internal report 406

Fish communities of Gulungul Creek – A landscape analysis

Phase 2: 'Second-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 2: 'Second-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 'second-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

June 2002

Study undertaken for the Environmental Research Institute of the Supervising Scientist

Contents

Figures

Tables

Summary

This report follows closely on from the Phase 1 ‘First-pass’ report of October 2001 (Internal Report 405 – Bishop & Walden 2003). That report investigated changes in fish communities in Gulungul Creek between a baseline period (1978–1990) and a current-condition sample taken in April/May 2001. Of particular interest in that report were 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).

To facilitate an interpretation of detected changes, the present investigation further explored baseline-to-current-condition shifts in community structure, and associated variability, through an examination of a diverse array of environmental correlates. The key elements of the investigation were:

- an assessment of what habitat changes have occurred in the censusing sites since 1989
- an assessment of how the hydrology of the 2000–01 Wet season varied from the baseline Wets
- an examination of a diverse array of hydrological and habitat correlates in order to:
  - develop an understanding of background flow- and habitat-driven processes, and
  - detect the presence of alternate post-1989 disturbances now operating in the creek (evidence of a break
  - down in baseline environmental associations was the basis of the detection)

<u>Habitat change.</u> Between 1989 and 2001 a number of within-site habitat changes had occurred. It was considered that only two of the changed habitat variables had the potential to alter a structural feature of the fish communities (the number of species present). It was concluded that the influence on this feature of the particular magnitude of the habitat changes was quite low.

<u>Hydrological change.</u> The 2000–01 Wet was a wet-Wet, having characteristics (including the length of the prior Dry season) different from all of the baseline Wets. It was considered reasonable to expect that these unique features could have translated into unique alterations in structural features of the creek’s fish communities.

<u>Understanding of background processes.</u> The structured and detailed approach taken in the correlation analysis revealed major insights into the hydrology- and habitat-driven dynamics of the Late-wet–Early-dry season fish communities in Gulungul Creek. This is vital knowledge for interpreting detected changes, assessing the weakness of existing methods, developing conceptual models and recommending more-attuned detection strategies.

In the process of the study it was recognised that the detailed information provided on hydrological correlates with the range of structural features of the fish communities, is likely to have high value for environmental-flow investigations across the wet-dry tropics of northern Australia.

<u>Evidence of alternate post-1989 disturbances?</u> Conceptually, these disturbances could be natural, anthropogenic (e.g. runoff and discharges from Jabiru township, Scenario-1 and Scenario-2 mining disturbances) and/or semi-anthropogenic (e.g. vegetation density increases arising from the eradication of water buffalo).

Evidence of the existence of such disturbances was obtained for only three structural features of the fish communities – a fish-community composition aspect (Ordination axis 2) which reflected the presence of a group of downstream-originating (i.e. upstream-migrating) fish species, the numerical density of a number of individual fish species, and the evenness index. The spatial focus of the effect of the disturbances on the features was generally in the upper reaches of the creek.

The disturbance effect on the fish-community-composition aspect appeared to be based on failed/weakened upstream migrations of a group of downstream-originating species. This occurred despite high flows in the 2000–01 Wet which would have normally facilitated the migrations. Bishop and Walden (2001) had noted unusual baseline-to-2001 shifts in this compositional aspect, but postponed its interpretation pending the present investigation. Furthermore, it was notable that two of the species within the downstream-originating group, the archerfish and the spangled grunter, were the species which Bishop and Walden (2001) had detected significant negative time trends in their abundances. In the present investigation it was suggested that a major long-term increase in the density of aquatic vegetation in further-downstream waterbodies (e.g. lowland billabongs), as caused by the eradication of feral water buffalo, was most likely responsible for the weakening of the migrations.

Many of the alternate-disturbance effects on individual fish species could be explained by the above finding. Of those that could not, it appeared <u>highly unlikely</u> that Scenario-1 mining disturbances could be their basis given that either: i) the effect was very remote (in the far upper reaches of the creek) and involved increases in the abundance of species potentially sensitive to water quality disturbances, or ii) it involved species which migrate during moderate-to-high flows through the creek section that is potentially exposed to seepage constituents – accordingly, they would normally only encounter highly-diluted contaminants.

Alternate-disturbance effects on the evenness index were also very remote and related to increases in the abundance of potentially sensitive fish species. Accordingly, it was considered <u>highly unlikely</u> that they were associated with Scenario-1 mining disturbances.

Three regular <u>field investigations</u> were recommended: **1)** continuing with the censusing on a year-to-year basis, **2)** developing a more sensitive and complementary means of detecting Scenario-1 mine disturbances (a feature that is likely to be useful is the ratio of the number of upstream migrants successfully negotiating difficult passage obstacles, to the number of upstream migrants present in the downstream staging-pool), and **3)** assessing the hydraulic character of key fish-passage obstructions every two years.

Extensive <u>data analyses</u> are still required to make the most of the extensive and valuable Gulungul Creek baseline datasets, and adjunct datasets on locally relevant fish communities. The highest priorities are: **1)** using hydrological variables as predictors, and with a focus on the baseline dataset, develop high quality models for a range of structural features of the fish communities, **2)** by altering fish-community structural features, and the nature of environmental variables, examine changes to the sensitivity of the developed models, and **3)** examine time trends in the abundance of pertinent species in a range locally-relevant fish-ecology datasets (in order to examine the reality, extent and basis of the apparent failed/weakened [2000–01 Wet-season] migrations of the group of downstream-originating fish species).

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 2: 'Second-pass' analyses of 1979–2001 Late-Wet–Early-Dry season data

KA Bishop & DJ Walden

1 Introduction

1.1 Background and rationale of this Phase 2 ('Second-pass') report

1.1.1 Connection with the previous report

This report follows closely on from the Phase 1 'First-pass' report of October 2001 (Internal Report 405 – Bishop & Walden 2003). That report investigated changes in fish communities in Gulungul Creek between a baseline period (1978–1990) and a current-condition sample taken in May 2001. To facilitate an interpretation of detected changes, the present report further explores baseline-to-current-condition shifts in community structure, and associated variability through an examination of a diverse array of environmental correlates. To allow the present report to be a stand-alone document, a number of background features and findings described in the previous report are repeated below.

1.1.2 Gulungul Creek and two possible types of mine disturbances

Gulungul Creek flows past the western lease boundary of the Ranger Uranium Mine (figure 1). 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.

1.1.3 Assessment of mine disturbances

eriss considered itself 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 which 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.

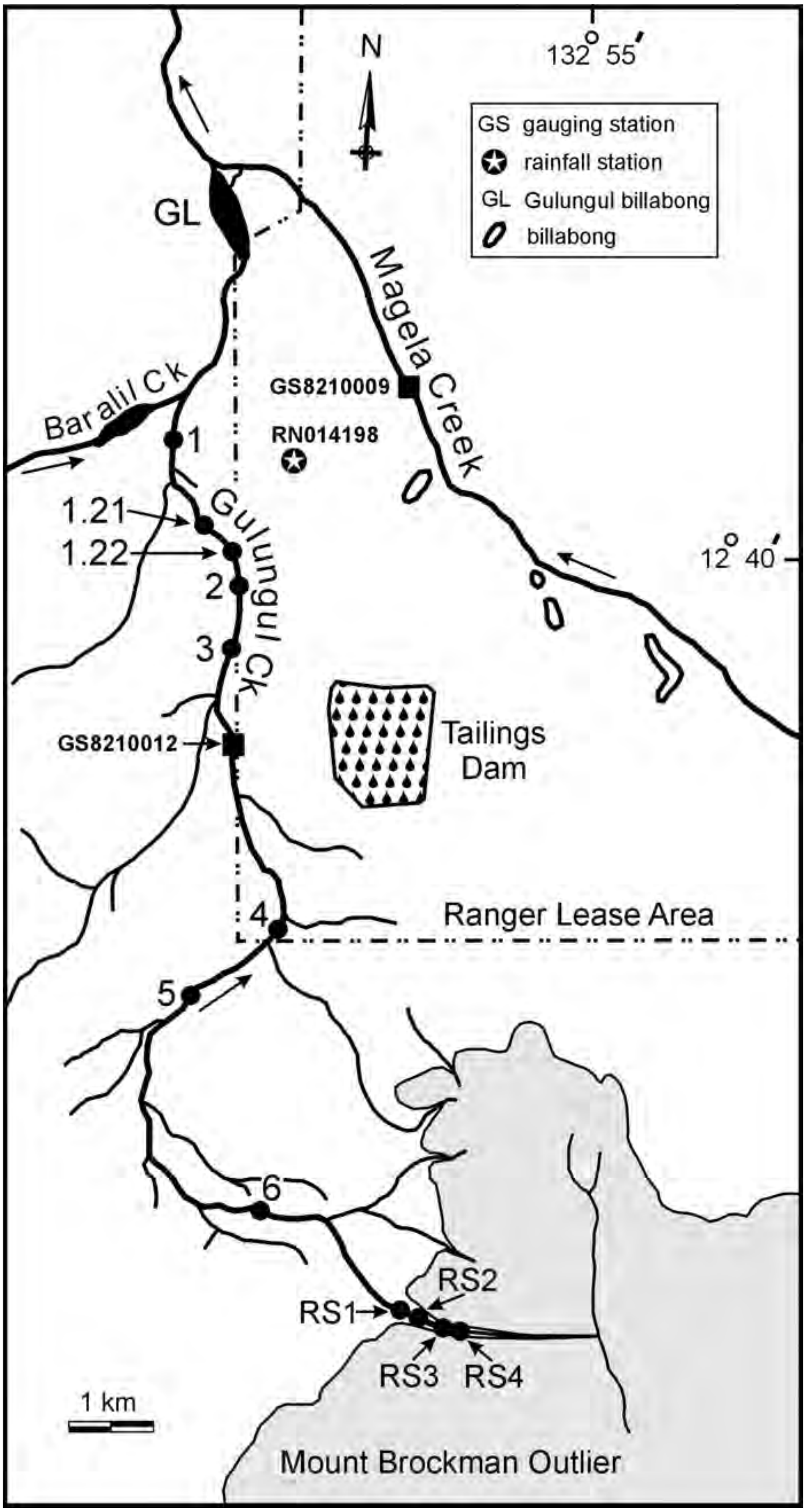

Figure 1 Sampling sites along Gulungul Creek (RS = Radon Springs)

In a first-pass context, the previous report (IR405 – Bishop & Walden 2003) aimed to initially determine whether there were 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).

1.1.4 Scenario-1 mine-disturbance signals

Data analyses undertaken in the previous report 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 <u>no evidence</u> of a disturbance signal at the potentially exposed sites.

1.1.5 Downstream-focused, non-specific disturbance signals

A range of analyses were undertaken in the previous report to detect these signals (which may or may not included Scenario-2 mine disturbance signals). The examination of time trends in the numerical density of each species revealed <u>evidence</u> 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, <u>no evidence</u> of a disturbance signal was obtained for four groups of sites examined.

<u>Additional evidence</u> 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.

1.2 Aims of this Phase-2 ('Second-pass') report[1]

1. Describe major year-to-year patterns in hydrology within and about Gulungul Creek.
2. Describe significant changes in physical-habitat conditions within the fish-censusing sites between 1989 and 2001 (Late-wet–Early-dry season focus).
3. Using a diverse range of hydrological and habitat correlates, examine the possible basis of baseline-to-current-condition shifts in fish community structure (and associated variability) detected in the 'first pass' investigation (IR405 – Bishop & Walden 2003).
4. Identify related fish studies which may assist in identifying the cause or the reality of fish community structure changes detected in the 'first pass' investigation.

---

[1] Note that some additional previous aims for this report were abandoned following the realization that the predicted time required to adequately analyse and examine the diverse array of available environmental correlates, had been greatly underestimated. The additional previous aims were:

a) Use modeling methods to account for natural variation; environmental variables used in the models could also be used to increase the ability of analyses to detect any mine-disturbance signals or other changes.

b) Investigate changes to the sensitivity of analyses by: i/ using a range of data transformations which progressively shift the analytical focus from abundant species to rare species, and ii/ using strategic ecological features of the fish species so to develop more diagnostic measures of structural changes in the fish communities.

2 Methods

2.1 Hydrological variables

Three groups of variables. The following three groups of hydrological variables (or hydrological-surrogate variables in the case of rainfall variables) were used to describe and understand major year-to-year, i.e. Wet-to-Wet patterns in hydrology:

- rainfall variables
- Magela Creek flow variables
- Gulungul Creek flow variables.

Within each of these groups, a set of variables was selected in a way which, it was assumed, best characterised the magnitude, duration and within-season timing of Wet season flows. The only exception to this was within the rainfall-variable group where one variable was selected which characterised the duration (= intensity) of the Dry season immediately prior to the Wet season.

Major patterns and reducing dimensionality. Major patterns were distinguished through ordination using Principal Components Analysis (PCA), a multivariate analysis technique considered to be a valuable tool in reducing the dimensions of environmental data (Clarke and Warwick 1994). The number of PCA-ordination axes subsequently used was determined using a rule-of-thumb whereby only the axes which explained greater than 10% of the variation were focussed upon.

Used as environmental correlates with time-lag = 0. The original variables, and their reduced components representing major patterns, were then used as environmental correlates[2]

---

[2] Relationships between river flow and structural features of fish communities are not well understood, but the theoretical basis for flow-fish links is strong and well accepted. In considering seasonal floodplain rivers, Welcomme (1979) noted that fish growth, reproductive success and mortality are all closely linked to the intensity of flooding and the severity of the 'drawdown'. Chapman and Chapman (1993) examined fish communities in tropical African floodplain pools and concluded that the haphazard trapping of fish during the flood decline contributed to a high year-to-year variation in the relative abundance of species. Rodriguez and Lewis (1994) in examining fish assemblages in neotropical South American floodplain lakes found the annual flood to greatly modify assemblage properties during the Wet season. Winemiller (1996) in examining fish assemblages in tropical floodplain rivers in South America, and Africa, concluded that assemblage variability was increased by short-term variability of rains and stochastic mortality associated with Dry season conditions.

Within Australia, advances in the understanding of fish-flow links in tropical freshwaters have primarily arisen from studies undertaken by ***eriss*** within Kakadu National Park. Bishop *et al* (1990) found that, within the lowlands, the Wet season flows allowed the influx and mixing fish communities which, in the Dry season, were restricted to the upper-reach escarpment areas, and the lower-reach corridor and floodplain areas. Both Bishop and Forbes (1991), and Bishop *et al* (2001), emphasised the vital importance of the Wet season flooding cycle to the breeding, feeding, migration and recruitment success of fish populations in the region. More specifically, Bishop and Walden (1991) found that:

- there was a strong negative relationship between the number of days when high numbers (>3000/hr)of chequered rainbowfish were migrating up Magela Creek, and the number of days flows were >30cumecs during the Wet season
- there was a strong negative relationship between the abundance of chequered rainbowfish in the lower reaches of Gulungul Creek (in March, April, May combined), and mean flow in the creek in March
- there was a positive relationship between the abundance of chequered rainbowfish in the upper reaches of Gulungul Creek (in March, April, May combined), and mean flow in the creek in March

Continuing specific information on flow-fish links in Kakadu NP, Pidgeon *et al* (1998a&b) found the early onset of flows in the Wet season, particularly during December, to be strongly positively associated with large upstream migrations of chequered rainbowfish and Ambassid perchlets later in the Wet season. Pidgeon *et al* (1998b) suggested that flow spates of sufficient magnitude in February and March may stimulate large-scale upstream movements of the above species by mid-March.

(see later) to the fish community structure data which had been gathered in the Late-wet–Early-dry season following each Wet season. Accordingly, these correlates essentially have no time lag as they would be related to data gathered at the end of the Wet season. Although probably ecologically relevant[3], it was considered out of the scope of the present investigation to examine correlates lagged one year or more (i.e. time-lag >= 1).

2.1.1 Rainfall Wet-season variables

Rainfall variables, derived from monthly summaries of rainfall observations at Rain Station RN014198 (Jabiru Airport), were used as surrogate hydrological variables because:

- the high likelihood that patterns in the rainfall data will mimic flows in Gulungul Creek given the station's closeness to the Gulungul Creek catchment (figure 1)
- the long non-interrupted time span of the data which included the 2000–01 Wet season
- the data being readily attainable
- the likelihood that the rainfall data may contain subtle, but biologically-significant signals to fish which are not apparent in creek-flow data (e.g. before flows commence, early rains causing pool expansion may trigger early spawning activity)

A list of the twelve variables selected is given in table 1. The basis of these variables is self evident from the table. The two derived PCA ordination axes are also included. The first seven variables (OCTMT to APRMT) provide an indication of the within-season timing of rains (and hence flows). The first three of these variables (OCTMT to DECMT), along with the eighth variable, OCTMT, were considered to be particularly useful in giving an indication of the early onset of rains in the Wet season. Variables FEBMT and MARMT may also have significance to fish migrations in Magela Creek, and hence Gulungul Creek (see Footnote 2). The variable >150MNS provides an indication of the length (or duration) of the Wet season. The variables >300MNS and >400MS provide an indication of the duration of moderate and high flow events during which the aquatic environment is greatly expanded by over-bank rises in water level. The variable <20DMNS provides an indication of the length (and hence severity) of the Dry season immediately prior to the Wet season.

2.1.2 Magela Creek Wet-season flow variables

Magela Creek flow variables, derived from daily flow data gathered at Gauging Station GS8210009 (figure 1), were used because of:

- the likelihood that flows in Magela Creek may influence Gulungul Creek fish communities, given potentially-linked recruitment areas and migration corridors
- the long non-interrupted time span of the data which included the 2000–01 Wet season
- the data being readily attainable
- the likelihood that patterns in the Magela Creek flow data may mimic flow patterns in Gulungul Creek given the station's closeness to Gulungul Creek

A list of the nineteen variables selected is given in table 2. The basis of these variables is self evident from the table and fully explained in Bishop (1991). The three derived PCA-ordination axes are also included.

---

[3] For example, Welcomme and Hagborg (1977) predicted that, in floodplain rivers, many differences in fish biomass induced by the flood regime are transmitted to the next cycle.

Table 1 Key to the codes for the rainfall (primarily) Wet-season variables (data supplied by the Bureau of Meteorology for rain station RN014198 (Jabiru Airport, figure 1))

Code	Variable description
OCTMT	total monthly rainfall in October
NOVMT	total monthly rainfall in November
DECMT	total monthly rainfall in December
JANMT	total monthly rainfall in January
FEBMT	total monthly rainfall in February
MARMT	total monthly rainfall in March
APRMT	total monthly rainfall in April
ONDMT	total rainfall in October, November and December
>150MNS	number of Wet season months with monthly totals >150mm
>300MNS	number of Wet season months with monthly totals >300mm
>400MNS	number of Wet season months with monthly totals >400mm
<20DMNS	number of Dry season months with monthly totals <20mm
PCA1	first principal component axis
PCA2	second principal component axis

Table 2 Key to the codes for the Magela Creek Wet-season flow variables (data supplied by the Northern Territory Department of Water Resources for gauging station GS8210009 (figure 1))

Code	Variable description*
D>1	number of days greater than 1 cumecs
D>3	number of days greater than 3 cumecs
D>9	number of days greater than 9 cumecs
D>27	number of days greater than 27 cumecs
D>81	number of days greater than 81 cumecs
D>243	number of days greater than 243 cumecs
D>729	number of days greater than 729 cumecs
D1-3	number of days with flows between 1 and 3 cumecs
D3-9	number of days with flows between 3 and 9 cumecs
D9-27	number of days with flows between 9 and 27 cumecs
D27-81	number of days with flows between 27 and 81 cumecs
D81-243	number of days with flows between 81 and 243 cumecs
D243-729	number of days with flows between 243 and 729 cumecs
DECMF	mean daily flow in December (cumecs)
JANMF	mean daily flow in January (cumecs)
FEBMF	mean daily flow in February (cumecs)
MARMF	mean daily flow in March (cumecs)
APRMF	mean daily flow in April (cumecs)
WETTD	total flow through December to April inclusive (cubic metres)
PCA1	first principal component axis
PCA2	second principal component axis
PCA3	third principal component axis

*The detailed origin of the variables is given in Bishop (1991)

The first thirteen variables (D>1 to D243-729) provide for a flow-magnitude partitioning of the correlates. This is likely to be useful as it is likely that different biological activities may be occurring at different flow magnitudes. During the higher-magnitude flows the aquatic environment is greatly expanded by over-bank rises in water level. The next five variables, DECMF to APRMF, provide an indication of the within-season timing of flows. The first of these variables, DECMF, was considered to be particularly useful in giving an indication of the potentially biologically-significant (see Footnote 2) early onset of flows in the Wet season. Variables FEBMF and MARMF may also have significance to fish migrations in Magela Creek, and hence Gulungul Creek. The variable WETTD provides an indication of the overall 'wetness' of the Wet season.

2.1.3 Gulungul Creek Wet-season flow variables

Gulungul Creek flow variables, derived from daily flow data gathered at Gauging Station GS8210012 (figure 1), were used because of:

- the very high likelihood that flows in Gulungul Creek will influence Gulungul Creek fish communities
- the long non-interrupted time span of the data
- the data being readily attainable

The major disadvantage of the data was the feature that no data were available for the 2000–01 Wet season.

A list of the seventeen variables selected is given in table 3. The basis of these variables is self evident from the table and fully explained in Bishop (1991). The two derived PCA-ordination axes are also included.

Table 3 Key to the codes for the Gulungul Creek wet-season flow variables (data supplied by the Northern Territory Department of Water Resources for gauging station GS8210012 (figure 1))

Code	Variable description*
D>0	numbers of days with flows greater than 0 cumecs
D>1	number of days with flows greater than 1 cumecs
D>2	number of days with flows greater than 2 cumecs
D>4	number of days with flows greater than 4 cumecs
D>8	number of days with flows greater than 8 cumecs
D>16	number of days with flows greater than 16 cumecs
D0-1	number of days with flows between 0 and 1 cumecs
D1-2	number of days with flows between 1 and 2 cumecs
D2-4	number of days with flows between 2 and 4 cumecs
D4-8	number of days with flows between 4 and 8 cumecs
D8-16	number of days with flows between 8 and 16 cumecs
DECMF	mean daily flow in December (cumecs)
JANMF	mean daily flow in January (cumecs)
FEBMF	mean daily flow in February (cumecs)
MARMF	mean daily flow in March (cumecs)
APRMF	mean daily flow in April (cumecs)
WETTD	total flow through December to April inclusive (cubic metres)
PCA1	first principal component axis
PCA2	second principal component axis

*The detailed origin of the variables is given in Bishop (1991)

The first eleven variables (D>0 to D8-16) provide for a flow-magnitude partitioning of the correlates. This is likely to be useful as it is likely that different biological activities may be occurring at different flow magnitudes. As before, during the higher-magnitude flows the aquatic environment is greatly expanded by over-bank rises in water level. The next five variables, DECMF to APRMF, provide an indication of the within-season timing of flows.

The first of these variables, DECMF, was considered to be particularly useful in giving an indication of the potentially biologically-significant early onset of flows in the Wet season. Variables FEBMF and MARMF may also have significance to fish migrations in Gulungul Creek. The variable WETTD provides an indication of the overall 'wetness' of the Wet season.

2.2 Habitat variables

Two groups of habitat variables. The utilised habitat variables for Gulungul Creek can be divided into two groups based on differences in the way the data were collected and the spatial focus of the data. The groups were:

- *Creek-long* data on physiography and riparian vegetation cover (referred to by Bishop [1991] as 'Study sub-component 3c: Longitudinal changes in gradient and cover in Gulungul Creek'), and
- *Within-site* data on habitat character (referred to by Bishop [1991] as 'Study sub-component 2b: 'Environmental characterisation of sites')

Full details of the variables mentioned or listed below are mostly given in Bishop (1991).

Habitat variables used as environmental correlates. Some of the original variables, and all derived variables (see below), were then used as environmental correlates (see later) to the fish community structure data which had been gathered in the Late-wet–Early-dry season following each Wet season. The fish-community-structure data from each site had been pooled down to four site-groups (see Section 2 of Bishop and Walden [2001]), and accordingly, the habitat data also required the same pooling. This was achieved by averaging the habitat data across sites within each site group.

2.2.1 Creek-long data on physiography and riparian vegetation cover

These data were only collected in the 1989 Late-wet–Early-dry season, from 3/5/89 to 21/6/89. The top nine variables listed in table 4, i.e. variables DIST to DN-GRMX, are derived from these data. The basis of these variables is generally self evident from the table. The four close-to-site variables (code prefixed with 'CL-') describe the creek within and around a given site up to 100 m upstream and downstream of the site. The two upstream-of-site variables (code prefixed with 'UP-') describe the creek upstream of the site to the next site upstream. The two downstream-of-site variables (code prefixed with 'DN-') describe the creek downstream of the site to the next site downstream. There is a clear emphasis on creek gradient as a variable (six variables; middle section of codes = 'GR'). This is because, through the increased occurrence of insurmountable cascades or vertical jumps, creek gradient strongly influences the structure of fish communities by restricting the upstream movement of a wide range of species.

2.2.2 Within-site data on habitat character

The location (figure 1) and a general description of the ten censusing sites in Gulungul Creek were given in Bishop and Walden (2001; Section 3.1). During 1989 the habitat-character data were collected from all ten sites in the Late-wet–Early-dry season, on 4/5/89, 5/5/89 and 29/6/89. Using the same data-collection method, the habitat data were again collected in the 2001 Late-wet–Early-dry season (on 9/5/01 and 14-16/5/01), but only in sites 2 to 8 (RS2). Site 1 was not resurveyed due to a perceived high risk of attack from a saltwater crocodile. Sites 9 and 10 (RS3 & RS4) were not resurveyed because they were assumed to be highly stable in their habitat character, a result of their location in a bedrock-controlled sandstone gorge.

Twenty-seven within-site habitat variables used as correlates are listed and described in table 4, i.e. variables WS-RIPC to WS-ODIV. The basis of these variables is generally self evident from the table. The first eleven variables, WS-RIPC TO WS-ROOT, are directly derived from these data (two riparian-cover variables, four inorganic-substrate variables, and five organic substrate variables).

The next set of five variables (WS-MDEP to WS-DEP) characterise water depths along the middle of the censusing sites. Only the first of these (WS-MDEP) is directly derived from the data. The remaining four are indirectly derived and characterise the occurrence of particular water-depth categories.

The next set of five variables (WS-MCUT to WS-DCUT) characterise submersed undercut bank depths along one side of the censusing sites. As for water depths, only the first of these (WS-MCUT) is directly derived from the data. The remaining four are indirectly derived and characterise the occurrence of particular undercut-depth categories. Submersed cavities under banks provide valuable cover for a range of fish species.

The next set of six variables (WS-DIS to WS-ODIV) characterise the diversity of habitat conditions within the censusing sites. All of these variables are indirectly derived from the habitat data. The diversity is partitioned into substrate type (inorganic, organic and overall), water depths along the middle and undercut depths. The variable WSODIV is the overall habitat diversity score which includes the occurrence of riparian far and close cover. Bishop and Forbes (1991) presented data from Magela Creek which showed a strong positive relationship between fish species richness and habitat diversity. Similar findings have been made in tropical rivers elsewhere (e.g. Gorman and Karr [1978]in South American streams).

2.2.3 Within-site habitat changes from 1989 to 2001

Habitat changes occurring between 1989 and 2001 were examined on a site-by-site basis. Examinations were only possible for sites 2 to 8 inclusive, representing site-groups A to D. Only one site (site 8) represented site-group D.

The changes were also examined on a variable-by-variable basis. Of interest were shifts in the frequency distribution across percentage-area-cover categories in the case of riparian cover and the substrates types. In the case of middle depths and undercut depths, the frequency distribution shifts were assessed across the following depth categories:

- middle depth: 0.2 m wide categories, and
- undercut depth: 0.1 m wide categories

The significance of the shifts in frequency, for all variables, was assessed using the Chi-squared statistic.

Table 4 Key to the codes for physiographic, habitat and habitat diversity variables

Code	Variable description
Creek-long variables:	
DIST	physiographic variable: distance by creek upstream of Baralil Creek confluence (km)
CL-GRMN	close to site physiographic variable: mean creek gradient
CL-GRMX	close to site physiographic variable: maximum creek gradient
CL-RIPC	close to site habitat variable:categorised % riparian close cover (< 2 m), median cat.
CL-RIPF	close to site habitat variable: categorised % riparian far cover (> 2 m), median cat.
UP-GRMN	upstream of site physiographic variable: mean creek gradient
UP-GRMX	upstream of site physiographic variable: maximum creek gradient
DN-GRMN	downstream of site physiographic variable: mean creek gradient
DN-GRMX	downstream of site physiographic variable: maximum creek gradient
Within-site variables:	
WS-RIPC	within-site habitat variable: categorised % riparian close cover (< 2 m), median cat.
WS-RIPF	within-site habitat variable: categorised riparian far cover (> 2 m), median cat.
WS-SAND	within-site habitat variable: categorised % bed cover by sand substrate, median cat.
WS-ROCK	within-site habitat variable: categorised % bed cover by rock substrate, median cat.
WS-BOUL	within-site habitat variable: categorised % bed cover by boulder substrate, median cat.
WS-BEDR	within-site habitat variable: categorised % bed cover by bedrock substrate, median cat.
WS-AQPL	within-site habitat variable: categorised % bed cover by aquatic plants, median cat.
WS-TWBR	within-site habitat variable: categorised % bed cover by twigs and branches, median cat.
WS-LELI	within-site habitat variable: categorised % bed cover by leaf litter, median cat.
WS-LOGS	within-site habitat variable: categorised % bed cover by logs, median cat.
WS-ROOT	within-site habitat variable: categorised % bed cover by root material, median cat.
WS-MDEP	within-site habitat variable: median middle depth in metres
WS-ADEP	within-site habitat variable: % of middle depths < 0.2 m
WS-BDEP	within-site habitat variable: % of middle depths 0.2 – 1.0 m
WS-CDEP	within-site habitat variable: % of middle depths 1.0 – 1.5 m
WS-DDEP	within-site habitat variable: % of middle depths > 1.5 m
WS-MCUT	within-site habitat variable: median undercut depth in metres
WS-ACUT	within-site habitat variable: % of undercut depths = 0 m
WS-BCUT	within-site habitat variable: % of undercut depths > 0.0 m & < 0.2 m
WS-CCUT	within-site habitat variable: % of undercut depths 0.2 – 1.0 m
WS-DCUT	within-site habitat variable: % of undercut depths > 1.0 m
WS-DIS	within-site habitat diversity variable: number of inorganic substrates present
WS-DOS	within-site habitat diversity variable: number of organic substrates present
WS-DSUB	within-site habitat diversity variable: number of all substrates present
WS-DDE	within-site habitat diversity variable: number of depth categories @ 0.2 m intervals
WS-DCU	within-site habitat diversity variable: number of undercut depth categories @ 0.2 m intervals
WS-ODIV	within-site habitat diversity variable: overall total number of diversity categories (incls. riparian)

Close-to-site variables describe the creek within and around a given site up to 100 m upstream and downstream of the site. Upstream-of-site variables describe the creek upstream of the site to the next site upstream. Downstream-of-site variables describe the creek downstream of the site to the next site downstream. All variables were averaged across sites within each site group. The detailed origin of the variables is mostly given in Bishop (1991). Category = cat

2.3 Analytical strategy: fish community structure *vs* environmental correlates

2.3.1 Fish community-structure data

The origin and nature of the Late-wet–Early-dry season fish-community-structure data were described in detail by Bishop and Walden (2001; Section 2). Described also in detail was the multifaceted analytical strategy whereby baseline-to-current-condition shifts in basic-structural and compositional-structure features were systematically examined. Only the features which were amenable to examination by correlation analysis are examined in the present investigation. These are:

- basic-structural features:
  - number of fish (total numerical density across all species)
  - numerical densities of each species
  - number of species
- compositional-structure features:
  - 'evenness' of densities across species (Pielou's [1975] evenness index)
  - MDS-ordination sample scores for axis one
  - MDS-ordination sample scores for axis two

Spearman's rank correlation co-efficients (r_s) were used at all times to examine the association between the above features and the environmental variables. The analysis strategy used varied between the examination of the hydrological and the habitat correlates. Both strategies were applied in the same way to all of the above six features. However, in the case of the examination of the numerical densities of each species, where seventeen variables were considered (species with more than 40 individuals recorded across the baseline and current-condition periods; table 5), a specific strategy was devised for summarising the results.

2.3.2 Hydrological correlation-analysis strategy

Understanding of background processes

To develop an understanding of background processes, the character of the arrangement of significant correlations were summarised in relation to:

- the total number of significant correlates (@ the <10% and <5% significance levels)
- site-group differences
- hydrological-variable group difference
- the sign (+ or -) of the correlates
- the nature of the correlates
- tentative interpretation of the configuration of the correlates
- Evidence of a post-1989 (stronger) non-hydrological disturbance

On a site-group by site-group basis, and as based on data collected across Wet seasons (i.e. year to year), correlations were calculated with each group of the hydrological variables: 14 rainfall variables, 21 Magela Creek flow variables, and 19 Gulungul Creek flow variables. (the numbers specified include the PCA ordination axes which depict major Wet-to-Wet patterns). This was done separately for:

- the baseline data (referred to as '*without*'; n = 8 for site-groups A-C; n = 9 for site-group D [1979 data additional]), and
- the baseline data plus the 2001 data set (referred to as '*with*'; n = 9 for site-groups A-C; n = 10 for site-group D]).

Table 5 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 or tandan	*Neosilurus ater*	208
Hyrtli's eel-tailed catfish	*Neosilurus hyrtlii*	5880
Longtom	*Strongylura krefftii*	101
Black-banded or black-striped rainbowfish	*Melanotaenia nigrans*	30 493
Chequered rainbowfish	*Melanotaenia splendida inornata*	10 357
Mariana's hardyhead	*Craterocephalus marianae*	11
Fly-specked hardyhead	*Craterocephalus stercusmuscarum*	1820
Blue-eyes	*Pseudomugil signifer + gertrudae*	2227
Chanda or Ambassid perchlets	*Ambassis agrammus + macleayi*	25 787
Pennyfish	*Denariusa bandata*	700
Banded grunter	*Amniataba percoides*	228
Sooty grunter	*Hephaestus fuliginosus*	577
Spangled grunter	*Leiopotherapon unicolor*	3447
Midgley's or the 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

Correlations analysis was only undertaken on seventeen species which had overall numbers greater than 40 individuals (species with less than 40 individuals are shaded grey)

Of interest were reductions in the number of significant correlations when the 2001 data were added to the baseline data. It was assumed that such reductions would imply a breakdown of natural responses to hydrology, thereby suggesting that it was likely that a stronger non-hydrological disturbance (natural or human-induced) had come into play. Correlations were deemed significant at the <10% probability level, although these were separated from those significant at the <5% level.

Results-summary strategy for the analysis of the numerical density of individual species

To obtain an <u>understanding of background processes</u>, the results across the seventeen fish species (table 5) were initially summarised in a manner which showed differences between site-groups, with the positive correlates separated from the negative correlates. The differences were shown by shading which indicated, per site-group, a category of the percentage number of significant correlates across all site-groups. The results were then summarised showing differences in the number of significant correlations arising from each of the groups of hydrological variables. The results were standardised between the variable groups by only considering baseline data (i.e. 'without 2001'), and then expressing the incidence as a rate per the number of variables examined.

Finally, the results were summarised showing changes in the number of significant correlations when the 2001 data was added to the baseline data. As before, this activity was seeking evidence of a post-1989 (stronger) non-hydrological disturbance (natural or human-induced) coming into play.

2.3.3 Habitat correlation-analysis strategy

The strategy used for the 27 habitat variables (physiography, habitat and habitat diversity variables) was much more restricted than that used for the hydrological variables. This was because the habitat data had been collected, at most, only in 1989 and 2001. Accordingly, across-Wet correlations were not possible. Instead, across-site-group correlations were focussed upon. This was done separately for the 1989 data and the 2001 data. This analysis was also very restricted as the sample size was n = 4, and accordingly, a significant correlation at the <10% probability level was identified when r_s reached a value of 1.0.

Understanding of background processes

To develop an understanding of background processes, the character of the arrangement of significant correlations were summarised in relation to:

- the total number of significant correlates (only at the <10% significance level)
- the sign (+ or -) of the correlates
- the nature of the correlates (separate between 1989 and 2001)

Evidence of a post-1989 (stronger) non-habitat disturbance

In a similar way as for the hydrological variables, of particular interest were the 1989-to-2001 reductions in the number of significant correlates. As before, this activity was seeking evidence of a post-1989 (stronger) non-habitat disturbance, natural or human-induced, coming into play within the creek.

To counter the restriction cause by a sample size of n = 4, another more-sensitive approach was developed which focussed on 1989-to-2001 changes in the spectrum of correlation magnitudes. Of interest were shifts in the frequency distribution across magnitude categories. It was assumed that a shift to smaller magnitude categories would imply a breakdown of natural responses to habitat. The significance of the shifts in frequency was assessed using the Chi-squared statistic.

3 Results

3.1 Major hydrological patterns across Wet seasons

Key variable loadings arising from principal components analyses of the hydrological-variable groups are shown in table 6.

Table 6 Key variable loadings arising from principal components analyses of the hydrological-variable groups (rainfall, Magela-Creek-flow and the Gulungul-Creek-flow variables)

Rainfall variables (12 in total)		**Magela Creek flow variables (19 in total)**			**Gulungul Creek flow variables (17 in total)**	
PCA1 ev = 4.16 %var.= 34.7	PCA2 ev = 3.61 %var.= 30.1 (PCA3: ev = 1.15 %var.= 9.6)	PCA1 ev =8.24 %var.= 43.4	PCA2 ev = 4.49 %var.= 26.3	PCA3 ev = 2.65 %var.= 13.9 (PCA4: ev = 1.22 %var.= 6.4)	PCA1 ev = 10.8 %var.= 65.5	PCA2 ev = 3.26 %var.= 19.2 (PCA3: ev = 1.07 %var.= 6.3)
+0.35 <20DMNS			+0.37 D9-27	+0.35 D81-243		+0.35 FEBMF
			+0.35 D3-9	+0.30 JANMF		+0.29 D8-16
			+0.31 D>1	+0.28 FEBMF		
			+0.30 DECMF	+0.24 D>81		
			+0.29 D>3			
			+0.25 APRMF			
-0.44 OCTMT	-0.51 ONDMT	-0.33 WETTD	-0.29 FEBMF	-0.40 D>729	-0.29 D>1	-0.43 APRMF
-0.44 FEBMT	-0.48 >150MNS	-0.32 D>27	-0.24 D>243	-0.36 D>243	-0.29 D>2	-0.42 D1-2
-0.42 >400MNS	-0.39 NOVMT	-0.31 D>9		-0.34 D243-729	-0.29 D>2	-0.38 D0-1
-0.30 >300MNS	-0.38 DECMT	-0.30 D27-81		-0.29 MARMF	-0.28 D>8	-0.31 D>0
	-0.34 JANMT	-0.27 D>3			-0.28 D>16	-0.26 JANMF
		-0.26 D>81			-0.28 D2-4	
		-0.26 MARMF			-0.28 D4-8	
		-0.24 D>1			-0.27 MARMF	
		-0.24 D81-243			-0.27 WETTD	
					-0.26 D8-16	
					-0.25 DECMF	

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). Positive and negative loadings are respectively given above and below the grey band. The magnitude of the loadings decrease going down the table

ev = eigen value of axis; %var = percentage of variation accounted for by the axis; these details are also given for the first not included PCA axis in order to given an indication of the reduced level of information content

3.1.1 Rainfall variables

Two PCA axes were considered and these accounted for 65% of the variation.

The first axis reflected a factor that longer (more intense) prior Dry seasons are usually followed by lower monthly rainfall totals in October and February, and fewer months with very-high rainfall totals. This is summarised by the following key phrase:

First axis (axis 1): *longer prior Dry season linked with lower October & February rains, and fewer very-high rainfall months*

The second axis reflected a factor that lower monthly total rains in October to January inclusive are associated with few months with total rainfall >150mm. That is, shorter Wet seasons generally result from lower rains in the early- to first-half of the Wet season. This is summarised by the following key phrase:

Second axis (axis 2): *lower early- and first-half Wet-season rains linked with fewer months with rains moderate or greater (i.e. shorter Wet)*

The relationship between Wet seasons in relation to both of the above axes is shown in figure 2. The Wet seasons in the baseline period varied greatly in respect to both PCA axes. The current-condition 2000–01 Wet season stood out compared with all other Wets in that it had low values on both PCA axes. That is, it was characterised by a short prior Dry season, higher October and February rains, more very-high rainfall months, higher early- to first-half Wet seasons rains, and a longer Wet season. In respect to the Axis 1 factor, the 2000–01 Wet was similar to the 1983–84 and 1986–87 Wets. In respect to the Axis 2 factor, the 2000–01 Wet was similar to the 1978–79 and 1984–85 Wets.

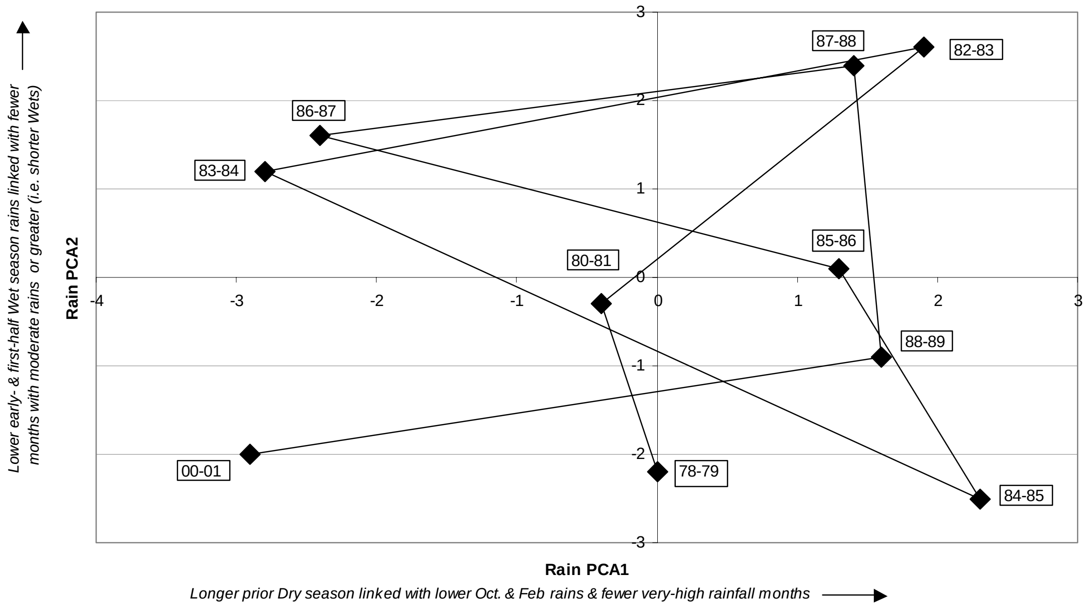

Figure 2 Principal components analysis of the year-to-year rainfall variables: PCA axis1 vs. PCA axis 2 showing the relationships between Wet seasons. The lines join Wet seasons in chronological order.

3.1.2 Magela-Creek flow variables

Three PCA axes were considered and these accounted for 84% of the variation.

The first axis reflected a factor that lower total Wet-season discharge was linked with a lower duration of low to high flows (up to ~250 cumecs), as well as lower flows in March. This is summarised by the following key phrase:

First axis (axis 1): *lower total Wet-season discharge, lower March flows, and lower duration of low to high flows*

The second axis reflected a factor that a higher duration of low-moderate flows was linked with higher December and April flows, but lower February flows, and a lower duration of high-to-very-high flows. This is summarised by the following key phrase:

Second axis (axis 2): *higher duration of low-moderate flows, higher December & April flows, but lower February flows and a lower duration of high-to-very-high flows*

The third axis reflected a factor that a higher duration of moderately-high flows was linked with higher January and February flows, but lower March flows, and a lower duration of high-to-very-high flows. This is summarised by the following key phrase:

Third axis (axis 3): *higher duration of moderately-high flows, higher January & February flows, but lower March flows and a lower duration of high-to-very-high flows*

The relationship between Wet seasons in relation to the first and second axes is shown in figure 3. The Wet seasons in the baseline period varied greatly in respect to both PCA axes. In respect to the Axis 1 factor, the 2000–01 Wet had the lowest axis score followed closely by the 1980–81 Wet. The 83–84 and 88–89 Wets were next most similar. In respect to the Axis 2 factor, the current-condition 2000–01 Wet was placed in the centre of the baseline Wets along the axis.

The relationship between Wet seasons in relation to the first and third axes is shown in figure 4. The Wet seasons in the baseline period varied to a lesser extent along the third axis. However, the 1980–81 Wet stood out in having a particularly low axis score. In contrast, the current-condition 2000–01 Wet stood out in having a particularly high axis score.

3.1.3 Gulungul-Creek flow variables

Two PCA axes were considered and these accounted for 85% of the variation.

The first axis reflected a factor that the lower duration of most flows is linked with lower total Wet season discharge and lower flow in December and March. This is summarised by the following key phrase:

First axis (axis 1): *lower duration of most flows linked with lower total-Wet discharge and lower December and March flow.*

The second axis reflected a factor that a higher duration of high flows is linked with high February flows, and a lower duration of low flows, and lower January and April flows. This is summarised by the following key phrase:

Second axis (axis 2): *higher duration of high flows, higher February flows, lower duration of lower flows, lower January and April flows.*

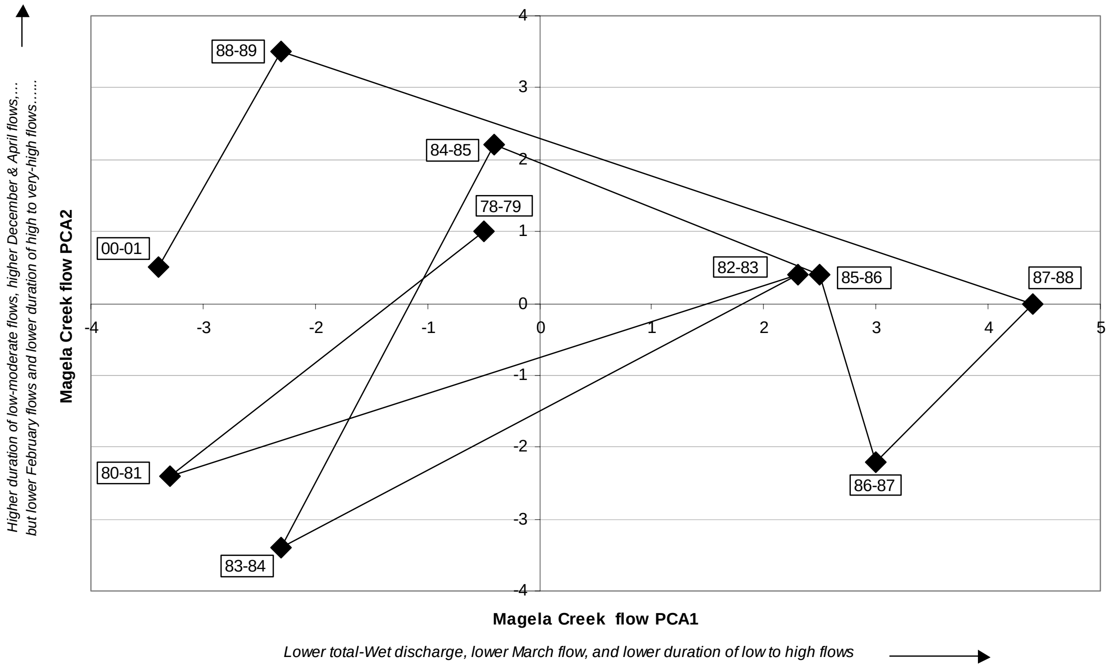

Figure 3 Principal components analysis of the year-to-year Magela Creek flow variables: PCA axis1 vs. PCA axis 2 showing the relationships between Wet seasons. The lines join Wet seasons in chronological order.

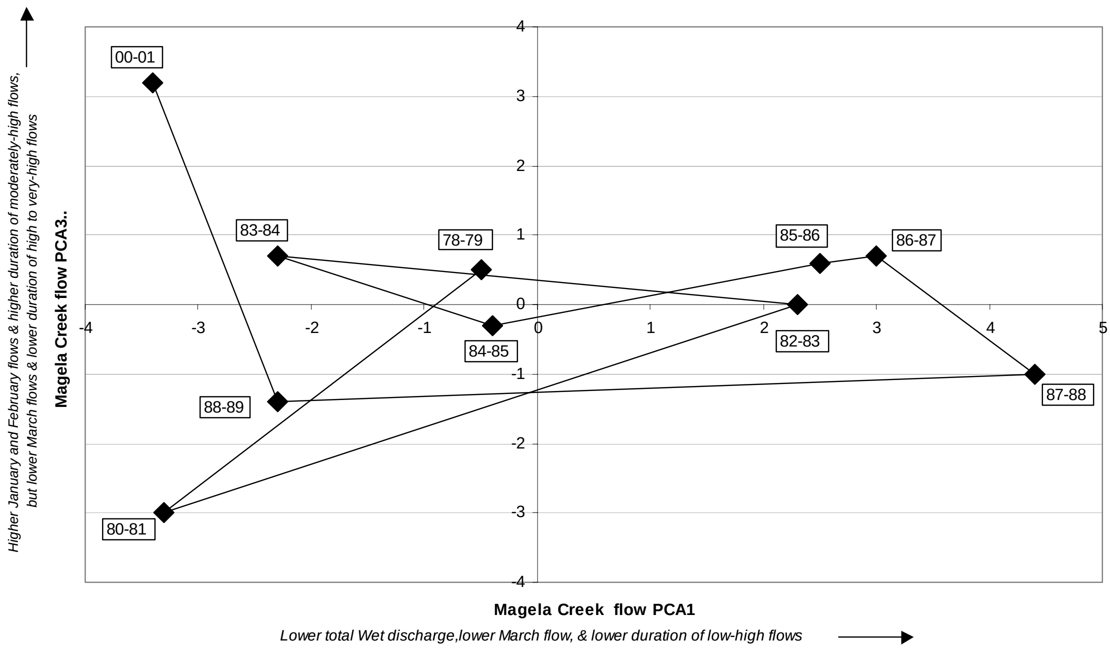

Figure 4 Principal components analysis of the year-to-year Magela Creek flow variables: PCA axis1 vs. PCA axis 3 showing the relationships between Wet seasons. The lines join Wet seasons in chronological order.

The relationship between Wet seasons in relation to both of the above axes is shown in figure 5. As for the previous groups of hydrological variables, the Wet seasons in the baseline period varied greatly in respect to both PCA axes. Along axis 1 the 1980–81 Wet season had the lowest axis score, i.e. higher duration of most flows and higher total-Wet discharge – a wet Wet. The 1987–88 Wet had the highest axis score, i.e. a dry Wet. No current-condition 2000–01 Wet-season sample was available. Along axis 2 the 1984–85 Wet season had the lowest axis score and. the 1986–87 Wet had the highest axis score.

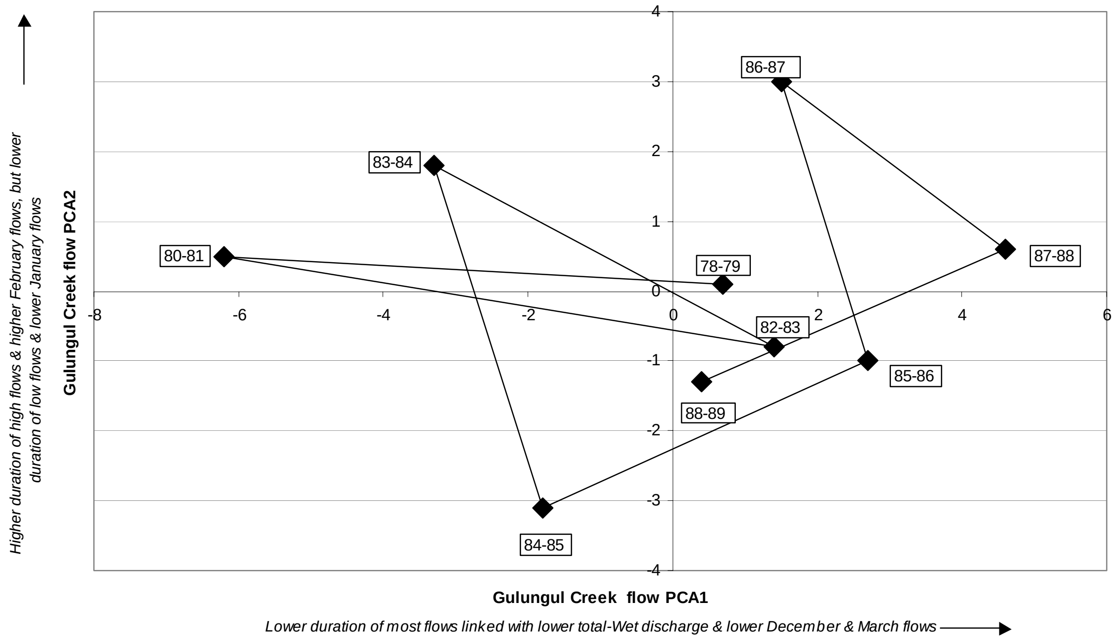

Figure 5 Principal components analysis of the year-to-year Gulungul Creek flow variables: PCA axis1 vs. PCA axis 2 showing the relationships between Wet seasons. The lines join Wet seasons in chronological order

3.2 Within-site habitat changes from 1989 to 2001

A summary of significant changes in with-in site habitat variables between 1989 and 2001 is given in table 7. These changes are described on a site-group by site-group basis below.

3.2.1 Site-group A (sites 2 and 3)

Within site 2 reductions in far-riparian cover and increases in sand cover were detected. In site 3 reductions in middle depths were detected along with reductions in aquatic plant and leaf-litter cover. As for site 2, increases in sand cover were detected in site 3. The root material cover also increased. It would appear in site 3 that an increase in sand bedload had smothered fine covers and reduced depths.

3.2.2 Site-group B (sites 4 and 5)

Site 4 showed many changes (increased middle depths, close and far riparian cover, and twigs & branches cover; decreased rock cover and leaf litter cover) and this would reflect a difficulty in correctly locating the exact site limits. Site 5 only showed significant increases in undercut depths and aquatic plant cover.

Table 7 Significant changes in within-site habitat-character variables between 1989 and 2001

Within-site habitat character variables	Site group A		Site group B		Site group C		Site group D
	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8 only
Middle depth	ns	- (11.2,3)	+ (8.9,3)	ns	ns	ns	ns
Undercut depth	ns	ns	ns	++(11.6,2)	ns	ns	ns
Riparian cover:							
Close	ns	ns	+ (8.1,3)	ns	ns	--(14.3,4)	---(13.1,1)
Far	---(34.3,5)	ns	++(15.1,4)	ns	ns	ns	ns
Inorganic substrates:							
Mud/silt	ns	ns	ns	ns	ns	ns	ns
Clay	ns	ns	ns	ns	ns	ns	ns
Sand	+(10.8,3)	++(10.9,2)	ns	ns	---(21.3,4)	---(23.9,4)	--(18.7,3)
Gravel	ns	ns	ns	ns	ns	ns	ns
Rock	ns	ns	---(26.1,3)	ns	ns	+++(16.5,3)	-(13.7,5)
Boulder	ns	ns	ns	ns	ns	+(9.5,3)	ns
Bedrock	ns	ns	ns	ns	ns	ns	ns
Organic substrates:							
Aquatic plants	ns	---(27.3,4)	ns	+(9.9,4)	+++(32.1,4)	ns	ns
Twigs & branches	ns	ns	+(7.7,2)	ns	--(9.7,4)	---(33.9,4)	---(13.9,1)
Leaf litter	ns	---(19.7,2)	---(20.7,3)	ns	++(13.8,4)	ns	---(20.3,2)
Logs	ns	ns	ns	ns	+(9.0,2)	+++(37.3,4)	ns
Root material	ns	+(9.8,3)	ns	ns	+++(16.0,4)	--(17.5,5)	+++(14.0,2)

Significant increases are indicated by plus signs (+) and decreases are indicated by minus signs (-). Significance levels: ns, not significant (p>0.05); one sign, 0.05>=p>=0.01; two signs, 0.01>=p>=0.001; three signs, 0.001>=p. Chi-squared values and degrees of freedom are given in parentheses

3.2.3 Site-group C (sites 6 and 7)

Site 6 showed many changes (increased cover of aquatic plants, leaf litter, logs, root material; decreased sand cover and twigs and branches cover) and this may reflect a difficulty in correctly locating the exact site limits. Site 7 (RS1) also showed many significant changes (increased rock, boulder and logs cover; decreased close-riparian cover, and decreased cover from twigs and branches, and root material). The exact site limits were identified for this site so the detected changes are definitely changes over time, not spatial differences. The changes are generally consistent with tree falls into the site as well as increased scouring associated with high flow events. Compared with the 1988–89 Wet season, the 2000–01 Wet had more high to very-high rainfall months (particularly January and February 2001), and so a greater-scouring explanation is plausible.

3.2.4 Site-group D (site 8)

Site 8 (RS2) also showed many significant changes (increased root material cover; decreased-close riparian cover, and decreased cover from sand, rocks, twigs and branches, and leaf litter). The exact site limits were identified for this site so these changes are definitely changes over time. As before, the changes are generally consistent with increased scouring associated with high flow events.

3.3 Correlates with basic-structural features of the fish communities

3.3.1 Number of fish (total density across all species)

Hydrological correlates – understanding of background processes

site-group differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and this basic-structural feature of the fish communities are shown in table 8 on a site-group basis. Across all site-groups, only 20 significant correlates were detected with only 4 (20%) of these being significant at the <5% probability level. Site-group A had the largest proportion of significant correlates (45%), although the largest proportion (75%) of significant correlates at the 5% level occurred at site-group B. Accordingly, if the detected associations were real, it appears that the feature is more influenced by hydrology in the lower site-groups, compared with the upper site-groups.

Table 8 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and a basic structural feature of the fish communities: the total density of fish across all species

	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	(+0.67,PCA2) (-0.63,>150MNS)	(-0.62,APRMF)		
	without	(+0.70,PCA2) (-0.66,>150MNS)	(-0.65,APRMF)		(-0.62,>300MNS)
Magela flow	with		-0.70,APRMF (-0.62,D>1)	(-0.69,D1-3) (-0.67,APRMF)	
	without			(-0.74,D1-3)	
Gulungul flow	without	(+0.63,D>1) -0.77,D>0 (-0.70,D0-1) (-0.67,JANMF) (-0.65,D1-2)	-0.89,D1-2 -0.80,APRMF	(-0.70,APRMF)	

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance. Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Hydrological-variable group differences. Considering only baseline ('without') correlates, the Gulungul Creek flow variables had a disproportionately high number of correlates (69% when 35% were expected; 100% *vs* 35% for 5%-level correlates), and Magela Creek flow variables had a low number (7.6% when 39% was expected). Accordingly, if the detected associations were real, it appears that the feature is more influenced by Gulungul Creek flows than Magela Creek flows.

Correlate sign and identity. By far the majority of the significant correlates were negative (94%; 100% of the 5%-level correlates were also negative; this excludes PCA axes which can have signs opposite to the flow variables). In terms of monthly flows or rains, 6 negative correlations were for April, 4 in site-group B and 2 in site-group C. This indicates that higher April flows and/or rains were associated with lower numbers of fish (densities) in the middle section of the creek. This may be related to less potential for fish stranding given that higher flows in this month allows migrating fish to reach Dry-season refuges. Another negative correlation was January and this was in site-group A. Duration-based correlates indicated that:

- *Site-group A:* lower numbers of fish were associated with longer Wet seasons and a longer duration of low flows
- *Site-groups B & C:* lower numbers of fish were associated with a longer duration of low flows
- *Site-group D:* lower numbers of fish were associated with more months with heavy rainfall (and hence greater flows)

The indications for site-groups A to C are consistent with a 'lower potential for stranding' explanation (i.e. successful refuge-seeking migration), particularly in relation to small fish species which can move during low flows. Given that site-group D is a refuge area, a stranding explanation is not relevant. A likely explanation here may be displacement downstream caused by high water velocities associated with high flows.

Three positive correlates only occurred within the site-group A, two of which were the 2nd-rainfall PCA axis which had a sign opposite to the flow variables. The interpretation of the association with the PCA axis is that higher numbers of fish were present in the most-downstream site-group (A) after shorter Wets, and particularly Wets with lower early- and first-half Wet-season rains linked with fewer months with rains moderate or greater. This is consistent with a 'reduced flows then stranding' mechanism.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Considering only the rainfall and Magela Creek flow variables, there was either no reduction or an increase in the number of correlates for site-groups A-C when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of a post-1989 disturbance operating within these site-groups. At site-group D the number of correlates decreased from one to zero. Little can be made of this small change.

Habitat correlates – understanding of background processes

No significant habitat correlates were detected with this feature of the fish communities (table 9) in either 1989 or 2001. The median correlates in both the 1989 and 2001 data were in the 0.4–0.6 range.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and this feature is also shown in table 9. No significant shifts in the spectrum were detected when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of a post-1989 disturbance operating within the creek.

Table 9 Summary of 1989-to-2001 shifts in the spectrum of Spearmans-rank correlations (r_s) between physiographic/habitat variables and two basic-structural features of the fish communities

Basic- structural feature variables	Number of correlates per r_s range: (sign ignored)						Correlates @ $r_s = \pm 1.0$		$\chi 2$ (df)	Significance?
	< 0.2	0.2 - 0.4	0.4 - 0.6	0.6- 0.8	0.8 - <1.0	1.0	+1.0	-1.0		
Total density of individuals across all species	1	11	11	9	4	0	none	none	3.6	ns
	1	15	14	3	3	0	none	none	(4)	
Total number of species	13	9	3	4	7	0	none	none	14.2	S
	3	8	10	7	5	3	WS-AQPL WS-ROOT	WS-BDEP	(5)	

Within each variable row the top sub-row is the 1989 result, and the lower sub-row is the 2001 result. Codes to the physiographic/habitat variable correlates are given in table 4. Chi-squared statistic = $\chi 2$; df = degrees of freedom; p = probability of occurrence by random chance (ns, p>0.05; S, significant, 0.05>p>0.01; H, highly significant, 0.01>p)

3.3.2 Numerical densities of seventeen individual fish species

Hydrological correlates – understanding of background processes

Site-group and sign-based differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and the seventeen fish species are shown in Appendices 1-17 on a site-group basis. A site-group and sign-based summary for the seventeen species is given in table 10.

Table 10 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and the numerical density of seventeen fish species: a site-group based summary

Fish species	Positive correlates					Negative correlates				
	n	Site groups				n	Site groups			
		A	B	C	D		A	B	C	D
Longtom	38					2				
Archerfish	36					4				
Banded grunter	31					0				
Narrow-fronted tandan	28					2				
Spangled perch	25					2				
Saratoga	22					3				
Hyrtli's catfish	15					7				
Black bream	6					3				
Midgley's grunter	7					5				
Fly-speckled hardyhead	5					4				
Pennyfish	0					3				
Mouth almighty	2					6				
Chequered rainbowfish	2					9				
Ambassid perchlets	1					19				
Blue-eyes	0					34				
Purple-spotted gudgeon	0					45				
Striped rainbowfish	0					59				

Only correlation values significant at p=<0.10 are included. Correlations with the principal component axes (PCA) are not included as their sign may be different from the hydrological variables. The total number of these correlation is broken up in relation to their sign, and graphically shown in relation the percentage distribution across the site groups A-D: Black, greater than 50%; dark grey, 25-50%; light grey, 10-25%;white, less than 10%. The species are ordered downwards in relation to decreasing dominance of positive correlates. n = number of significant correlates (excl. PCA axes)

Across all species most significant positive correlates occurred within site-group C, closely followed by site-group D. The least number occurred in site-group B. The ordering of species in relation to decreasing dominance of positive correlates appears also to correspond decreasing typical size of the species. That is, larger fish species tended to have a greater dominance of positive correlates, and this is most obvious in the most-upstream site-groups.

Across all species most significant negative correlates occurred within site-group B, followed by site-group C. The least number occurred in site-group D. It appears that species with a greater dominance of negative correlates were the smaller species.

Accordingly, it appears that large species were most frequently positively influenced by hydrological variables, particularly in the upper reaches of the creek. In contrast, small species were most frequently negatively influenced by hydrological variables, particularly in the lower reaches of the creek.

Hydrological-variable group differences. Considering only baseline ('without') correlates, the five highest incidence rates for significant correlates were as follows (see table 11):

- Striped rainbowfish – Magela Creek flow variables
- Striped rainbowfish – Gulungul Creek flow variables
- Archerfish – Gulungul Creek flow variables
- Purple-spotted gudgeon – Gulungul Creek flow variables
- Purple-spotted gudgeon and longtom – Magela Creek flow variables

It appears that larger species tended to have greatest incidences of correlates with the Magela Creek flow variables followed by the Gulungul Creek flow variables. Smaller species tended to have greatest incidences with Gulungul Creek flow variables followed by Magela Creek flow variables.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Changes in the number correlates when the current-condition sample was added to the baseline sample are given in table 11 for the seventeen fish species. Reductions in the number of correlates were apparent for the following species (in decreasing order):

- Archerfish – focus site-group C
- Longtoms – focus site-group D
- Narrow-fronted tandan –focus site-group C
- Banded grunter – focus site-group C
- Blue-eyes –focus site-group C
- Striped rainbowfish – focus site-group C

Accordingly, this is potential evidence for the involvement of a post-1989 disturbance. It appears that predominately larger species, which have positive relationships with flow/rainfall variables, were mostly affected. The upstream site-group focus for these reductions indicates that such a disturbance would not be operating in the lower reaches of the creek. It is notable that the archerfish was the species that Bishop and Walden (2001) detected a significant decline in abundance within two site-groups. No time trends were detected by Bishop and Walden for the other five species listed above. Bishop and Walden (2001) detected time trends for the spangled grunter and the mouth-almighty, yet no evidence of a post-1989 disturbance was apparent for them.

Table 11 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and the numerical density of seventeen fish species: summaries in relation to i) the disturbance-investigation, and ii) the across-hydrological-variable-group differences

Fish species	I) Disturbance investigation: (differences between 'with 2001' and 'without 2001' samples; only rainfall & Magela Ck. variables)			II) Across hydrological- variable-group differences: (standardised by only considering 'without 2001' data and then expressing the incidence as a rate per the number of variables examined)		
	with 2001	without 2001	difference: (with *minus* without)	Rainfall	Magela flow	Gulungul flow
Longtom	17	15	-3	0.71	1.09	0.84
Archerfish	4	10	-6	0.43	0.91	1.37
Banded grunter	13	15	-2	0.50	0.59	0.37
Narrow-fronted tandan	15	18	-3	0.86	0.68	0.05
Spangled perch	14	13	+1	0.64	0.68	0.53
Saratoga	14	12	+2	0.64	0.45	0.16
Hyrtli's catfish	9	8	+1	0.50	0.23	0.68
Black bream	8	6	+2	0.43	0.00	0.11
Midgley's grunter	9	6	+3	0.29	0.23	0.00
Fly-speckled hardyhead	7	3	+4	0.29	0.05	0.00
Pennyfish	3	2	+1	0.14	0.09	0.00
Mouth almighty	5	4	+1	0.21	0.05	0.00
Chequered rainbowfish	5	3	+2	0.00	0.23	0.53
Ambassid perchlets	6	3	+3	0.21	0.00	0.95
Blue-eyes	13	15	-2	0.50	0.82	0.84
Purple-spotted gudgeon	21	19	+2	0.86	1.09	1.26
Striped rainbowfish	24	26	-2	0.29	1.50	1.37

I) Disturbance investigation: a possible disturbance is inferred if the number of significant correlates decreases (negative difference) when the 2001 data is included in the analysis (analysis without the 2001 data is 'without 2001'; analysis with the 2001 data is 'with 2001'). *Shading Key:* dark grey = largest decrease; mid grey = 2nd largest; light grey = 3rd largest

II) Across hydrological-variable-group differences: a possible greater dependence on a hydrological variable group is inferred if the incidence rate is noticeably higher for one of the three groups. *Shading key:* dark grey = highest incidence per species; light grey = 2nd highest variable per species

The species are ordered downwards in relation to decreasing dominance of positive correlates. Only correlation values significant at p=<0.10 are included

Habitat correlates – understanding of background processes

Significant habitat correlates detected for each species are listed in table 12. It was apparent that the larger fish species generally had the greatest number of significant correlates, and these were predominately positive. The key correlate groups were:

- undercut-depth variables: *associated species* – narrow fronted tandan, saratoga and longtoms
- distance, stream-gradient & far riparian-cover variables: *associated species* – black bream, spangled grunter & Midgley's grunter

Only in site-group B was there a undercut-depth change (a small increase) between 1989 and 2001.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and the seventeen fish species is also shown in table 12. The only species which showed significant negative shifts (reductions) was the longtom. Accordingly, there was evidence of a post-1989 disturbance operating within the creek for this species. Longtoms also displayed reductions in the number of hydrological correlates. However, Bishop and Walden (2001) did not detect significant time trends for this species.

Table 12 Summary of 1989-to-2001 shifts in the spectrum of Spearmans-rank correlations (r_s) between physiographic/habitat variables and the numerical density of seventeen fish species (basic structural features of the fish communities)

Fish species	Number of correlates per r_s range: (sign ignored)						Correlates @ $r_s = \pm 1.0$		χ2 (df)	Significance?
	< 0.2	0.2 - 0.4	0.4 - 0.6	0.6-0.8	0.8 - <1.0	1.0	+1.0	-1.0		
Narrow-fronted tandan	0	6	1	10	18	1	CL-RIPF	none	6.6 (5)	ns
	1	7	1	15	6	6	WS-LOGS WS-MCUT WS-CCUT WS-DCUT WS-DCU WS-ODIV	none		
Black bream	0	6	1	10	18	1	CL-RIPF	none	13.4 (5)	S
	2	3	3	10	9	9	DIST CL-GRMX UP-GRMN UP-GRMX DN-GRMN DN-GRMX WS-RIPF	WS-SAND WS-ADEP		
Spangled grunter	0	6	1	10	18	1	CL-RIPF	none	13.4 (5)	S
	2	3	3	10	9	9	DIST CL-GRMX UP-GRMN UP-GRMX DN-GRMN DN-GRMX WS-RIPF	WS-SAND WS-ADEP		
Midgley's grunter	0	6	1	10	18	1	CL-RIPF	none	13.4 (5)	S
	2	3	3	10	9	9	DIST CL-GRMX UP-GRMN UP-GRMX DN-GRMN DN-GRMX WS-RIPF	WS-SAND WS-ADEP		
Saratoga	0	7	2	13	10	4	WS-TWBR WS-MCUT WS-CUT WS-DCU	none	5.8 (5)	ns
	3	3	3	7	17	3	CL-RIPF WS-DSUB	WS-ACUT		
Longtom	0	7	2	13	11	4	WS-TWBR WS-MCUT WS-CCUT WS-DCU	none	27.2 (5)	HS
	16	7	3	4	5	0	none	none		
Banded grunter	0	6	1	10	18	1	CL-RIPF	none	5.6	ns

Fish species	Number of correlates per r_s range: (sign ignored)						Correlates @ $r_s = \pm 1.0$		$\chi2$ (df)	Significance?
	< 0.2	0.2 - 0.4	0.4 - 0.6	0.6-0.8	0.8 - <1.0	1.0	+1.0	-1.0		
	2	3	4	7	17	3	CL-RIPF WS-DSUB	WS-ACUT	(5)	
Blue-eyes	6	2	8	10	10	0	none	none	10.5 (5)	ns
	3	7	12	6	5	3	WS-AQPL WS-BDEP	WS-DDEP		
Striped rainbowfish	1	10	12	9	4	0	none	none	4.1 (4)	ns
	1	14	15	3	3	0	none	none		
Chequered rainbowfish	1	10	12	9	4	0	none	none	4.1 (4)	ns
	1	14	15	3	3	0	none	none		
Pennyfish	2	1	6	10	15	2	WS-AQPL	WS-DSUB	10.2 (5)	ns
	2	5	1	6	22	0	none	none		
Mouth almighty	1	13	12	7	3	0	none	none	27.4 (5)	HS
	2	3	3	10	9	9	none	none		
Archerfish	36	0	0	0	0	0	none	none	0.0 (1)	ns
	36	0	0	0	0	0	none	none		
Purple-spotted gudgeon	1	10	12	9	4	0	none	none	24.1 (4)	HS
	3	5	1	6	21	0	none	none		
Hyrtli's catfish	2	19	6	6	3	0	none	none	19.7 (5)	HS
	3	4	3	12	12	2	none	WS-LELI WS-CDEP		
Flyspecked hardyhead	1	10	12	9	4	0	none	none	22.8 (5)	HS
	0	2	3	11	18	2	none	CL-GRMN WS-MDEP		
Ambassid perchlets	2	5	1	13	14	4	WS-ADEP	CL-GRMN WS-RIPF WS-MDEP	7.8 (5)	ns
	2	5	1	6	22	0	none	none		

Within each species row the top sub-row is the 1989 result, and the lower sub-row is the 2001 result. Codes to the physiographic/habitat variable correlates are given in table 4. Chi-squared statistic = $\chi2$; df = degrees of freedom; p = probability of occurrence by random chance (ns, p>0.05; S, significant, 0.05>p>0.01; H, highly significant, 0.01>p).

The species are arranged from top to bottom in relation to a decreasing dominance of r_s = +1.0 correlates (1989 and 2001 correlates combined).

3.3.3 Number of species

Hydrological correlates – understanding of background processes

Site-group differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and this basic-structural feature of the fish communities are shown in table 13 on a site-group basis. Across all site-groups, 31 significant correlates were detected with 18 (58%) of these being significant at the <5% probability level. Site-group C had the largest proportion of significant correlates (45%) closely followed by site-group D (42%). This placing also held for the number of significant correlates at the <5% level (56% and 19% respectively). Accordingly, if the detected associations were real, it appears that the feature is more influenced by hydrology in the upper site-groups, compared with the lower site-groups.

Hydrological-variable group differences. Considering only baseline ('without') correlates, the Magela Creek flow variables had a disproportionately high number of correlates (53% when 39% were expected; although 44% vs 39% for <5%-level correlates), and the rainfall flow variables had a low number (17.6% when 26% was expected). Accordingly, if the detected associations were real, it appears that the feature is more influenced by Magela Creek flows than rainfall.

Table 13 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and a basic structural feature of the fish communities: the total number of species present

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with		+0.71,NOVMT	(+0.62,NOVMT)	+0.69,>150MNS
	without		+0.71,NOVMT		(+0.68,DECMT) (+0.65,>150MNS)
Magela flow	with	(+0.61,D1-3) (+0.61,PCA3)		+0.80,D>9 +0.79,D>1 +0.78,D>3 +0.78,D9-27 +0.74,APRMF +0.70,PCA2	+0.77,JANMF +0.70,D>1 (+0.64,D>3) (+0.62,D>9)
	without			+0.78,D>9 +0.77,D>1 +0.77,D9-27 +0.75,D>3 (+0.71,APRMF) (+0.69,PCA2)	(+0.68,JANMF) (+0.65,DECMF) (+0.62,D>1)
Gulungul flow	without			(+0.65,APRMF)	+0.89,D0-1 +0.77,D>0 +0.75,PCA2 +0.71,JANMF

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Correlate sign and identity. All of the significant correlates were positive, including the PCA axes. In terms of monthly flows or rains:

- *Site-group B:* 2 correlates for November
- *Site-group C:* 1 correlate for November, 3 correlates for April
- *Site-group D:* 2 correlates were for December, 3 correlates were for January

This indicates that higher flows and/or rains in these months were associated with higher numbers of species in the respective site-groups. Given that i) the site-groups tend to be further upstream, and ii) Magela Creek flows appear to be a 'driver' of the feature, it is likely that successful upstream dispersal of fish, typically found in Magela Creek, is the basis of these associations. Large flows would allow larger fish species penetrate further upstream.

Duration-based correlates indicated that:

- *Site-group A & B:* greater numbers of fish species were associated with a longer duration of low flows

- *Site-groups C:* greater numbers of fish species were associated with a longer duration of low-moderate flows
- *Site-group D:* greater numbers of fish species were associated with longer Wet seasons and a longer duration of low-moderate flows

These indications are consistent with a 'successful upstream dispersal of Magela Creek fish' explanation.

PCA-axis correlations indicated that:

- *Site-group A:* greater numbers of fish species were associated with a higher duration of moderately-high Magela Creek flows, higher January & February flows, but lower March flows and a lower duration of high-to-very-high flows (i.e. Magela-Creek PCA-axis-3 scores)
- *Site-groups C:* greater numbers of fish species were associated with a higher duration of low-moderate Magela Creek flows, higher December & April flows, but lower February flows and a lower duration of high-to-very-high flows (i.e. Magela-Creek PCA-axis-2 scores)
- *Site-group D:* greater numbers of fish species were associated with higher duration of high flows, higher February flows, lower duration of lower flows, lower January and April flows (i.e. Gulungul-Creek PCA-axis-2 scores)

These indications are generally consistent with a 'successful upstream dispersal of Magela-Creek-derived fish' explanation.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Considering only the rainfall and Magela Creek flow variables, there was either no reduction or an increase in the number of correlates for site-groups A-D when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of a post-1989 disturbance operating within these site-groups. At site-group D the number of correlates decreased from two to one for the rainfall variables. Little can be made of this small change.

Habitat correlates – understanding of background processes

In 1989 no significant habitat correlates were detected with this feature of the fish communities (table 9is this the correct table reference?). The median correlate was in the 0.2–0.4 range.

In 2001 three significant habitat correlates were detected, positive associations with aquatic plants and root material, and a negative association with water depths in the range 0.2 to 1.0 m. The median correlate was in the 0.4–0.6 range.

From 1989 to 2001 the cover provided by aquatic plants increased in site-groups B and C, but decreased in site-group A. The cover provided by root material also changed between 1989 and 2001: an increase in site-group A, an increase and a decrease in site-group C, and an increase in site-group D.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and this feature is also shown in table 9is this the correct table reference?. A significant positive shift in the spectrum was detected when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of a post-1989 disturbance operating within the creek (a negative shift would possibly identify the presence of such a disturbance).

3.4 Correlates with compositional-structure features of the fish communities

3.4.1 'Evenness' of densities across species

Hydrological correlates – understanding of background processes

Site-group differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and this feature of the fish communities are shown in table 14 on a site-group basis.

Table 14 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and a compositional-structure feature of the fish communities: the evenness index

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with			-0.72,JANMT	+0.69,NOVMT +0.65,ONDMT (+0.64,>150MNS) -0.72,PCA2
	without	(+0.69,JANMT)		-0.74,JANMT	+0.66,NOVMT +0.65,>150MNS +0.65,ONDMT -0.74,PCA2
Magela flow	with		+0.73,D1-3		+0.68,DECMF +0.67,D>9 (+0.62,D>3) (+0.61,D9-27) (+0.60,WETTD)
	without		+0.74,D1-3		+0.73,D>9 (+0.68,D27-81) (+0.68,DECMF) (+0.66,D>27) (+0.66,D>3) (+0.65,JANMF) (+0.63,WETTD) (+0.62,D9-27) (-0.61,PCA1)
Gulungul flow	without		(+0.66,APRMF)		

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Across all site-groups, only 27 significant correlates were detected with 13 (50%) of these being significant at the <5% probability level. Site-group D had by far the largest proportion of significant correlates (78%). This also was the case (86%) for correlates significant at the <5% level. Accordingly, if the detected associations were real, it appears that the feature is more influenced by hydrology within the most-upstream site-group, compared with the downstream site-groups.

Hydrological-variable group differences. Considering only baseline ('without') correlates, the Magela Creek flow variables had a disproportionately high number of correlates (63% when 39% were expected). However, in terms of correlates significant at the <5%-level, the rainfall variables had a disproportionately high number (71% when 26% were expected). Surprisingly, the Gulungul Creek flow variables only had one significant correlate. Accordingly, if the detected associations were real, it appears that the feature is more influenced by Magela Creek flows and rainfall than Gulungul Creek flows.

Correlate sign and identity. By far the majority of the significant correlates were positive (92%; 83% of the 5%-level correlates were also positive; this excludes PCA axes which can have signs opposite to the flow variables). In terms of monthly flows or rains:

- *Site-group A:* 1 positive correlate for January
- *Site-group B:* 1 positive correlate for April
- *Site-group C:* 2 negative correlates for January; site-group C
- *Site-group D:* 6 positive correlates were for Early-wet season months; 2 positive correlates were for the total Wet season flows; 1 positive correlate for January

This indicates, for the positive correlates, that higher flows and/or rains in the above periods were associated with a greater evenness of fish communities, particularly in site-group D.

Duration-based correlates indicated that:

- *Site-group D:* higher evenness of communities were associated with longer Wet seasons and a longer duration of high to very-high flows
- *Site-group B:* higher evenness of communities were associated with a longer duration of low flows

The indications for site-group D may be consistent with small, numerous fish species (e.g. the striped rainbowfish) being displaced downstream by high to very-high flows. Reductions in the numbers of such species would result in the relative abundance of remaining species being more equal.

PCA-axis correlations indicated that:

- *Site-group D:* lower 'evenness' of fish communities was associated with lower early- and first-half Wet-season rains linked with fewer months with rains moderate or greater (i.e. rainfall PCA-axis-2 scores), and lower total Wet-season Magela Creek discharge, lower March flows, and lower duration of low to high flows (i.e. Magela Creek PCA-axis-1 scores).

For the rainfall PCA axis, there is some consistency with an explanation involving the downstream displacement of numerous small fish species.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Considering only the rainfall and Magela Creek flow variables, there was a reduction in the number of correlates for site-group D when the current-condition sample was added to the baseline sample. Accordingly, there was evidence of a post-1989 disturbance operating within this most-upstream site-group.

Habitat correlates – understanding of background processes

One significant habitat correlate (far-riparian cover close to the sites) was detected with this feature of the fish communities (table 15). The median correlate in the 1989 data was in the 0.8–1.0 range. In 2001 the median correlate was on the lower border of the 0.4–0.6 range.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and this feature is also shown in table 15. A significant negative shifts in the spectrum (reduction in correlate numbers) was detected when the current-condition sample was added to the baseline sample. Accordingly, there was evidence of post-1989 disturbance operating within the creek.

Table 15 Summary of 1989-to-2001 shifts in the spectrum of Spearmans-rank correlations (r_s) between physiographic/habitat variables Spearmans-rank correlations and three compositional-structure features of the fish communities

Compositional-structure feature variables	**Number of correlates per r_s range: (sign ignored)**						**Correlates @ r_s = ± 1.0**		**$\chi 2$ (df)**	**Significance?**
	< 0.2	**0.2 – 0.4**	**0.4 - 0.6**	**0.6- 0.8**	**0.8 - <1.0**	**1.0**	**+1.0**	**-1.0**		
Evenness index	0	6	1	8	18	1	CL-RIPF	none	11.1 (3)	S
	0	18	4	6	8	0	none	none		
Community composition: ordination axis 1	1	4	0	14	10	7	DIST CL-GRMX UP-GRMN UP-GRMX DN-GRMN DN-GRMX WS-DSUB	none	4.2 (5)	ns
	2	3	3	10	9	9	DIST CL-GRMX UP-GRMN UP-GRMX DN-GRMN DN-GRMX WS-RIPF	WS-SAND WS-ADEP		
Community composition: ordination axis 2	2	20	6	5	3	0	none	none	6.2 (4)	ns
	9	14	6	3	4	0	none	none		

Within each variable row the top sub-row is the 1989 result, and the lower sub-row is the 2001 result. Codes to the physiographic/habitat variable correlates are given in table 4. Chi-squared statistic = $\chi 2$; df = degrees of freedom; p = probability of occurrence by random chance (ns, p>0.05; S, significant, 0.05>p>0.01; H, highly significant, 0.01>p)

3.4.2 Ordination axis one

Hydrological correlates – understanding of background processes

Site-group differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and this feature of the fish communities are shown in table 16 on a site-group basis. Across all site-groups, only 24 significant correlates were detected with only 7 (29%) of these being significant at the <5% probability level. Site-group C had the largest proportion of significant correlates (58%). This also followed (71%) for correlations significant at the <5% level. Site-group D had the next highest number of correlates (25%). Accordingly, if the detected associations were real, it appears that the feature is more influenced by hydrology in the upper site-groups (particularly site-group C), compared with the lower site-groups.

Table 16 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and a compositional-structure feature of the fish communities: ordination axis one

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with			(+0.62,>300MNS) (-0.65,PCA2)	(-0.62,APRMT)
	without				(+0.66,OCTMT) (-0.61,APRMT)
Magela flow	with			(+0.66,D>243) (+0.66,D243-729) (+0.62,WETTD) (+0.60,D>3) (-0.66,PCA1)	-0.71,D1-3
	without		-0.79,PCA3	+0.82,D>243 +0.82,D243-729	(-0.68,D1-3)
Gulungul flow	without	(+0.64,D>0)	(+0.69,D1-2) (+0.67,DECMF)	+0.84,DECMF +0.77,D>0 +0.76,D>16 (+0.73,D>1) (+0.68,JANMF) -(0.70,PCA1)	(-0.66,APRMF)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Hydrological-variable group differences. Considering only baseline ('without') correlates, the Gulungul Creek flow variables had a disproportionately high number of correlates (60% when 35% were expected). However , when only <5%-level correlations were considered, the same number correlates were found for the Gulungul and Magela Creek variables. The rainfall variables had a low number of significant correlates (13% when 26% was expected). Accordingly, if the detected associations were real, it appears that the feature is more influenced by Gulungul and Magela Creek flows than rainfall.

Correlate sign and identity. The majority of the significant correlates were positive (76%; 83% of the 5%-level correlates were also positive; this excludes PCA axes which can have signs opposite to the flow variables). However, this varied between site-groups, specifically, Site-group D was dominated by negative correlates.

In terms of monthly flows or rains:

- *Site-group B:* 1 positive correlate for December
- *Site-group C:* 1 positive correlate for December; 1 positive correlate for January
- *Site-group D:* 1 positive correlate was for October; 3 negative correlates were for April

Given that Bishop and Walden (2001) found that the ordination axis was positively correlated with the abundance of escarpment-associated species, it is plausible that higher flows would allow these species to occupy the middle reaches of the creek (hence the positive correlations in site-groups B & C). The negative correlations with April flows in site-group D may reflect a flow-facilitated delay in upstream-returning movements of the escarpment- associated species.

Duration-based correlates indicated that:

- *Site-group A:* larger ordination scores were associated with longer Wet (flow) seasons
- *Site-group B:* larger ordination scores were associated with a longer duration of moderate flows
- *Site-group C:* larger ordination scores were associated with longer Wet (flow) seasons and a longer duration high to very-high flows
- *Site-group D:* larger ordination scores were associated with a shorter duration of moderate flows

Site-group D clearly stood out from the other site-groups. The basis of this is unclear.

PCA-axis correlations indicated that:

- *Site-group B:* lower ordination scores were associated with higher duration of moderately-high Magela Creek flows, higher January & February flows, but lower March flows and a lower duration of high-to-very-high flows (i.e. Magela Creek PCA-axis 3 scores)
- *Site-groups C:* lower ordination scores were associated with lower early- and first-half Wet-season rains linked with fewer months with rains moderate or greater (i.e. rainfall PCA-axis-2 scores), lower total Wet-season Magela Creek discharge, lower March flows, and lower duration of low to high flows (i.e. Magela Creek PCA-axis-1 scores), and lower duration of most Gulungul Creek flows linked with lower total-Wet discharge and lower December and March flow. (i.e. Gulungul Creek PCA-axis-1)

This arrangement of PCA-axis correlates appears to relate to a feature that fewer escarpment-habitat-associated species were found in the middle reaches of the creek when flows were lower, i.e. during drier Wets.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Considering only the rainfall and Magela Creek flow variables, there were increases in the number of correlates for site-group C when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of a post-1989 disturbance operating within this site-group.

At site-group D the number of rainfall correlates decreased from two to one. Similarly, the number of Magela Creek correlates decreased from one to zero at site-group B. Little can be made of these small changes.

Habitat correlates – understanding of background processes

A large number of significant habitat correlates were detected with this feature of the fish communities in both 1989 and 2001 (table 15). The variables combination for both years had the following correlates in common:

- distance, stream-gradient & far riparian-cover variables

These are the same correlates found in Section 3.3.2 to be associated with the black bream, spangled grunter & Midgley's grunter. It appears this ordination axis strongly reflects longitudinal habitat differences, particularly those associated with changes in physiography. These variables are unlikely to have changed between 1989 and 2001.

The median correlate in the 1989 data was in the 0.2–0.4 range. In 2001 the median correlate was also in this range.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and this feature is also shown in table 15. No significant shifts in the spectrum were detected when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of post-1989 disturbance operating within the creek.

3.4.3 Ordination axis two

Hydrological correlates – understanding of background processes

Site-group differences. Significant across-year Spearman's-rank correlations between the 'hydrological' variables and this feature of the fish communities are shown in table 17 on a site-group basis. Across all site-groups, 53 significant correlates were detected with 32 (60%) of these being significant at the <5% probability level. The high number of hydrological correlates suggests that this ordination axis reflected changes brought about by differences in hydrology between Wet seasons.

Site-group C had the largest proportion of significant correlates (43%). This focus persisted (59%) when correlates significant at the <5% level occurred were considered. Site-group D had the next highest number of correlates (25%). Accordingly, if the detected associations were real, it appears that the feature is more influenced by hydrology in the upper site-groups (particularly site-group C), compared with the lower site-groups. This focus was the same as for the first ordination axis.

Hydrological-variable group differences. Considering only baseline ('without') correlates, the Gulungul Creek flow variables had a disproportionately high number of correlates (58% when 35% were expected; 50% vs 35% for <5%-level correlates). Rainfall variables had a low number (16% when 26% was expected). However, when only <5%-level correlates were considered, the rainfall variables had comparable proportions to the Gulungul Creek flow variables: 43 (26% expected) vs 50% respectively. Accordingly, if the detected associations were real, it appears that the feature is most influenced by Gulungul Creek flows.

Table 17 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and a compositional-structure feature of the fish communities: ordination axis two

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with	(+0.64,>150MNS) (-0.68,PCA2)	(+0.68,NOVMT) (+0.60,APRMT)	(-0.61,MARMT)	-0.66,>300MNS
	without	(+0.67,DECMT) (-0.65,PCA2)	(+0.69,NOVMT) (-0.72,MARMT) (-0.68,>400MNS)	(-0.73,MARMT)	-0.82,>300MNS
Magela flow	with		(+0.67,PCA2)		(-0.64,MARMT)
	without		(+0.67,PCA2) -0.78,MARMT	+0.90,PCA1 -0.93,D27-81 -0.92,MARMF -0.90,D>243 -0.90,D243-729 -0.84,WETTD -0.81,D>27 -0.77,D>3 -0.75,D>9 -0.70,DECMF	
Gulungul flow	without	+0.85,JANMF +0.77,D>0 (+0.71,DECMF)	-0.76,MARMF	+0.88,PCA1 -0.92,MARMF -0.89,D2-4 -0.83,DECMF -0.87,D>16 -0.81,D>1 -0.79,D>2 -0.77,D>0 -0.74,WETTD (-0.65,D4-8) (-0.62,D1-2)	+0.75,PCA1 -0.82,D>1 -0.75,WETTD -0.75,DECMF -0.73,JANMF -0.73,D4-8 -0.70,D1-2 (-0.65,D>4) (-0.62,D>2) (-0.62,D>0) (-0.60,MARMF)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Correlate sign and identity. The majority of the significant correlates were negative (68%; 62% of the 5%-level correlates were also negative; this excludes PCA axes which can have signs opposite to the flow variables). However, this varied between site-groups. For example, site-group A only had positive correlates, site-group B had both positive and negative, and site-groups C and D only had negative correlates. Accordingly, a longitudinal shift in signs was apparent.

In terms of monthly flows or rains:

- *Site-group A*: 2 positive correlates for December; 1 positive for January
- *Site-group B:* 2 positive correlates for November, 3 negative correlates for March; 1 positive correlate for April
- *Site-group C:* 1 negative correlation for total Wet season discharge; 2 negative correlates for December; negative correlates for March
- *Site-group D:* 1 negative correlate was for December; 1 negative correlate was for January; 2 negative correlates for March

Clear differences in the sign and the month per site-group are apparent. The basis of these are unclear.

Duration-based correlates indicated that:

- *Site-group A:* larger ordination scores were associated with longer Wet (flow) seasons
- *Site-group B:* larger ordination scores were associated with a shorter duration of very-high flows
- *Site-group C:* larger ordination scores were associated with a shorter duration of moderate to very-high flows
- *Site-group D:* larger ordination scores were associated with a shorter duration of the Wet season and low to high flows

The basis of this configuration of correlates is unclear.

PCA-axis correlations indicated that:

- *Site-group A:* lower ordination scores were associated with lower early- and first-half Wet-season rains linked with fewer months with rains moderate or greater (i.e. rainfall PCA-axis-2 scores)
- *Site-group B*: higher ordination scores were associated with higher duration of low-moderate flows, higher December & April flows, but lower February flows and a lower duration of high-to-very-high flows (i.e. Magela Creek PCA-axis-2 scores)
- *Site-group C:* higher ordination scores were associated with lower total Wet-season Magela Creek discharge, lower March flows, and lower duration of low to high flows (i.e. Magela Creek PCA-axis-1 scores), and lower duration of most Gulungul Creek flows linked with lower total-Wet discharge and lower December and March flow (i.e. Gulungul Creek PCA-axis-1 scores)
- *Site-group D:* higher ordination scores were associated with a lower duration of most Gulungul Creek flows linked with lower total-Wet discharge and lower December and March flow (i.e. Gulungul Creek PCA-axis-1 scores)

The basis of this configuration of the PCA axes possibly relates to less-successful upstream penetration of downstream-derived species during drier Wets (lower flows and shorter duration). These species would only become common in the most-downstream site-group (A), hence the lower ordination scores there (Bishop and Walden [2001] showed that the downstream-derived fish species were negatively correlated with the ordination axis). They would be very uncommon in the most-upstream site-groups (C & D), hence the high ordination scores there.

Hydrological correlates – evidence of non-hydrological post-1989 disturbance?

Considering only the rainfall and Magela Creek flow variables, there was major reduction in the number of correlates for the site-group C when the current-condition sample was added to the baseline sample. Accordingly, there was evidence of a post-1989 disturbance operating within site-group C.

Habitat correlates – understanding of background processes

No significant habitat correlates were detected with this feature of the fish communities (table 15). The median correlate in the 1989 data was in the 0.2–0.4 range. In 2001 the median correlate was in the same range.

Habitat correlates – evidence of non-habitat post-1989 disturbance?

A summary of 1989-to-2001 shifts in the spectrum of correlations with habitat variables and this feature is also shown in table 15. No significant shifts in the spectrum were detected when the current-condition sample was added to the baseline sample. Accordingly, there was no evidence of post-1989 disturbance operating within the creek.

4 Discussion and conclusions

As for the previous ‘first-pass’ report (IR405 – Bishop & Walden 2003), the central interest of the present investigation was the detection of any disturbances on the fish communities of Gulungul Creek arising from the Ranger Mine. Before focusing on this aspect it is first necessary to synthesise findings in relation to what environmental changes have occurred since 1989, and what understanding of ‘background’ processes has arisen from the correlation analysis.

4.1 Environmental change since 1989

4.1.1 Hydrological change

In terms of rainfall, the 2000–01 Wet stood out from the other baseline-period Wets in having these features:

- shorter prior Dry season linked with higher October & February rains, higher early- and first-half Wet-season rains and more moderate, high and very-high rainfall months (i.e. longer Wet season rains)

Correspondingly, in terms of Magela Creek flows, the 2000–01 Wet stood out from other baseline-period Wets in having:

- higher total Wet-season discharge, higher January-March flows, and higher a duration of low, moderate and high flows, but a lower duration of very-high flows

In other words, the 2000–01 Wet was a wet-Wet, having characteristics (including the length of the prior Dry season) different from all of the baseline Wets. Accordingly, it is reasonable to expect that these unique features could have translated into unique alterations in structural features of the creek’s fish communities.

4.1.2 Change in the habitat character of the sites

Within the censusing sites changes were detected in some habitat features between 1989 and 2001. Of prime interest were such habitat features which were correlated with structural features of the fish communities. This restriction puts focus on the following two variables, both of which were positively correlated with the total number of fish species (TNS) present:

- aquatic-plant cover (losses & gains in site-group A, gains in B & C), and
- root-material cover (gains in site-groups A, C & D),

It appears quite unlikely that 1989-to-2001 changes in these environmental variables were of a sufficiently high magnitude to significantly influence TNS across the period given that: i) Bishop and Walden (IR405 – 2003) found no significant baseline-to-current-condition differences in TNS within and between the two downstream site-groups (A and B), and ii) within the present investigation there was no evidence of an alternate (stronger) post-1989 disturbance operating on TNS within the creek. Accordingly, the influence on TNS of the particular magnitude of the 1989–2001 changes in these variables can generally be considered to be quite low.

4.2 Understanding of ‘background’ processes

An interpretative summary of the correlation-analysis findings is given in table 18. As a caveat, it is noteworthy that the correlation-analysis approach was undertaken because of its time efficiency (high return of information per unit of effort), a necessary strategy given very limited time resources for the investigation. The ideal analytical tools would have been analysis of covariance linked with multiple-regression analysis. However, even the effectiveness of such tools would have been limited given the prior-pooling of the fish-community data in the 'first-pass' report (IR405 – Bishop & Walden 2003), as well as temporal limitations in the habitat data (only collected in 1989 and 2001). Nevertheless, the structured and detailed approach taken in the correlation analysis revealed major insights into the hydrology- and habitat-driven dynamics of the Late-wet–Early-dry season fish communities in Gulungul Creek.

4.2.1 Numerical density across all species

Variation in this feature appears to be strongly driven by stranding-then-concentration events. Near-stranding events are also likely to be important, eg. the accumulation of upstream migrants below difficult passage obstacles such as shallow runs or riffles. The driver for this is clearly very low flows, or no flows, particularly in April when small fish species (e.g. ambassid perchlets, pennyfish, rainbowfish, hardyheads) are attempting upstream refuge-seeking migrations. The lower reaches of the creek, i.e. site-groups A & B, is the spatial focus of such a process, an expected result given that flows first become critically low in this section of the creek as the Dry season approaches.

In the 2000–01 Wet, the flows in April were higher than most baseline Wets, and as expected, when compared with the baselines, the numerical densities were lower (IR405 – Bishop & Walden 2003). Also in the 2000–01 Wet, the densities were higher in the downstream site-group A compared with the upstream site-group B, a result opposite to that usually found in the baseline period. It is possible that since the baseline period the bed structure may have changed making upstream migrations more difficult within the site-group A section – thus accumulations and higher densities of fish would occur therein. In Section 3.2 it was noted that there appeared to be an increase in the sand bedload in the site-group A creek section. This may cause passage difficulties if small species need to negotiate wide, open shallow areas which have few substrate features to provide cover from water velocity and predators (the sand 'slug' would cover such substrate features).

A Scenario-1 mine disturbance in this section would be difficult to detect by just comparing this feature between site-groups A and B. On the assumption that a mine disturbance would cause physiological stress on non-migrants and upstream migrants in site-group A, it would be expected that:

- the density of *non-migrants* would be suppressed in site-group A (compared to B), and
- the density of *upstream migrants* would be elevated in site-group A as they would be less able to continue their migration because of reduced ability or inclination to surmount difficult passage obstructions

The response of the upstream migrants may be confounded if they discontinue their migration and return downstream (avoidance). Confounding may also occur with changes in the nature of the passage obstructions. To counter this problem the following feature (F1) should be investigated:

- F1: the ratio of the number of upstream migrants successfully negotiating a passage difficulty, to the number of upstream migrants present in the downstream staging-pool

This is likely to be quite sensitive to Scenario-1 mine disturbances as it avoids the confounding factor and, in essence, targets the *fitness* of fish. Observations would need a reference condition, ideally in a separate but similar creek system. Clearly, the hydraulic character of the passage obstacles would need to be standardised. The work would be best undertaken at the species level, with upstream-migrating species clearly distinguished.

Table 18 Summary and possible interpretation of the correlation analysis findings: understanding of background processes

Correlation feature	Basic-structural features			Compositional-structure features		
	Numerical density across all species	**Numerical density of individual species (17)**	**Number of species**	**Evenness index**	**Ordination axis 1**	**Ordination axis 2**
Hydrological variables						
Significant correlation incidence rate*	@ <10% level: 9%(20) @ <5%-level: 2%(4)	larger & small spp: many middle-size spp: few	@ <10% level: 14%(31) @ <5%-level: 8%(18)	@ <10% level: 12%(27) @ <5%-level: 6%(13)	@ <10% level: 11%(24) @ <5%-level: 3%(7)	@ <10% level: 24%(53) @ <5%-level: 15%(32)
Site-group focus	lower reaches (A & B)	larger species: C then D small species: B then C	upper reaches (C & D)	strongly upper (D)	upper reaches (C then D)	upper reaches (C then D), but also in lower reaches
Variable-group focus	High: Gulungul (69%) Low: Magela (5%)	larger species: Magela small species: Gulungul	High: Magela (53%) Low: Rainfall (18%)	High: Magela (63%) Low: Gulungul (42%)	High: Gulungul (60%) Low: Rainfall (13%)	High: Gulungul (68%) Low: Rainfall (13%)
Correlation sign	negative 94%	larger species: positive small species: negative	positive 100%	positive 92%	positive 76%	positive 68%; longitudinal trend with +ve downstream and -ve upstream
Nature of correlates	higher flows in April result in lower densities; shorter duration of low flows result in higher densities in site-groups A &B	*larger spp:* high flows promote high densities upstream *small spp:* high flows suppress high densities downstream	more species with higher flows early & late in the Wet	high evenness with higher flows especially at site-group D	low flows & shorter Wets result in lower ord. scores in the middle & lower reaches	higher flows result in higher ord. scores in the lower reaches and lower ord. scores in the upstream reaches
Possible interpretation	*lower reaches*: very low flows resulting in stranding of small fish species, i.e. failed refuge-seeking migrations; *most upstream:* downstream displacement of small & numerous fish species (MN) by high flows	*larger spp:* high flows allow successful upstream migration *small spp:* high flows tend to prohibit stranding in the lower reaches + very high flows downstream displace small species from the upper reaches	higher flows 'promote' successful upstream dispersal of downstream-originating fish species	downstream displacement of small numerous species (e.g. MN) by high flows	fewer escarpment-associated species found in the middle & lower reaches when flows were lower (drier Wets); such species 'retreat' from these reaches when flows are lower	fewer downstream-originating species in the lower reaches because higher flows allow movements to the upper reaches
Habitat variables:						
Significant correlation incidence rate**	0%(0)	large species – many small species -few	5.5%(3)	2%(1)	30%(16)	0%(0)
Correlate nature	none	+ undercut variables: TA,SJ & SK + distance, gradient & far cover: HF, LU, PM	+ aquatic plants + root material; - 0.2-1.0 depth	+ far riparian cover close to sites	+ distance, gradient & far cover (longitudinal habitat changes)	none
Possible interpretation	density too variable to have correlates	*undercut variables:* important cover for large spp *distance, gradient & far cover:* upper-reach character – escarpment spp. association	many small species shelter within beds of aquatic plants; root-material substrate may be an important source of aquatic invertebrate foods	the evenness shifts are most prominent in the upper reaches (upper-reach character – escarpment habitat)	the ordination axis is highly longitudinal-habitat change orientated (upper-reach character – escarpment spp. association)	the ordination axis is highly hydrology orientated, not habitat

* The incidence rate, for both the <10%-level and <5%-level significance, is the percentage number of the maximum possible number of significant correlates (220: 55 variables x 4 site-groups). The actual number of significant correlates is shown in parentheses after the percentage

** The incidence rate (only the <10%-level significance shown) is the percentage number of the maximum possible number of significant correlates (54: 27 variables x 2 years). The actual number of significant correlates is shown in parentheses after the percentage

na = not applicable; TA, narrow-fronted tandan; SJ, saratoga; SK, longtom; HF, black bream; LU, spangled grunter; PM, Midgley's grunter; MN, striped rainbowfish

4.2.2 Numerical density of individual species

For the small species, the main driver of their numerical densities is generally the same process as described above (Section 4.2.1), i.e. low-flow induced stranding or near-stranding of upstream-moving fish, i.e. failed refuge-seeking migrations. When attempting to detect a Scenario-1 mine disturbances, the more-sensitive feature F1 (see above) should be focussed on (upstream migrants; species-level work), rather than depending on comparisons of densities between site-groups A and B. The escarpment-associated species (e.g. striped rainbowfish) may be useful because they are likely to be more sensitive to poor water quality (Bishop 1987). Alternatively, the downstream-originating species (e.g. fly-speckled hardyhead, ambassid perchlets, pennyfish) may be useful because their presence may reflect environmental conditions in downstream areas, and therefore possibly Scenario-2 mine disturbances.

For the larger species, the main driver is prolonged high flows, particularly towards the end of the Wet season, allowing successful upstream migrations to the upper reaches; either downstream-originating species[4], or escarpment-returning species[5] are involved. The high flows result in higher densities in the upper reaches (site-groups C and D) of the creek. High densities of these species are also associated with more abundant undercut cavities along the margins of the creek. Again, rather than comparing densities between site-groups A and B in order to detect a Scenario-1 mine disturbance, the more-sensitive feature F1 (see above) should be focussed on at a species level. The differing advantages of the escarpment-associated and the downstream-originating species mentioned above are also relevant to the monitoring of the larger species. However, as monitoring targets for Scenario-1 mine disturbances, the larger species are likely to be less useful because they generally migrate at higher flows, the condition when seepage waters from the tailings dam area would be highly diluted.

It is noteworthy that the detailed information on hydrological correlates given on each species within Appendices 1 to 17 is likely to have high value for environmental-flow investigations across the wet-dry tropics of northern Australia, particularly those studies aiming to minimise flow-alteration risks to fish communities.

4.2.3 Number of species

Variation in this feature appears to be strongly driven by prolonged Wet-season high flows allowing the successful upstream migration of downstream-originating species: prolonged higher flows result in greater numbers of species. The upper reaches of the creek, i.e. site-groups C & D, is the spatial focus of the effect of such a process, an expected result given the species are likely to be attempting to reach refuge pools in that area. The process also appears to positively affect this feature in site-group B, and to a lesser extent in A. Greater numbers of species were also associated with more abundant aquatic-plant cover and root-material cover.

In the 2000–01 Wet, the flows were generally higher than most baseline Wets, and as expected, when compared with the baselines, the number of species was higher at site-groups B and A (IR405 – Bishop & Walden 2003). Also in the 2000–01 Wet, the number of species

---

4 Described by Bishop and Harland (1982) as species undertaking 'upstream returning movements from the lower reaches', e.g. longtoms, banded grunters, archerfish, and possibly the narrow-fronted tandan, Hyrtli's catfish, spangled grunter and the saratoga.

5 Described by Bishop and Harland (1982) as species undertaking 'downstream returning movements from the escarpment perennial spring area', e.g. black bream, Midgley's grunter and possibly the narrow-fronted tandan, Hyrtli's catfish, spangled grunter and the saratoga.

was higher in the upstream site-group B compared with the downstream site-group A, the same result as that usually found in the baseline period. The extent to which B was greater than A was not statistically different from that recorded in the baseline period.

Given that this feature is likely to be most responsive to the immigration of downstream-originating species (i.e. upstream-moving migrants), it is likely to be most useful in the detection of Scenario-2 mine disturbances. To provide a frame of reference for observations in relation to changing hydrological conditions, detailed modeling work[6] needs to be undertaken for each site-group. Scenario-2 mine disturbances may be confounded by Scenario-1 mine disturbances if the latter hampers upstream migrations within the creek (e.g. through avoidance or reduced 'fitness' of migrants). If it can be shown that Scenario-1 disturbances are not 'active', for example by the use of sensitive monitoring features such as F1 described above, then downstream-originating disturbances could be isolated out. Additional confounding could arise from changes in passage obstructions along the creek, although these are likely to be most problematic at low flows (hence small 'late-running' species would be most affected).

4.2.4 Evenness index

Variation in this feature appears to be driven by high to very-high Wet-season flows which displace small, numerous fish species downstream from the most upstream site-group (D). As a result relative abundances in site-group D becomes more even, while those in site-group C become less even. With higher flows evenness in site-group B also increased and this is likely to be caused by more successful upstream transfer of small, numerous upstream migrants. Greater evenness was also associated with more abundant far riparian cover, an association with the escarpment-gorge habitat (site-group D).

As before, in the 2000–01 Wet the flows were generally higher than most baseline Wets. Accordingly, compared to the baseline Wets, a higher evenness index was expected at site-group B given that there was a positive relationship with high flows. However, unexpectedly, when compared with the baselines, the evenness index at site-group B was not significantly higher (IR405 – Bishop & Walden 2003). Also in the 2000–01 Wet, the evenness index was virtually the same in site-groups A and B, the same overall pattern that occurred in the baseline Wets. A larger difference was expected given that evenness would be 'promoted' more with higher flows in site-group B than in site-group A.

Given that this feature in the lower reaches of the creek may be most responsive to the immigration of downstream-originating species (i.e. upstream-moving migrants), it is likely to have some use in the detection of Scenario-2 mine disturbances. To provide a frame of reference for observations in relation to changing hydrological conditions, detailed modeling work[7] needs to be undertaken for the downstream site-groups. Confounding factors are likely to be the same as for the previous fish-community feature (number of species). Given the likely complicated dynamics of this index, species-level investigations are likely to be more effective in detecting mine disturbances.

4.2.5 Ordination axis one

This axis reflected creek-long differences in the composition of fish communities whereby escarpment-associated communities in site-groups D, and to a lesser extent C, were

---

[6] The modeling should use hydrological variables as the predictors. The dataset should be limited to the baseline data.

[7] The modeling should use hydrological variables as the predictors. The dataset should be limited to the baseline data.

distinguished from the downstream communities. The key escarpment-associated species were the saratoga, black bream, Midgley's grunter, spangled grunter and the narrow-fronted tandan. The key downstream-associated species were ambassid perchlets, purple-spotted gudgeons, fly-speckled hardyheads, pennyfish, chequered rainbowfish, blue-eyes and mouth almighties. It is highly likely that the majority of these downstream-associated species are downstream- originating species.

This ordination axis had the highest incidence of habitat correlates, and as expected, the correlates reflected longitudinal habitat changes (distance, creek gradient and far-riparian cover, etc). Processes involving hydrology were also detected, particularly in site-Group C where higher flows appear to result in a larger proportion of escarpment-associated species being recorded. This is likely to reflect the late abandonment of the pre-gorge areas given that flows, being high, are not near critical levels which would restrict return movements to Dry-season refuges in the escarpment gorge. Signs of this process were also apparent in the more-downstream site-groups (A & B).

As before, in the 2000–01 Wet the flows were generally higher than most baseline Wets. Accordingly, compared to the baseline Wets, larger ordination scores were expected at site-group C and to a lesser extent in site-groups B and A. This only occurred in site-group B during the 2000–01 Wet. The basis of this may have been that, given higher flows, the escarpment-associated species had not even withdrawn from the site-group B section of the creek. A peak presence within the site-group C section may have occurred after the censusing.

As mentioned before, Bishop (1987) considered that the escarpment-associated species may be a useful species group for monitoring mining disturbances given their likely greater sensitivity to poor water quality. Accordingly, axis-1 ordination scores could be used in this context to detect Scenario-1 mining disturbances[8]. Modeling in relation to flow would need to be undertaken in order to obtain suitable frames of reference. Site-groups A-C would be the most appropriate focus.

4.2.6 Ordination axis two

This ordination axis identified a subset of downstream-originating species: the banded grunter, archerfish, Hyrtli's catfish, chequered rainbowfish and spangled grunters. The later three species could at times be present in escarpment dry-season refuges in substantial numbers, thus they are likely to have complex movement patterns. The ordination scores were inversely related to the abundance of these species, therefore a high ordination score for this axis indicated that few of these species were present (IR405 – Bishop & Walden 2003).

The axis had the highest incidence of hydrological correlates (of all the fish-community features examined) so it appears that it was highly hydrological-difference focussed. The background process appears to be based on higher flows allowing the above species to access further upstream into the creek. Accordingly, higher flows result in lower ordination scores (i.e. more of the above species) in the upper reaches of the creek (site-groups C and D). An effect of this is that higher flows result in higher ordination scores (i.e. less of the above species) in the lower reaches of the creek – a consequence of the species successfully moving out of the lower reaches and up into the upper reaches.

8 However, as the majority of escarpment-associated species are the larger species, their usefulness as monitoring targets may be low because they generally migrate at higher flows, the condition when seepage waters from the tailings dam area would be highly diluted.

As before, in the 2000–01 Wet the flows were generally higher than most baseline Wets. Accordingly, compared to the baseline Wets, lower ordination scores were expected at site-group C and D, and higher ordination scores were expected in site-groups A and B. The expected occurred in the lower reaches of the creek (IR405 – Bishop & Walden 2003). This simply reflected a low abundance of the above downstream-originating species. However, contrary to expectations:

- ordination scores increased considerably and reached record levels at site-group C (indicating that the group of species generally had particularly low abundances),
- ordination scores remained high at site-group D (indicating that expected gains [compared with other Wets] in the group of species had not occurred).

This result suggests that, based on baseline patterns, the upstream migrations of the above downstream-originating species failed to eventuate in expected strength. This is despite high flows which would have facilitated the migrations.

It is notable that two of the downstream-originated species, the archerfish and the spangled grunter, were the two fish species which Bishop and Walden (2001) detected significant negative time trends in their abundance (i.e. decreasing abundance over the years) at site-groups A and B. Time trends at the other site-groups were not examined by Bishop and Walden.

Environmental change downstream of the censused area of Gulungul Creek is the likely cause of the weak/failed migrations, given that the species were downstream-originating[9]. Many natural or anthropogenic factors may be behind this, including Scenario-2 mine disturbances. However, an obvious semi-anthropogenic factor is the massive increase in aquatic vegetation which has occurred in downstream waters over the last two decades, a result of the eradication of the water buffalo which commenced in the early 1980s. Bishop (1987) detected major changes in fish communities (shifts in dominance from large to small species) within lowland billabongs adjacent to Magela Creek[10] in response to this environmental change. This could well be the basis of the failed/weak migrations given that Bishop *et al.* (2001) indicated that, with the exception of the chequered rainbowfish, all of the above-mentioned downstream-originating species were associated with, at most, moderately-vegetated waters:

- archerfish – moderate (vegetation-dominance index)
- spangled grunter – low
- Hyrtli's catfish – moderate
- banded grunter – low to moderate

Clearly, ordination axis-2 scores are likely to be useful in detecting downstream-focussed disturbance signals. The detection process could possibly isolate-out the specific source of the disturbance signals if species-level environmental requirements are incorporated in some manner. Modeling in relation to flow would need to be undertaken in order to obtain suitable frames of reference. This should be done for all site-groups.

---

9 A Scenario-1 mining disturbance within Gulungul Creek appears to be highly unlikely given the very low levels of potential contaminants that have so far been detected in the creek; a summary of a time-trend analysis of mine-related water-quality was given by Bishop and Walden (2001)

10 Gulungul Billabong and Goanna Billabong (in Baralil Creek) were included in the study.

4.3 Evidence of an alternate post-1989 disturbance operating within the creek?

A summary of evidence supporting the existence of alternate, post-1989 disturbances operating within the creek is given in table 19. The disturbances may be anthropogenic, semi-anthropogenic (e.g. consequences of water buffalo eradication) or natural.

Evidence was obtained for only three of the six structural features of the fish communities – the numerical density of individual fish species, the evenness index, and ordination axis 2.

Table 19 Summary of the correlation–analysis findings: evidence of alternate post-1989 disturbances operating within the creek?

Environmental variable group	Basic-structural features			Compositional-structure features		
	Numerical density across all species	Numerical density of individual species (17)	Number of species	Evenness index	Ordination axis 1	Ordination axis 2
Hydrology	negligible	yes-TC (D)* yes-SK (D) yes-TA (C) yes-AP (C & D) yes-PS (C) yes-MN (D & C)	none	yes (site-group D)	negligible	yes (site-group C)
Habitat	none	yes-SK	none	yes	none	none

*species codes (site-group identification in parentheses); TC, archerfish; SK, longtom; TA, narrow-fronted tandan; AP, banded grunter; PS, blue-eyes; MN, striped rainbowfish; species arranged from greatest to lowest reductions

For all the features involving alternates to hydrology, the spatial focus of the effect of the disturbance was in the upper reaches of the creek.

4.3.1 The numerical density of individual fish species

Six species showed disrupted responses to hydrology. Two small species, the striped rainbow and blue-eye, had negative relationships with flow, yet in the 2000–01 Wet (a wet-Wet) higher than expected densities were recorded. The basis of this is unclear, but it is highly unlikely that it concerns either Scenario-1 or 2 mine disturbances.

The remaining species, all large, had positive relationships with flow yet lower than expected densities were recorded. For the archerfish and the banded grunter this can be explained in relation to failed/weak upstream migrations from the lower reaches of the creek. In Section 4.2.6 it was suggested that a massive long-term increase in the density of aquatic vegetation in waters downstream of the censused section of Gulungul Creek is likely basis of the weakening of the migrations.

The basis of the lower than expected densities of longtoms and narrow-fronted tandans is unclear. It is highly unlikely that any Scenario-1 mine disturbances would have been the cause as both are larger fish species which generally migrate at higher flows, the condition when seepage waters from the tailings dam area would be highly diluted.

4.3.2 The evenness index

The evenness index in site-group D had positive relationships with flow variables. However, in the wetter than usual 2000–01 Wet, lower than expected evenness-index values were recorded. The breakdown in the relationship with the escarpment-associated habitat variables would also arise from this finding. It is highly likely that greater than expected densities of striped rainbowfish in the site-group explains this. As before, the basis of this is unclear, but it is highly unlikely that it concerns either Scenario-1 or 2 mine disturbances.

4.3.3 Ordination axis 2

The ordination scores from this axis had negative relationships with hydrological variables in the upper reach site-groups, yet in the 2000–01 Wet (a wet-Wet) higher than expected scores were recorded. As discussed in Section 4.2.6, this can be explained in relation to failed/weak upstream migrations of a group of downstream-originating species. As before, it was suggested that major long-term increases in the density of aquatic vegetation in further-downstream waterbodies (e.g. lowland billabongs) were most likely responsible for the weakening of the migrations.

5 Recommended further investigations

5.1 Field investigations

1 Given that a) seepage constituents from the Tailings Dam area is commencing to become noticeable in the creek, and b) any impacts from cane toads may commence within the next five years, it is recommended that, in order to be in a good position to assess impacts, the censusing in Gulungul Creek should continue in the near future on a year-to-year basis. The format of the censusing, including the collection of within-site habitat data, should follow that undertaken in the 2000–01 Late-wet–Early-dry (i.e. the current-condition sample based on three censusing runs).

2 A more sensitive and complementary means of detecting Scenario-1 mine disturbances should be developed. The following feature (F1) is likely to hold great promise in this context because it generally avoids confounding factors and, in essence, targets the *fitness* of fish:

- F1: the ratio of the number of upstream migrants successfully negotiating difficult passage obstacles, to the number of upstream migrants present in the downstream staging-pool

Low F1 (ratio) values would be expected in sections of the creek where fish are suffering physiological stress or behavioural disorders. Observations downstream of seepage-input points (i.e. the upstream border of the site-group A section of the creek) would need a reference condition, ideally in a separate but similar creek system. Clearly, the hydraulic character of the passage obstacles would need to be standardised. The work would be best undertaken at the species level, with upstream-migrating species clearly distinguished. It would be prudent to target small fish species.

3 To maintain an awareness of the existence of a potentially-major confounding factor (relevant to the use of numerical-density data along the creek), it is recommended that the hydraulic character of key (difficult) passage obstructions be assessed every two years. The assessment would need to be standardised in relation to flow magnitude.

5.2 Data analysis and modeling

Extensive data analyses are still required to make the most of the extensive and valuable Gulungul-Creek baseline datasets, and adjunct datasets on locally-relevant fish communities. The highest priorities are:

1 Using hydrological variables as predictors, and with a focus on the baseline dataset, develop high-quality models[11] for the following structural features of the fish communities (highest to lowest priority):

- number of fish species (done separately for each site-group)
- the numerical density of selected fish species with emphasis on distinguishing downstream-originating species (small and large species) from escarpment-associated species (the site-group focus would change between species)
- ordination scores akin to ordination axis-2 (done separately for each site-group)
- ordination scores akin to ordination axis-1 (focus: site-groups A to C)

[11] For use in distinguishing expected natural responses to hydrology from other disturbance signals.

- the evenness index (focus: site-groups A and B)

2 Changes to the sensitivity of the models (used in detecting any mine-disturbance signals or other changes) should be investigated by:

- using a range of data transformations which 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)
- using various time lags on hydrological variables when modeling
- examining the data on a site basis rather than on a site-group basis

3 Time trends in the abundance of pertinent species should be examined in the following adjunct fish-ecology datasets (in order to examine the reality, extent and basis of the apparent failed/weakened [2000–01 Wet-season] upstream migrations of a number of downstream-originating fish species):

- the 1978–88 gillnet surveying of Magela Creek backflow billabongs,
- the 1994-to-present pop-net surveying of the backflow billabongs,
- the 1989-to-present surveying of Mudginberri Billabong, and
- the 1983-to-1998 censusing of fish movements in Magela Creek.

6 References

Bishop KA 1991. Biological monitoring using freshwater fishes of the ARR: Phase 1, review of data. Internal report 28, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Bishop KA 1987. Dynamics of the freshwater fish communities of the Alligator Rivers Region, tropical northern Australia. PhD Thesis, Macquarie University, Sydney, Australia.

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, AGPS, Canberra.

Bishop KA, Allen SA, Pollard DA & Cook MG 2001. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory: Autecology*. Supervising Scientist Report 145, Supervising Scientist, Darwin.

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, AA 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.

Bishop KA & Walden DJ 1991. Fish community structure. In *Alligator Rivers Region Research Institute, Annual Research Summary 1988-89*. Supervising Scientist for the Alligator Rivers Region. AGPS, Canberra.

Bishop KA & Walden DJ 2003. Fish communities of Gulungul Creek: a landscape analysis. Phase 1: 'First-pass' analyses of Late-wet–Early-dry season data (1979–2001). Study undertaken for the Environmental Research Institute of the Supervising Scientist, October 2001, Internal Report 405, Supervising Scientist, Darwin, Unpublished paper.

Chapman LJ & Chapman CA 1993. Fish populations in tropical floodplain pools: a re-evaluation of Holden's data on the River Sokoto. *Ecology of Freshwater Fish* 1993, 23–30.

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

Gorman OT & Karr JR 1978. Habitat structure and fish communities. *Ecology* 59, 507–515.

Pidgeon R, Bishop KA & Humphrey CL 1998a. Biological monitoring using fish migration in Magela Creek. In: *Annual Research Summary 1991-1992*. Supervising Scientist for the Alligator Rivers Region. Internal Report 276, February 1998.

Pidgeon R, Boyden J, Davies J & Humphrey CL 1998b. 2216: Biological monitoring using fish migration in Magela Creek. In: *Annual Research Summary 1992-1994*. Supervising Scientist for the Alligator Rivers Region. Internal Report 291 July 1998.

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

Rodriguez MA & Lewis WM Jr 1994. Regulation and stability in fish assemblages of neotropical floodplain lakes. *Oecologia* 99, 166–180.

Welcomme RL 1979. *Fisheries ecology of floodplain rivers.* Longman, London.

Welcomme RL & Hagborg D 1977. Towards a model of a floodplain fish population and its fishery. *Env. Biol. Fish*. 2, 7–24.

Winemiller KO 1996. Dynamic diversity in fish assemblages of tropical rivers. In *Long-term studies of vertebrate communities*, eds Cody ML & Smallwood JA, San Diego, USA.

7 Appendix

Significant across-year Spearman's-rank correlations between the 'hydrological' variables and the seventeen fish species on a site-group basis

Table A1 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and the numerical density of the saratoga, *Scleropages jardinii*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with	NR	(+0.63,JANMT)	+0.84,>150MNS +0.84,ONDMT (+0.64,NOVMT) (+0.64,DECMT) -0.80PCA2	(+0.62JANMT)
	without	NR		+0.85,ONDMT +0.83>150MNS +0.78DECMT -0.79,PCA2 (-0.72,>400MNS)	
Magela flow	with	NR		+0.82,D>1 +0.78,D9-27 +0.78,DECMF +0.77,D>3 +0.75,D>9 +0.73,PCA2 (+0.67,D3-9)	
	without	NR		+0.78,DECMF +0.76,D9-27 +0.75,D>1 +0.70,D>3 +0.70,PCA2 (+0.66,D3-9) (+0.65,D3-9)	
Gulungul flow	without	NR		(+0.65,JANMF)	(-0.66,D0-1) (-0.64,APRMF)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table 2A Significant across-year Spearmans-rank correlations between the 'hydrological' variables and the numerical density of the narrow-fronted tandan, *Neosilurus ater*

'Hydrological' variable group	**2001 included?**	**Site groups**			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with	NR	(-0.68,APRMT)	+0.84,NOVMT	+0.90,NOVMT +0.89,ONDMT +0.89,>150MNS (+0.63,DECMT) -0.87,PCA2
	without	NR	(-0.68,APRMT)	+0.88,NOV	+0.88,>150 +0.87,ONDMT +0.86,NOVMT (0.65,DECMT) -0.86,PCA2
Magela flow	with	NR		+0.78,D3-9	+0.89,PCA2 +0.81,D9-27 +0.74,D>1 +0.73,DECMF +0.71,D>9 (+0.68,D>3)
	without	NR		+0.80,D3-9 (+0.65,D>3) (+0.65,APRMF) (+0.65,PCA2)	+0.87,PCA2 +0.78,D9-27 +0.72,D>1 +0.72,DECMF (+0.68,D>9) (+0.68,JANMF) (+0.63,D>3)
Gulungul flow	without	NR			(-0.69,PCA2)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A3 Significant across-year Spearmans-rank correlations between the ‘hydrological’ variables and numerical density of the Hyrtli’s catfish, *Neosilurus hyrtlii*

‘Hydrological’ variable group	**2001 included?**	**Site groups**			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with		(+0.68,FEBMT)	(-0.68,APRMT)	(+0.64,>300MNS)
	without		(+0.67,FEBMT)	(-0.73,APRMT)	+0.90,>300MNS (+0.62,JANMT)
Magela flow	with	+0.70,PCA3 (+0.61,D1-3) -0.70,DECMF (-0.63,D3-9)		(-0.67,PCA3)	(-0.63,D3-9)
	without	+0.79,PCA3 (-0.71,DECMF)			(+0.65,D3-9) (+0.65,WETTD)
Gulungul flow	without				+0.76,D4-8 +0.72,D8-16 +0.70,D>1 +0.70,D>4 (+0.68,JANMF) (+0.66,FEBMF) (+0.65,DECMF) (+0.62,WETTD) (-0.60,PCA1)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by ‘+’ and ‘-’ respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A4 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the longtom, *Strongylura kreftii*

'Hydrological' variable group	2001 included?	Site groups			
		A **(down)** **(Sites 2&3)**	**B** **(up)** **(Sites 4&5)**	**C** **(Sites 6&7)**	**D** **(Sites 8&9)**
Rainfall	with	-0.78,APRMT		+0.89,>150MNS +0.84,ONDMT (+0.69,NOVMT) (+0.67,DECMT) -0.87,PCA2	
	without	-0.77,APRMT		+0.86,>150MNS +0.80,ONDMT +0.70,DECMT -0.84,PCA2	
Magela flow	with	(+0.66,D>729) (-0.70,PCA2)		+0.98,D>3 +0.96,D>9 +0.93,D9-27 +0.93,DECMF +0.92,D>1 +0.73,D27-81 (+0.63,JANMF) (+0.60,D>27) -0.72,PCA1	
	without	(-0.68,PCA2) (-0.67,D>729)		+0.97,D>3 +0.96,D>9 +0.95,DECMF +0.91,D>1 +0.91,D9-27 +0.79,D27-81 +0.77,D>243 +0.77,D243-729 (+0.65, JANMF) -0.77,PCA1	(+0.63,D>1) (+0.63,D>9) (+0.61,D>3)
Gulungul flow	without			+0.91,D>0 +0.85,D0-1 +0.82,D2-4 +0.81,DECMF (+0.73,D1-2) (+0.72,D>1) (+0.70,D>16) (+0.68,JANMF) (+0.66,D>2) -0.74,PCA1 (-0.66,PCA2)	

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A5 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the black-striped rainbowfish, *Melanotaenia nigrans*

'Hydrological' variable group	**2001 included?**	**Site groups**			
		A **(down)** **(Sites 2&3)**	**B** **(up)** **(Sites 4&5)**	**C** **(Sites 6&7)**	**D** **(Sites 8&9)**
Rainfall	with		(-0.68,MARMT)	-0.93,MARMT	
	without		(-0.73,MARMT) (-0.72,D<20)	-0.94,MARMT	
Magela flow	with	-0.80,D1-3	-0.79,APRMF -0.71,D>1 (-0.67,D9-27) (-0.66,D>9) (-0.66,D>3)	(+0.66,PCA1) -0.94,MARMF -0.78,D>243 -0.78,D243-729 -0.75,WETTD	+0.81,PCA1 -0.72,MARMF -0.72,WETTD -0.71,DECMF (-0.68,DECMF) (-0.68,MARMF) (-0.66,D>27) (-0.65,D>9) (-0.64,D27-81) (-0.63,D>3) (-0.62,D>81) (-0.61,D243-729) (-0.61,D>243) -0.60,JANMF
	without	-0.88,D1-3	-0.77,APRMF (-0.71,D9-27) (-0.70,D>1) (-0.68,D>3) (-0.65,D>9)	+0.86,PCA1 -0.95,MARMF -0.84,WETTD -0.79,D27-81 -0.76,D243-729 -0.76,D>243 -0.73,D>27	+0.83,PCA1 -0.71,DECMF (-0.68,MARMF) (-0.68,WETTD) (-0.66,D>9) (-0.65,D>27) (-0.65,D27-81) (-0.64,D>243) (-0.64,D243-729) (-0.60,JANMF)
Gulungul flow	without	-0.81,APRMF	(+0.66,PCA2) -0.82,APRMF -0.80,D1-2	+0.80,PCA1 -0.98,MARMF -0.88,WETTD -0.87,D>16 (-0.73,D>1) (-0.68,D>0) (-0.65,D2-4)	(+0.63,PCA1) -0.73,MARMF -0.70,D2-4 (-0.68,D>0) (-0.68,D0-1)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A6 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the chequered rainbowfish, *Melanotaenia splendida inornata*

'Hydrological' variable group	2001 included?	Site groups A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	(+0.67, PCA2) (-0.65,>300MNS)	(-0.62,JANMT)		
	without				
Magela flow	with	(+0.63,PCA1)	(-0.74,PCA3)		
	without	-0.73,D>243 -0.73,D243-729	(-0.63,PCA3)		
Gulungul flow	without	-0.80,JANMF -0.79,D>0 -0.76,DECMF (-0.69,D>1) (-0.69,D>16)			(+0.65,WETTD) (+0.64,D>16)

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A7 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the fly-speckled hardyhead, *Craterocephalus stercusmuscarum*

'Hydrological' variable group	2001 included?	Site groups A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	(+0.64,JANMT) (+0.62,MARMT)	(-0.60,<20DMNS)	+0.76,OCTMT (+0.61,>400MNS) (-0.62,<20MNS)	NR
	without	+0.79,JANMT -0.64,MARMT			NR
Magela flow	with		+0.74,PCA3		NR
	without			(-0.66,D1-3)	NR
Gulungul flow	without				NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A8 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of blue-eyes, *Pseudomugil* spp

'Hydrological' variable group	2001 included?	Site groups			
		A **(down)** **(Sites 2&3)**	**B** **(up)** **(Sites 4&5)**	**C** **(Sites 6&7)**	**D** **(Sites 8&9)**
Rainfall	with	-0.75,MARMT		-0.79,MARMT (-0.65,DECMT) (-0.61,<20DMNS)	NR
	without	(-0.72,MARMT)	-0.77,<20DMNS	-0.77,MARMT (-0.69,DECMT) (-0.65,>150MNS)	NR
Magela flow	with	(-0.66,MARMF)		(+0.65,PCA3) -0.81,DECMF -0.78,MARMF -0.78,D9-27 -0.76,D>3 -0.72,D>243 -0.71,D>1 -0.70,D>9	NR
	without			+0.79.PCA1 (+0.72,PCA3) -0.87,D>0 -0.87,D>3 -0.87,DECMF -0.85,D>9 -0.85,D9-27 -0.84,D27-81 -0.77,MARMF (-0.69,D243-729)	NR
Gulungul flow	without	(-0.68,MARMF)		+0.73,PCA1 -0.86,D>0 -0.81,MARMF -0.80,D1-2 -0.78,D>16 -0.76,D2-4 (-0.70,D>1) (-0.65,D0-1) (-0.65,WETTD)	NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A9 Significant across-year Spearmans-rank correlations between the ‘hydrological’ variables and numerical density of ambassid perchlets, *Ambassis* spp

‘Hydrological’ variable group	**2001 included?**	**Site groups**			
		A **(down)** **(Sites 2&3)**	**B** **(up)** **(Sites 4&5)**	**C** **(Sites 6&7)**	**D** **(Sites 8&9)**
Rainfall	with		-0.75,>300MNS	(-0.62,JANMT)	NR
	without		(-0.71,>300MNS)	(+0.66,<20DMNS) (-0.66,JANMT)	NR
Magela flow	with		-0.70,D27-81 -0.70,PCA1 (-0.65,D>27) (-0.62,WETTD)		NR
	without				NR
Gulungul flow	without	(-0.68,D>0) (-0.65,D>1) (-0.65,D1-2)	-0.84,WETTD -0.79,D>1 -0.78,D1-2 -0.78,D1-2 -0.74,D>8 -0.70,PCA1 (-0.69,D8-16) (-0.66,D>0) (-0.65,D4-8) (-0.64,D>4)		NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by ‘+’ and ‘-’ respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A10 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the pennyfish, *Denariusa bandata*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with		(-0.69,<20DMNS)	NR	NR
	without		-0.79,<20DMNS	NR	NR
Magela flow	with	(+0.60,D1-3)	(+0.67,PCA3)	NR	NR
	without		+0.77,PCA3	NR	NR
Gulungul flow	without			NR	NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance.

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group.

Table A11 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the banded grunter, *Amniataba percoides*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	+0.82,MARMT +0.74,>400MNS	+0.79,MARMT	+0.75,MARMT	
	without	+0.82,MARMT +0.77,>400MNS	+0.77,MARMT	(+0.72,MARMT)	
Magela flow	with	+0.70,MARMF	(+0.66,MARMF)	+0.70,MARMF (+0.65,D>3) (+0.65,D>9) (+0.65,D9-27)	+0.65,D27-81 (+0.64,D>729) -0.74,PCA1
	without	(+0.68,MARMF)		+0.79,D>9 (+0.73,D>3) (+0.72,D>1) (+0.69,D9-27) (+0.67,D27-81) (+0.67,MARMF)	+0.75,D>27-81 (+0.65,D>243) (+0.65,D243-729) -0.73,PCA3
Gulungul flow	without	+0.78,WETTD (+0.66,MARMF)	(+0.68,MARMF)	(+0.66,MARMF)	+0.73,D2-4

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A12 Significant across-year Spearmans-rank correlations between the ‘hydrological’ variables and numerical density of the sooty grunter, *Hephaestus fuliginosus*

‘Hydrological’ variable group	**2001 included?**	**Site groups**			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with	+0.76,NOVMT +0.76,ONDMT (-0.64,PCA2)			+0.70,>300MNS (+0.60,JANMT)
	without	+0.78,NOVMT +0.77,ONDMT (-0.65,PCA2)			
Magela flow	with	+0.78,PCA2	-0.70,D1-3		+0.66,JANMF
	without	+0.79,PCA2	-0.76,D1-3		+0.66,D1-3
Gulungul flow	without		(-0.65,APRMF)		

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by ‘+’ and ‘-’ respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A13 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the spangled grunter, *Leiopotherapon unicolor*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with		(+0.63,<20DMNS)		+0.82,DECMT +0.73,>150MNS +0.70,ONTMT -0.65,PCA2
	without				+0.90,>150MNS +0.85,DECMT +0.82,ONDMT (+0.62,NOVMT) -0.82,PCA2
Magela flow	with		(-0.68,PCA3)	-0.72,D1-3 -0.71,PCA3	+0.86,D9-27 +0.82,DECMF +0.71,D>1 +0.71,D>3 (+0.68,D>9) (+0.61,PCA2)
	without			-0.77,D1-3	+0.97,D9-27 +0.95,D>1 +0.91,D>9 +0.91,D>3 +0.86,DECMF +0.74,PCA2 (+0.67,D27-81)
Gulungul flow	without				+0.87,D1-2 +0.75,DECMF (+0.67,D>0) (+0.65,D>1) (+0.64,D2-4) (+0.63,JANMF) -0.80,PCA2

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance.

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A14 Significant across-year Spearmans-rank correlations between the ‘hydrological’ variables and numerical density of Midgley’s grunter, *Pingalla midgleyi*

‘Hydrological’ variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with			+0.70,ONDMT (+0.64,DECMT) (-0.66,>400MNS)	
	without			+0.74,ONDMT	(+0.63,DECMT)
Magela flow	with	+0.70,D1-3	-0.70,PCA3 (-0.68,D>1) (-0.61,D9-27)	(+0.67,PCA2)	+0.65,JANMT
	without	(+0.66,D1-3)	(+0.71,PCA3) (-0.66DECMF)	+0.76,PCA2	
Gulungul flow	without				

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by ‘+’ and ‘-’ respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow)

Table A15 Significant across-year Spearmans-rank correlations between the ‘hydrological’ variables and numerical density of the mouth almighty, *Glossamia aprion*

‘Hydrological’ variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	(+0.69,OCTMT) (-0.62,<20DMNS)	-0.77,<20DMNS (-0.63,PCA1)	-0.77,JANMT	NR
	without	(+0.66,OCTMT)	-0.78,<20DMNS	(-0.72,JANMT)	NR
Magela flow	with		+0.72,PCA3		NR
	without		(+0.73,PCA3)		NR
Gulungul flow	without				NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by ‘+’ and ‘-’ respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A16 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the archerfish, *Toxotes chatareus*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	B (up) (Sites 4&5)	C (Sites 6&7)	D (Sites 8&9)
Rainfall	with	(+0.68,MARMT) (-0.69,NOVMT)	(+0.68,MARMT) (-0.69,NOVMT)	-0.72,>300MNS	NR
	without	(+0.69,MARMT) (-0.68,NOVMT)	(+0.69,MARMT) (-0.68,NOVMT)	+0.90,>300MNS	NR
Magela flow	with	+0.75,D>729	+0.75,D>729	+0.88,D>243 +0.88,D243-729 (+0.69,WETTD) (+0.65,D>729)	NR
	without	+0.76,D>729	+0.76,D>729	+0.87,D243-729 +0.87,D>243 +0.83,WETTD +0.81,D>27 +0.76,D>81 (+0.68,D27-81) (+0.66,D81-243) (+0.66,D>729) (+0.64,FEBMF) -0.77,PCA1	NR
Gulungul flow	without		(+0.65,WETTD)	+0.89,D>1 +0.87,D>16 +0.86,D4-8 +0.84,D>4 +0.84,D>2 +0.81,D>8 +0.80,WETTD +0.80,DECMF +0.75,D8-16 +0.71,D>0 (+0.70,D2-4) (+0.69,FEBMF) (+0.66,MARMF) -0.87,PCA1	NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group

Table A17 Significant across-year Spearmans-rank correlations between the 'hydrological' variables and numerical density of the purple spotted gudgeon, *Mogurnda mogurnda*

'Hydrological' variable group	2001 included?	Site groups			
		A (down) (Sites 2&3)	**B (up) (Sites 4&5)**	**C (Sites 6&7)**	**D (Sites 8&9)**
Rainfall	with	-0.72,>150MNS -0.71,NOVMT		(-0.68,MARMT) (-0.68,>300MNS)	NR
Rainfall	without	-0.88,PCA2 (-0.69,NOVMT) (-0.67,>150MNS) (-0.65,<20DMNS)	-0.77,<20DMNS	-0.75,MARMT	NR
Magela flow	with	-0.89,APRMF -0.87,D3-9 -0.86,PCA2 -0.81,D>1 -0.77,D9-27 -0.72,D>3 (-0.69,D>9)		-0.75,D>27 -0.74,D27-81 (-0.67,D>3) (-0.63,D243-729) (-0.63,D>243) (-0.62,D>81) (-0.61,D>9)	NR
Magela flow	without	-0.91,APRMF -0.90,D3-9 -0.86,PCA2 -0.75,D9-27 -0.74,D>1	+0.75,PCA3	-0.81,D>243 -0.81,D243-729 -0.78,WETTD -0.77,PCA1 -0.75,MARMF (-0.71,D27-81) (-0.70,D>27)	NR
Gulungul flow	without	-0.82,PCA2 -0.75,APRMF		-0.95,D>16 -0.88,D>1 -0.86,WETTD -0.86,PCA1 -0.82,D1-2 -0.80,MARMF -0.79,D>0 -0.77,DECMF -0.71,D>2 -0.66,D2-4	NR

Correlation values not in parentheses were significant at p=<0.05. Correlation values in parentheses were significant at 0.05<=p<=0.10. Positive and negative correlations are indicated by '+' and '-' respectively. The correlates are ordered downwards in relation to decreasing significance

Keys to variable codes are given in tables 1 (rainfall), 2 (Magela Creek flow) and 3 (Gulungul Creek flow). NR = the species was not recorded within the site group