internal report 405

Fish communities of Gulungul Creek – A landscape analysis

Phase 1: 'First-pass' analyses of 1979–2001 Late-Wet–Early-Dry season data

KA Bishop & DJ Walden

February 2003

supervising scientist

Fish communities of Gulungul Creek: A landscape analysis

Phase 1: ‘First-pass’ analyses of 1979–2001 Late-Wet–Early-Dry season data

Examination of environmental correlates to facilitate the interpretation of changes detected in the structure of the fish communities during the ‘first-pass’ analyses

Dr KA Bishop[1] & DJ Walden[2]

[1]Freshwater biology consultant – Sugar Creek Rd, Bungwahl NSW 2423
Phone/Fax: 61 02 4997 6193 - Email: bishop@nobbys.net.au

[2]Environmental Research Institute of the Supervising Scientist – GPO Box 461 Darwin NT 0801 – Phone: 61 08 8920 1171, Fax: 61 08 8920 1195 – Email: dave.walden@ea.gov.au

October 2001

Study undertaken for the Environmental Research Institute of the Supervising Scientist

Contents

Figures

Tables

Summary

Gulungul Creek flows past the western lease boundary of the Ranger Uranium Mine. There are two primary scenarios by which aquatic biota within the creek are potentially exposed to contaminants arising from the mine:

Scenario 1: The creek flows close to Ranger's tailings dam, therefore disturbances on aquatic communities located downstream of the dam may occur if substantial quantities of mine contaminants seeped from the dam and into the creek via groundwater

Scenario 2: In the case of fish communities, during the wet season there is both (i) extensive movement of many fish species along Gulungul Creek and between Gulungul and Magela creeks, as well as (ii) recruitment of some fish species from the lower reaches of Gulungul Creek (including Gulungul Billabong located at the confluence of the Gulungul and Magela creeks), and from the adjacent Magela Creek, to the upper reaches of Gulungul Creek. Thus, contamination of Magela Creek and Gulungul Billabong (via backflow from Magela Creek) from mine wastes could be indirectly transferred to the middle and upper reaches of Gulungul Creek.

eriss is in a strong position to assess whether or not there are mine-disturbance signals on biotic communities of the creek, given their extensive landscape-scale data on fish communities of the creek, spanning the period 1978 to 1990. To facilitate such an assessment, ***eriss*** initiated an investigation in early 2001 that involved the collection of a current-condition fish community sample from the creek (Late-wet–Early-dry season focus), and an analysis of the gathered data in conjunction with the 1978–90 data.

In a first-pass context, the present report aims to initially determine whether there are any obvious *Scenario-1 mine-disturbance signals*, and less specifically, any *downstream-focused non-specific disturbance signals* which may be a mixed response to a range of disturbances (i.e. natural processes, Scenario-2 mine disturbances, and a range of other anthropogenic disturbances).

Scenario 1: mine-disturbance signals

Data analyses most attuned to the detection of a Scenario-1 mine-disturbance signal were those which focused on fish-community-structure differences between sites potentially directly exposed, and not directly exposed, to tailings dam seepage. These analyses, which examined four fish-community-structural measures, revealed no evidence of a disturbance signal at the potentially exposed sites.

Downstream-focused, non-specific disturbance signals

A range of analyses were undertaken to detect these signals. The examination of time trends in the numerical density of each species revealed evidence of a disturbance signal in terms of statistically significant negative time trends in the density of archerfish and spangled grunters (i.e. the density of these species had reduced through time). These trends were apparent in a number of sites.

Other analyses examined year-to-year changes in the composition of fish communities, focusing on differences between the 1978–90 data and the current-condition (2001) data. Using a range of similarity measures, and analytical techniques, no evidence of a disturbance signal was obtained for four groups of sites examined.

Additional evidence of a disturbance signal arose from an ordination analysis which showed that the composition of fish communities in 2001 had shifted beyond the defined 1978–90 ‘bounds’ at sites within the middle reaches of the creek. An understanding of the basis of these changes will be developed in ensuing data analyses, particularly the examination of hydrological, habitat and physiographic correlates, which will be reported in the more exhaustive Phase 2 report.

Acknowledgments

We thank Dr Chris Humphrey of ***eriss*** for his commitment to the project, the numerous valuable discussions, and the prompt provision of key information. Many other ***eriss*** staff assisted in making the project run smoothly. In this context, key inputs were provided by James Boyden (field assistance and database assistance), Dr Bob Pidgeon (valuable discussions and statistical advice), Gail Barrowcliff (data entry and checking), Jacqui Rovis-Herman and Sandra Peckham (liaison with traditional owners), Joan Mount (literature searches and other library services), and Helen Waterson (accommodation services).

For occasional assistance in the field we thank: Justin Cooper, Crystal Thomas, Jarrad Mitchell, Greig Taylor, Richard Lawrence, Guy Boggs, Robbie and Samuel Bishop-Taylor, and Chris Taylor.

Traditional owners of Kakadu National Park are thanked for granting permission to enter their lands. Staff of the Park are thanked for their crocodile-safety assessment and their prompt processing of camping permits.

The Northern Territory Department of Water Resources is thanked for the provision of creek-flow data. The Bureau of Meteorology is acknowledged for providing rainfall data.

Fish communities of Gulungul Creek: A landscape analysis

Phase 1: 'First-pass' analyses of 1979–2001 Late-Wet–Early-Dry season data

KA Bishop & DJ Walden

1 Introduction

1.1 Background and rationale for the study

1.1.1 Assessment of potential disturbances arising from the Ranger mine

Gulungul Creek (figure 1), a tributary of Magela Creek, flows past the western lease boundary of the Ranger Uranium Mine. There are two primary scenarios by which aquatic biota within the creek are potentially exposed to contaminants arising from the mine:

Scenario 1: The creek flows close to Ranger's tailings dam, therefore disturbances on aquatic communities located downstream of the dam may occur if substantial quantities of mine contaminants seeped from the dam and into the creek through groundwater[1]

Scenario 2: In the case of fish communities, during the wet season there is both (i) extensive movement of many fish species along Gulungul Creek and between Gulungul and Magela creeks, as well as (ii) recruitment of some fish species from the lower reaches of Gulungul Creek (including Gulungul Billabong located at the confluence of the Gulungul and Magela creeks), and from the adjacent Magela Creek, to the upper reaches of Gulungul Creek. Thus, contamination of Magela Creek and Gulungul Billabong (via backflow from Magela Creek) from mine wastes could be indirectly transferred to the middle and upper reaches of Gulungul Creek.

In assessing whether there is a mine-disturbance signal on biotic communities of the creek, there is clearly a need for long-term biological data, which spans a substantial baseline period and has some coverage of the current condition.

1.1.2 Extensive baseline available on fish communities of Gulungul Creek

Fortunately, there are extensive landscape-scale data available on fish community structure at a range of sites along Gulungul Creek, spanning the period 1978 to 1990.

Some of the very early data (1978–79) at one site arose from a broad regional baseline fish survey reported by Bishop et al (1986, 1990). After this, the *Gulungul Creek fish distribution*

---

1 Groundwater seepage from the western side of the Tailings Dam, as indicated by rising sulphate concentrations (to ~150 mg/L), was first detected in 1992 and reported by NTDME (1993). By May 2000 it was reported (NTDME 2000) that groundwater quality had deteriorated significantly in some of the western bores with the following levels reached for a range of water quality parameters: sulphate 1300 mg/L (bore OB6A), manganese 980 ug/L (OB6A), nitrate 0.75 mg/L (OB4A) and electrical conductivity 1300 uS/cm (OB6A). In terms of the quality of surface waters in Gulungul Creek, some time-trend analyses have been undertaken by Dr D. Klessa of the Supervising Scientist for the period 1981 to 1999. Over this period, the (4-season-cycle rolling) median sulphate concentration steadily rose from 0.1 mg/L in 1981-82 to 0.4 mg/L in 1989-99. These concentrations are clearly still very low and it was indicated that the detected rise could not be conclusively linked with mining activities.

and abundance study commenced and involved monthly censusing of fish communities across a longitudinal array of ten sites from the escarpment zone down to and across the lowlands. Censusing in 1980–81 was reported by Bishop and Harland (1982) and later by Bishop and Forbes (1991). Humphrey et al (1990) reported an analysis of censusing data collected up to1988 at one site in the upper reaches of the creek. A remarkably high level of year-to-year compositional stability – by world standards – was recorded.

The original aim of the study was to develop an understanding of the processes, which influence migration patterns of fishes within the creek. Gulungul Creek was chosen because it was considered to be a suitable small-scale replica of Magela Creek. i.e. interpretations from Gulungul Creek could be applied to the more geographically extensive and hydrologically complex Magela Creek[2]. As data from the study accrued, it became apparent that the data could be used for monitoring in a number ways[3]. During the 1980s the primary monitoring focus was not the detection of a mine-disturbance signal arising from seepage from the western side of the tailings dam. Nevertheless, to enable some form of such detection in the future, sites were censused in areas upstream and downstream of possible seepage-entry points.

To this end the 1978–90 dataset is viewed by ***eriss*** as being particularly valuable in detecting tailings-dam-seepage (Scenario-1) disturbances because:

- it spans in time a long period when there was no evidence of western-side tailings dam seepage, i.e. it can be considered to be a pre-seepage baseline dataset (even though it spans both pre-mining and early-operational phases of mining), and
- it spans in 'space' creek sections, which are likely to be directly, and not-directly exposed to surfacing seepage plumes.

1.1.3 Initiation of the present investigation

In April 2001 ***eriss*** initiated the present investigation, which involved the collection of a current-condition (i.e. contemporary), Late-wet–Early-dry season, fish-community sample, and a conjunctive analysis of the baseline data. Their motivation for this initiation was:

- at least eleven years have passed since the last data on fish communities were collected from the creek,
- it is now well into the later-production phase of the mine, and
- there are initial indications, albeit inconclusive, that water quality in the creek's lower reaches is commencing to change in response to western-side tailings dam seepage, which has been apparent for nine years (refer back to Footnote 1).

eriss has specific interest in determining: i) if there are any mine-disturbance signals within the current-condition data, ii) whether the remarkably high compositional stability reported by Humphrey et al. (1990) still continues, and iii) if any significant time trends in community characteristics are now apparent at any of the creek sites.

---

2 Knowledge of such processes in Magela Creek was considered desirable in order that 'natural' responses of migrating fish can be distinguished from mining-induced responses, such as that caused by the release of mine wastewaters.

3 The primary ways were: i) data collected on species (such as terapontids) which appear not to migrate out of the sandy creek habitat of Gulungul Creek, may be used as a spatial controls for migration data gathered in Magela Creek, and ii) data collected on species (such as ambassids) which appear to be recruited into the creek from Gulungul Billabong (figure 1) could be used as temporal controls for community information gathered from the billabong.

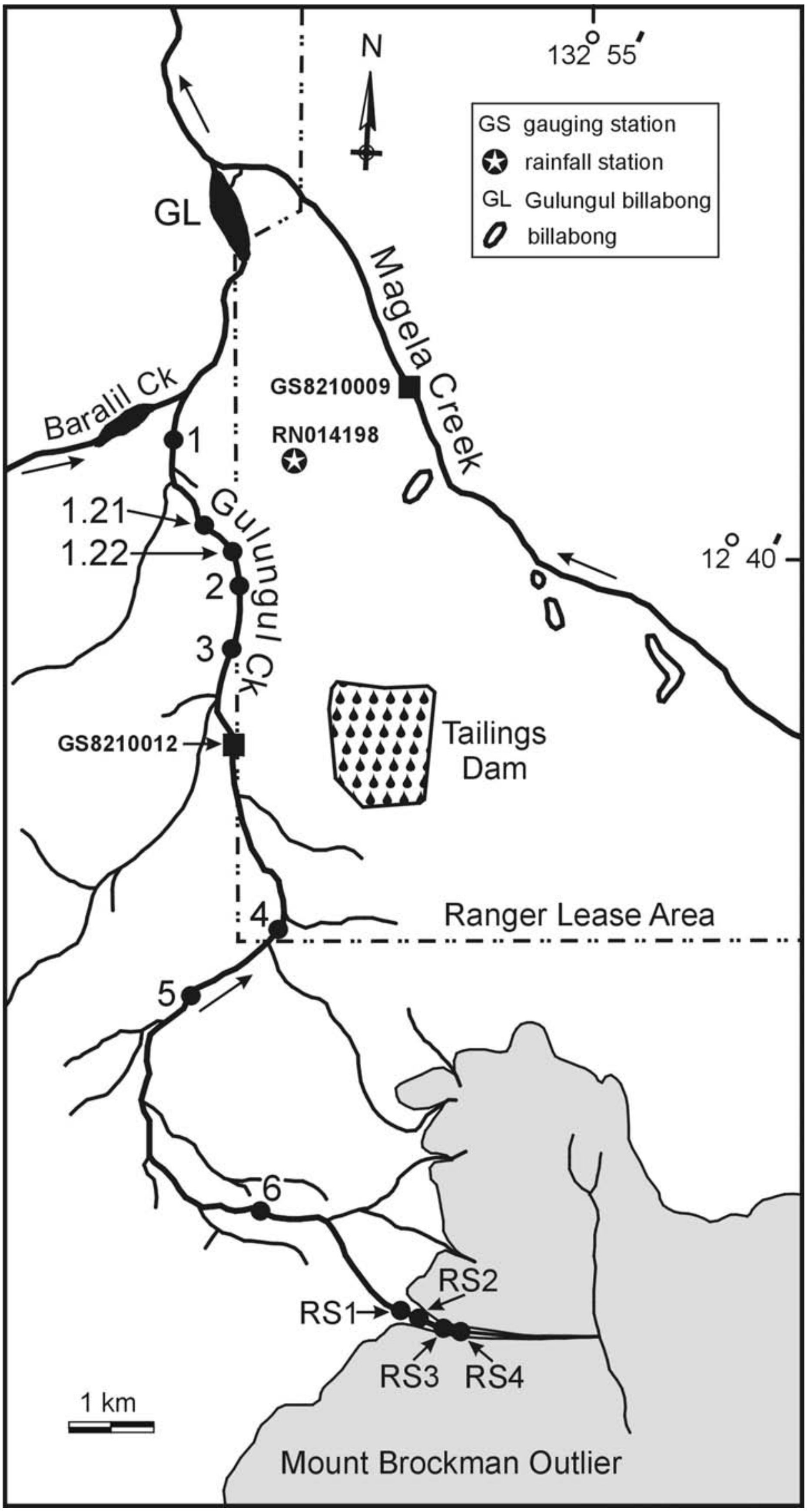

Figure 1 Sampling sites along Gulungul Creek (RS = Radon Springs)

It was recognised that the detection of Scenario-1 mine disturbances (tailings-dam-seepage disturbances) is far more straightforward than the detection of Scenario-2 mine disturbances (indirect disturbances arising from mine-affected downstream areas). This is because the Scenario-1 disturbance detection can be primarily based on simple data comparisons between separate sections of the creek that are directly and not-directly exposed to surfacing seepage plumes.

In the context of the data collected to date, Scenario-2 disturbance detection primarily relies on comparison of data across separate periods of time. Such comparisons can readily be confounded by natural year-to-year environmental changes as well as the considerable number of anthropogenic activities and potential sources of disturbance – apart from mining activity – that may arise in the lower reaches of Gulungul Creek. These include effects arising from Jabiru township, the Arnhem Highway and vehicular traffic at the creek crossing, campsites and associated refuse in or adjacent to the creek, and recreational and traditional fishing activities. Runoff from Jabiru township and sewage works drain into Baralil Creek, which enters Gulungul Creek between the Arnhem highway and Gulungul Billabong (figure 1). As a consequence of these collective non-mining activities in the lower reaches of Gulungul Creek, it is likely to be very difficult to isolate out Scenario-2 mine disturbances in fish community structure. However, if a conclusion of 'no change' was observed between the Gulungul fish data from the two sampling periods (baseline and current-condition samplings), it indicates downstream activities, direct and indirect – township, Ranger mining influences, Arnhem highway road crossing, recreational and traditional fishing activities, etc – are collectively insufficient in intensity at present to adversely affect fish ecology at the landscape scale.

1.1.4 Assessing possible impacts arising from cane toads

Recensusing of Gulungul Creek fish communities may be timely given that the introduced cane toad, *Bufo marinus*, will soon be reaching the area. The fish communities of the creek could be adversely affected by the toads through a range of mechanisms, the most obvious being poisoning after consuming toads or their tadpoles. If there were any risks to fish, it would be to frog-eating species such as the Saratoga and Black bream. Censusing before and after the arrival of the toads is important as it would potentially isolate any impact due to the toads, as opposed to any recent mining disturbances.

1.1.5 Aims of this Phase-1 report

Describe fish-censusing activities undertaken in Gulungul Creek in April/May 2001 (i.e. the Late-wet–Early-dry season, current-condition sample),

Identify the location of the censusing sites, and

Undertake, describe and report on analyses that aim, in a first-pass context, to initially detect any obvious:

- *Scenario-1 mine-disturbance signals* (i.e. as arising from seepage from the western side of the tailings dam), and less specifically,
- any *downstream-focused non-specific disturbance signals* that may be a mixed response to a range of disturbances (i.e. natural processes, Scenario-2 mine disturbances, and a range of other anthropogenic disturbances).

2 Methods

2.1 May 2001 censusing: the current-condition sample

2.1.1 Sampling sites and dates

Nine of the ten sites originally censused for fish in the baseline period (figure 1) were recensused in the 2001 Late-wet–Early-dry season. Site 1 was not recensused because it was not possible to confidently determine whether or not a saltwater crocodile was present in the site. The first field task was to relocate the sites, mark them (not in the escarpment area) and obtain coordinates using a GPS.

To offset the loss of Site 1 in future investigations, two additional sites were established and censused. These sites (Sites 1.21 and 1.22), which were located between Sites 1 and 2 (figure 1), were censused only once (on 9/5/01).

To obtain a reasonable level of representativeness of the season, and an indication of the level of within-season variation in the structure of fish communities, the nine baseline sites were censused on the following three occasions:

- Occasion 1: 1–4th May 2001
- Occasion 2: 14–17th May 2001
- Occasion 3: 24–26th May 2001

2.1.2 Censusing procedure

The structure of fish communities in the demarcated sites was determined using an underwater censusing procedure, i.e. counts based on visual observations. Importantly, the procedure was the same as used in the baseline period by Bishop and Harland (1982), Bishop et al (1986, 1990) and previous ***eriss*** researchers. The original reasons for using this visual-observation procedure were:

- it is non-destructive (i.e. no fish are captured or handled): therefore there are conservation benefits and investigation advantages arising from the absence of sampling interference being transferred to subsequent samples,
- it is very effective because of the constant high clarity of waters (due to its proximity to the sandstone escarpment headwaters),
- it can be effectively used in both deep and reasonably shallow waters, and within areas offering up to a moderate level of cover for fish, and
- it is cost effective: considerable quantities of data on fish communities can be gathered with a reasonably small effort.

Procedural details follow: A diver (snorkelling) made detailed observations in a standard area in a standard time through a demarcated site at swimming speeds of 0.2–0.5 m/s. Particular care was taken to examine all areas in the site, especially habitat elements providing significant cover. The diver recorded all fish species observed within the area along with estimates of individual species abundances and size ranges. Importantly, a progressive written tally was kept while the census was in progress. The area censused was then estimated in order to allow the later calculation of the numerical density of fish.

Underwater observation has long been considered a powerful tool for the enumeration of fishes in marine reefs (*tropical* examples: Bardach (1959), Thresher and Gunn (1986); *temperate*: Brock (1954), Lincoln-Smith (1989)), and the littoral regions of freshwater lakes (*tropical*: Hori et al. (1993), Werner et al (1978); *temperate:* Dibble (1991), Hall and Werner (1977), Keast and Harker (1977), Werner et al (1978)). They have also been used extensively in rivers and streams (tropical: Power (1984) ; temperate: Goldstein (1978), Griffith (1981), Griffith et al (1984), Hankin and Reeves (1988), Heggenes et al (1991), Hicks and Watson (1985), Matthews et al. (1994), Pollard and Bjornn (1973), Reed (1967), Teirney and Jowett (1990)). In terms of differences in results obtained with other sampling methods, the following has been indicated:

- underwater observations (UWO) missed small fish in shallow waters, but bankside observations missed fish under turbulence and in deep areas (Hegges et al 1991)
- UWO gave better estimates of numbers of individuals than mark-recapture investigations (Power 1984)
- compared with rotenone sampling, UWO obtained very similar relative abundance data, but fewer species and individuals (Dibble 1991)
- compared with seining, UWO obtained the same number of species, but higher numbers of individuals and less bias to small species (Matthews et al. 1994)

2.2 Analysis of fish-community data

2.2.1 Pre-analysis data treatment

2.2.1.1 Selection of baseline data

To allow meaningful comparisons with the 2001 data, only Late-wet–Early-dry season data were extracted from the baseline dataset. For each year of data the following two samples represented the season:

- late-April data (sometimes delayed into very early May), and
- late-May data (sometimes delayed into very early June)

Even though censusing data had been collected in 1978, none had been collected in the Late-wet–Early-dry season. Accordingly, the earliest data selected arose from the 1979 Late-wet–Early-dry season.

Where data were collected by both Keith Bishop (KB) and Dave Walden (DW), the KB data were selected as the 2001 data were only collected by KB.

Data collected at Site 1 was not used as no data were collected at this site in 2001. Data collected at Site 10 were also not used as it was not used any first-pass analyses which follow.

2.2.1.2 Data conversion

The abundance data were converted to numerical-density data by dividing abundances by the recorded area of each site. Accordingly, the units of the converted data were *number of fish per square metre.* Data standardisation was facilitated by this conversion.

2.2.1.3 Pooling of data

For each Late-wet–Early-dry season, the data from each site were pooled across the monthly samples by calculating the mean density across the samples. Generally, two samples were pooled for each season in the baseline period. Three samples were pooled for the current-condition period (i.e. the 2001 sample).

Also by the calculation of mean densities, data were pooled across selected sites as follows:

Site-group A:

- comprising Sites 2 and 3
- these sites are potentially directly exposed to surfacing plumes of seepage from Ranger's tailings dam
- both sites are in the lowland-sandy-creek section of the creek which has limited riparian vegetation cover; by the Mid- to Late-dry season this creek section dries out
- also referred to as the *downstream site-group*

Site-group B:

- comprising Sites 4 and 5
- these sites are not potentially directly exposed to surfacing plumes of seepage from Ranger's tailings dam, however, they are the closest upstream site-group
- as for Site-group A, both sites are in the lowland-sandy-creek section of the creek which has slightly more riparian vegetation cover; by the Mid- to Late-dry season this creek section dries out
- also referred to as the *upstream site-group*

Site-group C:

- comprising Sites 6 and 7
- these sites are not potentially directly exposed to surfacing plumes of seepage from Ranger's tailings dam; they are the second closest upstream site-group
- both sites are in the upper reaches of the creek just before the escarpment gorge and have thick riparian vegetation cover; water flow is permanent at these sites, although greatly reduced by the Mid- to Late-dry season; used as Dry-season refuges by fish, although access for upstream-migrating fish is restricted for some species because minor migration obstacles are present downstream of the sites
- also referred to as the *pre-gorge upstream site-group*

Site-group D:

- comprising Sites 8 and 9
- these sites are not potentially directly exposed to surfacing plumes of seepage from Ranger's tailings dam; they are the third closest upstream site-group
- both sites are within escarpment gorge in the upper reaches of the creek and have either thick riparian vegetation cover, or cover provided by boulders and cliffs; water flow is generally permanent at these sites, although greatly reduced by the Mid- to Late-dry season; used as Dry-season refuges by fish, although access for upstream-migrating fish is restricted to species which can ascend cascades and/or small vertical jumps
- also referred to as the *within-gorge upstream site-group*

2.2.2 Analytical strategy

A multifaceted strategy was used in an attempt to partially account for i) the multidimensional nature of fish community structure, ii) the many ways that structural data can be examined, and iii) the fact that two types of disturbance signals were sought (*Scenario-1 mine-disturbance signals*, and *downstream-focused non-specific disturbance signals* which may or may not include a Scenario-2 mine-disturbance signal).

2.2.2.1 Basic structural features

Three such features were examined:

Number of fish (total numerical density across all species)

This is the total numerical density of fish summed across all species.

Changes in density over time at Site-groups A and B were plotted. The mean density in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on downstream-focused disturbance signals.

Changes in the differences in density between Site-groups A and B were plotted over time. The mean density difference in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on Scenario-1 mine-disturbance signals.

Time trends in the densities of each species

Time trends in the densities of each species were searched for by calculating Spearman's rank correlation coefficients (denoted as *r* in the text) between time and the species' density. Separate coefficients were calculated for the downstream and upstream site-groups. This data examination focuses on downstream-focused disturbance signals.

Number of species

This is the number of species in a pooled sample. Because a limited number of 'species' may have contained at least two species (eg. blue-eyes, ambassid perchlets and sleepy cod), a more appropriate parameter name would have been the *number of taxa*.

Changes in the number of species over time at Site-groups A and B were plotted. The mean number of species in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on downstream-focused disturbance signals.

Changes in the differences in the number of species between Site-groups A and B were plotted over time. The mean number-of-species difference in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on Scenario-1 mine-disturbance signals.

2.2.2.2 Compositional structure

Five features and/or analytical approaches were used to examine compositional structure:

'Evenness' of densities across species

This is the Pielou's (1975) evenness index calculated by the PRIMER software package (Plymouth Marine Laboratory, Version 4). It provides an indication of how even densities are distributed across species. Low evenness (minimum = 0.0, maximum = 1.0) indicates that a community is dominated in abundance by a small number of species, and this may be an indicator that the community is under stress.

Changes in the evenness index over time at Site-groups A and B were plotted. The mean evenness index in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on downstream-focused disturbance signals.

Changes in the differences in the evenness index between Site-groups A and B were plotted over time. The mean evenness index difference in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). This data comparison focuses on Scenario-1 mine-disturbance signals.

Between-sample similarity: Bray-Curtis measure

Compositional similarity between all samples was calculated using the Bray-Curtis (1957) similarity measure[4]. The PRIMER software package (Plymouth Marine Laboratory, Version 4) was used for the calculation and the creation of a similarity matrix. To allow less-abundant species to have more influence in the analysis, the density data were 4th root transformed prior to the calculation of the similarity index, an approach recommended by Clarke and Warwick (1997).

To illustrate the level of temporal variability, similarity values between consecutive samples from Site-Groups A and B were plotted against time.

To illustrate the level of temporal variability in the compositional similarity between Site-groups A and B, the similarity values between these site-groups were plotted against time. The mean between-site similarity value in the baseline period was compared with the value from current-condition (2001) sample using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text). This data comparison focuses on Scenario-1 mine-disturbance signals.

The mean similarity value for all sample-combination pairs was calculated for the baseline-period samples. Correspondingly, the mean similarity value was then calculated for only pairs that spanned the baseline-period and current-condition period samples. These means were then compared using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). The comparisons were undertaken separately for each of the four site-groups. These data comparisons focused on downstream-focused disturbance signals.

Between-sample similarity: Spearman's rank correlation coefficients

To include another method of measuring similarity, compositional similarity between all samples was also calculated using the Spearman's rank-correlation coefficient. The MINITAB software package (Release 7) was used for the calculation and the creation of a correlation (similarity) matrix.

The mean correlation coefficient (= similarity value) for all sample-combination pairs was calculated for the baseline-period samples. Correspondingly, the mean coefficient value was then calculated for only pairs that spanned the baseline-period and current-condition period samples. These means were then compared using a Student's 't' test. (Any data transformation used to equalise variances are indicated in the text.). The comparisons were undertaken separately for each of the four site-groups. These data comparisons focus on downstream-focused disturbance signals.

---

4 Similarity measures are metrics that quantify the degree to which community composition differs between two samples, sites or occasions. The Bray-Curtis measure range from 0 (the taxa and relative abundance data share nothing in common) to 1 (the taxa and relative abundances of two samples are identical).

Between-sample similarity across many years: Kendall's rank-concordance measure

The Kendall's rank-concordance coefficient was calculated[5] in order to obtain a measure of simultaneous association (= similarity) across all yearly samples. This was done separately for each of the four site-groups.

The coefficient was calculated for the baseline-period dataset then the entire dataset that included both the baseline data and the current-condition (2001) data. Of central interest were any changes in the significance of the coefficient when the current-condition data was added. Attention to this change is essentially a focus on downstream-focused disturbance signals.

Ordination

Ordination analysis was used to obtain a visual depiction of compositional relationships between site-groups, as well as the nature of changes (extent and direction) over time. The specific ordination analysis used was multi-dimensional scaling (MDS; PRIMER software package used; Plymouth Marine Laboratory, Version 4). The inputed similarity matrix was the Bray-Curtis similarity matrix mentioned above (which was derived from 4^{th} root transformed density data). The MDS analysis was allowed 10 random starts and the two-dimensional ordination sample scores were used.

The baseline-period ordination space of each site-group was demarcated using the polygon approach described by Matthews (1998). Key year-to-year changes were indicated by identifying the location of the 1981 samples and marking the 1989-to-2001 trajectory. The trajectory indicates the shift from the last baseline-period sample to the current-condition sample.

To aid in the interpretation of the ordination axes, Spearman's rank correlation coefficients were calculated between the ordination sample scores and the numerical densities of each species.

2.2.2.3 Conventions and abbreviations

Conventions used to describe statistical significance are as follows (*p* is the probability that differences occurred by chance):

- marginally significant (0.10 >= p > 0.05),
- significant (0.05 >= p > 0.01),
- highly significant (0.01 >= p > 0.001),
- very highly significant (0.001 >= p).

Marginal significance was noted in an attempt to avoid false negative findings (i.e. Type II errors). This is a conservative approach that is frequently followed when investigating and managing high-value environmental features.

Within the text: SE = standard error, *t* = Student's *t* statistic, *p* = probability that differences occurred by chance, and *r* = Spearman's rank-correlation coefficient.

[5] Following Kendall (1962), the coefficient was calculated from the mean Spearman's rank coefficient for all possible year pairs. Following Stoodley et al (1980), statistical significance was determined from an approximation of the Chi-squared distribution.

3 Results

3.1 Location and description of censusing sites

The location of the censusing sites along Gulungul Creek are given in figure 1. The GPS coordinates of the sites are given below in table 1. Habitat characteristics of the sites are given in table 2.

Table 1 GPS coordinates of the Gulungul Creek censusing sites

Site name	UTM AGD66 coordinates	
	Northings	Eastings
Site 1*	8599832	0269441
Site 1.2a	8598878	0269762
Site 1.2b	8598512	0270140
Site 2	8597756	0270260
Site 3	8597014	0270010
Site 4	8594547	0270751
Site 5	8593285	0269858
Site 6	8590700	0270603
Site 7 (RS1)	8589236	0272297
Site 8 (RS2)	8589174	0272461
Site 9 (RS3)	8589057	0273180
Site 10 (RS4)**	8589052	0273240

* Site 1 is most downstream

** The coordinates of Site 10 (most-upstream site) were estimated as there was no satellite access within the steep-sided gorge

Table 2 Summary of the habitat character of the censusing sites during the Late-wet–Early-dry season

Site code	Length Surveyed (m)	Average width (m)	Middle depth (m)		Riparian vegetation percentage cover over water		Submerged undercut edges	Substrate	
			Max.	Typical range	Close (< 2m)	Far (> 2m)		Dom.	Sub-dom.
1	70	9.4	0.80	0.5-0.7	0.1-5.0	0.1-5.0	very rare & shallow	sand	Aquatic plants
1.21	56	5.5	0.83	0.2-0.4	0.1-5.0	0.1-5.0	not common & shallow	sand	Root material
1.22	56	8.5	1.60	0.15-0.25	0.1-5.0	5-25	not common & shallow	sand	root material
2	40	9.0	1.65	0.25-0.45	0.1-5.0	5-25	rare & shallow	sand	root material
3	48	10.0	0.32	0.15-0.20	0.1-5.0	0.0	virtually absent	sand	root material
4	100	9.0	0.78	0.1-0.3	0.1-5.0	0.1-5	not common & shallow	sand	root material
5	49	5.6	0.78	0.15-0.35	0.0	5-25	not common & shallow	sand	root material
6	56	4.0	0.86	0.2-0.5	0.1-5.0	50-95	not common & shallow	sand	root material
7 (RS1)	75	5.0	1.74	0.8-1.3	5-25	50-95	abundant & deep	root material	sand
8 (RS2)	40	4.8	1.53	0.3-0.9	0	75-100	abundant & deep	boulders	rock
9 (RS3)	31	5.7	2.70	1.3-2.3	0	0	common & shallow	boulders	rock
10 (RS4)	50	6.1	8.40	4.0-8.0	0	0	not common & shallow	bedrock	sand

3.2 Analysis of fish-community data

The entire 1979–2001 Late-wet–Early-dry season fish-community dataset comprised records on 86255 individual fish across twenty-two fish taxa. The taxa are listed in table 3 along with the overall numbers recorded. A total of 7482 individual fish were recorded across eighteen species in 2001.

Table 3 List of fish taxa recorded in Gulungul Creek during the Late-wet–Early-dry season from 1979 to 2001. Overall numbers recorded per taxa are also shown. Unidentified fry are not included

Common name	Scientific name	Overall numbers
Bony bream	*Nematalosa erebi*	30
Saratoga	*Scleropages jardinii*	64
Lesser salmon (fork-tailed) catfish	*Arius leptaspis*	4
Narrow-fronted eel-tailed catfish	*Neosilurus ater*	208
Hyrtl's eel-tailed catfish	*Neosilurus hyrtlii*	5880
Longtom	*Strongylura krefftii*	101
Black-banded rainbowfish	*Melanotaenia nigrans*	30493
Chequered rainbowfish	*Melanotaenia splendida inornata*	10357
Mariana's hardyhead	*Craterocephalus marianae*	11
Fly-specked hardyhead	*Craterocephalus stercusmuscarum*	1820
Blue-eyes	*Pseudomugil signifer + gertrudae*	2227
Ambassid perchlets	*Ambassis agrammus + macleayi*	25787
Pennyfish	*Denariusa bandata*	700
Banded grunter	*Amniataba percoides*	228
Sooty grunter	*Hephaestus fuliginosus*	577
Spangled grunter	*Leiopotherapon unicolor*	3447
Black-blotched anal-fin grunter	*Pingalla midgleyi*	1926
Sharp-nosed grunter	*Syncomistes butleri*	5
Mouth almighty	*Glossamia aprion*	74
Archerfish	*Toxotes chatareus*	47
Purple-spotted gudgeon	*Mogurnda mogurnda*	2099
Sleepy cod	*Oxyeleotris lineolata + selheimi*	5

3.2.1 Basic structural features

3.2.1.1 Number of fish (total density across all species)

The downstream and upstream site-groups

Both site-groups showed major fluctuations in the total density of fish during the baseline period (figure 2). Both groups showed a major peak in 1987.

The total density in the downstream site-group in 2001 (mean = 0.86 fish m^{-2}.) was marginally significantly less (t = -2.08, p = 0.075, data log10 transformed) than that in the baseline period (mean = 3.05, SE = 1.27). In contrast, the total density in the upstream site-group in 2001 (mean = 0.72 fish m^{-2}.) was very highly significantly less (t = -5.59, p = 0.001, data log10 transformed) than that in the baseline period (mean = 4.77, SE = 1.42).

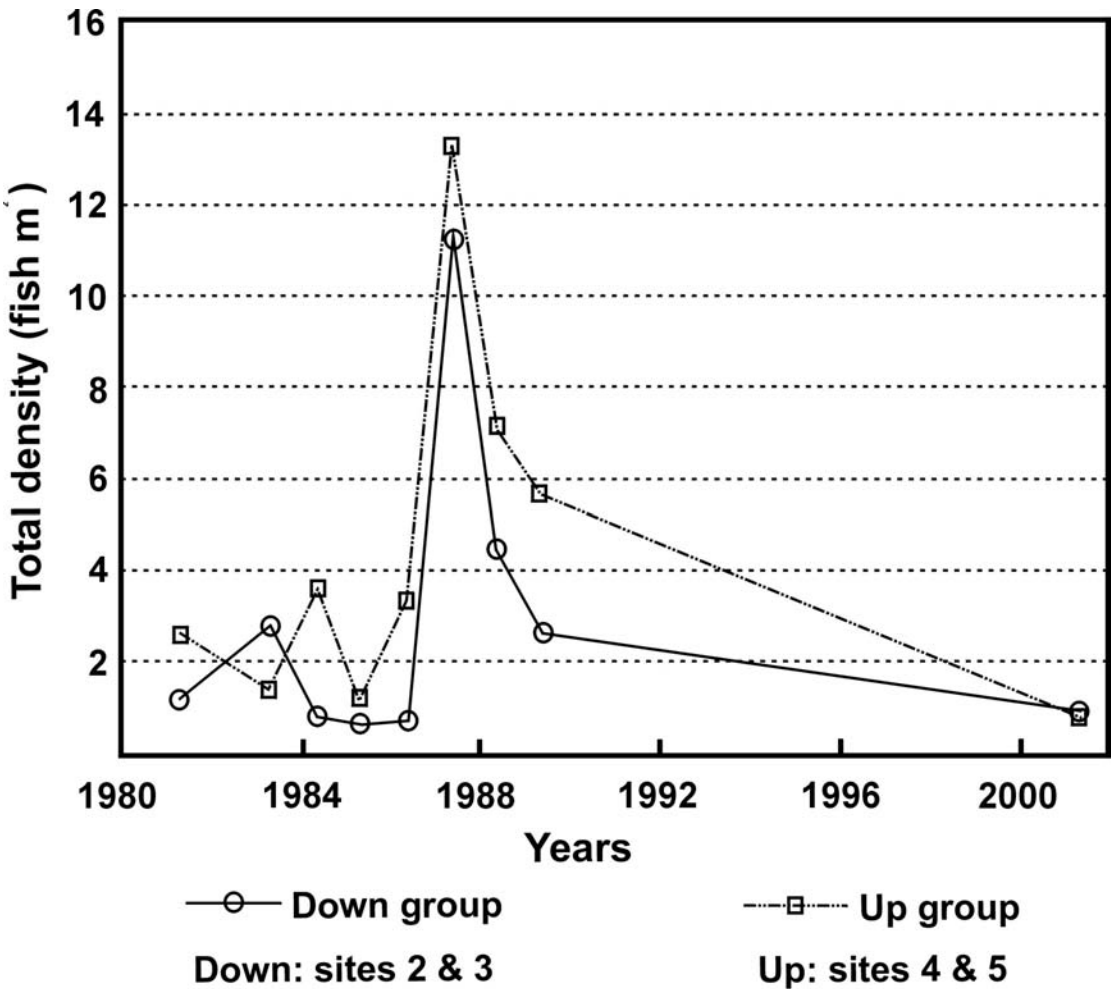

Figure 2 Changes over time in the total density of fish in Gulungul Ck: downstream and upstream site groups

Differences between the downstream and upstream site-groups

Within the baseline period the total density of fish was generally lower in the downstream site-group than the upstream group (figure 3; hence the difference is predominantly negative). The difference became positive in 2001 indicating that the total density had become relatively greater in the downstream site-group. The 2001 difference (+0.14 fish m^{-2}.) was significantly greater (t=2.42, p=0.046, data not transformed) than that in the baseline period (mean = -1.72, SE = 0.53).

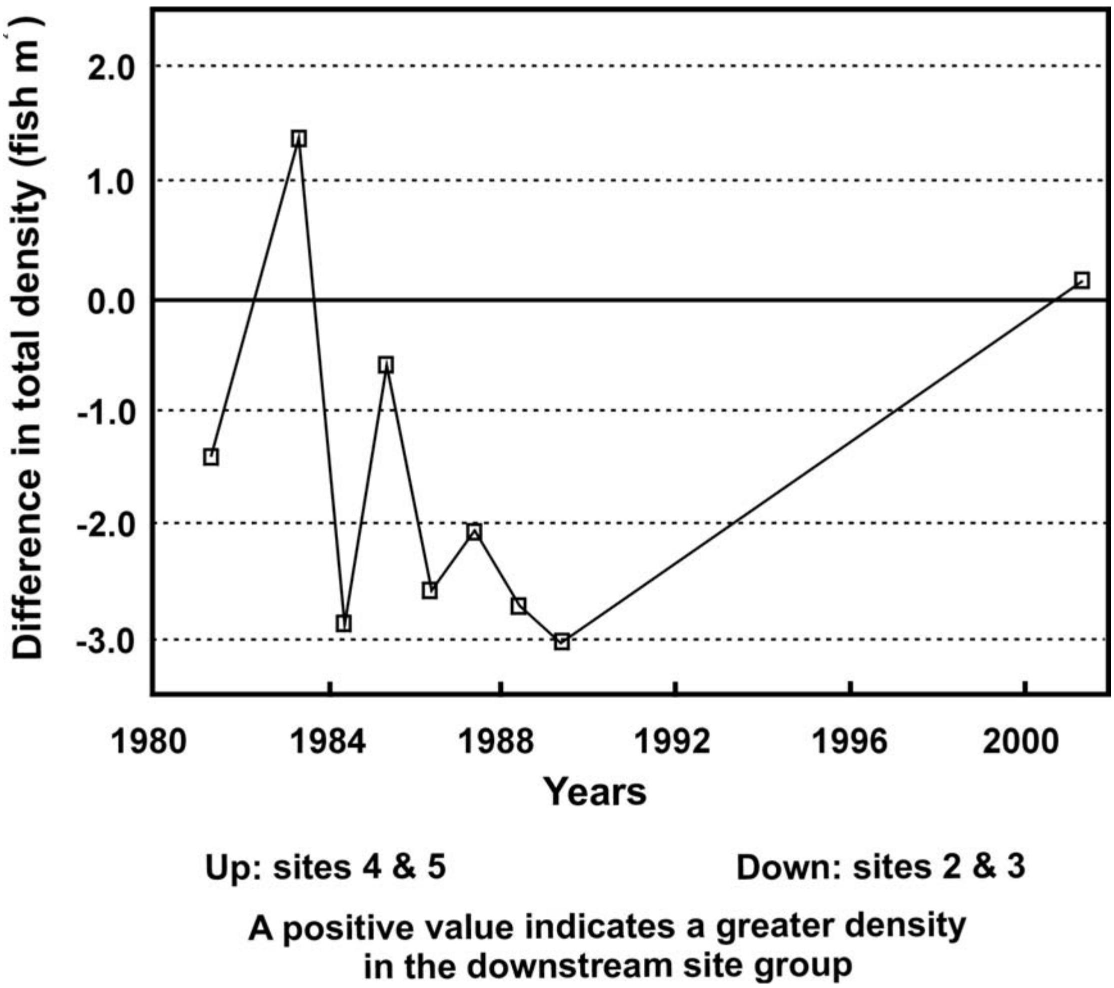

Figure 3 Total density of fish in Gulungul Ck: difference between the downstream and upstream groups

3.2.1.2 Time trends in the densities of each species

Downstream site-group

Two fish species showed decreases in their densities through time:

- archerfish, r = -0.73 (significant)
- spangled grunter , r = -0.68 (marginally significant)

One species showed an increase in its density through time:

- mouth almighty, r = +0.63 (marginally significant)

Upstream site-group

Two fish species showed decreases in their densities through time:

- archerfish, r = -0.73 (significant)
- spangled grunter , r = -0.63 (marginally significant)

No species showed increases through time.

3.2.1.3 Number of species

The downstream and upstream site-groups

Both site-groups showed moderate fluctuations in the number of fish species recorded during the baseline period (figure 4).

The number of fish species in the downstream site-group in 2001 (mean = 13.00 species) was significantly greater (t = 2.37, p = 0.049, data log10 transformed) than that in the baseline period (mean = 12.00, SE = 0.42). Similarly, the number of species in the upstream site-group in 2001 (mean = 15.00 species) was highly significantly greater (t = 4.20, p = 0.004, data log10 transformed) than that in the baseline period (mean = 13.13, SE = 1.25).

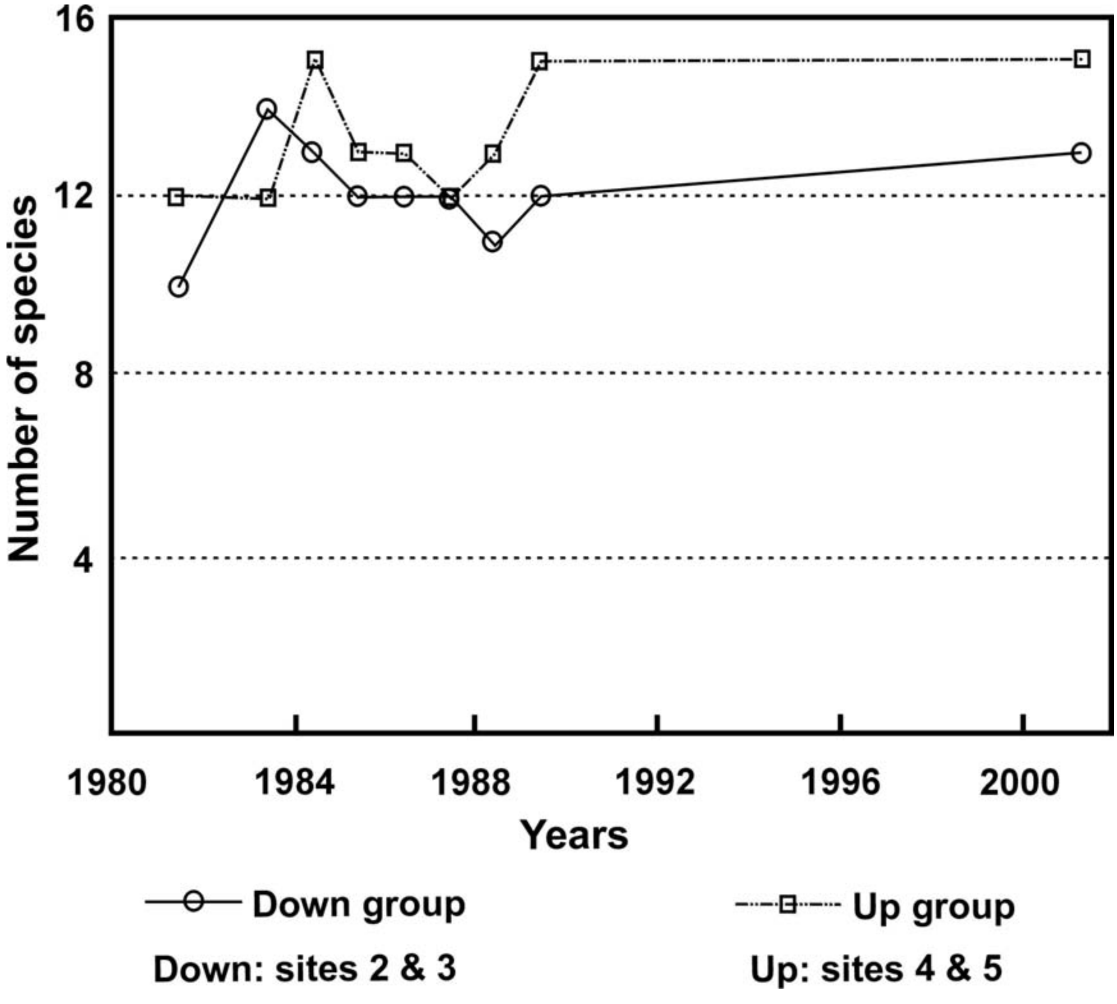

Figure 4 Changes over time in the number of fish species in Gulungul Ck: downstream and upstream site groups

Differences between the downstream and upstream site-groups

Within the baseline period the number of fish species was generally lower in the downstream site-group than the upstream group (figure 5; hence the difference is predominantly negative). The difference remained negative in 2001. The 2001 difference (-2.00 species) was not significantly different (t=-1.59, p=0.16, data not transformed) from that in the baseline period (mean = -1.13, SE = 0.55).

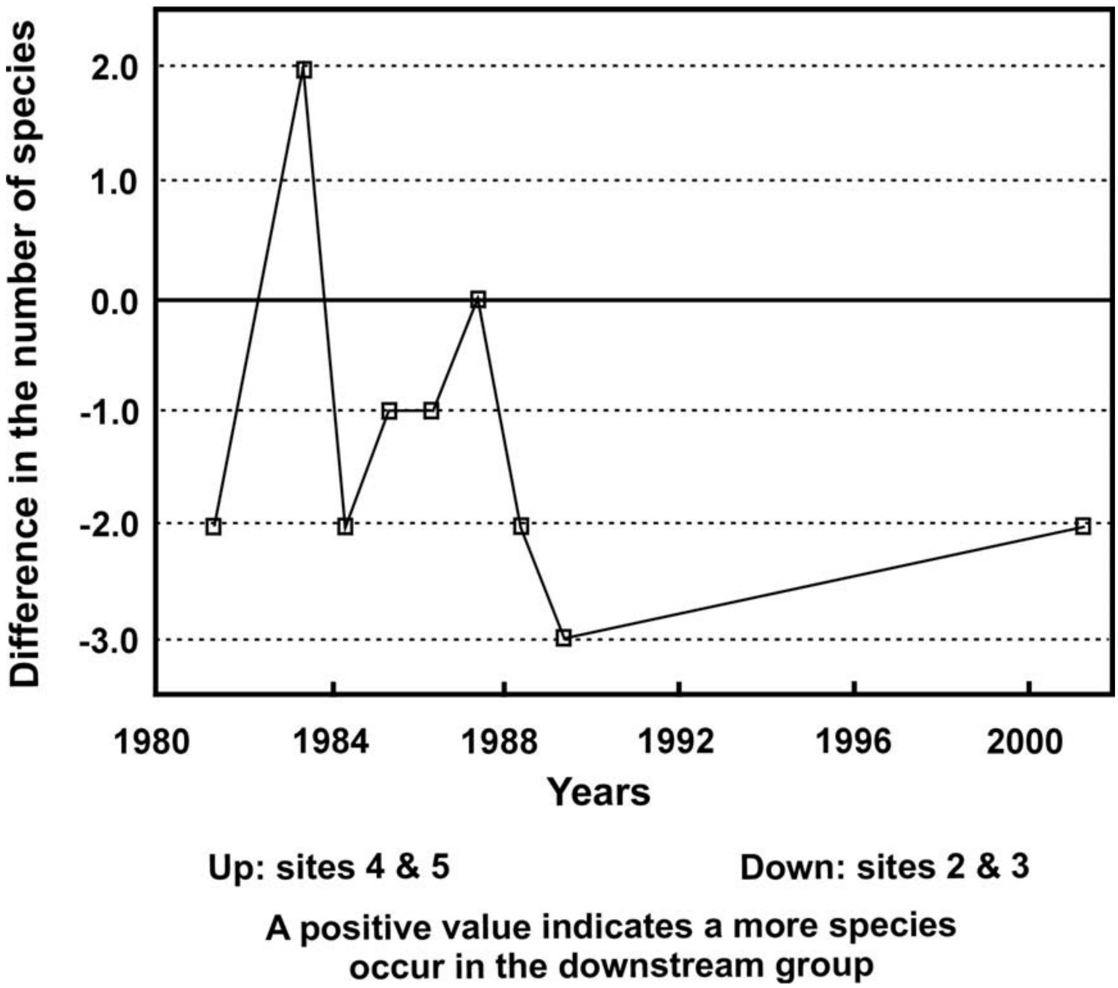

Figure 5 Number of fish species in Gulungul Ck: differences between the downstream and upstream site groups

3.2.2 Compositional structure

3.2.2.1 'Evenness' of densities across species

The downstream & upstream site-groups

Both site-groups showed major fluctuations in the Pielou's evenness index during the baseline period (figure 6).

The evenness index in the downstream site-group in 2001 (mean = 0.562) was not significantly from ($t = -0.82$, $p = 0.65$, data log10 transformed) that in the baseline period (mean = 0.595, SE = 0.057. Similarly, the index in the upstream site-group in 2001 (mean = 0.556) was not significantly different ($t = 0.053$, $p = 0.61$, data log10 transformed) than that in the baseline period (mean = 0.545, SE = 0.054).

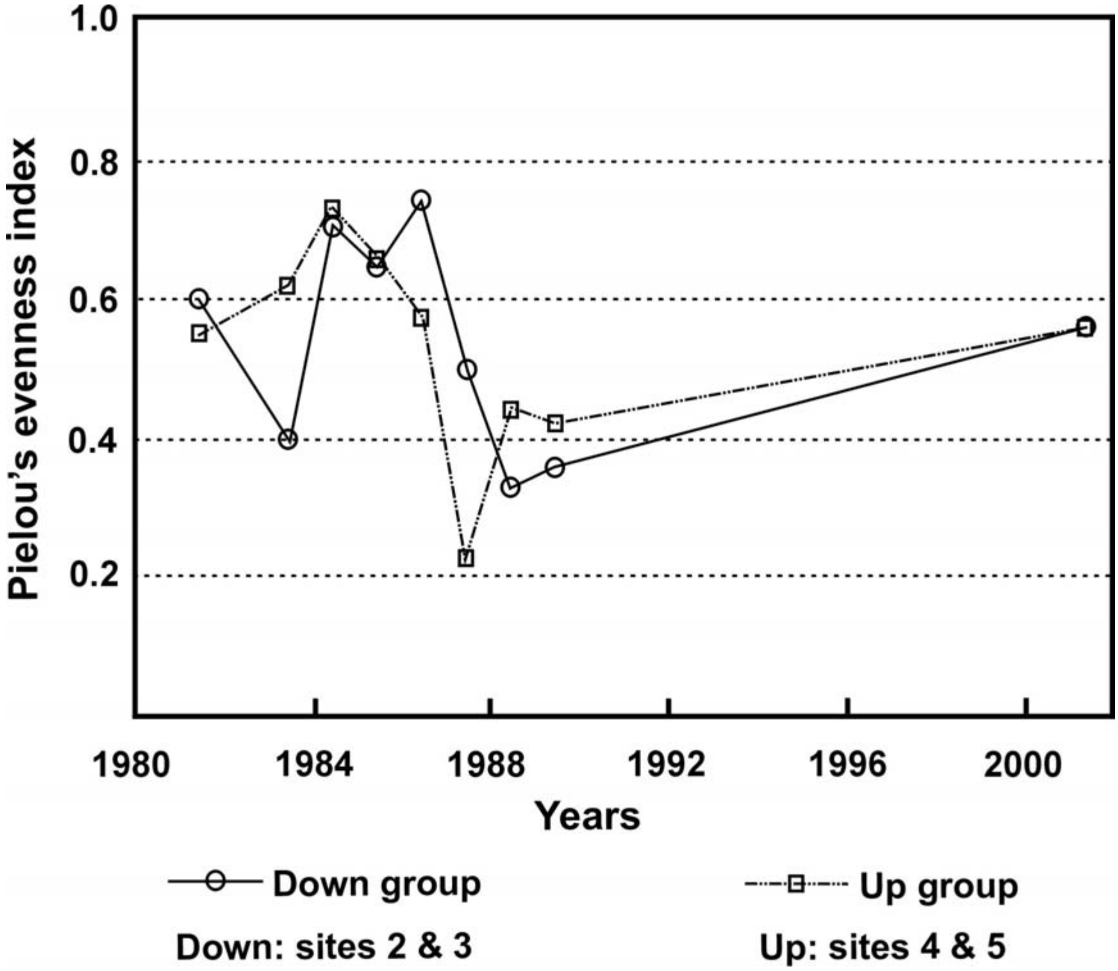

Figure 6 Time changes in the evenness of fish communities in Gulungul Ck: downstream and upstream groups

Within the baseline period the evenness index in the downstream site-group was at times less than or greater than that recorded in the upstream group (figure 7; hence the difference fluctuates between positive and negative values). The difference became (slightly) positive in 2001. The 2001 difference (+0.006) was not significantly different (t=-0.01, p=0.99, data not transformed) from that in the baseline period (mean = +0.006, SE = 0.056).

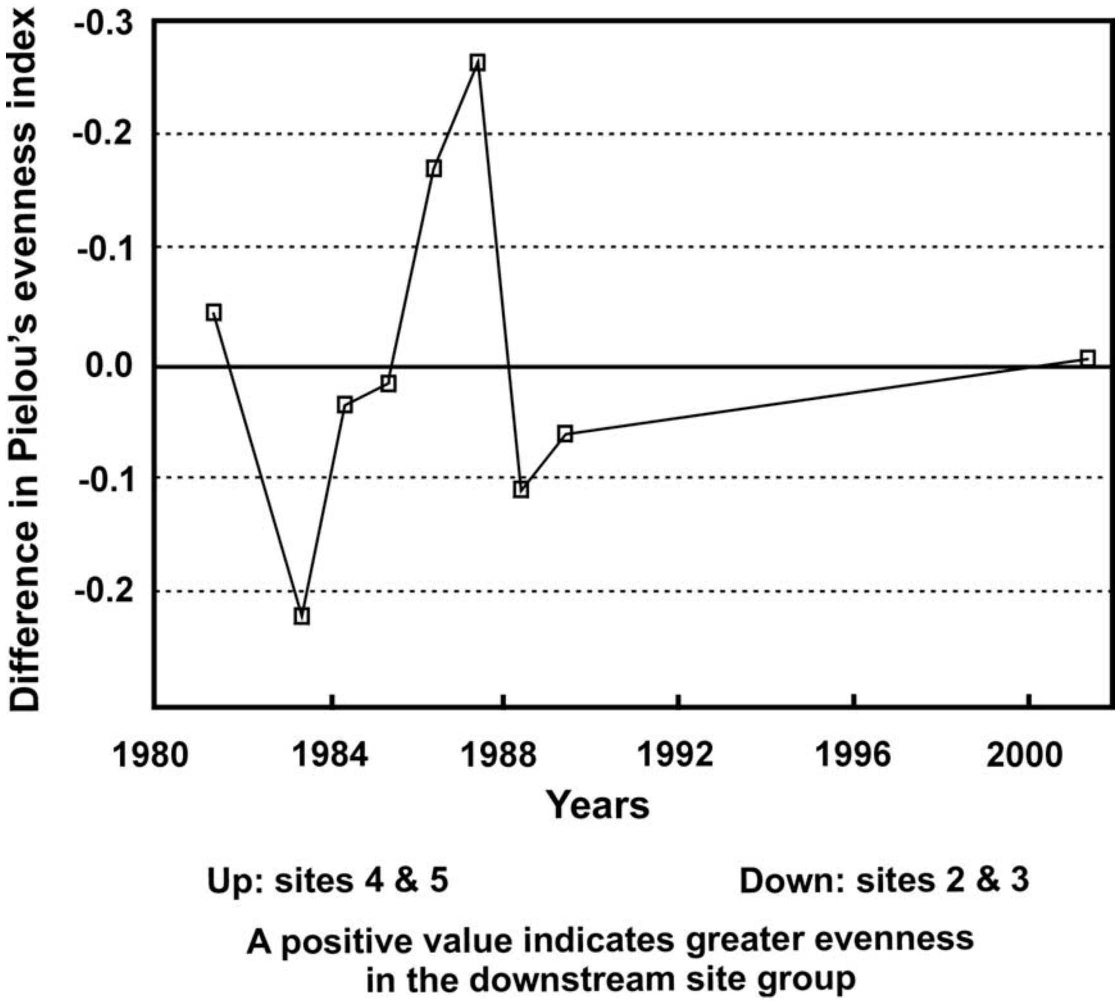

Figure 7 Evenness of fish communities in Gulungul Ck: differences between the downstream and upstream site groups

3.2.2.2 Between-sample similarity: Bray-Curtis measure

Similarity between consecutive samples

Consecutive similarities for both site-groups fluctuated only moderately during the baseline period and into 2001 (figure 8). A moderate level of variation through time is indicated.

Similarity between the downstream and upstream site-groups

Except for the 1981 sample, between-site-group similarities fluctuated only moderately during the baseline period and into 2001 (figure 9). The similarity in 2001 (76.99) was not significantly different (t =0.45, p=0.66, data not transformed) from that in the baseline period (mean = 78.24, SE = 2.76).

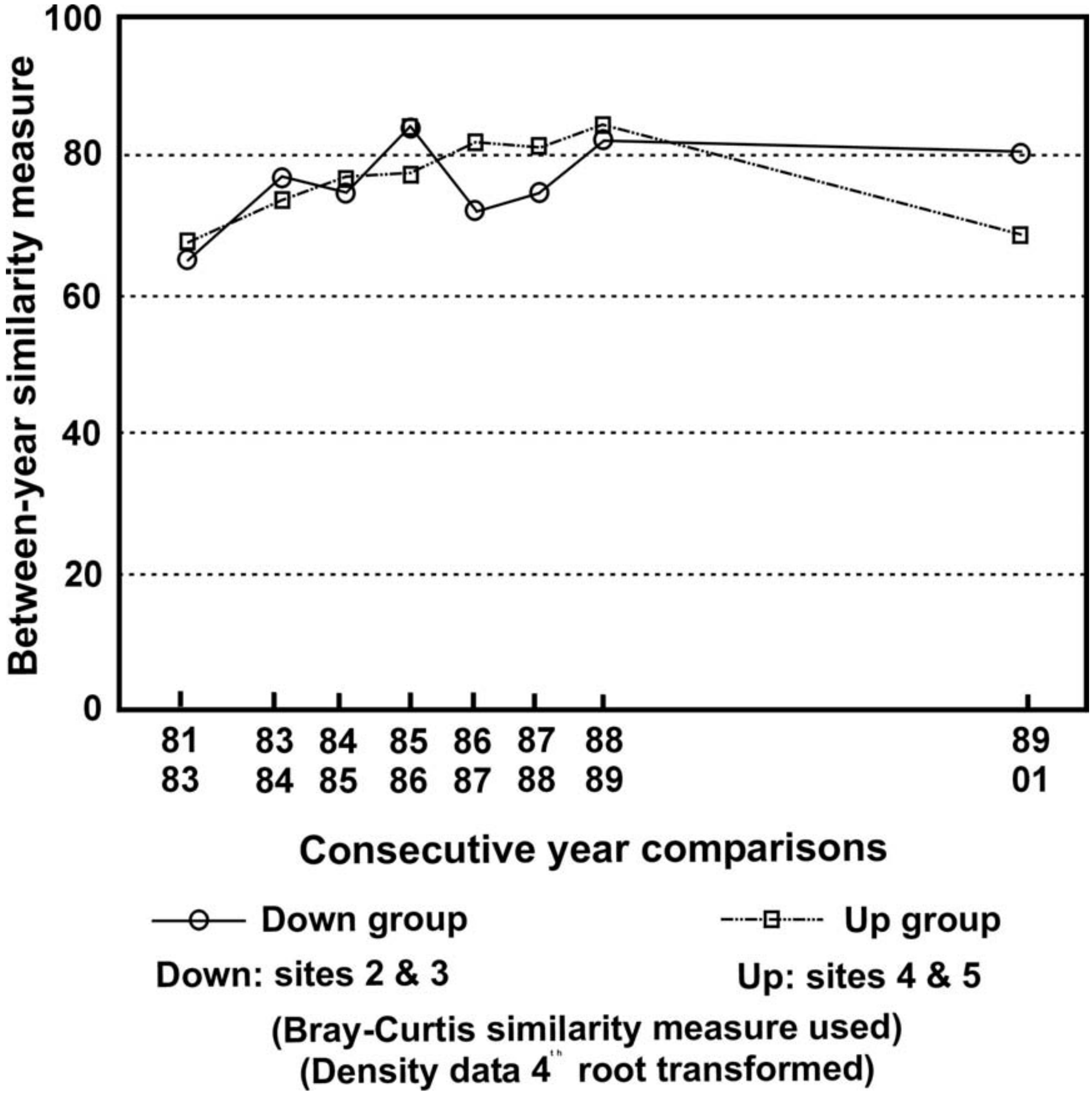

Figure 8 Similarity in fish community composition in Gulungul Ck: between consecutive years (up & down site groups)

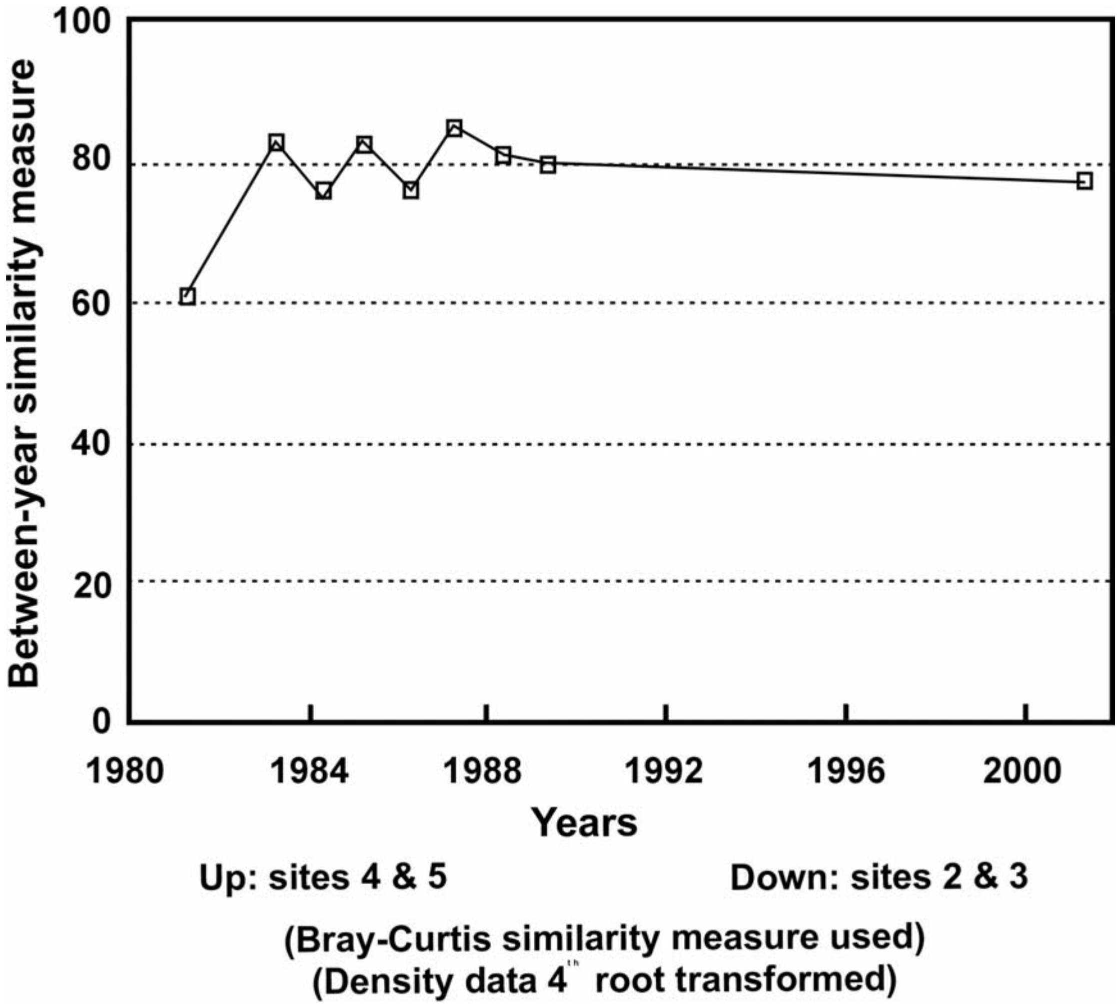

Figure 9 Similarity in fish community composition in Gulungul Ck: between the downstream and upstream site groups

Similarities between all pairs

Summary statistics of similarities arising from all within-baseline pairs, and within-baseline-plus-2001 pairs, are given for all site-groups in table 4. No significant differences were detected between the mean similarity values of these two sets of pairs for any of the four site-groups (table 5). Accordingly, the addition of the 2001 data to the baseline data did not significantly change the mean similarity value.

3.2.2.3 Between-sample similarity: Spearman's rank correlation coefficients

Summary statistics of correlations arising from all within-baseline pairs, and within-baseline-plus-2001 pairs, are given for all site-groups in table 4. No significant differences were detected between the mean correlation values of these two sets of pairs for any of the four site-groups (table 5). Accordingly, as for the Bray-Curtis similarity measure, the addition of the 2001 data to the baseline data did not significantly change the mean correlation value.

Table 4 Summary statistics of between-sample similarity measures: within-baseline pairs and 2001-vs-baseline pairs. The density data were 4th root transformed prior to analysis

Site group	No. of species	Span (years)	Similarity measure	Within-baseline pairs (BvB)			2001-vs-baseline pairs (2001vB)		
				Mean	Standard error	No. of pairs	Mean	Standard error	No. of pairs
A (Down)	17	81-01	Bray-Curtis	72.44	7.74	28	77.36	2.50	8
			Spearman's	0.724	0.027	28	0.811	0.052	8
B (Up)	21	81-01	Bray-Curtis	72.44	7.74	28	77.36	2.50	8
			Spearman's	0.753	0.037	28	0.744	0.041	8
C	19	81-01	Bray-Curtis	74.26	1.70	28	71.49	2.50	8
			Spearman's	0.700	0.027	28	0.668	0.043	8
D	11	79-01	Bray-Curtis	75.84	1.50	36	76.90	1.70	9
			Spearman's	0.826	0.018	36	0.795	0.014	9

Table 5 Comparison of between-sample similarity measures: within-baseline pairs (BvB) versus 2001-vs-baseline pairs (2001vB). The density data were 4th root transformed before analysis

Site-group	Similarity measure	BvB versus 2001vB comparison of means		
		Student's 't' value	Significance	Transformation
A (down)	Bray-Curtis	1.63	None (p>0.10)	Arcsine
(Sites 2&3)	Spearman's	1.47	None (p>0.10)	None
B (up)	Bray-Curtis	-0.91	None (p>0.10)	Arcsine
(Sites 4&5)	Spearman's	-0.16	None (p>0.10)	None
C	Bray-Curtis	-0.36	None (p>0.10)	Arcsine
(Sites 6&7)	Spearman's	-0.62	None (p>0.10)	None
D	Bray-Curtis	-0.45	None (p>0.10)	Arcsine
(Sites 8&9)	Spearman's	-1.32	None (p>0.10)	None

3.2.2.4 Between-sample similarity across many years: Kendall's rank concordance measure

All site-groups displayed very highly significant concordance across years within the baseline period, as well as in the baseline plus 2001 period (table 6**)**. Accordingly, the addition of the 2001 data to the baseline data did not significantly change the concordance values.

Table 6 Between-sample concordance across many years: within-baseline vs. within-baseline+2001

Site-group	No. of species	Only within baseline (79–89)			Within baseline + 2001		
		No. of years	Kendall's W	Significance	No. of years	Kendall's W	Significance
A (down) (Sites 2&3)	17	8	0.760	p<0.001*	9	0.772	p<0.001*
B (up) (Sites 4&5)	21	8	0.784	p<0.001*	9	0.779	p<0.001*
C (Sites 6&7)	19	8	0.739	p<0.001*	9	0.727	p<0.001*
D (Sites 8&9)	11	9	0.796	p<0.001*	10	0.845	p<0.001*

* p = probability that the concordance occurred by chance alone

3.2.2.5 Ordination

Distribution of samples in respect to axes 1 & 2

Following the rule-of-thumb guide of Clarke and Warwick (1994), a potentially useful picture of sample relationships is available with the two-dimensional ordination plot (figure 10) given a stress value of 0.12.

Site-groups were sequentially separated along axis one indicating that this axis reflects longitudinal changes along Gulungul Creek (see the marked baseline-period polygons in figure 10). The clearest site-group separation was between Groups B (upstream) and C (pre-gorge upstream). The least-clear separation was between Groups A (downstream) and B (upstream).

There was negligible site-group separation along axis two indicating a factor that is independent of differences in the character of the site-groups. A factor dependent on time may be involved given that i] the 1981 sample is at the base of the upstream site-group (B, C and D) polygons, ii) the 2001 sample is at the top of the polygons for Site-groups B and C, and iii] the 2001 sample is near top of the polygons for Site-groups A and D. However, the likelihood of this possibility is reduced when it is recognised that the 1981 sample is at the top of the polygon for the downstream Site-group (A).

The 1989-to-2001 time trajectories were within the baseline polygons for Site-groups A and D. However, for Site-groups B and C, the trajectories emerged from the baseline polygons upwardly along axis two and to the right along axis one. The trajectory for the downstream Site-group (A) also had an upward and right direction. In contrast, the trajectory for Site-group D (within-gorge upstream) exclusively had a to-the-left direction along axis one.

Species correlated with axis 1

Five species, which are typically more abundant in the escarpment upper reaches of the creek, were significantly positively correlated with axis one:

- saratoga, r = +0.85 (very highly significant)
- sooty grunter, r = +0.78 (very highly significant)
- black-blotched anal fin grunter, r = +0.74 (very highly significant)
- spangled grunter, r = +0.44 (highly significant)

- narrow-fronted eel-tailed catfish, r = +0.40 (significant)

Seven species, many of which are typically more abundant in the lowland lower reaches of the creek, were significantly negatively correlated with axis one:

- ambassid perchlets, r = -0.89 (very highly significant)
- purple spotted gudgeon, r = -0.81 (very highly significant)
- fly-specked hardyhead, r = -0.81 (very highly significant)
- pennyfish, r = -0.78 (very highly significant)
- chequered rainbow-fish, r = -0.72 (very highly significant)
- blue-eyes, r = -0.69 (very highly significant)
- mouth almighty, r = -0.45 (highly significant)

Species correlated with axis 2

No species were significantly positively correlated with axis two. Nine species were significantly negatively correlated with axis two:

- Hyrtl's eel-tailed catfish, r = -0.70 (very highly significant)
- chequered rainbow-fish, r = -0.60 (very highly significant)
- banded grunter , r = -0.52 (highly significant)
- spangled grunter, r = -0.42 (highly significant)
- archer fish, r = -0.40 (significant)
- mouth almighty, r = -0.32 (marginally significant)
- Mariana's hardyhead, r = -0.29 (marginally significant)
- longtom, r = -0.29 (marginally significant)
- bony bream, r = -0.28 (marginally significant)

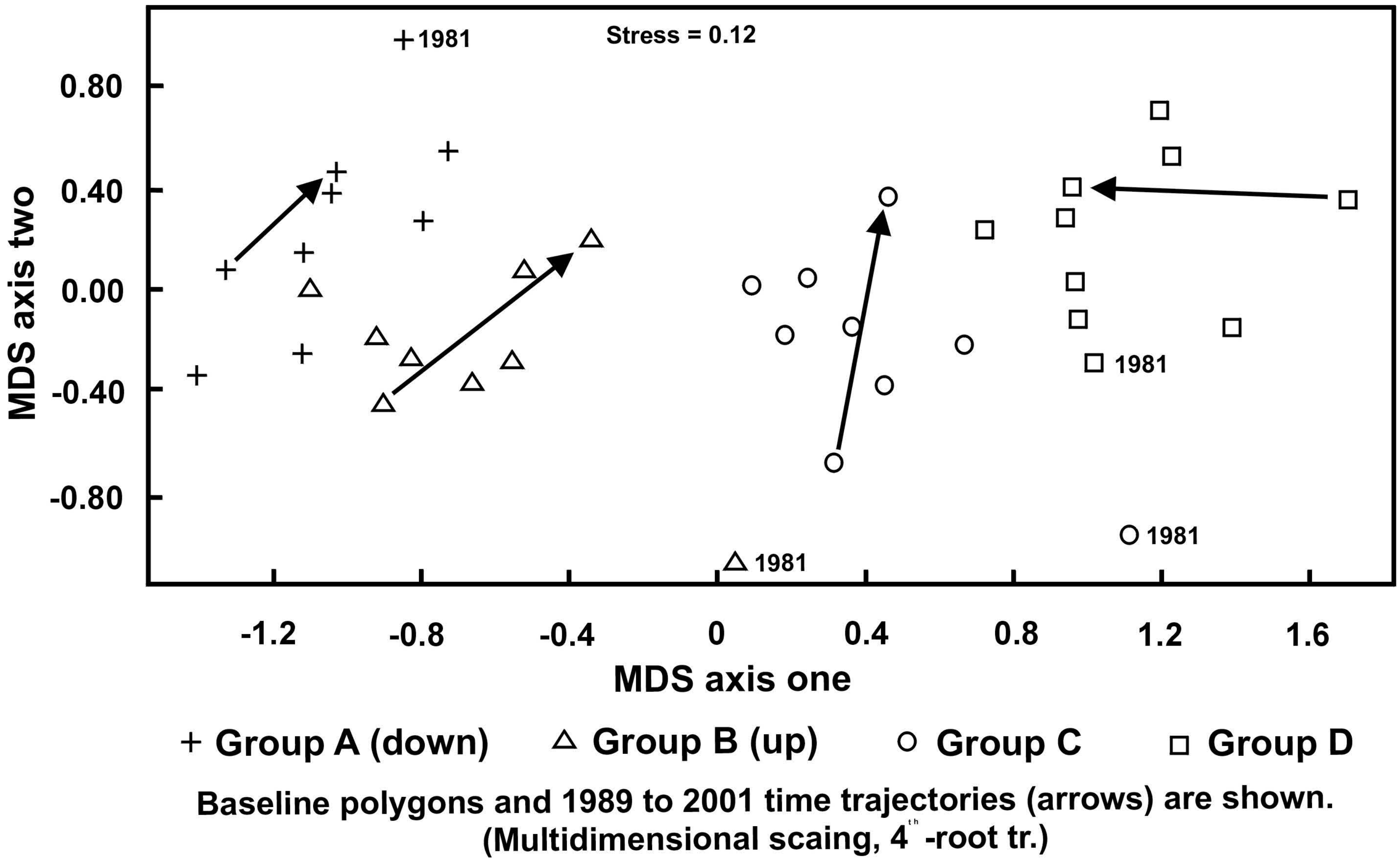

Figure 10 Ordination analysis of fish community composition in Gulungul Ck: site-group and year-to-year changes

4 Discussion

4.1 Scenario 1: mine-disturbance signals (as arising from seepage from the western side of the tailings dam)

The central focus of the present investigation was the detection of any disturbances on the fish communities of Gulungul Creek arising from the Ranger Mine. While the original study was not specifically designed to rigorously detect such disturbances[6], it is well placed to detect Scenario-1 mine-disturbance signals because:

- fish-community censusing has been undertaken over two decades, spanning an extensive baseline period (i.e. 1979–89, pre-seepage phase), and a brief contemporary period (i.e. 2001, seepage-commencement phase)
- the censusing has been undertaken at a landscape scale spanning creek sections directly exposed to, and not directly exposed to, seepage arising from Ranger's tailings dam.

Any direct disturbances attributable to the seepage would be focused on the downstream Site-group A. Accordingly, it is expected that the downstream site-group would be the first to display a mine-disturbance signal such as, for example, a reduction in the number of species in comparison to the upstream site-groups (B, C and D). However, it is recognised that disturbances may occur in the upstream site-groups via indirect mechanisms such as, for example, the inhibition of recruitment processes which have primary recruitment sources in downstream areas[7]. Nevertheless, it is expected that this 'blurring' of the disturbance signal would be considerably weakened by the existence of strong recruitment processes which have primary recruitment sources in the creek's upper reaches. Bishop and Harland (1982) identified a range of fish species in Gulungul Creek that are likely to be influenced by such processes.

Data analyses most attuned to the detection of a Scenario-1 mine-disturbance signal were those which focused on fish-community-structure differences between the downstream and upstream site-groups (i.e. A and B, respectively). These analyses, which examined four structural measures, revealed <u>no evidence</u> of an disturbance signal at the downstream site-group (table 7) .

For both Site-groups A and B, ordination analysis showed evidence of shifts in fish community composition between the last baseline sample (1989) and the current-current-condition sample (2001). This was evident in both ordination axes (1 and 2). The extent of these shifts was much greater for Site-group B, and accordingly, compositional differences between Site-groups A and B increased between 1989 and 2001. This could be viewed as <u>potential evidence</u> of a mine-disturbance signal. However, this appears to be quite unlikely as:

i) greatest compositional shifts occurred within Site-group B, the site-group not potentially exposed to direct tailings dam seepage disturbances, and

ii) the composition of Site-group A, the site-group potentially exposed to direct tailings dam disturbances, remained well within the demarcated baseline polygons.

---

6 For example, it did not include multiple out-of-catchment reference sites.

7 This lack of independence between the upstream and downstream site-groups, which potentially confounds strategic comparisons between the site-groups, is a common problem in disturbance-assessment studies. It is an example of a wider set of problems generically termed by Hulbert (1984) as *pseudoreplication*.

Table 7 Summary of findings of data analyses focusing on differences between the downstream & upstream site-groups

Type of fish community structure feature	Feature examined	Expected disturbance signal at the downstream site- group (A) compared with the upstream site-group (B)	What was detected moving from the baseline period to 2001?
Basic structure	Total density	A reduces compared with B	A increased compared with B; the change in differences was statistically significant
Basic structure	Number of species	A reduces compared with B	No change; no statistically significant change in differences between A & B
Compositional structure	Evenness index	A reduces compared with B	No change; no statistically significant change in differences between A & B
Compositional structure	Compositional similarity A & B: Bray-Curtis measure	Similarity between A & B reduces	No change; no statistically significant change in similarity between A & B

4.2 Downstream-focused, non-specific disturbance signals

As mentioned in Section 1, it is impossible to isolate-out the specific origin of any such detected signal because it would potentially be a mixture of responses to either natural processes (eg. due to year-to-year hydrological differences), Scenario-2 mine disturbances, or a range of other anthropogenic disturbances. This is particularly the case in the current first-pass analyses which, without taking into account environmental correlates (or covariates), focus in isolation on either baseline versus current-condition differences, or time trends in parameters. At least, however, the confounding influence of downstream effects of Scenario-1 mine-disturbance signals can be discounted given the apparent negative result above (Section 4.1).

4.2.1 Basic structural features

In respect to the basic structural features examined, the most compelling evidence of an disturbance signal were statistically significant negative time trends in the abundance of archerfish and spangled grunters (i.e. the abundance of these species had reduced through time). The trends were detected in both the downstream and the upstream site-groups (A and B respectively). The trends for the archerfish were consistently the strongest. Bishop and Harland (1982) identified archerfish as having upstream-returning movements in Gulungul Creek. Accordingly, the abundance of this species in the creek is likely to be controlled by a recruitment process that has primary recruitment sources in downstream areas. It follows then that the cause of the decline of this species may been taking effect somewhere downstream of the censused portion of the creek, either locally (eg. within Baralil Creek or downstream to Gulungul Billabong; see figure 1), or more remotely (eg. along Magela Creek.

Potential evidence of an disturbance signal also arose in relation to the total density of fish and the number of species present. At both the downstream and upstream site-groups, total densities had decreased, while the number of species had increased.

4.2.2 Compositional structure

Further analyses focused on differences in overall compositional similarity between datasets containing only baseline data, and those only focused on similarities between the baseline and the 2001 data. These analyses, which examined two types of similarity measure, revealed no evidence of an disturbance signal at the downstream site-group, as well as the three upstream site-groups (table 8).

Table 8 Summary of findings of data analyses focusing on compositional-similarity differences between datasets containing only baseline data, & those only focused on similarities between the baseline and the 2001 data

Type of fish community structure feature	**Feature examined**	**Expected disturbance signal (overall similarity of dataset BvB compared with dataset 2001vB)**	**What was detected in the comparison?**
Compositional structure	Compositional similarity of all pairs: Bray-Curtis measure	BvB greater than 2001vB*	No change; no statistically significant difference in overall similarity for all four site-groups
Compositional structure	Compositional similarity of all pairs: Spearman's correlation coeff.	BvB greater than 2001vB*	No change; no statistically significant difference in overall similarity for all four site-groups

* *BvB* = baseline dataset, *2001vB* = baseline-vs-2001 dataset

Another compositional analysis examined the overall year-to-year similarity of two types of datasets: one containing only baseline data (B), and the other containing baseline data plus the 2001 data (B+2001). Evidence of an disturbance signal was taken to be a reduction of the overall similarity (as measured by Kendall's rank concordance measure), whereby the similarity of the B+2001 dataset would be less than that for the baseline dataset. For each of the four site-groups examined, the similarity measure remained high, and very highly statistically significant. Accordingly, there was again no evidence of an disturbance signal. It is notable that the same similarity measure was used by Humphrey et al (1990) when they reported exceptionally high compositional stability (by world standards) of 1979-to-1988 Mid-wet-season fish communities at Site 8 (RS2; see figure 1), the site that is included in Site-group D in the present study. Comparable levels of similarity were recorded in the present investigation in all site-groups indicating that the earlier-reported high level of compositional stability apparently 'extends' to the Late-wet–Early-dry season, across an additional decade, and across the landscape down into the lowlands past the Ranger Uranium Mine.

Additional evidence of an disturbance signal arose from the ordination analysis that showed that the composition of fish communities in 2001 had shifted beyond the defined baseline 'bounds' within the upstream and pre-gorge-upstream site-groups (i.e. B and C respectively). Considerable vertical movement up the second ordination axis was involved. An understanding of the basis of these changes will be developed in ensuing data analyses, particularly the examination of hydrologic, habitat and physiographic correlates, which will be reported in the more-exhaustive Phase 2 report.

4.3 Focus of the next report (Phase 2)

The abovementioned examination of environmental correlates to be included in the next report facilitates the interpretation of changes detected in the structure of the fish communities. Using modelling methods to account for natural variation, these environmental variables will also be used to increase the ability of analyses to detect any mine-disturbance signals or other changes. Changes to the sensitivity of analyses will also be investigated by:

- using a range of data transformations that progressively shifts the analytical focus from abundant species to rare species.
- using strategic ecological features of the fish species to develop more diagnostic measures of structural changes in the fish communities (eg. developing a compositional index which reflects the proportion of fish species which are likely to be recruited from downstream areas)

Related fish studies will be identified which may assist in identifying the cause or the reality of detected changes. For example, a number of studies may be useful in probing the origin of the decline in abundance of archerfish in Gulungul Creek: the 1978–88 gillnet surveying of backflow billabongs, the 1994-to-present pop-net surveying of backflow billabongs, the 1989-to-present surveying of Mudginberri Billabong, and the 1983–1998 censusing of fish movements in Magela Creek.

5 References

Bardach JE 1959. The summer standing crop of fish in a shallow Bermuda reef. *Limnology and Oceanology* 4, 77–85.

Bishop KA, Allen SA, Pollard DA & Cook MG 1986. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume I: Outline of the study, summary, conclusions and recommendations.* Research Report 4 (i), Supervising Scientist for the Alligator Rivers Region, Australian Government Publishing Service, Canberra.

Bishop KA, Allen SA, Pollard DA & Cook MG 1990. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume II: Synecology.* Research Report 4(ii), Supervising Scientist for the Alligator Rivers Region, Australian Government Publishing Service, Canberra.

Bishop KA & Forbes MA 1991. The freshwater fishes of northern Australia. In: *Monsoonal Australia: landscape, ecology and man in the northern lowlands*, eds CD Haynes, MG Ridpath & MAJ. Williams, A.A. Balkema, Rotterdam, Netherlands, 79–108.

Bishop KA & Harland WG 1982. Further ecological studies (I) on the freshwater fishes of the Alligator Rivers Region 1982. Open file record 34, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Bray JR & Curtis JT 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr*. 27, 325–349.

Brock V 1954. A preliminary report on a method for estimating reef fish populations. *Journal of Wildlife Management* 18, 297–304.

Clarke KR & Warwick RM 1994. *Change in marine communities: An approach to statistical analysis and interpretation.* Plymouth Marine Laboratory, U.K.

Dibble ED 1991. A comparison of diving and rotenone methods for determining relative abundance of fish. *Trans. Amer. Fish. Soc*. 120**,** 663–666.

Goldstein RM 1978. Quantitative comparison of seining and underwater observation for stream fish surveys. *The Progressive Fish Culturist* 40, 108–111.

Griffith JS 1981. Estimation of the age frequency distribution of stream dwelling trout by underwater observation. *The Progressive Fish Culturist* 43, 51–53.

Griffith JS, Schill DJ, & Gresswell RE 1984. Underwater observation as a technique for assessing fish abundance in large western rivers. *Proceedings of the 63rd Conference, Western Association of Fish and Wildlife Agencies* 143–149

Hall DJ & Werner EE 1977. Seasonal distribution and abundance of fishes in the littoral zone of Michigan Lake. *Trans. Amer. Fish. Soc*. 106, 545–555.

Hankin DG & Reeves GH 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. *Can. J. Fish. Aquat. Sci.*45, 834–844.

Heggenes J, Brabrand A & Saltveit SJ 1991. Microhabitat use by brown trout, *Salmo trutta* L., and Atlantic salmon, *S. salar* L., in a stream: a comparative study of underwater and river bank observations. *J. Fish. Biol*. 38, 259–266.

Hicks BJ & Watson NRN. 1985. Seasonal changes in abundance of brown trout (*Salmo trutta*) and rainbow trout (*S. gairdnerii*) assessed by drift diving in the Rangitikei River, New Zealand. *N.Z. Jour. Marine & Freshwat. Res*. 19, 1–10.

Hori M, Gashagaza MM, Nshombo M & Kawanabe H. 1993. Littoral fish communities in Lake Tanganyika: irreplaceable diversity supported by intricate interactions among species. *Conservation Biology* 7, 657–665.

Hulbert SH 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54, 187–211.

Humphrey CL, Bishop KA & Brown VM 1990. Use of biological monitoring in the assessment of effects of mining wastes on aquatic ecosystems of the Alligator Rivers Region, tropical northern Australia. *Environmental Monitoring and Assessment* 14, 139–181.

Keast A & Harker J 1977. Strip counts as a means of determining densities and habitat utilisation patterns in lake fishes. *Environ. Biol. of Fishes* 1, 181–188.

Kendall MG 1962. *Rank correlation methods.* Charles Griffin & Company Limited, London.

Lincoln-Smith MP 1989. Improving multispecies rocky reef censuses by counting different groups of species using different procedures. *Environ. Biol. of Fishes* 26, 29–37.

Matthews WJ 1998. *Patterns in freshwater fish ecology.* Chapman and Hall, New York.

Matthews WJ, Harvey BC Power ME 1994. Spatial and temporal patterns in the fish assemblages of individual pools in midwestern (USA). *Environ. Biol. of Fishes* 39, 381–397.

Northern Territory Department of Mines and Energy 1993. Northern Territory Supervising Authorities – Alligator Rivers Region: *Environmental surveillance monitoring in the Alligator Rivers Region. Report for the six-month period to 31 March 1993*. Report Number 25.

Northern Territory Department of Mines and Energy 2000. Northern Territory Supervising Authorities – Alligator Rivers Region: *Environmental surveillance monitoring in the Alligator Rivers Region. Report for the six-month period to 30 September 2000.* Report Number 40.

Pielou EC 1975. *Ecological diversity.* Wiley, New York.

Pollard HA & Bjornn TC 1973. The effects of angling and hatchery trout on the abundance of juvenile stealhead trout. *Trans. Amer. Fish. Soc*. 102**,** 745–751.

Power ME 1984. Habitat quality and the distribution of algae-grazing catfish in a Panamanian stream. *J. of Animal Ecology* 53, 357–374.

Reed RJ 1967. Observation of fishes associated with spawning salmon. *Trans. Amer. Fish. Soc*. 96, 62–67.

Schill DJ & Griffith JS 1984. Use of underwater observations to estimate cutthroat trout abundance in the Yellowstone River. *Nth. Am. J. Fish. Man*. 4, 479–487.

Stoodley KDC, Lewis T & Stainton CLS 1980. *Applied statistical techniques.* Ellis Horwood Limited, Chichester, U.K.

Teirney LD & Jowett IG 1990. *Trout abundance in New Zealand Rivers: an assessment by drift diving.* New Zealand Freshwater Fisheries Report No. 118, August 1990.

Thresher RE & Gunn JS 1986. Comparative analysis of visual census techniques for highly mobile, reef-associated piscivores (Carangidae). *Environ. Biol. of Fishes* 17, 93–116.

Werner EE, Hall DJ & Werner MD 1978. Littoral zone fish communities of two Florida Lakes and a comparison with Michigan Lakes. *Environ. Biol. of Fishes* 3, 163–172.