rock, soil, bulkhead, etc.) 2-0 2-0
6. **Shading** sun overhead full leaf-out	25-90% of the water surface shaded; a mixture of conditions; areas fully shaded, fully open, and degrees of filtered light 20-16	> 90% of water surface shaded, full canopy; entire water surface receives filtered or no light 15-11	no scoring in this category 10-6	< 25% of water surface shaded; lack of a canopy; full sunlight reaches water surface 5-0
7. **Riparian Zone Width** (⇒ while facing downstream)	no evidence of human activity within 18 meters (60 feet) left 10-9 right 10-9	no evidence of human activity within 12 meters (40 feet) 8-6 8-6	no evidence of human activity within 6 meters (20 feet) 5-3 5-3	evidence of human activity within 6 meters (20 feet) 2-0 2-0

column totals ______ ______ ______ ______

Figure 4 Example of the type of data collected in the field for each site assessed. The data collected from this habitat assessment form are compiled in Tables 1 and 2.

Habitat Assessment Field Data Sheet - Supplement
(MACS Workgroup Method - USEPA 1997)

Date: ____________ Time on: ____________ Time off: ____________ Crew: ____________

Station ID/location: ________________________________

General:

photos taken: ______ high water mark (ft): __________ recent weather: ______________

flow (cfs): ________ mean velocity (ft/sec): ____________ maximum velocity (ft/sec): ____________

water surface width (ft): ________ mean depth (ft): __________

channel type: (circle one): natural channelized no channel (braided/wetland) other (specify):

bottom type (circle one): hard (sand,gravel) soft (easy to walk) very soft (hard to walk) not wadable (too deep)

upstream habitat (as compared to the assessment area): ______________________

macroinvertebrate sample collected: yes no if yes, describe how collected (circle one)

throughout along edge top of bank

Proportion of Habitats Sampled for Macroinvertebrates:

	sampled # jabs	sampled %	condition
snags	___	___	______________________
banks	___	___	______________________
macrophytes	___	___	______________________

Description (land use, type of vegetation) of the Riparian Zone:

	width (meters)	description (left bank)	description (right bank)
near (e.g., 1-2 meters)	________	______________	______________
mediate (e.g., 2-10 meters)	________	______________	______________
far (e.g., 10-20 meters)	________	______________	______________

Comments:

Plate 1 Site 1 on the River Yallahs, a fast flowing eroding stream bed

Plate 2 Site 3 on the Yallahs river, immediately upstream of the road crossing. Note evidence of sand and gravel working.

Plate 3 Site 2 on the Rio Minho looking downstream

Plate 4 Site 5 on the Rio Minho

Plate 5 Site 6 on the Rio Minho looking upstream

Plate 6 Site 7 on the Rio Minho (Ashley Hall) with disused bridge structure

4. Results

4.1. YALLAHS RIVER

The location of the sampling points can be seen in Figure 1. Details of the species found are listed in Appendices 2 and 3.

A total of five individuals were identified to family, genus or species level using appropriate taxonomic keys. Abundance of these species was very low at all the sites sampled but 2 species were much higher at sites 1 and 2 when compared to 3 and 4. Only two species were present at sites 3 and 4. Site 4 was downstream of the road causeway, and therefore physically separated from site 3. Despite this both site 3 and 4 had a very similar faunal composition possibly due to the massive scouring and erosion taking place at these localities.

When commonly used species indices were applied to these data, it became clear that diversity varied for a site depending on the index used (Figure 5). The Shannon biodiversity index shows a decline with progression along the river to the fan delta. In contrast Berger Parker (not shown) increased towards the delta due to the bias placed upon the importance of the single species.

SHE analysis (Figure 6) showed a change in evenness after site 1, that persisted along the remainder of the river suggesting a change in ecotone.

The Yallahs cluster analysis separated the sampling locations (Figure 7) into two distinct sets comprising sites 1 and 2 and sites 3 and 4. This is also reflected in the PCA plot which separated the same data sets (Figure 8). Similarly Figure 6 showed that the species distribution was also biased in this manner.

Figure 5 Shannon biodiversity index for the Yallahs river

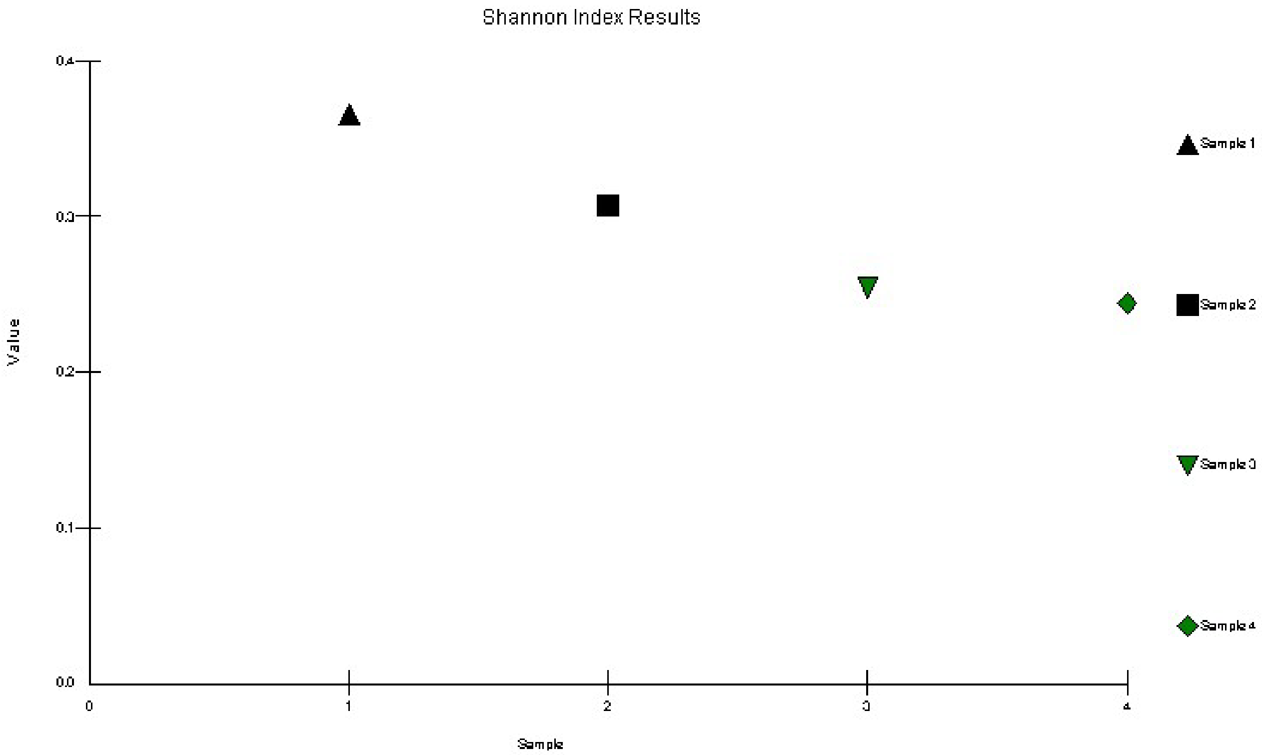


Figure 6 SHE analysis for the Yallahs river

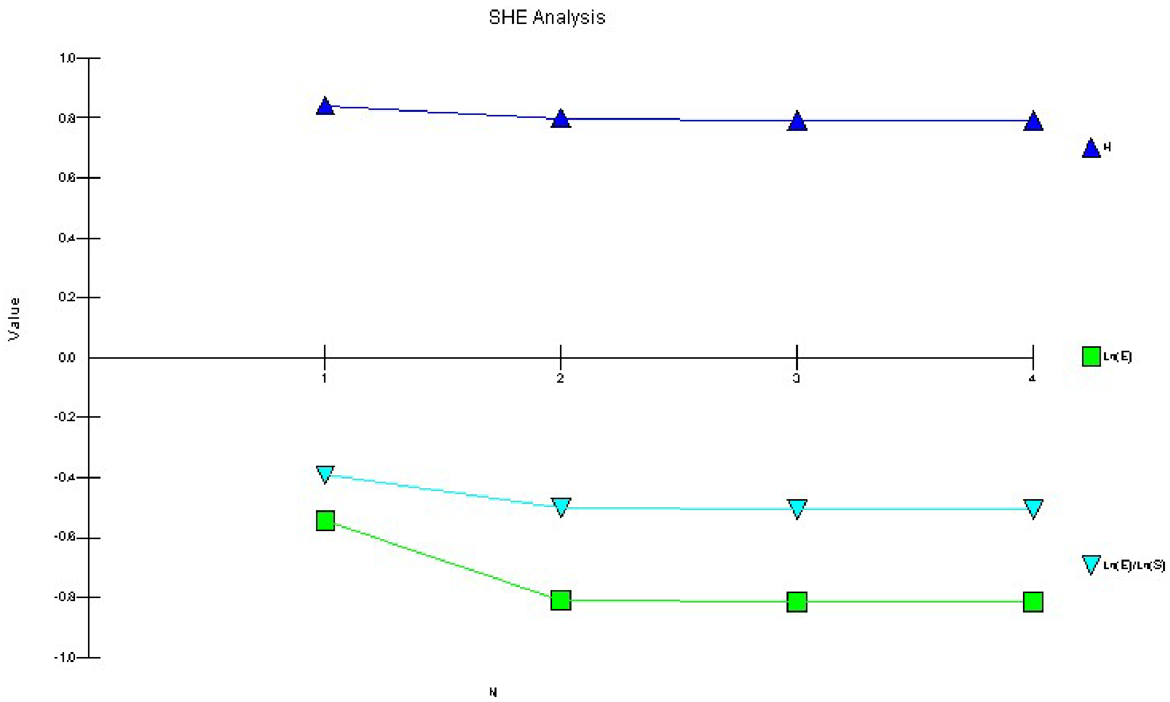


Figure 7 Cluster analysis for the Yallahs river

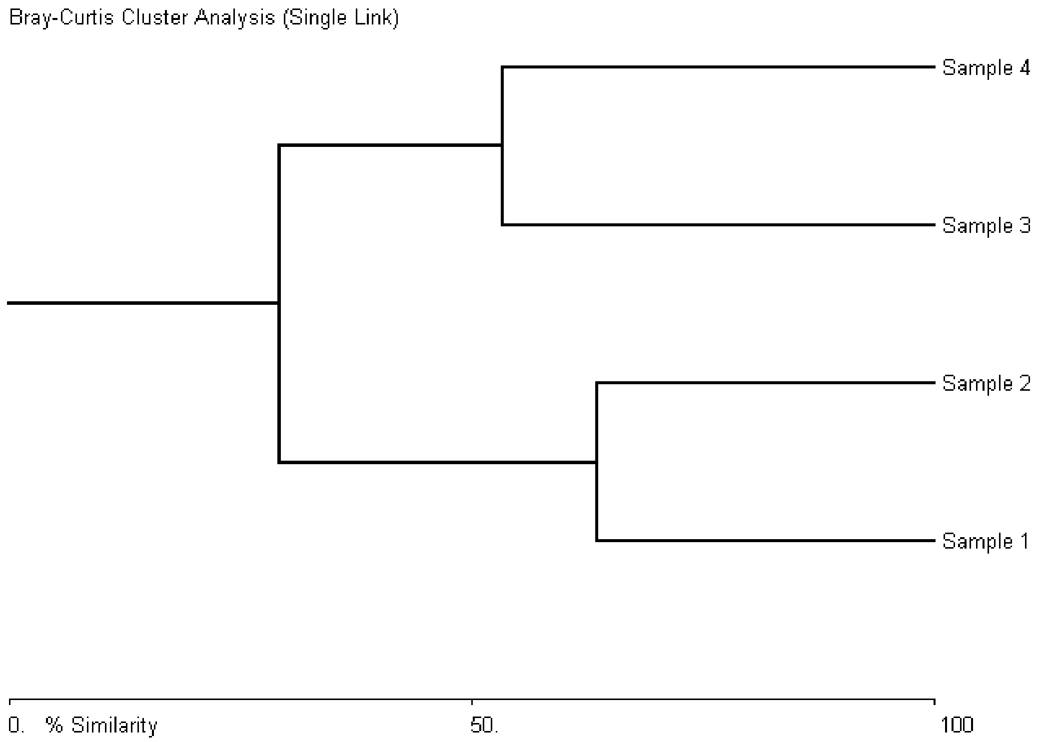


Figure 8 Principal components analysis for the Yallahs river

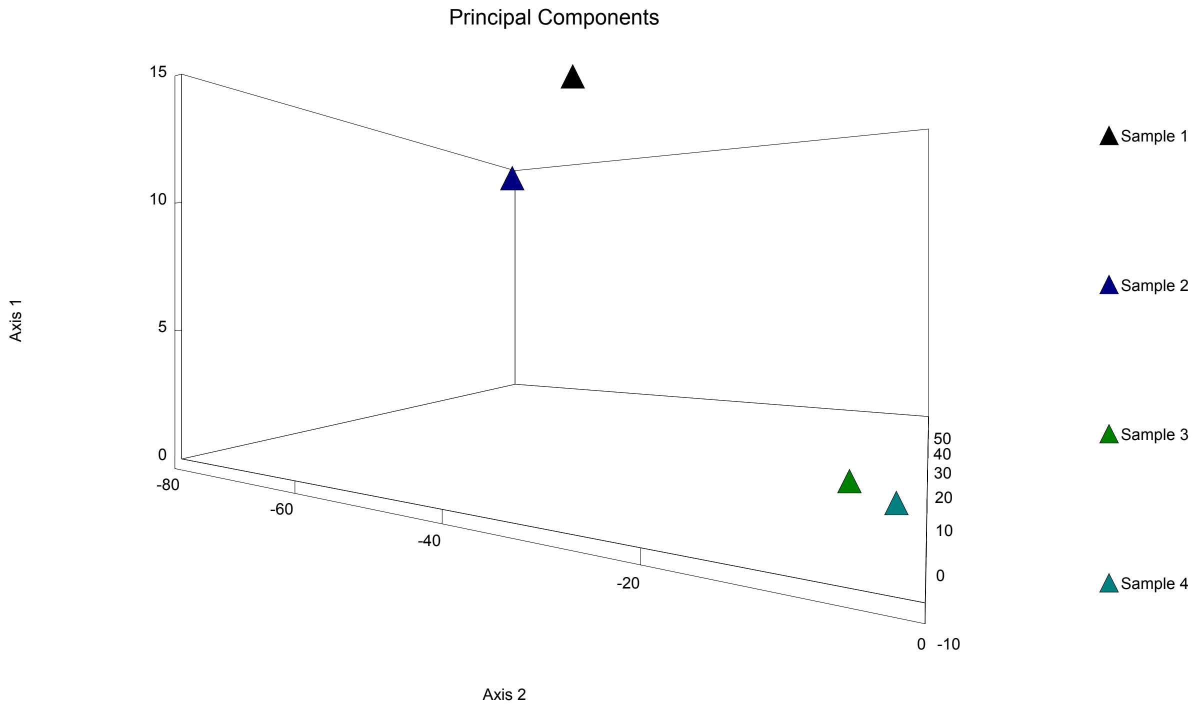
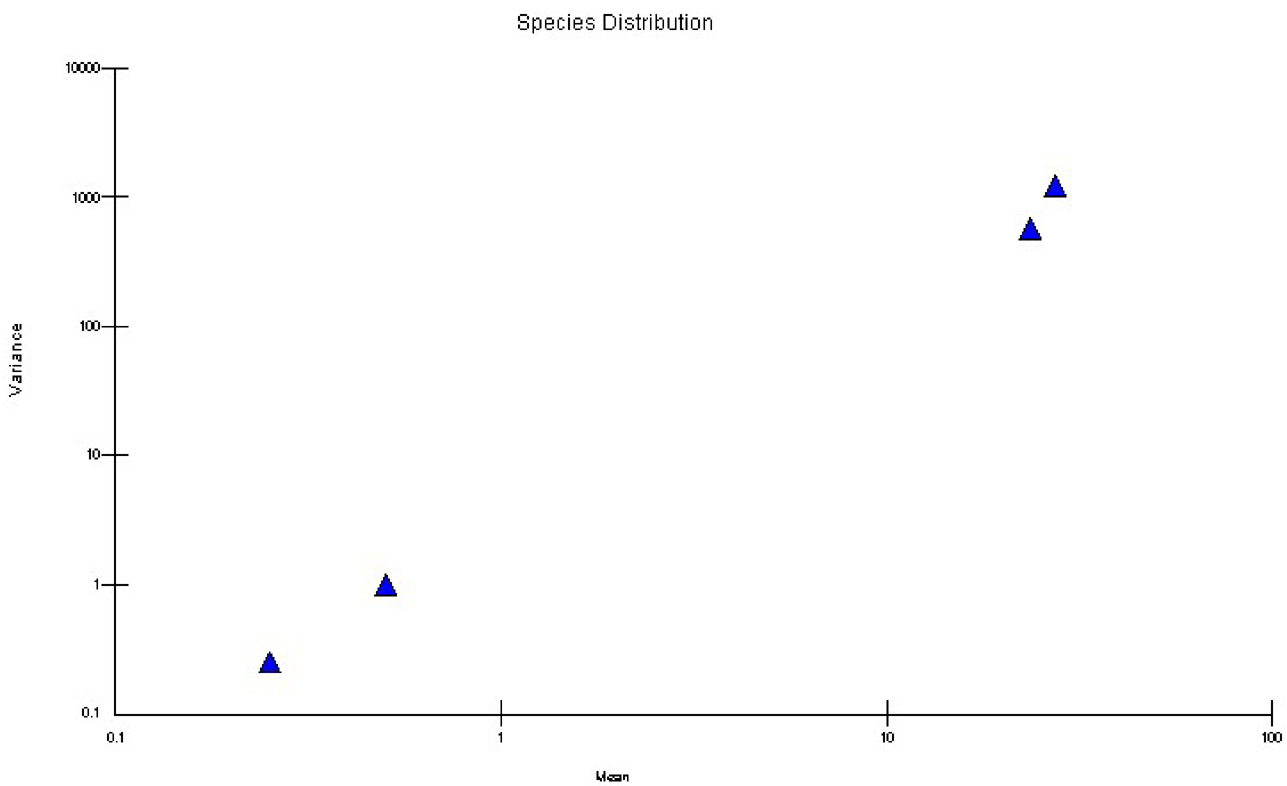


Figure 9 Species distribution analysis for the Yallahs river



4.2. RIO MINHO RIVER

A total of thirty-five individuals were identified to either family, genus or species level using appropriate taxonomic keys (see Appendix 2). Abundance of these species ranged from low to very high depending on the characteristics of the sampling sites (see Table 2). Two species in particular had high numbers at all sites apart from sites 6 and 7 (see Appendix 2). Site 5 was considered to be a non-impacted site. Sites 1 through to 3 were considered upland sites and therefore anticipated to have different faunal compositions to the low-lying floodplain sites.

The Shannon diversity indices (Figure 10) showed a decline in biodiversity from site 1 to 3 a rise at site 4, similar values for sites 5 and 6 and an increase at site 7. However, Berger Parker a simple intrinsic diversity index based on the proportional importance of the most abundant species and therefore reflected a different diversity to that shown by the Shannon in Figure 11. It is equability biased and so shows the truer importance of high numbers of single species at sites 2, 3 and 5.

Rarefaction - the expected numbers of species when plotted against number of individuals on the x axis is plotted in Figure 12 and showed that sampling point 7 in the lower reaches of the Rio Minho River is predicted to have more diverse communities present than the other localities.

The PCA analysis (Figure 13) showed a separation of 4 groups; sampling sites 1 and 3 being separated (which agreed well with the cluster analysis in Figure 14), 6 and 7 were very similar and thus grouped and sampling sites 2, 4 and 5 clustered together. The cluster analysis diagram similarly showed 6 and 7 as being similar and site 3 as being very different and the remainder other than site 1 (highland upstream) as again being similar in biological diversity.

The species distribution and richness data Figures 15 to 16 showed that most of the available species have been collected from the sampling sites in the Rio Minho River. Furthermore, Figure 16 suggested that the kinks in the plotted line revealed a trend for distinct ecotones (discreet habitat types i.e. isolated mini-habitats) to be developing along the river possibly as a consequence of the disturbances of river mining interrupting the normal continuum of the stream.

4.3. CHEMISTRY DATA

It was thought that the process of sand and gravel extraction may impact on the ambient concentrations of heavy metals (re-suspension of fine material and the associated burden of heavy metals usually binding to the surface of such fine sediments and organic particles) in the overlying waters. Therefore waters were sampled at the time of biodiversity assessment in order to quantify any elevation of metals at the disturbed sites. Additionally, the collected waters were also analysed using a simple screening methodology to assess any impacts of other contaminants such as organic compounds associated with the vehicles etc. used for the extraction process. It was also necessary to isolate potential additional spurious/ diffuse sources of contamination such as that resulting from pesticide spray drift or inputs from agricultural run-off at some sites.

Water samples for organic analysis were liquid-liquid extracted with dichloromethane, particulate material removed and GCMS performed using a Fisons MD-800 instrument.

There was (see Appendix 1, Table 1) no elevated anthropogenic inputs of organic contaminants to either river system, nor were there excessive concentrations (in terms of comparative exceedences of European guidelines (EQS – Environmental Quality Standards) in measured dissolved total heavy metal concentrations of the determinands (Zn, Cu, As, Pb & Cd).

The data suggest that there was little elevation of heavy metals at any of the sites investigated (see appendix for details of measured determinands). No polycyclic aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs) were present (data not shown).

Figure 10 Shannon biodiversity index Rio Minho

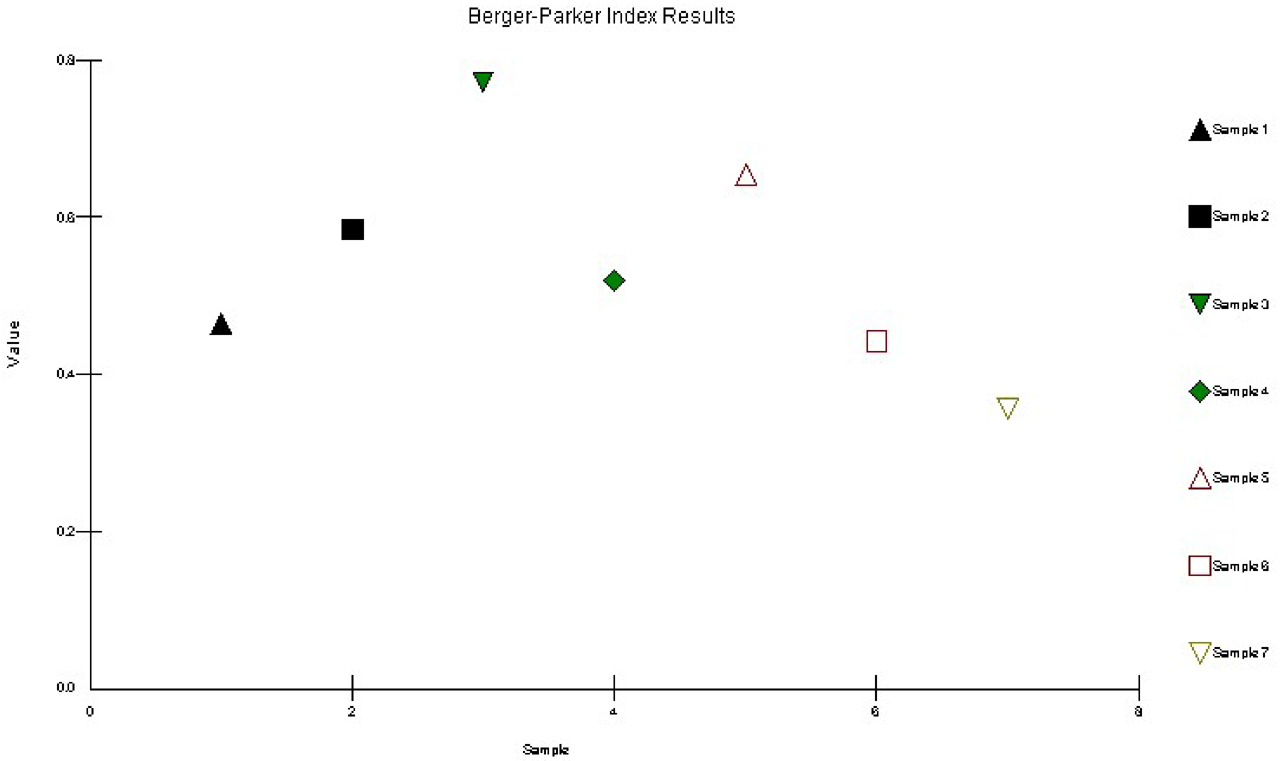


Figure 11 Berger Parker diversity index for the Rio Minho

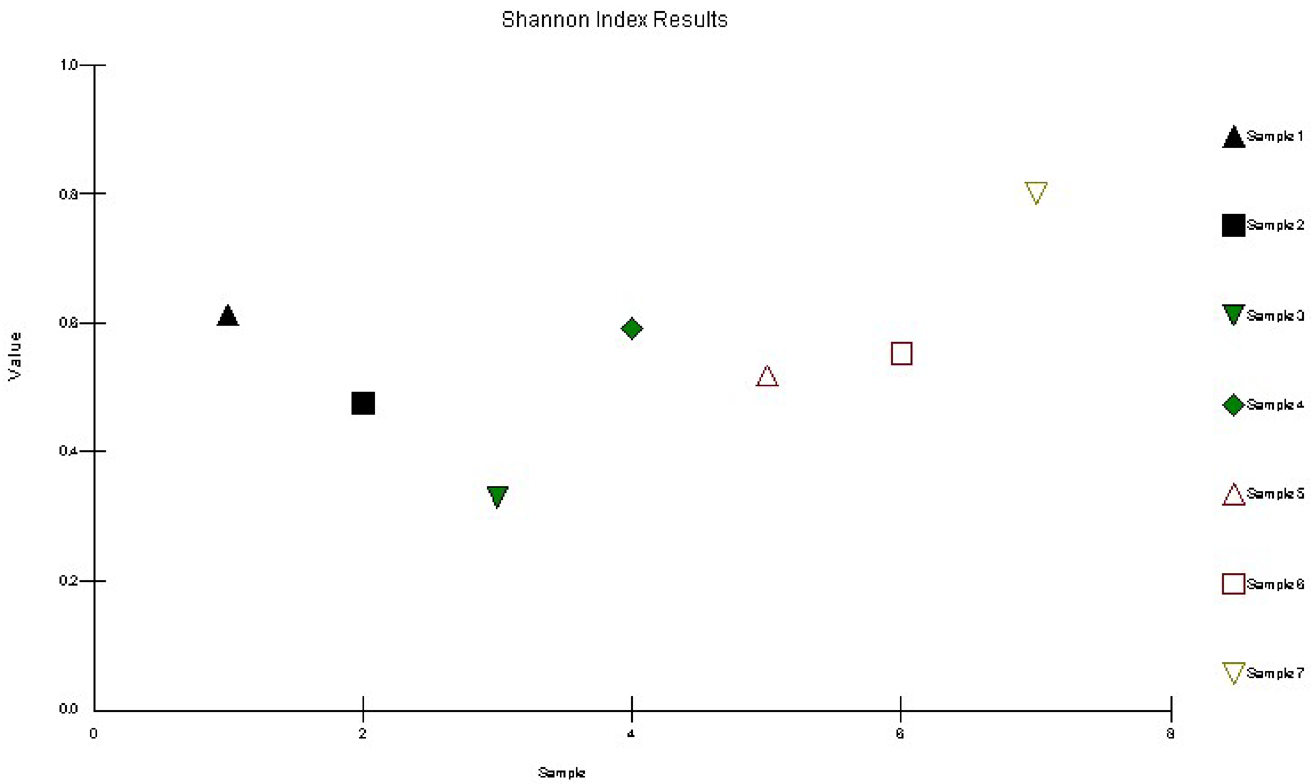


Figure 12 Species diversity in the Rio Minho using Rarefaction analysis

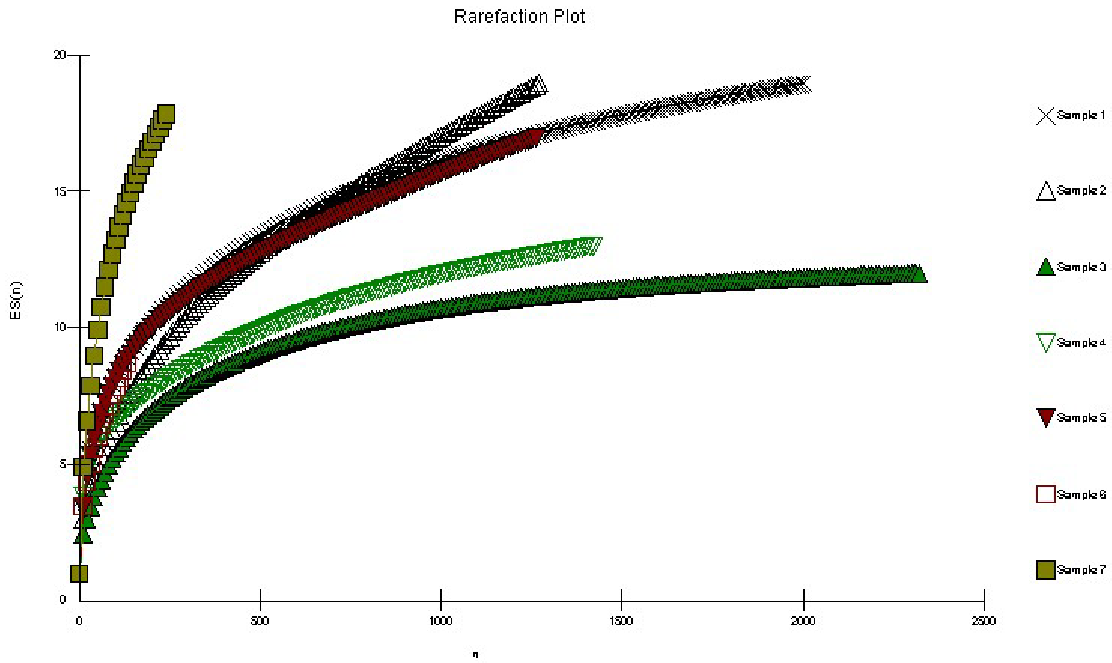


Figure 13 Principal component analysis for the Rio Minho

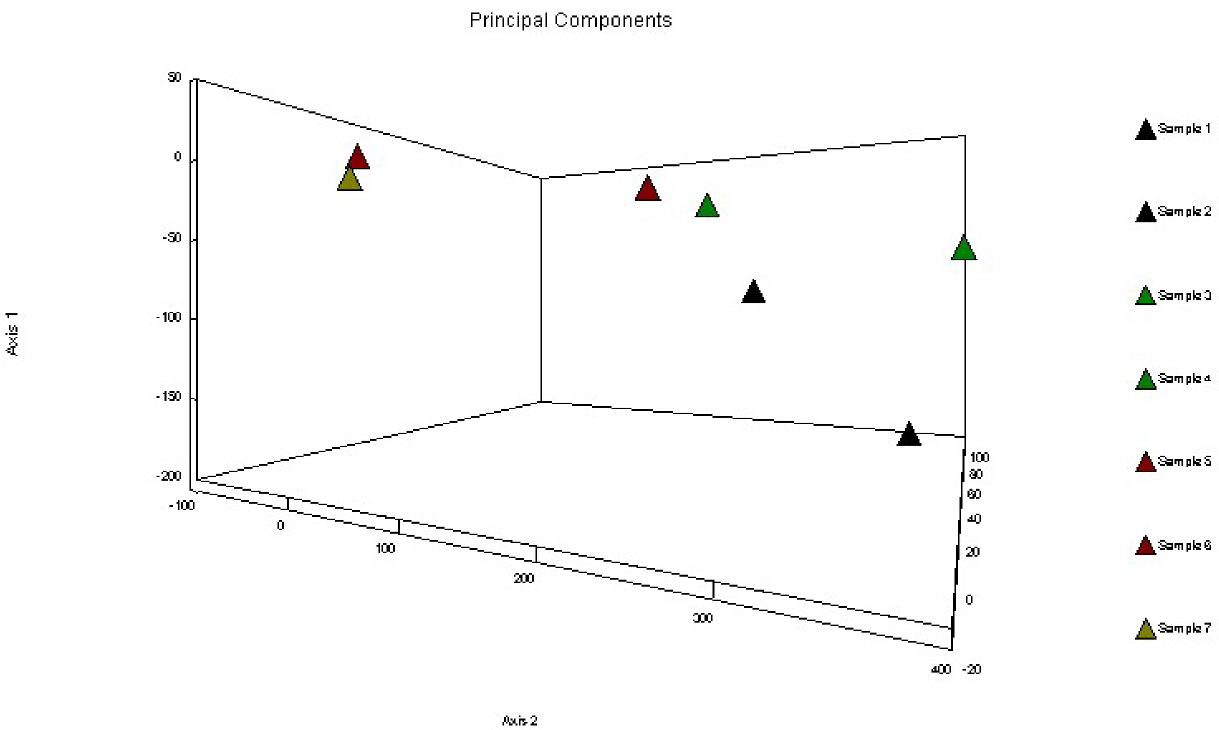


Figure 14 Cluster analysis for the Rio Minho

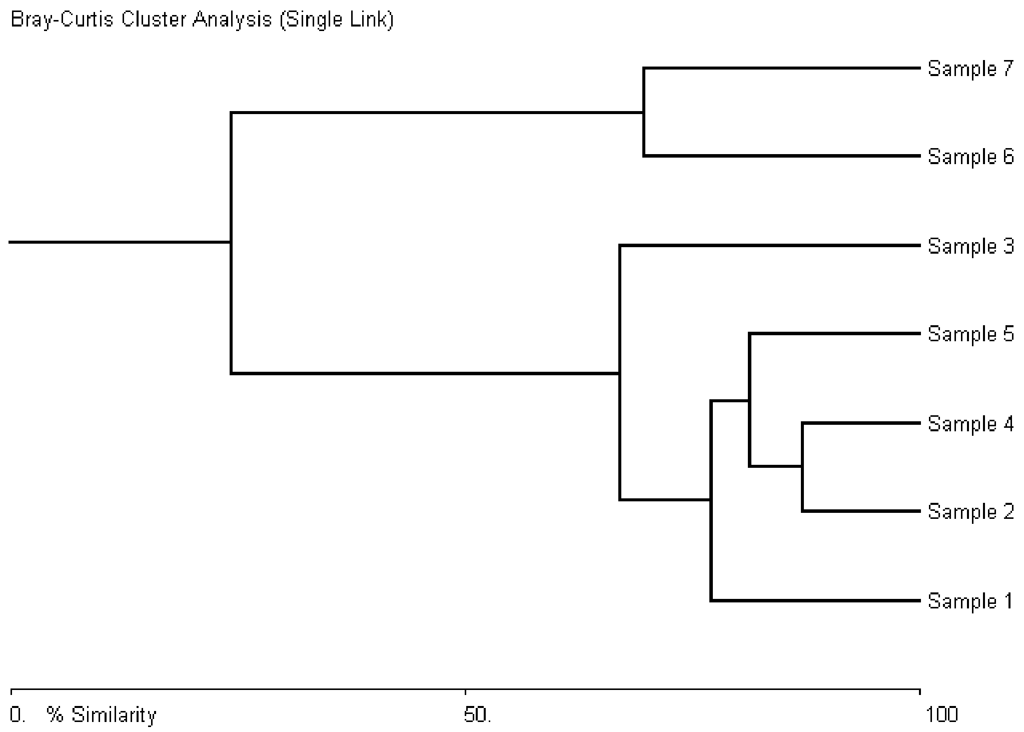


Figure 15 Species distribution analysis for the Rio Minho

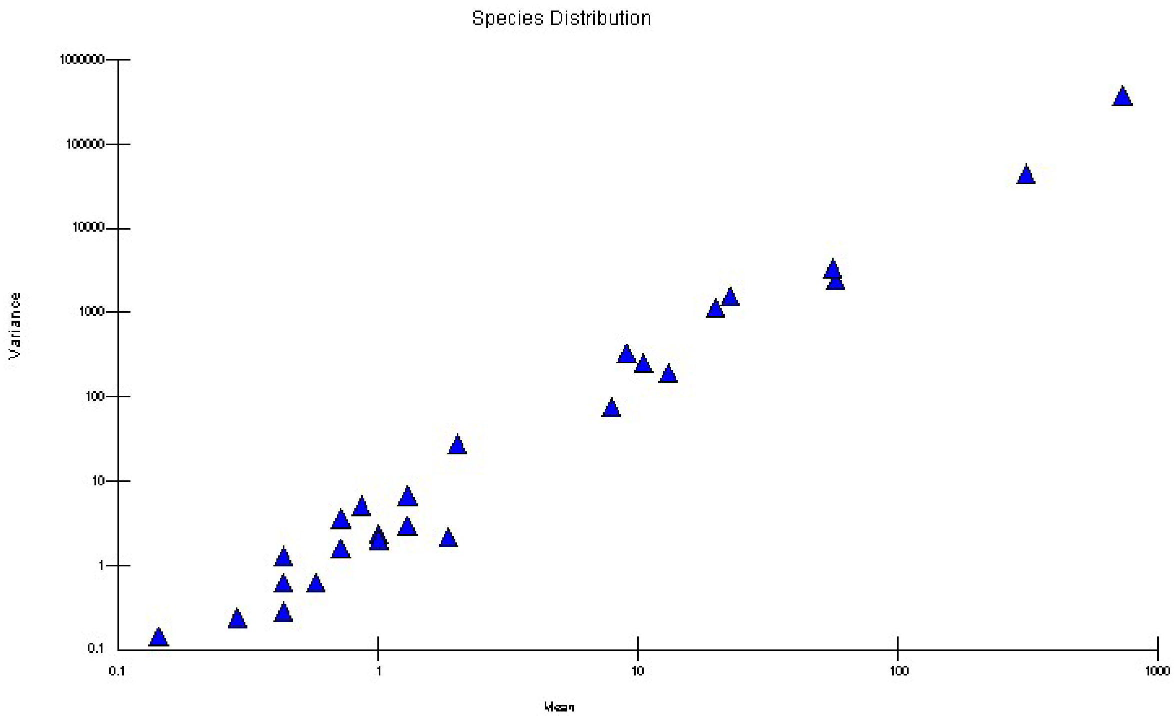


Figure 16 Species richness analysis (pooled sample) for the Rio Minho

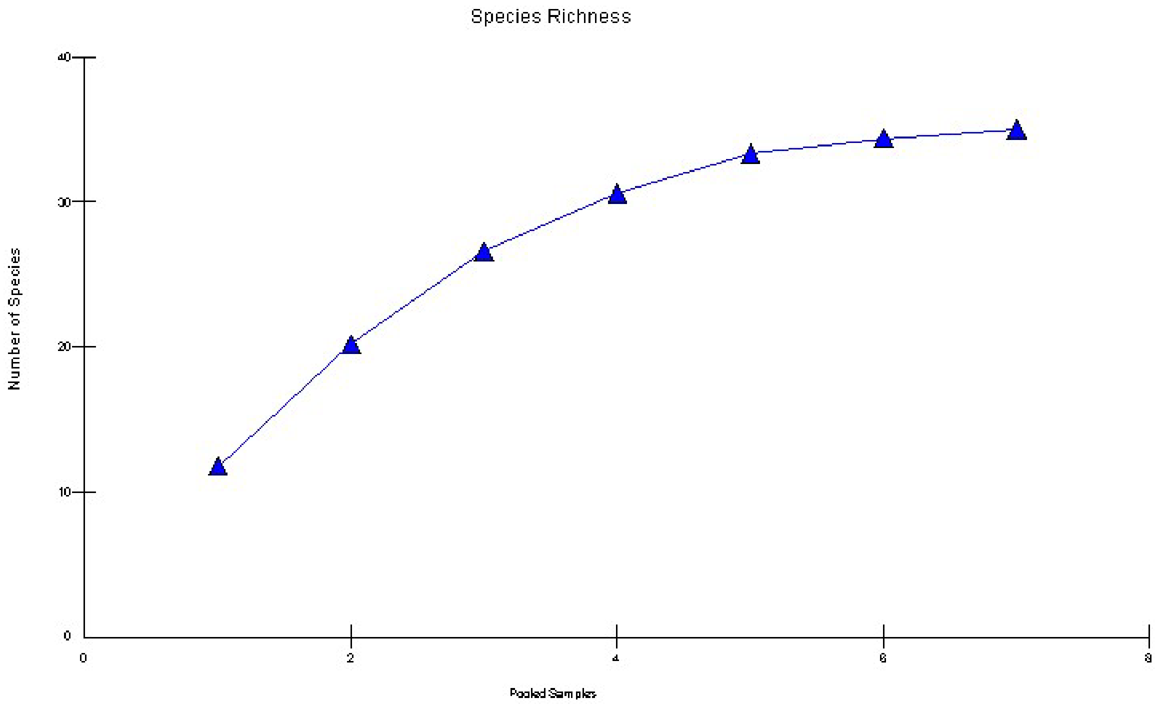
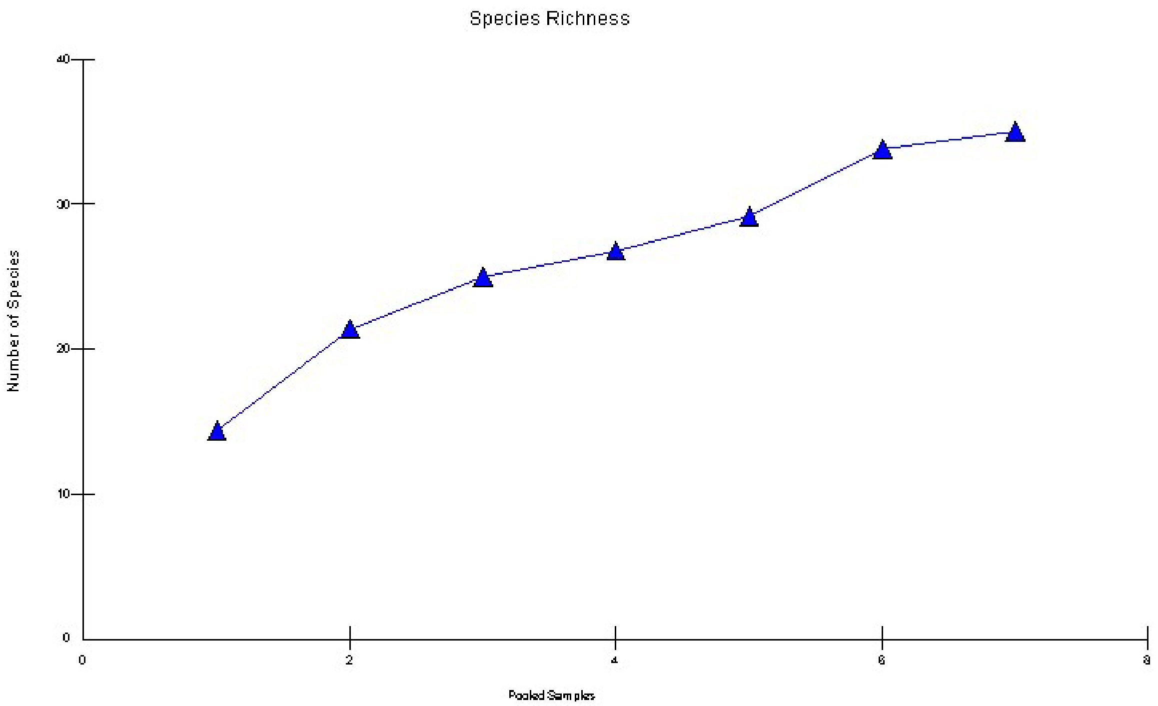


Figure 17 Species richness analysis for the Rio Minho



5. Discussion

Comparisons of perturbed sites using species indices alone can be unreliable. If indices from the data in this study are compared then we observe that the biological measure of biodiversity – the Shannon index - when considered alone, puts an emphasis on rare species. In perturbed sites, sensitive species may decrease in number without disappearing and increase the species index. Low evenness values have been found to be characteristic of disturbed sites (Lauga-Reyrel and Deconchat, 1999) and such sites typically have lower diversity values than undisturbed sites. However, a perturbed site with a high diversity may not be as functionally competent as a 'clean' site, because species that have replaced the missing sensitive species may not fulfil the same roles in the ecosystem. Also, species indices are not species sensitive and take no account of indicator species. With that caveat we have identified clear differences along the sampling points we have selected for both rivers.

Some general statements can be made;

- The lower Rio Minho, which is meandering and consequently depositional in nature, has far greater biodiversity and abundance than the Yallahs (which is a braided river). Reasons for this are due to the steep gradient, high flow, and the very abrasive nature of the benthic sediment of the Yallahs River.

- The Yallahs River has higher diversity and higher total individual numbers at two sites up-stream (where evidence of sand and gravel mining activity is present) than at sites down stream including the heavily mined delta. There was evidence of recent massive erosion of the floodplain to the foot of the causeway, which was ongoing during the sampling period. It is possible that there has been a recent massive flushing of this river basin and that perhaps the populations we sampled were still in the early stages of recovery.

- Statistical analysis of both data sets is problematical due to the changing nature of the rivers and the intermittent effects of any sand and gravel mining activity. Clearly it is not simply a question of comparing upstream and downstream sites. For the Yallahs River the observed lowered biodiversity as one moves downstream could be linked to the effects of the large mining operations. This decline, however, did not start until after site 2, the location of a relatively minor (in comparison) mining operation. In the absence of any other obvious candidate cause (no detected organic or heavy metal elevations) it is suggested that any observed change in biodiversity is linked to sand and gravel mining operations along the length of the Yallahs. There are caveats, of course, in that there were very few data points collected and very few data for each of these sampling locations and events. The natural variability of population data is further confounded by the massive variability in water flow rate, substrate type and associated mining activities.

- Diversity and abundance in the Rio Minho dropped dramatically from site 1 to 3, recovered at site 4 and increased to site 7. Again the evidence of mining activity on a large scale coincides with the observed decline in biodiversity. The trend for increasing biodiversity as one progresses down the river is due to the recruitment in small numbers of new species, however, as stated above high biodiversity is not necessarily a sign of good health, as the evenness is lowered, as is the species abundance. In essence the river proper as it flows into the floodplain of the Rio Minho has overall lowered species numbers which may be regarded as an integrative impact of mining activities further upstream.

- Several species groups such as the Trichoptera and Odonata appear to be good general indicators of impact (see appendix for site data), but not Ephemeroptera. However, this may be a spate phenomena.

- Gomphus Dragonfly nymphs, found at sites 1 and 2, (Yallahs) may be new records for the Island. A paper by Donnelly on the Odonata of Dominica British West Indies does not make any mention of this genus (Donnelly, 1970).

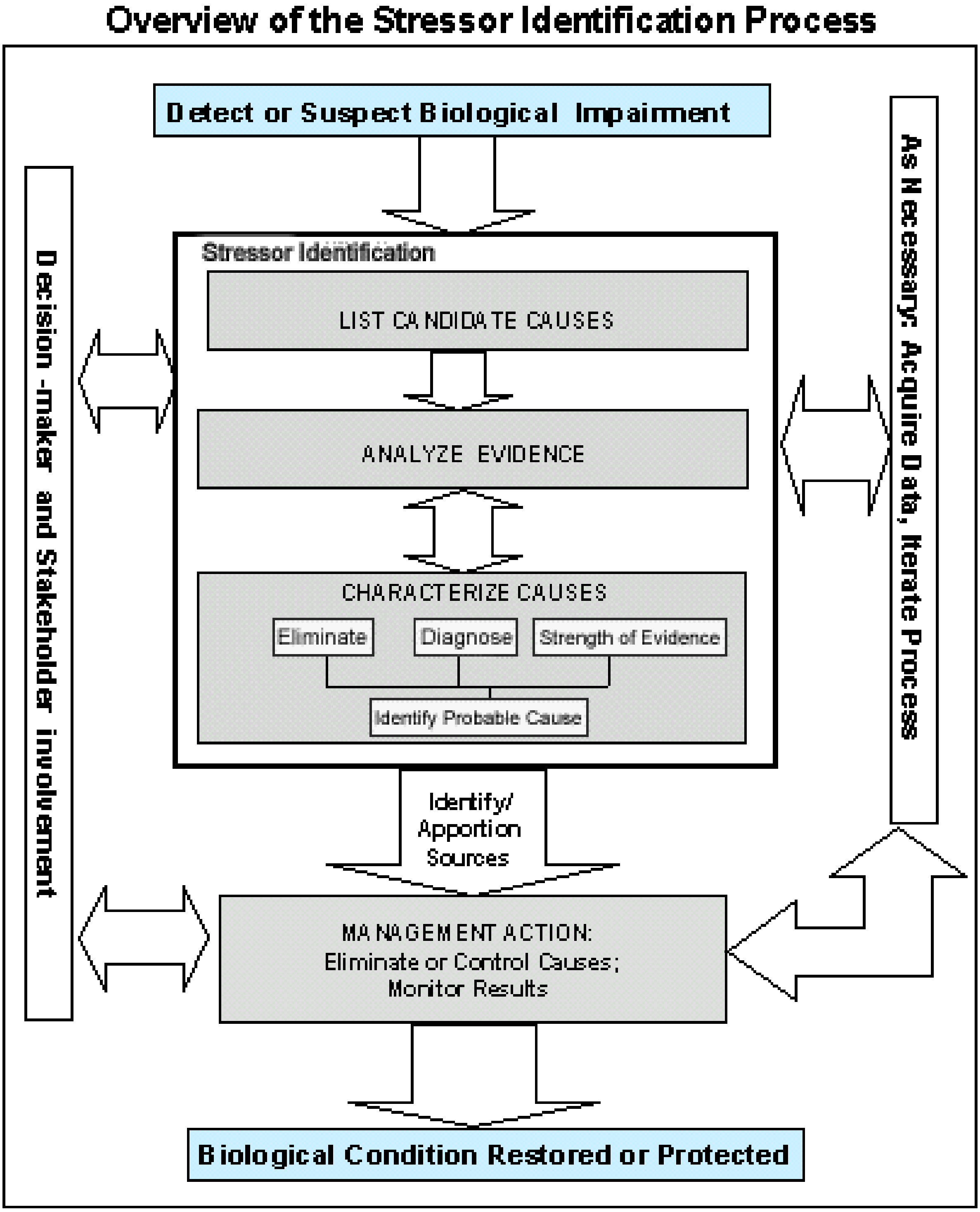
- The Simulidae larvae collected from the Rio Minho do not match the (limited) descriptions of 2 of the 3 Simulid species listed by Stone (1969) for Dominica and may be a new island record (see appendices).

In summary, the limited findings from this study have shown major disturbances (both an increase and decrease) to the overall biodiversity of the benthic macroinvertebrate fauna at both rivers as one moves downstream along the watercourses sampled. The greatest change in faunal assemblage occurs in the immediate vicinity and immediately downstream of sand and gravel mining localities and that biological recovery from these activities is slow following the catastrophic removal of the streambed resulting in massive habitat loss and very low diversity of the benthic fauna. Consequently, it is anticipated that recolonisation of these disturbed habitats is slow, resulting in areas of lowered biodiversity.

A serious stressor to these rivers appears to be the removal of benthic sediments (gravel/ sand) from the watercourse. The flowchart below (Figure 18) serves to illustrate the stressor identification process adopted in this study. The process is simple, iterative and tiered. It requires a suspected biological/ ecological impact which results from a number of candidate causes. These need to be investigated through a series of environmental analyses and data capture and the source (stressor) identified. Once identified then a management plan/ decision tree can be put in place enabling the return (through planned action) in the restoration of the biological moiety or habitat, including further protection from such activities in the future.

One recommendation from this initial simple study is the requirement for further longer term and more detailed comparative studies with more data collection (or possibly a reanalysis of the data already held by various departments or by members of staff at the university) from a larger number of impacted rivers and enhanced dialogue with the stakeholders and the decision makers.

Figure 18 A simple, tiered, iterative step wise flow chart for the resolution of a suspected biological problem resulting in the impairment of an ecosystem.



6. Conclusions

The work carried out in this study represents a small proportion of the research that is required in order for the process described in some detail in the introductory section of this report to be acted upon; and to generate adequate data from sufficient examples for the work to be representative and easily interpretable. This work is isolated in that few published works exist on the aquatic fauna of Jamaican streams and rivers. Those audits that have taken place are largely piecemeal and mostly result from the energies of the few interested naturalists or university academics and their students.

In the US, Canada and Europe such cataloguing has occurred not by chance, but as a result of a deliberate plan, to collect, collate, interpret and understand the biodiversity of rivers and streams and to use such information in the further classification of different stressors and their impacts on the respective aquatic habitat. In this way, large databases exist on the likely species complement to be found in more or less every water body - certainly in Europe. That should be the ambition for Jamaica, to conduct longer term, intensive cataloguing of the species complements of streams and rivers such that there is a starting place on which one can then begin to fuel scientific questions and opinions and act accordingly in response to the various pressures applied to them.

The trend reported in this study suggests that the abstraction of sand and gravel from river beds is deleterious to the ecosystem and certainly to sustained biodiversity. However, the nature of biological studies has shown large inherent variability and subtle complexities in the translation of this seemingly obvious and damaging action into a certifiable effect. What may at first seem an obviously damaging activity - removing the river bed from a river - does not appear to have a robust impact on the river ecosystem. The data collected here, in the absence of any other likely activities, suggest that the mining activity is responsible for the observed negative changes in biodiversity. The system operated in Europe, is for the operator to prove the negative, that the removal of sand and gravel from the river bed does not have any negative impacts on the surrounding habitats.

7. References

Brinkhurst RO. 1971. A guide for the identification of British aquatic oligochaeta. Scientific Publication 22, Freshwater Biological Association.

Chutter, F. M. 1969. The effect of silt and sand on the invertebrate fauna of streams and rivers. *Hydrobiol.* **34**, 57-76.

Death R.G., & Winterbourn, M.J. 1995. Diversity patterns in stream benthic invertebrate communities: The influence of habitat stability. *Ecol.* **76**(5), 1446-1460.

Donnelly TW 1970. The Odonata of Dominica, British West indies. Smithsonian Contribution to Zoology 37. Smithsonian Institution Press, Washington, DC.

Hayek L.C & Buzas M.A. (1997) Surveying Natural Populations, Columbia University Press, New York.

Hinton HE 1971. The Elmidae (Coleoptera) of Trinidad and Tobago. *British Museum (Natural History) Bulletin, Entomology* **26**:245-265.

Lake P.S., Doeg, T. J., & Marchant, R. 1989. Effects of multiple disturbance on macroinvertebrate communities in the Acheron River, Victoria. *Aust. J. Ecol.* **14**, 507-514.

Lauga-Reyrel, F. and Deconchat, M. (1999). Diversity within the Collembola community in fragmented coppice forests in south-western France. *European Journal of Soil Biology* **35**, 177-187.

McAleece, N. 1997. BioBiversity Professional Beta. The Natural History Museum and The Scottish Association for Marine Science. Devised by P. J. D. Lambshead, G. L. J. Patersen and J. D. Gage.

Murray-Bligh, J.A.D., Furse, M.T., Jones, F.H., Gunn, R.J.M., Dines, R.A., Wright, J.F. (1997). Procedure for collecting and analysing macroinvertebrate samples for RIVPACS. Report by Environment Agency and Institute of Freshwater Ecology.

Nuttall, P. M., & Bielby, G. H. 1973. The effect of china-clay wastes on stream invertebrates. *Environ. Pollut.* **5**, 77-86.

Robinson, C. T., & Minshall, G. W. 1986. Effects of disturbance frequency on stream benthic community structure in relation to canopy cover and season. *J. North Am. Benthol. Soc.* **5**, 237-248.

Scrimgeour, G. J., & Winterbourn, M. J. 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand River. *Hydrobiol.* **171**, 33-44.

Stone A 1969. Black flies of Dominica. *Proceedings of the Entomological Society of Washington* **17**:312-318**.**

Taylor S.A.G., & Chubb, L. J. 1957. The hydrogeology of the Clarendon Plains, Jamaica. *Geologists Assoc. Proceed.* Vol.**68**(3), 204-210.

Thorp JH & Covich AP. 2001. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press, London, UK.

Travers JR 1938. Mayflies of Puerto Rico. *Journal of Agriculture of the University of Puerto Rico* **33**:5-40.

Wallace ID, Wallace B & Philipson GN. 1990. *A key to the case-bearing caddis larvae of Britain and Ireland.* Scientific Publication 51, Freshwater Biological Association.

Appendix 1 Chemical data

Table 1. Details of the total concentrations of selected heavy metals (Cu, Zn, As, Cd and Pb) collected for each of the sampling locations at both rivers.

Sample no	Total dissolved Metal concentrations (ug/l)				
	Cu*	Zn	As	Cd	Pb
Minho 1	9.7	3	1	<0.1	<0.1
Minho 2	8.1	2	2	<0.1	<0.1
Minho 3	11.1	5	2	<0.1	<0.1
Minho 4	5.6	1	3	<0.1	<0.1
Minho 5	4.6	<1	1	<0.1	<0.1
Minho 6	4.5	<1	1	<0.1	<0.1
Minho 7	7.9	3	1	<0.1	<0.1
Yallas 1	4.4	4	<1	0.2	<0.1
Yallas 2	2.9	1	<1	<0.1	<0.1
Yallas 3	3.3	4	<1	<0.1	<0.1
Yallas 4	2.8	4	<1	<0.1	<0.1

*The EQS (Environmental Quality Standard for Cu is linked to water hardness

Appendix 2 Biological species complement for the Rio Minho

Rio Minho Site No 1

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/21/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	933
	(Snails, limpets & mussels)	(Snails & limpets)		*Thiara*	*granifera*	24
	INSECTA	Diptera	Chironomidae			1
	(Insects)	(Flies)	Simulidae			108
		Coleoptera	Elmidae	*Neoelmis*	*pusio*	49
		(Beetles)				
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	7
		(Mayflies)				
		Lepidoptera	Pyralidae			10
		(Moths)				
		Trichoptera	Hydropsychidae	*Smicridea*		663
		(Caddis Flies)	Hydroptilidae			165
		Odonata / Zygoptera	Cordullidae sp. A			4
		(Damselflies)	Cordullidae sp. B			7
		Odonata / Anisoptera	Libellulidae			2
		(Dragonflies)	Gomphidae	*Gomphus*		1
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		26
	(Worms & Leeches)	(Worms)		*Rhynchelmis*		1
			Naididae	*Dero*		2
				Nais		3
		Hyrudinea	Erpobdellidae	*Motobdella*	*montezuma*	1
		(Leeches)				
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		3
	(Prawns, Crayfish & Crabs)	(Prawns)				

Rio Minho Site No 2

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/21/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	744
	(Snails, limpets & mussels)	(Snails & limpets)		*Thiara*	*granifera*	9
	INSECTA	Diptera	Chironomidae			1
	(Insects)	(Flies)	Simulidae			1
		Coleoptera	Elmidae	*Neoelmis*	*pusio*	10
		(Beetles)				
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	1
		(Mayflies)				
		Lepidoptera	Pyralidae			10
		(Moths)				
		Trichoptera	Hydropsychidae	*Smicridea*		388
		(Caddis Flies)	Hydroptilidae			85
		Odonata / Zygoptera	Protoneuridae			3
		(Damselflies)	Coenagrionidae			1
		Odonata / Anisoptera	Cordullidae sp. A			2
		(Dragonflies)	Cordullidae sp. B			1
			Libellulidae			4
			Gomphidae	*Gomphus*		1
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		9
	(Worms & Leeches)	(Worms)	Naididae	*Nais*		1
		Hyrudinea	Piscicolidae	*Illinobdella*	*richardsoni*	1
		(Leeches)				
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		1
	(Prawns, Crayfish & Crabs)	(Prawns)				

Rio Minho Site 3

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/21/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	1797
	(Snails, limpets & mussels)	(Snails & limpets)		*Thiara*	*granifera*	15
	INSECTA	Diptera	Chironomidae			2
	(Insects)	(Flies)	Simulidae			12
		Coleoptera	Elmidae	*Neoelmis*	*pusio*	4
		(Beetles)				
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	36
		(Mayflies)				
		Lepidoptera	Pyralidae			6
		(Moths)				
		Trichoptera	Hydropsychidae	*Smicridea*		401
		(Caddis Flies)	Hydroptilidae			44
		Odonata/Anisoptera	Cordullidae sp. A			3
		(Dragonflies)	Libellulidae			1
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		5
	(Worms & Leeches)	(Worms)				

Rio Minho Site 4

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/17/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	830
	(Snails, limpets & mussels)	(Snails & limpets)		*Thiara*	*granifera*	38
		Bivalvia / Corbiculoidae	Sphaeriidae	*Sphaerium*	*occidentale*	1
	INSECTA	Diptera	Chironomidae			8
	(Insects)	(Flies)	Simulidae			32
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	88
		(Mayflies)				
		Lepidoptera	Pyralidae			16
		(Moths)				
		Trichoptera	Hydropsychidae	*Smicridea*		224
		(Caddis Flies)	Hydroptilidae			13
		Odonata / Zygoptera	Protoneuridae			2
		(Damselflies)				
		Odonata/Anisoptera	Libellulidae			1
		(Dragonflies)				
		Hemiptera / Heteroptera	Pleidae	*Neoplea*		1
		(Bugs)				
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		9
	(Worms & Leeches)	(Worms)		*Rhynchelmis*		1
		Hyrudinea	Erpobdellidae	*Motobdella*	*montezuma*	1
		(Leeches)				
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		3
	(Prawns, Crayfish & Crabs)	(Prawns)	Atyide	*Syncaris*		1

Rio Minho Site 5

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/17/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	11
	(Snails, limpets & mussels)	(Snails & limpets)		*Thiara*	*granifera*	3
				Fossaria		2
	INSECTA	Diptera	Chironomidae			45
	(Insects)	(Flies)	Scyomyzidae	*Sepedon*		1
			Ceratopogonidae			3
			Tipulidae			5
			Tabanidae	*Chrysops*		6
			Nymphomyiidae			1
		Coleoptera	Haliplidae	*Peltodytes*		1
		(Beetles)	Hydrophilidae	*Tropisternus*		1
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	63
		(Mayflies)	Caenidae	*Caenis*		1
		Trichoptera	Hydropsychidae	*Smicridea*		88
		(Caddis Flies)	Hydroptilidae			8
	ANNELIDA	Oligochaeta	Tubificidae	*Rhynchelmis*		1
	(Worms & Leeches)	(Worms)	Naididae	*Nais*		3
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		4
	(Prawns, Crayfish & Crabs)	(Prawns)				

Rio Minho Site 6

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/18/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	4
	(Snails, limpets & mussels)	(Snails & limpets)		*Fossaria*		1
	INSECTA	Diptera	Chironomidae			13
	(Insects)	(Flies)	Scyomyzidae	*Sepedon*		1
		Ephemeroptera (Mayflies)	Baetidae	*Baetis*	*garcianus*	62
		Lepidoptera (Moths)	Pyralidae			1
		Trichoptera (Caddis Flies)	Hydropsychidae	*Smicridea*		54
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		3
	(Worms & Leeches)	(Worms)		*Rhynchelmis*		1
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		1
	(Prawns, Crayfish & Crabs)	(Prawns)				

Rio Minho Site 7

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/18/02	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	739
	(Snails, limpets & mussels)	(Snails & limpets)		*M.*	*amabilis*	14
				Thiara	*granifera*	4
				Fossaria		1
	INSECTA	Diptera	Chironomidae			3
	(Insects)	(Flies)	Simulidae			4
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	143
		(Mayflies)				
		Lepidoptera	Pyralidae			95
		(Moths)				
		Trichoptera	Hydropsychidae	*Smicridea*		341
		(Caddis Flies)	Hydroptilidae			74
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		3
	(Worms & Leeches)	(Worms)	Naididae	*Dero*		1
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		1
	(Prawns, Crayfish & Crabs)	(Prawns)				

Appendix 3 Biological species complement for the Yallahs river

Yallahs River Site 1

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/16/2002	MOLLUSCA	Gastropoda	Planorbidae			1
	(Snails, Limpets & Mussels)	(Snails & Limpets)				
	INSECTA	Diptera	Chironomidae			1
	(Insects)	(Flies)	Scyomyzidae	*Sepedon*		2
		Coleoptera	Elmidae	*Neoelmis*	*pusio*	1
		(Beetles)				
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	49
		(Mayflies)				
		Trichoptera	Hydropsychidae	*Smicridea*		78
		(Caddis Flies)				
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		10
	(Worms & Leeches)	(Worms)				
	PLATYHELMINTHES	Turbellaria	Tricladida	*Dugesia*	*trigrina*	3
	(Flatworms, Flukes & Tapeworms)	(Flatworms)				
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		2
	(Prawns, Crayfish & Crabs)	(Prawns)	Atyidae	*Syncaris*		3

Yallahs River Site 2

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/16/2002	MOLLUSCA	Gastropoda	Lymnaeidae	*Melanoides*	*tuberculata*	1
	(Snails, Limpets & Mussels)	(Snails & Limpets)				
	INSECTA	Diptera	Chironomidae			1
	(Insects)	(Flies)	Scyomyzidae	*Sepedon*		6
		Ephemeroptera	Baetidae	*Baetis*	*garcianus*	39
		(Mayflies)				
		Trichoptera	Hydropsychidae	*Smicridea*		22
		(Caddis Flies)	Hydroptilidae			2
	ANNELIDA	Oligochaeta	Tubificidae	*Tubifex*		1
	(Worms & Leeches)	(Worms)				

Yallahs River Site 3

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/16/2002	INSECTA (Insects)	Ephemeroptera (Mayflies)	Baetidae	*Baetis*	*garcianus*	3
		Trichoptera (Caddis Flies)	Hydropsychidae	*Smicridea*		1
	CRUSTACIA: Decapoda	Caridae	Palaemonidae	*Machrobrachium*		2
	(Prawns, Crayfish & Crabs)	(Prawns)	Atyidae	*Syncaris*		1

Yallahs River Site 4

Sampling date	Phylum	Class	Family	Genus	Species	No. present
1/16/2002	INSECTA (Insects)	Diptera (Flies)	Chironomidae			1
		Ephemeroptera (Mayflies)	Baetidae	*Baetis*	*garcianus*	3
		Trichoptera (Caddis Flies)	Hydropsychidae	*Smicridea*		8
	ANNELIDA (Worms & Leeches)	Oligochaeta (Worms)	Tubificidae	*Tubifex*		1
	CRUSTACIA: Decapoda (Prawns, Crayfish & Crabs)	Caridae (Prawns)	Atyidae	*Syncaris*		3